

"Towards an Earth-Moon Economy - Developing Off-Planet Resources"

# Moon Miners' Manifesto



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MMM Classic Themes

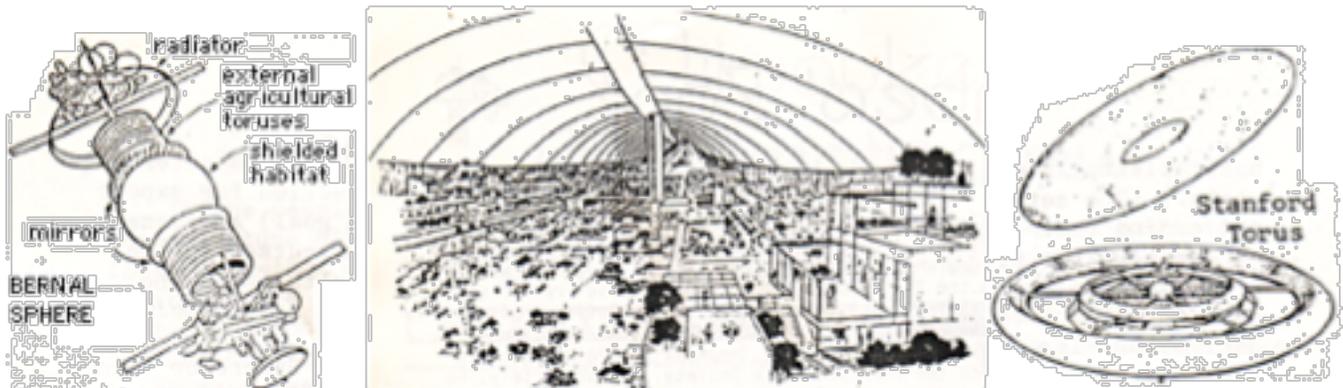
Our Solar System

As The Moon, Mars, and Asteroids each have their own dedicated theme issues, this one is about the "rest of the Solar System" as we have covered it in MMM through the years.

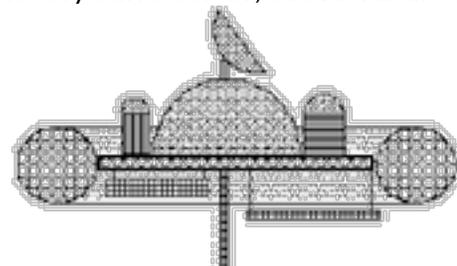
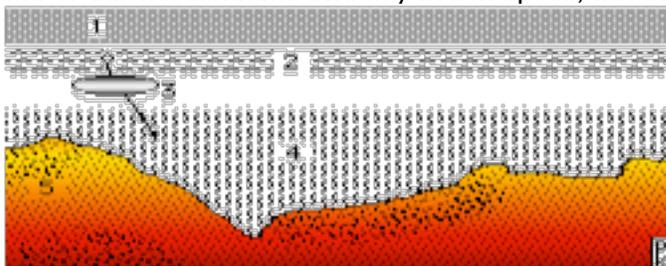
Not yet having ventured beyond the Moon, and not yet having begun to develop and use space resources, these articles are speculative, but we trust, well-grounded and eventually feasible. Included are articles about the inner "terrestrial" planets: **Mercury** and **Venus**. As the gas giants **Jupiter**, **Saturn**, **Uranus**, and **Neptune** are not in general human targets in themselves, most articles about destinations in the outer system deal with **major satellites**: Jupiter's **Io**, **Europa**, Ganymede, and **Callisto**. Saturn's **Titan** and Iapetus, Neptune's **Triton**. We also include past articles on "Space Settlements."



Europa with its ice-covered global ocean has fascinated many - will we one day have a base there?



Will some of our descendants one day live in space, not on planetary surfaces? Or, above Venus' clouds?



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## MMM #11 – December 1987

### SPACE OASES & LUNAR CULTURE

MOON MINERS' MANIFESTO. has been cast, even by well-meaning admirers, as a "special interest" newsletter. As editor, I have to take responsibility for this widespread misappraisal. I had stated that we wanted to explore the heights to which a self-sufficient lunar civilization could rise, given the constrain that it must seek to develop as far as possible relying solely on lunar ores that are poor in hydrogen, carbon, and nitrogen. The MANIFESTO has gotten good marks for this effort. But for many whose dream is life on O'Neillian space colonies, these discussions have perhaps seemed irrelevant.

This shows our failure to realize that what may be perfectly obvious to us, doesn't necessarily suggest itself to others: namely, that in the early decades, the availability of volatile-rich ores from asteroids and other sources cheaper to access than upports from Earth, will be at best sporadic. As a result, pioneers in free space oases will find them-selves in much the same straights as hardy lunar settlers. Unless they are fantastically prosperous [pluck your brains out of free fall!] and can afford heavy dependence on Earth-sourced materials, they too must build their cultures largely on the possibilities inherent in volatile-poor lunar ores. Lunar cultures will be the rule.

Thus, in the early decades, space colonists too will be forced to give up a way of life based on the causal use of paper, wood, plastics and the whole host of addictive synthetics based on hydrogen, carbon, and nitrogen so very abundant on Earth. This will color their whole way of life with its implications for building products, household furnishings and other domestic wares, clothing, information media, sporting goods, toys, arts and crafts etc. If you are truly interested in pioneering free space, you will find enlightening ideas on what such frontier life will be like in the pages of MOON MINERS' MANIFESTO.

We belated invite you aboard our Mainline Express to a thousand space futures. To catch up, as we have already left the depot, check out the articles and essays from the earlier issues. – Peter Kokh 11/87

The original article is online at: [what://www.asi.org/6/9/3/2/011/space-oases-intro.html](http://what://www.asi.org/6/9/3/2/011/space-oases-intro.html)  
This and the following two issues of MMM are dedicated to those for whom lunar settlement is only a necessary means to another horizon on which their true interest lies.

## SPACE SETTLEMENT QUIZ

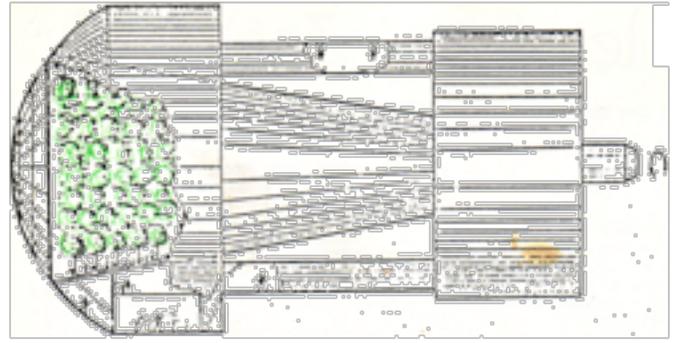
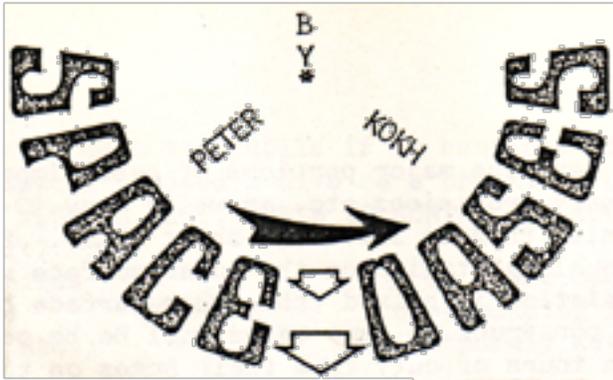
### QUESTIONS

- 1.The trailing lunar co-orbital field "Trojan" position usually referred to as L5 is no longer seen as the best space colony location. But if one were located there, how long would it take to orbit the Earth?
- 2.Of what use is the preceding co-orbital "Trojan" called L4?

3. How much easier is it to reach the 2:1 resonant orbit than L5 from L2?
4. In the proposed resonant orbit, how close will the colony come to Earth at perigee, and how close would it come to the Moon at every other apogee?
5. What environmental problems does a space colony face that will be less troublesome for a lunar settlement?
6. Name some interesting groups of characters that you are less likely to meet on a space colony than in a lunar settlement.
7. You live on a space colony and your doctor says you need more exercise and advises you to start jogging, but cautions that you should run only westward at first. Why?
8. Which traditional performing art will be somewhat more difficult to master on a space colony than on Earth?
9. What will homes inside a space colony be built of?
10. What sort of trees and other plants would you expect in a space colony park?

## ANSWERS

1. Same as on the Moon, of course: 27.5 days by the stars, 29.5 days by the Sun.
2. Same as L5. Since taken together these two positions offer an unchanging vantage point over 5/6th of the Moon's surface (all but "deep farside") they will be important for communications, surface navigation etc., especially as there is no moon-synchronous orbit, only these two moon-synchronous positions. But quite apart from this, again taken together, L4 and L5 form a very convenient baseline about 400,000 miles (650,000 km) long for astronomy, providing the opportunity for unprecedented interferometric resolution, for radio astronomy,
3. A Delta V of only about 30 ft/sec (vs. 1400 ft/sec to L5) is needed.
4. About 100,000 miles from Earth and on the order of 40,000 miles from the Moon.
5. Removal of waste heat (the lunar subsoil at  $-50^{\circ}\text{F}$  and the two week long nights both help) and the dust and debris from manufacturing and processing (one sixth gravity will scavenge these out of the near-surface vacuum whereas they will tend to form a Sargasso Sea about the space colony, sharing its orbital momentum and following it about, dissipating possibly at a slower rate than that at which it builds up.
6. One could mention amateur astronomers, prospectors, over the road drivers, mountain climbers, spelunkers, etc.
7. Running westward, against the direction of spin, you will be subject to lessened centrifugal force (artificial gravity) and thus "weigh" less, and this will be easier on your lazy heart. Seasoned runners will head eastward, in the direction of spin.
8. Dancing, especially Ballet and Modern Dance, because of especially strong Coriolis forces within rotating environments with short radii like space oases. Rocking in place will be easier.
9. Lunar concrete, ceramic blocks, and glass-glass-composites will be cheapest. Pure metals and alloys will be reserved for accent or subsystems. Wood? Never! Withdrawals from the bio-sphere Biomass will be discouraged as they will cost the replacement value of the precious volatile elements involved.
10. The exact species will depend on the colony's climate, but since space will be at a sever premium, one would expect only utilitarian plants: fruit trees, berry bushes, herbs, and plants that are a source of useful cosmetics, pharmaceuticals and dyes. The challenge will be to arrange these in a way that is delightful as well as practical. MMM



**Right:** Earliest concept of a rotating space station with artificial gravity – Konstantin Tsiolkovski 1905

## SPACE OASES Part 1: FIRST LOCATIONS

By Peter Kokh

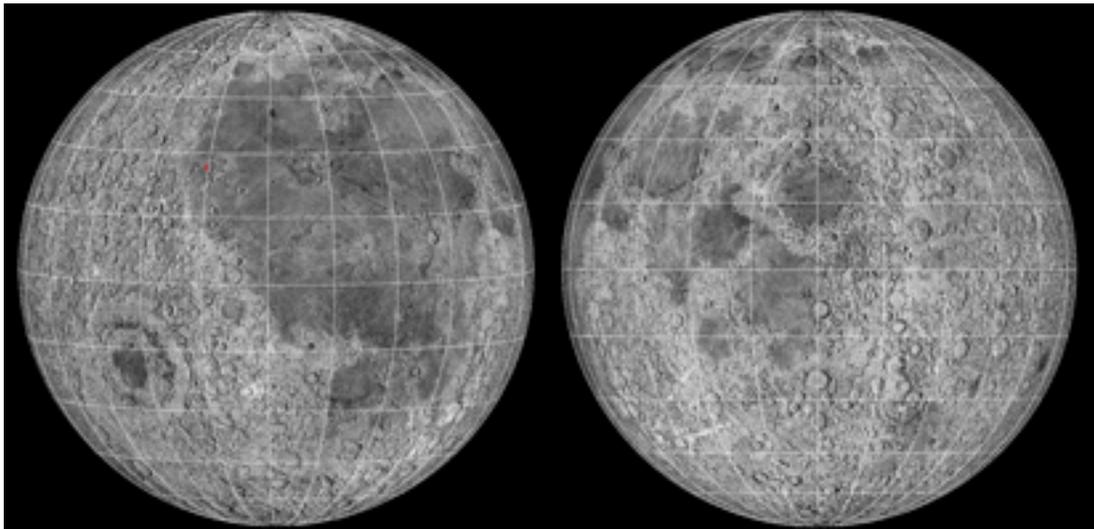
"SPACE OASES" as used in this article are defined as durable free space structures providing:

- **Artificial gravity through centrifugal force,**
- **Closed life support system** for air, water, and at least some food,
- **Shielding against long term exposure** to solar and cosmic radiation and micrometeorites, and
- **Habitation for at least a transient community** of people.

This is a more generous definition than "space colony" or "space settlement" which is conceived of as supporting a non-transient population of a size large enough (minimum 10,000?) to enjoy a respectable measure of self-sufficiency. We believe that smaller and cheaper space oases will pave the way.

Where in free space are we likely to find such oases for human life? Certainly in stable low Earth orbits (500 – 1000 km) where they will support manufacturing and processing, tourist, convention, education, and hospital functions. But for most of us, these close-in possibilities only whet the appetite for real breakout. Even geosynchronous orbit (37,500 km) fails to stir our space pioneering spirits.

The original "space colony" scenario outlined by Princeton physicist Gerard K. O'Neill, proposed a semi-stable area which trails the Moon in its orbit some 60° (about 5 days) behind in a sort of lock-step formation. Known as the 5th Lagrangian spot, or "L5", this location remains equidistant from the Earth and the Moon and is not difficult to reach. However, it is not as stable as once thought owing to perturbations by the Sun.



The view of the Moon from L4 Left – from L5 right

It has since been found that a two week period highly elliptical orbit which would precess rather swiftly under the Moon's dominant influence, the so-called 2:1 resonant orbit, would not only be more stable, but easier to reach from the Moon (directly or via L2) and Earth. "L5" remains important as a Moon-synchronous location for communications relays, and as part of a long astrometric baseline together with "L4", but is otherwise a historical curiosity, good material for a trivia question.

A whole archipelago of space colonies at L5 was called for in a grand design to rescue an energy-starved Earth from a bottomless oil crisis. Unfortunately, there has been a very temporary respite in that crisis, but it was enough to squelch all political interest in this country which has raised short-term planning to the level of an art. Interest in solar power satellites, the anticipated principal export of these space colonies, remains strong in the U.S.S.R and Japan.

Meanwhile, a 2nd energy gambit to a future space-anchored economy, mining lunar Helium-3 (600 times as abundant on the Moon as on Earth) to fuel a very clean form of nuclear fusion plant that would essentially emit no neutrons, is under serious study at the University of Wisconsin in Madison. Both scenarios require a permanent return to the Moon, but the export tonnage in the newer scheme is far less.

Yet a third possibility awaiting further development in high temperature superconductivity is a girdle of Moon-sited solar power stations linked by superconducting cable so that solar energy could be beamed by way of relay satellites to all parts of Earth at all times of the month. Neither of these new energy schemes would drive substantial development of space colonies, settlements, or "oases". But any plan which calls for integration of the Moon into the economy of Earth will need at least some space-based manufacturing. Space oases will be built.

Once lunar resources form the major portions of Oases' import tonnage (not only raw materials but necessary provisions, etc. as well) -- say 90% to 95% or more -- it will be far more logical to site them in low lunar orbit (LLO). Since it is far cheaper to build and maintain equal habitation on the lunar surface where everything is at hand and expo-sure to radiation is halved (the lunar surface blocks half the sky), these manufacturing and construction camp oases will be occupied principally by production workers on tours of duty from their homes on the Moon where their families remain.

Since only production personnel are involved, and since what will be essentially dormitory space with condensed recreation facilities can be provided in significantly greater density, the productivity of such LLO oases per ton of structural mass should exceed that anticipated of the classical L5 colony by an order of magnitude (10) or better, making it far more economically viable. Since these workers would be adjusted to one-sixth Earth-normal gravity on the Moon, their construction camp oases would provide the same level. This is another enormous advantage since, given the supposed maximum spin rate of 1 rpm to avoid serious Coriolis problems, the lower gravity facility can be built with a proportionately reduced radius and would be subject to proportionately reduced structural stress.

From LLO, finished products, even very large structures, could be sent on their way to destinations closer to Earth, just as easily and cheaply (if not more so) as the bulk raw materials from which they would be constructed. Nor is alleged reduced access to sunlight in LLO a real problem. Even at the equator, the boost available from lunar rotation is only nine miles an hour (compared to 1,000 MPH on Earth) so that positioning and launching to and from LLO oases in sun-synchronous lunar polar orbits along the terminator is no problem at all. Around the clock sunlight will be available except during eclipses which equally affect L5 and other proposed sites. And higher lunar orbits would provide the same solar access at lesser inclinations.

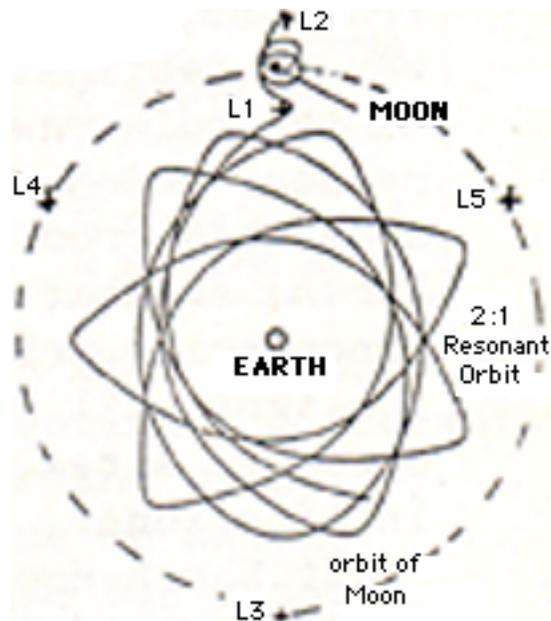
If Earth-Moon tourism ever develops volume sufficient for it, a cycling cruise oasis or transitel (transit hotel) would allow first-class travelers to spend at least the major portion of their journey in comparative comfort and luxury. At each end, short and cramped shuttle trips would probably always be their lot. A more elaborate and specially equipped "transitel" might someday allow any emigrants to Mars a more tolerable sojourn.

Such a transitel would not be a grand resort but probably provide on board education for the settlers about Mars and the technologies needed to render life possible there, and even assembly bays where they could assemble equipment that had been put aboard as parts to be used on Mars.

So much for the siting of space oases. Perhaps someday, space colonies in the now classical sense will be built, and the economic needs that drive their construction will determine where they are located. This we cannot now foresee clearly.

MMM

The original article is online at: <http://www.asi.org/adb/06/09/03/02/011/first-locations.html>



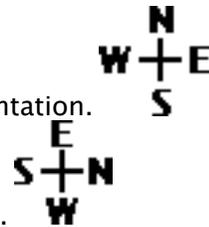
## SPACE OASES Part 2: Internal Bearings

EAST BY ANY OTHER NAME ... “Spinward” and “antispinward” are common parlance for space colony enthusiasts. A prestigious author, for some unclear reason, coined these terms and they have been parroted ever since. Why is a mystery. On Earth, which also spins, “Spinward” is quite simply EAST. “Antispinward” is equally plainly WEST. There is no good reason not to transfer these familiar terms to the space oasis environment. Since it will be important that captains of incoming ships not be confused, the external convention that when facing East, North is to the left, will be preserved. This will result in an apparent reversal inside the oasis. That is, when facing East (the direction of spin), the wall to the right will be the North wall, etc.

The only other adjustment involved is for up/Zenith and down/Nadir. These are not quite simply reversed, since on Earth they are defined in respect to the center point of the planet, while on the space oasis, they will refer to the axis line of rotation -- not the same thing. Why is this? Because Earth gravity is inward toward the center of a sphere. Oasis gravity is not just outward, but toward the outer surface of a cylinder.

How can we expect to reach the public if we continue to use esoteric terms needlessly? “Antispinward” indeed! Give me a break! Repeat after me one thousand times: “East is East, West is West, North is North, South is South.” Now that’s not so hard, is it?

On Earth, custom gives the place of honor to North in both map and globe orientation.



On Space Oases, the corresponding legend will surely key on East.

The space oasis or colony provides simulated gravity through centrifugal force against the outside wall by spinning at 1 rpm, 1440 times faster than Mother Earth. This produces exaggerated Coriolis effects and prevents us from trying even faster rates for sustained daily activity. One of the things a first artificial gravity facility in low Earth orbit (LEO) ought to determine is whether it makes a difference if work stations are set in the line of rotation (against a North or South wall) or perpendicular to it (against an East or West wall.) It may make no difference. But if it does, it may be advisable to provide subtle heading (vector) clues, for example by color coded strips at eye-height on buildings and room walls alike, that would alert the subconscious to the direction one was facing and automatically (learned instinct) adjust the way one made changes of orientation or movement.

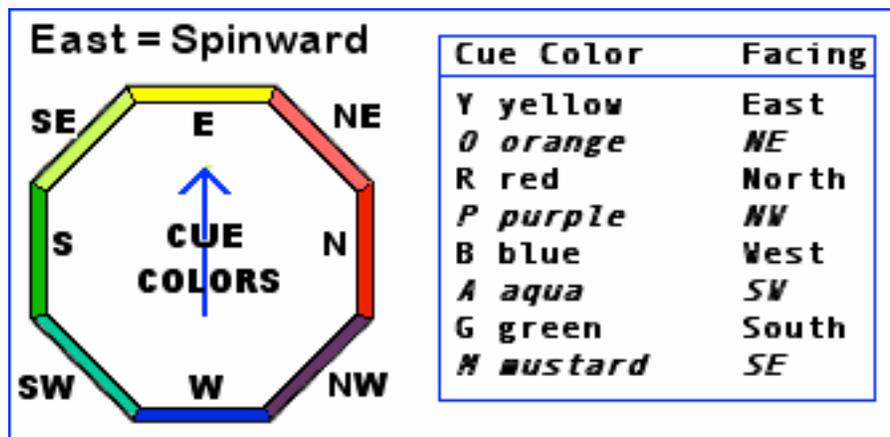


Illustration by Peter Kokh

Above is one possible arbitrary color-cue scheme (based on the well-known “color wheel”.) While color-cueing may not be critical to survival, it could speed adjustment. Certainly, an experiment could do no harm.

Sports will be drastically altered by the “English” put on balls, etc. by Coriolis effects. Orienting a court or playing field North-South would produce an entirely different “game” than with an East-West orientation. Experimentation will quickly determine which orientation will be standard for each sport.

At the start of each game or match, opposing players or captains might toss not only to serve/bat/receive but also to see which side faces East, or North, as the case may be. Changing directions of play at halftime or between quarters would produce an even-handed game and the proverbial “level playing field.”

Some teams and players may be more adept at playing in one direction rather than in the other. If there is a league, with each team having its own home field, “home field advantage” would take on a whole new meaning.

Coriolis effects will make oasis sports far more challenging and difficult to master than corresponding sports on Earth. And, of course, it will be the young players who catch on more easily. At first the results are bound to produce slapstick play. But as players get the feel of this strange environment in which direction matters, and master it well enough not only to compensate for Coriolis effects but also to take advantage of them, telecasts of inter-oases matches may rise to the pinnacle of popularity with armchair spectators on Earth.

### **SPACE OASES, Part 3: the Moon, and Different Drums**

I have met space colony enthusiasts who look down their noses at those preferring planetary situations, as if they/we were mentally inferior, capable of believing any old none-sense (“flat-Earth” or “hollow Earth” types.) They pride themselves as members of a vanguard elite having graduated to a transcending view-point which rightly sees planetary preference as a leftover of some Neanderthal protomind. After all, simple mathematics shows that “Sun-space” could support population enormously more vast if the planets were dismantled to support construction of billions of space colonies!

But it is not just a question of adjusting to life on an interior surface as opposed to an exterior one. One must also be prepared to abandon nature-carved environments for ones totally man-made and artificial – great “zooscapes” in the sky for people! The strength to make such a transition does not come to everyone. Yet for some, this sacrifice will be easy. Either they are not vulnerable to the Sirenic wiles of natural beauty or they have the fortitude to cast such temptations aside, confident that nature survives in the microscopic elements that make up even artificial things. It takes an ability to be wholly satisfied and fulfilled by nature in little bits and pieces as afforded by planned landscaping such as we see everywhere in urban and suburban places.

It could be that this new breed of person is at the forefront of human evolution, while those of us who yet feel the call of the wild, of raw and untamed nature, and who need occasional “fixes” by immersing themselves in “surroundings not made by man,” are relics of an earlier age, displaying some

sort of mental tailbone. If we fail to adapt, do we not deserve to be bypassed, doomed to some develop-mental cul de sac?

It may be that those who cannot make the leap to total acceptance of the space colony vision are driven by silly misgivings, such as the fear that the inviting posters of colony interiors showing replicas of the Golden Gate Bridge and great pine forests are cruel hoaxes. After all, the demand for maximum utilization of limited space within each colony oases must inexorably crush all other considerations.

Or perhaps they/we fear that the promise of Athenian (direct) Democracy notwithstanding, space colonies may never succeed in casting off startup status as vast "company towns". Or might it be that some of them/us are antisocial and prefer a rural life such as may well be afforded by scattered inter-settlement sites on the Moon and Mars?

Perhaps they/we are addicted to star-gazing and cherish scanning the heavens at a more indolent pace than once a minute. Or do they/we harbor shameful suspicions that the very population pressures on Earth which motivate many to embrace the space colony concept will nowhere be more acute than on those very colonies themselves, transforming them from early Edens-Regained to the ultimate in stifling ghettos with no escape.

Some few of them/us may be eccentric artists and craftsmen who imagine some intangible advantage in being close to the source of the raw materials they work with. Then too, it may be the glorious megastructure concept which frightens some, being accustomed as they/we are to human settlements that add one abode at a time and continually redefine and reinvent themselves in search of youth. Such archaic throwback attitudes ought not to be lamented, however. One must accept that not everyone can be ancestral to the (space colony) future!

However, it serves no purpose to argue which of these two mentalities is the superior. Why not rejoice that there ARE people of both types FOR BOTH ARE NEEDED to develop the space frontier!

Those "risen above" planetary chauvinism have sketched scenarios in which the planetary bonds (such as the "degrading" lunar mines) are wholly teleoperated. But there is no need to find ways to avoid condemning some people to life on the Moon so long as there are people, atavistic and misguided or not, who would cheerfully embrace just such an opportunity. It is not necessary for would-be space colony citizens to understand this strange caste, only to accept them/us as an alternate form of humanity and let them/us be happy in their/our own quaint ways.

Someday we will all be grateful that there were, in our day, people up to the challenge of a rough and rugged frontier. To borrow a phrase, **Vive la difference!**

## MMM #12 - February 1988

### Space Oases Pioneers Quiz

#### QUESTIONS

1. What are the principal advantages touted for space colonies over lunar settlements?
2. Why are O'Neill cylinder colonies usually depicted as paired and connected at the poles by cables?
3. How much more Nitrogen is needed in a sphere versus a torus per person, all else being equal?
4. The proposed maximum of 1 rpm rotation rate puts minimum size limits on a space oasis. However, they may be built to larger radii at lower rpms. Is there anything which might motivate standardizing the diameter?
5. In a torus, the purpose of the spokes is
  - a) to provide structural tension & support;
  - b) to function as freight conduits for supplies/products to/from the colony exterior via a central hub;
  - c) to allow people to travel to and from the zero g areas in the hub/axis;
  - d) to cluster convenient high-rise office & apartment complexes at intervals within the torus interior;
  - e) to serve as a short cut to the other side
6. How many O'Neill cylinders will it take to exceed the Moon's surface area?

#### ANSWERS

1. Three advantages are especially mentioned:
  - a) The availability of full time sunshine;
  - b) The freedom to select any gravity level desired, especially Earth-normal or 1 G
  - c) Ultimately, a far greater habitable surface area, given enough colonies -- if there is enough economic advantage in actual space development to support expansive outmigration from Earth.
2. A rotating cylinder tends to precess in its orientation in a surrounding gravity field, such as Earth's, just as a top will. If two counter-rotating cylinders are tied together, this tendency of their orientations to drift will be neutralized. This "elegant" solution is yet another instance of static thinking: mating two cylinders essentially for life. A more biodynamic alternative would temporarily pair one completed colony with another under construction which, when completed, would be set free to "reproduce" in like manner. The first colony would then begin construction anew on yet another offspring. This is the pattern in which many one-cell organisms reproduce in nature.
3. Assuming 1 rpm, 1G, 1 ATM of air pressure at standard mix, a density of 1 person/67.2 square meters (/730 sq. ft.) for both, the sphere would require 25.7 tons of nitrogen per person, the torus only 4.4. The sphere needs to import almost six times as much nitrogen per person! The cylinder would be somewhere in between, making the torus the most efficient in this one respect.
4. Because Coriolis forces are so noticeable in centrifugal environments, and because their strength varies with the rpms, inter-colony sports will only be fair to all if each colony has a standard radius and rotation rate as well as gravity level. There will be two leagues and no interplay between them: an Earth-normal league and a Moon-normal league. A colony which chose non-standard parameters would likely not be invited to join the league in its gravity class.
5. a, b, and c are all important, but in that order. d is purely frosting on the cake, an opportunistic usage. e is something perhaps everyone will try once, but as it will be disorienting and probably not save time, few will try it again, except the children.
6. An O'Neill cylinder with a radius of 900 meters and length of 9 km would have about 14 square miles of habitable area if you subtract for windows. The Moon's surface exceeds 14 million square miles. It would take a million O'Neill colonies of the size mentioned to equal that area. Starting at the rate of one a year, doubling that rate every year (an improbable goal) it would take 10 years to build the first 1023, and the millionth would be completed before the end of year 20. Such a rate of increased construction, workers, materials supply, energy etc. could never be maintained. This touted goal would likelier take centuries if it could be maintained at all.

**MMM**

## **SPACE OASES Part 4: Static Design Traps**

What is the shape of things to come in free space? The economical torus or the great spherical and cylindrical megastructures with their sweeping world-at-a-glance views? These possibilities all have their partisans, often on purely aesthetic (subjective) grounds. However, work done before and during the 1977 Stanford design study workshop suggests some important advantages of the torus and corresponding disadvantages of the sphere and cylinder that will constrain real world choices.

The original "Island I" design proposed by Dr. O'Neill was the Bernal Sphere depicted above right. It would have had a circumference of one mile, had room for 10,000 residents and, to provide Earth-normal gravity, would spin at a rate faster than 3 rpm. It is now widely agreed that because of the physiological effects of strong Coriolis forces, the maximum spin rate ought to be no more than 1 rpm. At that spin rate, a Bernal Sphere of the size proposed would have 0.3 gravity maximum. Thus a sphere of this size (or a hair larger) is a likely "starter" colony for those willing to live in a Mars-like gravitational field, and certainly (at a yet slower spin or even smaller radius) for those content with lunar gravity levels of 1/6th Earth-normal. But for those who insist on a full "G," the Bernal Sphere at 1 rpm must be up-sized considerably to almost 3 and a half times the radius (a diameter of 3.5 miles) which would square the area enclosed and cube the mass and the construction materials needed, and have a capacity for 120,000 residents at the same density. This is now hardly a "starter" project!

### **Superiority of the Torus**

However, a torus of the same radius, rpm, and with an internal radius of 65 meters (about 420 feet wall to wall) -- the parameters of the chosen Stanford Torus design -- would be sized right for 10,000 persons. By the same token, a Mars-gravity torus could be sized for 3,800, and a Moon-gravity torus for 1,600 (in both cases, keeping the 65 meter radius for the habitable interior of the torus.)

Nor is the much lower threshold size of the torus its only advantage. For the sphere and cylinder, the interior and exterior radius are the same. But the far smaller interior radius of the torus translates to a greatly reduced structural mass per habitable acre needed to contain a given atmospheric pressure. More, the amount of Nitrogen needed as atmospheric buffer gas, a constituent that must be imported from Earth, Mars, or even Titan at great cost, is obviously greatly reduced in the torus design.

But the list goes on! Neither the sphere or cylinder lend themselves to segmentation, and thus cannot be built in modular fashion. They are "megastructures", "archologies", which must be built all at once and which in the beginning will be underpopulated, then briefly just right, and thereafter ever over-populated.

In contrast, a torus can be built two segments at a time (two, because construction must always be balanced 180° if the structure is not to become eccentric in its angular momentum distribution.) As soon as a hub, two spokes and two segments are built -- essentially a barbell -- occupancy can begin.

Closable bulkheads are likely to be a relic as such segmented construction and this is a great safety advantage for it provides distributed vulnerability as opposed to the shared vulnerability (to catastrophic puncture or rupture) of the sphere or cylinder. Yes, the torus can also be built all at once, if recklessness has the upper hand.

The point is that a segmented approach reduces the threshold of habitability to a third (a pair of 60° wide segments) or less (smaller starter segments.) The settlers can move in and set up shop and begin production for export and expand their worldlet to a full torus (the "imago" or design goal) as success warrants. This flexibility will be of especial importance at the outset of the free space colonization venture, when there will still be many doubts about the validity of all the paper studies, and while the financial backers remain spiritual natives of the State of Missouri.

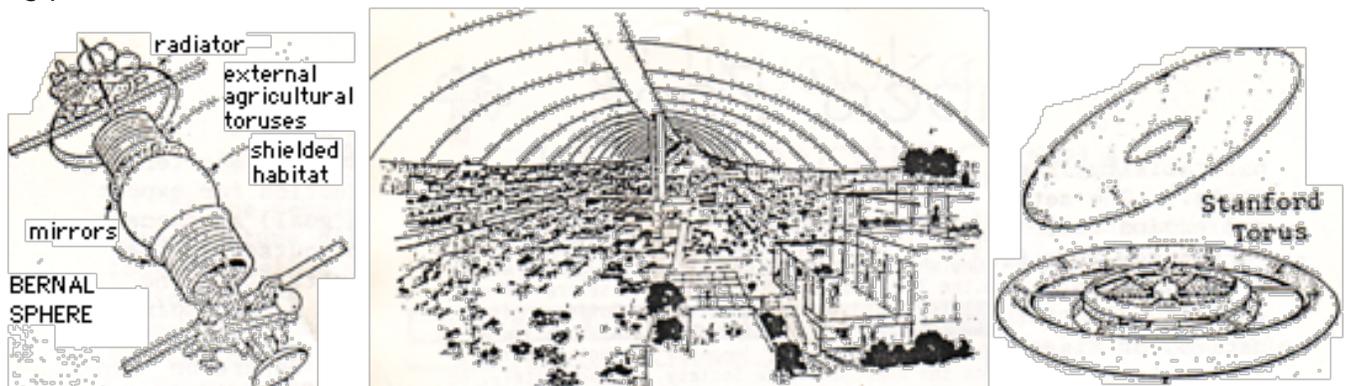
Consider, what is a "world?"

Nor is this all! Surely the most Sirenian feature of the Bernal Sphere or "Sunflower" Cylinder is the spectacular sight of the whole worldlet in one pan from wherever one is situated inside. But just as in Homer's Odyssey, this feature is a siren that lures the unsuspected into a psychological whirlpool.

It is customary to define "world" as a total or integral theater for human life. But that is an incomplete definition.

"World" also denotes a contiguous set of life-spaces only a small portion of which is within sight or above the horizon at a time.

We are used to most of the world being beyond our survey at any given moment. There is the suspicion, felt by the Stanford group, that this is the healthier situation. Given the parameters of the Stanford Torus, no more than 30% of the torus would be visible below the upward curving horizon provided by the torus ceiling at any one time. Cabin-fever would at least be delayed or mitigated accordingly.

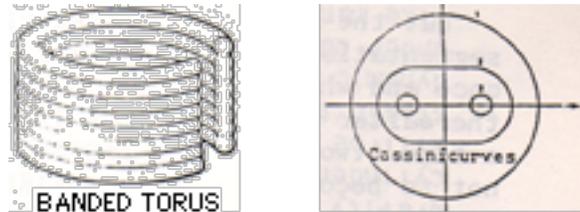


**Left to Right:** Bernal Sphere, inside and Outside of a Stanford Torus

It is the likeliest scenario then, that the real world "Island One" will begin as an expandable barbell able to grow into a full torus if the economic expectations of space development are proved out.

This low-threshold foot-wetting is far more likely to see the light of day (than the original "Island One" -- the Bernal Sphere) given the conservative nature of venture capital.

But this is only a beginning. Can such a beginning lead somewhere? As designed in the limited ten-week time-frame allowed the 1977 Stanford Study participants, the torus seems a dead-end, incapable of growth, due largely to the solar access system planned for it which involves a large unitary free-floating mirror (at an angle above the torus in the illustration top left.) The mirror's purpose is to direct sunshine through chevron portals into the interior of the torus. I can just see this mirror suddenly shattered or dislodged and floating away in some accident waiting to happen! (The Island III cylinder's "sunflower" petal mirrors, subject to up to 6 Gs at the tips, whirling through space at over a thousand mph, tied to the cylinder itself through cables, seems even more fate-tempting!) But the point is that this system does not allow the torus to expand easily by adding extra bands or clones, side by side.



A banded torus could expand to constitute a world-let of the projected population capacity of the sphere or cylinder. The banded torus, if an alternate solar access system were developed, would still have some less than ideal features. Each torus band closes in on itself, biting its tail. While an improvement over the sphere and the cylinder in many significant respects, each of its bands is an all too tiny world unto itself. As a whole, a banded torus would be over-compartmented disjointed whole promoting excessive neighborhood loyalty at the expense of any at-large settlement identity: an open invitation to fiefdom politics and unhealthy rivalry between band bosses. I might take external threat to encourage cooperation.

But why dwell on space opera plots if there is yet another choice? Whoa! you say. The barbell, sphere, cylinder, and torus are the only possible three dimensional balanced forms allowed by rotation of the appropriate subset of Cassini curves. Such is the Ivory Tower belief of the all too common mathematician-engineering types who would not dream of crossing disciplines to sully themselves with the dirty examples to the contrary provided by Mother Nature in happy abandon.

What is more important? Professional superiority complex of bursting open the barriers to free space settlement? If biology suggests a bypass of the Cassini impasse, I say let's have a look. So dynamic an idea as free space settlement is inappropriately hamstrung by STATIC DESIGN TRAPS.

## SPACE OASES Part 5: A Biodynamic Masterplan: The Triple Helix

### The Ivory Tower at its Worst

If those involved in space colony design to date had been consultants to Mother Nature billions of years ago, none of us would be here today. For one overlooked possible derivation of the Cassini curves is generated quite simply simply by moving figure 3 [above] along the r axis as well as around it. This elementary innovation provides the dynamically balanced double helix of venerable DNA antiquity, genetically radical to life as we know it.

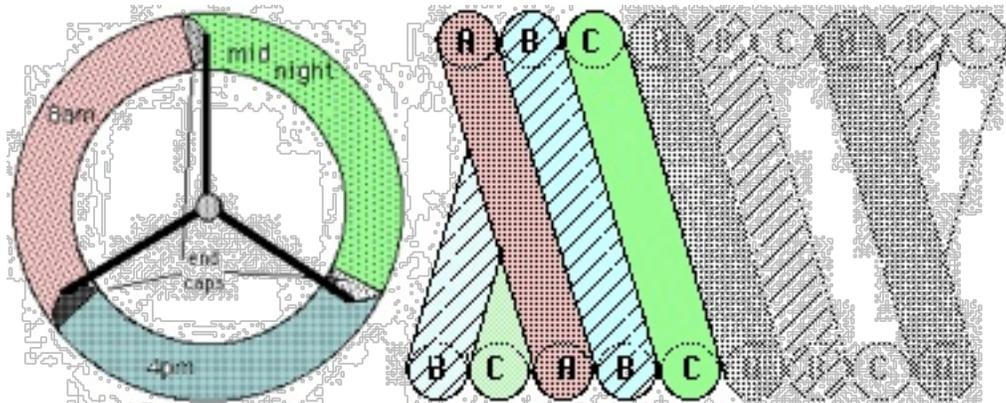
### Exploring the Helix Architecture

Because the helix is double, it can grow indefinitely at tips  $180^\circ$  apart and always be stable. [To construct a crude model, take two thick helical springs with gaps about the same size as could thickness, spray paint one a different color, and intertwine them with end tips diametrically opposed.] The double helix has the same starting point (conceptual and construction-wise) as the torus: the barbell; but its growth is canted either North or South as the segments are added so that when a half-whorl is completed, it lies adjacent to the start of the opposite whorl and so on. The result is a "twin valley" system which can be extended indefinitely apace, creating a larger, and most importantly, an open-ended worldlet.

A dozen double whorls of the same parameters as the Stanford Torus would provide, in a space a little more than a mile wide and a little less than two miles long, two valleys, each forty miles long,

and room for a quarter million people. The two valleys of a Double Helix Oasis or DHO could be similar or one could be given to a residential centered mix of land uses, the other to a commercial-industrial centered mix.

A triple helix starting with a “Y” shape 3-armed dumbbell with arms and growing points 120° apart is another possibility, which would allow time zones eight hours apart for the ideally “fair” three-shift work system. This would allow factories and schools and other facilities to be used cost-effectively around the clock, all manned by persons on their own personal “first shift.”



The DHO spokes would line up in opposing pairs “hand over hand” fashion along the central axis, maintaining structural integrity. This extends the comparison with the architecture of the DNA molecular structure. One pole of the axis would serve import-export functions, the other, continued expansion. At the original starting end, the twin coils could be extended vertically pigtail fashion to the axis, allowing graduated adjustment zones to and from lower gravity levels for immigrants and emigrants as needed. This, of course, would effectively close the interior “bay” at one end -- a choice which would, I suspect, have more pluses than minuses.

A significantly greater greater fraction of a DHO interior would lie beyond the horizon. In the sample twelve double whorl metropolitan colony sited above, no more than 1.25% would be visible from any one vantage point, while still offering vistas of the order familiar to Earth-side city-dwellers. Certainly this would provide a much more world-like situation!

### Life Expectations for Oases Youth

Children born in a DHO or THO, could grow up assured that they could continue to live out their lives, if they so choose, in their familiar growing homeland, rather than being forced to migrate to a new colony because their parental one was already at capacity. To be sure, expansion might someday reach a point at which further growth would be seen as undesirable, but then limits in one form or another will always act as gravity to human spirits. For sustainable mental health, the DHO or THO is the only choice. The Bernal Sphere, Sunflower Cylinder, and Stanford Torus might be “great places to visit, but you wouldn’t want to live there!” Perhaps these classic space settlement designs are best suited for use as resorts or even “national parks” -- places to visit, not to live in!

### Design Challenge: Sunlight Delivery Systems

The big design obstacle to the DHO or THO -- as well as to any banded torus -- is the perceived difficulty in furnishing adequate insolation: solar access to all parts, bringing in the sunshine! I say “perceived” difficulty, because it results from an unnecessary restriction to a mirror delivery system.

In conventional space oases designs -- sphere, cylinder, torus -- some two meters or six feet of fused lunar oxides surround the exterior as shielding against radiation, solar flares, and micro-meteorites.

This shielding is co-rotating and attached, except for the Stanford Torus in which it is immobile, separated from the rotating exterior surface of the torus (relative speed is 205 mph) by a gap which hopefully would be maintained by some sort of failsafe system. In either case, the shielding mass serves no additional function and is seen as but a handy repository for that fraction of imported raw lunar soil not actually used for other construction or manufacture -- tailings residue.

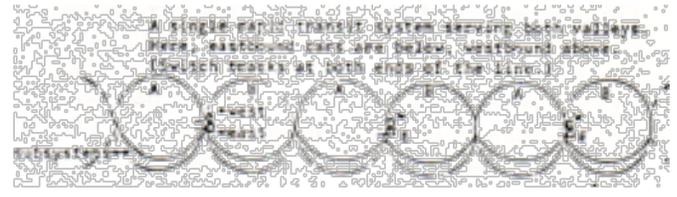
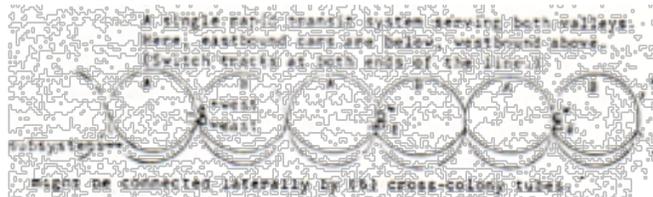
Such a solution is not as elegant as it might be.

[“Elegance” can be defined as the killing the most birds with the least stones.]

Instead, at least a major portion of this shielding mass could consist of fiber optic cables. At each point along the exterior (the axis of the DHO or THO would be perpendicular to the Sun and not pointed at the Sun as in the mirror-using designs), the sunlight catching ends of a set of strands of varying lengths would point outward. As construction proceeds, optic cable coils originating at various points would be unwound in a bias ply pattern with the ends of many coil-sets entering the colony at each point along the ceiling curvature to distribute sunlight evenly throughout the whorls. This should not interfere with periodic lateral openings from one valley to the neighboring one. Such a sunlight delivery system is modular, expands apace with the colony, and contributes tensional strength to the envelope as well as contributing a major portion of shielding mass. It would be less subject to catastrophe than any mirror system using a combination of great outrigger mirrors (with high angular momentum) and cumbersome, structurally suspect, chevron panels. The degradation on the optic fiber system over time due to adverse exposure would befall other systems as well, and is a challenge (design, materials, changeout facility -- or all three) that needs to be addressed.

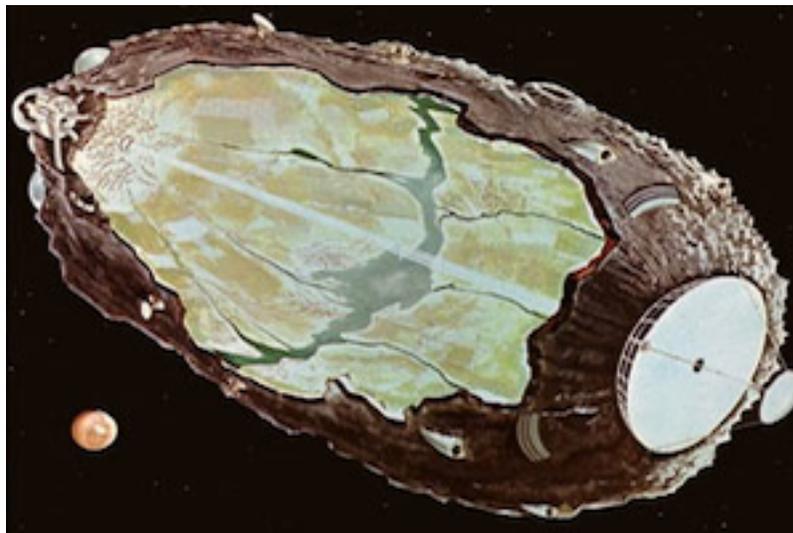
**Escaping the Static Design Trap**

The Double or Triple Helix Oasis plan is offered here as a way out of the static design traps inherent in the torus, sphere, and cylinder. It is a concept which has benefited from only one person's input and is hereby thrown open to constructive criticism needed to bring it to design maturity. It is the only oasis plan that would provide an environment in which I can picture myself without unendurable restlessness.



**Left:** The transportation Grid of a DHO/THO

**Right:** A single rapid transit line, mounted in the sidewall of just one valley in a DHO would link the entire growing complex.



The idea of hollowing out asteroids preceded the plan to build space settlements from scratch.

**MMM #13 - March 1988**

**Space Oases Artificial Gravity Quiz**

**Questions**

1. Will an approaching shuttle craft find it easier to dock at the hub of a spinning space oasis or at the rim?
2. If anything has to be vented from the oasis, where will be the best place from which to vent it?

3. L5 at this future time is just a construction site, but tourist ships from Earth and from the Moon visit it anyway to take in the grand sight. What's to see?
4. Why is the "erector set" boom the most expensive part of the current NASA space station design? And would this same consideration affect a boom for a spinning barbell shaped artificial gravity facility
5. If at 1 rpm, the required radius of rotation to simulate Earth-normal gravity is about 900 meters, what would be the required radius of a training facility for volunteers to crew an aerostat/balloon laboratory in the upper reaches of Jupiter's atmosphere?

## Answers

1. the conventional wisdom is at the hub. To dock at the rim would take perfect timing, leaving no room for error. On the other hand, docking at the rim will not be the straight-forward maneuver one might expect. Whether the hub-port co-rotates with the oasis (as in the film 2001: a Space Odyssey, making it necessary for the shuttle to match spin rates -- and axes of spin -- before nosing in) or whether the hub-port does not share the general rotation, there is an overlooked factor that could be very troublesome. No matter how carefully the oasis has been or is being built, with attention to diametrically balancing both exterior shell and interior structures, it will be difficult to keep the actual center of mass and artificial gravity lined up precisely with the physical hub-port structure. Add ongoing movements of personnel and goods within the station, and there must be a non-zero residual "wobble." To the incoming shuttle pilot, the hub-port will appear to oscillate eccentrically once a minute. If this wobble can be kept to under an inch -- a tall order -- docking will only be bone-jarring. More than that, and it might be impossible. "Passengers will keep vomit-bags handy!"
2. The rim, where centrifugal momentum will carry the substance away from the oasis on a tangent. Anything vented at the hub will tend to hang around, adding to a hub-hugging fog.
3. Perhaps the most beautiful sight this side of the Moons of Saturn: the twin worlds, Earth and Moon, suspended together in space 60° apart, an ideal compromise between too close (to take them both in at one stereoscopic glance) and too far (to see the usual naked eye detail). The Moon will appear the same size as seen from Earth, Earth the same size (3.7 times as wide as the Moon) as seen from the Moon, and sixty-some times as bright, phase for phase. The two will show phases some 60° out of sync, and watching this celestial pas de deux through a four week phase set will be a once-in-a-lifetime dream.
4. In LEO, low Earth orbit, the space station will transit from sun to shadow and from shadow to sun-light every 45 minutes or so. It must be prevented from flexing as it warms or cools alternately lest the micro-gravity sensitive work inside the station be disturbed. This could have been arranged by loosely wrapping all the boom elements in crumpled foil, but NASA chose to develop a special composite with zero-coefficient of thermal expansion (great for spinoff but tending to financially preempt further space achievement steps.) This sensitivity will not be important for an artificial gravity facility.
5. Gravity at Jupiter's cloud deck "surface" is about 2.7G, so the training facility will need a radius of 2.4 km (1.5 mi.) at 1 rpm.

## Space Oases Part 6: Back at Square One: Baby Steps with Artificial Gravity

By Peter Kokh

I remember my somewhat bitter disappointment on first seeing early NASA proposals for a space station. Where was the great wheel? Didn't they want artificial gravity? How could they take so lightly the great visions of Tsiolkovski, Noordung, Von Braun, Clarke, and others? At first the answer seemed to be that the purpose of this station was to allow micro-gravity research in materials processing, and this would, of course, rule out pseudo-gravity.

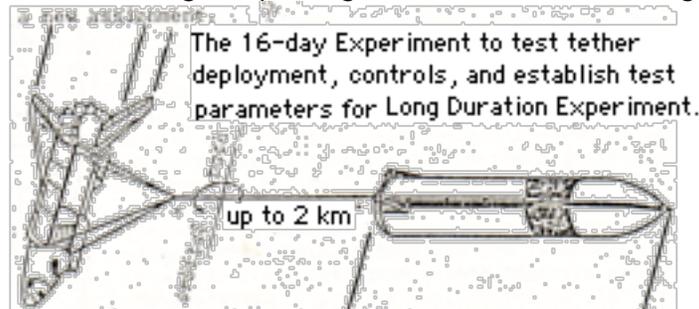
However, there are more profound considerations why our first station could not be a rotating one. To induce full Earth-normal gravity, all the early, now classic, designs necessarily counted on a much higher rotation rate allowing a correspondingly smaller radius, than we now feel humans can reasonably be expected to endure on any sort of long term basis. At a more reasonable and leisurely 1 rpm the radius of a full Earth-normal gravity providing station must be on the order of a discouragingly

large 900 meters, more than half a mile. Such a reality check requirement renders the traditional torus/wheel a development well into our future.

But what about reducing the torus to its barest essence, a rotating barbell? Even this, on the scale necessary, would be an ambitious way to start. Yet, if we wanted artificial gravity bad enough, it shouldn't be that difficult a challenge. Sooner or later -- far better sooner than later -- we must get our feet wet with artificial gravity. Too much depends upon it. Will humans, plants, and animals thrive indefinitely at such mid-gravity levels as the 0.38 G of Mars and the 0.16 G of the Moon? If so, how much lower is the threshold above which physiological deterioration will level off on a plateau we can live with? Will the 0.03 G of Ceres be sufficient? Will we be better off providing artificial gravity on the six to nine months long journeys to and from Mars? And what is the minimum radius/maximum rpm that will be suitable for a general population environment such as on a free space oasis or settlement?

There is no reason why our first experiment with artificial gravity in space cannot be arranged at quite low cost within the next two years.

NASA has already agreed to begin flying the External Tank to orbit on request. Studies have already outlined the possibility of releasing the External Tank on a tether, inducing rotation into the Orbiter-tether-Tank "system" in the plane of the orbit and simultaneously releasing the orbiter at the bottom of the swing so it de-orbits without the usual burn, while the External Tank is released at the top of the swing to coast into a safe higher "parking orbit" to await retrofitting for a new assignment.



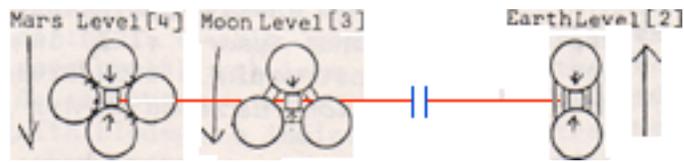
A much more limited but similar test was carried out in September 1966 on the Gemini II mission in which Richard Gordon, in an EVA, fastened a tether from the Gemini capsule to the Agena 11 rocket after the latter had been used to boost Gemini into a record 850 mile apogee orbit.

If the tether can be reeled in or out to say 2 km, the Orbiter and External Tank combo could afford experimentation with varying radii and rpms and gravity levels over the length of an Orbiter mission, at first, no more than eight days, but eventually up to sixteen days if the extended duration capability that NASA now wants is approved, as is likely, since it was a Congressional idea. [This capability will be available at an estimated \$126 M about 45 months after project commitment.] Since this will be a temporary rotating system with the crew already aboard and resupply unnecessary, docking and undocking need not be addressed,

While such a short experiment -- even at a maximum 16 days -- will not answer questions about long-term physiological and biological effects, it should allow us to document current expectations about what the design parameters -- radius and rpm -- should be for the first long term facility. If, for instance, a 16 day mission shows no problem with say a 1.5 rpm rate, this would be extremely important.

Given the minimal development & mission costs of this entry level experiment in artificial gravity, and the importance of this concept basic to all space development scenarios, the National Space Society should, without delay, adopt strong advocacy of such a demonstration.

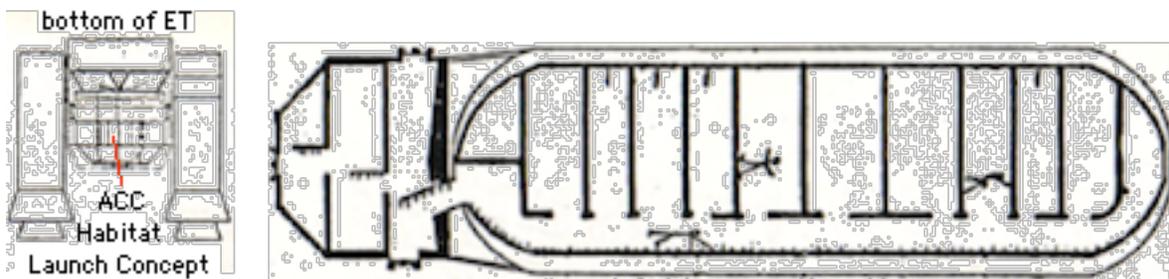
Moving Beyond -- what should be the minimal design requirements for a long-duration artificial gravity facility? I would think, considering mankind's future ambitions, that we should be looking at a barbell arrangement that balanced an Earth-normal habitat/lab at one end with Moon-normal and Mars-normal facilities at the other. Our "suburban tri-level" should have ample space to test effects on plants, animals, and humans, with the necessary lab equipment.



Arrangement of the Clusters of habitat/Lab Units seen from above (along the boom). The large arrows show the direction of spin. The small arrows show entrance to the commuter pod traveling inside the boom.

The expectation would be that, barring unforeseeable emergencies, a crew could remain aboard for a year or two without relief. Therefore the crew could be put aboard prior to spinup and taken off after spindown. Thus docking facilities need only be provided for consumables and volatiles that can be pumped through conduits (or moved on snag-proof conveyors through same.) Visits between the three gravity levels could be provided by a pressurized pod traveling through the boom.

As to the habitat/lab units themselves, we could combine a sparingly appointed liquid Hydrogen tank (lower 2/3rds of the ET, 97 ft. long and 27.5 ft wide and twice as spacious as Skylab) with an elaborately equipped Aft Cargo Compartment module to ride into space just below the External Tank.



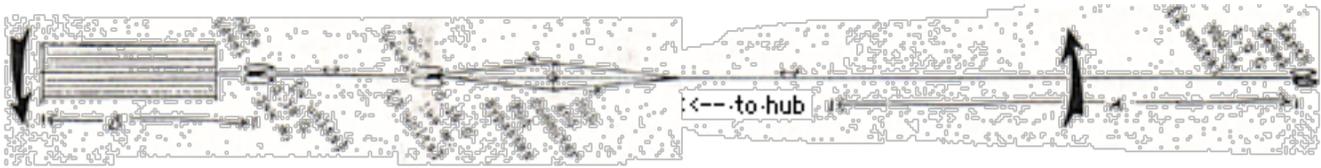
**Above:** ACC is seen attached to the bottom of an outfitted Shuttle External Tank

Putting all the electronics and laboratory equipment in the ACC would minimize the retrofitting task for the emptied hydrogen tank. As to the tank, I find suggestions of inflatable floors and dividers a little humorous when a simple alternative can be pre-built into the tank with zero effect on its fuel-feeding performance: floors, walls, shelves, and stairs or ladders out of aluminum grating through which the LH2 would flow with ease. Once in orbit, it could be quickly retrofitted with a simple wiring harness and flexible plumbing. "Carpets" could be unrolled on grating floors, blanket tapestries hung on grating walls for privacy, and sleeping bags moved in. On the experiment floors, biology trays need only be carried in and set on the grating shelves. It should take less than a day for the crew to make the tank home sweet home. There is no need to be more elaborate than this< if we put all the complex stuff in the pre-outfitted ACC.

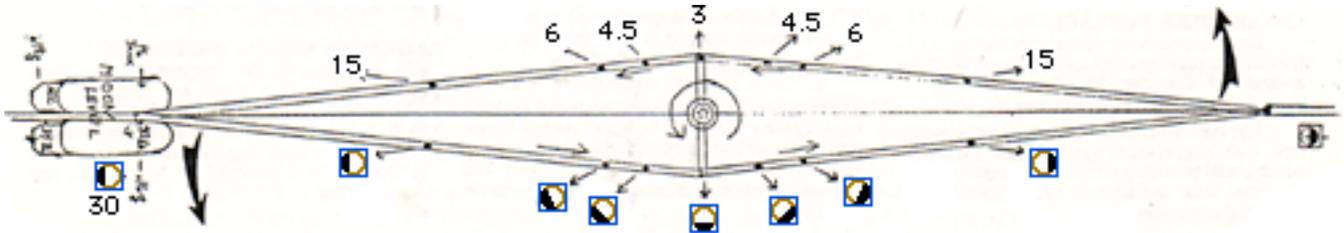
Extra insulation could be applied from the outside perhaps by simply unrolling fiberglass batts around the tank and applying a thin micrometeorite shield (does not need airtight seams) over that. All the hard-to-install equipment (medical, biological, life-support, computer/communications etc.) would already be in place in the "dry" ACC before it left Earth.

How do we balance this orbiting teeter-totter? Neglecting the boom for a moment, we find that quite conveniently, two of our LH2/ACC units at the Earth-normal end are perfectly balanced in angular momentum by three such units at the Moon-Normal level and four at the Mars-normal level. Assuming the radius at the Earth-normal level is 900 m. at 1 rpm, the Lunar facility will be centered at 144 m past the hub on the other side, and the Mars complex at 342 m. from the hub, down the boom from "Little Luna." [How much space is ideal at each level does not enter into the equation. That "Mars" gets the most space is an opportunistic result of neutral mathematics, and not of personal preference.]

The greater boom length with its attendant angular momentum on the Earthlubbers end [A] can be counterweighted by extending the opposing boom past the Martian facility and using it as support for an appropriately sized Solar Power Panel [B] This panel could be slide-mounted to act as an adjustable ballast to keep the overall structure's axis of rotation centered on the physical hub/docking apparatus. [illustration below.]



Travel from one side to the other through the hub necessarily introduces a moment of chaotic disorientation. For this reason the boom splits in the middle (“Cislunar”) section to straddle the hub, 14 m. to either side. The commuter pod has a weighted pressurized squirrel cage compartment that neatly swivels to remain plumb to the local up/down vector. By skirting the hub, the occupant(s) will maintain some weight at all times and experience no sickening topsy-turvy period. This is shown in the diagram below with the floor of the cage shaded in black and the “weight” felt by a 180 lb. person at each point is indicated. One would always travel to the East (Spinward)



This modest Tri-Planetary Simulator needs just nine (9) ET Hydrogen Tanks and ACC units. The LOX tank and intertank are not used in the plan and can be assigned other reuses such as for a co-orbiting fuel tank farm, etc. As such it is not inherently difficult nor expensive by current standards. The LH2/ACC units, if standardized, should cost significantly less than planned Space Station modules. The shuttles that ferry them to orbit can also bring along on the same missions, the following items carried in the Orbiter payload bays: boom materials, commuter pods, solar panels and modest retrofitting items needed, etc. These requirements sum up as a less expensive project than the current MASA planned micro-gravity “space station.” Moreover, they would put in place an element that is urgently needed if we are indeed serious about permanent emigration beyond Low Earth Orbit. **MMM**

## MMM # 37 - July 1990

# SUN HELIOS SOL IN COPERNICA

## SHOULD “THE SUN” HAVE A NAME?

By Peter Kokh

While many could perhaps care less, it seems appropriate to this writer at least, that all peoples of Earth share one common name for their life-giving star. This is hardly the case.

“The Sun” is one single word into which we put two quite distinct references.

1. “The Sun” is our name for a particular star, the one we orbit.
2. “The Sun” is a vocational relationship which makes this star special: it centers a planetary system, which it bathes with warmth and life-giving energy.

In the first sense, “the Sun” is very unique, our very own star. In the second sense, it is a relationship of fostering paternity (and the origin of the idea of “the Demiurge” with semi-divine co-responsibility for our existence). And this relationship is most likely not unique. Any star with planets is, for them, “the Sun,” then is a word a lot like ‘Father’ and ‘Mother,’ i.e. a title rather than a name.

So long as mankind's horizons and its expectations of spreading domain do not overflow the Solar-System-of-our-Origin, this dual function word serves reasonably well. But as we consider the eventual out-migration forming a human diaspora that could include any number of “solar systems,” the need to come up with a non-generic name for our Sun becomes increasingly relevant.

Almost all science fiction writers who have been faced with the problem, have taken to referring to our Sun as ‘Sol’. This choice has two burdensome liabilities. First, “Sol” is once more, “the Sun” in another language, ancient

Latin. Second, the derivative, "solar," will very likely be used generically of all planetary systems, and of all star-planet relationships. In this light, "Sol" makes a rather poor and unhappy choice.

Other than Latin, we could borrow from the other classic language of antiquity. In Greek, the Sun is Helios. And again, the derivative, "helio-," is also already in use in a general sense (e.g. heliostats) and is likely to go with us to the stars as yet another generic. One way around this particular problem is to coin slightly altered adjectives to refer to out particular parent-star and its realm. For example, we could say Solaric System when we are referring to our own, and use solar systems in the generic. I can't think of a plausible parallel for helio-serving the same specific function, but I'm sure Greek-adepts could coin one. Then it becomes a matter of public education.

What about the ancient Greco-Roman god of the sun, Apollo? Alas, the word has existing currency (manned lunar program of the sixties) making it a confusing choice.

Already well known, simple, and easily internationalized, is "Ra", name of the ancient Egyptian sun god once revered in Heliopolis. But a case could be made for "Bast", another Egyptian deity who represented "the life-giving power of sunlight." Also less known is the ancient Sanskrit "Ravi" and Hindu "Surya."

Quite a different solution would be to give our own Sun a proper name adapted from that of a figure in world history who played some especially significant role in our understanding of the Sun's place in the scheme of things. My vote would go not to any recent solar astronomer but to Copernicus, the first of our species to teach effectively that the Sun, not our Earth, is the center of our system. Now his name is already given to a very prominent lunar nearside crater. One way to avoid confusion would be to use a variant form of his name. Instead of the original harsh sounding Polish "Kupernik", we could use a feminine form of the common Latinization i.e. "Copernica". Admittedly this flies in the face of the almost universal chauvinist convention of using only masculine names for the Sun, with feminine ones reserved for Earth, i.e. the Earth-Mother/Sky-Father theme of folk myths.

Perhaps you would like to suggest yet another choice? My own preference?

I would pick "Copernica" and "Ra," in that order, over the other options listed above.

It's a wide open question!

MMM

## MMM #56 – June 1992

# NAMING THE SEAS OF SPACE

By Peter Kokh

Vacuum is vacuum, right? Okay, but only in the sense that water is water! Admit the differences between salt water and fresh, between sheltered harbor waters within the breakwater and the untamed waves and currents beyond, between shallow coastal waters and deep open waters, between waters with strong currents and the brackish waters of ever-circling eddies, between crystal clear waters and sediment-laden and debris-filled waters – admit that and very similar differences must be granted descriptive of the vacuum of space.

Space does have its special "seas", and the differences between them are far more than a simple matter of "location" alone. The idea of naming them thus takes on a much greater significance than one of simple convenience or local color.

Traveling outward from Earth's surface, we first encounter that boundary layer space in which, if you want to be technical, there are still wispy traces of the atmospheric gases below. Here, in the range of low Earth orbits, in LEO, we are on the calm lee side of a "breakwater" ("breakspace"?) of sorts. For the energetic Van Allen Belts trap and divert most of the magnetically charged particles traveling through space, coming principally from the Solar Wind blowing constantly off the surface of the Sun, but also including charged particles coming in from interstellar space, cosmic rays.

This "fresh-vacuum" "lee-space" of the "Terrestrial Lagoon" can be recreated on the Moon by erection of work and construction site sheltering canopies, or "ramadas", under which radiation-damping "hardsuits" needn't be worn. Lighter "pressure suits" will do. But within and beyond the Earth-life protecting Van Allen belts, our ships will need "windbreakers" of sorts, especially if we are going to linger in these radiation-swept reaches for any appreciable length of time.

Meanwhile, we should have noticed that while Earth's coastal vacuum is relatively "unsalted" with radiation, it has also become increasingly dirty with dust and debris derived from unnecessarily sloppy and careless human activities. This **LEO Sargasso** could have parallels, if we don't clean up our act, in Earth-Moon **L4 and L5 Sargassoes**, areas where dust and debris will tend to collect and hang around. The other Earth-Moon Lagrange points are less stable and will tend to purge themselves more quickly. The corresponding Earth-Sun L4 and L5 areas centering 60° preceding and trailing Earth in its orbit around the Sun, could already be Earth-Sun Sargasso seas in space. But out here that would be a plus, if the denizen "plankton" of those "circling currents" are asteroidal chunks and snuffed cometary hulks of mine-worthy size.

The surface-lapping vacuum above the Moon, while it offers no protection from raw solar ultraviolet, cosmic rays, and solar flares, is nonetheless uniquely clean of dust, any particles with less than orbital speed being quickly purged by the lunar gravity. While only a sixth as strong as Earth's, the Moon's pull operates without the interference of atmosphere. This "**Littoral Vacuum**" will be of great usefulness to vacuum-dependent industry and scientific research.

Moving inward towards the Sun from the orbital range of the Earth-Moon system, inward from our native eco-range, we'll notice as we approach the orbit of Venus, and even more so as we encroach upon the haunts of Mercury, two things. First, the tenuous "Solar Wind" is significantly less tenuous and more blustery by a factor of 2:1 near Venus, and by more than 6:1 near Mercury, increasing with the inverse square of the distance from the Sun. This won't be a practical problem really. On naked-surfaced Mercury, neutral particles of the solar gale might have created even more of a soil-trapped endowment of useful volatiles than is the established case on the Moon: Carbon, Nitrogen, and the noble gases Helium 4 and 3, Argon, Krypton, and Xenon.

But growing correspondingly more dangerous, again with the inverse square of the distance from the Sun, will be the potential exposure to intermittent and seasonal Solar Flare radiation flood-bursts, deadly storms for the unsheltered.

Second, as we travel inward we'll notice that, vacuum or not, space is brighter and brighter. Whatever the temperature of space itself, Sun-facing surfaces grow hotter and are harder to cool – again the problems increase with the inverse square of the distance out. The plus side is that solar energy collection becomes correlatively easier and more efficient. And Sun-powered lasers for propulsion, communication, or energy relay become more feasible and attractive. As we travel Sunwards, we are heading deeper and deeper into brighter, hotter, windier, and stormier space: the "**Solar Maelstrom**".

On the other hand, as we go outwards from the orbital range of our Earth-Moon bi-planet, the opposite is true. Space becomes less windy and less stormy but also colder and darker, again with the inverse square of the distance out from the Sun. At the mean range of Mars and its moonlets Phobos and Deimos, we will need twice as much solar collector surface to gather in the same amount of energy available in the vicinity of Earth and Moon. At the distance of Ceres, queen of the asteroids, collectors will have to be seven times as large to do a given job. And out by Jupiter and the Galilean moons, twenty seven times as large. Ultimately solar power becomes an impractical proposition. We are heading into what we might call the (Solar) "**Twilight Sea**".

Out around the great gas giants of Jupiter, Saturn, Uranus, and Neptune, it will be difficult to operate human-crewed ships within the powerful magnetospheres around these planets, giant versions of our own "**Van Allen Bay**", which is deadly enough to those taking too long to transit it. The "**Bay of Jupiter**" will be particularly treacherous, possibly confining human exploration and eventual settlement to Callisto and beyond, putting great frozen Ganymede, ice-lidded ocean-girt Europa, and pizza-hued volcanic Io forever beyond the encroachment of human history, and keeping us from ever plying the relatively placid "**Jovian Lagoon**" at the center.

Hopefully, the "**Bay of Uranus**" will be negotiable enough to allow us to "mine" the abundant Helium-3 reserves in Uranus' atmosphere, thousands of times more vast than the "pump-priming" deposits on the Moon's surface, and quite possibly THE greatest economic resource in the outer system.

Within the Solar System, and to an unknown reach beyond Neptune, the Solar Wind will act to purge the vacuum of volatile dumpings and "pollutants" carrying them out to the "heliopause" where the force and direction of the Solar Wind becomes indistinguishable from the currents of "interstellar" space. We will at last have left the "**Circumsolar Sea**" (comprising both the Solar Maelstrom and the Twilight Seas).

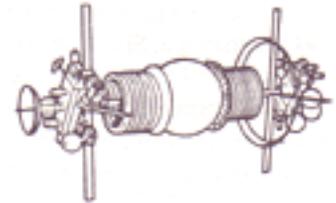
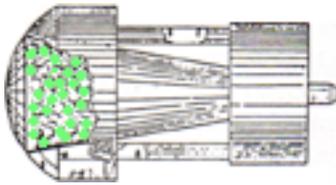
Here between the stars, we will not yet be in truly empty uneventful space. Interstellar dust and gas clouds are scattered here and there, in the “Disk Sea”. Even as we get out beyond the “rim” or out above the “plane” of the Milky Way, we will still be in the “Halo Sea” for some distance.

So where, finally, is the “Vacuum of Vacuums”? Perhaps in the empty bubble-pockets of nothingness hundreds of millions of light years across that balloon between the great filament strands of galactic superclusters. And who in his/ her/its right mind would ever want to journey way out there?

To experienced sailors on Earth, sea is not just sea. It matters a lot if one is sailing stormy north Lake Michigan in November, or the treacherous waters between South America’s Cape Horn and Antarctica, or the placid intracoastal waters behind barrier islands, or in the Inland Sea between Nippon and Shikoku. Each body of water has its quirks, its own friendly and not so friendly moments. So it will be in space for veteran spacers. Only “Earthlubbers” and other non-initiates will speak of “Space” as if it was all one and the same thing. MMM

**MMM #57 July 1992**

## Space Oases Part: Re-Dreaming and Redrafting the Vision



[Pioneering concepts: the forested space station of Tsiolkovsky above **left**

The organically complete sphere of Dr. Bernal above **right**.]

We best do homage to the legacy of Dr. Gerard O’Neill not by fundamentalist doctrinaire attachment to his conceptions of space settlements, but by adopting his dedication to the dream and rethinking the trial visualizations he gave us. “Xities” in Space! – See the four articles about “Xities” below.



**Series Cont. Pronounced KSIH-tees’ not EX-i-tees**

[Human communities beyond Earth’s cradling biosphere]

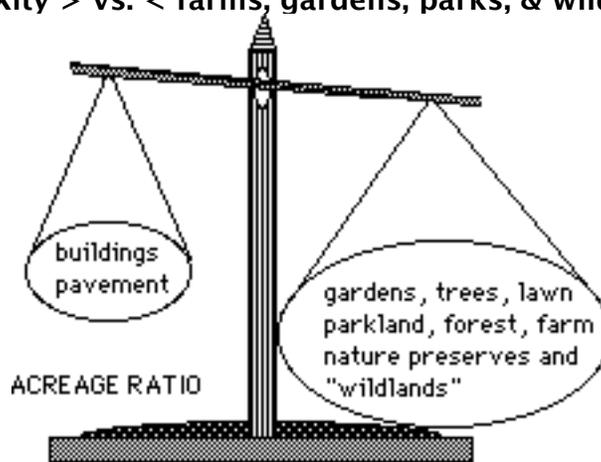
**“XITIES” in SPACE (set of four articles below) By Peter Kokh**

This month we take a look at mini-biosphere maintaining communities in free space, i.e. space settlements, or space colonies as they were first called. We took a unique fresh look at the architecture of these proposed oases in space in a set of 3 theme issues, MMM # 11, 12, & 13, DEC ‘87 to MAR ‘88. These articles, which approached the subject from a vantage point from which they had never been treated before (or since), are still timely [MMM Classics #2].

While we seem to be no closer today to realizing this grand vision of life unshackled to planetary surfaces than we were four years ago, the topic is long overdue for further review and constructive elaboration. Alas, there has developed in some space enthusiast circles, a certain quasi-fundamentalist unquestioning dogmatic acceptance of the now classic expositions of the late 70s space settlement ideas. Given the high average intelligence of space enthusiasts, this is unsettling. We think that a better testimony to the inspiration of Dr. O’Neill is to be had in a no-holds barred critical review.

# Space Xity Biomass Ratios

Xity > vs. < farms, gardens, parks, & wilds



By Peter Kokh

Making a successful space settlement, one in which air and water quality are maintained by a biological flywheel, is quite a bit more than a matter of simply reserving enough acreage for adequate food production. Yet that was the extent of the consideration given in the 1976 NASA Space Settlements Study. Our experience with Biosphere II, a complex life-cycle experiment now underway, should be sending everyone more than casually interested in human communities beyond Earth a jarring wake-up call. In this ambitious trial, several acres of luxuriant vegetation are proving insufficient a match for the carbon dioxide exhalations of a tiny band of eight Biospherians and CO<sub>2</sub> scrubbers have had to be turned on.

We could simply adjust, rather radically, our expectations, providing plants for food and ambience, but relying on chemical engineering methods for recycling air and water, with some bio-assist, of course. Yet the whole idea is to provide a secure environment. It is one thing to acquiesce in one's dependence on machinery to provide electricity. It is quite another to accept that the very freshness of the air we breath and the water we drink are hostage to machinery that could fail for want of a simple part stored in some warehouse a quarter million miles away.

If we do choose to forgo the security blanket of a relatively carefree biological flywheel, we'll need to provide redundancy in equipment, vigilant maintenance beyond all past precedent, and a religiously guarded surplus of spare parts. The probable philosophy of choice, will be to maximize the biological-assist component, relieving stress on the chemical backup systems, and providing more forgiving repair time in case of serious breakdown.

**To this end, we need a change in philosophical outlook toward space xities, one that portrays the human as guest and plant life as host, rather than the other way around.**

Farmland (and/or hydroponic gardens) must be provided in generous measure, ensuring food reserves for episodes of crop failure and disease. Residential areas must be more verdant than the most luxuriant of Earthside neo-suburban garden suburbs. Walkways and other pavings should be kept to a functional minimum. Rooftop space should be gardened. Interior spaces should use plants as the principal item of decor rather than as mere color accessory. Children should learn to care for plants. Green thumbs should be the rule.

To some extent this will all come natural as space settlers seek to wrap themselves in life against the searing stark sterile suction of the nothingness outside the xity's containment hull. Yet xity architects and planners must adopt codes and standards that will make such deliberately nurtured symbiosis with nature easy, not hard. There must be a pervasive tilt towards plant life.

When we look at the more commonly known and celebrated designs for space settlements, the early Bernal sphere, sometimes dubbed "Island I", stands out as an example. In it alone, a minimum agricultural vs. urban ratio is guaranteed by the very architecture - a garden-town gracing the "lower" terraces inside the sphere while generous farm space is provided in an adjacent expandable banded torus section.

**Island II and Island III: Both designs, as they have now become classic-fixed in our minds, should be rejected out of hand as unviable.**

In contrast the bigger Stanford Torus design of “Island II”, and the bigger yet “Sunflower” design of the “Island III” O’Neill cylinder, each have no such architecturally guaranteed preserves but must rely on common sense to balance the amount of limited acreage given to the actual settlement areas and that reserved for agriculture. This is an unstable tug-of-war arrangement which over the political long haul is likely to prove fatally fragile. I would submit that both designs, as they have now become classic-fixed in our minds, should be rejected out of hand as unviable.

Let’s try some remedial surgery. The torus can be expanded to a banded version, several bands reserved to agri-culture and nature preserves to each band “open” to settlement.

In the “sunflower”, the acreage given to the threefold chevron-shielded window-rows are wasted, especially as more efficient ways of importing available sunshine are possible. For one, sunshine can be concentrated some three dozen times before being poured through proportionally smaller windows without over heating the glass, and subsequent diffusion.

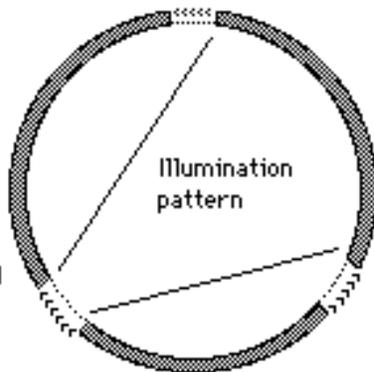
Next, consider that more sunshine is collectible by outrigger mirrors than can be utilized within the single-tiered surface of the classical Island III design. The elegant solution is to have a number of concentric agricultural “basement” levels, each with adequate sunshine piped in through “suntubes”, beneath the classic inner surface of the cylinder which can be reserved for settlement, gardens, and tame or wild parklands.

**CLASSICAL SUNFLOWER DESIGN**

Cross section

KEY:

- ..... Chevron shield windows for Sunshine access
- Hull with shielding Farms, Parks, and Settlements on inner surface

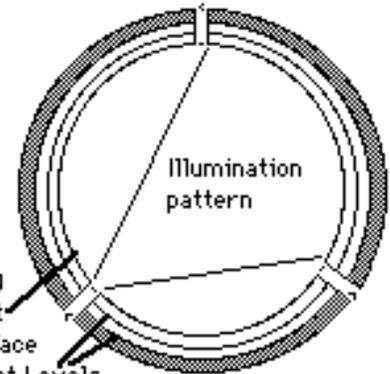


**ENHANCED SUNFLOWER DESIGN**

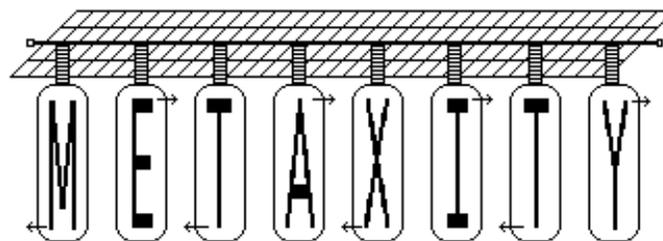
Cross section

KEY:

- Downsized Chevron shield windows for concentrated
- Sunshine access
- Hull with shielding Garden settlement on innermost surface Farms on Basement Levels



In both of the above revisions, architectural resistance to encroachment of settlement area upon agricultural and natural space is provided. I submit that it will be tantamount to mass suicide to build and settle such megastructures without such safeguards in place. Mere reliance on “common sense” and “good intentions” flies in the face of thousands of years of contrary human experience. FRAMPA



**RESIDUAL PROBLEMS of Classical Space**

**Settlement Designs and SYNTHESIS via Polymerization on the “METAZOAN” Plan**

**Escape from Premature Completion**

If it is a critical challenge to maintain a sustainable symbiotic balance between acreage surrendered to settlement and that dedicated to agriculture and the air and water bio-regenerative flywheel, then the ultimate devil in the works is population growth and pressure. The fixed size, expansion-unfriendly character of individual Bernal sphere, torus, and cylinder space settlement megastructures, each as classically conceived, is reason enough to look for altogether different architectures. Is it possi-

ble to postpone, if not ultimately avoid, the soul-decaying stagnation of limits to growth in individual settlement megastructures?

As we pointed out four years ago in our previous double article “Space Oases: Static Design Traps” and “A Biodynamic Masterplan”, the ivory tower assertion that the only possible architectures are sphere, barbell, torus, and cylinder is so much arrogant pedantic static-thinking hogwash. None of us would be here if nature hadn’t found an escape from such limits in the “double helix” of DNA. To put it conceptually, a barbell is moved sidewise along its axis as it rotates, to generate a doubly open double helix rather than a closed self-suffocating tail-in-maw torus.

In the classic designs, completed structures must be built before occupancy can begin. In the biodynamic double or triple helix twist on the torus, occupancy can begin as soon as an initial “dumb-bell” section is completed, and the xity can grow and grow and grow as needed towards some eventual desired maximum population capacity, ever adjusting its biomass ratio as it grows. Here we have an architecture which is both biologically and psychologically and socially healthy.

The classical solution to population growth in space settlements is, of course, to simply build more of them, letting individual settlements suffocate in their own limits while all or almost all the young must move out in some weird lemming-like parody of “coming of age.” We think there is another alternative, an option other than wholesale generational abandonment of one’s atrophying fixed-size home xity; other too, than that of the more imaginative growth-friendly Double and Triple Helix Settlement architecture. First let us look at some other unanswered residual problems of the classical designs.

### **Xity Economies and the Three Shift Problem**

Protests of trendy brain-fried economists to the contrary, there can be no such thing as a post-industrial “service” economy – except locally. Somewhere, “out of sight out of mind”, every economy must start on the farm and continue to pyramid through the factory. Ah yes, manufacturing, where the expense of plant and machinery demands around the clock use. Three shifts!

The majority of space advocates seem to be employed in managerial, office, engineering, and service occupations plied during daytime hours. We might expect them then to be chauvinistically content to continue the Earth-rotation imposed tyranny that condemns many to work at night and sleep by day. Yet isn’t the very glory of the space settlement that it provides an opportunity to pick and choose the Earthlike conditions we want to keep and those we want to discard? In the LRS Prinztown rille-bottom settlement design study, the town was segmented into three interconnecting villages with day-night cycles staggered 8 hours apart so that everyone could sleep “at night” and work “by day” while the machinery continued to be operated around the clock. Night shift in one village would be crewed by 1st shift workers from another.

While the same elegant solution can be provided by the architecture of a Triple Helix Oasis, with its three strands observing staggered time zones, it would seem that blue collar workers in one of the more classically designed Space Settlements would be condemned to the same life-shortening fate that is their common lot on Earth.

Almost, but not quite. In external work, at least, i.e. the construction of new space settlements or of solar power satellites, two or more space xities could team up to do the job, each with shift-staggered sunrises and sunsets.

Indeed, a sort of Siamese pairing has been suggested, in which two oppositely rotating cylinder type settlements are connected to one another at both ends by torque sharing cables. In such a setup, travel between the pair could be quite routine. But this still does not provide three shifts, the conventional ideal. Perhaps one doubly massive prograde cylinder could team up with two retrograde rotating cylinders each half the size in a torque-free system? The larger one would house the managerial, office, and commercial class as well as its share of shift workers. Another surmountable engineering problem?

### **Other Rationales for Settlement Match-Making**

Apart from task sharing by shift management, could settlements be paired to correct biosphere flywheel imbalance? i.e. could the connecting torque-sharing cables also pipe fresh and stale atmosphere back and forth? An over-settled over populated settlement could be paired with a heavily rural one. The engineering problems to be overcome are just that.

These are not new problems. Nature faced a similar situation several hundred million years ago when the design limits of one-celled creatures threatened to bring further evolution to a incrementally

moot halt. Colonial organization like that in the order of sponges allowed some of these design limitations to be transcended.

Why not take this discussion of limited pairing to its logical conclusion and design workable aggregations of space settlements to enable them to do physically together what they could not hope to do physically apart, even with cooperation?

Eventually, nature came up against severe limitations in the colonial organization also. The shackles came off when some colonial cells started to specialize, allowing organs and organization to appear: metazoan life, of which we are the present climax on this planet. Can physically colonial associations of space settlements go beyond sharing to group specialization? Can meta-xities be possible?

If so, the standard expectation (to the great glee of the anarchists among us) that each space settlement is likely to be a politically sovereign entity, encouraging a bloom of social and political experimentation, may be realized only in boondocks areas of space such as Earth-Moon resonant orbits where any meta-structure would tend to break apart from tidal forces. Both in Earth-Moon and Sun-Earth L5 and L4 areas at least, physically stable colonial and meta-organization, if possible, are likely to prevail, each settlement being but a county, state, province or whatever of some greater much more capable and richly endowed space nation. But we get ahead of ourselves.

Let's throw out some architectural ideas – meant as trial balloons. If you find a flaw, and please do play the devil's advocate, go on to find a solution and further improve the suggestion or supplant it with something better. Here we are not trying to pose ultimate solutions. Rather our intention is to break the mold of stagnant thinking on space settlements, leading to an outburst of fresh designs, some of them perhaps able to reignite public enthusiasm as the now classic designs did fifteen years ago in the late seventies.

**THESIS:** if an Island hub is non-rotating, it can be docked thereby to a common utility and service platform along with other islands with non-rotating hubs. Take another look at our title graphic METAXITY at the start of this piece. It is meant to be deliberately suggestive.

**SHOWN:** a giant solar collector power grid system for power sharing among a number of cylindrical settlements, each attached to the grid at a swiveling pole, half of them rotating prograde, half retrograde for overall torque neutrality. There is also a transitway linking the “docked” hubs of the several settlements to allow easy travel between them.

**NOT SHOWN:** A shared radiator system, a common space port, shared zero-g and fractional-g warehousing, agricultural, manufacturing, and laboratory areas.

And use your imagination to suggest what other things permanently docked Islands might now economically do together as an archipelago that any one Island might be too small to do alone. Nor rest content with embellishing this basic architecture. Try to come up with other architectures for physical association and task sharing.

The classic Island designs are great for daydreaming. Now is the time to start sketching the outlines of a more realistic future world in free space.

### **The promise of the Meta-Xity**

- correct biosphere flywheel imbalance for Islands whose architectures do not make them individually expansion-friendly.
- shared zero-g food-production agricultural acreage
- shared recycling air and water grids
- energy and heat-radiation grids
- facilitate inter island travel in people and goods and supplies and energy
- provide three staggered daytime shifts without pain
- more easily shared construction projects
- shared warehousing of incoming raw materials, solid, liquid, and gaseous, and outgoing manufacturing products.
- spaceport sharing and space traffic control
- shared metropolitan center for culture, entertainment, educational and governmental institutions
- a sound basis for a common market and political federalism

- manage L4,L5 crowding without catastrophic collisions and expensive station- and formation-keeping fuel expenditures

### **No Settlement is an Island unto Itself**

Thus the island concept familiar to most of us is like a conceptual “monomer”. The unsuspected promise is in the unlimited versatility and innovative chemical freedom afforded by polymerization. Space Meta-Xities (Metas?) or Shelf-Sharing Archipelagoes (SSAs?) of space oasis island settlements will make O’Neill’s dream come true. XXXX

[Space Xity Architecture Issues Cont.:]

### **“Artificial” (Centrifugal, not Centripetal)**



### **What level should be “the Standard”?**

In the world of Space Settlement enthusiasm, there is no cow more sacred than Earth-normal gravity. The ability of rotating megastructures in space to provide customary weight levels for masses of people is taken without question as one of the keystone assets of the whole space settlement concept.

Indeed to question “the standard” is tantamount to heresy. Maybe. But even more certain is our conviction that anyone afraid to question the truth does not deserve to possess it. Let us then risk heresy and dare to ask questions.

#### **The ISSUES: A) Settler & Visitor Health; Readaptability to Earth-Normal Conditions; Health Insurance Dictates**

The classical arguments for Space Settlements as opposed to those on planetary surfaces would seem to be twofold:

- 1) far more total livable surface can be created with a multiplicity of rotating shallow hulls on the inner surfaces of which artificial gravity is provided by centrifugal force than on the surfaces of deep-cored planetary surfaces through the centripetal force of natural mass/inertia provided gravity. This argument becomes important only as the economic justifications for very large off planet populations are actually realized. This scenario is more likely to follow heavy reliance on Solar Power Satellites than a decision to go with Lunar Based Solar Arrays or a Helium-3 power generation economy. The jury is out and it will be some time before the choice or exact mix of choices is settled on either economic or political grounds.
- 2) In rotating space megastructures, it is possible to set any gravity level desired, and not be restricted to the fractional gravities provided by natural bodies on which settlement has been proposed. [16% on the Moon, 38% on Mars; physiologically negligible on even the largest asteroids]. In absence of evidence to the contrary the conservative assumption is that the human physiology which has evolved in Earth’s gravity, will continue to do best in a similar environment. Hence Earth-normal 1G should be provided.

This argument would seem to be strong. Certainly, settlers and visitors to an off planet 1G environment would undergo no physiological deterioration and could readily return to Earth if they so desired. This point is especially important to space enthusiasts who down deep aren’t quite sure they are ready to burn their bridges behind them. Certainly, it is inarguable that freshman settlers should opt for a 1 G space settlement, at least as a temporary home (much like New York City has been for wave after wave of immigrants) until they are sure they like living in space enough to care not whether they ever returned home. This is a sad commentary really. Most of the immigrants to this country from Europe came without any such uncertainties or reservations. In plain fact, the “right stuff” is nowadays a very uncommon virtue, even amongst our own ranks.

We won't dispute that if we are talking not about permanent space settlements but temporary "construction shack towns" in which rotating crews come up from Earth on limited tours of high pay duty to build Solar Power Sats, 1 G ought to be the standard. Employer-paid insurance will no doubt demand it as a condition of coverage.

But what about settlements for those who are sure at the outset, or become convinced after a trial, that life in free space suits them fine, that they do not miss the attractions of old Earth (tourism; many sports and outdoor activities which will not translate well to Space Settlement environments; their relatives and friends left behind)? What in fact would be the health implications of another choice?

It would not seem likely that anyone would want to pick a gravity environment in which they would weigh more and have to work harder. Those who hope to someday settle Mars may wish to live in the meantime in a Space Xity that offered Mars-level gravity 3/8ths that of Earth-normal. Other than that, those making repeated long trips (deep space exploration, asteroid prospecting and mining, etc.) in a zero or near-zero gravity environment would probably much prefer a home base that offered a gravity level much lower than Earth's but just high enough to sustain a lowered plateau of physiological normalcy. It would be far easier for inveterate spacers to call the Moon or some Moon-like space xity "home" than Earth. In plain fact, those who need to readapt periodically to Earth will simply not choose such occupations.

One of the weirdest examples of twisted logic now prevalent is that if human physiologies deteriorate unacceptably in zero-gravity, then by Sagittarius (and by Pisces and by Libra etc., if you catch the aspersions), the 1/6th level offered on the Moon's surface is something to be avoided at all costs. In point of fact, we have no sufficiently prolonged experience with any level of fractional gravity to offer in evidence one way or the other. Apollo stays were much too short.

Logic says that very low gravities are functionally the same as no gravity at all, at least if we are talking about gravity-assisted blood circulation patterns. There must be some point at which the lowered gravity is canceled out by the coefficient of friction in veins and arteries. My guess is that such a situation will be the case on the asteroids. Even Ceres, the largest and most massive, offers no more than 3% of Earth-normal and that might as well be zero as far as physiology goes, however much it might be helpful mechanically in construction, and domestically in keeping things put.

At the same time, there is absolutely no grounds to believe, timid nelly notwithstanding, that long-duration stays on the Moon or in a 1/6th G simulation facility in LEO will show anything other than that decline in physiological health and muscle tone levels off at an acceptable plateau, one that can be maintained on a life-long basis, from which rehabilitation to Earth-normal life may be difficult, but not impossible.

Oh yes, insurance! Insurers may be conservative, but they are not stupid. In point of actual fact, in the real world most of us like to ignore there are some number of physical conditions which are much aggravated, necessarily now, by the naturally high level of gravity on this planet. Rheumatism and arthritis, cerebral palsy and other motor impairments, to name a few. Might not insurers, if forced to continue coverage for the sufferers of such ailments (against their obvious desire to cover only the healthy who won't be making claims), have an obvious interest in "encouraging" clients suffering from such conditions to "move" to lower-G environments when they become available? In time, conservatism or not, the G-level should become an insurance-neutral question.

### **The ISSUES: B) Structural Integrity and Safety; The Size and Mass Threshold for Occupancy**

If the health question eventually does prove to be moot, as we predict, are there any architectural motives to pick a different standard than that of Earth-normal 1G? At the time the classical space settlement designs were being put forth, the conventional wisdom was that humans could adapt to a rotation rate of 3 revolutions per minute. Since then the indications are that while this may be so for a small select minority, if we want to make life acceptable for others qualified and willing to out-settle on all other accounts, we may have to observe a 1 rpm constraint. For very large islands like the Sunflower cylinder (Island III) this is no problem. Its radius is in excess of the 1km (1,000m or 3,000 plus ft) necessary to provide 1G at 1rpm.

But for many of the torus designs proposed, certainly the Von Braun wheel from the film 2001(!), only much lower fractional gravities could be produced at 1rpm at their proposed much smaller radii. This goes for the Bernal sphere as well. In fact cutting design rpm from 3 to 1 while maintaining design gravity levels automatically demands an increase in radius by a factor of 3, **an increase in shielding mass by a factor of 9, and of structural mass by a factor of 27.** Suddenly the economic threshold for

their construction becomes dauntingly high. Indeed the first such space colony might never be built. End of dream.

In contrast, if while the rpm is cut from 3 to 1, the design gravity level is also cut from 1 to 1/6th, then the original radius proposed can be cut by 2, **shielding mass and the cost of outfitting cut by a factor of 4, and structural mass by 8**. The population capacity is also quartered. Suddenly the threshold for the construction of such space habitats is lowered and is more economically attainable. The first such habitat will be markedly easier to sell to its investors and take much less time and money to build and be the more certain to prove a profitable venture. Lunar standard space settlements will multiply and thrive, the per immigrant cost markedly lower.

In this light, it begins to seem odd that some of the same folk paralyzed by the need to lower the cost per payload weight to orbit, would want to insist on unnecessary Building Codes certain to escalate greatly the cost of space construction. Timeout, fellas! Time for a review of hidden assumptions.

Along with ease and lowered costs of construction, a lowered G standard per se lowers the level of centrifugal structural stress and with it the probabilities of structural failure (especially for essential exterior paraphernalia like cable-bound outrigger mirrors). A lunar standard space oasis will be a measurably safer place in which to live and work, one whose integrity is maintained much more easily, one whose life expectancy is measurably longer.

For all these reasons, the 1/6th G lunar standard is likely to be adopted by all long-trip spacecraft providing artificial gravity: cycling hotel ships on the Earth-Moon and Earth-Mars runs; the habitat ships of asteroid miners, etc. In contrast 1 G standard space habitats and ships, if ever built, are likely to be pink elephants from the drawing board to their premature decommissioning.

**It's time to desanctify the cow of the Earth-normal gravity "standard" once and for all.**

Our conclusion is simply this. The impassioned proponents of a 1 G Earth-normal standard should be honest enough to realize that theirs is a chauvinism every bit as quaint and curious as that of those who want to live on the sky-facing outside of some planetary surface. It is time to desanctify this cow once and for all. MMMM

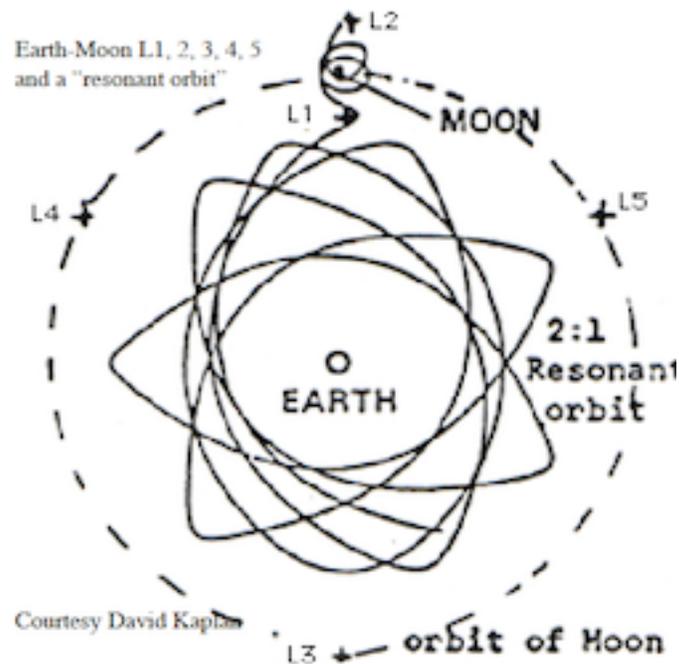


By Peter Kokh

**What orbits will Space Xities ply? Who will allocate them? Will there be annual "parking" taxes? Will this extend the authority of Earth to the "Unreal Estate" of special orbits in Cis-Lunar Space? in Earth's Solar Orbit? The battle over the Moon Treaty may be just the beginning!**

#### 1. L5 or Resonant Orbit?

Back in the mid-70s, it was proposed that Space Colonies be established at one or both of the two stable Earth-Moon Lagrangian points, L4 and L5, centering 60° ahead and behind the Moon respectively in its orbit about the Earth where they would fly forever in equilateral formation with Earth and Moon. These co-orbital fields required little energy to reach from the vicinity of the Moon, whence the raw materials necessary to build them would come. This insider wisdom gave the L5 Society its strategically esoteric name.



Subsequently, this conventional wisdom was replaced by one allegedly more savvy which proposed that such habitats be built in Earth-Moon resonant orbits, eccentric ellipses that would bring the community close to Earth and then close to lunar orbit twice a month in an orbit whose apogee precessed around the clock once a year. Many jumped on the bandwagon of the resonant orbit idea, convinced by the numbers of orbital mechanics. The trouble is this suggestion does not stand up under scrutiny. Yes, it is the sort of orbit easiest to reach from the Moon. But, if we are going to see a great many space settlements, they will have to be placed in a succession of such orbits such that one succeeds the other in reaching apogee as the Moon orbits by, in a what would appear to be a stationary wave. If one was allowed near the Moon per day, that would leave room for only 28, every twelve hours 56, every hour 684. Because of tidal forces, "metacity" physical agglutination of such island communities sharing facilities and assets in common, would be quite impossible. Thus the room for space cities in resonant orbits, and the limits placed on their evolution there, are quite severe. A nice ivory tower idea, but that's all it is.

Resonant orbits will be used, of course, but not for permanent space settlements. Rather such orbits should and must be reserved for something entirely more appropriate, cycling Earth-Moon transit hotel ships, in which settlers and tourists can make the several days long journey in luxurious comfort. These orbits will be allocated, and the companies using them may pay an annual fee to do so.

## 2. L5 and L4?

So the original L5 concept was right on target after all! Here not only can great numbers of individual (rural) space settlements be built, but also they can come together to form metropolitan metacity complexes, physically contiguous space nations. Without this development, space settlements cannot reach their full potential, and the total number safely allowed in the Lagrangian field will have to be more limited.

L5 will need some governance. Orbits of discrete individual settlements and larger meta-cities will need to be allocated with complexly choreographic care to minimize the risk of near collisions with the minimum of reserve station-keeping and emergency maneuvering fuel. While the authority allocating resonant orbits for the transit trade will probably be Earth-based, L5 could be regulated by a cooperative association of the settlements already there. They would collectively have the autonomy to decide if, when, and where more settlements are to be allowed. While such Lagrangian home rule is proper, it may have to be fought for in a political struggle, especially if proposed newcomers would be owned and puppeteered by Earthside nations.

And L4? Why not? It has the same physical characteristics and orbital mechanics, same carrying capacity.

**Lesser "unreal estate" for "parking" space cities: GEO, LEO, LLO, L1, L2, L3**

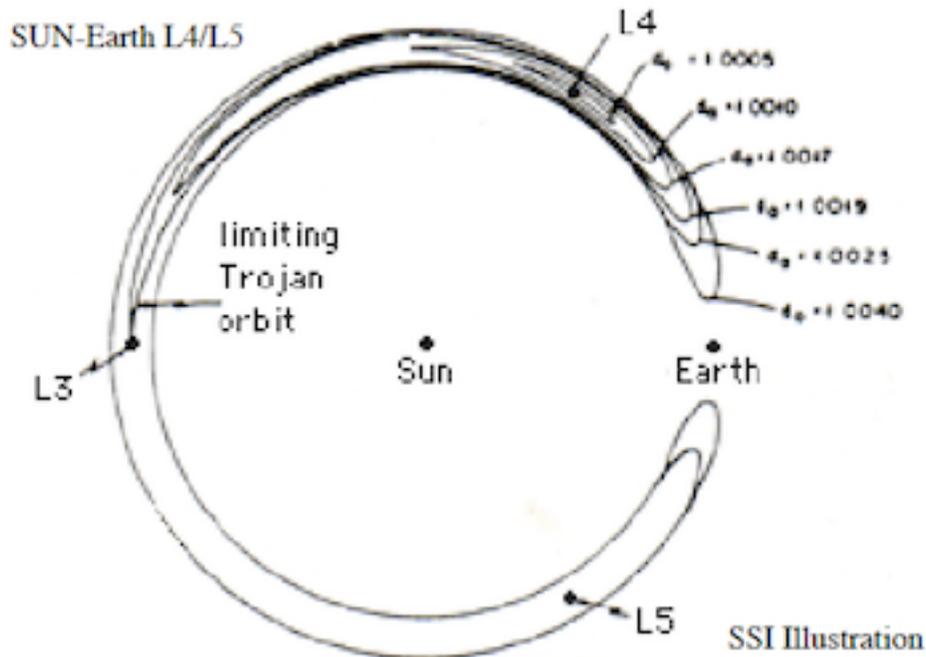
The economic rationale behind the majority of space cities in Cis-Lunar space will be the manufacturing of Solar Power Satellites along with more of their own number in anticipation of a steadily accelerated need. However there will be lesser niches. There may be room for one, two, at most three in GEO[synchronous Earth Orbit] where their livelihood would be twofold. First they would maintain communications and weather satellites whose total numbers will have increased dramatically once they are “packed” together aboard fewer crystal-tight power sharing platforms. Second, they would maintain and repair Solar Power Satellites in GEO.

There will be room for one or more “resort” cities in LEO, low Earth orbit, catering to the bulk of Earth tourists venturing into space. They will offer angelic views, zero and simulated other planetary gravities, unique recreational and athletic opportunities, and perhaps pursuits outlawed on Earth. There may be one which serves as a hospital complex specializing in zero-G and fractional-G treatments.

A city in LLO, low lunar orbit, may be the principal gateway to the Moon, the transfer point for space-captive luxury craft and orbit-to-surface taxis, shuttles, and lighters.

Some sort of facility at L2, 40,000 miles above the lunar center farside, is a possibility if it proves necessary to “herd” the volley traffic from below. Lunar mass drivers will boost payloads of raw materials and smaller containerized value-added products through this point. A city at L2, and any at L1 above nearside, would need station-keeping fuel as these Lagrangian points are unstable.

In any political geography, there is always the spot for which there is no economic justification, off the beaten track, therefore of value to the idle rich wishing not to have to brush shoulders with those who have to toil to earn there keep. In space, L3, the Lagrangian point at lunar distance on the opposite side of Earth from the Moon is just such a place. An orbital Scottsdale or Palm Springs at this location would not mind the necessary expense of station-keeping required.



### Location, Location, Location: The assets of SUN-Earth L4 and L5

Yet it could be a mistake to assume from the above that the vast bulk of space cities will be in the Earth-Moon advance and trailing co-orbital Lagrange fields, L4 and L5. These may simply be the most crowded places in Cis-Lunar space, the space around the Earth within the Moon's orbit.

For once asteroidal resources begin to be tapped, and this should occur simultaneously or quite shortly after raw materials begin to flow from the Moon, then two other much vaster more capacious locations suggest themselves centering 93 million miles away, 60° ahead of and behind the Earth in its orbit around the Sun, SUN-Earth L4 and L5.

SUN-Earth L4 and L5 emerge as the premier sites for space cities involved principally in the processing of asteroidal resources for two reasons. First there is likely already a certain amount of as-

teroidal material in these twin co-orbital fields. That no chunks have yet been identified or located there puts an upper limit on the size of what we can expect to find of perhaps 3 km (2 mi) in diameter. But the astro-chunks or planetesimals easiest to mine and process will be these smaller ones anyway. This lode may include self-snuffed comet hulks.

Second, if it is necessary to range into independent solar orbits in search of exploitable flying mountains of ore, our first hunting grounds will be the near-Earth orbits of the Apollo, Amor, and Adonis asteroids wholly without, intersecting, and wholly within the Earth's solar orbit respectively. We will look principally for those small enough to be corralled and with trajectory energies relative to Earth (i.e. DV) low enough to be brought into more convenient parking orbits for further\* processing. (\*The mass driver which will accomplish this trick, will in the process have begun separating prized ore from "tailings" to be ejected as reaction mass.)

And where will we reserve such parking space? Contrary to common expectation, not anywhere in Earth-Moon space. First, Earth-Moon parking slots will be reserved for inhabited megastructures. Second, it is unlikely that the public on Earth would welcome the minute but finitely positive chance that a herded asteroid could by human error or simple lack of a mid-course correction be sent plummeting directly Earthward in a dinocide re-run. Politics and public fear are likely to demand a safer herding ground: SUN-Earth L4,L5.

So even if these vast circum-solar Lagrange areas are currently a resource desert, they are likely to become resource dense by human intervention. Hence here will be the bulk of asteroidal resource processing. Some manufacturing will be done here. The balance of these processed materials will be container-shipped back to the Earth-Moon vicinity.

If Space Settlement is ever to develop a mutually interdependent economy in which exports to Earth-Moon become a lesser factor, it will be here, in SUN-Earth L4 and L5. Here the "circumsolar" economy will come of age, succeeding the Earth-Moon economy. Here will be built the most extensive, most populous, most ambitious and most organically differentiated meta-xities. Here may be built great powerful solar lasers to power near-interstellar robotic probes and the even more ravenous C.E.T.I. beacons, in century-long dedication to the task of sending messages to unknown listeners around other unknown suns. Here, some distant day, may be born the economic launchpad to the stars!

#### **Other Space Xity sites out of Earth Orbit**

There will be many other specialized limited niches for human communities in free circum-solar space. Cycling hotel ships serving settlers and tourists bound from Earth-Moon to Mars. Miner settlements in elevator-anchored surface-synchronous spots above the larger Main Belt asteroids. Grand Tour retirement communities doing the sights of the outer System including an unforgettable close ring-pass of Saturn. Helium-3 mining communities in orbit above Uranus. These are some of the more likely possibilities.

#### **Site Rationing**

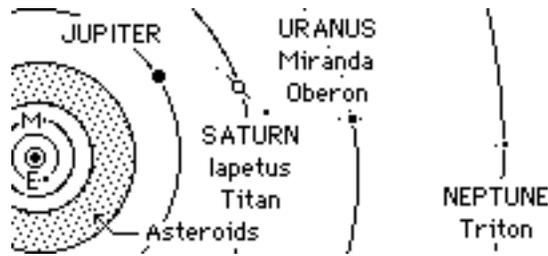
Suitable parking spots in space are more abundant in some areas than others. Where the "carrying capacity" of the niche is either economically or traffic-wise limited, there may well arise the need to allocate, lease, or sell and tax such spots. However unreal and limitless empty vacuum may seem, orbits and trajectories are very real and finite indeed. It will be these, not sheer vacuum, that have economic value.

Alas, there may be no escaping the assessor!

MMM

**MMM #59 – October 1992**

**A Place for Humans in the Outer Solar System?**



Last month we sketched how Xities Serving Asteroid Miners might eventually follow this hardy corps of rugged individualists out into the Asteroid Belt itself. What might be the economic rationale for going out even further into the dark and cold of the Solar System? What obstacles must be overcome? Three articles on the opportunities, challenges, and Xities of the Outer Solar System:



**Series Cont. Pronounced KSIH-tees' not EX-i-tees**

[Human communities beyond Earth's cradling biosphere]

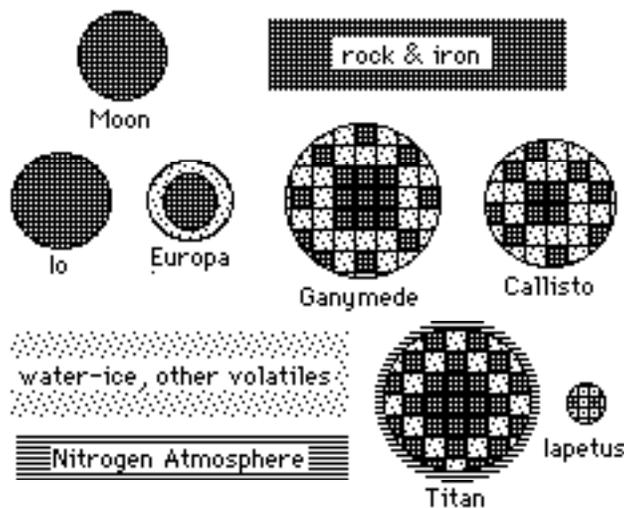
By Peter Kokh

## Economic Opportunities in the Outer Solar System

### Resources for Local Settlement Consumption

By Peter Kokh

While tapping the resources of the gas giant planets themselves may seem a formidable challenge, for settlement purposes, those resources available on the many outer system moons should be enough in most cases to support self-sufficiency. Whether or not such resources provide a basis for competitive export of materials and products to trade for those items which must, at least initially, be imported from the inner system worlds (Earth, Moon, Mars) is another question. Unlike the volatile impoverished Moon, with the exception of volcanically hyperactive Io, most of the larger satellites of Jupiter, Saturn, Uranus, and Neptune hold ample quantities of both metallic silicates and volatile ices. Settlements on any of these worlds would not have to import major tonnages of raw materials. Lesser amounts of some metals strategic to advanced technological civilization may need to be brought in at first until economically recoverable local lodes can be identified.



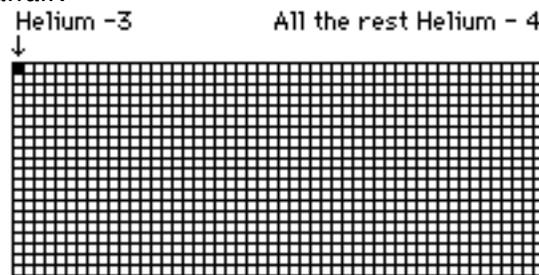
**SIX IMPORTANT SATELLITES OF THE OUTER SYSTEM** shown with the Moon for comparison. Jupiter's Galilean quartet is a varied mini solar system in its own right. Sulfur spewing hypervolcanic Io has long since purged any volatiles it may have once had. Europa has an ice crust surface probably hiding a hundred km deep ocean of water. The "calico twins" of Ganymede and Callisto have rocky

iron cores with mantles and crusts of mixed rock and ice. The same holds for Saturn's great satellite, Titan, which however has a Nitrogen atmosphere half again as thick as Earth's laden with hydrocarbon soup clouds covering a surface of rock, ice, methane ices and slushes, and possible hydrocarbon 'tar' pits, lakes, and seas.

### Exportable Resources: Energy Stuffs

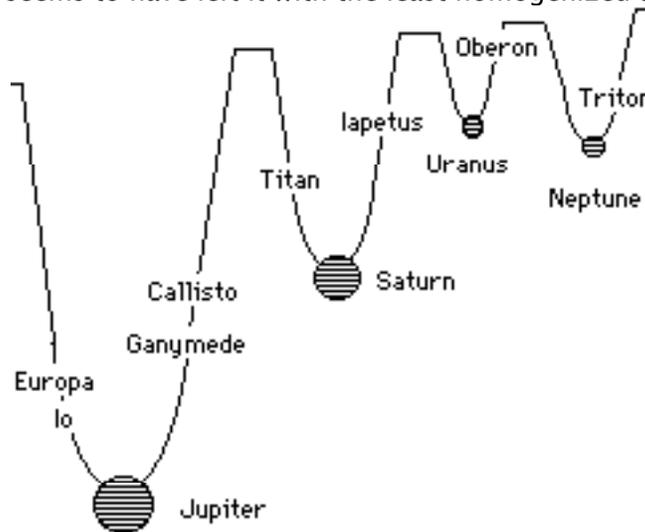
However, development of volume exports IS the question, and without this, settlements in the Outer System will be hard pressed to survive, let alone thrive. All four of the Gas Giants, happily, contain significant atmospheric resources that, if not strictly inexhaustible, will serve us well for many centuries at foreseeable rates of growth in demand. The rock and metal cores of Jupiter, Saturn, Neptune, and Uranus - while each quite a bit larger than the whole globe of Earth - make up only a lesser fraction "seed mass" component of their entire bulks. The rest is predominantly Hydrogen and Helium salted with methane, ammonia, and other gasses and cloudstuffs.

As fusion power, primed with the Helium-3 endowment from the Solar Wind 'sponged up' by the powdery lunar regolith 'topsoil' over the preceding billions of years, becomes ever more and more the vital wellspring of our advancing circumsolar civilization, the vastly greater reserves of this rare isotope available in gas giant atmospheres will become the Klondikes of centuries to come. Such mining will not be a simple scooping affair.



"HELIUM" must first be separated from the atmosphere by freezing out the other gases, then the small amount of the Helium-3 isotope must be separated from everyday Helium-4.

Intuitively, the first place to go would seem to be Jupiter, both because it is the closest and because, being most massive, it contains easily the greatest reserves. Counter-intuitively, instead **we will head for distant Uranus**, both because it lies in the shallowest gravity well of the four giants, and because its planetary history seems to have left it with the least homogenized atmospheric soup.



### OUTER SOLAR SYSTEM GRAVITY WELL HANDICAPS.

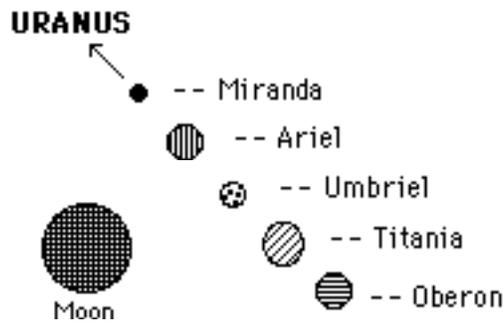
**Uranus is easily the most economical source of resources common to gas giant atmospheres, such as Helium-3.**

Once a "pipeline" of LHe3 tankers, likely uncrewed drones, is in place, the greater distance will be no more of an obstacle to supply than is the greater distance of Kuwait or Prudhoe Bay as compared to off-shore Texas or Louisiana. Outpost settlements will be needed somewhere in the Uranian system for maintenance of the fleet and teleoperation of the Helium-3 recovery systems. If it proves more economic to send loaded tankers on one way journeys inbound, i.e. if reusing them means sending them

back out empty at a greater expense than building replacements, there could arise a significant tanker manufacturing enterprise on one of Uranus' major moons. We predict this will indeed prove to be the case.

How big of a settlement outpost will be needed? It will have to manufacture a steadily increasing number of tankers per year to keep the "pipeline" flowing to Earth and other population centers in the Inner System. Those involved in this manufacture will need to be supported by miners, farmers, and producers of other products needed to keep the settlement self-supporting in a major way. Even with automation, we are talking a few thousand pioneers in due time.

Operations in the Uranian System will be tricky because of the skewed equatorial plane of the planet, shared by its moons. Uranus' axis is tilted 98°\* to the general plane\*\* of the Solar System. (\* Astronomers say 98° rather than 82° to show that the direction of rotation of Uranus and of the orbital motion of its satellites about it, is retrograde or clockwise, the opposite of the Solar System norm). (\*\* We now define the "ecliptic" as the plane of Earth's orbit about the Sun. This chauvinism will in time be replaced as we recalibrate every-thing with reference to the plane of Jupiter's orbit wherein lies 74% of the angular momentum of the entire Solar System, Sun included!) A ruddered aerobraking maneuver in the outer reaches of Uranus' atmosphere will allow us to make moonfall in this side-rolling equatorial plane.



**DIAMETERS, DISTANCES FROM URANUS, & TELEOPERATION TIME LAGS**

	Size*	kilometers	secs
Uranus-Miranda	550	130,500	<b>0.87</b>
Uranus-Ariel	<b>1500</b>	191,800	1.28
Uranus-Umbriel	1000	267,200	1.78
Uranus-Titania	1800	438,400	2.92
Uranus-Oberon	1600	<b>586,300</b>	3.91
(Earth-Moon)	3476	376,284	2.56

KEY: \* diameter in thousands of kilometers. **Miranda** is highlighted because it is the closest moon of size and offers the shortest, easiest time delays for teleoperations. **Ariel** is highlighted because in addition to offering short lag times, it is a moon substantially larger and more massive than Miranda. **Oberon** is highlighted because while its teleoperation lag is barely acceptable, its very distance from Uranus places it on the shoulder of the gravity well, making it the easiest moon to reach from Earth. Earth-Moon stats are shown for comparison.

**OBERON-MIRANDA and OBERON-ARIEL**

window every	1.58 days	3.10 days
trip time lasts	6.43 days	7.28 days
send-receive lag	3.04-4.00 sec	2.63-5.18 sec

**Exportable Resources: Terraforming Materials H2O from HYPERION, N2 from TITAN**

Many space dreamers inspired by Freeman Dyson and Gerard O'Neill look upon the outer planets as cachés to be dismantled for building materials with which to build a vast ecosphere shell surrounding the Sun and trapping all its energy capable of supporting megadrillions of people (Dysonsphere concept) or alternately innumerable individual O'Neill space settlement structures. But unless you postulate a future ability to transmute overabundant unwanted elements into more useful ones, and or you postulate our development of ways to mine the planetary cores of these giants that lie buried under unimaginably crushing overburdens of hot liquefied gasses or ways to blast into space these massive

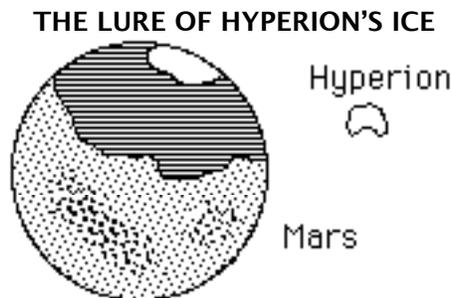
atmospheric envelopes to lay naked the metal rich cores within, such dreamers are indeed just dreaming. In fact, 80 some % of the total mass of the Outer System is Hydrogen, much of the rest Helium. NOT the stuff of which Dyson Spheres or space colonies are made.

Significantly more humble but still involving a collection of development and logistic challenges that could well remain dauntingly out of reach perhaps for centuries, is the wholesale transport of raw materials intended to help “terraform” Inner System worlds like Mars, Venus, Mercury or the Moon. Full blown terraforming is heady stuff. Ambitious schemes to move from one place in the Solar System to another the enormous quantities of volatiles, specifically Hydrogen (or water or water-ice) and nitrogen, will involve efforts on so large a scale over periods covering many decades if not centuries, that it strains the imagination. Someday, we may have the energy and the wealth to reengineer the System to suit our liking. That day would seem far off, and the near term significance for economic opportunity small.

Yet, when the day does come, it is already clear where we might look for the materials needed. There are enormous amounts of water and water-ice in the Galilean moons of Jupiter. There is yet more in the satellites of Saturn. How much is needed? If Earth’s oceanic blanket could be removed into space intact, and then allowed to shape itself by its own gravity into a ball thereupon ice-crusting over, it would form a moonlet 1100 km or 690 miles in diameter. If we want to put an ocean even remotely comparable to ours on Mars, we are talking about a lot of material.

It would be easier to get that ice from a small moon-let with negligible gravity than from a more gravid body like Callisto, for example. How about dismantling wholesale Saturn’s moons Mimas (392 km) or Enceladus (500 km)? The public hue and cry would be loud: “let them be!”

But further out, orbiting just beyond Titan in a 4:3 resonance with it, is another “right-sized” moon, Hyperion, which nature has already begun to “dismantle”. No longer spherical, Hyperion has suffered from a major recent blow, and with its new “hamburger-like” shape (240x250x400 km), it wobbles about like a top in its orbit. Perhaps we should finish the job. Alternately and less drastically, we could simple whittle it down to spherical size, taking only the form-protruding excess. And if transporting even that much mass to Mars is a forbidding prospect, why not cache this water lode in orbit around neighboring Titan itself for future use?



**HYPERION'S “MANIFEST DESTINY”?** The wobbling, already half-dismantled Saturnian ice-moon of Hyperion contains enough frozen water-ice to fill the Northern Hemisphere Boreal basin on Mars to create an ocean as expansive as the North or South Atlantic with an average depth of 1000 feet. There will be significantly less opposition to “finishing” the dismantling of this moon for its contents than to disturbing any of the other “intact” worldlets.

For Venus, the need is not water, but hydrogen with which to make it from the abundant enough oxygen locked in the planet’s very thick carbon dioxide atmosphere. An accompanying stable sink for the unwanted carbon must be found, possibly in the form of some sort of Venus-Sun L1 parasol to lower the amount of incident solar heating. The hydrogen itself could be harvested from any of the gas giant atmospheres.

**TITAN'S NITROGEN:** – Titan has a hundred times as massive an atmosphere as does Mars. Just 10% of all that nitrogen (i.e. leaving Titan with an atmospheric pressure still 35% greater than Earth’s) would raise the atmospheric pressure on Mars 10-fold. One third of Titan’s atmosphere (leaving Titan with air pressure equal to Earth’s) would give Mars a third as much pressure as Earth. And there’s enough oxygen in Mars’ soil to sweeten that imported Nitrogen breath-fresh.

Will a slow but steady “pipeline” of liquid nitrogen tankers someday begin the transit to Mars? It will surely depend on what effects the loss would have on Titan. If it some-how improves conditions for

settlement on Titan, the go ahead may be given. Mars would pay Titan for the shipments with goods and materials needed out there.

### **Universe Class Tourism in the Outer System**

Yet another foundation upon which to build a human presence in the Outer System is tourism. Chesley Bonestel, and other artists since, have given us dramatic paintings of breathtaking sky-filled views of riotously colored, storm raked Jupiter and of Saturn with its rings, both giants viewed from the imagined surfaces of their several moons. But alas, it seems we can't just put all these moons on a tourist itinerary!

The inner three of Jupiter's great Galilean moons – Io, Europa, and Ganymede – lie within the big planet's intimidating radiation belts. And all lie at various depths within the most challenging planetary gravity well in the System.

At Uranus, little Miranda is geologically the most intriguing object in the Solar System. It features a long escarpment with cliff faces 15 km high. Those out that way to "pump" Helium-3 are sure to pay it a side trip. But it is unlikely that even the well-heeled will come out all this distance from the Sun just for a ten-minute long bunjy jump.

Neptune itself is serenely beautiful, if the pictures from Voyager II tell the truth. Its large moon Triton has been revealed to be a fascinating world. Maybe someday when either time or energy is irrelevant, people will come.

You may have noticed we skipped Saturn, rightly suspecting we've chosen to leave the best to last. Even these days when we know that Saturn's rings are not per se unique and that probably all gas giant planets anywhere in the galaxy have them, Saturn is still the single crowning wonder sight within the realm of the Sun. Its ring system is far and away the most extensive, the most massive, the most intricate, the most colorful, and the brightest.

However, as Bonestel himself realized and brought out faithfully in his paintings, all the moons from Hyperion and Titan on inward lie precisely in the equatorial plane shared by the rings. Standing on one of these moons, you would see Saturn assuredly filling the sky, but would be hard pressed to pick out the razor thin line of the rings themselves, seen edge on. Want close up views of Saturn and views of the rings in open perspective to boot? That's like wanting your cake and eating it too. Actually, tourists will see such a sight – en route to or from moonfall and a tourist center.

It turns out that the moon Iapetus is the best place for such a tourist haven. It is the closest moon – if you can call 3.3 million km or 2.2 million miles close! – to Saturn not in the ring plane. From its vantage point, on alternate swings above and below the ring plane, the rings (and Saturn's pole and cloud belts) alternately tilt up to 14.7° towards and away from the viewer over the course of Iapetus' 80 day long month (from Earth we can see the rings open up to 26.7°). Happily, even at this distance, some nine times the Earth-Moon gap, hefty Saturn still fills 2° of sky (compare with the Moon's half degree as seen from Earth) covering 12.4 times as much sky and shining less glaringly with 3.8 times as much light as our full moon. The view won't be as spectacular as some of the glimpses en route, but from Iapetus, tourists could watch, photograph, and paint at leisure, tracking Saturn through its phases and moods over Iapetus' 80 day orbital period.

Not only is Iapetus the place to make systemfall at Saturn for those interested in the view, it is also quite high up the shoulder of Saturn's gravity well, and is thus the easiest of Saturn's major moons to visit. Iapetus will be the jumping off spot for both tourist and scientific expeditions to the retinue of other moons. There will be sorties outward to remote Phoebe; inward to broken Hyperion, mighty Titan, and to Rhea, Dione, Tethys, Enceladus, Mimas, Janus and several lesser moonlets.

We've already mentioned the potential far future importance of Hyperion and Titan to the terraforming of Mars. And Titan itself will undoubtedly merit the most intense scientific scrutiny. Setting up an outpost on Titan will be very challenging, in current polls right up there behind Mars itself! We predict such exploration and settlement will escalate hand in hand with the strong wave of tourism we've outlined, one piggy-backing on the other as the situation allows.

To get to Iapetus and sibling moons, visiting craft must shed momentum by a dramatic aero-brake maneuver in the upper wisps of Saturn's atmosphere. This will be overtured by a breath-arresting ride over (under) the rings before skimming the lightning-speckled atmosphere on the night side and scooting under (over) the rings on the way out.

Iapetus then, is not only the ideal tourist stop at Saturn, it is Saturn's ideal "Grand Central". To experience such "Universe Class" tourist attractions, once we have a means of reliable, comfortable transportation that can make this "trip of a lifetime" in a routine fashion – even if it takes 3 or 4 years one way – the trickle of tourists will begin.

Thus, while eventually there may be human outposts and settlements throughout the Outer Solar System, we predict the very first of these will be on **Oberon** around Uranus, and on **Iapetus** around Saturn. Unfortunately, we won't be around to collect any bets! 

## **“Sun-forsaken” XITIES of the Outer Solar System ... and Beyond**

By Peter Kokh

### **“Port Herschel,” Oberon**

As a center for tended systems and teleoperations to run Helium-3 harvesting aerostats afloat in the atmosphere of Uranus and the transfer of liquid Helium-3 to tankers for the trip Sunward, a settlement would be needed, perhaps on Oberon. But, given the time delays involved, actual teleoperations might be easier from a forward post on Ariel.

The settlement would also do needed repairs and maintenance, have as complete a hospital as practical and manufacture as much as feasible of its own needs. This could perhaps even include manufacture of the Massive, Unitary, Simple components of the tankers themselves, using imported Complex, Lightweight, and Electronic components according to the “MUScle” formula for strategic settlement manufacturing priorities. Thus imports would be held to a minimum, vitally important when it takes a decade or more to fill an order no matter how urgent. The settlement would grow its own food and, logically, power itself with Helium-3 fueled fusion.

An observatory for close up study of Uranus and its moons could be supported as a sideline. In addition, a principal outpost on Oberon would support excursions to the other moons in the system for mostly for scientist but possibly also for a trickle of tourists, drawn principally to Miranda.

Bear in mind that Oberon shares Uranus 98° orbital tilt. The north and south poles alternately point towards the Sun for 42 years at a time. To the extent, given the greatly reduced amount of sunlight, that this is a practical concern, it may be decided to build a pair of polar outposts, one North, one South and switch occupancy and operations from one to the other every 42 years. If just one outpost is to be built, the equator would be the logical site. Oberon's rotation would give it “spring” and “fall” “days” of 13.5 standard days long.

### **“Bonestel Point,” Iapetus**

**IAPETUS:** 1440 km (893 mi.) in diameter.

Surface area 17%; Gravity 1/20th g (5%).

Escape velocity .67 km/sec (1496 mph)

Day/night cycle (“sol”) = 79 d 22 h 5 m = 80 days (40/40)

(a full set of phase changes of Saturn & rings as seen from Iapetus = 1 “Saturnalia”)

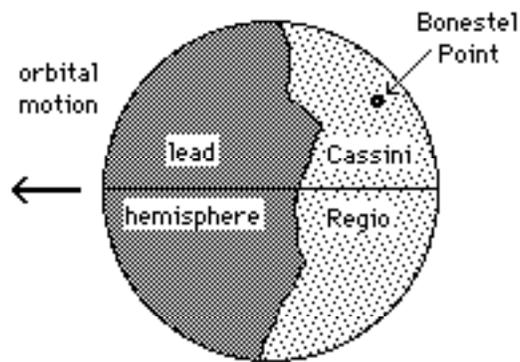
Saturn-Earth Synodic year 378 days = launch window intervals

Teleop & Communications lag to Titan 15.6 – 32 seconds.

Light trailing (50% albedo)/dark (4% albedo) lead side areas; Craters have been given names from the Charlemagne period.

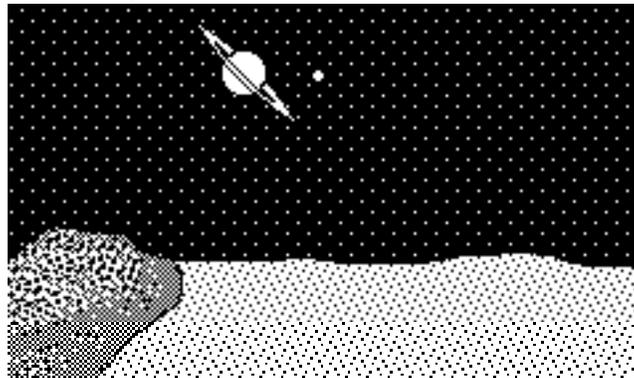
**TRIVIA:** In the original 2001 story of Arthur C. Clarke, it was not Jupiter, but Saturn's enigmatically bright/dark shaded moon Iapetus that was the target of the ship Discovery.

**IDEAL VANTAGE POINT SITE FOR OBSERVING SATURN AND RINGS:** 45° E (330°W)(in the bright protected trailing area) and 45° N or S in Cassini Regio. The actual site may be chosen for offering a dramatically scenic Iapetan landscape as foreground for the spectacle of Saturn and Rings.



**OBSERVATION TRIVIA: Saturn 30° above horizon**

- Rings open to 14.7° (vs. 26.7° from Earth) tilt to horizon 45°
- Apparent diameter of Saturn 2° (4 times apparent breadth of Moon from Earth and covering 12.43 times as much sky)
- Full Saturn 3.78 times as bright as full Moon
- Ring phases (open, edge-on) precesses full cycle in 7 1/3 yrs.



**VIEW OF SATURN from "Bonestell Point," Iapetus.** Moon at right is our own as it appears from Earth, shown for comparison of apparent size. **DANCE OF MOONS:** The apparent diameters of Saturn's other moons in Iapetus' sky: Titan 1–7' (The Moon is 29–31' in diameter in our own skies), Rhea 2', Dione 1.5', Tethys 1', Enceladus and Mimas 0.5, 0.2'. Only Titan would ever show an appreciable disk. These moons would all appear in the plane of the rings, to one side or other of Saturn, in front of it or behind.

A Tourist complex on Iapetus would serve as the logical center of operations for all traffic in and out of the Saturnian System. From a sheltered vantage point on Iapetus, tourists and students could observe Saturn and its ring moods and phases through a full 80 day cycle of perspectives as the moon slowly orbits its giant host. Watching the orbital dance of the other 20–some moons would also be part of the show.

There'd be surface excursions on Iapetus and available side trips to some of the other moons, especially Titan. And, of course, the dramatic arrivals and departures via Saturn itself dashing over and under the rings – front row on the 50 yd line!

As a logistics center for the Saturnian System, the outpost at "Bonestell Point" would outfit expeditions to the other moons and serve as the export/import junction for trade with a trial outpost on Titan. Iapetus might self-manufacture some of its own needs, and some things needed to open Titan.

If an inner moon outpost is desired, 658 mi. diameter Tethys may be a good choice. It has two Phobos-sized (15 mi) natural companions, Telesto and Calypso, in the formation-keeping L4 and L5 positions of its orbit around Saturn.

**IAPETUS and TITAN**

Iapetus orbits Saturn in a 4:1 resonance with Titan. Minimum energy Hohmann transfer trajectory windows open up for 50 day long one way trips either way between Iapetus and Titan every 20 days. The full circuit communications lag between the two varies from 16 to 32 seconds.

## **Astrometric Observatory on Iapetus**

An Observatory is a must, and tourists might pass time staffing it in assistant capacities. Besides studying Saturn and the other moons of the system, such an observatory could be engaged in a search for trans-Jovian asteroids and comets.

But most importantly, the observatory would be dedicated to astrometrics and stellar parallax measurements, i.e. measuring the position of stars and using triangulation to determine their distance. Present parallax measurements use the diameter of the Earth's orbit as a baseline, yielding data of diminishing accuracy out to about 20 parsecs or 65 light years. Here we'd have the ten-fold larger span of Saturn's orbit to compare astrometric positions taken 14.73 years apart (half a Saturnian year instead of the 6 months it takes Earth to get from one point of its orbit to the point opposite).

Instead of the 8,000 stars within the radius now available to our methods, from Iapetus, measurements of equal accuracy would take us out to 650 light years, encompassing 1000 times the volume of space and 8 million stars. Conclusions drawn from this much greater sampling of stars would greatly improve our knowledge of stellar populations. Iapetus would be a scientific springboard for our destiny among the stars!

## **University of Saturn**

A University of Saturn headquartered on Iapetus might play a major role on the long cruises inbound/outbound from the population centers on Earth, Moon, L5, and Mars. Campuses would be established on each of the Earth-Saturn transitel ships. The four year long journeys one way would mean time to burn for both settlers and tourists. Curricula could be custom designed personally for each. Most suitable subjects would be those that are library- rather than lab-intensive.

Courses might include Art/crafts for recyclable media; Performing arts; Literature; Languages; Sciences, especially Solar System astronomy and economic geography, and astronomy of the neighboring stars; Mysticism; Monasticism; Agriculture & Horticulture; Medicine. Curricula intended especially for prospective settlers as opposed to tourists would be mentor-run and aimed at jack-of-all-trades proficiencies. For practical project and homework, there might well be assignments and projects requested by various settlements.

Given the long cruise times the bane of slow rockets this true University "in" space could offer Baccalaureate, Masters, Doctorate, and Post Doctoral programs.

Besides education, rotation of ship/community chores would have a strong role in relieving boredom as would a full calendar of breaks, holidays, festivals, and other events to be anticipated and prepared for. Brainstorming sessions might be a popular diversion. Shipboard sports might be augmented by carefully supervised "EVA sports" and dinghy races.

## **"Xenopolis," Titan**

**NOTE ON ADJECTIVES:** Keeping in mind that Uranus has a moon called Titania, "**Titanian**" should be reserved for things and settlers pertaining to that world. To use the same term for things pertaining to Saturn's moon Titan would be misleading. We propose using "**Titanic**" for the latter.

A frontier settlement on Titan would be desirable for several reasons. First of all, a forward outpost there would give biochemists and planetologists a unique laboratory in which to study further the boundary conditions of life on the low temperature end, and offer a glimpse of the primitive reducing atmosphere of ancient Earth. Second, if the settlement effort could be sustained, it would considerably expand the envelope in which human existence is tenable.

**For convenience sake, let's christen such an outpost "Xenopolis" (Stranger City)  
for truly on Titan, humans will find themselves "strangers in a strange land".**

## **Xenopolis' MISSION includes:**

1) **Exploration:** Titan's geography, geology, meteorology, seismology, economic geography, volatile cryo-cycling in the atmosphere, etc. In support of this effort a unique transportation infrastructure and novel vehicles would need to be developed. A network of remote telestations and tended out-posts would support surface excursions for scientists and occasional tourists. "Gateways" (surface ice-free "roads" elevated above graded terrain), hovercraft, and mag-lev rail beds are possible, along with a special family of Titanic aircraft.

2.) **Research and Development:** to support settlement, we'll have to achieve economic use of Titanic resources: rock, water and methane ices, nitrogen, and assorted atmospheric organic chemicals (Hydrogen & Deuterium, Helium, Methane, Ethane, Acetylene Propane, Diacetylene, Methylacetylene, Hydrogen Cyanide, Cyanoacetylene, Cyanogen, CO<sub>2</sub>, CO). Refined "titanochemicals" (cryo-plastics, synthetic feed-

stocks) will be the buzz word. Export development will be a major goal as will self-manufacture of most of the xity's own needs.

"Titanochem Inc." might include surface refineries as well as atmospheric aerostat plants. "Cryoplast Corp." might mill cryo-hardy synthetic building materials; a "Superstable Cryomaterials Laboratories", do advance work in chemistry.

Xenopolis' mission would also include 3) Pushing the Envelope of the Human Ecosphere. How can a community survive in such an extreme and hostile environment, one so utterly different than any in which we have previously attempted to establish ourselves? Self-manufacturing autonomy using an exotic suite of resources would be a major challenge. Xenopolis would need to produce its own shelter, furnishings, and transportation devices. The xity would be the center for developing habitat and transport systems for ice-rich "cryothermal" worlds. There will be external facilities and outposts that need to be teleoperated. Fuels and power systems that work in the surrounding cold must be designed and tested to unprecedented levels of dependability. Environmental systems allowing some thermal and gas exchange between the sheltered biosphere and the host surroundings need be designed.

A successful demonstration of communal living on Titan would be an envelope-pushing feat well beyond the most daring past precedent. In comparison, survival on the Moon or Mars will be seen to have been as easy as survival in Eden.

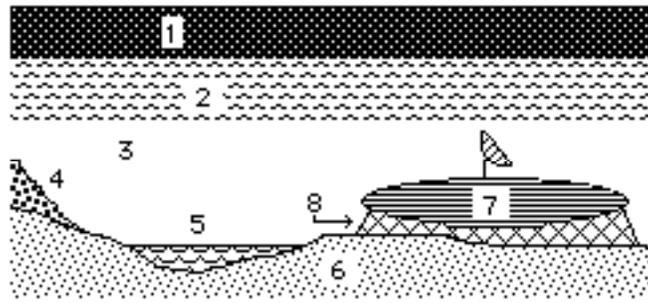
Building such a xity would be quite a challenge. We now know little about the surface of Titan and our guesses are constrained by insufficient data. We've narrowed down our estimates of the surface temperature range which will be the governing factor. Probably we have a surface that is some combination of extremely cold diamond hard water-ice and rock outcroppings or nunatuks (exposed mountain peaks in a glacial sea). "Near" the "triple point" of methane (where the gas can coexist with its solid and its liquid), there are possibly fields of methane snow, slush, and ice or lakes of liquid methane salted with an anti-freeze of other hydrocarbons rained out of the atmosphere. The European built Huygens probe which will ride piggyback out to Titan aboard Cassini, will hopefully tell us much more - though sadly not equipped to take pictures.

Some things are already clear. A xity on Titan would be a relatively hot thermal pocket in a deeply permafrozen world, a combination that spells trouble. Building it directly on, let alone into, the surface would spell disaster. The xity's heat would melt the surface underneath. The entire installation would slowly melt its way into the subsurface, sinking until its heat generating capacity stopped or was overcome.

Instead, Xenopolis must be a thermal preserve, a heat island insulated from the surface. Perhaps a "wind-lined" megastructure built on some sort of non-thermally conductive stilt-work footing near surface winds circulate freely underneath, carrying heat leakage away into the atmosphere's thermal sink.

The amount of human activity Titan could bear without upsetting the prevailing thermal equilibrium of the environment may be limited. Almost certainly, however, there is enough leeway in that equilibrium to tolerate a few isolated settlements and auxiliary outposts. We should be able to speculate more accurately after Cassini-Huygens.

Xenopolis must be designed to be heavily insulated from the surrounding cold, for the mutual protection of both exterior environment and interior ecospace. The heat generating activities within, basic life and agriculture activities and the mix of commercial and industrial activities, must be carefully planned with the thermal budget in mind. So first the xity-hull or shell must be designed and its "R" value pinned down with accuracy. Next the thermal budget equation must be worked out, desired industrial activities balanced against the remaining leeway in the equation. Probably practical efficiency will dictate a certain overall size and population capacity. In general, as with animals (compare the mouse and the whale) the larger the overall structure, the smaller the volume to surface ratio, the easier to retain needed heat.



Erecting such a xity in such adverse conditions will be a challenge beyond ready comparison. Would it best be built in the upper atmosphere, suspended by lift balloons or dirigibles, then when completed lowered to the surface? We invite your further speculation. Meanwhile here are some trial balloon sketches to whet your imagination.

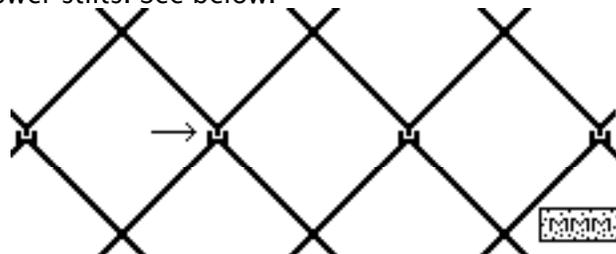
**XITY ON TITAN - XENOPOLIS:** 1) Space and Vacuum above N<sub>2</sub> atmosphere; 2) unbroken cloud cover and strata; 3) possible transparent area of atmosphere near surface; 4) mountain; 5) liquid hydrocarbon lake or sea of ethane?; 6) surface of unknown proportions of rock and ices (water ice, ammonia ice, etc.); 7) hull of xity, saucer shaped to deflect winds and dissipate heat; 8) open trusswork of stilt supports to allow winds to circulate beneath xity and keep frozen terrain insulated from xity heat.

For scale of trial outpost settlement and one suggestion of interior arrangement, see below.



Settlement "arcology" of size indicated for 3,000 people.

To act as a thermal barrier and further lessen heat conduction to the surface, one entire level of supportwork joints are physically separated. The main settlement mass and thermal island is magnetically levitated above the lower stilts. See below.



Keeping **WARM**

**SURVIVAL Beyond the BELT**

By Peter Kokh



AMOUNT OF LIGHT AND HEAT RECEIVED FROM SUN AT: E Earth, M Mars, J Jupiter, S Saturn, U Uranus, N Neptune. “Insolation” decreases as the square of distance from the Sun. Solar Power Systems become ineffective much beyond Mars.

#### COMMUNICATIONS TIME-LAG

ROUND TRIP RADIO TIMES: Earth to/from outposts at

The MOON	2.5 secs
MARS, Phobos, Deimos	6 – 44 min
JUPITER, Callisto, Himalia	1.1 – 1.8 hrs
SATURN, Titan, Iapetus	2.2 – 3.1 hrs
URANUS, Miranda, Oberon	4.8 – 5.8 hrs
NEPTUNE, Triton	8.0 – 8.7 hrs

The Moon orbits at a “teleoperable distance” from Earth. “Conversation” between Earth and Mars would be strained even at opposition when the two are closest. Beyond that, communication might as well be via the Post Office.

#### The Challenges to Settlement in the Outer System

There is more to survival out beyond the asteroids than finding and tapping a complete technology-supporting range of resources. Thermal budgets – keeping warm, and powered – will be primary concerns. Options available in the Inner System, specifically Solar Power, will not apply out here. Architects, builders, and engineers will face new challenges in balancing thermal inputs and outputs, in the creation of Oases not only of life in barren sterilizing surroundings, but of warmth in the midst of heat-sucking cold.

Communications with the inner human worlds and outposts will lack immediacy. Time delays by radio range up to several hours, making casual exchange impossible, carefully planned and prepared transfer of information the rule.

But if these irremediable difficulties are not enough to discourage, the difficulties of actual travel between Outer System outposts and the Inner System worlds of Earth, Moon, Mars and sunshine-basking space settlements – and indeed between the far scattered Outer System cities themselves – will be enormous. With chemical rockets any such journeys must take years, entailing mortal risk of accumulative exposure to cosmic radiation and solar flares, and spirit-snuffing boredom.

Clearly, we will not essay in the flesh into the Outer System, much less establish permanent presences there, until we’ve developed and perfected much speedier modes of travel. Even with nuclear rockets, no one will venture out-system without accepting that in medical, biospheric, or mechanical emergency they will be left to their own resourcefulness. Resupplies will need to be scheduled proactively anticipating likely emergencies, not reactively in response to actual ones.

The process of shedding umbilical support lines from the Mother World will have begun with Lunar Settlement. But Lunans will yet have access to props, relief, and rescue that will be out of the question for Martian trailblazers. These New Worlders will need to be much more self-reliant, much more accepting of risk without backups. Slowly, as the range of the human species expands at first beyond the cradle world to its moon, then beyond the Earth-Moon system to Mars and the near asteroids, the links of communication, commerce, and travel will become skimpier and skimpier, yet always remain enough to maintain a sense of joint community, of family.

#### The Oort Cloud, the Heliopause & Beyond

There is a long list of scientific unknowns about the Oort Cloud, a conjectured spherical halo of distant comets that may accompany the Sun in its galactic wanderings. What is the characteristic chemical makeup, mass and size range of this comet population? How pristinely undisturbed is that makeup? Do these comets, innocent of visits to the warmth closer in to the Sun, show tell-tale traces of close encounters with other passing stars? Is there a Rosetta stone to unlock the history of such encounters? How densely populated is the cloud?

Space dreamers need to know if the Oort Cloud holds significant practical implications for human expansion into the Solar fringe and beyond. Cometary ice can serve as impact bumper shielding

for hypervelocity craft, or as fuel cachés, but will the DV penalties of shedding expensively bought momentum in order to rendezvous and load be worth the effort? Do such comets contain any reserves that are not more easily tapped in sufficient abundance within the more easily accessible Outer Solar System? Do they contain enough of everything we would need to establish a scientific outpost on one of the larger of the host? At this point we can only wonder.

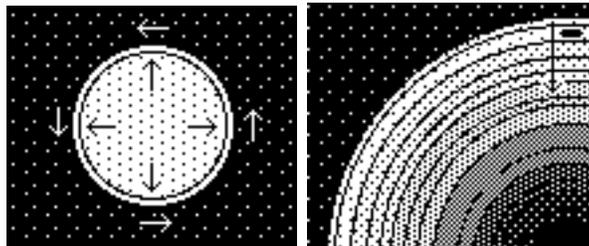
Between “the Cloud” and the nearest true stars, are there as yet unsuspected systems, planet and moon bearing rogue Brown Dwarfs? Such “infrars” are massive enough to glow with the warmth of slow gravitational contraction but not massive enough to experience or sustain nuclear ignition and burning, the source of true starlight. We can statistically expect to find a dozen or more such dud stars and systems neighboring us more closely than Alpha/Proxima Centauri. Would experience gained learning to survive and thrive in the frigid Outer Solar System, e.g. on ice-firmamented oceanic Io and on exotic Titan prepare us, even give us enthusiasm for settling such “Brown Systems” as destinations in their own right? For surely they will serve no purpose as stopovers! Settlement of such systems would have to stand alone, not be dependent on the crutch of import-export trade or sold on the basis of bene-fits to the parent circumsolar economy.

For our inevitable toe-wetting extra-solar excursions out beyond the haunts of Neptune & Triton, Pluto & Charon, Helium-3 Fusion Arks would, at this juncture, seem to make the best bet. Engineering wise, “Matter-Antimatter Drives” are still very much in the realm of Science Fiction no matter how theoretically legitimate. Compared to other nuclear fission and fusion choices, clean He3/D will require significantly less massive shielding and superstructure distance between engine drive and the crew quarters of the “ark”. That will dramatically lower the threshold, hasten the first breakout foray.

MMM

## MMM #60 – November 1992

Creating “terra firma” where there is none.



Three dimensional beings, our existence is utterly polarized by an up-down gravitational gradient structuring our lives along a resisting two-dimensional surface: terra firma, hard ground. In space, left, we can create effective terra firma from scratch by rotation. On surfaceless or surface-hostile planets, right, we can create hard ground in high-floating atmospheric aerostat structures. See article below.

# XITIES

**Series Cont.** Pronounced KSIH-tees' not EX-i-tees  
[Human communities beyond Earth's cradling biosphere]

By Peter Kokh

**PUSHING THE ENVELOPE:**

## AEROSTAT XITIES “AFLOAT” IN THE ATMOSPHERES OF VENUS, JUPITER, SATURN, TITAN, URANUS, NEPTUNE

We think of Venus and the outer “Gas Giant” planets as forbidding places forever “off limits” to humans. Each has a thick crushing atmosphere and either an unsurvivable surface or no real surface at all, abysses or abysmal lands where the temperatures and pressures far exceed all human capacity to adapt – even within techno-miraculous protective cocoons.

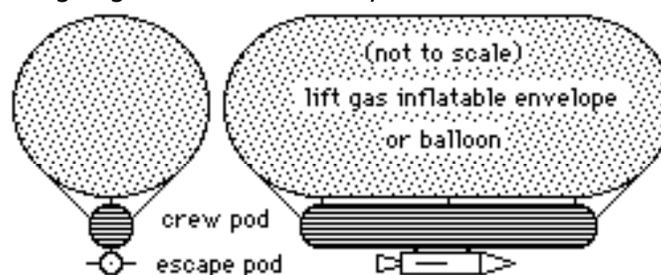
Yet there are thinner, higher, more temperate regions in the atmospheres of each of these hell planets where the conditions are relatively benign. Such planet-girdling pseudo “ecospheres” lack but one thing to make them attractive sites for human outposts or settlements – “terra firma”, solid land at the seemingly benign levels.

But this lack is something we can, with determination, do something about. We only need to expand conservatively on the known concepts of lighter-than-air craft. Several people have been predicting the return of great dirigibles to Earth’s own skies. Visionaries have gone further to speculate about aerostat outposts high in Earth’s atmospheres – not transportation vehicles but lighter-than-air “platforms”, either free-floating or tethered to a surface location. These could serve various purposes: remote sensing, air traffic control, military command posts, and rocket launching space ports above the thickest layers of the atmosphere.

In the oxygen-rich atmosphere of Earth we would need to use helium gas for buoyancy. But in the atmospheres of the gas giant planets, a helium balloon would sink! These atmospheres are largely hydrogen with smaller portions of heavier gasses: helium, ammonia, methane, and lesser contributors. There we would have to separate the gasses and use just pure hydrogen which would weigh less, volume for volume at given pressure, than an equal amount of mixed gas-giant “air”. As the advantage in buoyancy in this case, about 1.15:1 will be nowhere near as favorable as the 7-fold+ lifting power of helium in terrestrial air, the ratio of buoyancy container volume to gas envelope mass and platform mass supported would have to be quite large for aerostat facilities on Jupiter and its kindred planets.

Yet gas giant aerostats remain barely doable using the lightweight composite materials and fabrics now available or in the works, many of which could be fabricated in situ by mining the atmosphere itself. Available in gas giant atmospheres, as well as in Titan’s, are hydrogen, carbon, nitrogen, oxygen, sulfur, phosphorous, and germanium and other elements present as methane, ammonia, ethane, propane, phosphine, hydrogen sulfide, carbon monoxide, acetylene, water vapor, germanium tetrahydride, and other compounds.

In the case of any of these planets, the feasibility can be tested by dropping into the upper atmosphere a pressurized crew compartment carrying an inflatable gas envelope, the lift gas with which to inflate it, and an underslung Pegasus-like shuttle by which the crew could escape to orbit.



Such a demonstrator aerostat could help define the ideal float altitude, stabilization mechanisms, and thermal management strategies. The crew could experiment with pilot atmosphere mining and processing equipment, with options for deriving energy from the atmosphere, and identifying problems. Surface observations (Venus, Titan) and atmospheric science would be done on a contingency basis.

### Why Aero-Xities on/in the Gas Giant Planets?

If large enough xity-sized aerostats could indeed be built, in whole or part, with atmosphere mined and processed materials, they could serve for extended meteorological research and biospheric experiments within the pseudo ecosphere levels of the host atmospheres. If indeed they do not already exist, could we bioengineer bacteria and eventually higher unicellular and multicellular plant and animal

varieties – even whole ecologies – to survive in atmospheric sargasso oases on these planets? Several Science Fiction writers, Arthur C. Clarke among them, have already speculated along such lines.

If eventually successful, such research would teach us much about the adaptability of life, and better prepare us for the greater universe of possibilities beyond our home System. As little as we can as yet safely say about planetary systems in general, having examined but one example, there can be no doubt that gas giant planets must vastly outnumber terrestrial or terraformable ones.

We must see our role not only as spreaders of our own species, but of life period. There must be places where life cannot arise on its own, but could survive, once introduced. Only intelligent species can serve as the means of such propagation. Gas giant planets may provide us the vast majority of our opportunities, even if they do not (now seem to) make ideal settlement hosts for significant numbers of our own kind. Our mission, not to rape virgin worlds but to turn them into new mother worlds, dates not from 1957 (Sputnik), nor 1902 (Tsiolkovsky), nor 1867 (Verne), but back billions of years at the dawn of life itself. Humanity and technology are come together as the reproductive organs of Earth-life: Gaia.

### **On the Oceans of Uranus and Neptune?**

Voyager II revealed Uranus to have a molten rocky core 13,000 km (8,100 mi or about the size of Earth) in diameter with an ocean of water 8,000 km (5,000 mi) thick. That's a volume of water almost eleven times as vast as the entire volume (rock and water) of the Earth and more than 40,000 times as great as the volume of Earth's ocean alone which, if our continents could be plowed into the ocean basins to create a uniform solid surface, would lie 2.7 km or 1.7 mi thick. But Uranus' ocean, a brine of water, liquid methane, and ammonia, must be super-heated to a thousand degrees or more, prevented from boiling by the crushing burden of the atmosphere above which is 11,000 km or 6800 mi thick. Neptune's inner structure must be similar. So while these planets are not totally gaseous as once thought, and do have "surfaces", reaching them even with robotic instruments will be enormously more difficult than reaching the surface of Venus. Aerostat xities, if any are ever built, would be limited to float levels very high up in those thick Hydrogen-Helium atmospheres.

The all but absent signs of lightning and whistler waves on either planet indicates relatively little updraft and thus probably not much in the way of 'rain' or 'snow'.

Neptune has 3000 times as much high atmosphere methane (thus much greater supply of carbon at aerostat float altitudes) as Uranus' meager 10 ppm.

### **Titan and Venus**

The outlook is actually much better for aerostat xities in Titan's rich dense atmosphere, where the full available lift of hydrogen is available in the much heavier nitrogen milieu, as can be seen in the chart below. A Titanic aero-xity might be the way to go if Titan's surface proves too treacherous or too challenging to host a settlement directly.

The lift numbers are also good in the case of Venus. The Veneran atmosphere, mostly carbon dioxide CO<sub>2</sub>, has an even higher average molecular weight, 44, than does our own atmosphere, 29. Further, since carbon dioxide suffocates rather than feeds combustion, it would be quite safe to use hydrogen (molecular weight 2) for buoyancy. The 22-fold lift advantage would mean a given dirigible volume structure in Venus atmosphere could support 3 times as much platform mass as a similar structure in Earth's atmosphere where the helium to air lift factor is 7.24.

Hydrogen, in the form of water vapor, is present in Venus' atmosphere but in nowhere near the same abundance as on Earth. We'd have to process an enormous amount of Air de Venus to get enough for our needs. Helium is unavailable on Venus so ammonia (NH<sub>3</sub>, molecular weight 17) and methane (CH<sub>4</sub>, molecular weight 16) are the next lightest gases that could be processed on site. But since they both incorporate hydrogen, the same strictures apply.

There are alternatives. We could either separate out nitrogen, N<sub>2</sub>, molecular weight 28, or process the CO<sub>2</sub> to produce equal amounts of carbon monoxide, molecular weight 26, and oxygen, molecular weight 32. We'd save the oxygen for the internal breathing atmosphere of our aerostat xity, and use the CO for buoyancy, making do with a 1.7:1 lifting ratio for a mere 1/13th the payload or supported platform mass. That is, for an aerostat xity of given design size and mass, our gas bags would have to have 13 times the volume (2.36 x both radius and length) if they are to be filled with CO rather than H<sub>2</sub>. While discouraging, the prospect of having no lighter buoyancy gas than carbon monoxide would not

rule out aerostats for Venus, just raise the engineering threshold. Even with CO, Veneran aerostats, size for size, could support half again as much platform mass as their Jovian equivalents.

Earth H2	<b>Earth He</b>	Titan H2	Jupiter H2	Venus H2	Venus CO
14.5	<b>7.25</b>	14	1.15	22	1.7
					

**RELATIVE LIFT OF AEROSTATS FOR VARIOUS PLANETS.**

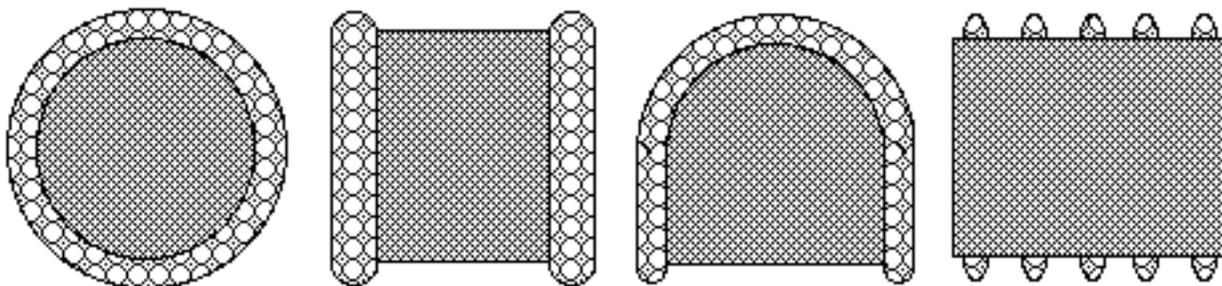
(Relative Mass of Platform Supportable per buoyant volume) The 2nd column shows the standard situation and practice on Earth where Helium is now used instead of Hydrogen for safety reasons. By comparison, an otherwise similar hydrogen aero-stat on Venus could lift 3 times the platform mass. But CO lift at Venus and Hydrogen lift at Jupiter are quite handicapped.

Of course, aboard an aerostat, one would experience weight just as one does aboard an airliner. That weight would be the same as one would feel standing on a mountain at the same height. For aerostat xities, there will be no need for artificial gravity. The environment will supply plenty.

**GRAVITY AND WEIGHT IN AEROSTAT XITIES**

<b>Earth</b>	<b>1.00 G</b>	<b>150 lbs</b>
Venus	0.90	135
Jupiter	2.64	396*
Saturn	1.16	174
Titan	0.15	22
Uranus	1.17	176
Neptune	1.20	180

\* Obviously, a Jovian aerostaty would attract few volunteers.



**OPTIONAL AEROSTAT PLANS (Overhead):** A gas filled hull providing buoyancy support of the central platform on which habitats etc. sit, or from which they are suspended, could be in the form of a torus (top left), catamaran (top right), horseshoe (bottom left), pontoon raft (bottom right)

**POWER AND THERMAL MANAGEMENT**

How would an aero-xity get energy with which to go about its business? Solar Power is not an option anywhere in the Outer Solar System, or beneath the cloud decks of Venus. Helium-3 and Deuterium are available in the atmospheres of the gas giants for use as fusion fuel. The availability of Helium-3 in Titan’s atmosphere is uncertain, however.

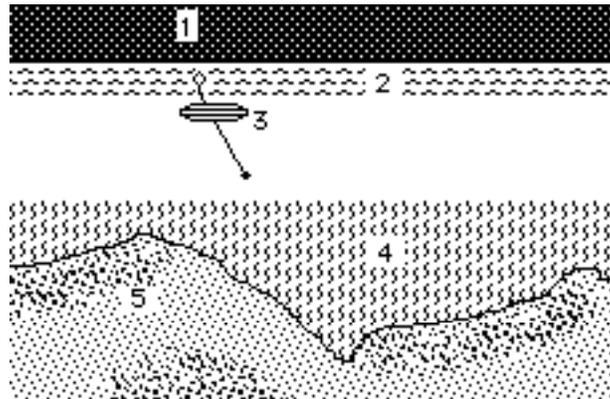
Energy production on Venus will have to be more resourceful. Could lightning be harnessed? What about some analog of OTEC, circulating a working refrigerant liquid between hot lower atmospheric levels and cooler upper ones? As to thermal management, that should be a simple matter of picking a float altitude with the right temperature.

**THE STRUCTURE:** Since the chosen flotation level is thermally and barometrically neutral, the ‘tight’ hulls of habitat structures supported on the central platform are needed less to insulate and pressurize than to contain breathable air in a setting of unbreathable ambient atmosphere. Bladders in the torus or catamaran “pontoons” can moderate buoyancy if it becomes desirable to float at some higher or lower altitude.

## “Valentine Heights”: Aero-Xity “on” Venus

While there may be valid reasons one would want to someday build aero-xities in the gas giant planet atmospheres, especially at Uranus where the economic opportunities are greatest and the gravity well penalties most manageable, [see last month’s articles in the Xities series.] it is clear that the most negotiable venues for such floating outposts are Titan and Venus. Let’s expand somewhat on the latter possibility.

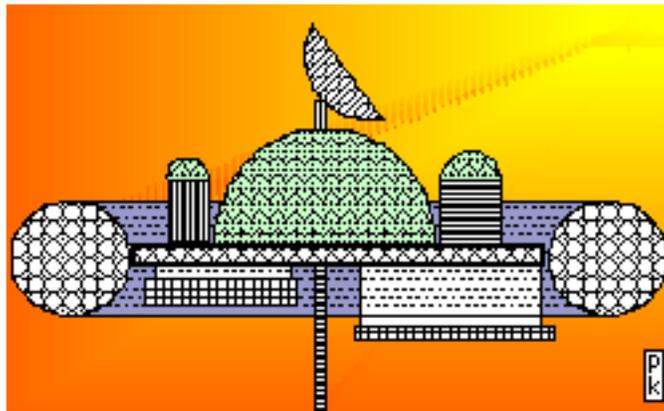
First we’ll attempt to satisfy your growing visual curiosity with some MacPaint ‘artistic’ renderings to suggest what such constructs might look like. Then we’ll discuss why on Earth (or Venus!) we might someday want to deploy them.



FLOAT LEVEL OF VENUS AEROSTAT XITY: 1) Space and vacuum above the atmosphere; 2) Unbroken cloud level 30=40 miles above the surface; 3) Venus aerostat xity floating just under the cloud deck about 30 miles (150,000 ft.) above the surface in cool CO<sub>2</sub> atmosphere at the 1 ATM pressure level with a clear view of the surface. An upper atmosphere meteorology station is borne on tethered balloon above while a lower atmosphere station is trailed by tether below; 4) the super oven-hot super dense lower layers of the atmosphere; 5) Super hot surface of Venus: continents, empty oceanic basin, craters, volcanoes live and dormant, mountain massifs, valleys and trenches.

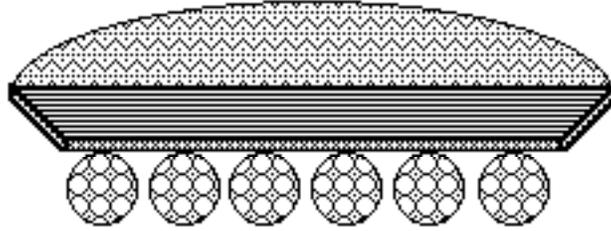
While on the surface dusky daylight and lightning-punctuated darkness cycle every 118 days, aboard the aero-xity riding 300 kph winds, dawn comes every four days.

## “Valentine Heights”



SKETCH OF VENERAN AEROSTAT XITY: Cutaway of a large donut torus or horseshoe float with cellular ballonets and bladders provides buoyancy support for the xity. Hydrogen gas is preferred, but carbon monoxide processed more easily from the atmosphere will do. The torus directly supports the central main spaceframe platform. Standing on the platform are a central residential-agricultural-environmental dome and auxiliary domed vertical cylinder structures. Below is suspended an elevator to a lower meteorology station and two open-air platforms: the one on the left supports teleoperated refining, processing, and manufacturing from atmosphere-sourced chemical feedstocks; the one on the right is a landing & take-off platform for unpiloted drone aircraft for close near-surface observation and teleoperated surface sampling and mining.

## “Cupid’s Blind”



This advanced scheme would employ a larger pontoon-raft for support. The “open air” environment would feature terraced interior side slopes under an overall skyblue dome.

**BUILDING IT:** While structurally, there is no reason why such xities could not work, actually building one is quite another problem. Would it be built in space and then lowered with “sufficient gentility” into the atmosphere? Would you instead bring in only a starter structure i.e. a buoyant processing plant, then begin to mine the atmosphere for feedstocks from which to make building materials (e.g. carbon into Kevlar and structural graphite?) out of which to fashion the great remaining bulk of the structure? The atmosphere of Venus offers much less diversity of elements with which to work chemical magic than do the atmospheres of the four gas giant planets or Titan. The architectural, engineering, and construction challenges either way are rather daunting. So the sketches and concepts above may prove to be as unrealizable as much of the great “glimpse of the future” cover sketches of issues of Popular Science and Popular Mechanics of half a century ago. Anyway, we have tried to stimulate your imagination.

**INDUSTRY:** If all that Veneran “cloud miners” have to work with are C, O, N, H, and S – carbon, oxygen, nitrogen, hydrogen, and sulfur, then in addition to agricultural products (importing phosphorus and other micro-nutrients) what serviceable synthetic materials could they produce? And what sorts of things could they make from them? Structural elements from which to expand? Mere low-performance furnishings and craft stuffs? Are exotic nitrogen-based ceramics and Kevlar among the possibilities?

The fewer basic needs can be met by self-manufacture from ambient elements, the more must at first be imported at high cost. Eventually raw materials for manufacturing might be supplemented by ores “tele-dredged” from the torrid surface.

**MISSION?:** What purposes might a Veneran aero-xity serve? Well, for one sure thing, such a supremely isolated and self-quarantined place might make the ultimate ‘Alcatraz’. You wouldn’t even need guards. Supplies and fresh inmates could be brought in by tele-piloted craft with no manual overrides. Anyone want out? Just step out the airlock and take a breath of Veneran air, or walk the plank off the main platform and plummet into the incinerating sulfurous hell depths below. Hey, Halloween is coming up!

On a less ghoulish note, such a facility would offer unequalled opportunities to conduct Venus science and exploration: An economic geography of the planet could be pieced together against a far future day when we might somehow be able to transform the pressure-cooker atmosphere into something humans can handle, with unproxied access to the surface.

A down-facing observatory would map the Veneran terrain below using multi-spectral remote sensing techniques. More ambitiously, rugged oven-hardened ceramic-hulled, diamond-wired teleoperated explorers, samplers, and eventually miner vehicles, etc. might be developed to serve as our stand ins on the surface, operated by crews in the aero-xity. These could be stationary surface stations or mobile ones. Prior to this, we could begin to get our feet “hot”, probing every lower and lower as the hardness of our equipment allows, by drone airborne craft teleoperated from “The Heights”.

Philosophically, the ultimate rationale behind an aerostat settlement over Venus may simply be our drive to continue brazenly pushing the “human envelope”. Born “naked apes”, we seem to have a deep-seated characteristic need to keep learning to first survive and then thrive in one seemingly more hostile environment after another. On Earth we’ve already long left our native tropical home lands and mastered the deserts and swamps, the temperate forests and grasslands, and even the arctic tundra and ice. The ocean deeps too have seen our first timid encampments. All of this courtesy of technology, be it so humble as clothing, hunting and fishing tools, shelter building skills, and thermal management tricks of the trade.

Those who deem unnatural human expansion into the for-a-little-while-yet hostile reaches of space, only show that they do not understand our own history. Had they been in control, we'd still be in the cave or swinging from the vines or timidly darting across the savannas. Our species has no limit on where we might live and pursue our needs except those it sets for itself. And those who would confine our beachheads in space to the inner hulls of artificially gravid zoo-like imitations of old Earth, are hardly more daring than the stay-at-homes. There will always be some of us, however few, that will want to get away from the common haunts of our kind and test new niches, vault new hurdles, face new challenges. Homo est animal incognitum probans. We will build a xity over Venus because Venus is there.

Easier said than done, to be sure. To transform such a vision into reality, we will have to find ways to make economic sense of it all. But before even considering what such a community might trade with the human universe beyond the all-hiding cloud deck, we'll have to demonstrate ways to push local self-sufficiency to the limits with the very limited material feedstocks available locally – and for a long time that will mean “mining” the atmosphere alone, period!

Surely one of the activities furthered by such a cloud-hugging settlement would be brainstorming of the possibilities, challenges and strategies for “**terraforming**” this runaway greenhouse world. Most of what has been written to date, even by well known authors, fits the category of garbage in, garbage out. They all conveniently neglect one or more harsh realities which constrain the possible avenues of approach. We've been keeping a “Friday File” [Venus = Norse Fria] on the subject for a future speculative article. MMMM

## A se by any other name

### The Proper Adjective for Venus?

Alert readers will have noticed that NASA/JPL-folk use the term **Cytherean** as an adjective, e.g. the “Cytherean atmosphere” or surface or whatever. Why? Because the adjectives for names originating in Latin, like Mars, Jupiter, and Venus, are customarily built on the genitive (possessive case form) stem of the word. Thus we have Martian from Martis, Jovian from Jovis. But apparently these prudes, or if prudes they're not then these people scared silly of a Bible-toting public, are afraid to use the genitive of Venus. You see it happens to be Veneris, from which, oh yes, our word **Venerial**, as in disease.

Now Science Fiction Writers, equally skittish about seeming propriety, have gotten around the problem by using the nominative stem: Venus, **Venusian**. That seems harmless enough but the linguistic scholars howled foul. Hence the public servants in charge of space science have avoided the matter by using a totally different word from some beat-around-the-bush association. Cytherea was an island near the mythological ocean birthplace of Aphrodite, the Greek love goddess identified with the Venus of the Romans.

For our money, the Russians seem to have come up with the best solution. Use the genitive root, but add simply **-an** rather than the ‘offensively suggestive’ -eal, -ean, or -ian. Thus simply “**Veneran**”. The reason it works is because the stress now falls on the first syllable instead of the second. A simple and elegant solution! If any one out there is still so uptight about his/her own sexuality as to be still squeamish about that, so be it. The use of Cytherean is absurdly pathetic. So we've adopted the Russian use which is both linguistically defensible and free enough of other associations. MMMM

**MMM #61 December 1992**

### **LARGE FLOATING STRUCTURES ON JUPITER**

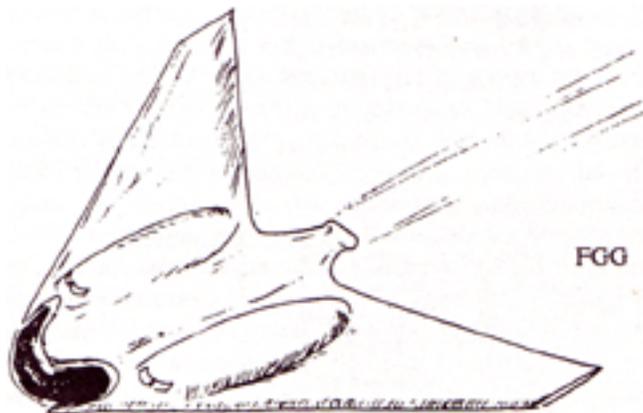
By Laotian C. Faust, Oak Ridge, TN

The large floating cities envisioned by Kokh in the concluding chapter of the Xities series indeed would be excellent laboratories for the further exploration and utilization of the gas giant planets such

as Jupiter, Saturn, and Uranus using technology one century of human progress more advanced than ours. These types of planets contain elements in solar abundance needed to perform the most difficult of all space missions, i.e., construct and power star ships of the type envisioned by John MacVey in **Journey to Alpha Centauri**, which attain a small percentage of the speed of light using enormous fusion power.

In addition, large gas giants are foreseeably the only planets we will easily be able to detect around other star systems, using infrared excess, radial velocity variation, or perturbation methods, from Earth-based or Earth-orbiting telescopes. Hence the technology to utilize them as bases, or as resource gathering centers for restocking preparatory to another interstellar voyage is important, whether by "generation travel" human colonies or long-lived AI [artificial intelligence] machine systems.

Aerostat Xities in the pre-interstellar age would likely be useful as bases conducting technological experiments in resource utilization of the gas giant planets, possibly then preparatory to the development of interstellar systems.



Twenty years ago I too suggested large floating structures in the atmosphere of Jupiter, driven by ice-water cycle engines. The floating bases could be connected by a transportation net of "inverse jets", i.e. aircraft with an oxygen supply and intakes for hydrogen. It was at Bruce Hapke's Planetary Physics class in 1978 that I first made this suggestion publicly. On Jupiter, the oxygen would be freed from atmospheric compounds such as water vapor, by dissociation.

Francis G. Graham, East Pittsburgh, PA 15112

[Francis Graham is Editor of **Selenology**, the quarterly of the American Lunar Society of which he has been a past president. He has an association with the Allegheny Observatory in Pittsburgh, and teaches at Kent State U. in East Liverpool, Ohio. An SSI Senior Associate, he has done Earth-based observations for sodium vapor over the Lunar poles leading to a pessimistic conclusion about the chances of appreciable caches of water ice there.]

[The following two letters in response to the above material were printed in MMM #62, and as germane, are also printed in this volume of MMM Classics.]

### **Reflections on the Xities Series**

As a new reader, I have several thoughts in response to your series on Xities. [snip first part]

### **The Lessons from Biosphere 2**

5. A most pregnant experiment in life support systems is Biosphere 2. I had formed an impression that the place leaked air as if it were drafty. I find instead that it leaks only 2% as much as the Shuttle spacecraft; and that change in the mix of atmospheric gas has been a most useful item to track for this first year. I believe that "man in a can" can't make it for very long or very far, out there. Several thousand other living species will have to go along for the ride, and incidentally to furnish the food, scrub the air, provide occupation and learning, and staff the recycle center. Biosphere 2 started with 3,800 logged species, and doubtless some stowaways of unknown capability. "Out there" it may take 50,000 species and a few pixies. Do we acknowledge that farming and fishing are still the most fundamental occupations of humanity anywhere, and that our other great industries and institutions all depend on the folks with the hoes or their tractors, using energy (solar or mined) to raise our groceries? Asteroidal, Lunar, Space Station, and Vehicular Gardening will be major challenges, but I question the assumption that

humanity can make it as one species alone, outside [Earth], on a sustainable basis. Who ever stocked a multi-generation pantry?

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## Aerostat Xities: Corrections to “Lift” Values

By Joe Suszynski, Chicago, Illinois

I enjoyed your series on Xities and the look further out. A few words about lifting gasses. The figure of merit that you chose, ratio of molecular weights of atmospheres to lifting gasses, may be misleading. At a particular design condition (say, one bar pressure), the important number is the difference in weights. A unit volume of Earth’s air might weigh 29 units, while the same volume of helium weighs 4 units, and the lift is (29-4) = 25 units. For hydrogen the lift is (29-2) = 27 units, only 8% more whereas a quick look at your chart implies a 100% improvement by using H2. As a thought experiment, imagine that there was a totally weightless gas. By your figures the lift would be 29/0 = infinite! – Here’s your chart, reworked to show differences in mole weight.

Earth H2	<b>Earth He</b>	Titan H2	Uranus H2	Venus H2	Venus CO	Venus Air
27	25	26	0.3	42	16	15
0.93 <b>1</b> 0.96 830* 0.60 1.56 1.67						
Volume of the gas bag needed compared to that of a helium balloon on Earth, same payload						

[\* ED.: e.g. with radius 9 times, and length 10 times as large.]

As you can see, Venus looks quite friendly to airship designers, thanks to its heavy air, while the gas giants seem terribly hostile. On Venus, the habitat’s air can provide nearly the lift of CO [so that they could live in the gas bag!].

There are tricks which can be used to improve on these numbers, and on Uranus the designer needs all the help he can get. One trick is to lower the operating altitude. At 10 bar, the buoyancy of a given volume is ten times as great. On Venus and the gas giants this is a possibility. The other trick is to heat the lifting gas, as hot air balloons do. At the colder upper atmosphere altitudes in most planets, 30–50°C [86–122 F] of warming helps big time. The heating can come from power plant waste heat, solar, or microwave sources. Aerostats scale up nicely, thanks to the square/cube relationship of surface area/enclosed volume, so at 90 km above Venus, you might have solar geodesic domes that are miles across.

### A late 70s Uranus aerostat design exercise

Back in the heyday of the Preposterous Systems Design Group [Chicago Society for Space Settlements], we did a number of takeoffs from the BIS [British Interplanetary Society] Project Daedalus’ He3 processing balloon. A move from Jupiter to Uranus seemed in order, and we decided a dirigible would be preferable to a free floating balloon, even though a streamlined gas bag would weigh more and the air-ship’s motion would increase the cooling of the lifting gas. Mobility would be useful on several counts: (1) avoiding storms, if any; (2) staying near the equator, because Uranus’ rotation could provide several times the head start to departing space-craft that Kourou gives to Ariane. The banded nature of the gas giants makes this fairly easy at the right altitudes, but in the late 70’s we didn’t know which altitudes would be helpful. (3) leaving the He3-depleted exhaust behind, preventing re-ingestion; (4) making it easier for arriving planes to dock.

The model U-1 airship had an extendible arresting system somewhat like an aircraft carrier’s. it was a straightforward blimp whose propulsion was provided by the processing plant’s enormous mass flow. The U-1B was similar, but the aft end of the gas bag was wider to improve its efficiency as a lifting body. Model U-2 was much larger, with a lens shaped, cable-reinforced gas bag attached to a circumferential compression ring. Tail surfaces allowed it to operate as an enormous flying wing. We played with slower moving designs of this sort: the U-2A blew the exhaust out-ward over the upper surface of the hull, producing lift by Coanda effect, and the U-2B had wings extending radially. As the airship revolve, merry-go-round style, it became a helicopter. Because of the rigid airframe, it seemed possible

to deploy the U-2 from orbit, in a somewhat stripped down state. With a dis-posable heat shield, the atmospheric entry vehicle would have a reasonable L/D ratio & low wing loading.

Joe Suszynski, Chicago, Illinois



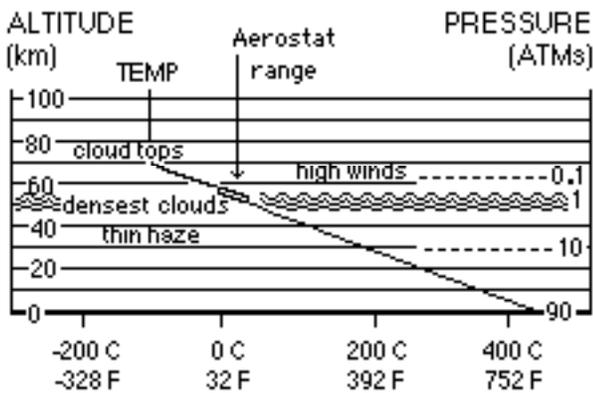
## postscript ↩ Aerostat Xities:

### Altitude, Pressure, Temperature Charts for Venus, Titan, Jupiter, and Saturn

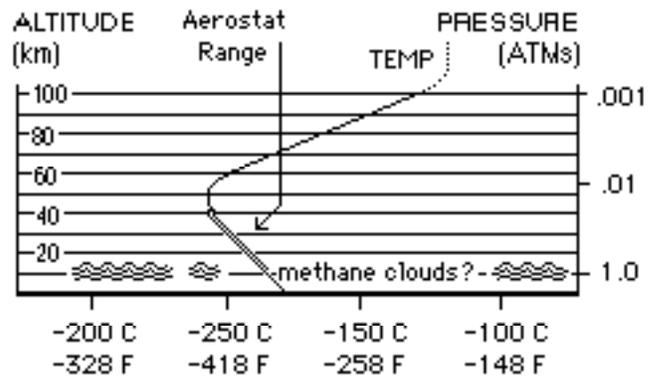
By Peter Kokh

In October, I looked all over for altitude vs. pressure vs. temperature charts I knew I had seen for Venus, Jupiter, Saturn, and Titan. I finally found information with which to reconstruct such charts two days after #60 went to press. In none of these cases does the information suggest an ideal altitude. A choice will have to be made on the basis of tradeoffs and it is possible that on some of these planets no viable altitude will be found. Anyway, here is the situation:

[VENUS]



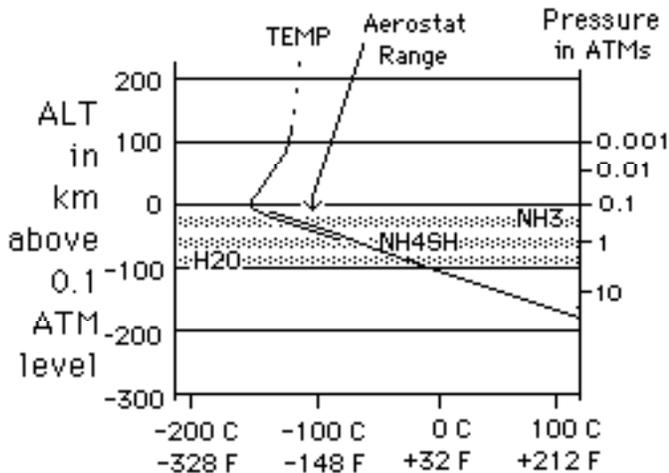
[TITAN]



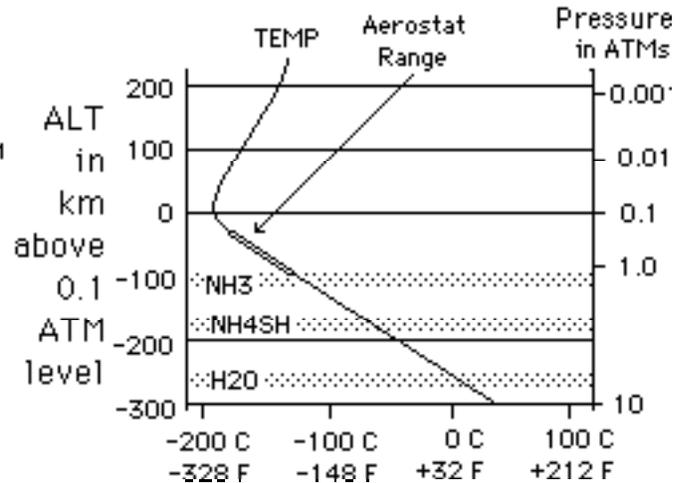
**VENUS COMMENT:** An aerostat should be overpressurized relative to the surrounding atmosphere - to keep out unbreathable gasses. At the 1.0 ATM level we are unfortunately in the middle of the clouds. And below the clouds where it is possible to monitor the surface the air gets thicker and hotter. A trailing tethered Surface Observer Station might be the answer. With no ideal compromise, safety, stability, thermal, and other practical concerns will be paramount.

**TITAN COMMENT:** At all altitudes it is extremely cold on Titan. But above 70 some kilometers (230,000 ft) it is at least warmer than on the surface. But in the rarefied upper air that would be of little thermal benefit.

## [JUPITER]



## [SATURN]



**JUPITER COMMENT:** The altitude levels of the various prominent cloud layers is shown with their chemical composition. The "temperate" region of manageable pressures and temperatures runs through these levels.

**SATURN COMMENT:** Again the level and chemical composition of three cloud layers is shown. It is somewhat colder at the desired pressure levels on Saturn than on Jupiter, but stationing aerostat outposts there should be workable PK

## MMM #78 September 1994

# Mercury

### THE OTHER TERRESTRIAL PLANET

By Michael Thomas, MMM Contributing Editor

As a result of the recent discovery of polar caps on Mercury, presumed to be composed of water ice, the innermost planet is a much more exciting world than it was before. It is also a much more likely target for possible human habitation, as there are now known to be two small oases of cold on this world of unimaginable desert heat. We know there are places on Mercury where a craft could land without having to insulate itself from the searing heat and radiation of the nearby sun.

Are these polar caps really made of water ice? There is a possibility that they are not, but a more recent radar study of Mercury seems to confirm that their reflection pattern is consistent with what would be expected from water ice. I think it would be fair to say that there is an 85% probability that Mercury's polar caps are water ice. But even if they are not, these oases of cold would be far more habitable than any other part of the planet's scorched surface.

In the past Mercury has been dismissed or overlooked for a variety of reasons. It is too far from Earth, too close to the Sun, and much too hot. Solar radiation is almost seven times more intense at the surface of Mercury. There is no appreciable atmosphere to shield out the more intense and harmful ultraviolet rays. Mercury has been visited by only one spacecraft, Mariner 10, which photographed just half of its surface. The other half is still terra incognita. It is the only terrestrial planet so neglected.

But Mercury offers compensating advantages all the same. Although it is only about half as massive as Mars, and its diameter is only 71% that of Mars, the two planets have almost identical surface gravities. For Mercury has a higher average density than Mars because of its much larger iron rich core. So although it is the smallest of the terrestrial planets, its surface gravity is suitable for human habitation.

Mercury also possesses a planet wide magnetic field. There is some limited evidence that terrestrial life requires the presence of a magnetic field to thrive. (Mars may also have a planet wide magnetic field, but if it does it is weaker and less likely to be biologically significant.) Mercury's proximity to the Sun offers advantages as well. If Helium-3 is to be found in the lunar regolith, surely even more of it is to be found in the regolith of Mercury, which is closer to the source. And with solar energy being almost seven times more concentrated in the orbit of Mercury than in the orbit of Earth, there is a wealth of energy too great to be ignored.

The average intensity of solar radiation at Earth's orbit is 1390 watts per square meter. At Mercury it is 9271 watts per square meter. This has a curious result. A square meter of solar cells in Earth orbit, operating at 15% efficiency would produce 208 watts of power. The same solar cells in Mercury orbit would produce 1390 watts of power! In other words, moving the solar cells from Earth to Mercury has the same effect on their output that increasing their efficiency from 15% to 100% would have. This makes the vicinity of Mercury a far better place for Solar Power Satellites than Earth orbit. A one terawatt collector (operating at 15% efficiency) in Earth orbit would have to have 4,807 square kilometers of solar cells, but a one terawatt collector orbiting Mercury would only need 719 sq. km. of solar cells.

And how better to support the power needs of a terra-watt laser than with a terawatt solar array. Such a collector would be far cheaper and less massive in the orbit of Mercury than it would be in the vicinity of Earth. A pair of terawatt lasers located in the Mercury/Sun L4 and L5 positions could also be directed at a solar array in high Earth orbit as a means of exporting energy to Earth. They could probably maintain near continuous transmission to Earth as they would never both be behind the sun at the same time. Mercury could also be a base for launching power satellites closer to the Sun, where they could collect even more energy.

Yet Mercury offers more than just a base for solar power collection. Just as small island nations like Japan, Great Britain and Taiwan support populations of millions, so the polar oases on Mercury and the immediate surroundings could also support populations of millions of people each, making Mercury a significantly populated world. Areas just outside of the permanently shaded oases would receive intense sunlight, but at a very low angle, so regolith temperatures would be much lower in the daytime than at lower latitudes, so these near-oasis areas would be relatively habitable as well and could be used to collect solar energy for the communities within the oases. In the long term (centuries) the higher latitudes (above 70 degrees perhaps) could be widely inhabited with each pole supporting perhaps 100 million people.

So while Mars is more accessible and more hospitable than Mercury overall and should be the next planetary destination for humans after the Moon. — Mercury should not be dismissed and forgotten. We should begin to view Mercury as the third planetary target for human habitation after the Moon and Mars because this scorched little world really has much to offer!

MT

## Why hotter Mercury may have polar ice while the colder Moon may have little

By Peter Kokh

**AVAILABILITY:** It is quite clear that fewer comets intrude into the deeper regions of the Sun's gravity well where Mercury orbits than visit the orbit of the Earth-Moon system.

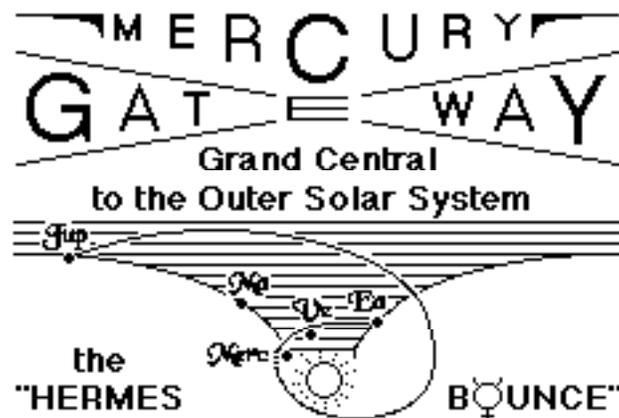
**HOWEVER:** Mercury may be much more effective in snaring approaching comets than the Moon. Mercury's mass is 5 times that of the Moon. Further, its deeper gravity well presents a much greater "cross section" expressed as an angular fraction of its orbit, in fact a "target" comparable to Earth's, some thirteen times as great as that of the Moon.

**FURTHER:** Two factors work together to make Mercury much more efficient in holding on to cometary volatiles.

✓ Mercury's gravity is 2.3 times that of the Moon.

✓ Its sunset to sunrise "nightspan" period is more than 6 times longer than the Moon's, giving volatiles released by comet impacts that much more time to migrate to the polar permashade cold traps.

The intense solar power available in Mercury's orbit could one day make this now dismissed hot rock the



By Peter Kokh

For Science Fiction, there has never been a problem with opening up the outer Solar System. Its “simply” a matter of inventing faster rockets, atomic ones probably. In point of fact, Mars represents the limit of “doability” of the venerable chemical rocket for crewed expeditions. No plausible improvements will extend this margin in any practical sense. Chemical rockets cannot carry enough fuel to take expedition-sized payloads much further. More, maximum efficiency travel times in Hohmann transfer orbits (without which chemical rockets could not even take crews to Mars) mean many months in space and unwelcome total exposure to solar flares and cosmic radiation.

Nuclear rockets are still largely on the drawing boards, but promise faster trips to Mars, doable trips to the Main Asteroid Belt. But even for them, trips to outer planets may be unacceptably long, ... and infrequent. For any vehicle must await proper planetary orbital alignments – the “window”.

**Some Trip Window Frequencies (bidirectional) and average Hohmann travel times (both in 30 day months)**

<i>between</i>		<i>window frequency</i>	<i>travel time</i>
<b>Earth/Moon</b>	<b>Mercury</b>	<b>3.45</b>	<b>3.51</b>
Earth/Moon	Mars	25.87	8.63
<b>Mercury</b>	<b>Mars</b>	<b>3.36</b>	<b>5.68</b>
Earth/Moon	Ceres	15.55	15.75
Mars	Ceres	38.67	19.13
<b>Mercury</b>	<b>Ceres</b>	<b>3.09</b>	<b>12.01</b>
Earth/Moon	Jupiter	13.30	33.27
Mars	Jupiter	27.21	37.56
Ceres	Jupiter	91.81	48.43
<b>Mercury</b>	<b>Jupiter</b>	<b>2.99</b>	<b>28.36</b>
Earth/Moon	Saturn	12.60	73.65
Mars	Saturn	24.46	79.20
Ceres	Saturn	66.56	92.96
Jupiter	Saturn	241.9	121.8
<b>Mercury</b>	<b>Saturn</b>	<b>2.96</b>	<b>67.33</b>
Earth/Moon	Uranus	12.33	195.2
Mars	Uranus	23.42	202.8
Ceres	Uranus	59.47	221.4
Jupiter	Uranus	168.1	259.2
Saturn	Uranus	550.5	331.6
<b>Mercury</b>	<b>Uranus</b>	<b>2.94</b>	<b>186.3</b>

Anyone who studies this list should quickly get the idea, that, Delta V and fuel cost aside, The quickest way to get from anywhere to anywhere else in the Solar System might be to “detour” by Mercury. What about alignments? So what if you get to Mercury and have just missed a window to Jupiter. Another will open up in just 3 months, an insignificant delay parked in Mercury orbit.

Ah, but Delta V and fuel cost do matter, you say! My point is that much of the extra Delta V needed to do the detour by way of Mercury can be managed by free deceleration into orbit around Mercury, and free acceleration into a trans destination trajectory — free courtesy of giant solar lasers in orbit about Mercury.

In going to Mars or Ceres this presents a problem. The Mercury–boosted ship will arrive with a great deal of excess momentum. This will require a lot of fuel to shed. But ships going out to any of the moons around any of the Outer System gas giants, can shed that excess momentum free in an aerobrake maneuver through the upper atmosphere of the gas giant (Jupiter, Saturn, Uranus, Neptune). In fact, the only Delta V that need be provided for by fuel carried on board is that for the boost in toward Mercury, and the landing fuel at the destination moon that would be the same in either case. The benefits would be astounding

### **LEAVE ANYTIME and GET THERE MUCH MUCH SOONER.**

Building such a giant laser facility near Mercury would be something for a “United Planets” government. It would establish singlehandedly a transportation infrastructure that will open the gates of human expansion into the Outer System, in search of energy (e.g. Helium-3 from Uranus), the ultimate in tourist experiences (Saturn’s rings), raw materials for terraforming (water, hydrogen, nitrogen, carbon), and exploratory knowledge.

Because ships arriving at Mercury will have to wait up to 3 plus months for a reboost to their destination, there will be a major service market in orbit about the planet. This will include ship repairs (engines, environmental systems, bio–sphere systems), warehousing, trading, transshipments, health care, entertainment and diversion, surface excursions and stays, even continuing education courses. And all the more interesting things that are usually found in wide open international marketplaces. Mercury Gateway could over time grow to become the nerve center, financial center, trading center, even the political center of the Solar System.

Yes it’s hot!, Yes it’s dry! Yes it’s barren! But so what! Mercury’s location deep down the throat of the Sun’s gravity well and its location in very bright space (averaging seven times as much light and heat from the Sun as reaches Earth/Moon) — these are the real estate pluses that will make this unsuspected oasis in the solar desert bloom and boom.

First, of course, nuclear rockets will have to come on line, and mature. Next, economic motives must surface that would drive the expansion of the human economy into the Outer Solar System. Finally, some taxing authority has to build the necessary facilities in Mercury orbit. Then this “god of speed” will be not only speedy himself, but impart some of that swiftness to us mortals and our “Quick–silver Fleet”.

**Mercury, it’s a detour that makes sense!            PK**

## **MMM #110 November 1997**

### **Welcome to New Atlantis: A Report on the Europa II Workshop**

First Contact IV Science Fiction Convention, Milwaukee, September 27, 1997

By [Peter Kokh](#), Mark Kaehny, Doug Armstrong, and Ken Burnside

**Mission Control™ Workshops** are an educational activity of the Lunar Reclamation Society, Inc.

#### **Forward**

The widespread interpretation of the Voyager photographs of Jupiter's 2nd innermost great moon Europa, is that here we have a world with a global ice crust floating on top of a global ocean of considerable depth, covering a rocky crust–mantle–core. Current best guesstimates, reargued from scratch from recent Galileo mission photographs, are amazingly close to those offered a decade or more ago by astronomy “bad boy” John Hoagland. The ice crust is on the order of 1–5 km thick, the ocean beneath it could be a 100 mi. or 60 km deep, likely holding almost twice as much water as all the

oceans of Earth. While we have not had on scene the instruments necessary to make direct measurements, it'd be surprising, if this picture is "way off".

Tidal stresses caused by Europa's not quite circular orbit around Jupiter evidently supplies the heat to keep this ocean liquid. In ancient mythology, Rhadamanthus was the son of Europa by Jupiter. So The Rhadamanthic seems an ideally appropriate choice as a name for this hidden global ocean. Water and vacuum do not socialize. But ice and vacuum get along quite well. A thick enough self-derived icy "firmament" can contain an ocean just as effectively as does Earth's thick atmosphere.

The conditions for the formation and maintenance of Europa-like moon worlds seem rather easy to meet in the vicinity of gas giant planets. And gas giants should be quite commonplace throughout the galaxy. It will matter little if the Jove-like primary of the candidate moon does not orbit a sun-like star. The upshot is that there may be far more "Europids" in the galaxy than planets more like "Earth". What we are able to do at / with Europa, may provide the major theme of any human thrust to the stars. [see MMM # 36 JUN '90, pp. "[Oceanids](#)", P. Kokh]

What do we, and don't we know about Europa? Maximum elevation differences in the surface are on the order of 100 meters, 300 feet, making Europa flatter than Florida, globe-wide. But ice, even very cold ice, is plastic, so we can argue from the analogy of icebergs that the surface profile is matched by an exaggerated unevenness of the ice crust undersurface. And where we have low spots on the surface, there the ice is correspondingly thicker, being matched with an exaggerated concavity on the underside.

We don't know the amount of impurities in the ice nor of salinity in the ocean. The mechanism that led to Earth's "briny deeps" was /is continual runoff from above ocean continents into the oceans via the river systems. This mechanism does not operate on Europa. There could be some level of salinity, however, if there are, or have been in the past, undersea volcanoes or deep vent ridges. Some of the material from eruptions could percolate into the water and go into suspension or solution. Volcanism is also the only possible source of dissolved gases (e.g. carbon dioxide) in the water.

But we don't know if there is, or ever has been geological activity in this undersea crust. We don't know if it has mountains and undersea continents and basins – or is relatively flat. We don't know a lot. No mission to Europa is now in the works, although a number of missions have been brainstormed to some degree. One cheap and elegant mission proposal would "sample" the chemical content of the ice crust by a simple flyby mission. Upon nearing Jupiter, the probe would aim a "shot" at Europa calculated to splash representative material into space. The probe would then "catch" some of this sample in an aerogel shield as it flew through the splashout cloud. On board instruments would analyze the "catch" and send the information back to Earth by radio.

Our Workshop series aims to ferret out ideas for robotic and follow-up manned missions to Europa, both to its ice crust and through the crust into its Rhadamanthic Ocean.

#### **PRECURSOR ROBOTIC MISSION(S)**

At the recent Europa II workshop, as we lacked a critical mass of participants to break up into sub groups, we decided to concentrate on manned mission possibilities. This is perhaps a good thing, because we quickly realized that for a manned assault to be successful a number of questions would already have had to have been decided by robotic missions. So the manned mission is the dog that wags the robotic tail, and any brainstorming of robotic missions without consideration of the needs of follow up manned efforts would be so much irrelevant ivory tower scientific curiosity scratching. Let us hope we will soon graduate to "prospecting mode" following the lead of Lunar Prospector.

Using as a criterion what we'll have to know to mount a human expedition to Europa's ocean, the horseblindings of individual scientific investigators specializing in this or that mini scientific cubbyhole will be off. We won't spend lot's of money learning irrelevant things. What do we need to know? Here are some tasks that need to be done by orbiters and surface missions or rovers.

- orbital topography/altimetry and an ice bottom profile deduced from iceberg top/bottom ratios
- orbital chemical mapping, Europa Prospector ground truth probes
- orbital photometry – ice phases
- orbital detection of differential ice crust libration and oscillations vs. solid core sea bottom
- orbital "sniffing" of "transient phenomena", e.g. outgassings, geysers, etc.
- orbital surveillance for fresh cracks

- surface seismic network aimed at mapping ice crust thickness; stations monitor radiation exposure variation
- Surface engineering tests
- kind of ice easiest to melt thru, drill through
- kind of ice easiest to redeploy (or melt and reform) as shielding e.g. over some inflatable hanger

### Robotic Portion of Manned Mission

The following submarine robotic investigations can be carried out either before or in conjunction with a manned landing / submarine expedition. In the former case, a tethered sub-ice mother probe could send out a number of robotic submarine mini-probes reporting back by sonar to the mother probe. These could either have independent active propulsion or, leaving results to chance, allowed to drift on whatever ocean currents there are.

- actual survey of ice crust underside topography
- identification of any gas/air pockets trapped in concavities in the ice crust underside.
- mappings of water pressures, salinity, dissolved gasses, currents, hot spots, ocean convection cells
- orographic map of ocean floor
- ocean bottom seismic net to map core layers
- thermal map of ocean floor

### A Manned Mission: Assumptions

Jupiter space, inwards of Callisto, is filled with deadly radiation, that is, Io, Europa, and Ganymede, along with the lesser inner satellites (Amalthea and company) orbit the gas giant primary within its vastly stronger more deadly version of Earth's Van Allen Belts. The success of the Galileo mission shows we know how to tackle the problem on the level of short duration robotic missions.

For human expeditions, the challenge is much greater and cannot be underestimated. There are those who have concluded man will never venture inwards from Callisto, the Mercury-sized outermost of Jupiter's mighty four, the Galilean moons known since 1610 and seen by countless millions in small amateur telescopes, even in good binoculars.

Providing material shielding against this radiation would add prohibitive amounts of mass to the manifest. For the purposes of our mission, we assume that it takes place in an era in which the engineering challenges of providing electromagnetic shielding have been mastered.

After a short debate, we assumed that we could land safely on the ice surface without sinking into a pool of fresh water melted by the descent rocket motors. We could use a bevy of smaller scattered rockets (an aerospike configuration?) or simply cut the motors just before touchdown.

On the ice crust surface, where on site material is available, a simple hanger can be erected to cover the base operations site. This could be done in modular fashion, by deploying an inflatable to be covered with shredded ice, which is then solidified into a self-sustaining igloo arch by microwaves. The inflatable form can then be deflated and moved along the axis to shape the next section, and so on. The surface base modules, any fuel storage tanks, vehicles, and other equipment regularly manned or tended can be regularly housed under this hanger.



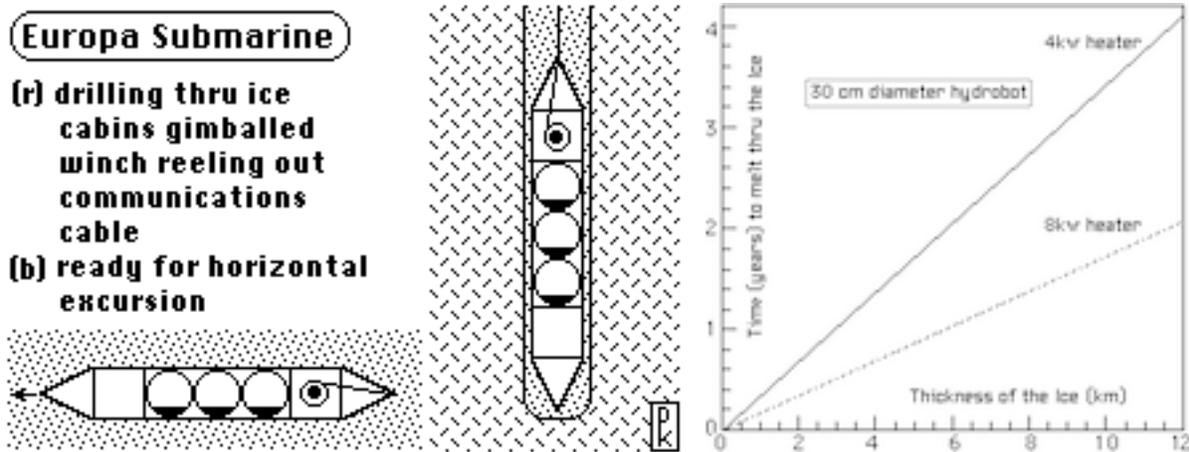
Ice-shielded surface base hanger: elevation (L), plan (R).

### Through the Ice Crust, Into the Ocean

At the prior (Duckon) workshop, we had discussed thermal melting of a shaft through the ice, using a vertical cabin cylinder of minimum cross-section with a heated (lower) prow cap. This vehicle might be about 10 feet or 3 meters in diameter or whatever the practical minimum. It could have spherical gimbaled rooms that would be stacked one atop the other for the descent and fore and aft of one another horizontally for submarine excursion once through the ice. If a cable winch was employed, it would be best to have the winch reel aboard the descending submarine. That way neither continued

descent nor communications would be interrupted if the melted water or slush slurry in the shaft above refroze, seizing the cable.

In the second (First Contact) workshop, we wondered if it might not be more efficient to equip our vertically deployed submarine vehicle with a drill head to create a shaft somewhat wider than the vehicle to allow the crushed ice slurry to pass alongside to the rear (above) the descent vehicle. We did not do any math at this time to have a basis for comparing the melt vs. drill methods for energy efficiency and progress speed. We were simply identifying concepts to put them on the table.



### How Long Will it Take to Melt Thru Europa's Ice Crust into its Ocean?

<http://www.phys.cmu.edu/~clark/icepic.html> -- Russel Clark

### Roaming Free in the Rhadamanthic Ocean

We imagined that upon breaking through to liquid ocean water, the sub would keep descending vertically, reeling out extra communications cable, until it was below the lowest downward protrusions of the ice crust in the area [see illustration, below]. At this point, an antenna would be affixed to the cable, and the cable cut below this point.

The submarine would then be free to roam through the Rhadamanthic, maintaining communications with the surface base by radio or sonar to the antenna suspended below the descent shaft. Joining the antenna at cable's end would be a beacon, to guide the submarine back to the point in the ice crust underside directly below the surface base.

We did not discuss means of ascent, but did wonder if the water/ice slurry in the shaft would not have refrozen in the meantime. In this eventuality, a new parallel escape shaft may have to be bored upwards when the crew's mission was done.

We briefly considered how the shaft might be kept open [percolated bubbles?] to allow routine travel between surface base camp and cable's end, a luxury feature that will probably wait for a second or later follow up manned mission. The writer (PK) personally thinks the ice is too plastic, the cold too intrusive – the hole would quickly freeze solid.

### The Submarine Mission

The intra-oceanic mission has already been outlined. It consists of undertaking the deployment of swimming, floating, and ocean bottom probes and science stations (see "Robotic Portion of Manned Mission" above). If an "easier" portion of this science chore list has already been done as part of an especially ambitious precursor robotic mission agenda, then the mission is to continue the work.

Inevitably, findings will pose new questions and if the manned vehicle is equipped to shed light on them, its mission may be expanded accordingly.

### Duration of the Manned Mission

#### Size and Disposition of Personnel

The duration of the overall combined manned mission to Europa, and the division of crew between surface base and submarine vessel, should be figured backwards from the amount of work to be done and the location from which it is to be conducted. Simple as that. We determine the list of tasks to be accomplished, any necessary sequencing, any necessary time-sharing of equipment, and factor in the man hours, travel time, and crew talents needed in redundancy, toss in a healthy percentage of unassigned time (repairs, recreation, etc. – and then we can sit down and size up the mission. Europa is

too far to go not to do the whole job that needs to be done on the first visit. This undertaking will surely dwarf the crew, equipment manifests, and costs of the first Martian Expedition.

### **Now Just What If? Air, Down Below?**

The writer (PK) had wondered if there might be ongoing volcanic outgassing from points along the ten million square miles of Europa's ocean bottom. If so, the likeliest major component would be carbon dioxide, CO<sub>2</sub>. If so, the ocean would become ever more carbonated (for as long as the volcanism continued) until a saturation point was reached. Beyond that point, free gas might build up in some / all of the concavities of the underside of the ice crust. The gas pressure would have to counterbalance the weight (in Europa's 1/7th Earth standard gravity) of the ice above. Possibly, from time to time the gas pressure would rupture the ice along weak fault lines and escape into space. Could this be at least a secondary source of ice crust fracturing?

There are a lot of ifs here, and the speculation that follows is far less "anchored" than I'd like it to be. Readers are encouraged to give their input, whether constructive or showstopping, and on that basis we'll decide whether continuing brainstorming along the lines that follow should be part of the final workshop in this series, at ISDC '98 next May.

Mentioning all this to my workshop mates, it excited their imaginations, sending them into overdrive. Are such "air" pockets over lagoon like calm ocean surfaces common? How big can they get in area (air-exposed water surface) and volume (air)? How oppressive will be the air pressure? Something that divers on Earth have managed in pressure-equalized sea floor habitats? If there are no naturally occurring gas pocket/lagoons, can we create them by electrolysis of the ice? How stable would they be in either case? And in such high pressures, might not the freezing point be on the balmy side? in the 50's?

There is a tradeoff: higher temperatures come with greater pressures. lower with less. We can live with 32° so minimum depth below surface = minimum thickness of ice overburden = lowest atmospheric pressures = the best situation, all else (size/surface/ volume) being equal.

Pitch dark, they could be lit. We could put together a floating outpost in such a pocket, even equipping it with a pressurized dome so the staff could look out on the "cavern" roof and the "lagoon". We could use water heat pumps to maintain interior comfortable conditions through diurnal and seasonal changes, effecting "weather-like" cycles. In these lagoons, we might do high CO<sub>2</sub> agriculture on floating platforms, growing some food on the spot. Maybe mini OTEC installations could supply ample power.

Proximity to ocean floor thermal vents could be strategically important. Two possibilities: (1) gas saturation is homogeneous – there might be a real "sea level" above which there are always gas pockets. But what happens if one is breached and vented? (2) if there are pronounced oceanic convection cells, gas saturation may vary accordingly, and "sea" levels may be local or nonexistent.

What is the global distribution of such coves? Are there any clusters of fair sized anchorages? Are there gas pockets large enough to host sizable floating settlements? Cities? If so, such clusters might be where a European civilization to be should make its beachhead. Individual outposts could be named after classical harbors of old: New Syracuse, New Carthage, New Tyre, New Alexandria, New Atlantis, and so on.

A big whoa! Are there enough dissolved metal salts in the Rhadamanthic to allow for advanced extraction processing of building and manufacturing materials so that this European adventure might become an overture to a very unique European settlement and civilization? And if there are deep ocean floor hot vents such as host oases of Earth life not dependent on chlorophyll or sunshine, then aquaculture is possible. If they exist but are lifeless, they could be seeded with specimens from Earth.

How would one transit between coves? By submarine, or by shafts to the surface and transfer to suborbital surface hoppers? When anchorages are close by one another or clustered, might man-made tunnels above "sea level" work?



Could Europa, rather than boring Callisto, become the major human population center of Jove Space, with active trade to the other Galilean moons? Maybe there are no such places, and all we have done is to provide science fiction writers with a new class of venues for their stories.

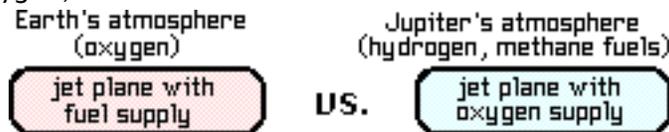
MMM #111 December 1997

## The Jovgo Jupiter Jet

By Francis F. Graham – Kent State University, Physics Dept

With the great interest in planetary probes recently engendered by the discovery of life on Mars (at some point) and the success of the Jupiter Galileo mission, it's time to bring up an interesting idea that I originally had in 1966, and developed somewhat in 1978 at a presentation in grad school.

I learned from the only book about Jupiter in 1965, "The Planet Jupiter" by Bertrand M. Peek, that Jupiter was surrounded by an immense atmosphere of hydrogen, helium, methane and ammonia. Two of these molecules, molecular hydrogen and methane, are flammable if mixed with oxygen. Hence it seemed logical that the best sort of Jupiter probe into the atmosphere would be one that was able to fly around the atmosphere of Jupiter using onboard oxygen (or an oxidizer) and sucking in the Jovian atmosphere; in other words, a jet airplane that carried its own oxygen rather than its own fuel, and drew in the fuel, rather than oxygen, from the outside.



The "Jovgo" as originally proposed would be a heavy probe capable of many tasks, and would be boost to Jupiter on a Saturn V, aerobroke into the Jovian atmosphere and unfold variable-geometry wings. It could then spend several days using a supply of oxidant to fly around the 0.1-100 bar level of Jupiter's atmosphere, from equator to poles, taking samples and performing unique analyses. The size of a fighter jet, it would have a one-way range of about 40,000 miles near the Jovian cloud tops, with careful choice of rising and sinking columns.

By 1978, post-Pioneer 10, it was clear the belts of Jupiter and zones of Jupiter were ascending and descending atmosphere. Thus, the Jovgo probe could extend its life by gliding up on zonal upwelling, and overflying some of the belts. Slowly, as Jovgo approached the poles of Jupiter, it would begin to glide into the denser layers of the planet and finally succumb to the high-pressure, high temperature auto da fe that did in the entry probe of the Galileo spacecraft last December. With Jovgo however, the atmosphere of Jupiter would be more rigorously explored by a probe that would give a cross-section of the atmosphere from the equator to the poles.

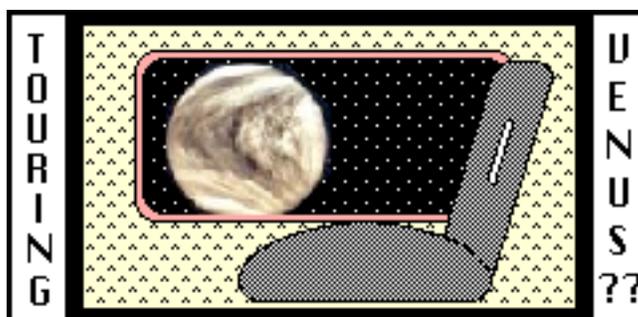
Hopefully, the Jovgo concept is an interesting one and perhaps it may see fruition someday. In any case, the design of aircraft for planets other than Earth is an interesting challenge. The Russians launched two balloons in the atmosphere of Venus in 1985, it is to be noted, from their Vega spacecraft, perhaps the first extraterrestrial "aircraft" per se.

FG



### Venus — 35 years of Embargo is Enough!

Its time to quit our over-prolonged pouting tantrum since learning that Venus was as close to the traditional picture of Hell as we might ever fear to visit. IF we put put aside our crushed expectations and take another look, trying to see apparent extreme disadvantages in another light, we might just find the door ajar for human presence and activity after all. All it takes is an open mind and imagination. More below.!



### TOURING VENUS: A Fresh Look at a Forgotten World

By Peter Kokh

Prior to 1960, we basked in our mainstream expectation that underneath Venus' perpetual cloud cover, we would find a very warm oceanic world with scattered islands covered with steamy jungles and forbidding swamps. Writers like C.S. Lewis and Robert Heinlein made Venus a common setting for Solar System interplanetary adventure tales.

Suddenly, crudely, without warning, in the early 60s, Earth-based radar shattered this unsuspected illusion. Venus was dry, self-cleaning-oven-hot, cursed with an unbreathable brimstone-dosed carbon dioxide atmosphere of crushing density.

Overnight, Venus was "off the list." Off the list of places to explore. Off the list of places to tour. Off the list of worlds that might harbor life. Off the list of human colonization. Off the list of human horizons altogether. Venus remained in the heavens, of course, as an astronomical object, as an environmental object lesson, as a deceptively beautiful siren beacon, and as a significant gravity well useful for redirecting and accelerating objects bound for the outer solar system (Galileo).

This once-upon-a-time paradise world of C.S. Lewis' "Pearlandra" was suddenly the perfect illustration for medieval concepts of the Hell of the Scriptures. As a "purely" scientific curiosity, (don't you believe that for a moment!) Venus remained high on the priority list as a destination for our probes. We "wanted to know" not only what Venus was really like: its topographic features, contours of could-have-been continents and could-have-been ocean basins and mountains and trenches and volcanoes and impact craters. Down deep our aim has always been to "terraform" our lost Sister Planet, at least in our imagination. We would dissipate its excessive atmosphere and radiate out into space all that trapped heat, and refill its oceanic basins drop by drop with comet water.

Still smarting from our loss, we masochistically needed to know how much of a Sister World we could have had, had not something gone terribly awry. Even though Venus is closer to the Sun and gets twice as much solar warmth, that does not explain why it is many times twice as hot on the surface, nor why its atmosphere became so crushingly dense.

Practically, while as “dispassionate, uninvolved” scientists we still wanted to know more, we all personally resigned ourselves to Venus being off the list as a target for future manned exploration, future outposts and farther future settlements, and, of course, as a future tourist destination.

If we but clean up our radar screens of emotional noise, Voilà! Venus reappears! A planet that can support manned scientific outposts, and an exotic tourist stop.

Okay, we have had 35 years to pout. It is time to grow up and take another look. We did it for China, and Russia. We are doing it for Cuba. Why not Venus too? And what do you know? Suspend our wounded spirits and Voilà! Venus reappears, both on the screens of human expeditions and outposts, and on the screens of tourist destinations. Yes, despite the fact that it remains a “hell hole”!

In MMM # 60 NOV '92, pp. 3–6 “PUSHING THE ENVELOPE: Aerostat Xities ‘afloat’ in the atmospheres of Venus, Jupiter, Saturn, Titan, Uranus, & Neptune”, we pointed out **some advantageous facts lost in the static of woe-is-us reports about Venus**. The thick and visually impenetrable cloud deck over Venus is very high up over the surface compared to clouds on Earth –indeed about 30–40 miles up (150–200,000 feet. Just below this cloud deck it is

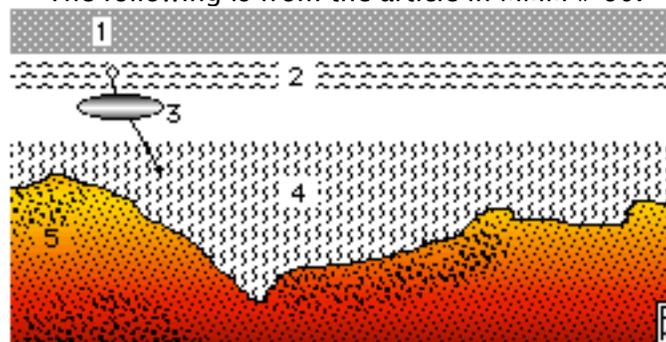
- (1) clear, affording panoramic views of the surface free of any obstructing clouds;
- (2) not so dense, in fact, about as thick as our own atmosphere at sea level; \
- (3) not so hot, well within temperature ranges we find comfortable on Earth.

**NOTES:** “Aerostat” means a buoyant structure such as a balloon, blimp, or dirigible, capable of staying airborne indefinitely so long as its relative buoyancy is maintained. On Venus, sufficient buoyancy can be provided by either hydrogen, helium, or less efficiently, by carbon monoxide.

“Xity”: a communal habitat beyond Earth’s life-sustaining envelope that must provide and maintain its own biosphere.

**NOTE:** Venus and Titan are the most favorable worlds. It would be very difficult to sustain buoyancy in the low average molecular weight atmospheres of gas giant planets: Jupiter, Saturn, Uranus, Neptune.

The following is from the article in MMM # 60.



#### **FLOAT LEVEL OF VENUS AEROSTAT XITY:**

- 1) Space and vacuum above the atmosphere;
- 2) Unbroken cloud level 30–40 miles above the surface;
- 3) Venus aerostat xity floating just under the cloud deck about 30 mi (150,000 ft.) above the surface in cool CO<sub>2</sub> atmosphere at the 1 ATM pressure level with a clear view of the surface. An upper atmosphere meteorology station is borne on tethered balloon above while a lower atmosphere station is trailed by tether below;
- 4) Super oven-hot super dense lower layers of the atmosphere;
- 5) Very hot surface of Venus: continents, empty basins, volcanoes (live and dormant), craters, mountain massifs, valleys and trenches.

#### **Back to our subject — Tourism**

So where does this leave us? Obviously, we should be as busy planning a floating science outpost over Venus as we are planning science outposts on Mars’ surface. From such an outpost, with a variety of instruments, we could study the Veneran surface below from relative proximity, with both visual and other instruments. Tethered probes could sample lower atmospheric levels and those higher up. And, if we could devise thermally hardened instruments that would survive for days or longer on the surface, we could teleoperate them from our aerial perch. Even teleoperated rovers are not beyond the realm of the possible, using greaseless magnetic bearings, etc.

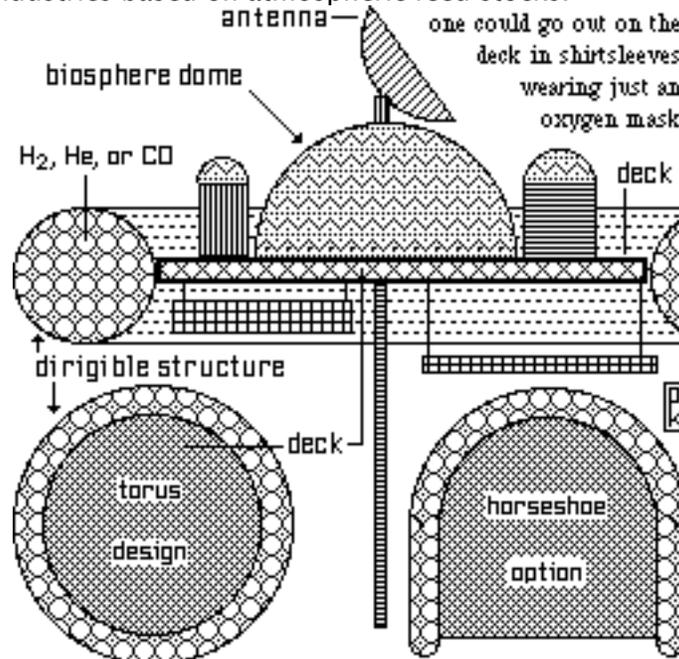
Okay, but we promised to talk about tourism! While surface excursions remain as far-fetched as they have been for the past 35 years, tourists could descend by ship through the upper atmosphere to rendezvous and dock with a floating hotel just below the cloud decks, staying long enough to get the feeling of Venus topography – or as long as it takes before the return-to-Earth window opens.

**GRAVITY/WEIGHT IN VENERAN AEROSTAT XITIES**

Earth	100%	110 lbs	150 lbs	200 lbs
Venus	91%	91 lbs	136 lbs	182 lbs

From a gravity point of view, visitors to Veneran aerostat stations would feel quite at home.

“Valentine Heights” from the MMM #60 article, conceived as an aggressive interactive outpost engaged in science and industries based on atmospheric feed stocks.



**A VENERAN “SUBNUBILAR” AEROSTAT XITY**

: Cutaway of a large torus or horseshoe float with cellular ballonets and bladders providing buoyancy support for the Xity. Hydrogen gas is preferred, but carbon monoxide processed more easily from the atmosphere will do. The torus directly supports the central main spaceframe platform. Standing on the platform are a central residential-agricultural-environmental dome & auxiliary domed vertical cylinder structures. Below this deck is suspended an elevator to a lower meteorology station and two open-air platforms: the one on the left supports teleoperated refining, processing, and manufacturing (e.g. kevlar) from atmosphere-sourced chemical feedstocks; the one on the right is a landing & takeoff platform for drone unpiloted aircraft for close near-surface observation and teleoperated surface sampling and mining. The original structure is made of Earth-produced metals to be cannibalized later. New structures would be of Kevlar made in situ from CO<sub>2</sub>

The plan above, or any of many conceivable alternative architectures could serve just as well as a tourist resort complex. OR, a science outpost could have facilities to host “a handful of tourists” coming to visit and be nosy from time to time. This makes sense, at least initially. Indeed, the few early tourists could prove very useful to the scientists stationed there, in a work-study type of vacation, fully accredited by universities on Earth. They could also relieve the regular staff in food-production and other distractions from their scientific tasks. As such these tourists would in fact “help pioneer” any next steps toward major expansion of this beachhead presence on the once Forbidden Planet.

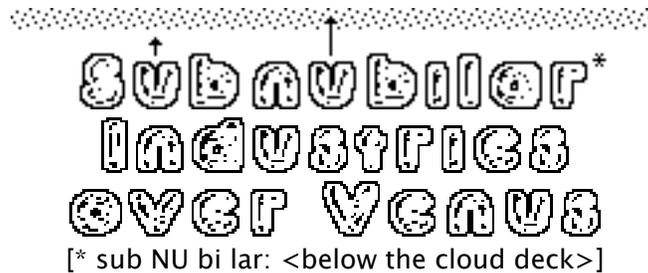
**Ticket Co\$t – The Bottom Line**

How expensive would it be to make such a tourist excursion to Venus? Less, it turns out, than a comparable visit to Mars!! — Consider:

- \* Using Economical Hohmann Transfer Trajectories
  - Slightly less Delta V and Fuel Expenditure is needed to go from Earth to Venus and back (5.47 kps), than from Earth to Mars and back (5.54 kps).

- Shorter in-Transit Times Earth  $\leftrightarrow$  Venus (5 months) than Earth  $\leftrightarrow$  Mars, (8.5 months avg) thus less exposure to the radiation hazards of space.
- Shorter at-Planet Stays Waiting for the Earth-return launch window to reopen, typically 11 months on Venus versus 18 months on Mars.
- Shorter Interval Between Launch Windows in either direction, 19+ months for Earth  $\leftrightarrow$  Venus vs. 25+ months for Earth  $\leftrightarrow$  Mars.

When? Sooner than we think! **Before midcentury. MMM**



## Economic Opportunities on Venus to begin with Atmosphere Mining 30 miles above its Torrid Surface

By Peter Kokh

**ATMOSPHERE RESOURCES** — An “opportunist” is only as good as s/he is capable of seeing every first-blush-drawback as an advantage worth leveraging. Venus’ atmosphere, the only easily accessible local resource depository, is mostly (97%) Carbon Dioxide, CO<sub>2</sub>. That represents 70.5% Oxygen by weight and 26.5% Carbon. Less abundant elements represent some definite industrial-economic worth as well as dispropor-tianately large greenhouse responsibility.

MOLECULE	%age	GREENHOUSE CONTRIBUTION
CO2	97	55%
H2O	0.1	25% Water Vapor
SO2	<0.1	5%
MISC.	2	15% Cloud Stuffs *

\* CO carbon monoxide, HCl hydrogen chloride, HF hydrogen fluoride, H<sub>2</sub>S hydrogen disulfide, COS carbonyl sulfide, and SO<sub>2</sub> sulfur dioxide.

**FUEL** — CO<sub>2</sub> can be reacted with available water vapor to produce methane CH<sub>4</sub> and oxygen O<sub>2</sub> to burn in rocket aircraft plying between the various aerostats, and in station-keeping/attitude thrusters, and to fuel internal combustion engines.

**POWER** Aero-factories can tap solar energy filtering through the cloud deck to provide primary electrical power for industry, appliances and lighting. They may need to keep pace with the terminator so as to be always in daylight to maintain a constant solar power flux or use methane-oxygen generators at night.

**CARBON** — Oxygen is needed for aerostat-living space atmospheres, along with Nitrogen, which is the 3rd most abundant element present. But as an industrial keystone, the sheer abundance of carbon in Venus’ atmosphere makes it king. Carbon along with hydrogen, oxygen, and nitrogen is a principal ingredient of living tissues. But here we are concerned with industrial significance. With the development in recent decades of Kevlar, a carbon-carbon composite, carbon emerges as a structural material of great strength and low weight, from which many things can be made, things formerly made out of metals, ceramics, woods, and plastics. It will be a challenge of heroic significance to chemical engineers to find chemical pathways from carbon dioxide to Kevlar fiber that can be implemented on an industrial scale.

The goal is modular building components out of which an original aerostat with modules made on Earth can be duplicated with local Kevlar equivalents. Interior furnishings can also be of

Kevlar. The original aerostat can then be cannibalized for strategic metals. These are absent in Venus' atmosphere. Whether processes developed for use on Venus can be operated efficiently enough to produce competitive exports for other off-Earth products is to be seen. Graphite is also made of carbon, as is diamond, buckminsterfullerene and other less familiar materials.

**SULFUR**– Sulfuric acid  $H_2SO_4$ , sulfur dioxide  $SO_2$ , carbonyl sulfide  $COS$ , and hydrogen disulfide  $H_2S$  are far more significant both industrially, and as part of any future terraforming equation than their abundance in the atmosphere might lead one to think. We'll save the second part of that assertion for the next article. On Earth quite a few very serviceable products have been made of sulfur from building blocks to water-impervious hard shells from hot-sulfur-impregnated fabrics. Why not analogous products from hot-sulfur impregnated Kevlar meshes and gauzes. These might be less expensive than all-Kevlar products e.g. for making the shells of hydrogen gas buoyancy tanks that make aerostats possible. Worth exploring.

**ORGANICS & SYNTHETICS** — Carbon, hydrogen, oxygen, nitrogen! We can grow food, and fibers for clothes, bedding, and upholstery; make handy plastic products; even pharmaceuticals. We need more than structural materials alone!

**GOING DOWN FOR THE NITTY GRITTY** — Need, iron, aluminum, silicon, other nonvolatile elements? We can't advance further towards diversifying our brash sky-bound Veneran startup industries until we can access material on the ever so hostile, charring-hot surface. Scoops at the end of drag line tethers lowered thirty miles to the surface then hauled up with their booty, would be one way. A line loop anchored to the surface establishing a bucket conveyor would be another, binding the aerostat factory overhead to a particular site. Chute dropped, helium balloon-returned scoops might be simpler and a more logical choice to start off, especially if only trial amounts of surface materials are required. Methane and oxygen fueled sample rocket returns run up against the high temperature problem. We mentioned metals, but an earlier prize goal might be the simple raw silicates which would yield raw glass stuffs and ceramic stuffs.

**Aerostat-produced products of glass, fiberglass, glass composites, ceramics, fiberglass ceramics, and sulfur/fiberglass composites** would enormously diversify a startup industry whose prime products were graphite and Kevlar, and sulfur composites.

**Venus has major industrial potential! <MMM>**

# Geomorphing Venus

## How to make Venus an "M class" Planet

By Peter Kokh

In the first two articles, we have seen how the supposed fire & brimstone hellhole of Venus can not only become, in its subnubilar reaches, 30 miles or so above the surface, a venue for scientists and even hardy tourists, but how it can develop industrially from such aerostat perches to potentially support someday sooner than anyone imagines, a respectable population of committed Venerans. As full and as satis--fying as life might become for these "Sky Folk" (remember when writers used to dismiss imaginary Venerans as fog-eaters, swamp rats, and such?) their dream must assuredly be to someday descend to a cooled surface and colonize its twin "continents" and many "islands", and to sail across rewatered oceanic basins. "Terraforming" will fuel their culture.

How will it happen? All the schemes we've read about to date seem to be cases of GIGO, "garbage in, garbage out". It is useless to theorize if starting assumptions are wrong or only half the truth. Seeding Venus' upper atmosphere with blue-green algae and hoping for "the big rain" is pretty Quiotic. There is not enough water vapor left on Venus to make such a scheme work.

**TOOL ONE** — The challenge seems truly daunting. All that heat buildup in a runaway greenhouse. That unimaginably thick carbon dioxide atmosphere. Ninety times too dense, an unbreathable composition. Not enough water. An task impossible? The facts themselves point the way and we can find it if we respect the facts. They are not a crushing set of disadvantages, but a rather happy set of leveraging points. The first tool we need is attitude, the right attitude.

**LEVERAGING OUR PRESENCE** — We'll have to be on site in numbers, engaged in significant economic activity in the pattern sketched in the preceding article. How we do industry there in the heights can be tweaked in our favor. Making maximum withdrawal from the atmosphere of hydrogen and sulfur

in their several compounds will eat away at the source of 45% of the greenhouse effect. That is significant. Water vapor would be collected in aerial reservoirs to support extensive agricultural operations. This vapor is 25% of the problem. Cloudstuffs and sulfur contribute another 20%. Further, remove the cloustuffs, clarify the atmosphere from top to bottom, and you open the oven door, allowing substantial hear-radiation to space. Encouraged by the potential good side effects of our industriousness, to what does the rest of the problem reduce? "Too much CO<sub>2</sub>, too little H<sub>2</sub>O."

**FIRST BLUSH** — The agenda would seem to be twofold, (1) blast the bulk of that crushing atmosphere into space, (2) bring in a zillion cometfuls of water-ice.

**REASSESSMENT** — On second look, that oppressively thick carbon dioxide atmosphere is not surprising. It represents about the same amount of CO<sub>2</sub> absorbed into Earth's crustal rocks as carbonates. Indeed, if their were to be a runaway greenhouse here, all that potential carbon dioxide what be baked out of the rocks and released, "Veneraforming" the Earth. To consider is the apparent loss to space of 99% of Venus' one time reservoir of water. Now there seems no magic button to push to make the events roll back in reverse. The water is largely gone, and without it as a catalyst, the carbon dioxide can't be reabsorbed into the surface rocks. We could bring in a zillion comets, a major undertaking. The clouds would soon thicken a hundred fold with water vapor. If somehow we could cool the place and just let it rain ...

**BACK TO THE INDUSTRIAL TOOLS WE WILL HAVE BUILT UP** — We will have mastered the chemical engineering challenges to wholesale extraction of carbon from the carbon dioxide. Why stop with producing Kevlar products for domestic aerostat civilization consumption. Can we extract hundreds, even thousands of times as much carbon as we'll need for these needs and somehow shoot it into space to the realm of the Venus-Sun Lagrangian point 1. Either as a thick carbon dust cloud or as some sort of Kevlar parasol, this carbon is available for blocking the Sun, and to thwart its heat maintenance engine. Meanwhile we will have been working on the source of the other 45 percent of the runaway greenhouse effect.

**HYDROGEN PIPELINE** — The atmosphere becomes less CO<sub>2</sub>, more molecular oxygen O<sub>2</sub>. Now for every nine zillion tons of cometary water ice we would have brought in, we need to find a way to bring in only one zillion tons of hydrogen. Combine it with the waiting hydrogen, the dissipating greenhouse effect, and Voilà, the big rain begins. If we were to bring in enough hydrogen to mate with all the oxygen freed by extracting all that carbon, we'd get an honest to goodness ocean many hundreds of feet in average depth - many times the volume of water Venus once had. We'd end up with a Nitrogen Oxygen atmosphere of similar ratios to Earth but about two and a half times the density. Anyway, it is beginning to look like a plan.

**WE ARE THE ANSWER** — An initial aerostat city uses made-on-Venus materials to duplicate itself. Two become four become eight become sixteen become thirty two and now we see the parable in the film 2010 in which the monoliths multiplied in Jupiter's atmosphere exponentially. Slow and insignificant at first, there is an inexorable crescendo as the Sun is blocked, the atmosphere changes in composition and cools and then dissolves in an incoming flood of hydrogen into the Big Rain. There are problems! But this makes much more sense than any previous plan. Best of all the human presence grows apace, not waiting for the process to be completed. <MMM>

**MMM #115 MAY 1998**

## Visits to Venus en route to Mars

By Peter Kokh

**STANDARD MARS TOURIST ITINERARY** windows open every 25+ months

- Spend **8 or 9 months en route to Mars.**
- Tour till you've seen enough then
- hibernate for the rest of your 18 month stay until the return launch window opens.
- Send **8 or 9 months in space on way back to Earth.**
- **Total time away from Earth two and a half to three years.**

**STANDARD VENUS TOURIST ITINERARY** windows open every 19 months or so

- Spend 5 or 6 months on route to Mars.

- Spend 11 months on an aerostat, looking at Venus' surface features through telescopes, and work for the science crew there until the eleven month wait for your
- 5 or 6 month return trip to Earth.
- **Total round trip time two years.**

That's the deal using minimum fuel expenditure Hohmann transfer paths to Mars and Venus.

### BEHOLD THE TWO FOR LESS THAN ONE DEAL

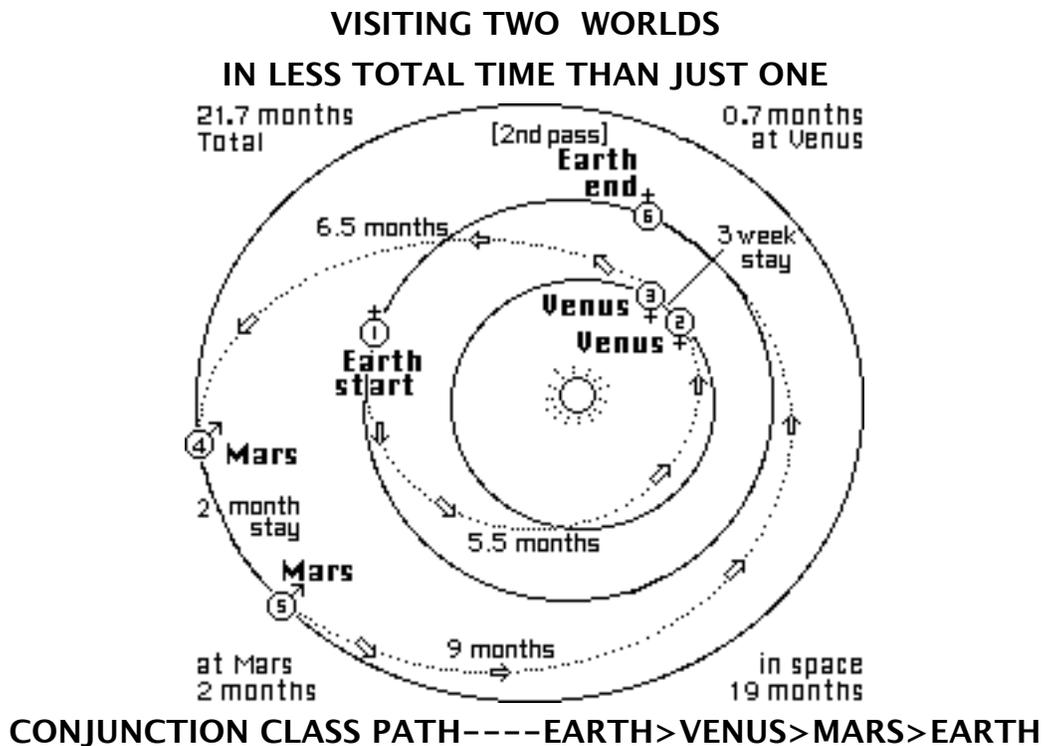
But if you had to get to Mars in between, there is a way using the so-called "conjunction class" trajectory to Mars,

First swing in toward Venus for a gravitational boost. It takes about a year in space to get to Mars by way of this detour.

You'll get there just two months before it is time to return home the ordinary way.

But leave from Earth a couple of weeks sooner if willing to pop for the fuel to break into Venus orbit, and then launch out again three weeks earlier, and

**You get nice length stays at both worlds and still get home in under two years, less time than it takes to visit one. A deal which should prove very popular!**



## High Sky Aircraft for Venus

By Peter Kokh

### JOB DESCRIPTION

If we are going to have any number of science station and industrial aerostat hamlets in "the high skies" over Venus, we'll need reliable, easily kept up, worry-free, locally co-manufactured<sup>1</sup> means of transporting people and cargo in between. That's a mouthful of design constraints. Can we deliver?

With the surface off limits to casual ventures, aerial transit is it. And none of our Veneran aircraft will be "landing" or "taking off". They will be "arriving" and "departing" — from midair docking gates.

Craft suited for such purposes may have very limited ability to cope with the greater pressures and heat levels of successively lower layers of the atmosphere. It would seem essential to design into them passive fail-safe buoyancy systems to prevent such misadventures.

## **FUEL & ENGINES**

Methanox (methane/oxygen) is a serviceable fuel combination for both reciprocating prop engines and for rockets. Most importantly, both fuel and oxidizer can be processed on Venus from the atmosphere where its exhaust will return it in the form of the original ingredients.

As landing is not an option in distress situations, some form of back-up power for electric taxi props would be prudent. Another option, however, is to have the entire upper surface of the craft serve as a rectenna for guide-beam slaved Solar Power Satellite microwave transmissions. Such systems, it'd seem, would be pioneered on Earth long before we'll need them on Venus, and by then be a stock item.

Where sprint-rescue speeds are not needed, propeller-driven craft promise the greatest fuel efficiency with adequate speeds as well as superior low speed performance for dock approaches and departures. Aircraft can safely fly at the 1 ATM aerostat level but need climbing ability to reach thinner air for more efficient cruising.

While fuel tanks should be ample for long range and extended cruising and bad weather and other emergency situations, again because landing is not an option, Veneran aircraft should have midair refueling capability. Midair docking capacity for exchanges of crew, passengers, and cargo would be an invaluable advantage, bringing enormous flexibility.

To avoid construction of aerial runways that offering surface friction to assist braking and deceleration and provide a platform for acceleration to lift speeds, aircraft should either be buoyant or have some sort of Harrier or other type VTOL or hovering capacity. This would help in midair docking.

## **CONSTRUCTION & COMPONENTS**

Lightweight Kevlar components, manufactured in Veneran high sky facilities, will provide greater strength and lessen the weight to be managed in maintaining lift, buoyancy, and hovering ability. Small complex subassemblies (navigation avionics, other electronics, control & communication systems, airtight docking ports, etc.) can be imported from Earth to mate with Venus-made fuselages, wings, fuel tanks, cabin interiors, and other items designed for ease of on site manufacture and assembly.

A whole family of Veneran aircraft will be needed: small crew transports, smaller and larger passenger craft, craft dedicated for cargo, fast sprint rescue and response craft. Maintaining a "family" resemblance along with the maximum percentage of interchangeable parts will be of compelling benefit.

## **FAIL-SAFE & JUST-IN-TIME LIGHTER THAN AIR**

Obviously, the dirigible is one viable option along with other possible lighter-than-air architectures (there is now a renaissance in interest along with increased exploration of new design options). But full-time partial buoyancy and buoyancy-on-demand with fail-safe, dead man deployment systems will also work while allowing more streamlined designs and faster cruising speeds.

Hydrogen-filled bags that passively inflate whenever certain impeding conditions degrade will make the High Skies safe for all Venerans to fly. These conditions include minimum speed, maximum desirable or tolerable air density and/or temperatures, as well as certain internal conditions (loss of fuel, power, active crew).

To more efficiently negotiate different altitude ranges as well as variable speeds, wing and/or lift surface designs that allow the loading to be varied are a downrange design consideration.

## **SPECIAL DUTY CRAFT FOR SURFACE EXPLORATION**

On Earth, we have built oceanic submersibles that have withstood over 1,000 ATMs of external hull pressure. So it is temperature, not pressure, that looms as the most challenging hurdle facing would be surface exploration craft, including VTOL aircraft and wheeled gondola cabins lowered and lifted by collapse and store balloons. As an interim measure, mid-altitude aircraft could lower retrievable instrumented science/communications packages on tethers.

## **COMMUNICATIONS**

How serviceable line-of-sight radio communications will be, is unknown. With less of a magnetosphere, solar or cosmic noise could be a big problem on Venus. Satellites could offer GPS navigation assist as well as communications relay. But so could heat and pressure-hardened surface relay stations.

On this as on other challenges above, the old adage applies. "Where there is a will, (and no defeatist attitude!) there's a way." "High Skies!" <MMM>

# Venus, Geomorphed

## Fast Forward X-Hundred Years What could we expect from our Project?

By Peter Kokh

### I. The New Atmosphere

Venus' new atmosphere would be a carefully selected residual of its old one. How closely can we get it to resemble Earth's? Our familiar mix is:

76.084 % Nitrogen    0.934 % Argon  
20.946 % Oxygen    0.031 % Carbon Dioxide  
"up to" 1.0 % Water Vapor

The game plan is to end up with a breathable mix of nitrogen, argon, and oxygen, with just enough carbon dioxide to make a biosphere work, no more. Currently, Venus has about 3,000 times more carbon dioxide in its atmosphere than does Earth. This CO<sub>2</sub> is fair game. The tactic we've floated is to disassociate the gas into carbon and oxygen, O<sub>2</sub>, and use the carbon to produce Kevlar and graphite products and, in some fashion, to use the excess to create a giant parasol at the Venus-Sun Lagrange 1 point to intercept continued solar heating for as long as necessary.

The residual 60.5 ATMs of oxygen would be reacted with imported hydrogen to make water vapor which would eventually rain out as temperatures fell. Just enough oxygen would be preserved to create a breathable mix with the Nitrogen and Argon in Venus' present atmosphere. That is perhaps 2 to 3 times as much N<sub>2</sub> and Ar as we have. An elegant way of reducing these gasses has not occurred to us.

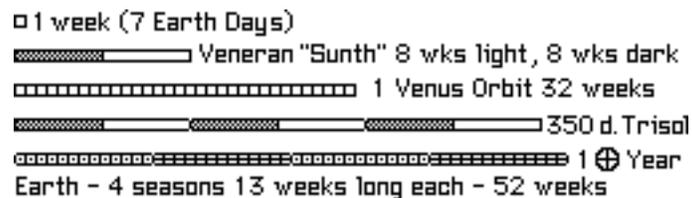
The upshot is an atmosphere that will still be noticeably heavier than what we are used to, and with a much greater capacity to absorb water vapor than has our own atmosphere. This water vapor will have a greenhouse effect, but one that probably cannot be avoided. Compensating, the planet should be just as overcast as it is presently, with water vapor clouds. A seasonal (see immediately below) pattern of winds, fogs, and thunderstorms should develop.

And, oh yes, the niche of friendly pressures and temperatures enjoyed by the interim aerostat-based subnubilar Veneran civilization (last issue) will have dissipated. That's a substantial trade off to be anguished over, as it will be irreversible.

### II. Where Day and Night are Seasons

Venus' year is 224 days long, covering 1.6° of its orbit each day. It rotates on its axis once every 243 days, turning 1.48° per day. If it rotated in the same counterclockwise direction as it orbits the Sun, as does Earth, its rotation would lag behind its revolution so slightly that it'd take  $360/(1.60-1.48) = 2,960$  days or 8.1 years for just one day-night cycle!!

Fortunately, the direction of rotation is just the opposite so that the daily 1.60° and 1.48° increments are added instead of subtracted, the smaller from the greater.  $360 / (1.60+1.48) = 116.78$  days or **58.39 days (c. 2 months) of daylight, alternating with 58.39 days of darkness.** This **117.68 day "sunth"** is not quite four times as long as the dayspan/nightspan "sunth" cycle on the Moon (29.53 Earth days long).



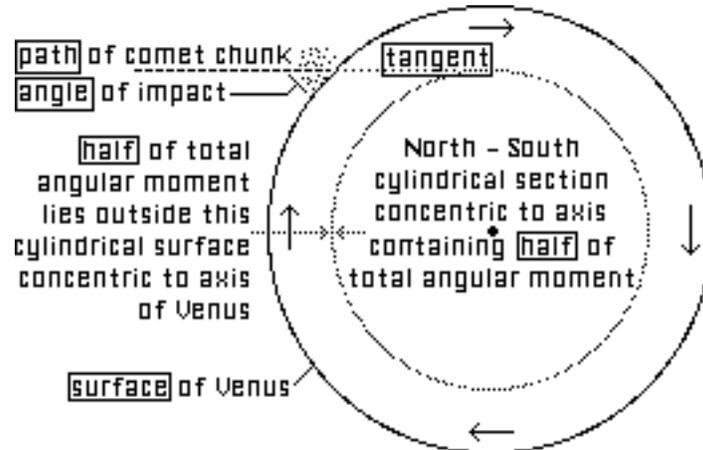
The upshot is that there are two day/night cycles per Veneran Orbit Year. Actually, not quite. Two Veneran "Sunths" are 233.57 days long, about 9 days longer than one Veneran "Versary". There are 25 pairs of Sunths (50) in a 26 Versary period.

Keep in mind that as Venus axial tilt to the plane of its orbit around the Sun is only about 2°, there is no "seasonal pattern" tied to the Veneran Versary or Orbital Year. It is the "Sunth" with its hotter 8 week long dayspans and cooler 8 week long nightspans that produces the true "Seasons" on Venus.

We predict that Venerans will count their year-like periods as three sunth-sets (“trisols”?) of  $3 \times 116.78 = 350.35$  Earth dates long. Their sunth would come out to an even 112 dates of 16 weeks if they marked dates as 25 hrs. 1.5 min. long. Or they could keep the Earth minute, hour, day, and week, but mark their own sunths and “trisols”.

### III. Shortening the days/night cycle

IF we were ever to tamper with that cycle, by impacting comets at the equator and in the equatorial plane, at an angle of roughly  $45^\circ$  to “aim tangentially at” the subsurface point along which Venus’ mean angular momentum of rotation lies, it would be far more effective to go with the flow and try to speed up the “retrograde” rotation, than to first slow it to a dead stop, then induce rotation in the “right” direction.



AIMING water-ice comets for max. rotation speed up

If we decided we wanted more water than to be had by reacting hydrogen with oxygen liberated from the carbon dioxide in the atmosphere, and we wanted it bad enough, we’d have to get it from comets or from dismantled ice-moons (Saturn’s Hyperion is already half dismantled from past impacts.) We could guide the comet ice chunks in their incoming trajectory to best speed up Venus rotation. We’d add this “extra” water before reacting imported hydrogen with atmospheric oxygen, i.e. while the surface was still dry.

Shortening the Veneran sunth would be an uphill battle. To cut it in half down to 58.4 days ( 4 weeks each of daylight and darkness), it would be necessary to speed up the period of rotation more than three times, from 243 days to less than 79.

### IV. A Tale of Two (Veneran) Cities

There may be a very good reason to leave well enough alone. Venus’ dayspan/nightspace cycle is slow enough that we are really dealing with a 2 month long daylight season and a 2 month long darkness season with substantial temperature swings. Now it is fantasy to expect that a terraformed Venus will have moderate temperatures. We’ll be lucky to have them on the underside of boiling. If we succeed in forming an ocean, it would be steam-room hot. There are people who find such an environment “renewing,” at least for an hour or two. I’m not one of them, preferring dry sauna heat instead. Extreme heat coupled with extreme humidity would be disabling, if not immediately fatal. So what can we do?

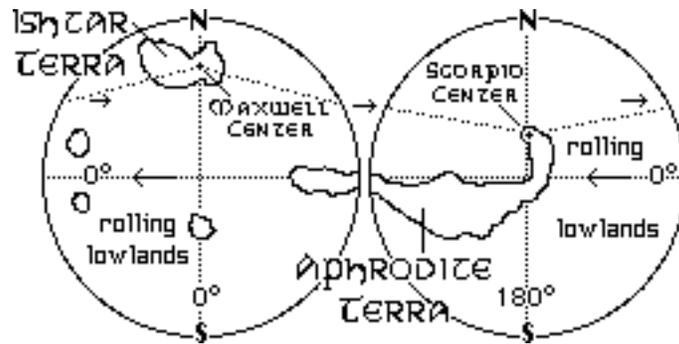
**Can we find a surface beachhead or two of more moderate temperatures on our rehabbed Venus?**

**Nightspace at higher elevations** seems the best bet. Fortunately the highest spot on the planet, **Maxwell Montes** (pinning the  $0^\circ$  longitude) is paired at  $180^\circ$  by another high spot. When one passes into dawn, the other passes into nightfall. We could establish a pair of outposts from the very outset, and migrate from one to the other leaving each sunrise for sunset. Such a lifestyle is not so different from that of “snowbirds,” people who migrate annually from the snow-belt down to Florida or Arizona. On Venus there’d be three migration cycles in the space of one Earth year.

So we suggest these two settlement areas:

11. Maxwell Montes in eastern Ishtar Terra  $0^\circ$  longitude,  $65^\circ$  N — “**Maxwell Center**”

12. Tip of the “Scorpion’s Tail” in eastern Aphrodite Terra at  $180^\circ$  E-W,  $18^\circ$  N — “**Scorpio Center**”



[Venus: two “continents” tower over rolling lowlands.  
As Sun rises in the West, migrations are to the East.]

## V. Oceans & Continents

Venus’ new oceans and seas will be less deep than Earth’s, there being no deep abyssal basins on Venus. Further, the amount of water producible by reacting imported hydrogen (1/9th the mass of comet ice needed in other schemes) with oxygen liberated from atmospheric carbon dioxide (MMM # 114 MAR, “Geomorphing Venus”) is enough to produce a layer an average 800 meters or 0.8 km (2,700 ft.) deep. That’s less than a third as much water as Earth boasts, but still a respectable amount and we could look for depths of 4,000 feet as common.\*

\*[BOE (back-of-envelope calc.):  $90 \text{ atms} / 0.91 \text{ G} \times 0.73 \text{ (\% oxygen in atmospheric CO}_2\text{)} \times 1.125 \text{ (with hydrogen added)} \times 15 \text{ lbs/inch}^2 \times 144 \text{ sq. in /sq. ft} \times 64 \text{ lbs of water/cubic foot} = \text{a column of water } 2,731 \text{ ft. high or c. } 800 \text{ meters, i.e. if most Venus’ atmospheric oxygen was hydrogenated.}]$

As a result, the new seas will be subject to significant evaporation during dayspan, and heavy precipitation and refilling during nightspan. If it were not for this natural seasonal redistribution of the waters, we might choose to preferentially deep-fill select basins closest to the two suggested population hubs. But evaporated water will refill by rain any available basins, on cue from seasonal wind and rain cloud circulation patterns. Some seas will be “ephemeral” not lasting the whole of dayspan before becoming dried mud flats. Others will shrink noticeably in surface area as each day season progresses. Others, with steeper shores, will lose volume but not much apparent area. These will be the first targets for seeding with heat-tolerant living species.

Deep water forms of marine life in deeper basins may fare better than shallow water and surface water forms which have to cope with higher temperatures and considerably greater temperature variation. Other species will time their reproductive rhythms, even their feeding (and fasting?) patterns to the long dayspan/nightspace seasons.

On Earth, it is the Ocean, covering 3/4 of the Earth’s surface, that is the great thermal flywheel which rules the weather on a global basis. It would be a challenge to give Venus an ocean as extensive in area, even though, there being only two comparatively small continental elevations, and no deep abyssal basins, it would take a much lesser volume of water to cover a greater expanse of surface on Venus than does Earth’s multi-lobed global ocean.

To improve drainage and reduce the number of unconnected “landlocked” basins, an equivalent of our Army Corps of Engineers could channel thru basin sills and natural dams and dig canals to inter-connect the various bodies of water and globalize the possibilities for marine navigation.

### Biosphere-wise, jobs 1 and 2 are:

1. Seed the oceans with hot-water-loving microbial cultures, plankton, and nekton: the bottom of any future food chain.
2. Fix the soil with rain-hardy erosion-resisting algal mats. etc., and with microbes to produce good, fertile soil, and to reduce soil temperatures.

## VI. A Question of Goals

Whether the two settlement sites proposed above, or any other Veneran surface outposts ever become full-fledged human settlement communities or just the science stations involved in the great terraforming and biosphere genesis project is another question. Even if we were to succeed in cooling the planet, cannibalizing its present ponderous atmosphere for sunshade materials and for the oxygen portion of a reconstituted shallow ocean, and then successfully seed the latter along with the raw now

rain-washed rock-strewn lands, it may well take centuries for the infant biosphere to find its new equilibriums. There may be false starts and global setbacks. Until the new Veneran biosphere settles down and proves itself stable, Venus may not be a sufficiently friendly place for a pioneering commitment.

Even with major changes in its atmosphere, significant heat reduction, and reformation of a significant ocean, as long as Venus remains as close to the Sun as it is, we might have to rest content with concreting a world where we can watch to see what happens. Indeed, Venerans will not see Terraforming as an episode that introduces them to a new future, but as their future for all foreseeable time to come. The process of making Venus a friendly place for Earth-derived life will be a very open-ended one. Indeed, it will give Venerans a sense of collective vocation and purpose that seems to be utterly lacking in most, if not all Earth cultures of our time. To turn Venus into an enormous biological and biospheric labor-atory will be a tremendous feat, even if we never do settle the surface in numbers.

## VII. But what if we don't?

Our Veneran descendants may choose to keep their dearly won aerial civilization and to remain a cloud-top civilization like that teasingly illustrated in "The Empire Strikes Back," Part II of the Star Wars Trilogy. They might grow to cherish this "good life".

The terraforming strategy we've outlined may pay much greater respect to the given facts than any of the garbage-in-garbage-out schemes in circulation. But even with a philosophy of "going with the grain of nature", it would be a gargantuan "cathedral-building" task absorbing the energies of many generations.

Further, our radical departure proposal has yet to benefit from peer review. There may be show-stoppers. It may be impractical to make any kind of sunshade in space from liberated carbon, even  $1.24 \times 10^{19}$  tons of it. The 89% mass savings of importing just hydrogen instead of water ice may be mooted by the technical and engineering difficulties uncovered.

Let's first brainstorm every unexplored option, One thing we've got for sure is lots of time.

<MMM>



## THE FRIDAY FILE

FRIA is the Norse Equivalent of Roman VENUS

## VENERAN RECLAMATION PROJECT STARTER LIST OF R&D PRIORITIES

Calling all "Friends of Fria". Want to contribute by helping brainstorm, engineer and design aerostats, Veneran aircraft, surface probes & rovers, atmosphere mining, tourist opportunities, or terraforming scenarios? Send your home-worked ideas to: [kokhmmm@aol.com](mailto:kokhmmm@aol.com)

There are a lot of challenges to overcome in rehabilitating Venus. But the biggest of all is not out there, not in or at Venus or Venus' orbit, but in getting rid of our own mental blocks to "imagineering".

### A Starter List of Priority "Friday" R&D Agenda Items

#### Industrial

- Kevlar from CO<sub>2</sub> — chemical engineering options
- Methane from CO<sub>2</sub> & H<sub>2</sub>O
- Sulfur extraction and byproducts
- Sulfur/Kevlar mesh composites

#### Power

- nuclear (imported plants, servicing)
- lightning harnessing via tethers?

- solar thru the clouds – SPS/microwave systems  
NB. no Venerosynch “Clarke” orbits  
NB. low 2° axial tilt means nightspan SPS eclipses

#### **Sun shading**

- VSL1 station keeping parasols
- VSL1 dust clouds

#### **Surface exploration & mining**

- heat-resistant sensors, electronics, gears, etc.
- ceramic and kevlar parts
- magnetic greaseless bearings
- Pressurized dewar–thermos crew cabs/habs?

#### **Communications**

- short wave radio transmission uncertain
- Orbital relays
- Surface relays (see above)

#### **Transport: Airborne and to/from Space**

- methane/oxygen fueled propeller craft
- methane/oxygen fueled rocket craft
- stall and hover ail–safe buoyancy bags
- midair docking & transfer of cargo, people, fuel
- Space arrivals – chutes/bags slow to stop & taxi
- Rockoon launching — aerostat spaceports <MMM>

## MMM #117 August 1998

### **DRUMROLL FOR MERCURY**

### **A snail–pace rover on a century long mission**

By Francis Graham, Kent State University

On the planet Mercury [where, because of its closeness to the Sun, sunlight ranges between 4.6 and 10.7 times as intense as at Earth’s orbital range, at Mercury’s furthest and closest approaches to the Sun respectively] the temperature variations are the most extreme for any planet.

- By noon the temperature rises to 700°K [427°C = 801°F]
- At sunset [44 Earth days later] it drops to 150°K [-123°C = -189°F]
- Just before dawn [88 Earth days later] it descends to 100°K [-173°C = -279°F]

If we take advantage of this 600°K [1080°F] range in the [nearly 6–month long dayspan/night–span] diurnal cycle of Mercury, a unique perpetually roving probe is possible.

In my design, a battery of cylinders with pistons surrounds a central axle. These cylinders are filled with

bismuth\*, which expands upon solidification and shrinks upon melting at 544°K [271°C = 520°F] in the volumetric ratio 9.67/10. A heat engine is thus possible across the phase in the 176–Earth day Mercurian solar cycle. A train of cylinders, with appropriate linkages and gear trains, could provide many revolutions of the drum–shaped probe, allowing it to move far [over a span of many years]. In addition, the use of a mechanical system would be much more reliable over the huge temperature variation than a system using electric motors.

- Bismuth, Bi – a brittle, grayish white, red–tinged, metallic element used in manufacture of fusible alloys, and in medicine. Atomic No. 83, at. wt. 209 Of course the probe would have instrumentation too, and this would have to be especially hardened for high temperature variations and thermal expansions. Simple high reliable technology would be preferred if the probe is to transmit images and data for many decades. Such technology could be precursors to the highly reliable technology required for interstellar probes. Thus “our drum on Mercury” could provide surface data at a variety of sites throughout the 21st century. <FG>

Francis Graham, P.O. Box 209, East Pittsburgh, PA

### **Friendly Comment by the Editor**

A heat engine of this sort would seem to cycle but once each Mercurian day, the bismuth melting as noon approaches, freezing and resetting the engine after local sunset 3 months later. At 205 Mercurian days per century, this wouldn't allow much progress. This will not be the case if as each cylinder stroke discharges it moves other previously discharged cylinders into the shade. Once in the shade, with no atmosphere to support heat transfer by convection, the bismuth of a discharged cylinder would soon enough refreeze, thus resetting the cylinder.

Graham's cylinders are arranged radially on the drumroll rover. So cylinders at the top would be in full sunlight, melt and discharge, advancing the drum roll, bringing previously discharged cylinders toward the bottom, into the shade. Cylinders on the far side would come out of the shade and advance into the sunlight again to melt and discharge anew. And so the motion would perpetuate itself as long as a part of the drumroll rover remained in the sunlight.

The time it takes a cylinder to refreeze, upon being shaded, and to melt and discharge upon being reexposed to the sunlight, would determine the rate at which the device cycled. The freeze time would not seem to be variable. But the melt time would be shorter the higher the sun was in the sky (unless the cylinders could shift attitude to catch the sun as full on as possible) and the closer Mercury was to the sun in its elliptical orbit. Thus progress would be swifter nearer perihelion. <PK>

## **Ideas for Earth Simulations of Europa Submarine Exploration Missions Continue to Surface**

[includes material from Florida Today Space Online 7/22/98  
[www.flatoday.com/space/today/072298a.htm](http://www.flatoday.com/space/today/072298a.htm)]

MMM has reported previously on ideas to take advantage of a unique Antarctic geological curiosity, Lake Vostok to test concepts for through the ice crust exploration of Europa's global ocean [which we have dubbed "The Rhadamanthic" after Rhadamanthus, mythical son of Europa fathered by Jupiter.]

Lake Vostok is a body of water the size of Lake Ontario and lies beneath 4 miles of ice. The lake is estimated to be 500,000 to 1 million years old and, like the ocean on Europa, has never been seen or sampled. The deepest ice sample from Lake Vostok is from 328 feet above the underground water. NASA and others are studying bacteria and microorganisms trapped in the ice.

NASA hopes to follow up the Galileo spacecraft now making orbital passes of Europa and Jupiter's other major moons, with a probe that will orbit Europa directly, map its surface as well as the varying depth of its ice crust. This would happen sometime after 2005, to be followed by yet another spacecraft to land on the ocean moon. A third mission would feature a special bullet-shaped lander called a "cryobot," with a small radioactive heater to melt through Europa's thick ice crust. Heating is more reliable than drilling as it requires no moving parts that can break down. Upon reaching water, the cryobot would dispatch a mini sub called a "hydro-bot" to search for any signs of life.

So it seems that robotic craft being designed for duty in Earth's oceanic depths may also serve as testbeds for equipment that would be useful on any similar "hydro-bot" exploring Europa's ocean. It happens that a robotic submarine is now investigating Atlantic waters east of New Jersey's Little Egg Inlet as part of Rutgers University's Long-Term Ecosystem Observatory-15. Called REMUS [Remote Environmental Monitoring Unit], this remote submersible has lights, a camera and other sensors also needed to explore Europa's depths unreached by the sunlight that shines on its icy crust. REMUS-like subs could lead to a fleet of small, intelligent, autonomous deep-water high-pressure craft.

Chris von Alt, a Woods Hole robotics engineer, built REMUS and other underwater vehicles that found the Titanic. Von Alt has begun consulting with engineers at JPL designing the Europa missions. "The challenge is to take a vessel like REMUS and see how small we can make it and still survive the hazards on Europa," says Linda Herrell, JPL systems engineer. It would have to be small. JPL estimates a payload sent to Europa probably could be no longer than 3 feet and weigh no more than about 65 pounds. This package has to include any surface station, the cryobot and the hydrobot it would release as well as any separate communications equipment needed to make this doubly remote mission work.

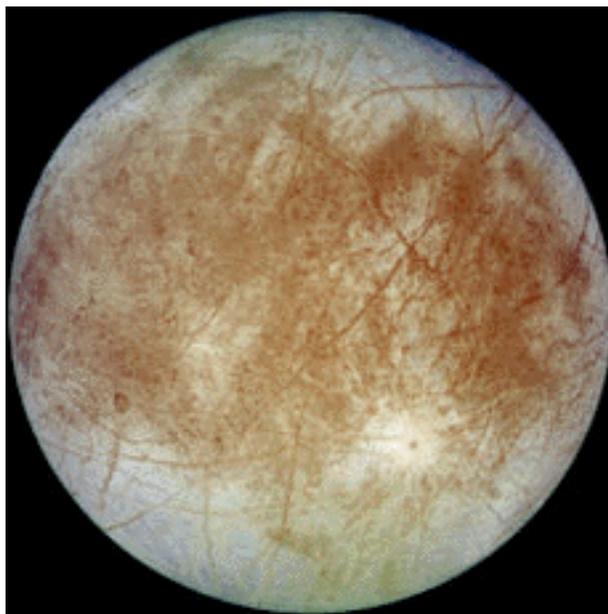
It takes 35 to 50 minutes for signals traveling from Earth at the speed of light to reach a spacecraft at Europa, 400–600 million miles away. It takes just as long for confirmation signals to be sent to Earth from the spacecraft. So a Europa hydro-bot could not be steered from Earth because of the transmission time delay. It would have to be almost completely independent. It might need some kind of artificial intelligence or problem-solving abilities to navigate the expectedly uneven undersurface of the ice crust or challenging terrain of the ocean floor.

Another important question is how the hydro-bot would communicate to a surface station and/or orbiting relay, without some sort of weight-hogging through-the-ice umbilical cable. One individual has suggested that a test be designed to see if the cylinder of refrozen melt water left behind the descending cryo-bot would conduct radio signals well enough to allow placement of simple relay antenna at the surface entry and under-ice exit points. While melt water would sublimate, it would refreeze faster, choking off the sublimation process. Thus the descending cryo-bot would be surrounded by ice but enveloped in its own teardrop of melt-water following it all the way down. This expectation could also be tested on Earth, even by going so far as to create a vacuum over the ice entry point.

Lake Vostok could provide a handy test site for a prototype Europa cryo-bot and hydro-bot combo mission through the ice and into the lake/ocean. Some tests could be done in nearer-by Greenland, however.

That all of these things are coming together in the same general time frame lends encouragement and confidence that the time for such an ambitious Europa submarine mission may be ripe.  
<MMM>

## MMM #118 September 1998



**Galileo finds Brine Salts on Ice Surface – Europa's Ocean Seems to be Carbonated**



## European Pioneers “Living Off the Ice”? Why Not?

One of two “either/or” scenarios on Europa:

(a) Robot probes find life in the ocean; (b) We do not find life.

Either way we’ll need a permanent outpost (a) to explore; or (b) to seed the ocean with Gaian stock. The recent discovery of salts on the ice gives us needed stuffs to support a “Live Off the Ice” effort.

**Sample habitat:** Mg magnesium; L Lexan; G graphite; C nylon/resin composites; P plastics; S styrofoam.

# Living “Off the Ice” on Europa

By Peter Kokh

We had previously suggested that Europa’s ocean would be free of those salts common in Earth’s oceans that derive from sedimentary erosion of the continents. We’d also predicted that carbon dioxide from ocean bottom volcanoes along with other soluble volcanic and hydrothermal vent exhalations would characterize the water. We even suggested (in an email letter) that CO<sub>2</sub> in excess of what could be dissolved would build up in pockets under the ice [cf. MMM # 110, NOV ‘97, pp. 1, 8–10] and could be the principal method of triggering fissures that would spew this special brine out onto the surface. Salts are left when the water evaporates.

### FIRST FINDINGS

Its extended Europa mission, Galileo, has now found two of these telltale salts on the ice crust with its Near Infrared Mapping Spectrometer (NIMS). Various compounds absorb and reflect sunlight differently, and thus leave distinctive signatures.

So far, the Galileo NIMS has detected the signatures of Natron [hydrous sodium carbonate] and Epsom salts [hydrated magnesium sulfate] traces in several dark line areas of Europa. Traces of these salts have been found at several dark line areas, indicating a global ocean that is fairly homogenized.

The hope that Europa’s Ocean [we’ve suggested it be named “The Rhadamanthic” after Rhadamanthes, mythical son of Europa sired by Jupiter] might harbor life is stimulated by the relatively recent discovery of rich oases of ocean bottom life on Earth around the hydrothermal vents found along the kind that such theoretically possible vents are a feature of the sea bottom of the Rhadamanthic. But the presence of a saturation abundance of dissolved carbon dioxide (seltzer or soda water) makes this a very believable scenario, indeed hard to explain otherwise. And this makes the hope that we will find primeval life in the Rhadamanthic more realistic, less romantic.

Detection of the signatures of nitrate and phosphates would turn this hope of finding life into a strong expectation. The interaction of Jupiter’s giant magnetic field with the deep salty global currents of the Rhadamanthic may also give rise to a magnetic field island around Europa that could moderate the harsh radioactive climate previously expected. It’s strength is yet to be measured, and its existence confirmed.

### SEA SALT BONANZA?

Natron and Epsom Salts?!? Carbon, Sodium, Sulfur, Magnesium? What’s that? This does not seem a lot upon which to base a “life-off-the-ice” effort at partial industrial self sufficiency for a pro-

spective human community engaged in continued exploration and research on this very fascinating world. Yet these six elements (not to forget hydrogen and oxygen in the water) form more of a “critical mass” of chemical feedstocks than one might suspect at first thought.

Moreover, these are just the first findings. Hopefully, we will find other elements present on Europa’s surface in the form of evaporated sea salts.

**EARTH SEA SALT INGREDIENTS FOR COMPARISON**

To whet our imaginations, here’s the scoop on Terrestrial Seawater (based on salinity of 35g/kg): ocean bottom volcanic ridges that cause ocean floor spreading

<b>Main Salts in Earth Seawater</b>			
Cations	g/kg	Anions	g/kg
<b>Sodium</b>	10.76	Chloride	19.35
<b>Magnesium</b>	1.30	<b>Sulfate</b>	2.71
Calcium	0.41	<b>Carbonate</b>	0.14
Potassium	0.40	Bromide	0.07
Strontium	0.01	Boric acid	0.03
* <b>Bold</b> – also now found on Europa			

Some 3.5% of terrestrial seawater consists of dissolved substances in which 40 elements (other than hydrogen and oxygen) are represented. Of this, 82.86% is Sodium Chloride, NaCl, common table salt. In the other 17.14% of seawater are sulfates, magnesium, bicarbonates (all detected on Europa), but also calcium, potassium, strontium, fluoride, boron, bromide, silicon, nitrogen and phosphorus. (underlined elements essential for life, along with many lesser micronutrients.)

We also find salts of the other engineering metals: iron, aluminum, titanium; these common alloy ingredients: zinc, copper, nickel, manganese, cobalt, vanadium, tin, chromium; these precious metals: gold, silver, lead; other halogens: iodine and barium; miscellaneous elements: mercury, bismuth, tungsten, antimony, thorium. beryllium,, arsenic, uranium.

Can we expect to find all of these in European seawater? Hopefully some of them. Detection by Galileo or follow-on probes of the major nutrients vital for life as calcium, potassium, nitrogen, and phosphorus would be encouraging. But on Earth, salts find their way into the ocean by two routes: erosion runoff from the continents, and submarine emissions from sea-bottom volcanoes and hydrothermal vents. Only the latter processes operate on Europa – maybe.

**PLANNING FUTURE EUROPA MISSIONS**

Scientists are even now excitedly preoccupied brainstorming future missions to Europa that will:

- confirm the presence of a global ocean
- map the global topography of ice crust thickness
- penetrate the ice to sample the ocean directly ocean currents temperature gradients and flux submarine hot spots and thermal plumes salinity and chemical composition signs of living organisms or building blocks

We suggest prioritizing the orbital detection of evaporated brine salts on Europa’s ice surface – as this would give us three important things:

1. an earlier read on the likelihood of life in the ocean. If we find nitrates and phosphates, the outlook for life will be greatly improved.
2. a clear preview of the geological processes that have been operating on Europa’s sea floor, like volcanism and hydrothermal deep sea vents, etc.
3. a more complete list, especially if we have some idea on relative abundances, of the building blocks available for self-supporting industry for a substantial human presence engaged in a much more thorough scientific exploration of European geology, oceanography, and biology.

It is a happy confluence that what those of us interested in expansion of the human envelope to Europa need to find to flesh out our brainstorm further, will also cast a brilliant first light on the questions most interesting to both the planetary geologists and the exo-biologists. A Europa Brine Salt Mapper (or mapping instrumentation on the first Europa orbiter) is a no-brainer win-win for all.

**GOING WITH WHAT WE KNOW NOW**

What we have on the table already, thanks to Galileo's recent finds, gives us a situation similar to that awaiting those who would "Live Off The Clouds" in aerostats just below Venus' cloud deck. From carbon dioxide (carbonates on Europa) we can make spun graphite products and, maybe Diamondite.

Add to the mix the hydrogen and oxygen from water (or water vapor) and sulfur, plus nitrogen, chlorine, and fluorine (the last three, so far, only on Venus) and we have the building blocks for hydrocarbons and organic synthetics: plastics (& fibers )

- Cellulose (rayon) • polyester (and dacron)
- Polypropylene (herculon, olefin fibers)
- Polystyrene • polysulfones
- Urethanes and other urea (nitrate) derivatives
- Polyamides (nylon and Kevlar™ fabrics)
- Polycarbonate– Lexan™ windows, lenses
- Resins for making nylon and olefin composites
- Fuels like methane and propane
- Solvents, and much more and hydrofluoric acid cloud droplets:
- Vinyl, polyvinyl chloride (PVC pipe)
- Teflon™ abrasion/corrosion resistant coatings
- And more

Even if, on Europa, we do not find nitrates (that would kill the chances of finding life forms on Europa) or chlorine (despite the gigatonnage in our own oceans) or fluorine, that would still leaves a tidy repertoire of feedstocks for fuels and manufacturing plastics, fibers, resins and more.

If indeed the halide elements found in the Veneran clouds are not to be found in European brine salts, there is one big consolation. European pioneers will have a supply of at least one useful engineering metal: magnesium, and at least one potential ceramic: magnesium oxide. See the article below.

Get the chemical engineers busy and design minimal capital equipment (lowest shipping weight) factories to produce graphite, a variety of basic fuels, plastics, fibers, and resin-composites, as well as magnesium castings and sheet metal and magnesia ceramics. That would enable European pioneers to go a long way to meet their basic needs for shelter, furnishings, food production, transportation and recreation.

Sounds like a World Seed to me. If Galileo or follow up probes detect nitrogen, phosphorous, potassium, calcium, chlorine, fluorine – why then we can be really optimistic. Nor need we be rosy eyed to expect to find at least some of these.

#### **ENTREPRENEURIAL "SPIN-UP" HOMEWORK**

In the meantime, there is plenty of occasion and spin up entrepreneurial opportunity to experiment in stretching the applications of the above materials to cover uses ordinarily filled by other materials. On Earth we ordinarily concentrate on developing a new material just for those applications at which it will excel, or at least compete on price. Uses where a material will come in second best are rarely pursued. The result is that most materials are more versatile in potential application than we imagine. Has anyone experimented with fabricating items other than window panes and eye wear lenses out of Lexan™ polycarbonate?

Has anyone tried to form curved shapes of the stuff by laminating thin flexible sheets? How far can graphite be pressed? When there are few metal alternatives, cost may not matter. The neglected homework list is long.

The essence of the frontier is a readiness to reinvent everything to meet an unfamiliar set of challenges with less than the usual list of resources – and finding a way to thrive anew – therein giving glory to whatever Creative Energies are responsible for our existence. Europa, and Venus are challenges we must accept, or we do ourselves and our creation less than full justice. It is a matter of being true to ourselves, hidden talents and all.

#### **HOW DO WE DO WE HARVEST THIS BOUNTY?**

Those elements we do find on the surface in the form of precipitated salts can be concentrated by bacterial cultures. "Bioprocessing" would use a number of bioengineered bacteria that concentrate available elements differentially grown in nutrient vat cultures, their bodies then harvested for a benefi-

ciated, concentrated product, or for life nutrients, added to the food supply in one form or another, either indirectly via hydroponic solutions, or directly as dietary supplements.

We are optimistic about detecting nitrate salt signatures, and guardedly so about phosphates, potassium salts, and calcium. We are even more guarded about chances of detecting dissolved silica, minute traces of which are efficiently absorbed by diatoms and sponges. Indeed, trying to grow such creatures may be the only way to both detect and harvest available silica. A source of Silica means true glass, concrete, ceramics, and more. Such early era experimental aquaculture will be a top priority in efforts at further industrial diversification.

To be kept in mind, of course, is that there is no providential logic that guarantees that elements will be available in abundances proportionate to the relative quantities we would like to have. That is why we have to go to the Moon for

Helium-3, for example. It is why we have trade between nations and regions differently endowed. It is why those pioneers thrive who are resourceful enough to “make do” with what they find and who learn how to make happy substitutions, and why those pioneers fail who do not do so.

### **EUROPAN FRONTIER LIFESTYLES**

Lets muse a bit about the lifestyles of the resourceful and industrious on Europa’s frontier. More than a one town world! “New Woods Hole” in a thin but stable ice crust area at the site of the elevator exploration shaft to the ocean below – equipped with water-locks, of course “New Oceanside” station at the elevator terminus on the underside of the ice crust, possibly afloat in an honest-to-goodness-air-pressurized cave pocket excavated in the bottom of the ice crust handy to the shaft terminus.

“Cornu Copia” situated in the midst of the richest brine salt evaporate fields in a dark line area, chief industrial settlement and population center “Europaport” at the most favorable site for arrivals and departures from Europa orbit and from elsewhere in the Jovian system and beyond “Jove View” Resort at a near limb Joveside local where Jupiter seems to hang just over the horizon “Funlands” Chaotic Terrain Excursion and entertainment escape area “Captain Nemo’s” submarine oceanographic exploration ship and forward base for teleoperated robotic deep submersibles.

Giving European landscapes the human touch: Ice regeneration, melting rough ice and then allowing to refreeze flat and clear, perhaps under vapor escape retarding polyethylene film might be a useful side industry. One can imagine ice skating and ice dancing rinks, not just in the open vacuum but in pressurized shelters – or at least in man-made ice caves filled with diffracted blue light (those who have visited ice caves on Earth, such as the ones up Washington’s Mt. Ranier, will know what we mean!)

Man-made surface ice caves could also best house a growing ice sculpture collection. Since such sculptures would not melt, even were they to be exposed to full Europa-strength sunlight, their production would invite more carefully cultivated skills and more serious talent, than that already respectable craft we see on display in our northern cities during winter festivals.

And why not European hockey? Again either in pressure suits under the stars or in bluelight ice caves, or indoors without air masks. Regenerated snow could transform higher pressure ridges and ice fault scarps into ski hills, with magnesium ski jumps added for excitement.

Man-carved or molded ice “ramadas” would house tank farms for volatiles, warehouse various incoming goods awaiting delivery or manufactured items awaiting export, and in general for storage and routine “out-vac” tasks in a “lee” environment that shields from radiation and micrometeorite. Ice tunnels could carry surface highways through pressure ridges. Roadway surfaces at the cryogenic temperatures out on Europa’s surface would not be as slippery, no thin layer of lubricating water molecules would develop. Just the reverse: the surface could be micro-ridged to improve traction.

Better yet, magnesium-rails could support hovering MagLev coaches also made of magnesium, whisking people and goods between settlements. Someday, if abundance is no problem and public largess for the arts is high, we might even see man-sculpted magnesium “nunataks” (exposed mountain peaks) rising out of the ice sheet paralleling some tourist-trafficked MagLev route between major settlements. Those who have had the fortune to fly over southern Greenland will get the picture. These could be of thin sheet stock on this windless moon.

### **Pleasant cityscapes**

One can imagine Lexan™-thermopaned geodesic domes and vaults covering public spaces. Covered with transparent regenerated ice, they would offer radiation free softly blued sunlight – no need for sunglasses at this distance from the Sun where it shines with only a 25th the brilliance we are accustomed to in the Inner System “bright space” areas.

To avoid the china-syndrome-like problem of warm habitat structures inexorably melting their way into and through the ice crust, hard/soft styrofoam foundation sandwiches over smooth regenerated ice could provide an adequate thermal barrier. Whereon the Moon, regolith serves as both radiation and thermal shielding, on Europa this job might be left to ice and styrofoam or other foams respectively.

At least some waste heat from habitat space might be used to premelt brine crusted ice for use in the various processing industries

### **Change of scenery getaways**

The floating habitats in under-the-ice gas pockets that we first suggested in MMM #110, pp. 1 and 8–10, will be built as working outposts. But rooms and suites in a hotel module expansion unit would not likely go unrented. It would provide quite a change of scenery, even the chance to go outdoors with a medium weight jacket if the atmosphere pressurizing the pocket were a breathable oxygen/ nitrogen (or helium) mix. At such a complex, even swimming in the ocean itself would not be out of the question. But if you can't swim, or tire easily, it will be a long way down to the ocean floor an estimated 100 km or 60 miles down!



As relatively smooth as Europa is – highest and lowest elevations do not differ by more than a thousand meters, 3,000 feet over the entire Africa-sized globe, there are areas where the ice is especially fractured and jumbled in a chaotic way. Such a terrain might not be the easiest place to put an amusement park – or an “Old Frontier” type movie set – but mix the possibilities with imagination and you get an explosive mix.

And somewhere, both on the Jove-facing side and the averted side will be places aplenty for private ice wilderness retreats, licensed retreat houses, even monasteries.

### **Fuels and Power for all this?**

As on Mars and Venus, the elements necessary to produce methane for combusting with bottled oxygen are there. This can take care of non-railed surface transport and other uses.

At Jupiter's (i.e. Io's, Europa's, Ganymede's, and Callisto's) distance from the Sun solar power seems at first totally unrealistic. Some would tap the enormous power differentials in Jupiter's radiation belts for power, but that seems a more far distant prospect than another more familiar energy scheme, which to my knowledge, been totally overlooked. It would not be without its engineering challenges.

We speak of OTEC (Ocean Thermal Energy Conversion), i.e. tapping the considerable heat differences between European surface industry waste-heated water reservoirs and cold ocean waters – through the ice – using magnesium heat exchanger pipes if necessary to dam the shaft to prevent catastrophic blow-outs.

On Earth, at depths of approximately 1,000 m (3,300 ft) in certain areas of the ocean, such as the Gulf Stream, temperature differences are 15–22° C (27–40° F) exist. On Europa we are talking about a similar vertical distance scale and a similar, if not greater temperature range.

Warm surface water is drawn into an evaporator where, under low pressure, some of this water flashed into low-pressure steam and used in a steam turbine. Exhaust steam passes into a condenser, at a still lower pressure, and is condensed by cold water brought up from the ocean depths, producing power. Vast quantities of water must be handled, and the component parts of the plant must be very

large. For a 100,000-kW plant, the pipe bringing up the cold water might have a diameter of 30 m (100 ft). Maintaining the structural integrity of such a large pipe against the ice pressures working to collapse it might be no small design challenge. It would help efficiency, at the expense of greater complexity of working parts, to use ammonia, isobutane, or propane as the working fluid to be boiled by the warm surface water in order to power the turbine.

We have yet to work the engineering bugs out of an Earth-based OTEC system. Not a few have given up the challenge. But it will perhaps be the better part of a century before we are ready to add Europa to the list of human worlds. By then the economics of energy supply on Earth may have dictated that solutions to daunting engineering problems be found. The translation to a Europa system would then be easier.

Yet, while OTEC may be possible in theory, it would require a sizable installation that may be way too ambitious for a populace of a few thousands. Perhaps, even given the 25-fold diminution of the strength of sunshine at this distance out, solar power should not be dismissed. Everything else equal, that means that per design power output, a collector needs to be only five times larger side for side. Given improvements in efficiency and the use of concentrating mirrors, that should be no problem at all for surface based installations, as unworkable a solution it may be for weight-limited space craft in transit.

Europa's day/night cycle is 3.55 standard Earth days (85.2 hours) long, the same as its orbital period around Jupiter with which it is rotationally locked (as are most natural satellites). This period is less than an eighth as long as the Moon's dayspan/nightspace cycle or sunth, and thus it will be that much easier to store up power for Europa's much briefer night period (42.6 hrs long). If fuel cells are used, it will be important to redesign them to use locally made components as much as possible.

#### **REALITY CHECKS**

Because the ions that are present in terrestrial seawater exist in minute amounts, more than 200 m (about 660 ft) of salt water must evaporate to precipitate mineral deposits 1 m (3 ft) thick. But on Earth the area of surface water available for evaporation has been relatively great. On Europa, such thick deposits are most unlikely as the total surface area of liquid water exposed to evaporation at one time on average has been comparatively minuscule.

Salt harvesting on Europa would entail mobile equipment roaming far afield from scattered primary processing stations. This should not discourage the scenario above. We are talking about some few thousands of pioneers at best, not billions as on Earth

Just as important as industry will be food production and biosphere maintenance. Discovery of nitrate and phosphate salts will be encouraging. Not finding them will discourage any "Live Off the Ice" efforts. Calcium deposits on Earth are biogenic, that is derived from shells and bone of living creatures. If we find the signature of calcium that means it most likely that relatively advanced lifeforms evolved in the ocean. For industry, concrete could be possible if we find aluminosilicates too. Expect not!

Will we find meteorite strewn fields exposed on the glacial surface of Europa as we have in our own Antarctic? They could be a source of silicates and metals to round out local industry. Given the nature of the processes that have brought buried meteorites to the glacier surface and left them exposed on Earth, processes which certainly will have no counterpart on Europa, that is most unlikely. Most meteorites on Europa, if they migrate at all, are likely to work their way through the ice to fall to the ocean floor.

Can the industries we outlined be realized on a scale small enough to serve that market? That is a question for the chemical engineers and low-capacity modular factory engineers to decide. What will it pay to produce on Europa from local chemical feedstocks given this small market? Could Europeans export any surplus products and value added manufactures to neighbor outposts on Ganymede and Callisto where such surface brine salts are much less likely? If so, the potential market becomes as large as the human population of the entire Jovian mini-system.

#### **"MUS/CLE" FOR EUROPA & STOWAWAY IMPORTS**

Some parts of our scenario above will prove to be easier to implement than others. The nature of pioneering is learning to live with a different suite of resources than that to which one is accustomed. On Earth we are used to having it all. On Europa, we will have to make do with a much smaller list. We will have had to do likewise on the Moon – only the lunar list and the European list are going to be quite radically different from one another. In both cases, the deficiencies will determine and color the local material culture, and set the stage for vigorous trade. Both the lunar and European frontiers will create

demands that will inevitably open up new supply markets. Europa's needs will reinforce other reasons to establish human communities elsewhere in the Jovian system where needed materials are to be found. And where supply must be sought further afield, from the asteroids, from Mars, from the Moon, even from Earth itself, the economic equation will force three things:

- **Special industrial design options** to Earth-source only those components impossible to manufacture on Europa or on its sibling moons, designed to be easily mated to locally made components to make integral assembled items.
- **An interplanetary packaging materials industry** that will make packaging containers, dividers, and fill out of scavengable elements scarce if not impossible to come by locally. Packaging for the Moon would be rich in simple hydrocarbon thermoplastics and/or press-aggregates of missing major and minor nutrients for food production. Packaging for Europa could include silicon, calcium, aluminum (glass, ceramics, concrete, alloys) as well as missing nutrients. Such carefully designed co-import packaging provides a relatively cheap "stowaway" option.
- **Entrepreneurial opportunities** are created in filling missing needs, along with increased life-style and career options, and this keeps the Solarian human community in strong interactive contact.

## CONCLUSION

Here we sit on Earth, not yet returned to the Moon, farther than we'd like to be from launching the first human expedition to Mars. Yet we find ourselves talking about human futures on a much more distant if not less intriguing world – Europa. The ships that could take us there are not yet on the drawing boards – 3rd generation nuclear craft. We won't build the first generation prototype for some years to come. But dreams have power. After all, we are the "Ad Astra" people. We dare dream of being star folk. And as Europa-like worlds may be far more common than Earth-like ones, learning what we can do on Europa is clearly on our critical path to the Stars!

We have sketched quite an ambitious picture of what it might be like to live on Europa someday, grounded on too small a number of chemical tidbits. It may read to some that we would attempt to make a meat and potatoes meal out of mere seasonings stuffs. But many a delicious meal has been conjured up by chefs of outcast populations from ingredients looked down upon as garbage by the have-it-alls. It is a matter of attitude. To adapt an old saying for inclusion in the Space Pioneer's Bible, "Attitude, if not everything, beats the hell out of whatever's second!".

Dream with us. <MMM>

# Magnesium – Mg+2 Workhorse Metal for Europa

By Peter Kokh

## INTRODUCTION

Magnesium is the lightest of the engineering metals with a density of only 1.74 g/cm<sup>3</sup>. However, it is used as a structural metal in an alloyed form and most magnesium alloys have a density a bit higher.

Magnesium is a reactive metal and is usually found in nature as a carbonate or silicate oxide, often together with calcium. Because of its reactivity, production of the metal is very energy intensive.

World production of magnesium is small compared to the other structural metals such as steel and aluminium at only about 300,000 tons per year. Half of this is used directly in aluminium alloys to harden and strengthen them. [E.g. an aluminium can body has ~ 1.5% Mg, a cantop ~ 4.5% Mg.]

### Properties of pure Mg (partial list)

Atomic number 12	Atomic weight 24.31	Color silvery gray	Density 1.74 g/cm
Melts at 650°C, 1202°F		Boils at 1103°C, 2017°F	Valence states Mg <sup>2+</sup>

## ORES OF MAGNESIUM

Magnesium is the 6th most abundant element metal in Earth's crust, about 2.5% of its composition. However, its high chemical reactivity means that it is not found in the metallic state in nature.

Terrestrial sea water contains 0.13% Mg and some production facilities use this content for the production of the metal, after the precipitation of other sea salts to leave a magnesium-enriched brine.

(Many known magnesium silicate minerals are pure enough to warrant processing to metallic magnesium.)

The annual tonnage of magnesium oxide or magnesia used to make refractory items far exceeds the annual production of magnesium metal.

### **MAGNESIA & REFRACTORY PRODUCTS**

Magnesia[MgO]-Carbon brick is resin-bonded with a high proportion of fused grain magnesite [MgCO<sub>3</sub>]. It is used as refractory brick [maintaining shape and composition at extreme high temperatures] in furnaces and in other hyperthermal situations. A range of qualities is available by varying proportions of fused grain magnesite.

On Europa, where other ceramic options may be unavailable, fused magnesia might “make do” “well enough” for many other construction and manufacturing uses. Magnesia could also be useful in making glass if we find silicon compounds anywhere on Europa (surface-accumulated meteorites?) But Europa-made polycarbonate (Lexan™) is a proven substitute for glass window panes and eye wear.

### **SAND OR DIE CAST METAL COMPONENTS**

This is the area of strongest demand growth for magnesium, particularly in automotive and aviation markets driven by the legislated need to meet fuel economy standards. The aluminum industry has been more successful at achieving this substitution, due in part both to the better corrosion resistance of aluminum and the wider familiarity with its use.

However, in recent years magnesium has been gaining popularity as the chemical purity of the alloys has been improved, resulting in a significant increase in corrosion resistance. The excellent castability of the common magnesium-aluminum alloys now sees use in large structural components such as seat frames, steering wheels, support brackets and instrument panels can now be successfully cast, often replacing complex multi-piece steel stampings.

If we cannot make such corrosion resistant alloys on Europa, magnesium products could be reserved for external use in unpressurized environments or in structural sandwiches, bonded between unreactive layers of magnesia ceramic or plastic.

Vapor deposition of magnesium (e.g. on surfaces of fused magnesia brick or ceramic) is one of the ways available magnesium on Europa could be stretched further in producing pressurized shelters.

### **MAGNESIUM ALLOYS**

Magnesium products are made of alloys. The addition of other elements can strengthen and harden the metal and/or alter its chemical reactivity.

The common magnesium alloys incorporate aluminum (3-9%), zinc (0.7-1%), and manganese (0.13-0.2%). Zirconium, silicon, and rare earth elements are also sometimes used. Of these, we might hold out the most hope for finding manganese in European sea water. Assuming that other common magnesium alloying ingredients are unavailable on Europa, more work needs to be done in magnesium metallurgy to come up with (a) serviceable alloy(s).

Magnesium alloy development is a strong area for research at this time, with a view to improving the corrosion resistance and high temperature creep resistance of castings. This ongoing R&D offers an ideal climate for exploration of other “make-do” uses of magnesium, to substitute “wellenough” if iron (steel) and aluminum prove unavailable on Europa.

The problem with increased use of magnesium on Earth is that demand for magnesium die cast components is growing at about 15% per year and is scheduled to outstrip supply of available primary metal by the end of the decade. This keeps the price of magnesium metal high and is a disincentive for research and experimentation for additional uses.

### **MAGNESIUM & FOOD PRODUCTION**

Magnesium is an important nutrient for living tissues. Now we have to hope we find phosphate and nitrate salts on Europa as well. <MMM>

### **Europa: Facts of Interest**

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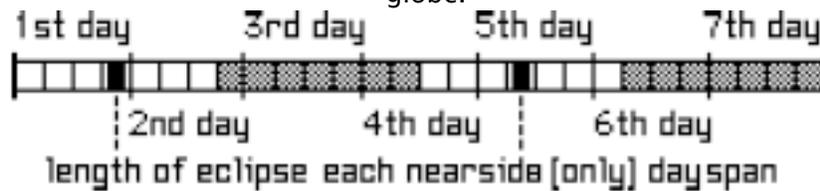
**SIZING UP EUROPA:** Europa is 3126 km (1942 mi) in diameter and its ice crust surface is 11.8 million square miles in area. That is some 81% of the Moon's surface, virtually the same area as Africa, and about 26% more surface than North America.

Europa contains lots of water and ice whereas the Moon is all rock and thus it is only 91% as dense as the Moon and has just 82% of the Moon's gravity level, or less than 1/7th (13.5%) the gravity of Earth. Anyone used to lunar gravity would be comfortable on Europa as well as on Io, Ganymede, Callisto, or Titan (111%, 87%, 75%, and 84% lunar gravity respectively) [\* To get the relative gravity, multiply the ratio in diameters by the ratio in densities].

**EUROPA WEATHER FORECAST:** Europa (& Jupiter) are on average 5.2 times Earth's distance from the Sun and so get only 1/27th as much light and heat from the Sun (inverse square of the distance). That's still more than 15,000 times as bright as the full moon on Earth – plenty of light to see what you are doing! The Sun would have an apparent diameter of only 6.1 minutes of arc compared to the 31.8 minute disk we see on Earth. The intensity of the light would be the same – there would be just less of it. Looking away from the Sun, you wouldn't need sunglasses. But helmet visors would still need to offer protection against glare. The surface temperature at noon is likely to be some – 200° F.

**EUROPA'S CALENDAR:** Europa orbits Jupiter once every 3.55 Earth days. By happy coincidence, two such periods are just over one week, 7.1 days or 7 d, 2 hr, 24 min. So if European pioneers wanted to keep the hour, minute, and second for the convenience of scientific calculation, they could use digital clocks which would reset after 24:20:34 h/m/s instead of 23:59:59. Each European clock day would be only 20 min. 34 sec. longer than the 24 hr standard we enjoy. The beauty of this is that no matter where one makes camp on Europa, every 7th clock day, the lighting phases repeat exactly (sunrise, noon, sunset, etc.). That would make planning ahead a snap for the pioneers.

To make this digital timing solution work, there would be but one common time zone for the whole globe.



Typical weekly dayspan/nightspan lighting pattern. The day and night spans are each 42.6 hrs long.

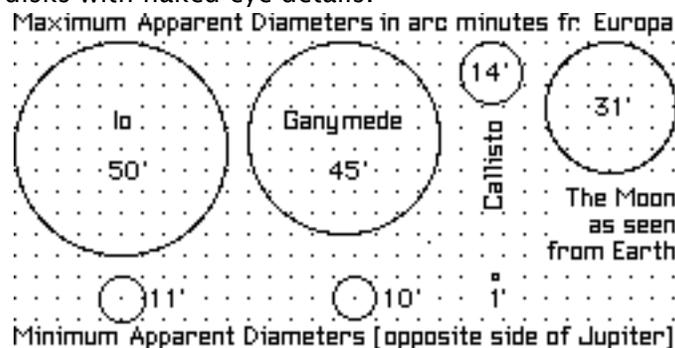
There would be 51.44 European Weeks (EW) to a standard Earth year, and 610 EW per Jovian year.

**EUROPA'S SKY SHOW:** The black airless skies of Europa host one of the most brilliant shows in the Solar System. But to take in the entire "Dance of the Worlds" one has to have a seat on the 50-yard line so to speak, i.e. along the Jovian nearside/farside limb. A polar perch (N or S) offers the best views, with all choreography at, and parallel to, the crisp horizon.

Europa orbits Jupiter at a distance of 671,000 km or 417,000 miles out (75% more than the Moon's average distance from Earth). But Jupiter is 11 times the diameter of Earth, so it will appear 6+ times as wide as Earth's 2° globe seen from the Moon. Jupiter will be a brilliant multihued ball in the sky some 12° across, filling 40 times as much sky as Full Earth from the Moon, 550 times as much sky as Full Moon from Earth. But at Europa's poles only its northern or southern hemisphere would be above the horizon.

For about 2 3/4 hours every 3.55 day orbit, Jupiter's bulk eclipses the Sun (as seen from Jovian nearside only) as Europa orbits swiftly through Jupiter's shadow cone at 30,750 mph (13.74 kps). The local dayspan time (morning, midday, afternoon, etc.) of the eclipses depends on the E-W longitude.

At their closest approach, Io (between Jupiter and Europa), Ganymede and Callisto (both to far side) present respectable disks with naked eye details.



While the Moon is always appears about the same size as seen from Earth, Europa's sibling moons revolve not about it, but about Jupiter, and that takes them to quite some distance when they are on the opposite side of Jupiter, as shown above.

Of course, they will be eclipsed by Jupiter for short periods. The best views of Jupiter and Io are 10° or more into the nearside from the limb and poles. And the best views of Ganymede and Callisto will be from at least a few degrees into farside. The limbs, and especially the poles, are the only and best points (respectively) to see them all, and the best points for a European Jovian System Observatory complex.

Closest approaches of Io to Europa occur every 3.53 days; of Ganymede to Europa every 7.04 days; of Callisto to Europa every 4.51 days. Their phases (new, crescent, half, full etc.) will vary. These "synodic periods" are the same as the intervals between launch/arrival windows to and from these sibling moons. The Jovian mini-system will be an interesting place to relocate! <MMM>



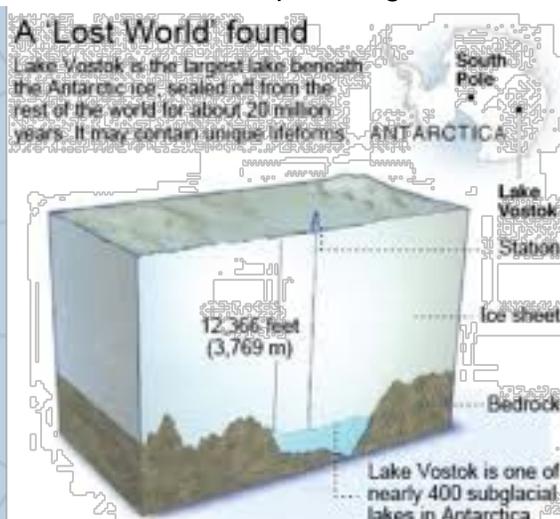
## An Antarctic Europa Mission Training Camp?

By Peter Kokh, from various sources

**Vostok Antarctic Station** (Russian), early 1996, at 78° S, 107° E [below Singapore], about 800 miles N of the South Pole and a similar distance W of McMurdo.

A three-nation team had been drilling into the ice here for ice-core samples when echo-sounders located a lake of liquid water another 300 meters [620 ft.] further down. The drill was stopped. At that point, they were 3,350 meters [11,040 ft.] down, and had retrieved ice cores 420,000 years old looking for data on the climate record of that time.

The lake's discovery came just in time to prevent possible catastrophic damage, giving an international scientific team time to work out how to examine the water without polluting it. The existence of the lake was confirmed in reports to the 20th Antarctic Treaty meeting in Utrecht in May '96.

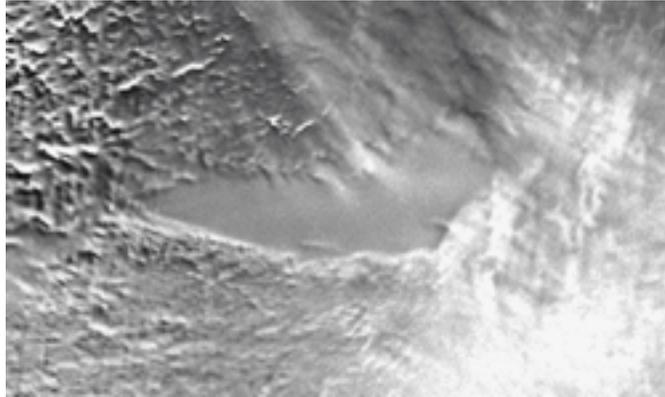


Called "Lake Vostok, the sub-glacial lake is covered by 3,700 meters [11,500 feet or 2.1 miles] of ice at the coldest spot on Earth, nearby the South Magnetic Pole, deep in the interior of Antarctica. It lies in a basin area 230 kilometers by 50 kilometers [143 mi. x 31 mi., the size of Lake Ontario ], averages 400 feet deep, with no air space between it and the ice above. It is the largest under-ice lake so far discovered. It may have lain undisturbed for at least 500,000 years. During all that time, any mi-

crobes and simple plants living in it would have been isolated from external biological and environmental contact. This is of considerable international interest.

It is not yet known how the water could lie unfrozen beneath such an ice mass. It may have been warmed by geothermal heat from below, or perhaps the ice pressure had formed the water.

Scientists have to figure out how to sample Lake Vostok without contaminating it. Russia warned that random unprepared penetration of the lake could be catastrophic. Two scenarios to be avoided are (a) a blow-back that might send the pressurized water up the drill shaft like an oil strike, and (b) man-made materials, e.g. drilling fluid, spoiling the sampling of the lake. Fortunately, there are several smaller sub-glacial lakes to experiment upon, so that scientists can be confident they know what they are doing when they penetrate into the biggest, and probably the oldest such lake.



The flat space in the ice betrays the shape of the lake deep below

Back to the present: an unprecedented expedition to search for ancient life in a lake deep beneath the ice sheet near Russia's Vostok research station, is being planned. A sterile probe ["cryobot"] will penetrate the more than two miles of ice that has sealed Lake Vostok since early in the era of hominid evolution. American, British, and Russian scientists will take extreme precautions to ensure that the drill doesn't contaminate the lake's pristine waters. Recent satellite data has helped to assess Lake Vostok's boundaries and chemical composition.

The drilling should be completed in about two years. Then a NASA-designed probe, the Hydrobot, released by the Cryobot drilling probe upon reaching the open water, will search the lake bed for any forms of life that may still survive in this dark, hostile environment. The pressure of the ice, and/or subterranean vents, may produce very warm conditions at that depth.

Scientists drilling deep under the oceans have discovered microbes that live off underground mineral deposits. And investigations of subterranean caves have found thriving communities of creatures that have survived thousands of years in isolation.

NASA hopes this activity will serve as a training ground for similar drilling experiments through the ice of Jupiter's moon Europa. A mission with a similar hydrobot could be undertaken within the next few decades to search for life beyond Earth.

That we should find the ideal place to simulate future missions to Europa in Antarctica should come as no surprise. Antarctica's unique Dry Valleys in Victoria Land, not far from the principal U.S. Antarctic complex at McMurdo Sound, offers the best available verisimilitude of conditions on Mars (extreme dry cold) for testing equipment and procedures for future robotic or manned missions to Mars. Without such ideally suited, and relatively handy, "Spring Training Camps", we would not be able to develop real confidence for future missions.

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## [Possible Future Europa Missions] **Europa Orbiter Mission**

As part of NASA's Outer Planets/Solar Probe Project, preliminary development has begun on a mission to send a spacecraft to Europa to measure the thickness of the surface ice and to detect an underlying liquid ocean if it exists. Using an instrument called a radar sounder to bounce radio waves through the ice, the Europa Orbiter science craft would be able to detect an ice-water interface, perhaps as little as 1 km below the surface.

Other instruments would reveal details of the surface and interior processes. This mission would be a precursor mission to sending "hydrobots" or remote controlled submarines that could melt through the ice and explore the undersea realm.

Category 1A objectives are the minimum set of science investigations that would support an exploration mission. These objectives are determined by the international science community in the early planning stages of a mission. The Europa Orbiter Science Definition Team was formed in '98 to select Category 1A objectives. They are:

- Determine presence/absence of subsurface ocean.
- Characterize the 3-dimensional distribution of subsurface liquid water and its overlying ice layers.
- Understand the formation of surface features, including sites of recent or current activity, and identify candidate landing sites for future lander missions.

## Europa Ocean Observer

### Science Objectives

- Verify presence of liquid layer
- Measure ice thickness and interior properties
- Image surface features

### Mission Description

- Delta II Launch
- Direct to Jupiter in 2.5 yr
- 10 Europa fly-bys in 1.0 year
- Possibly combined with Ganymede/Callisto fly-by S/C or Io Orbiter

### Measurement Strategy

- Radar sounding for ice thickness
- Tracking for gravity field
- Spectral imaging, angular resolution for global and local features
- Scatterometer by telecom for surface roughness

### Technologies

- Low Mass Propulsion
- Radiation tolerant components
- Efficient, lightweight solar power generation at **Jupiter** distance

## Europa Lander Network

### Technology

- High performance, low mass propulsion
- Radiation tolerant components
- Efficient, lightweight solar power generation at Jupiter distance
- Filtered seismometer for low S/N
- Miniature in-situ instruments

### Science Objectives

- Measure ice thickness
- Tomography of layers
- Chemical analysis of surface

### Mission Description

- Minimum of 3 landers through precursor mission could use just 1 for seismicity measurements
- Semi-hard landing with caging
- Some penetration of ice surface (for rad protection and seismic improvement)
- Precursor mission

### Measurement Strategy

- Seismic vibration from natural / induced collision
- Analysis of organics on surface (GCMS)

## IcePic: Europa Ocean Explorer



[ Written Sept 1998 – Updated Oct. 2012 ]

**Icepic:** the Europa Ocean Explorer Project (was) an effort to generate a design for a future mission to Europa. The probe's mission would explore the liquid water ocean that surface evidence suggests exists beneath Europa's surface. Larry Klaes' article in the April '98 issue of SpaceViews kicked off this effort.

The Europa **I**ce **P**enetrator **I**nternet **C**ommittee (**IcePIC**), is organizing the project on a Web site and has a mailing list. These collaborative tools bring together project participants from around the world in a variety of disciplines. (Web: team no longer exists)

This discussion (was) very active. You (could) expect messages on a daily basis. MMM editor Peter Kokh (was) one of the participants and subscribers (included) plain interested wanna-be-involveds as well as heavyweights with varied relevant expertise.

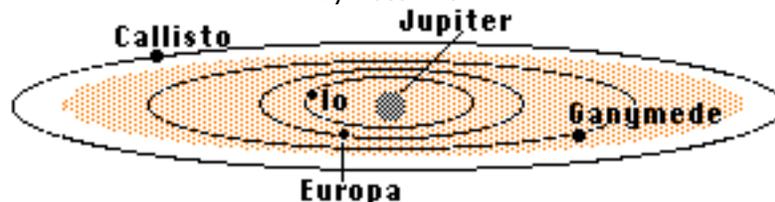
Discussion (covered) both technical and nontechnical questions and issues. The name IcePic was the result of about a week of spirited dialogue with many great suggestions from several contributors. Agreement was unanimous on the final suggestion. People at JPL and elsewhere (monitored) this activity for good suggestions as well as problem identification.

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## MMM #119 October 1998

# Braving Jupiter's Rad<sup>⚡</sup>at<sup>⚡</sup>on Belts Callisto's Place in the Sun

By Peter Kokh



Only Callisto orbits outside Jupiter's Radiation Belt

There would seem to be a major problem with the idea of planning human expeditions to Europa and the establishment of outposts there. Of the four great Galilean moons, only more distant Callisto lies safely beyond the reach of Jupiter's deadly radiation belts. This has led several writers to predict that humans would be able to land on Callisto alone, and not on Ganymede, Europa, or Io, all further in. The amount of protection we would need would be quite a bit greater than that routinely needed against cosmic rays and random solar flares in general. Extra shielding in the traditional form of

water, cargo, lead or other mass would entail an unwelcome fuel penalty just to take it along for use inwards of Callisto. Electromagnetic shielding is an alternative that seems to us a long ways from coming off the drawing boards. Further, the apparatus to generate the needed field might be no less massive.



<< Jupiter: LR: Io Europa Ganymede Callisto

### CALLISTO JUNCTION

Here's our trial balloon work-around. Ships from Earth, Moon, Mars, or Ceres could pull into orbit around Callisto first, there to be "jacketed" with "extra" water derived from Callisto's surface. Thus the first Jovian System installations would have to be established on **Callisto** and in Callisto orbit. Let's call them **Callisto Springs** and **Callisto Junction** respectively. From Callisto orbit, radiation super-hardened ships would then proceed to any of the inner moons. They would need extra fuel for lugging around this extra shielding weight only for this last 3-6 day\* leg of the long journey from Earth, and for this they could also be refueled with liquid hydrogen and liquid oxygen produced from Callistan ice.

5.80 days Callisto to Ganymede

**4.66 days Callisto to Europa**

3.77 days Callisto to Io [Trip times reflect needed DeltaV not distance]

The "jacket" to be filled with Callistan water could be an integral part of the ship, brought along from Earth empty i.e. uninflated – e.g. a Kevlar bag cradling the crew compartment and any sensitive cargo. Eventually, such jackets could be manufactured on Callisto itself, using local hydrogen, carbon, oxygen, and nitrogen to produce the Kevlar fabric.

Prior to this, it is conceivable that the position of getting Callistan water into Callisto orbit to a waiting transfer tank could be managed entirely by robotic means. This would make sense at the outset when traffic is just beginning and crewed ships from Earth are few and far between. The first crewed ship wouldn't leave the Inner System for Callisto Junction until a first precursor robotic mission had succeeded in storing water there.

As usual, solve one problem and you create another. Getting to a parking orbit around Callisto without plunging into the radiation belt area to shed momentum via a close Jupiter flyby (recall the "ballute" used in skimming the upper reaches of Jupiter's atmosphere in Arthur C. Clarke's movie 2010) will be tricky. We welcome your suggestions.

### CALLISTO-EUROPA TRADE INTERDEPENDENCE

Callisto, too, has an ice crust, much thicker than Europa's and much dirtier with rocky material which means alumino-silicates, calcium, iron. Those things which a Europa colony (colony used here as a global complex of pioneer settlements) cannot produce for itself from the brine salts evaporated on its surface, a Callisto industry should be able to supply. Sourcing as much as possible within the Jovian system will be top priority, with all Jovian outposts striving for integral interdependence. The logistics of supply from Earth is simply too strained.

In exchange, Europa can supply Callisto with plastics, fibers, graphite items, magnesium products, Lexan, and fiber/ resin composites, thus easing the burden on the Callistan settlements and allowing them to concentrate on glass, ceramics, alloys, etc.

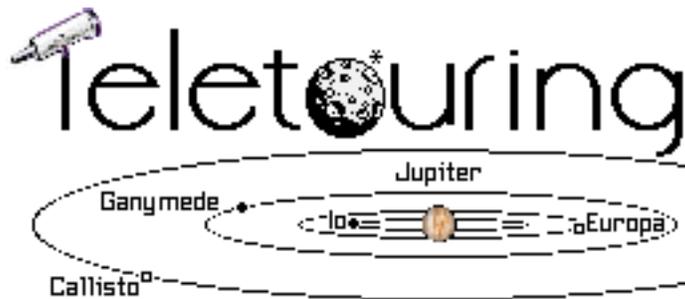
### The Dope on CALLISTO

Diameter: 4820 km (2996 mi., cf. Mercury, 3031 mi.) Gravity: 12.3% of Earth's; 84% of Moon's  
 Surface Area: 28,862,000 sq. mi. (cf. Africa + Asia) (cf. twice Moon's surface of 14,657,000 sq. mi.)  
 Distance from Jupiter: 1,884,000 km; 1,171,000 mi. Jupiter's Apparent Diameter 2° (cf. Earth from Moon)  
 Orbital Period (Dayspan/Nightsan) 16.68 days= 8.34 days of daylight, night each

Calendar Option: Weeks 8.34 d long divided into 8 calendar or clock days of 25 hrs. 1.2 min each using digital watches that reset after 25:01:12 44 weeks or 22 periods = 367 day “Versaries”

### Meanwhile, on EUROPA’s “hot” icy surface

Ice, probably regenerated (melted and then refrozen for fracture-free translucency), can be used to “canopy” highways and Maglev lines, providing shielding as well as the soft ambient blue light seen in ice caves on Earth. Regenerated ice could also be used to carapace surface vehicles individually. The clear ice would be used to shield geodesic domes and vaults made of Lexan thermopanels set in magnesium framing, to shield and brighten habitat spaces. No problem! Anything is threatening until dealing with it becomes second nature. That has been the experience of pioneers from time immemorial. And no doubt, we will find both the motives and the means to deal with life on Ganymede – and even sulfurous Io – as well. <MMM>



## Backyard & Armchair Teletouring of the Jovian System

By Peter Kokh [\* Moon Icon by Simon Rowland] [Jupiter and satellite orbits to same scale]



### SEEING JUPITER’S GREAT MOONS FOR YOURSELF

To see **Io**, **Europa**, **Ganymede**, and **Callisto** with your very own eyes, all you need is a pair of good binoculars or a small telescope. They are easy to pick out – Galileo saw them right away when he aimed the first crude telescope at Jupiter in 1610, and the big four have been part of the “known universe” for 388 years now. Of course they look just like bright stars, too far away and too small to show “disks.”

The current copy of either Sky & Telescope or Astronomy Magazines (at your library) will have the night by night positions relative to Jupiter of all 4 Galilean Satellite for the next month. (1= Io, 2= Europa, 3 = Ganymede, 4 =Callisto, J or O=Jupiter) e.g. 43210, 32014, 41032, 20143, lined up in a row with Jupiter's equatorial cloud belt (easy to see).

No scope? Visit your local astronomy club on its monthly public viewing night for a preview. This first sight of the Galilean moons may satisfy you. If not, join the club and use some of their instruments regular. Club members will be happy to help you decide what kind of first telescope to buy for using in your own backyard on your own schedule.

Jupiter is the brightest planet in the night sky after Venus (an unmistakably bright beacon visible only just after dark/just before dawn) & Mars (brighter only when near opposition and always easy to tell apart from Jupiter by its distinctive reddish orange color). Jupiter is easy to pick out from the field of stars as with its unblinking yellow-white light, it is far brighter than the brightest of them. (Note: It is also fairly easy to pick out Saturn with the naked eye, and its major moon Titan through a small scope.) Jupiter and its moons are 5.2 times as far from the Sun as Earth. Their closest distance from us is 366 million miles, the greatest 552 million. The lag in electronic conversation would vary between 33 and 49 m. Hohmann transfer orbit transit time to Jupiter is 2.73 years, with windows every 13.1 months.###

### GOING BEYOND THE TELESCOPE & THE TABLES

To imagine yourself in your own personal rocket ship flitting to and fro between the Galilean moons, use these simple formula to determine launch window frequency, total transit times etc.

- **Surface Area** =  $4p(D/2)^2$  (square miles or km)
- **Gravity:** relative gravity = the ratio in diameters times the ratio in densities
- **Launch Window Frequency** (this is the same as the **Synodic Period**, the length of time it takes an inner body to lap or overtake an outer one):

$$\text{in days} = 360/[360/PdI - 360/PdO]$$

PdI = orbital Period in days of the Inner body      PdO = orbital Period in days of the Outer body

### Hohmann Transfer Orbit Trip Times:

Add the distances of the two bodies from Jupiter and divide by two = dh (distance [semi major axis] hohmann orbit). Plug this into the formula "distance ratio cubed = period ratio squared" [ $d^3 = p^2$ ]. In our example, add 671,000 km and 1,071,000 km = 1,742,000 km, and divide by 2 = 871,000 km, the semi major axis of the Hohmann transfer orbit between Ganymede and Europa. This is 1.298 times the distance from Jupiter of Europa. Cube that (=2.187) and take the square root (=1.479) to get the ratio of the Hohmann orbit period to Europa's period (3.55 days) = 5.25 days and take half of that because you are getting off when you get to your destination and not making a return trip or full orbit). The result, 2.625 days, is the hohmann transfer time between Ganymede and Europa. (cf. fast crude estimate of 2.8 days).

### BASIC TABLES FOR THE GALILEAN MOONS

**D** = diameter km [mi]; **d** = density (spec. grav. H<sub>2</sub>O = 1)

**md** = mean distance fr. Jupiter in thousands of km [620 miles]

**p** = orbital period in days;

**E\*** = escape velocity km/sec; **O\*** = orbital velocity km/sec

	Io	Europa	Ganymede	Callisto
D	3630	3126	5276	4820
[D]	2255	1942	3278	2996
d	3.55	3.04	1.95	1.8
md	422	671	1071	1884
[md]	262	417	675	1171
{md}	5.914	9.404	15.01	26.05
p	1.77	3.55	7.16	16.68
E*	2.4	2.02	2.8	2.4
O*	1.69	1.46	1.98	1.63

### INTER-MOON SURFACE TO SURFACE DELTA V \*

km/sec	I	II	III	IV	
I		5.7	8.1	9.4	
II			5.7	6.8	
III				5.7	
IV					[*Pournelle]

# The “Maculas” of Europa

By Peter Kokh

A small number of “large round dark spots,” including three larger than 20 km or 12 miles in diameter, show up on Voyager II and Galileo photos of Europa. Given their distinctiveness in admittedly exaggerated false color photo-maps, we’ve begun to name them, e.g. Tyre Macula, Thrace Macula, and Thera Macula.

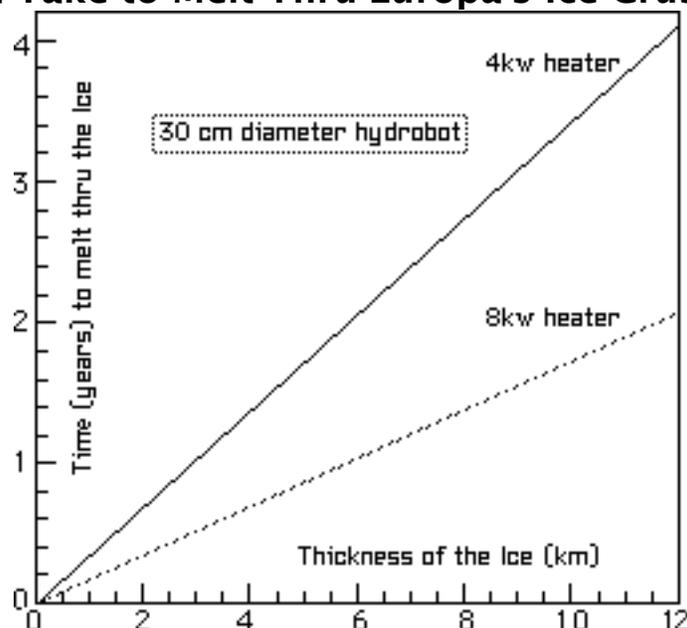
Our guess is that these features are relic impact points of sizable asteroids that have crashed through the ice crust, the dark deposits representing evaporated sea brine salts.

Thera Macula below



- (1) these “Maculas” may be the richest “salt mining” or “brine harvesting” regions on Europa, with the thickest deposits. Promising sites for industry.
- (2) if the impacting asteroids were rubble piles, they may have reassembled in rubble heaps on the ocean floor. But if impacting asteroids had sufficient integrity, their speed may have been slowed in the ocean enough for them to “sink” intact to the ocean bottom an estimated 100 km or 60 miles below. The angle of the asteroid impact would make little difference as the resistance of the ocean water would soon neutralize any residual lateral motion. The impact relics should be recognizable on the ocean floor directly below the Macula. Depending upon the makeup of the impacting body, they may constitute a future mineral resource MMM

## How Long Will it Take to Melt Thru Europa’s Ice Crust into its Ocean?

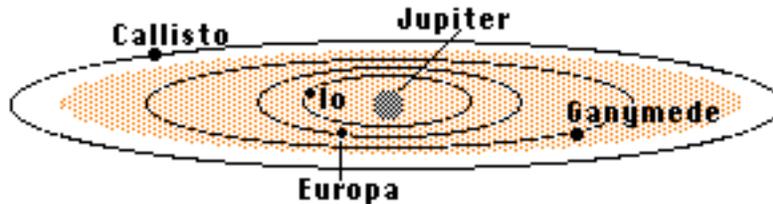


## MMM #120 – November 1998

### Europa: Facts of Interest

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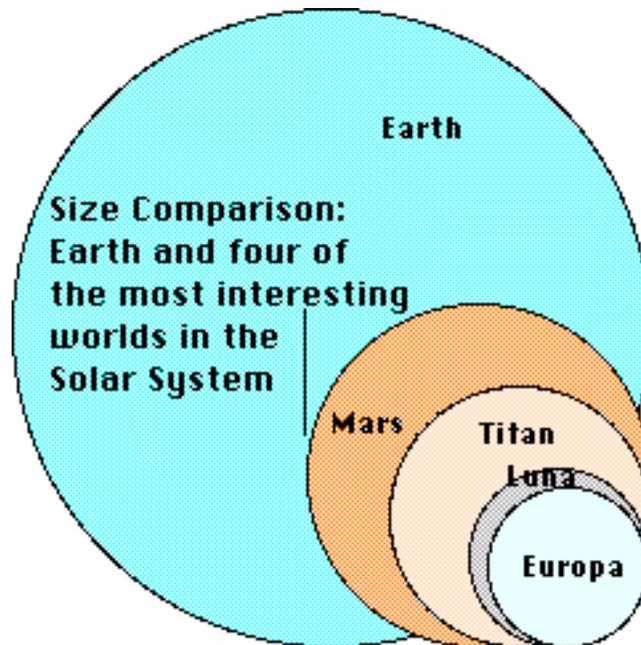
#### Just the Facts:



Only Callisto orbits outside Jupiter's Radiation Belt

- Europa orbits 416,200 miles out from Jupiter
- (The Moon orbits 238,500 miles out from Earth)

**SIZING UP EUROPA:** Europa is 3126 km (1942 mi) in diameter and its ice crust surface is 11.8 million square miles in area. That is some 81% of the Moon's surface, virtually the same area as Africa, and about 26% more surface than North America.



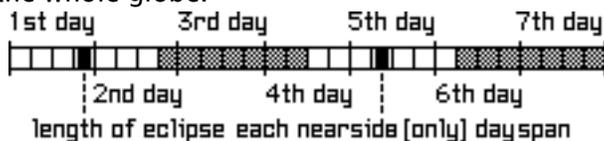
Europa contains lots of water and ice whereas the Moon is all rock and thus it is only 91% as dense as the Moon and has just 82% of the Moon's gravity level, or less than 1/7th (13.5%) the gravity of Earth. Anyone used to lunar gravity would be comfortable on Europa as well as on Io, Ganymede, Callisto, or Titan (111%, 87%, 75%, and 84% lunar gravity respectively) [\* To get the relative gravity, multiply the ratio in diameters by the ratio in densities].

#### EUROPA WEATHER FORECAST:

Europa (& Jupiter) are on average 5.2 times Earth's distance from the Sun and so get only 1/27th as much light and heat from the Sun (inverse square of the distance). That's still more than 15,000 times as bright as the full moon on Earth – plenty of light to see what you are doing! The Sun would have an apparent diameter of only 6.1 minutes of arc compared to the 31.8 minute disk we see on Earth. The intensity of the light would be the same – there would be just less of it. Looking away from the Sun, you wouldn't need sunglasses. But helmet visors would still need to offer protection against glare. The surface temperature at noon is likely to be some 200° below zero Fahrenheit.

**EUROPA'S CALENDAR:**

Europa orbits Jupiter once every 3.55 Earth days. By happy coincidence, two such periods are just over one week, 7.1 days or 7 d, 2 hr, 24 min. So if European pioneers wanted to keep the hour, minute, and second for the convenience of scientific calculation, they could use digital clocks which would reset after 24:20:34 h/m/s instead of 23:59:59. Each European clock day would be only 20 min. 34 sec. longer than the 24 hr standard we enjoy. The beauty of this is that no matter where one makes camp on Europa, every 7th clock day, the lighting phases repeat exactly (sunrise, noon, sunset, etc.). That'd make planning ahead a snap for the pioneers. To make this digital timing solution work, there'd be but one common time zone for the whole globe.



Typical weekly dayspan/nightspace lighting pattern. The day and night spans are each 42.6 hrs long. There would be 51.44 European Weeks (EW) to a standard Earth year, and 610 EW per Jovian year.

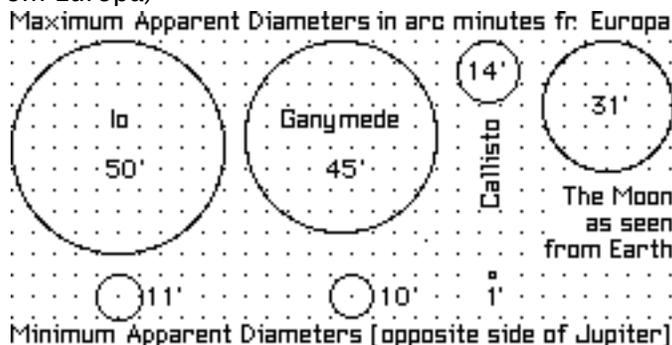
**EUROPA'S SKY SHOW:**

The black airless skies of Europa host one of the most brilliant shows in the Solar System. But to take in the entire "Dance of the Worlds" one has to have a seat on the 50-yard line so to speak, i.e. along the Jovian nearside/farside limb. A polar perch (N or S) offers the best views, with all choreography at, and parallel to, the crisp horizon.

Europa orbits Jupiter at a distance of 671,000 km or 417,000 miles out (75% more than the Moon's average distance from Earth). But Jupiter is 11 times the diameter of Earth, so it will appear 6+ times as wide as Earth's 2° globe seen from the Moon. Jupiter will be a brilliant multi-hued ball in the sky some 12° across, filling 40 times as much sky as Full Earth from the Moon, 550 times as much sky as Full Moon from Earth. But at Europa's poles only its northern or southern hemisphere would be above the horizon.

For about 2 3/4 hours every 3.55 day orbit, Jupiter's bulk eclipses the Sun (as seen from Jovian nearside only) as Europa orbits swiftly through Jupiter's shadow cone at 30,750 mph (13.74 kps). The local dayspan time (morning, midday, afternoon, etc.) of the eclipses depends on the E-W longitude.

At their closest approach, Io (on the same side of Jupiter as Europa), Ganymede and Callisto (both to far side) present respectable disks with naked eye details. At their farthest (when they are on the other side of Jupiter from Europa)



While the Moon is always appears about the same size as seen from Earth, Europa's sibling moons revolve not about it, but about Jupiter, and that takes them to quite some distance when they are on the opposite side of Jupiter, as shown above. Of course, they will be eclipsed by Jupiter for short periods.

The best views of Jupiter and Io are 10° or more into the nearside from the limb and poles. And the best views of Ganymede and Callisto will be from at least a few degrees into farside. The limbs, and especially the poles, are the only and best points (respectively) to see them all, and the best points for a European Jovian System Observatory complex.

Closest approaches of Io to Europa occur every 3.53 days; of Ganymede to Europa every 7.04 days; of Callisto to Europa every 4.51 days. Their phases (new, crescent, half, full etc.) will vary. These

"synodic periods" are the same as the intervals between launch/arrival windows to and from these sibling moons. The Jovian mini-system will be an interesting place to relocate!

### Other Europa Quick-Look Statistics

- Discovery: Jan 7, 1610 by Galileo Galilei
- Mass (Earth = 1) 0.0083021
- Mass (Moon = 1) 0.67
- Surface Gravity (Earth = 1): 0.135
- Mean Distance from Jupiter: 670,900 km; 9.5 Jupiter radii
- Mean Distance from Sun: 5.203 AU (times Earth's distance from the Sun)
- Orbital period: 3.551181 days = Rotational period: 3.551181 days
- Density 3.04 gm/cm<sup>3</sup>
- Orbit Eccentricity: 0.009
- Orbit Inclination: 0.470°
- Orbit Speed: 13.74 km/sec
- Escape velocity: 2.02 km/sec
- Visual Albedo: 0.64 (The Moon's albedo is about 0.14, much darker)
- Surface Composition: Water Ice with evaporated sea salts

Europa is the smoothest object in the solar system with a mostly flat surface, nothing exceeding 1 km in height. The surface of Europa is also very bright, about 5 times brighter than our Moon.

There are two types of ice crust terrains. One type is mottled, brown or gray in color and consists mainly small hills. The other type of terrain consists of large smooth plains criss-crossed with a large number of cracks, some curved and some straight. Some of these cracks extends for thousands of kilometers. The cracked surface appears remarkably similar to that of the Arctic Ocean on Earth. The ice / water crust may be no thicker than 150 km. There are very few large craters observed on Europa, indicating a young surface, no more than 30 million years old.

Europa's inner core is suspected to be iron-sulfur, similar to that of Io. Since Europa has a lower density than Io (3.01 gm/cm<sup>3</sup>), the size of the inner core is expected to be smaller than Io's. <MMM>

## Magnesium – Workhorse Metal for Europa

By Peter Kokh

### INTRODUCTION

- Magnesium is the lightest of the engineering metals with a density of only 1.74 g/cm<sup>3</sup>. However, it is used as a structural metal in an alloyed form and most magnesium alloys have a density a bit higher.
- Magnesium is a reactive metal and is usually found in nature as a carbonate or silicate oxide, often together with calcium. Because of its reactivity, production of the metal is very energy intensive.
- World production of magnesium is small compared to the other structural metals such as steel and aluminum at only about 300,000 tons per year. Half of this is used directly in aluminum alloys to harden and strengthen them. [E.g. an aluminum can body has about 1.5% Mg, a can top about 4.5% Mg.]

### PROPERTIES OF PURE MG (PARTIAL LIST)

- Atomic number 12
- Atomic weight 24.31
- Color silvery gray
- Density 1.74 g/cm
- Melts at 650°C, 1202°F
- Boils at 1103°C, 2017°F
- Valence states Mg<sup>2+</sup>

### ORES OF MAGNESIUM

- Magnesium is the 6th most abundant element metal in Earth's crust, about 2.5% of its composition. However, its high chemical reactivity means that it is not found in the metallic state in nature.

- Terrestrial sea water contains 0.13% Mg and some production facilities use this content for the production of the metal, after the precipitation of other sea salts to leave a magnesium-enriched brine. (Many known magnesium silicate minerals are pure enough to warrant processing to metallic magnesium.)
- The annual tonnage of magnesium oxide or magnesia used to make refractory items far exceeds the annual production of magnesium metal.

### **MAGNESIA & REFRACTORY PRODUCTS**

Magnesia[MgO]-Carbon brick is resin-bonded with a high proportion of fused grain magnesite [MgCO<sub>3</sub>]. It is used as refractory brick [maintaining shape and composition at extreme high temperatures] in furnaces and in other hyperthermal situations. A range of qualities is available by varying proportions of fused grain magnesite.

On Europa, where other ceramic options may be unavailable, fused magnesia might "make do" "well enough" for many other construction and manufacturing uses. Magnesia could also be useful in making glass if we find silicon compounds anywhere on Europa (surface-accumulated meteorites?) But Europa-made polycarbonate (Lexan™) is a proven substitute for glass window panes and eyewear.

### **SAND OR DIE CAST METAL COMPONENTS**

This is the area of strongest demand growth for magnesium, particularly in automotive and aviation markets driven by the legislated need to meet fuel economy standards. The aluminum industry has been more successful at achieving this substitution, due in part both to the better corrosion resistance of aluminum and the wider familiarity with its use.

However, in recent years magnesium has been gaining popularity as the chemical purity of the alloys has been improved, resulting in a significant increase in corrosion resistance. The excellent castability of the common magnesium-aluminum alloys now sees use in large structural components such as seat frames, steering wheels, support brackets and instrument panels can now be successfully cast, often replacing complex multi-piece steel stampings.

If we cannot make such corrosion resistant alloys on Europa, magnesium products could be reserved for external use in unpressurized environments or in structural sandwiches, bonded between unreactive layers of magnesia ceramic or plastic.

Vapor deposition of magnesium (e.g. on surfaces of fused magnesia brick or ceramic) is one of the ways available magnesium on Europa could be stretched further in producing pressurized shelters.

### **MAGNESIUM ALLOYS**

Magnesium products are made of alloys. The addition of other elements can strengthen and harden the metal and/or alter its chemical reactivity.

The common magnesium alloys incorporate aluminum (3-9%), zinc (0.7-1%), and manganese (0.13-0.2%). Zirconium, silicon, and rare earth elements are also sometimes used. Of these, we might hold out the most hope for finding manganese in European sea water. Assuming that other common magnesium alloying ingredients are unavailable on Europa, more work needs to be done in magnesium metallurgy to come up with (a) serviceable alloy(s).

Magnesium alloy development is a strong area for research at this time, with a view to improving the corrosion resistance and high temperature creep resistance of castings. This ongoing R&D offers an ideal climate for exploration of other "make-do" uses of magnesium, to substitute "well-enough" if iron (steel) and aluminum prove unavailable on Europa.

The problem with increased use of magnesium on Earth is that demand for magnesium die cast components is growing at about 15% per year and is scheduled to outstrip supply of available primary metal by the end of the decade. This keeps the price of magnesium metal high and is a disincentive for research and experimentation for additional uses.

### **MAGNESIUM & FOOD PRODUCTION**

Magnesium is an important nutrient for living tissues. Now we have to hope we find phosphate and nitrate salts on Europa as well. <MMM>

## Venus: Balloons & Aerobots

Bruce Moomaw <[moomaw@jps.net](mailto:moomaw@jps.net)> writes:

For [continued exploration of Venus], there has been [quite a bit] of work on exploring with what is called phase change variable-buoyancy balloons. Let's suppose we have a Venus balloon floating along in the clouds filled with two substances: a simple buoyant gas (helium), and a liquid that boils into gas above a certain temperature, increasing the balloon's buoyancy (plain water). As the balloon sinks to the hotter levels of Venus' atmosphere, the water starts evaporating into steam and the balloon goes back up -- and then, when it rises above the equilibrium level, the water condenses and the balloon goes back down. Moreover, since there's a delay between the time a substance absorbs or dumps enough heat to undergo a phase change and the time it actually completes that change, the balloon keeps perpetually oscillating several kilometers above and below the equilibrium altitude rather than settling down at that altitude -- like one of those bobbing mechanical drinking ducks.

What does that get us? Well, suppose that the balloon has a small water tank fastened to its bottom which the condensing water runs into. When the balloon is on the negative-buoyancy part of its cycle and headed down, you just shut a valve on the tank to trap the water -- and the balloon retains its negative buoyancy and keeps going down, all the way down to the surface of Venus. After an hour or so taking pictures and analyzing the surface, when the instrument gondola is starting to heat up dangerously, you open the valve, the water boils back into steam, and the balloon takes off for Venus' cloud layer again, where the gondola can cool off until Earth decides it's time for the next dive. (On the way down, you can open the valve part way to slow the balloon's descent -- or even stop it to hover in the lower atmosphere instead of going all the way to the surface.)

Neat, eh? And by taking into account the speed and direction of Venus' winds (which are 400 kph in the clouds but drop down to only 4 kph at the surface), you can land fairly near a specific location. (This is complicated by the fact that, while you can slow down the balloon's descent by opening the valve, you can't speed it up again -- so you have to deliberately "undershoot" your target and then slow down the balloon's descent by some extra amount later so it gets blown to the point you want.) Nice surface and aerial photos, weather data and surface composition analyses. The balloon would be made of a remarkable plastic film called "polybenzoxazole", several times tougher than steel, and which holds up beautifully to Venus' savage surface temperatures.

In another LPSC paper, Ronald Greeley details a simpler Venus mission called VEVA that he proposed as a candidate for the latest Discovery mission selection. Two balloons just blow along at a fixed altitude in Venus' clouds, with each one dropping four small multispectral camera-equipped impact probes at appropriate locations. Anyway, both the Venus and the Titan phase-change aerobots are very high on NASA's intermediate-term Solar System wish list (with the giant-planet Montgolfier balloons being lowerpriority).

## Balloons vs Planes or Dirigibles to Explore Titan

Bruce Moomaw <[moomaw@jps.net](mailto:moomaw@jps.net)> writes:

Exactly the same technique can be used for a Titan aerobot -- except, of course, that the phase-change material must be something that's still gaseous on Titan's -180 C. surface, but liquifies in its still colder stratosphere. Argon fills the bill perfectly. And this balloon, unlike the Venus one, can sit on Titan's surface indefinitely if we choose. (By the way, the tendency of such a phase-change balloon to oscillate up and down has already been tested on an Earth balloon, using ethylene chloride as the phase-change liquid.)

Ralph Lorenz, in an LPSC Conference paper last March, pointed out that a Titan balloon has one odd problem -- Titan's east-west winds are quite strong but its north-south winds are virtually nonexistent, so the balloon just keeps orbiting round and round Titan at the same latitude and looking at the same terrain. He suggested an airplane instead -- Titan's unique mixture of an atmosphere 1.6 times as dense as Earth's and a surface gravity actually slightly less than the Moon's (Titan's icy interior has a low density) means that a plane can stay aloft either with very small stubby wings or (better) with a very low-powered engine.

But since one of a Titan aerial explorer's main goals is to keep landing and analyzing the surface organics, a dirigible with N-S pointing engines might be better.

## Balloons over Jupiter

The problem of heating the hydrogen to keep a balloon aloft in the atmospheres of Jupiter and the other giant planets has been solved by using passive heating. You paint the upper half of the balloon black to absorb sunlight and thus heat the balloon's skin; and since all these planets emit a large excess of IR energy from their interiors, you also make the bottom half of the balloon IR-transparent and line the inside of the upper half with an IR-reflective coating so that the planet's IR radiation heats the balloon's gas directly. The technique is very weight-effective for all the giant planets but Neptune (too far from the Sun, but it works somewhat even there) <BM>

MMM #184 APR 2005



### Visiting Hell & Living to Tell About it: Mission Goals for Future Venus Probes

By Peter Kokh & David Dietzler

See "Rehabilitating Venus as a Human Destination"

[www.lunar-reclamation.org/papers/venus\\_rehabpaper.htm](http://www.lunar-reclamation.org/papers/venus_rehabpaper.htm)

Synopsis: Manned aerostat outposts are possible on Venus, floating just below the cloud deck where temperatures and pressures are manageable and from where the Veneran surface is visible. The atmosphere and clouds can be mined for carbon, oxygen, nitrogen, sulfur, hydrogen, and other elements to make building materials for outpost expansion or replication. Tourist hotels could be built in this way to serve tourists taking "window shortcuts" between Earth and Mars via Venus.

### Goals of ESA's Upcoming Venus Express

Condensed for MMM from <http://sci.esa.int/science-e/www/area/index.cfm?fareaid=64>

In large part based on the successful Mars Express orbiter, weighing 1270 kg = 2794 lbs., Venus Express is set for launch Oct-05 on a Soyuz-Fregat rocket and intended to operate for 500 days in a polar orbit around Venus.

**The Venus Express payload** comprises a combination of spectrometers, spectro-imagers and imagers covering a wavelength range from ultraviolet to thermal infrared, a plasma analyzer and a magnetometer. The aim is to enhance our knowledge of the composition, circulation and evolution of Venus atmosphere. The surface properties and the interaction between the atmosphere and the surface will be examined and evidence of volcanic activity will be sought.

- **ASPERA-4** (Analyser of Space Plasmas and Energetic Atoms) will investigate the interaction between the solar wind and the atmosphere of Venus
- **MAG** The Magnetometer instrument will provide magnetic field data and study the interaction of the solar wind with the atmosphere of Venus.
- **PFS** (Planetary Fourier [infrared] Spectrometer) will perform vertical optical sounding of the atmosphere, to:
  - Perform global, long-term monitoring of the 3-D temperature field from cloud level up to 100 km
  - Measure concentration and distribution of known minor atmospheric constituents
  - Search for unknown atmospheric constituents

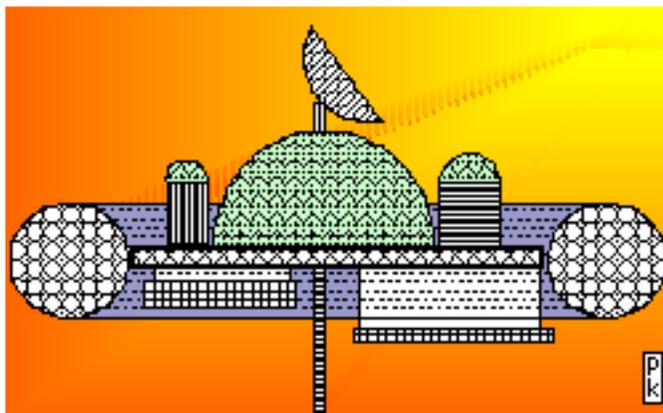
- Determine the size, distribution and chemical composition of atmospheric aerosols
- Study global circulation, mesoscale dynamics & waves
- Analyse surface to atmosphere exchange processes
- VeRa (Venus Radio Science) is a radio sounding experiment to examine the ionosphere, atmosphere and surface of Venus by means of radio waves. The instrument will determine the dielectric characteristics, roughness and chemical composition of the planetary surface.
- VIRTIS (Visible and Infrared Thermal Imaging Spectrometer) in the near ultraviolet, visible and infrared parts of the spectrum to analyze all layers of the atmosphere and clouds, make surface temperature measurements and the study of surface/atmosphere interaction phenomena.
- VMC (Venus Monitoring Camera) operates in the ultra-violet, visible and near infrared spectral ranges. VMC will map the surface brightness distribution and search for volcanic activity. VMC images and movies will make a significant contribution to the public outreach program.

## Mission Goals for Future Venus Probes

Dave Dietzler & Peter Kokh

### Top Priorities Beyond Venus Express: – Kokh's List:

- Temperature hardened and corrosion resistant components for future Venus & Mercury landers with enhanced viability (months instead of minutes) and redesigning chemical / mineralogical sensing equipment, and heatflow drill taps, etc. accordingly
- A fleet of balloon probes (100s) in Venus' atmosphere at various levels to map circulation cells and patterns, wind speeds, and variations in atmospheric chemistry at different levels, for data to locate any "sweet spot" – a best tradeoff between lower temperatures & pressures (higher up) and better visibility of the surface (lower down). Ideal pressure (1 ATM) and the best temperature (50–70 F?) may not occur at the same level..
- A balloon borne processing unit to demonstrate production of carbon, carbon composites and carbon-based compounds, sulfur and sulfur-based compounds, etc.
- A subsatellite lowered from a tether from a high-floating balloon for low-level high resolution surface photo atlas as well as high resolution geochemical mapping, from which to create a short list for priority sites to test future ground probes and rovers



### Top Priorities Beyond Venus Express: – Dietzler's List:

- Map light intensity and spectrum at various altitudes in different locations longitudinally and latitudinally for future agricultural and solar power generation needs.
- Determine risk from lightning and up/down drafts to floating outposts.
- Test a Veneran Atmosphere Thermal Energy Gradient Converter power system on balloon borne probes.
- Surface samplers to locate, qualify and quantify mineable surface resources.
- A spectrometer capable of locating industrially interesting resources not just geologically interesting ones.

- Measure solar flare radiation influx at various altitudes (Venus' weak magnetic field generates no Van Allen Belt shield, and we are relying on the atmosphere for radiation protection. Secondary particle generation when ions from solar flares hit the Venusian atmosphere could be pretty bad. Venus is also much closer to the Sun so solar storm particle fluxes are more intense there. We'd want to examine this in detail before we plan high-floating human science stations and outposts. <PK/DD>

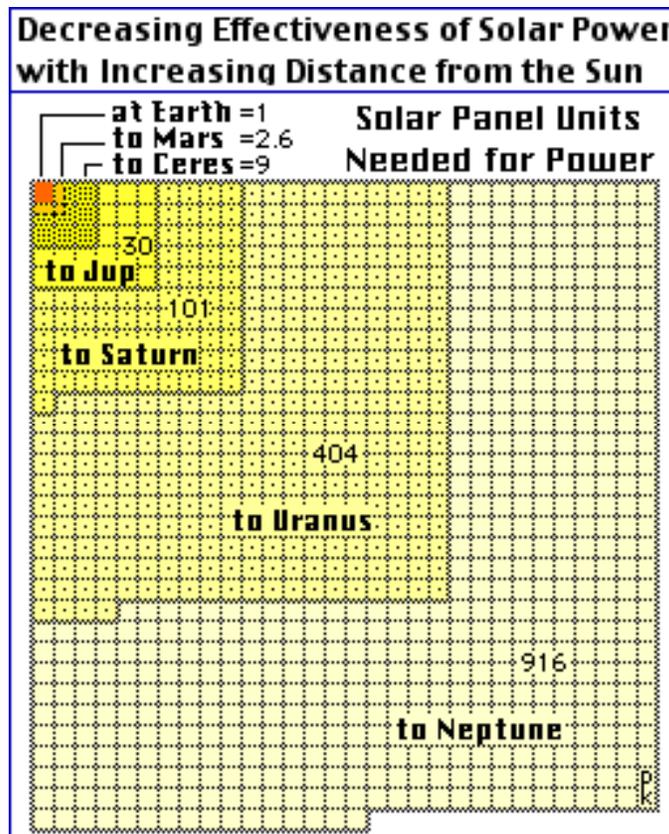
**MMM #197 – August 2006**

## The Challenges of Migration into the Cold & Darkness of the Outer Solar System

By Peter Kokh [kokhmmm@aol.com](mailto:kokhmmm@aol.com)

We are not yet back on the Moon, have not yet made our first footfall on Mars. But that does not stop our Ad Astral aspirations from trying to project our presence further out: on the asteroids Ceres & Vesta, on Jupiter's Callisto and Europa, on Saturn's Titan & Iapetus, and ever beyond. It is part of the process of imagining far away places from a frontier-perspective.

It will be quite some time before there is any concerted effort to "talk up" and "think out" human expeditions beyond Mars. But that day will come. When it does, what we imagine as possibilities today, may seem quaint, Jules Verne-ish to those who follow with access to science and technology that we can only dimly glimpse. Going further out, will, however, be challenging to the extreme.



**These challenges are threefold.**

- 1) As we go further from the Sun, the amount of light and warmth we receive from it diminishes with the square of the distance: at 2x the distance there is only 1/4 the light and heat. This makes solar energy collection ever more difficult and less feasible a way to derive power. Surrounding space gets **ever darker, colder and colder.**
- 2) The spacing between planets gets larger and larger. Low energy Hohmann transfer orbits take years, decades, even centuries, not just months as to Mars and back. Places to visit become **ever further**

**apart** from one another. Trade in supplies and goods becomes increasingly more difficult, let alone journeys by individuals for business or pleasure.

3) Because of the greater heat in the inner solar system at the time of planet formation, the inner system planets are predominantly rocky: silicates and metal oxides. Further out, the proportion of ice and water, and other volatiles in comparison with rocky elements becomes greater and greater. Indeed, on the icy moons of Jupiter, Saturn, Uranus, and Neptune, and probably the more so on KBOs and TNOs – Kuiper Belt and Trans-Neptunian objects, while water, oxygen, nitrogen, and carbon are abundant for life support, the challenge will be to extract metals for technology. The situation we find on the Moon is stood on its head further out. That could discourage development of human frontier exclaves except in locations where a happy medium can be found.

Perhaps nowhere will trade be more necessary, and at the same time, more difficult to the point of futility, as anywhere in the Outer Solar System except within the planet-moon systems of Jupiter, Saturn, Uranus, and Neptune, a complementary full suite of needed materials may be a very rare occurrence.

### **What we stand to learn on Ceres – Cryoplastics**

On Ceres, the next likely frontier beyond Mars, the availability of both volatiles and rocky elements in an appreciably colder (than Mars) environment, makes a frontier settlement there the ideal testing ground for a greater reliance on new **cryoplastics**, synthetics build of volatile elements but tolerant of temperatures significantly lower even than those we find in the lunar night or in the Martian winter. If it proves possible to develop a versatile suite of such cryoplastics and cryosynthetics, then we will be prepared for the Moons of Jupiter and beyond, as far as the material side of human existence is concerned.

While solar power becomes ever more impractical a solution the further out we go, we might still find a use for it on Ceres. A collector 1 meter on a side on Earth or the Moon would have to be scaled up to 3.5 meters on a side. Nuclear power in some form seems sure to become the solution of choice.

The danger from solar flares will lessen as we go further out, but not that of cosmic radiation. Ice will become the shielding material of choice.

Transportation will be the biggest challenge. Goods and cargo can always be shipped in a continuous pipeline fashion, unmanned ship after ship. How long it takes to go through the pipeline is irrelevant, so long as the “faucet” is always spitting something out on time, and in the amount needed. Special orders, however, will take years, even decades or centuries to fill. That will but ever greater urgency on achieving the highest degree of self-reliance. And that means settling only where all the needed elements are economically available. As we go further out, an ever increasing number of world-lets will not pass that muster.

### **The low gravity question**

Callisto, Ganymede, Europa, Io around Jupiter, and Titan around Saturn have gravity levels between 19% and 15% normal, comparable to the Moon’s 16+%. A population adapted to lunar gravity will have no difficulty adjusting to life on those large satellites. We can hope that the physical deterioration we see in Earth orbit will level off at an acceptable level in lunar sixthweight, meaning that not only will our offspring be healthy, but theirs in turn.

Physiological zero-gravity occurs when the friction within blood vessels is no longer overcome by the gravity gradient. The only instrument worth reading is the body. Ceres’ 3% gravity may flunk the test. If so, we will become increasingly reliant on artificial gravity. Bioreengineering ourselves is unlikely to be an early generation choice. One danger that may become a growing problem, is too shallow a gene pool, that could spell doom. <MMM>

**MMM #204 April 2007**



## Myth 1) “Mercury is too Boring”

On first hearing, the suggestion of human settlements on the planet Mercury seems nothing short of ludicrous. Virtually every astronomy or space travel textbook we have read describes the planet as utterly hostile to human life. Generally described as a slightly larger Moon, Mercury is often ignored as being either too difficult to reach, too dangerous to live on, or just too plain plain. Let the unmanned probes go there. After all, Mars is more interesting. It depends on just what you are interested in.

Any reasonable concept for human expansion beyond Earth must include hum drum activities like mining, energy production, manufacturing of common and exotic items, and the transport around of people and their stuff. This will be the case wherever we go. If we are wise, those of us who truly want to see bona fide human expansion into space – as opposed to mere exploratory visits – will weave the common, mundane issues into our planning. On that basis, we will do well to consider colonization of Mercury.

### Mercury is one of the most energy-rich planets in the Solar System

Energy is the key to whatever we want to do in space. Historically, we have always sought out cheaper energy sources and have experienced economic booms when they are developed. So it will be in space. On Mercury, the energy situation is analogous to taking a shower under Niagara Falls: we’ll most likely never use all of the available energy. In fact, if energy were the only criterion of concern, we would not even bother with Mars. With the possible exception of geothermal energy, Mars is wantingly poor in energy sources, having only 1/20th\* the solar flux available on Mercury. [\*solar flux varies with the inverse square of the relative distance from the Sun.]

Photovoltaic and thermodynamic power systems operating in Mars orbit would still have only 45%, on average, of the solar flux to work with as is available on The Moon. Systems operating on Mars surface would have even less owing to the atmospheric effects. While would-be Mars colonists can be assured of having enough energy with which to survive, they will always be at the bottom of the well looking up, when it comes to Mercury.

[Ed. Mercury and Mars may be on a par in uranium and thorium sources for fission power.]

**Material resources on Mercury are known to include all the same base elements found on the Moon:** Silicon, oxygen, iron, aluminum, titanium, sulfur, calcium, potassium, and magnesium have all been identified as constituents of minerals that remain stable in Mercury’s thermal environment. We do not yet know the exact details of abundances or distributions. What we have learned has been gathered from interplanetary distances using spectrographic analysis. This implies the resources mentioned above must be in substantial supply if they can be detected from such a great distance.

Importantly, hydrogen is also a proven resource on Mercury. We know that hydrogen is available as a constituent in Mercury’s atmosphere from both space craft observation and spectrographic analysis. Properly described as an exosphere, the abundance of hydrogen there is paltry by almost any standard. Still, it is a constant supply as it is derived from solar wind sources and is available over the planet’s entire surface. Superconducting ion ‘scoops’ deployed over large areas and running constantly can collect substantial quantities of hydrogen. Liquefying the hydrogen is an energy intensive proposition, but Mercury had the energy.

The importance of this hydrogen, diffuse as it is, cannot be overstated. First it means that people on Mercury are assured a self-sustaining source of water, even if the data indicating water ice at the poles is wrong. Second, it assures the ability to provide hydrogen fuel for flight into Mercury orbit, and,

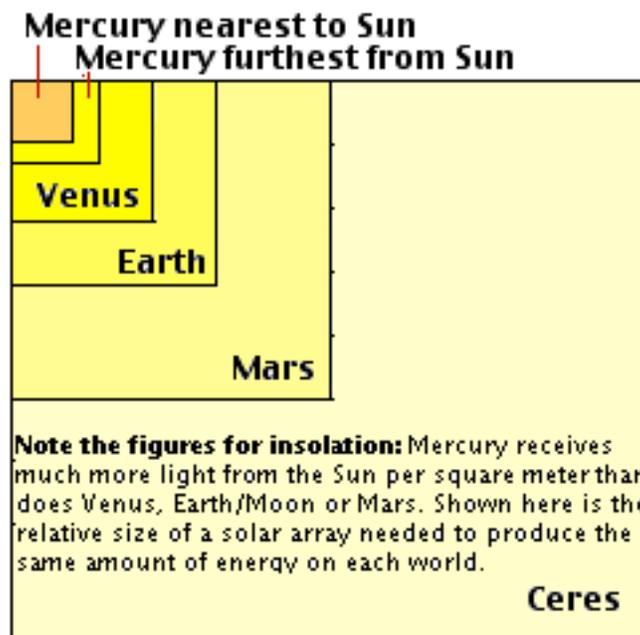
eventually, into interplanetary trajectories. This favorably alters the economics of flight to and from Mercury in a big way.

[Ed. Note that Mercury also possesses **abundant oxygen reserves** locked in the minerals of its crust, for use as a fuel oxidizer.] Industrial processes involving hydrogen as a feedstock, or as a reagent, also become possibilities.

[Ed. Does the regolith on Mercury adsorb solar wind protons (hydrogen nuclei) as is the case on the Moon? **The solar wind** is stronger at Mercury than at the Moon. On the other hand, Mercury's global magnetic field may lower the number of solar wind particles getting through. We need a surface probe to find out.]

### How does Mercury Stack Up?

M	Merc	Venus	Earth	Moon	Mars		
Mass 10 <sup>24</sup> kg		0.33	4.87	5.97	0.07	0.642	
Diameter km		4879	12104	12756	3475	6794	
Density kg/m <sup>3</sup>		5427	5243	5515	330	3933	
Gravity m/s <sup>2</sup>		3.7	8.9	9.8	1.6	3.7	
Escape Vel km/s	4.3	10.4	11.2	2.4	5		
Day hours long	4222	2802	24	708.7	24.7		
Sun Dist10(6)km	57.9	108.2	149.6	0.384*	227.9		
Insolation avg	6.68	1.91	1	1	0.43		
Orb. Period days	88	224.7	365.	7.3	68.7		
Orbit Speed km/s	4	7.9	35	29.	8	1	24.1
Orbit Inclined		7°	3.4°	0°	5.1°	1.9	
Orbit Eccentric		0.205	0.007	0.017	0.055	0.094	
Axis Tilt		0.01°	177.4°	23.5°	6.7°	25.2°	
Mean Temp °C		167	464	15	20	-65	
ATM Pressure bars		0	92	1	0	0.01	
Number of Moons		0	0	1	0	2	
Magnetic Field?		Yes	No	Yes	No	No	



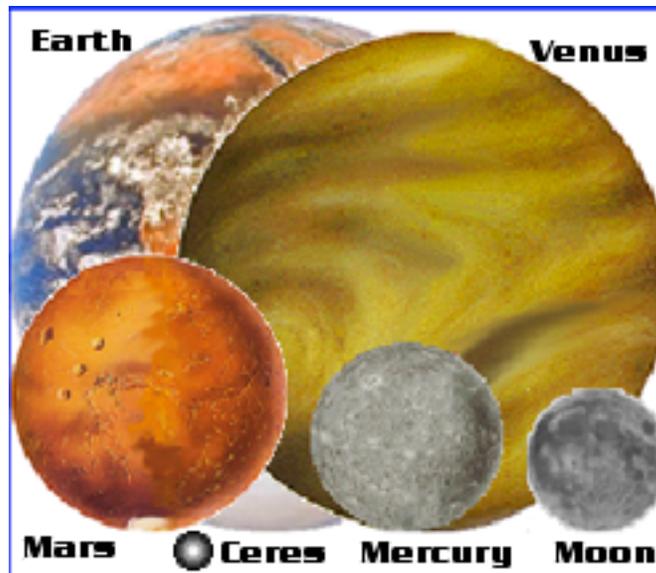
**Gravity:** while smaller than Mars, Mercury is much denser, and has a similar level of gravity.

**Surface area** varies with the square of diameter. Mercury's surface is 2x that of The Moon but only half as large as Mars' (or of Earth's total continental area.).

**Seasonal factors:** Mercury's eccentric orbit means that it alternately it gets much more, and much less light and heat from the Sun than the average figure indicated.

Energy and raw materials are two of the four pillars upon which a planet's economy are supported. The other two are human creativity and time. The careful reader will note that 'location' -- which we hear about often -- is not on the list. In space travel, location is entirely a function of energy. Expend a certain amount of energy, and you will completely change your location. The implication here is that the cost of generating energy is what will largely determine the cost of transporting from one planet to another.

[Ed. We have another take on this issue. "Location" can matter, and far from being a handicap, it's all in favor of Mercury's economic potential. It is Mercury's proximity to the Sun that endows it with an energy rich environment, as well as with a very short orbital period. That, in turn, is the reason Mercury has such short intervals between arrival and launch windows with all the other bodies in the solar system. Thus its location will one day make it the Grand Central station/transport hub of the Solar System.



## Myth 2: "Mercury is too hard to reach"

Which brings up the first of the three great myths about Mercury that have kept it out of the limelight these many years: the myth that Mercury is just too hard to reach. To best understand the issue of flight to Mercury, it is helpful to compare it with a flight to Mars. Suppose, then, we consider two missions, one to each. Both have a crew of four. Both use identical engines, spacecraft and other equipment to the extent the different planets allow.

Both missions leave from Low Earth orbit. For the Mars-bound craft to reach Mars' orbit from Earth's orbit requires a delta-V (change in velocity) of 2.9 km/sec. Not bad. Its delta-V to enter orbit around Mars will be 2.6 km/sec, total 5.5 km/sec. Also not bad.

For the Mercury-bound mission, a delta-V of 7.5 km/sec is needed to reach that planet's orbit, and another 9.6 km/sec to go into orbit around Mercury: 17.1 km/sec total. This is more than three times what is needed for the Mars mission. However, the inference that a manned mission to Mercury will require three times as much propellant as a mission to Mars does not follow.

Using a Hohmann transfer (most economic trajectory) as a baseline for both flight, the one to Mars takes 245 days while we reach Mercury in just 105 days. That translates to a need for only 42% as much food and other consumables needed for the Mercury flight as for the one to Mars. Food would be about 0.75 kilograms per person per day. The 4 person Marsbound crew needs 736 kg, the Mercury crew just 315 kg.

If we assume a 'standard' LOX/LH2 propulsion system, it will take approximately 1.88 kg of additional propellant and spacecraft structure to deliver one kilogram of payload to Mars orbit. The same system would need three times as much propellant/structure mass to get a kilogram of payload to Mercury. However, in terms of actual mass in LEO needed to the respective missions, the Mercury-bound craft would be carrying considerably less payload for a given crew size. In the end, a Mercury-bound ship would require less propellant mass than the delta-V figures above would suggest. An exact figure requires an iterative process for both missions which is really beyond the scope of this study. Our point

is that a crew of four could be delivered to Mercury using a craft (with fuel) 25% lighter than a similar one headed for Mars. (Note that propellant mass would be utilized as radiation shielding during solar flares in both cases.)

Off-loading one crew member from the Mercury mission results in a further reduction of mass required. For a 3 person Mercury craft, the weight in (low Earth) orbit is roughly the same as for a 4 person Mars craft. The point here is that mission duration has an equal part in determining mission cost and energy requirements.

A manned flight to Mercury will still require more propellant [per kg of payload] than an equivalent mission to Mars. The Mercury mission could use the same technology and same Earth-LEO vehicles – at cost levels only slightly more than those for Mars. The assumption that we could not do a Mercury mission at ‘reasonable cost’ is just plain wrong.

There is more.

If both spacecraft are solar-powered, the Mercury vehicle will have a power system (presumably a photovoltaic array) weighing much less than thirty percent of its Mars counterpart. A solar array designed to generate 10 kw at Earth’s distance from the Sun would be 25 sq m in area; at Mars distance from the Sun 55 sq m; but at Mercury’s distance, just 4 sq. m. Power inverter systems would be the same mass in each case, but the net difference in system mass is significant. Each kg of array mass must be boosted from Earth with the requisite mass of propellant as outlined above. Mercury craft array mass is 1/20th the size and mass of that for the Mars craft. This is further to the advantage of a Mercury craft.

Going to Mercury is not necessarily cheaper than going to Mars. Our point is that the delta-V figures do not give an accurate, or even fairly approximate, picture of what a manned flight to Mercury would actually cost. Nor for that matter, do delta-V figures give any indication of whether a transportation system can be operated profitably between a given pair of planets. Of course, all of the foregoing assumes use of chemical propulsion systems. Now it happens that there is an alternative that can make Mercury settlement a very practical proposition – and even reduce the cost of settling Mars in the bargain.

Solar sails hold the prospect of being able to deliver incredibly large payloads to Mercury orbit without expending massive amounts of expensive propellant. Solar sails have numerous advantages over any chemical system, including nuclear systems. They are relatively low maintenance, completely reusable, totally insensitive to plane-change requirements and the usual launch window constraints, extremely flexible in their payload capacity and pose no risk to crews from either explosions or radiation exposure. A single Ares launch vehicle can deploy a solar sail 25 square kilometers in area, large enough to deliver a 400 metric tonne payload to Mercury in just 600 days. Three such payloads could be launched every year if need be. There is no chemical technology that can begin to approach this capability for any planet.

In reality, there is no real likelihood of such massive payloads being sent anywhere. The Ares vehicle mentioned is designed to launch something like 150 metric tonnes to LEO. It would require at least three such launches thoroughly equal 400 tonnes. There is an argument that this is not particularly cost efficient.

With solar sails, the issue is more about how fast do we want to get our payload to Mercury. If solar sails have an Achilles’ heel, it is that they can take a comparatively excessive amount of time to build up the velocities needed to reach Mercury. Ironically, and this is good news, getting a solar sail back from Mercury is a lot easier and faster, owing to its proximity to the Sun. As a transportation system comprised of several sails, more or less constantly in transit, the average payload could be reduced in size to enable faster transfers. Entire round trips lasting less than a year are easily achievable.

### **Myth 3: “Mercury is too dangerous to live on”**

Radiation on Mercury is considerably more severe than on the Moon or Mars. Depending on its orbital position, Mercury can receive anywhere from six to ten times the radiation flux encountered on the Moon. By implication, that means people would build up radiation-induced damage at a proportionally greater rate. This in turn means a crew on Mercury would need much more radiation shielding to reduce dosage levels to a particular point than on the Moon. It also means that the crew could not be exposed to natural radiation levels on Mercury for as long as a lunar crew. But just how long could they go unprotected before accumulating a career limit dose?

There is remarkably little direct information on ionizing radiation effects on Mercury. Most writers on the subject tend to focus on thermal radiation and do not consider that ionizing radiation, by itself, is a hazard because of the damage it causes on the cellular level. Mercury's extreme heat would destroy any unprotected living tissue very rapidly; in mere minutes. Ionizing radiation, on the other hand, destroys by overwhelming the body's ability to repair itself. This takes a bit longer.

Excluding intense solar flares, calculations indicate that a crew could work on Mercury's surface for at least five weeks with only their spacecraft or their space suits for protection. At that point, they would need to be under shielding -- as much as 15 meters of shielding, if it is comprised only of Mercury regolith. Five weeks is more than enough time for an experienced, well - equipped crew to build a small base under adequate shielding. Training such a crew on the Moon prior to Mercury would be logical and beneficial.

To clarify the five-week limit, that would be the length of time it would take the crew to receive a cumulative dosage that would cause a substantial increase in their likelihood of developing life-threatening cancers. It does not mean "five weeks and they are dead." There are some estimates that go as low as only two days (but do not specify the level of protection needed) and others that go up to ten weeks. Uncertainty remains and this is the subject of more study. What is clear is that a crew would have a window of time to establish adequate shielding.

For a crew of four people with just two days working simultaneously, this works out to a total of 192 man-hours or eight man-days - in which to get an initial base built. The more likely scenario is that only half that time would be productive. This still leaves four man-days of actual productive time to deploy the shielding: a worst case scenario that might not pass NASA safety rules.

[Ed. on the question of shielding, I asked the author about the possibility of lavatubes on Mercury. We have only photographed a little more than half of the planet's surface and do not see Moon-like maria. His reply:

"There are 'sinuous rilles' on Mercury. Mostly they are in the Caloris basin region and they are not likely to have been formed by exactly the same process as lunar rilles. Uncollapsed lava tubes are not yet identified, so far as I know anyway. I have a CD of Mariner 10 images and am poring over them with great interest and will let you know if I see anything NASA missed. Hey, it could happen. . ."

]

As for thermal radiation, the logical approach is not to be out on the surface during times when the Sun is high enough to heat the ground to excessive levels. For current technologies, that still leaves about three weeks after sunrise and three weeks before sunset in which to explore by daylight. Of course, the entire 88-day nightspan is available for surface work, albeit under artificial lighting. Three weeks is more than enough time to conduct very extensive exploration sorties or surface construction work.

Mercury can be reached. We can cope with its environment, if not enjoyably. The rewards for making the effort are great. Abundant energy: a strategic transportation hub allowing access from Earth to Venus and Mars at intervals and with flight times better than direct routing; resources of metals, silicates, and volatiles that ensure self-sufficiency in vital needs such as construction materials, life support elements and even spacecraft propellants. ... The potential is impressive.

Given the advantages of solar sails for low cost transportation, combined with Mercury's many attributes (including the greater accessibility based on shorter synodic periods with other planets) it is even conceivable that Mercury could be developed much more rapidly and at far less total cost than Mars.

That's a subject for a future report ... <BJ>

See MMM #78, Sept. '94, p. "Mercury: Gateway Grand Central" republished in MMM Classics #8 p 36, 38-9. [www.moonsociety.org/publications/mmm\\_classics/](http://www.moonsociety.org/publications/mmm_classics/) Note also that all this solar energy can be used by lasers to decelerate inbound, and accelerate outbound spacecraft.

#### **Mercury Probe Updates:**

**Mercury Messenger** is due to fly by Venus on June 5, 2007. and go into orbit around Mercury on March 18, 2011 (in four years.) <http://messenger.jhuapl.edu/>

**BepiColumbo** (ESA/Japan) mission in planning [www.esa.int/esaSC/120391\\_index\\_0\\_m.html](http://www.esa.int/esaSC/120391_index_0_m.html)  
MMM

## More on Mercury as a Human Frontier

From Dave Dietzler and Peter Kokh

**DD:** Much of what we know about Mercury was gained by Mariner 10 during 3 flybys in 1974 and 1975.

A total of 2,300 photos were taken but only 45% of the surface was imaged at an average resolution of 1 km. and less than 1% of the surface at resolutions between 100m and 500m. The other half of Mercury is a mystery.

High resolution radar images of the un-photographed side show three bright features. One may be a large fresh impact crater. Another has a radar signature similar to a shield volcano as big as Mars' Olympus Mons. The third has no known radar counterpart elsewhere.

Mercury's surface is cratered like the Moon and has impact basins similar to those on the Moon. The largest lava plain is the Caloris Basin, 800 miles across. On the opposite side of Mercury there is a feature called the Hilly and Lineated Terrain which probably formed when seismic waves from the Caloris Basin impact converged. Radar studies done by JPL scientists using the Goldstone antenna and the VLA indicate the presence of water ice in northern polar craters and radar images from Arecibo confirmed the results and even discovered a bright patch in the southern polar region.

Because the obliquity of Mercury to its orbit is 0° the planet does not experience seasons (as such) and temperatures in the polar regions should be less than minus 248 F. In permanently shaded craters it could be as cold as minus 290 F. Since the radars could penetrate the ground and the surface of Mercury based on infrared temperature measurements seems to be covered with a porous soil or rock power like the lunar regolith that is a good thermal insulator, the ice could be subsurface. **DD**

**PK:** That Mercury's axis is not tilted at all, leads some to say that the planet has no seasons: yet the eccentricity of the orbit is such that there are both clearly distinct climactic regions, and a set of seasons in each.

When Mercury is at perihelion, the Caloris basin is always sunward, the antipodal chaotic area in darkness. When Mercury is at aphelion, the Caloris antipodal chaotic area is sunward, Caloris in darkness. These areas experience very different climates even if at the same latitude.

At the equator, shade has to be overhead. Away from the equator, shade walls may work, and surface temperatures will be lower (less insolation per sq. meter.) Peri-arctic regions will have the most reasonable temperatures as well as close proximity to ice.

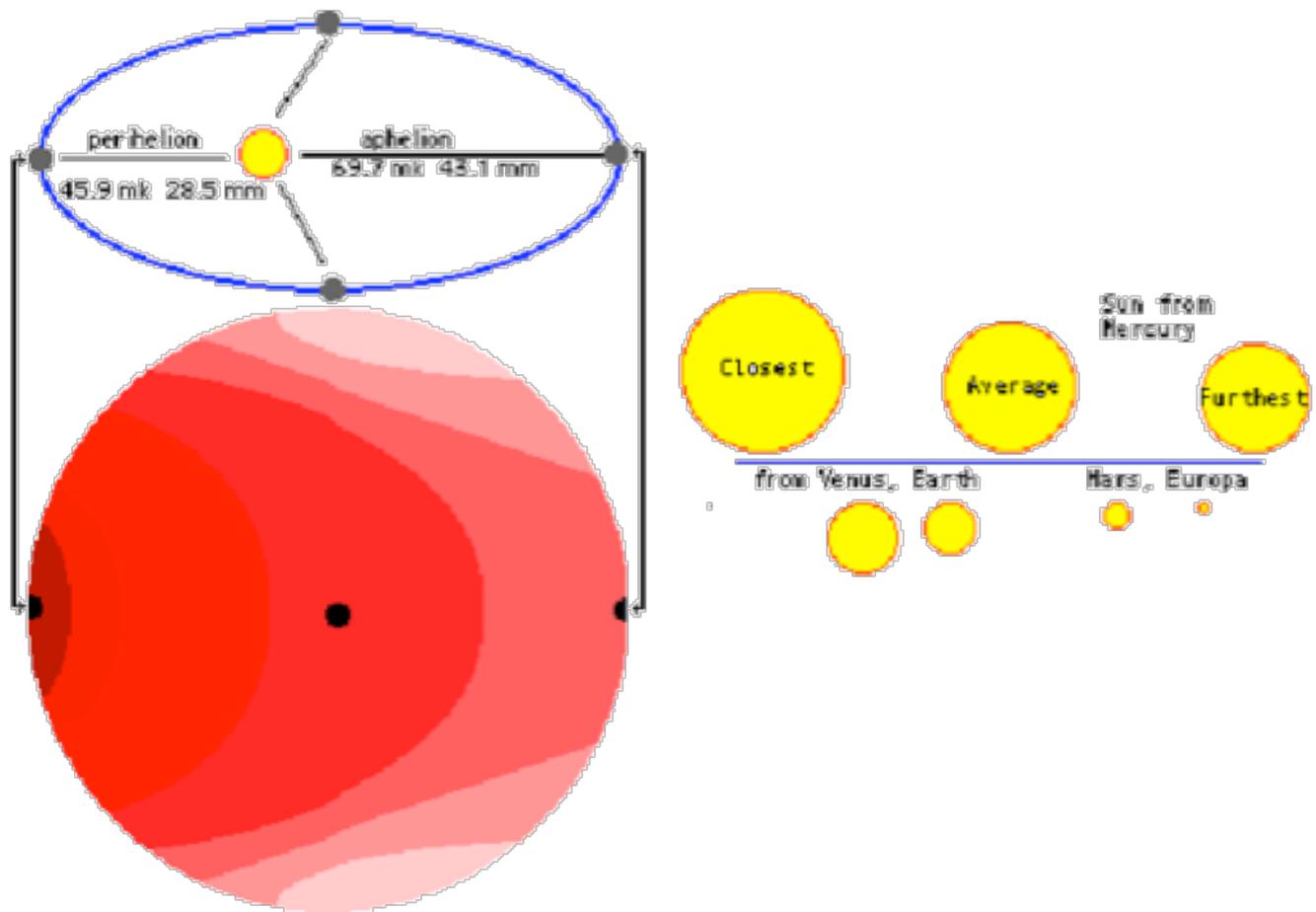
Mercury's day, noon to noon, is 176 Earthdays long. One need travel only 3.75 kph or 2.33 mph to keep up with the advancing sunrise or sunset, at the equator. On Earth, a couple of meters down, the temperature may be temperate (40-60 depending on latitude.) I think Mercury's subsurface temperature will vary strongly with both latitude and longitude along with the local mean insolation per square meter. There not be much relief underground away from the periarctic areas. **PK**

MMM #205 May 2007



**Mercury Frontier Speculations for the fun of it!**

By Peter Kokh



### Climate Zones – dayspan temperature swings

Notice the cooler area surrounding the poles hugs the pole more closely on the side of Mercury that faces the Sun at perihelion, than the aphelion facing side. The idea of creating this climate zone graphic is to show in which areas it would be relatively easier or relatively harder to set up a manned presence.

### Shade, Thermal Shielding, and Burrowing Down

Shade is one thing. Shade protects you from further heating from the Sun above. It does not protect you from the heat already accumulated in the ground below. To find lower temperatures, we'll have to do what we do on Earth, dig down. On Earth, and we think on the Moon, the temperature a couple of yards or meters down stays fairly even year around. That temperature level is higher the closer you are to the equator, and colder, the closer you are to the pole. Tap water is wonderfully cold in the northern states and Canada, but almost luke warm in the southern states.

As Mercury is much closer to the Sun, it receives an average of nearly seven times the solar influx per square meter as does Earth or the Moon. The subsurface ground temperature will vary with the climate zones we sketched at right. But the subsurface temperatures are likely to be quite high by our standards.

Above you will see how much larger the Sun looks from Mercury at its closest approach to the Sun in comparison to its furthest recession. From Earth, the Sun looks much smaller, yet quite a bit larger than it does from Mars. By the time you get out to the great moons of Jupiter, The Sun still looks round, but now very much smaller. From Neptune and Pluto, it looks more like Venus looks in our sky, only, much, much brighter.

Obviously the light colored (graphic above) polar zone would be the coolest area for a settlement. But, I, for one, am not confident that the subsurface temperatures will be low enough for even there. We need ground probes that can drill 10–20 meters (31–62 feet) down to be sure of that.

According to Bryce Johnson's research (see last month's article on Mercury), we'll have to burrow that far down (or tuck ourselves under a blanket of regolith that thick) to protect ourselves from Mer-

cury's much greater solar flare flux than we are used to in Earth-Moon space. As to Cosmic Rays, their intensity will be the same everywhere we go within, and without, our solar system.

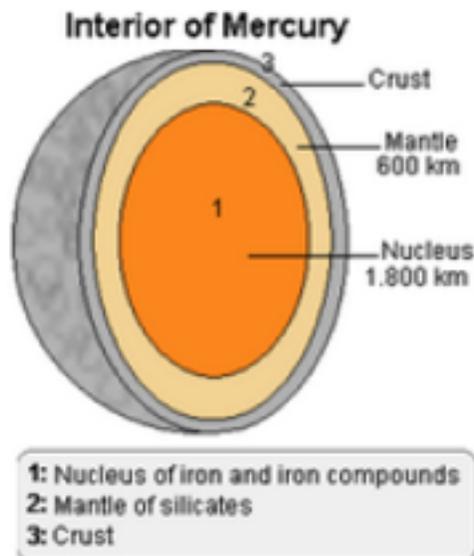
Obviously, the discovery of intact lavatubes will be of even greater significance for shelter than for the Moon or Mars. While the one side of Mercury that we have mapped on a quick swingby, shows no abundance of maria like features, there do appear to be some lava flows, and wherever there are lava sheets, there are likely to be lavatubes. If we find areas in which there have been more than one episode of lava flooding, there may be lavatubes intact in each layer. And the lower we go down the more protection we will find.

But there is a possible Catch-22. Here on Earth, in deep mine shafts, we find that the lower we go the hotter it gets and that the cool temperatures between 6 and a thousand feet down or so, are all the buffer zone we get. Below that zone, we start to feel the heat of the Earth below. That heat comes from billions of years of radioactive decay. Will we find a similar situation on Mercury. Maybe, maybe not. Read on.

### Mercury is not evenly hot all over

Mercury's rotation is sun-locked -- sort of. It does not always keep the same face to the Sun at all times, but in its very eccentric orbit, it revolves at a pace that allows it to present the same face towards the Sun when Mercury is closest to the Sun (Perihelion) and the opposite face is always turned towards the Sun when the planet is furthest from away in its orbit (aphelion.) The diagram sketches both Mercury's orbit and the resulting climate zones, hottest to coolest. Those of you who get MMM as Black & White hardcopy only, will not be able to see the climate zones. So we put this diagram online at: [www.lunar-reclamation.org/images/mercury\\_zones.gif](http://www.lunar-reclamation.org/images/mercury_zones.gif)

### Mercury's Internal Heat



**The \$64 question is** what is the temperature of the subsurface layer in which both solar heat and internal heat bottom out? Will there be a sweet cool layer that is thermally friendly?

It matters not how well endowed the planet is with resources that could support an industrial civilization if there is nowhere on the planet's surface or not too far below it, that we will find cool enough? What is cool enough? Human activity, especially in our current state of energy use, produces surplus heat. We will need a heat sink. We'd like to find a subsurface area that is well below freezing. Therein, just the heat of daily living will keep us as warm as we want to be.

We can do our best to come up with an educated guess, but there is nothing so reassuring as actual readings, meaning, we have to go there, and find out, if not in person, then via our robots.

### The Polar areas

If we confirm the existence of frozen water-rich volatiles in permashade craters near both the Moon's poles, we are likelier to find plenty in similar coldtraps on Mercury. Mercury, even though it is closer to the Sun, and therefore both warmer, and possibly a less frequent target of impacting comets,

has an edge in that there is only a small fraction of a degree, ~ one arc minute, of tilt in Mercury's axis to the plane of its orbit. The Moon's tilt is about 1.5° – thus on the Moon, there are crater areas that are shaded most, but not all of the time.

The Goldstone 70-meter antenna transmitting and 26 antennas of the Very Large Array receiving, has provided evidence for the presence of polar ice in craters around the north pole of Mercury, in 1991, seven years before Lunar Prospector found evidence of polar ice deposits on the Moon. Some, confusing the usually poor odds of good luck, with nature's laws want to find any other explanation. But hydrogen is the most common element in the Universe, with oxygen third. No molecule is more likely to be abundant than water, H<sub>2</sub>O. If Ockham's Razor is worth considering, water is easily the most elegant, the most simple, and the most natural explanation.

Evidently, Mercury's polar subsurface temperatures are cold enough, any internal planetary heat notwithstanding. That is good news! It means that if we dig down elsewhere, it will likely be cold enough there also.

### Mercury's Lavatubes

On Earth, we find lavatubes wherever runny, not-so-viscous lava has flowed. We find them in shield volcanoes, with gentle profiles unlike Mt. Fuji or other classical cone volcanoes. Thus the Island of Hawaii, which in its entirety consists of that portion of the flanks of the twin volcanoes, Mauna Loa and Mauna Kea, above sea level, is honeycombed with lava tubes. Now we find shield volcanoes of gargantuan proportions on Mars, but none on the Moon that we have yet identified as such.



However, we find them on Earth and on the Moon in lava sheet flows. The first evidence was the many sinuous or winding rille valleys, which are now universally believed to be collapsed lavatubes of vast proportions. That lunar tubes are so much larger in scale than terrestrial ones, both in length and in cross section, suggests that in this case, size is in an inverse relationship with the host planet's gravity. The gravity on Mercury and Mars is two plus something times greater than that on the Moon and about three eighths that of Earth. So we might expect lavatubes on Mercury to be comparable to those on Mars, and somewhere in between in size, but still eminently usable as ready made shelter from the hazards of cosmic weather and thermal extremes.

Bryce Johnson reports several sinuous rilles in mare-like areas on Mercury. The total volume of uncollapsed lavatubes on Mercury is likely to be much smaller than that on Mars were such flows were immense, or on the Moon, both because lunar tubes are likely to be much larger in scale and because on the one hemisphere of Mercury that we have photographed, the extent of lava sheet flooding has been comparatively minor.

Any intact lavatubes on Mercury, could support settlements, industrial parks, warehousing, you name it. Those nearest the poles in the more thermally less extreme climate zones will have the edge.

[Since this was written, **extensive lava floods (suggesting lavatubes) have been mapped conveniently near Mercury's North Pole.**]

### Around and around – Keeping up with the terminator

That Mercury's dayspan-nightspan cycle is so long, 176 days or 6 months long, provides an advantage. On Earth, the terminator advances at over a thousand miles an hour at the equator and about 750 miles an hour at mid latitudes (mid 40's, north or south). On Mercury, at the equator, the sunrise and sunset terminators advance some 87 km = 54 mi per day, or just 3.6 kph = 2.2 mph. One can almost walk that fast, though probably not in a space suit. As you go further away from the equator towards either pole, that slow walk becomes a crawl.

Put it another way, the sun marches across the sky at just 2° a day, compared to 360° here on Earth.

The area just behind the sunrise terminator will likely be much more pleasant than the area just ahead of the sunset terminator. Ten days after sunrise, the Sun will be only 10° above the horizon at best, less, away from the equator. One could linger in an area for a week or more before moving on.

Imagine, if you will, a circumpolar railroad, that hugs the pole on the side of the planet facing the sun at perihelion, and dropping to lower latitudes on the side facing the Sun at aphelion, say along the interface between the coolest two zones in the graphic, page 30.

Now imagine six settlements along the track. One could move to the next settlement every 29.3 days, or if there were just five settlements, every 5 weeks.

The permanent part of each settlement would be living space, with the highly functional spaces on railway cars, along with the expensive mining and processing equipment. It would be a different way of life, but one more settled than that of terrestrial nomads. Consider how many persons now have two homes, one for winter months, another for summer months.

Each trackside settlement would have to be dud in, of course, just to be safe from radiation hazards. If actual time spent traveling from one location to the next was relatively trivial, say a day or two at most, the railroad track could be simply covered with a shielded shed all along its route.

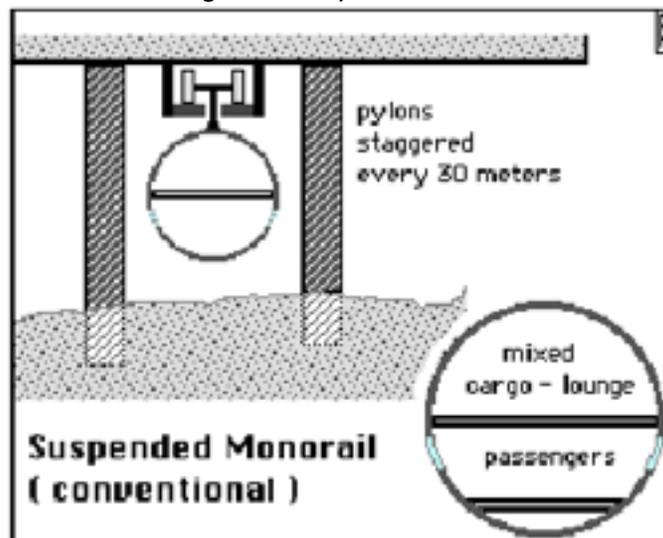
Sound like too much of an adjustment? Consider the adjustment northern peoples have made since leaving Africa. Humans are amazingly adaptable, and quickly adjust to new surroundings and conditions, learning to be at home there, learning to love their new life style. In time, humans will spread wherever they can find away to support themselves long term.

On the Moon, Mars, and Mercury, there is no real need to stick with narrow gauge tracks. Right of way is not a problem. We just need to make wider bridges, cuts, and tunnels. An average rail car could be two floors and double the width we are accustomed to having.

On Mercury, solar power at nearly seven times the intensity at which sunlight is available on Earth, could power rail systems. Overhead monorails would fit in nicely with overhead shielded shed structures.

Of course, if we can find sufficiently abundant materials with which to make a circumpolar superconducting maglev line, that would work too.

All we have to do is survey the route, and if the terrain does not lend itself, make the necessary alterations. Now a monorail system under a shield shed all along the way, would simply adjust pylon length rather than smooth out the host right-of-way terrain.



North circumpolar or south? The overall ease of the terrain and the comparative wealth of resources along each route would be factors to consider. Just were the north and south magnetic poles are located might also be something to consider.

#### Mercury Trivia

- **The surface area of Mercury** is about one seventh that of Earth: ~28,000,000 sq. mi, ~73,000,000 sq km, or put in more familiar terms, **about as large as North and South America and Africa together**, and twice as extensive as the surface area of the Moon.

- **No intra-Mercurial planet** or asteroid has ever been found, false reports of one hastily christened Vulcan, notwithstanding.
- **Mercury's orbital eccentricity and inclination** of its orbit to the main plane of the Solar System (which should be that of Jupiter's orbit, not Earth's) are both much greater than for the other inner planets. Is this the relic of some major impact earlier in its history? The Caloris Basin, is the largest impact site we are aware of on Mercury, but we have only photographed one hemisphere.

#### **Mercury Messenger Trivia**

- This is a Discovery class mission
- To become the first spacecraft to orbit Mercury, Messenger must follow a path through the inner solar system, including one flyby of Earth, two flybys of Venus, and three flybys of Mercury
- Due to arrive in orbit about Mercury four years from now, March 18, 2011, Messenger is the first craft to orbit around the quicksilver planet
- These seven instruments are on board: Mercury Dual
  - Imaging System (MDIS), Gamma-Ray and Neutron Spectrometer (GRNS), X-Ray Spectrometer (XRS),
  - Magnetometer (MAG), Mercury Laser Altimeter (MLA)
  - Mercury Atmospheric and Surface Composition Spectrometer (MASCS), Energetic Particle and Plasma Spectrometer (EPPS)
- Mercury Messenger is designed to answer six broad scientific questions:
  - Why is Mercury so dense?
  - What is Mercury's geologic history?
  - What is the structure and state of Mercury's core?
  - What is the nature of Mercury's magnetic field?
  - What unusual materials lie at Mercury's poles?
  - What volatiles are important at Mercury?

official site: <http://messenger.jhuapl.edu/>

#### **Brainstorming for fun and profit?**

Well, I don't know about profit, but the fun of this exercise is in looking for ways to extend a human presence on Mercury beyond the poles. We learned that not all of Mercury is uniformly hot, that there may be natural shelters in convenient places, in the form of near polar lava tubes.

We realized that the slow march of the Sun across the Mercurial sky opens up plausible semi-nomadic lifestyle options. By the time we get to go, we'll probably have found many more choices than these.

**MMM #238 September 2010**

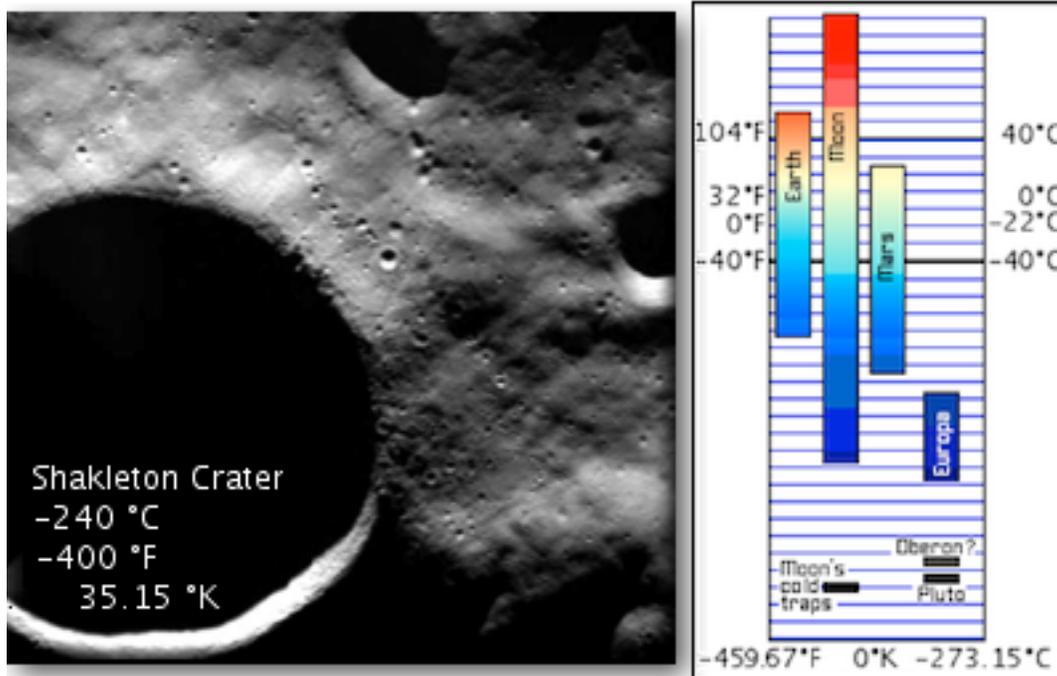
## **Conquest of Moon's Cold Traps Is the Key to anywhere in The Outer Solar System**

By Peter Kokh

We always knew that the floors of the Moon's permanently shaded polar craters would be cold. After all, the brightest thing in their heavens, except for a rare passing comet, would be a star less brilliant than Sirius.

We always knew that we would have to bite the bullet and develop such cryomaterials, cryolubricants and other systems, that is, if we wanted to land rovers and long-operating probes on the fascinating moons of the Outer Solar System. But we thought that was a long way off, a challenge for another generation. Now it is suddenly our challenge.

Perhaps most writers and planetary scientists and lunar enthusiasts, see the availability of water-ice as an overriding reason to set up shop first at one of the Moon's poles. But now it seems that the challenge of learning to store power so that we can get through the lunar night, and to scavenge volatiles from moon dust, may be the less daunting challenge. After all, the reward for doing so is to open the Moon globally, not just at the extremely atypical poles.



Yet, while the priority of “doing the poles” might now seem to be a peg or two down the line, we do need to get busy developing the materials and systems that will allow us to study the lunar cold traps, and study their frozen bounty in depth. Will we need to use super-magnetic bearings instead of still science-fictional cryolubricants? Won't the recently discovered fact that these craters are electrically charged rule that out? We have a lot of homework to do, and the “readiness state” of the needed technologies is about 1, if not less, on a scale from 1-10.

But think! If we meet this challenge, suddenly the Outer Solar System is ours as well, decades ahead of the wildest expectations! The Moon is suddenly the key to the Outer Solar System! Not Mars, not Ceres, not even Europa or Callisto. The Moon? Suddenly planetary scientists bored or disinterested in the Moon, have a very big stake in the next decade of lunar exploration. The Moon will become the proving ground for outer system rovers.

### What we could see sooner in the Outer Solar System

What we have learned with orbiters has been nothing short of amazing, and it continues to get more so. Scientists find ever more elaborate ways to coax more significance out of readings that once might have been considered noise. This is nowhere more true than with the Cassini team and the ongoing investigations of Saturn and its extensive family of moons and moonlets. What they continue to discover beneath the clouds of Titan, which vies with Europa as the most intriguing world beyond Mars, brings startling new information month by month as the extended mission continues.

That said, capable rovers on Jupiter's Europa, and on Saturn's Titan, Iapetus, Enceladus and other moons around the ringed giant could tell us more. Now that the need to develop some of the needed cryo-technologies is urgent because we need those materials and systems to unlock the Moon's tightly held secrets, can but advance the day when we can send similar cryohardy instruments to the icy outer worlds.

### Ceres, Pallas, Vesta

Dawn is on its way to Vesta. The plan is to orbit the brightest of all asteroids, as seen from Earth, for 12 months, then move on to an eventual visit to Ceres where it will go into polar orbit around it. Such an orbit will allow very thorough mapping as Ceres rotates below.

Ceres is the only asteroid massive enough to reshape itself into a really spherical body. Its surface likely hides an ocean, and as the first planet or moon to reach this stage, just might have been the first place in the system to give birth to some form of life.

Ceres dominates a significant area: almost 15% of all Main Belt Asteroids lie within 60° of Ceres at any given time and remain there for fifteen years or longer before drifting out of range. It will someday be the primary center of population, industry and services for the belt. And many of the technologies developed there will be useful in opening up the Jovian system. Ceres' temperature range is lower than that of Mars, but higher than that of Jupiter's four great moons. We look forward to Dawn's visit in 2015.

Pallas orbits at a similar distance from the Sun, but has a unique vantage point for study of the Sun and the inner solar system. Its 35° inclination to the ecliptic gives it a high perch both above and below that plane.

Vesta may be the biggest object in the system with a cold solid core. At Vesta's center of gravity, you would have a "negative zero-g" as the masses overhead would cancel each other out. That could make that point a unique physics lab. This world may also have lavatubes.

### **Oberon and Miranda**

I have singled out the moons of Uranus, because along with their mother planet, their plane of rotation is almost perpendicular to the plane of their orbit around the Sun. That means that for half of Uranus' 84 year long circuit around the sun, alternately the north and south poles of its moons are pointed not just perpendicular to the sun, but away from it. Vast circumpolar areas on Oberon, Titania, Umbriel, Ariel, and Miranda will be in darkness for decades, which could lower temperatures below those experienced on Neptune's moons twice as far out from the Sun. But that is a very uneducated guess, and we welcome a real calculation.

### **Pluto & Charon**

The calculated temperatures at Pluto's (and Charon's) poles are some 10° C, 6° F higher than those recently measured in permanently shaded lunar polar craters. But to be honest, we must keep in mind that Pluto is still not too far past its closest point to the Sun, and that in its very eccentric orbit, it will receive less than half the amount of sunlight it now gets, before it rounds the "aphelion" corner some 120 years from now and starts the slow arc back inward. Given this consideration, Pluto's poles may become as cold as the Moon's. Yet the Moon's cold trap craters may not have seen sunlight for billions of years. So Pluto might still be second.

### **The Pioneers and the Vikings – are RTGs the answer?**

These probes are significantly beyond the traditional "outer limits" of the solar system and just keep on sending back data. But they do not have moving parts, or, if any, they are warmed by an RTG, a radioisotope thermoelectric generator, a marvelous device without which much of what we have accomplished in space would still be on the science-fiction wish list. Are they part of the answer to the challenge of ground-truth probes in permanently shaded craters at the Moon's poles? Maybe – if we can shield the surface we want to study from the heat output of the RTG. Remember Heisenberg's uncertainty principle. What we observe is altered by our observation of it. Now that principle may be the case for quantum dimensional investigation. But a parallel effect may hamper ground truth probe whose instruments and "claws" and "drills" are kept warm enough to operate by any kind of heat device.

So we think, that this is not the answer if we want unstilted results. Heat may or may not be a problem for harvesting polar ices; but it will be for studying them. TTG powered instruments will do to the icy moondust what the scalpel does to the frog in order to learn from dissecting it. So we think that the best approach is to take the plunge and by trial and error, challenge after challenge, in one area after another, develop true cyro-materials and cryo-technologies. The rewards of doing so will be to advance the pace of Outer Solar System science, and to telescope the time it takes us to go from being an intercontinental species to one that is truly interplanetary, and interplanetary with interstellar dreams.

Suddenly, the Moon becomes important for more than those who have been interested in uncovering its secrets and putting to use its resources for the benefit of human survival on a cleaner, greener Earth.

In a future article, Dave Dunlop will tell us how we can accelerate our development of cryo-technologies through X-Prize type programs and NASA engineering challenges. At the very early stages of this process, there may be groundbreaking advances that will prove to be within the scope of student and university scale projects.

It clearly falls within the Moon Society's mission to instigate and encourage this type of research. On the Moon in general, we need lubricants that will perform well at both colder and hotter temperatures than normally encountered on Earth. Looking down "paths not taken" during the development of silicones and silicone technologies, we may make some useful advances that will help in "ordinary" lunar hot and cold conditions, but not at the poles. Here we may need to start from scratch. Break-throughs may come slowly at first, but we need to take the plunge and keep on plunging. PK

MMM #242 February 2011

## O'Neill's High Frontier Updated and Modified

By Dave Dietzler

Choosing the machines for the lunar industrial seed<sup>1</sup>, designing them and building them will require years of careful consideration and a small army of engineers, but there is no fundamental scientific or philosophical reason that this cannot be done.

### Introduction

It has been over thirty years since "The High Frontier"<sup>2</sup> was published and during that time most of the people I've discussed it with have agreed upon a modified version of things. In discussions and e-mails most of us have agreed that

The 100 million ton plus space colony is out of the picture and most SPS assembly work should be done in GEO with teleoperated robots.

O'Neill and others focused on the space colony and kind of slighted the Moon.

They figured the mining machines and mass driver would be launched from Earth with low cost Shuttle Derived Vehicles landed on the Moon in pieces and assembled by a crew of about 50 Moon miners<sup>3</sup>.

Raw regolith would be launched into space where it was processed into metals for construction, oxygen for rockets and excess raw regolith and slag that would be used for space colony radiation shielding as well as mass driver propelled space ship reaction mass. Regolith processing would be done at L5 construction shacks. These modular construction shacks would be launched from Earth, assembled in LEO and propelled with arc-jets to L5. The space colony would come next and 10,000 workers would be transported from Earth to do the work of SPS construction. Solar Power Satellites built at L5 would be moved down to GEO to sell power and start accruing profits.

The Moon plays a much more complex role in our vision. We will include tourism, astronomy and scientific research, SETI, asteroid mining, asteroid deflection and materials for ships to Mars and other destinations in the solar system. Moon mining will not be limited to simple open pit mining of regolith. Mining bases will be located on mare coasts where aluminum and calcium rich highland regolith as well as basaltic iron, magnesium and titanium rich mare regolith can be accessed.

There will be polar ice mining camps, KREEP mining in the Imbrium rim, mining of pyroclastic glass for native glass and elements that can be extracted from the surfaces of glass particles more easily than by extraction from complex minerals, and possibly even drilling for volcanic gases. Mining of vast areas of the mare for solar wind implanted volatiles including normal helium 4 and possibly helium 3 that are not likely to be found in polar ices of cometary origin - these all feature prominently in our vision.

Numerous mining bases will be linked by dirt roads and railways to mass driver sites and a circumlunar power grid will emerge for 24/7 power. All materials, or at least the 99.5%, needed for bootstrapping of lunar industry, creation of construction shacks and space tugs, and for SPSs will come from the Moon and possibly from the asteroids as well.

We are not certain about launching materials and finished products to L5. It might be possible to launch to L2 mass catchers and then haul cargos down to GEO or even launch directly to GEO. It might also be more plausible to launch to LLO (low lunar orbit) and collect the payloads, and then haul them down to GEO.

It is probable that L5 will not be very important and that construction shacks will all be located in GEO and that these will be mostly robotic.

While the nearly three second lag time that exists for teleoperation of robots on the Moon will hamper robotic operations on the Moon but not prohibit them entirely, the fraction of a second lag time for teleoperation of robots in GEO will not be a significant barrier to robotic construction in space.

#### Transportation System

Earlier it was thought that the space shuttle or a space shuttle-derived vehicle would launch cheap and that LH2/LOX fueled rockets would be used to propel cargoes from LEO to the Moon. Our view is quite a bit different. Launch costs are high, even with Falcon rockets that offer the lowest price to LEO at present.

- We propose the use of **electric drives** to move cargoes from LEO to an L1 space station economically. Propellant masses for electric drives will be only a fraction of the mass of the cargo. Chemically propelled rockets would require propellants that amass several times the cargo mass and subsequently the cost of launching this extra mass to LEO would be several times higher than with electric drives.
- At the **L1 station** space storable water from lunar polar ice would be converted to LH2 and LOX for landers. The first payloads would consist of solar panels, digging machines, regolith refining equipment and fueling systems for aluminum and liquid oxygen powered reusable landers.
- **Lunar fuels** must come on-line early to eliminate the cost of launching propellants for landers from Earth's surface to LEO.

#### Bootstrapping and ISRU [In Situ (Latin for "on site") Resource Utilization]

We will not ship a complete mining system to the Moon and then focus on space construction. To reduce upported<sup>4</sup> mass and costs, we will land an industrial seed that will include manned habitat to bootstrap up industry on the Moon.

We will start out with small mining machines and build bigger ones. We will even build the mass driver or drivers on the Moon. We will mine at **multiple sites** (poles, mare coast, pyroclastic glass fields, KREEP terrains, crater central peaks, lava tubes, perhaps even drilling near volcanic domes) to get all necessary materials and link the mining sites with railroads to the mass driver sites.

Several years, perhaps decades, of work will be needed to build up industry on the Moon to the point at which SPS construction can begin. Long-term bonds will have to be sold to finance this project along with support from international governments.

The bootstrapping and ISRU concept will be applied to the SPS construction shacks too. We will launch the "bare bones" for these stations from Earth and enlarge them with metals and finished products from the Moon until we have the space infrastructure needed to build SPS. The construction shacks will be located in GEO. Lunar mass drivers will launch materials into space and mass catchers will haul those materials to GEO instead of L5. The GEO construction shacks will house only enough humans to supervise the robots that are teleoperated by Earthside crews with only a fraction of a second lag time for radio waves to travel from Earth to GEO and back.

#### More Brains Equals Less Payload and Lower Costs

The construction of lunar industry and SPSs will require a lot of planning and intelligence to figure out just how to do; But physically, it will involve no more time, energy, robot labor and manpower than building a giant space colony for 10,000 people would!! Why build that space colony when we need more infrastructure on the Moon and 90%+ work in space can be done with teleoperated robots and ground crews around the world connected by the internet???

We need more than just a single strip mine in the mare. While the **mare** can supply plenty of iron, titanium, magnesium, silicon and oxygen and lesser amounts of aluminum and calcium, the **highlands** can supply more vital aluminum and even cement produced by roasting highland soil in solar furnaces. There are highland areas where the regolith is 98% anorthite and this would be ideal feedstock for aluminum, calcium, silicon and oxygen production.

**Calcium** might become the conductor of choice since it is a better conductor than copper and highland soil is richer in this metal than mare soil. Calcium metallurgy and manufacturing for out-vac cables and perhaps even mass driver coils must be developed. So the coasts become attractive.

There might even be blasting into hard rock with magnesium/LOX-based explosives if we find rock out-crops rich with industrial metals. The Imbrium coast is attractive because it contains lots of KREEP that can supply rare earth elements, potassium, phosphorus, thorium and uranium.

The Aristarchus pyroclastic glass fields that could supply nickel, copper, zinc, gallium, chlorine and other elements and the Marius Hills beneath which there might be chambers of volcanic gas evoke curiosity. Crater central peaks have never been sampled. Could they contain heavier elements thrust up from the mantle?

I have speculated that since chromite is found in mare regolith, and this heavy mineral sinks in lava to form thin layers like those of the Bushveld igneous complex in South Africa, there might be layers of chromite deep beneath the mare that have been thrust up in some crater central peaks. If so, this would be quite a find, since chromite is a source of the vital industrial metal chromium.

The best mining sites and the best mass driver sites might not match so it will be necessary to build a **system of roads and railways** to link them. While it has been stated that mineral processing would be best done in space where solar energy is constantly available, a system of cables and solar power plants at the limbs of the Moon could supply energy to mining and mass driver bases constantly and when we are looking at things on this scale it should not be impractical to build a lunar power grid. It's also possible that a lunar power beaming system might prove to be superior to GEO powersats. The major obstacle here is not the construction of vast solar power farms at the limbs of the Moon for LPS but the construction of transmitting dishes miles in diameter. Perhaps large farms of small phased array dishes could do the job of transmitting microwaves 240,000 miles to reasonably sized rectennas on Earth but I am no expert when it comes to this so I might be way off target.

Choosing the machines for the lunar industrial seed, designing them and building them will require years of careful consideration and a small army of engineers, but there is no fundamental scientific or philosophical reason that this cannot be done. Three dimensional printers guided by computers that can crank out parts made of basalt, glass and metals could be at the heart of the bootstrapping lunar industrial seed. Robots will be key to assembly work.

Metal casting seems likely, but we will rely on cold working like forging and extruding as much as is possible. A manned presence will also be essential. Skilled human workers are the ultimate multi-purpose robots. Humans might need biological sustenance, rest and recreation, but we are very versatile. Robots tend to be better and rapid repetitive jobs where high accuracy and reliability are required.

**DD**

#### **Footnotes & comments by editor:**

##### **1 The (Lunar) Industrial Seed:**

"Defining the Lunar Industrial Seed", Part 1, D. Dietzler, MMM #229 October 2009

"The Lunar Industrial Seed", Parts 2, 3A, D. Dietzler, MMM #230, November 2010

Note: these issues of MMM are only available by member username and password from  
<http://www.moonsociety.org/members/mmm/>

However much of this material is also available from

<http://groups.google.com/group/international-lunar-research-park?pli=1>

Also check out these Google Dox files

[https://docs.google.com/document/edit?id=1n3OXXV0zYqfMCNCjj4Znaqf3lVw8s\\_0u7ChuGwMXKDzQ&hl=en#](https://docs.google.com/document/edit?id=1n3OXXV0zYqfMCNCjj4Znaqf3lVw8s_0u7ChuGwMXKDzQ&hl=en#)

##### **2 The High Frontier** by Gerard O'Neill,

an Apogee Books Publication: "In the mid-1970's the late physics Professor Gerard K. O'Neill published his book High Frontier. In it he laid out a possible road map for human settlement."

<http://www.apogeespacebooks.com/Books/Highfrontier.html>

##### **3 O'Neill branded people who preferred living on a natural world to living inside constructed space settlements as "planetary chauvinists."** He firmly believed that as few people as possible should be stationed on the godawful Moon, and then in short tours of duty only. To this day he has a strong fol-

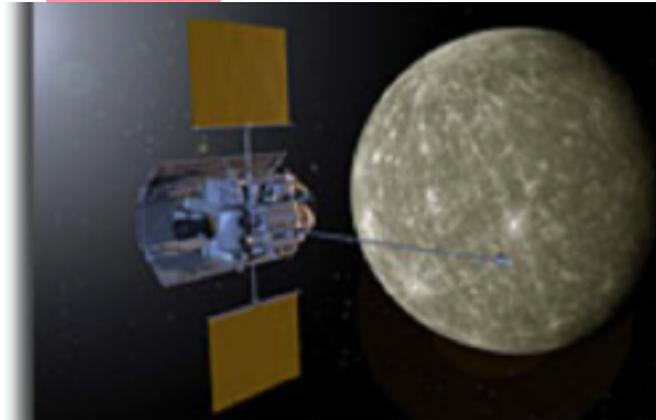
lowing. For our critique of his space settlement concepts see: "Reinventing Space Oases"

[http://www.moonsociety.org/publications/mmm\\_papers/reinv\\_so.htm](http://www.moonsociety.org/publications/mmm_papers/reinv_so.htm)

4 "upport, upported, upports" – shipping "up" Earth's steep gravity well. (thus, "downports" as well) DD

## MMM #244 April 2011

### MERCURY - A Coming Attraction



**MESSENGER** (Mercury Surface, Space ENvironment, GEochemistry, and Ranging) enters orbit about Mercury on March 17<sup>th</sup>. 2011. The Science Mission begins April 4<sup>th</sup>.

By Bryce Johnson

We are about to add another planet to the short list of potential New Worlds for human habitation. Much of the planning being done today for lunar bases is founded on data gathered by the Lunar Reconnaissance Orbiter. That mission gave us a global picture of the Moon's composition. With it we are able to strategically plan lunar exploration and settlement using real-world facts, not just wishful thinking. The Messenger mission to Mercury has a similar role. Over the next year, data gathered by Messenger will educate us about Mercury's surface chemistry to a level far surpassing what we knew about the moon prior to the Apollo landings. Aside the Moon and Mars, Mercury will be the only other planet for which we have so much knowledge.

Messenger is already an unqualified success. The space craft has photographed the Earth and the Moon, flown by Venus twice and Mercury three times. The three Mercury flybys have revealed details about Mercury's atmosphere; the presence of relatively recent volcanic vents; higher than expected abundances of Titanium and Iron in Mercury's regolith; the presence of a molten outer core and a much better understanding of Mercury's weak, but persistent, magnetic field; all that in less than a week's worth of combined encounter observations.

The orbital mission is expected to last a year and the spacecraft is healthier than expected. In particular its existing fuel reserves are about 40% of what they were when the spacecraft left Earth. This is better than expected and is owed to the incredible accuracy with which Messenger has hit its planned targets during its long flight. The targeting has been so accurate that 21 of 38 originally planned Trajectory Correction Maneuvers (TCMs) were cancelled as unnecessary.

A possible result of this efficiency is that Messenger may have enough propellant on board after its planned mission to support an extended mission of at least 90 days – an entire Mercury year. This has yet to be suggested by the science team, however. The science data likely to come from the orbital mission is planned to dwarf the data already in hand from the flybys. It will take years to shake out firm conclusions about Mercury's history and present phenomena. However, as a foundation for human development, what is in hand to date portrays Mercury as a potent venue for industrial scale resource development.

**"Understanding Mercury is fundamental to understanding terrestrial planet evolution."**

For starters, Mercury is evidently the most Titanium-rich planet in the Solar System. According to one report from the University of Arizona, there are at least three locations on Mercury's surface where Titanium concentrations exceed 25% of the regolith bulk material. Most of this is contained in oxides of Titanium, such as rutile or mineral garnet. In one particular region west of the Caloris Basin, rutile concentrations of up to 37% were derived from both mid-infrared telescopic observations and data from the second Messenger flyby. Pure rutile is 60% Titanium by weight. This would imply that a metric tonne of regolith in this region would contain as much a 222 kg of actual Titanium metal. For other regions of Mercury, rutile seems to have roughly the same compositional role as ilmenite does on the Moon. Ilmenite has also been suggested in noticeable quantities elsewhere on Mercury. This was initially evidenced by spectrographic observations made shortly before the probe's launch

Iron in Mercury's regolith was previously thought to be in concentrations limited to no more than 3% iron-oxide. Messenger data now indicates concentrations may be more like those in "high titanium/high-iron" lunar mare basalts, such as those collected by Luna 16 (15.1% iron) and Apollo 11 (15.45). Actual iron oxide (FeO) abundances on Mercury may be between 7 and 10 percent.

Mercury's iron is apparently distributed differently. Rather than have tiny amounts mixed more or less evenly through the regolith, Mercury's surface iron appears to be in the form of 'blebs' or tiny bits of iron situated inside basaltic rocks much like tiny bubbles of air might be seen frozen into an ice cube. This could explain the seeming conflict between the historical observations indicating low iron content in the regolith and Messenger's data. As with so many similar mysteries, the orbital phase of the mission should provide some conclusive answers.

Generally, Mercury's surface mineralogy includes magnesium-rich orthopyroxenes and olivines (the latter curiously low in concentration inside the Caloris basin); clino-pyroxenes rich in calcium, magnesium and sodium; potassium feldspars and sodium-bearing feldspars. Both calcium- and sodium-rich garnets, such as pyrope and grossular, are also apparently present in insignificant quantities. Actual percentage abundances have yet to be confirmed and will require consistent data from a number of orbits by Messenger to be characterized with certainty.

Messenger's second flyby also revealed the astonishing presence of water in Mercury's atmosphere. The word "water" is something of a misnomer here as what Messenger actually discovered were hydroxyls - various molecules that include the (OH) hydroxyl radical, minerals which may have formed in the presence of water. The particular instrument that revealed the presence of hydroxyls was the Fast-Imaging Plasma Spectrometer (FIPS) that measures energetic ions. Water or hydroxyls are detected by first collecting energetic ions in Mercury's atmosphere, then determining a ratio of their mass to their charge.

What the FIPS instrument discovered were 'free radical' ions corresponding to molecular weights of 16 and 18. Oxygen has an atomic weight of 16 while water molecules have molecular weights of 18. No plausible elemental combination has been envisioned for these particular readings, leading the Messenger science team to conclude that there must be a source of water molecules on Mercury itself. The abundance of the hydroxyls is roughly one for every three or four sodium ions in Mercury's atmosphere. This is likely to be more than can be reasonably expected from solar wind deposition alone. Getting more definitive data for the presence of water is a high priority for the orbital phase of the mission.

Messenger's orbit over Mercury will start out with a highly elliptical near-polar orbit with a perihelion [near Mercury] distance of 200 kilometers and aphelion [away from Mercury] of about 15,000 kilometers. It will be oriented more or less over the terminator with about six degree inclination referenced to it. In other words, the orbit will be inclined to Mercury's equator by about 82 degrees. This will bring it over both of Mercury's poles and it should allow confirmation of any polar ice deposits, if they exist. The low point of Mercury's orbit corresponds to a point on Mercury's surface centered at about 60° north longitude. Messenger will be in constant sunlight while not having to be too severely heated by sunlight reflected from Mercury's surface. The same orbit strategy might be followed by early manned missions to Mercury as well, particularly if a polar site is chosen for the initial base.

Physical features on Mercury include an astonishing system of over 200 "graben", or trench faults, radiating from the crater Apollodorus located inside the Caloris Basin. There are similar features of this type elsewhere in the solar system. Scarp formations have been identified all over the planet and the overall picture is that Mercury at one time went through a period when the planet's crust uniformly shrank.

To date no lavatubes have been identified, but that is not surprising as they are subsurface features sometimes betrayed by local "skylight" collapses on very high resolution photographs. Mercury's gravity is similar to that of larger but less dense Mars -  $3/8^{\text{th}}$  G. So lavatubes on this planet like those on Mars are expected to be of intermediate size between smaller ones found on Earth and much vaster ones found on the Moon. Mercury has extensive areas covered with lava sheets so it would be surprising if we did not find equally extensive tube networks in time.

Taken as a whole, Mercury is a planet with all the energy and resources needed to economically construct advanced facilities; sustain agriculture and comfortable, large-scale habitats; support large-scale space transportation systems; conduct valuable solar, planetary and stellar science programs and, eventually support numerous industries.

Mercury's solar flux is perhaps its single greatest asset, averaging 8.2 times the solar flux at Earth's distance. This flux generates temperatures on Mercury's equator over  $700^{\circ}$  Kelvin,  $427^{\circ}$  C,  $800^{\circ}$ F. It would be easy focus this energy to process metals out of the regolith (surface rock powder blanket.) Surplus energy combined with the presence of workable resources generally results in export-scale productivity. In Mercury's case, even relatively low-grade oxides can be worked economically due to the super-abundance of energy available. What is then needed is an economical transportation system that can transfer substantial masses of product to consumers.

The high velocity requirements for trips between Earth and Mercury do not favor 'high-impluse' transportation systems such as LOX.LH2 rockets, at least for very large payloads. However, solar sails are capable of delivering hundred-tonne payloads to Mercury from Earth. Sails starting from Mercury can deliver payloads to any planet in the solar system with flights departing every 116 days to Earth 145 days to Venus, 101 days to Mars and just over 8 days to just about everywhere else. The time of flight for solar sail missions is a function of the area and mass of the sail and the mass of the payload. Typical solar sail missions usually involve spiraling orbits around the Sun requiring trip times that can be several times longer than classic Hohmann transfers. This why solar sails are often relegated by some writers to unmanned cargo service.

In truth, solar sails can be considered for manned flights from Mercury if it is assumed the manned payload has its own propulsive system and the sail itself is left on a high velocity, flyby trajectory past the target planet. Since solar sails require no in-space servicing, repair or refueling and since they can, in all likelihood, be use for several flights, they do not have the recurring cost issues that plague all other reusable, high performance technologies. As a result, in net terms, Mercury can produce anything made with the metals and alloys commonly used in industry today. Silicates and silicate composite materials are also possible. Cast basalt items are bound to be common products.

Glass is a Much better bet on Mercury than on the Moon, owing to the greater abundances of the additives used for special properties. For example, high quality optical glass requires 318 parts of pure silicon, 125 of potassium, 56 of zinc, 37 of sodium, and 9 of boron per 1000 parts of product, the remaining 545 parts being oxygen. With the probable exception of boron and maybe zinc - together just 6% of the total - all the rest is available in Mercury's surface material. Since boron and zinc are likely available on Mars, there is potential for coordinated trade. The high grade optical glass produced would be available for construction of very large mirrors used in telescopes that would easily have several times the size and power of the Hubble ST. And Mercury's 88-day-long nightspan makes it an ideal platform for astronomy of all.

Volatiles are still a major unknown. Hydrogen has been detected by Messenger in Mercury's atmosphere. Surface resources of hydrogen are another matter. The quantity of free hydrogen has been estimated at around 200 atoms per cubic centimeter but this predates Messenger and it is not clear that this is an estimate for the surface or at orbital altitudes. This does not sound like much, but it is way more than can readily be explained by solar wind implantation alone given the high temperatures of Mercury's surface. Evidence has accumulated for water ice deposits in shadowed craters near both poles. Whether this ice contains any other volatiles remains to be determined. However, Mercury does have a resource of carbon, hydrogen, nitrogen and chlorine available; Venus' atmosphere.

In an industrial development scenario, there is incentive for cislunar facilities to tap Venus' atmospheric resources preferentially to Mars'. Venus does have a light mission energy advantage, over seven times the solar flux, a slightly more frequent launch window frequency to Earth when compared to Mars. The problem is that with the notable exception of high solar flux, the advantages enjoyed by Venus over Mars are usually less than a factor of 1. This means that, from the point of view of real costs

o access and develop either planet, there is not enough difference between the two to ignore the inaccessibility of Venus' surface.

Mercury, on the other hand, has every incentive to access Venus' atmosphere and would probably not need any materials from Venus' surface. Flight opportunities between Mercury and Venus are six times more frequent than from either Earth or Mars to Venus. Solar sails are still quite efficient as mass transporters from Venus and some sail materials can actually be produced from Venus' atmospheric carbon.

Venus' atmosphere can also slow down an inbound spacecraft even at the velocities characteristic of Mercury-Venus transfers. The net effect is that a routine transfer of materials between Mercury and Venus can be an economically competitive option. An ongoing combination of Mercury's resources and energy abundance combined with Venus' atmospheric resources and energy abundance would have massive implications for progressive exploration and settlement in the Solar System.

Colonization of Mercury rests on the need for a variety of bulk materials, manufactured products and operational characteristics represented by Mercury's unique environmental attributes or its location in the Solar System. Other planets have 'hard' vacuum available on a scale equal to Mercury's. Other planets have high heat of day available; ditto intense cold at night. But no other planet outside of Earth-Moon space contains them all simultaneously. As solar sails become a proven transportation technology, accessing Mercury will become a much easier proposition than is now the case with chemical propulsion.

Mercury is not without dangers. Writers go out of their way to point out how hot it gets on Mercury's surface at noon. What is never mentioned is just why anyone would want to be out on the surface at that time. Science fiction scenarios aside, Mercury's surface does not become deadly hot the second the Sun pops up over the horizon. Since Mercury rotates so slowly compared to the Moon, it actually takes about six weeks before the Sun is high enough above the horizon to raise temperatures to the boiling point of water.

Structures on Mercury do need to be protected from extremes of temperature, ionizing radiation, and micro-meteorites. These are all issues for bases on the Moon as well. Superficially, the only real difference between the two might be the greater thickness of regolith shielding needed by the Mercury facility. Suitably protected, the same technology used to build bases on the Moon can be directly applied to Mercury.

Looking downrange, Mercury can leverage much more rapid development of Mars and serve as a hub for development of the asteroids and outer planets. It can be successfully developed even if more potent transportation technologies, namely nuclear based, are not developed right away. It can provide unique and advantageous assets to science and industry.

The research goes on. For now, the nail-biting phase of the Messenger mission no longer preoccupies the work of our ad hoc committee. We are now monitoring the Messenger data return and will be able to answer, more authoritatively, all of the issues raised here, plus a host of others, before many more months. **BJ**

- Bryce is a former Moon Society Director from Rockford, IL

**MESSENGER LINKS:**

[http://messenger.jhuapl.edu/mer\\_orbit.html](http://messenger.jhuapl.edu/mer_orbit.html)

[http://messenger.jhuapl.edu/news\\_room/Mercury\\_PK\\_Web.pdf](http://messenger.jhuapl.edu/news_room/Mercury_PK_Web.pdf)