Our Solar System, Our Galaxy, then the Universe

Al Globus, April 2012

Orbital Space Settlements

When thinking about space settlement, most people think in terms of cities on the Moon or Mars. However, in the 1970s Princeton physicist Gerard K. O'Neill came up with a very interesting alternative: cities in free space, in orbit around the Earth or other bodies. These kilometer-scale spacecraft have a number of advantages relative to settlements on the Moon or Mars. These advantages include artificial gravity similar to the Earth, continuous solar energy, easier access to Earth for supplies and markets, larger sizes, and weightless recreation. The primary disadvantage of orbital settlements compared to those on the Moon or Mars is access to materials. Dr. O'Neill resolved this issue with a system to deliver lunar materials to carefully chosen near-Moon orbits where he proposed the first settlements should reside. With the subsequent discovery of Near Earth Objects (NEO), asteroids and comets in orbits crossing Earth's, the orbital space settlement materials problem is elegantly solved by simply co-orbiting with a NEO; and it turns out that orbital settlements built from small-body materials has radical implications for the future of humanity.

NEOs

With the discovery of hundreds of large NEOs, the obvious place to build orbital settlements is close to NEOs that supply the materials. It may even be possible to bring large numbers of small NEOs into High Earth Orbit (HEO) so that early settlements can be near Earth for resupply and to provide a market for goods produced on settlements.

The smallest space settlement that makes sense for permanent habitation may be around the size of the 5,000 person, 1.57 x 0.65 km living area Kalpana One design[1]. Although larger settlements can be built, we will use this design as our unit of measurement. The mass of any space settlement is dominated by radiation shielding, which requires about 10 tons/m^2 to mimic the protection of Earth's atmosphere. Assuming this level of shielding, each Kalpana One has a mass of about ten million tons. Conservatively assuming a NEO density of two tons/m^3, a 150 m cubic NEO will contain sufficient materials for one settlement. As most of these materials are for radiation shielding, any materials will do. Many NEOs have large quantities of metals, water, carbon, and nitrogen for structure and

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[1] "The Kalpana One Orbital Space Settlement Revised," Al Globus, Nitin Arora, Ankur Bajoria, and Joe Strout, April 2007, http://alglobus.net/NASAwork/papers/2007KalpanaOne.pdf

life support, so a large fraction of NEOs of this size or greater are a potential target for settlement. Estimates of the number of NEO's 100m diameter or greater run around 22,500 although the number of 150 m objects is somewhat less[2]. As many of these objects are big enough to supply materials for many Kalpana One sized settlements, it is not unreasonable to expect that perhaps 50,000 space settlements can be developed near NEOs, with a total population of 250 million or more. That's just the start.

Asteroid Belt

Most asteroids are not in Near Earth Orbits. They are in the asteroid belt between Mars and Jupiter which contains roughly 1.7 million asteroids one km or greater across. As each of these has sufficient materials for around 200 Kalpana One sized settlements or more, a total of over 400 million settlements might be built with a total population of perhaps two trillion.

At this distance from the sun, solar energy is still a practical source. The solar arrays must be much bigger than those used near Earth, but the size is still manageable, particularly for an advanced spacefaring society many centuries or even a few millennia from now.

Small Objects from Jupiter to Neptune

As Life pushes out beyond the asteroid belt, there are a number of small objects suitable for supplying materials for orbital space settlements. These are referred to by various names depending on where they are and what we believe their history to be. These names include the Centaurs, the Jupiter Family of Comets, and the Trojan Asteroids of Jupiter and Neptune.

As we move outward from the Sun the objects have less and less rock and metal and more volatiles: water, methane and ammonia. Thus, it will be less feasible to build settlements out of metal. Fortunately, methane contains carbon and carbon is an excellent structural material. Today, high performance cars, bicycles, aircraft and even spacecraft are increasingly built out of carbon-based materials.

However, as we move further from the Sun the solar flux becomes less and less useful for energy production. At Neptune's orbit solar arrays must be roughly 900 times larger than in Earth orbit to generate the same amount of energy. Thus, it would be best to find another source of energy. One approach is to mine hydrogen and helium from the atmospheres of the giant planets and Titan, separate the isotopes and use them in fusion reactors[3]. This is beyond today's technology but the basic physics are understood.

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[2] "NEOWISE Observations of Near-Earth Objects: Preliminary Results," A. Mainzer, et al., Accepted to APJ, http://arxiv.org/abs/1109.6400

[3] This idea is explored in some detail in Chapter Eight: "Settling the Outer Solar System" of Robert Zubrin's *Entering Space: Creating a Spacefaring Civilization*, Putnam, 1999.

The Outer Solar System

Beyond the last true planet, Neptune, stretches a vast region populated by icy bodies. Parts of this are referred to as the Kuiper belt, Scattered Objects, and the Oort Cloud. The furthest portion, the Oort Cloud, may reach half way to the nearest star, Proxima Centauri, about 4.2 light years from Earth.

While they are widely spread out, the material resources of this region are vast. The Oort Cloud is believed to contain up to several trillion objects one km across or bigger. These objects are very light weight, but even assuming one object per space settlement we get a trillion or more Kalpana One sized settlements with a total population of over five quadrillion.

If these objects can be settled, then Earth will at long last be freed from any possibility of a devastating collision. All the large asteroids will have long since been consumed or at least shadowed by human settlements, insuring that these will not strike Earth. Settlement of the vast reaches of the outer solar system will bring under observation the source of the comets, the last reservoir of objects threatening Life's birthplace.

There is a huge catch, though. We don't know how to generate energy so far from the Sun and there are no vast supplies of hydrogen or helium. Solar arrays are next to useless, continent size arrays will only produce modest power. It may be possible to ship hydrogen and helium from the gas giants, but the distances are immense making this option a poor one. Fortunately, we will have many millennia to develop the physics and engineering necessary. Given the advances of the past few centuries, it is certainly plausible to believe that we will find a way in the thousands of years it will take to settle the small bodies out to Neptune.

If we do find a solution to the energy problem to settle beyond Neptune, remember that these objects may extend half-way to the nearest star. If Proxima Centauri has a similar cloud, then there is an unbroken string of small bodies from here to the nearest star. Instead of slowly expanding, settlement by settlement, out away from Sol, we will begin slowly expanding, settlement by settlement, in towards Proxima Centuari. Assuming that Proxima Centauri has asteroids and comets circling it as does Sol, instead of each new settlement step being harder, with bodies more spread out and energy ever scarcer, expansion will become easier since bodies are closer together as we approach the star. Close in, of course, there will be ample energy supplies in free space all around us.

Thus, we can get to the nearest star not by some heroic journey by dedicated adventurers, but by simply living in the comfort of orbital settlements we've inhabited for hundreds of generations. On our trip to the nearest star we will take friends, family, and neighbors – our whole community. Space settlements by this time will be vast, tens or even hundreds of kilometers across, the size of large cities today. Also, one might expect groups of settlements to travel together for safety and variety. We will also take the plants, animals, and other organisms needed for survival or delight. Indeed, it will not just be a journey for humanity, but for Life itself.

The Milky Way

We live on the edge of the Milky Way galaxy. Our galaxy has 200-400 billion stars spread out across 100,000-120,000 light years. We are on the edge, where stars are far apart. If we can get from here to the nearest one, then we can star-hop throughout the entire galaxy. As we approach the center, settlement becomes easier as the stars are closer together. We don't need stars with planets, just stars with junk around them, the small bodies we, by then, will have subsisted on for perhaps a million years. Near stars we can use their energy, and as we pass to the next we can use the energy technology developed for settling the outer solar system.

We will not need high-speed travel because we will be living off small bodies at every step. Even at 0.01% of the speed of light we can settle the galaxy in about 100 million years. While this is forever to us, it is little in the history of the universe, or even Earth. By this time, there will be at least one living galaxy, ours. Then comes the hard part.

The Next Galaxy

While the distances between stars are vast, light years, they pale compared to the distance between galaxies, which are typically around one million light years. However, while we have never observed them, it is reasonable to expect that, like the space between stars, there are small bodies, perhaps even entire star systems, in these spaces. Can we develop the technology to send the first orbital space settlement across the vast void between our galaxy and the next? Only time will tell, but 100 million years is a long time. Modern science has only existed for a few centuries in the hands of a few billion people, and look what we have accomplished. What could we do in 100 million years with a population measured in quadrillions around each of hundreds of billions of stars? Here's one possibility.

Scientists at the Harvard-Smithsonian Center for Astrophysics recently discovered that galactic black holes can eject stars from the galaxy at up to four or five percent of light speed[4]. Furthermore, planets and other bodies orbiting the star can, under the right circumstances, stay bound to the star. If the direction of this ejection could be controlled, perhaps by a gravity tractor[5], then we could use the Milky Way's black hole to send stars, complete with orbital space settlements, to the next galaxy in a about twenty million years.

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[4] http://www.csmonitor.com/Science/2012/0323/Runaway-planets-ejected-from-galaxy-at-insane-speeds

[5] Gravity tractors have been proposed for moving dangerous NEOs. The idea is to fly a large mass in formation with the NEO and use the gravitational attraction of the mass to nudge the NEO into a slightly different orbit. For stars approaching a black hole, an extremely advanced version of this technique could manipulate the stars trajectory without physical contact.

The energy resources of a star can easily support a civilization for this long and with reasonably careful use of asteroidal and planetary materials a group of orbital space settlements with a population of millions could make it, living in comfort and style the whole way.

Stay tuned.

Editing assistance by David Brandt-Erichsen