KEYNOTE ADDRESS:

"Why We Should Colonize Space"

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I'm very happy to be here. I thank Freeman Dyson for inviting me, and it's a great pleasure to be introduced by him because he is one of the great thinkers in this field. It's also a great honor to be here at a conference inspired by Gerard O'Neill because he too is indeed one of the great thinkers in this field.

I want to say in my talk today, in the Keynote Speech, why what you all are doing here is very important. We hear the question: Why should we send people into space? And sometimes when you see this discussed on television, people say, "spirit of adventure," "because it's there," and so forth. You hardly ever hear the word SURVIVAL mentioned, but I think the word *survival* is important, and it should be mentioned. I was glad to see in the last Space Manufacturing Conference proceedings that the word *survival* was mentioned. Survival is very important.

I think the goal of the human space flight program should be to improve our survival prospects by colonizing space. If we stay on the Earth, we will surely go extinct, and on a timescale that is likely to be short compared to the future main sequence lifetime of the Sun.

The ancient Greeks put all their books in the Alexandrian library and I'm sure they guarded it very well, but eventually it burned down, and we lost most of Sophocles' plays. But we do have seven of those plays today, out of 120, because people did store copies of those elsewhere. So it's good to make copies and store them elsewhere. Space colonies are our life insurance policy against whatever catastrophes might occur to us on Earth. And this is a planet littered with the bones of extinct species, showing us that such catastrophes on Earth do happen to individual species routinely. The great *Tyrannosaurus rex*, which was the greatest predator of its time, or perhaps of all time, was superbly suited for its environment, but it went extinct after only 2.5 million years. We stay consigned to Earth, a small habitat, full of dangers, at our peril. I think survival is an important reason why we should be sending people into space--and we should understand this.

Now, in thinking about these matters, it's useful to think of the Copernican principle. The Copernican principle is one of the most famous and successful scientific hypotheses of all time. In the 20th century, when Hubble discovered that there were other galaxies fleeing from us in all directions and furthermore that there were the same number of galaxies when you looked in all directions, it looked like we were at the very center of a vast explosion. But after Copernicus, we were not going to fall for that.

No, we couldn't be special. If it looked that way to us, it must look that way to anyone sitting on any galaxy. And then you're led to the homogeneous, isotropic, big bang models that were used by George Gamow and his colleagues Robert Herman and Ralph Alpher, to predict the existence of the cosmic microwave background radiation and even its temperature in 1948. This background radiation was then discovered by Penzias and Wilson in 1965, for which they later won the Nobel prize. This is one of the most extraordinary predictions ever made in the history of science to be verified later, and all because of taking very seriously the idea that your location is not likely to be special.

In 1969, I thought of a way to use the Copernican principle to make an estimate of how long things you were observing were likely to continue to be observed. In 1969 I was at the Berlin wall just visiting Europe after college. People wondered at that time how long the Berlin Wall might last. Some people thought it was a temporary aberration, while others thought it was a permanent fixture of modern Europe. I reasoned, according to the Copernican principle, as I explained to a friend of mine, Chuck Allen, who was there with me at the Wall at the time: "Look, there's nothing special about my visit. I could be visiting anywhere during the Wall's history--the Wall just happens to be here when I'm looking. Well, if there's indeed nothing special about my visit, then I should expect to be located at some random point in its existence, because I'm not special. There's thus a 50% chance that I'm somewhere in the middle 50%, in the middle two quarters. Now if I'm at the beginning of that epoch, then one quarter of the Wall's history is past and three quarters remain in the future. So the future of the Wall is three times as long as it's past. If I'm at the end of those middle two quarters, then three quarters are past and one quarter is in the future. So the future is one third as long as the past. So if I'm in the middle two quarters, then the future is somewhere between one third as long as the past and three times as long as the past. If I'm not special, I expect that 50% of the time, the future should be between one third and three times as long as the past. (The end comes either when the Wall ends or when there is no one left to observe it, whichever occurs first.)

The Wall was then eight years old, and eight years divided by three is two-and-two-thirds years, while eight multiplied by three is 24 years. So I predicted to my friend that the Wall would be around in the future for between two-and-two-thirds years and 24 years, with 50% confidence.

Twenty years later, I was watching television and was able to call up my friend Chuck Allen and say, "Look at your television set. You remember that prediction I made of the Berlin Wall coming down," and he did because we had talked about it many times. I said, "Well, turn on your TV because Tom Brokaw is at the Wall and they're tearing it down now." This was 20 years later, in 1989. The Wall could have lasted for thousands of years or it could have been gone a millisecond after I made the prediction. This was in the middle of the Cold War and a nuclear bomb could have landed on Berlin just after I made the prediction. So, when the Wall came down within the limits that I had predicted, I thought that maybe I should write this up!

Now scientists like to make predictions that are right more often than 50%, and so we usually use a 95% confidence limit. How does this change the argument? Well, there's a 95% chance, if you're not special, that you're living somewhere in the middle 95 percent. That means NOT in the first two-and-a-half percent and not in the last two-and-a-half percent. If you're at the beginning of this middle 95%, then you're two-and-a-half percent from the beginning. Two-anda-half percent is 1/40th, so 1/40th is past and there are 39/40ths in the future. So the future is 39 times as long as the past. If you're at the other end of the middle 95%, there's 1/40th left, so 39/40ths have past. In that case, the future is 1/39th as long as the past. So, in this way, if you're in the middle 95 percent, the future is between 1/39th as long as the past and 39 times as long as the past.

I thought I should apply this to something important, so I applied it to the future of the human race. Our species, *Homo sapiens*, is 200,000 years old. That's the time back to Mitochondrial Eve in Africa. If you divide this by 39, you get 5,100 years, and if you multiply by 39, you get 7.8 million years. So in the paper I wrote in *Nature*, May 27, 1993, I said with 95% confidence that I would expect the future of the human race to be somewhere between 5,100 years and 7.8 million years.

Those numbers are very interesting because they're based solely on our past longevity as an intelligent species. The total longevity of the human race according to this estimate is between 205,000 years and 8 million years. The lower limit is 205,000 years--that's the 200,000 years we've had already plus the 5,000 years lower limit, making 205,000 years. The 8 million-year upper limit is 7.8 million plus the 200,000 we've had already. This is the range that I would expect if I begin just basing it on our own past lifetime as an intelligent species.

Interestingly, *Homo erectus*, which is our ancestor species, lasted for about 1.6 million years and the Neanderthals, who were our cousins, but a different species, lasted 300,000 years. So these are in the same ballpark. Mammal species have a mean longevity of 2 million years, while for all species, the average lifetime is between 1 million years and 11 million years.

Now all these numbers above are much shorter than the age of the universe, the lifetime of the sun, age of the sun, and so forth. These numbers represent very short timescales and they're all nearly equal to each other. In fact, a disappointing thing to notice is that there seems to be no correlation between longevity and intelligence. Mammals are smarter than the average species, but they don't live any longer. And other hominids are smarter than the average mammal, but they didn't live any longer, and so forth.

So, why might these numbers be similar? Well, if we stay on the Earth, we are subject to the same sort of extinction events, epidemics, climate changes, ecological disasters and other catastrophes, that end these other species. Also, I should mention that most species do not leave any descendant species when they go extinct. That's the typical thing. And my estimate would apply to our future intelligent descendants. We're the first intelligent species, as far as we know, on the Earth, able to ask questions like, "How long will my species last?"

I wanted to apply my argument to the space program. I'm interested in this. So in my 1993 *Nature* paper, I noted that the human space flight program was then 32 years old, so again dividing by 39, and also multiplying by 39, I predicted with 95% confidence that the future of the space program was likely to be greater than 10 months, but less than 1,250 years. Now we know that those 10 months have passed and the space program is still going, so it's true that it has survived past this lower limit. If the space program had ended within 10 months, as it might have done if there'd been some catastrophe in an American space launch and if the Russian space program, which was in trouble, had ended. If that had happened within 10 months, then my paper would have been very unlucky to have been at the very end. But that didn't happen. Likewise, if the space program lasts for longer than 1,250 years, my paper will be very lucky to be at the very beginning of the space program.

This upper limit of 1,250 years is independent of whether you divide it up into one segment or several. We may have several epochs of space travel. We may abandon it for a while and then pick it up again. But in any case, if the total number of years in which space travel by humans is practiced in the future is larger than 1,250 years, then my 1993 paper would be very lucky to be in the first 2.5% of the list of human spaceflight years.

So this is a warning to us. These calculations are all based on assuming that you're not particularly lucky or unlucky. And I would say that a good policy should be one that would protect us even in the case of some bad luck. This is a warning that we might have a period of space travel that's shorter than the duration of the human race and we might be stranded on the Earth.

History shows that expensive technological projects are sometimes abandoned after a while. The pyramids were the greatest technological project of ancient Egypt--it's what ancient Egypt is famous for. But interestingly, there was only a 90-year period between the building of the first pyramid, which was about 140 feet tall, to the largest pyramid, the great pyramid of Cheops, which was 481 feet tall. After this, the Egyptians built smaller and less well-made pyramids until they quit entirely after another thousand years. Most of those later pyramids were built so badly that they've long ago fallen into ruin. So most of the pyramids that you will see were built in a 90-year period.

The pyramid-building enterprise came to an end. Let me mention that this was a government project. But someone in ancient Egypt might have said, "Well, eventually, technology will increase to the point when even private individuals can have their own pyramid--with enough increase in technology, anyone would like to have a large and permanent tomb, such as a pyramid which could last for thousands of years." People went on to build other kinds of buildings, but they didn't go back to building this kind of stone pyramid.

Why did the Egyptians abandon them? There's a very interesting book on this, written by Kurt Mendelssohn, a physicist. He says that, although the ostensible purpose for building the pyramids was to make a tomb for the pharaoh, that that was really rather useless to the Egyptian people. There's no practical advantage, so why did they do this expensive thing? He said that they did it because, as a big public works project, it brought the economy together, enabling the establishment of the Egyptian state, once this goal had been achieved--once the state had been founded--then that hidden reason for pyramid-building disappeared and they quit doing it.

Mendelssohn related this to the space program: "There is only one project in the world today which, as far as one can see, offers the possibility of being large enough and useless enough to qualify for the new pyramid. In the end, the results of space exploration are likely to be as ephemeral as the pharaoh accompanying the sun." But then he says, "Perhaps we should build the space pyramid and the effort in doing so together may be the necessary sacrifice which we must bring to gain a new and peaceful world community." So, he thought that today the space program did have a hidden use, which was to bring the countries of the world together to establish a world government or world peace. In this vein, I remember it was proposed that one of the reasons we should go to Mars with the Russians was in order to avoid World War III. And this was worth a great expense to do, because it would bring the two superpowers together. Well, I think we found a cheaper way to avoid World War III: just be friends with the Russians. And so that reason for going to Mars evaporated.

When I read Mendelssohn's book, my heart sank because, first of all, I do not think the space program is useless. I think it has a very important reason for being, namely, survival. What could be more important?

Second, I was unhappy to read this because if Mr. Mendelssohn is correct, and the real reason we're doing this has something to do with trying to bring about world peace, that's troubling. Recall that one of the motivations keeping the vote in the Congress up for the space station is indeed cooperation with the Russians. The space station came within one vote of being canceled. Yet when cooperation with the Russians was brought up as a reason, then it had enough votes to sustain it. But if that's the real reason we are doing space travel, then if we *do* get world peace, that hidden reason will go away, and we'll abandon the space program, just as the Egyptians abandoned the building of pyramids long ago.

Now, of course, we know the cause for the space race that put man on the Moon. Although its ostensible purpose was space exploration, we know the hidden reason for it--not hidden to us at all--the Cold War. Khrushchev launched Sputnik; Sputnik proved to the American people that his missiles had the military capability of delivering nuclear weapons to the United States. And the space race was the consequence.

Now that the Cold War is over, though, we run the danger that this particular impetus for the space program has gone away.

Now, let me mention that since the days of Apollo, we have done less well in space than we might have done. In 1968, Arthur C. Clarke proposed that a manned fly-by of Mars could be launched in 1978 using Saturn V technology. And it's too bad we didn't do that. Furthermore, it's too bad that the Russians didn't do that. I can easily imagine that after the Russians had been beaten by the U.S. in the race to land a man on the Moon, a great response would have been to launch a Mars fly-by, because it would have taken advantage of their experience in long-duration space flight and wouldn't have needed an expensive landing. And then, if they had done that, probably the Americans would have had a Mars landing program by now.

In 1969, Wernher von Braun had plans to land astronauts on Mars by 1982. President Nixon decided against that program, and we didn't do it. I remember in the 1960s, people said, "Why should we go to the Moon now, in the '60s? It's very expensive. We should just wait until the 1990s when the technology will make it much cheaper to go to the Moon." And yet, when we got to the 1990s, it was certainly harder to raise money to go to the Moon than it was in the 1960s. It's good that we went to the Moon in the 1960s while we had the chance, and didn't wait for the 1990s, hoping that we would have a better opportunity then.

Then there was the remarkable, wonderful paper in 1974 of Gerard O'Neill, who pointed out that if we exerted ourselves, the number of people living in space could be as large as 100,000-200,000 by the year 1996. I remember him giving talks on this, and I thought the most exciting thing about those talks was that he pointed out that these projects were cheaper than one would think, because most of the work was done by the space colonists themselves. But we didn't do that by 1996 and it's a shame that we haven't done that yet.

In 1989, President Bush (senior) proposed sending astronauts to Mars by 2019. You'll notice that Mars is getting further away. In 1969, von Braun had plans to go to Mars by the year 1982. After we'd spent 20 years not doing anything toward Mars, President Bush proposed going to Mars 30 years later. Kennedy, remember, established a one-decade limit for going to the Moon. In 1969, people thought that there would be astronauts on Mars by 1985. After all, if it took you 10 years to go to the Moon, another 15 would surely suffice to get you to Mars. But by 1989 President Bush was only proposing to send astronauts to Mars by 2019. On November 10, 2084, there will be a spectacular transit of the Earth and the Moon across the face of the Sun, visible from Mars. Will there be any astronauts there to witness it? I mention this because Arthur C. Clarke wrote a short story in 1972 about an astronaut viewing such a transit of Earth from Mars. But this was about the transit of May 11, 1984. That's because in 1972 it seemed plausible to Clarke that astronauts might be on Mars by 1984.

If I would be at a press conference at the White House, I would have a question for George W. Bush today: "Are you going to honor you father's pledge to put astronauts on Mars by 2019, and how much money are you going to spend in your administration directly for that particular goal?" There is not a large amount of money today for sending astronauts to Mars. The longer we have put off things, the longer they seem to get put off in the future as well.

It's important that we have a goal. President Kennedy set a wonderful goal. He said we should land a man on the Moon and return him safely to Earth before the decade of the 1960s was out, a short time limit. This goal was very galvanizing to the engineers. All the kids' books on going to the Moon written in the 1950s had shown us building a big space station before we went to the Moon. A lunar ship was constructed on the space station; then it would take off, go the Moon, and return to the space station. This was the vision of the 1950s. But when the engineers were confronted with Kennedy's goal, they said, "You know, we could skip the space station. We should go directly to the Moon. We don't need to build a space station. In fact, we don't have the time to build a space station. We should go directly to the Moon."

After 1989, this is the sort of thing that motivated Robert Zubrin to talk about going to Mars direct: If you're interested in going to Mars, why not just go to Mars direct? So goals can have an influence on what you're doing. Zubrin thought that if you took hydrogen with you, you could use the indigenous materials on Mars, the CO2 in the atmosphere, to make fuel to come back for the return trip. And that made the expedition cost a lot less than it would have if you took all that fuel with you.

Well, I have an even better idea: leave the astronauts on Mars! That's where we want them. That's where they're giving us a survival advantage. And all we have to do is find people who are willing to go to Mars and stay there--in fact, there's one person in the audience that just raised a hand. I. talked to Story Musgrave recently, an astronaut who fixed the space telescope. He told me, "I'd be willing to go to Mars and not come back." We just need people who are willing to go to Mars and stay to found a new civilization there--who would rather do that than have a ticker tape parade back in New York City.

Colonies can found other colonies, something that Gerard O'Neill understood. The first words spoken on the Moon were in English, not because England sent astronauts to the Moon, but because it founded a colony in North America that did. So colonies are an incredible bargain, and if we have that as the goal, then it may improve our ability to do it.

We should be aware that there is some possibility--there is a danger--that we will fail to do this and we will be stuck on the Earth. And what is the indication of this danger? It's that we're having this conversation on the Earth right now. This is a meeting about space manufacturing. We should be having this meeting on space manufacturing in space. It'd be a shame if all of the meetings on space manufacturing occurred on the Earth! We could be having this conversation about space manufacturing on a space colony. Indeed, if people colonize, then colonists make up most of the population.

We, in fact, are colonists. We're in North America. People didn't start out in North America; they started out in Africa 200,000 years ago. So we are continental colonists. We find ourselves in a colony, not on the home continent. Likewise you could have been born and found yourself living on a space colony and not on the home planet of the Earth. If we end up stranded on the Earth, then your observation that you find yourself living on the Earth is quite typical. If we end up colonizing space in a large way, then you're special because you're lucky to be on the home planet at the beginning when most human beings would be born elsewhere. So, it's a warning to us that we should not take space colonization for granted; this is something that we have to work on.

Colonization is important. Christopher Columbus is very famous. What's Christopher Columbus famous for? For discovering America? No. No, the Indians were here long before that, and even the Vikings beat him. Christopher Columbus is important because a large wave of colonization came here from Europe after him and this changed the course of world history. Christopher Columbus is more famous in world history, for example, than Edward Bransfield. Who? Edward Bransfield. He's the man who discovered Antarctica. That's something the likes of which Christopher Columbus did not do. Mind you, there are several claimants for this and there's a little controversy, but this is the British claim, and it's probably the strongest one. Bransfield sighted Antarctica. So he discovered a continent that no one had ever seen before. Then why isn't his name as familiar to us as that of Columbus? Well, because as near as I've been able to tell, there are only about a dozen or so people who have actually been born in Antarctica. And since you're not special, you're not likely to be one of them. Is there anyone here who was born on Antarctica? No. If we all lived in Antarctica and were having this conference in Antarctica, then Mr. Bransfield would be more important to us.

That explains why space colonization is important and particularly so for the United States, because the United States has already made a big investment to put Neil Armstrong on the Moon. There was once a wonderful speech given by then Congressman Torricelli in defense of the manned space program, in which he said, "If we abandon the manned space program, then Neil Armstrong's great leap for mankind will turn out to have been a small step after all." The importance of Neil Armstrong's trip is yet to be determined. If it turns out to be a one-time thing and we end up stuck on the Earth and don't colonize space, then Neil Armstrong will be a figure like Sir Edmund Hillary, who climbed Mount Everest, or Amundsen, who first visited the South Pole. But if Armstrong's trip leads to a wave of colonization through the galaxy, then he will be a pivotal figure in all of human history.

We should be colonizing space now while we have the chance. In setting the goal of landing a man on the moon, President Kennedy said, "We choose to go to the Moon in this decade and do the other things, not because they are easy but because they are hard ... because that challenge is one we are willing to accept, one we are unwilling to postpone." Space colonization is a challenge we should be willing to accept, one we are unwilling to postpone.

REFERENCES

Gatland, K. *The Illustrated Encyclopedia of Space Technology* (2nd ed.). New York: Orion Books, 1989

Gott, J. Richard. "Implications of the Copernican Principle for Our Future Prospects." *Nature* 363, 315 (1993).

Gott, J. Richard. "Our Future in the Universe." In *Clustering, Lensing, and the Future of the Universe*, Astronomical Society of the Pacific Conference Series, ed. by Virginia Trimble and A. Reisenegger, Vol. 88, 140. San Francisco: Astronomical Society of the Pacific, 1996.

Maor, Eli. June 8, 2004: *Venus in Transit*. Princeton, NJ: Princeton University Press, 2000.

Zubrin, Robert. *The Case for Mars*. New York: The Free Press, 1996.