In: *New Trends in Astrodynamics and Applications III*, American Institute of Physics Conference Proceedings, Volume 886, Edward Belbruno, editor, AIP, Mellville, New York., 2007.

LONGEVITY OF THE HUMAN SPACEFLIGHT PROGRAM

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ABSTRACT:

The longevity of the human spaceflight program is important to our survival prospects. On May 27, 1993 I proposed a method for estimating future longevity, based on past observed longevity using the Copernican Principle: if your observation point is not special the 95% confidence level prediction of future longevity is between (1/39)th and 39 times the past longevity. The prediction for the future longevity of the human spaceflight program (then 32 years old) was greater than 10 months but less than 1248 years. We have already passed the lower limit. This Copernican formula has been tested a number of times, correctly predicting, among other things, future longevities of Broadway plays and musicals, and the Conservative Government in the United Kingdom. Recently, a study of future longevities of the 313 world leaders in power on May 27, 1993 has been completed. Assuming none still in office serve past age 100, the success rate of the 95% Copernican Formula is currently 94.55% with only one case (out of 313) left to be decided. The human spaceflight program has not been around long and so there is the danger its future will not be long enough to allow us to colonize off the earth. Policy implications are discussed. A smart plan would be to try to establish a self-supporting colony on Mars in the next 45 years. This should not require sending any more tons of material into space in the next 45 years than we have in the last 45 years.

INTRODUCTION

On May 27, 1993, I published a paper in *Nature* (Gott 1993) titled "Implications of the Copernican Principle for Our Future Prospects." It contains a formula for estimating the period of future observability of something observable today. It is based on the Copernican Principle, the idea that your location is not special. This has been one of the most successful scientific hypotheses in the history of science (see Gott 2001a for discussion).

Suppose you are observing something. The Copernican Principle suggests that, if your location is not special, you are simply observing it at some random point in its period of observability so there is a 95% chance that you are seeing it in the middle 95% of its period of observability (i.e., in neither the first nor the last 2.5%). Now 2.5% is 1/40th, so if you are at the beginning of the middle 95%, 1/40th of its history is past and 39/40ths remains in the future. In this case, its future longevity (t_f) is 39 times as long as its past longevity (t_p). The end comes either when the thing being observed goes out of existence or when there is no one left to observe it, whichever comes first. If you are at the end of the middle 95%, you are 39/40ths from the beginning and the future is 1/39th as long as the past. If your location is not special there is a 95% chance that you are in the middle 95% and therefore between these two extremes, i.e. :

$$(1/39)\ t_p < t_f < 39\ t_p \quad (P = 95\%) \qquad (1)$$

This formula was used to predict the likely future longevity of the human spaceflight program and the human race (*Homo sapiens*). The human spaceflight program, then 32 years old, was predicted with 95% confidence to have a future longevity: 10 months < t_f < 1248 years. The human spaceflight program has passed the lower limit already, so the first half of the prediction has already come true. It could have ceased sooner--another Shuttle accident could have ended the U.S. program and the Russian program was in financial difficulties, but then my paper, Gott (1993), would have been unlucky to be in the last 2.5%. *Homo sapiens*, 200,000 years old, was predicted (P = 95%) to have a future longevity: 5100 years < t_f < 7.8 million years. Importantly, this estimate, based *only* on our past longevity as an intelligent species, gives us a projected total longevity between 205,000 years and 8 million years, which is quite similar to other species. *Homo erectus* lasted 1.6 million years, and *Homo neanderthalensis* lasted 300,000 years. Mammals have an average longevity of 2 million years (an exponential distribution with an *e*-folding time of 2 million years). If we were to assume that we were not special among mammal species and were to use this *actuarial* data, we would predict a future longevity for a random mammal species at the 95% confidence level to be more than 50,000 years but less than 7.4 million years (Gott 2001a). The similarity between this estimate for mammals and the Copernican estimate based *only* on our past lifetime as an *intelligent* species (which does not assume we are a typical mammal species) is sobering. If we stay on the earth we are subject to all the extinction events that usually take out mammal species (disease, climate change, ecological disasters, etc.) It would improve our survival chances to expand into space, giving us more chances. But since the predicted future longevity of the human spaceflight program is short compared to the past longevity of our species, there is a significant danger that we will fail to colonize off the earth and be stranded on earth where we are likely to go extinct in less than 7.8 million years.

TESTING THE LONGEVITY FORMULA

Importantly, the ability of the Copernican formula to predict future longevities can be checked. As Popper has noted, any good scientific hypothesis is one that can be falsified and the Copernican Principle is no exception.

On September 30, 1993, in *Nature*, Landsberg, Dewynne and Please used my formula to predict how long the Conservative government in Britain would continue in power. Since the Conservative Party had been in power for 14 years in 1993, they estimated with 95% confidence that it would remain in power for at least 4.3 more months but less than 546 more years. The

Conservative party went out of power 3.6 years later, on May 2, 1997, in agreement with the prediction (cf. Gott 1997a).

In *Equinox* magazine (October 1993), I used the formula to predict with 95% confidence that the future longevity of Canada (t_{past} = 126 years at that time) would be

3 years < t_{future} < 4914 years

Now we know it's true that 3 years < t_{future}.

The day my *Nature* paper came out, May 27, 1993, I checked the *New Yorker* magazine to find all the Broadway and Off-Broadway plays and musicals that were then open—there were 44. I then called up each theatre to find out how long each play or musical had been open, and noted when they closed (cf. Gott 1996). So far, 40 of the 44 plays and musicals have closed, all of them within the limits predicted by the 95% Copernican formula. Notable examples include:

Marisol (t_{past}= 7 days, t_{future} = 10 days)
Kiss of the Spider Woman (t_{past}= 24 days, t_{future} = 765days)
Oleanna (t_{past}= 226 days, t_{future} = 234 days)
Miss Saigon (t_{past}= 777days, t_{future} = 2803 days)
Cats (t_{past}= 3885 days, t_{future} = 2663 days)

In each case $(1/39)t_{past} < t_{future} < 39\, t_{past}$. Thus, there is a success rate of 100% so far, with 4 cases left to be decided. All the remaining plays and musicals have lasted beyond their lower limits.

Cats famously advertised itself as "*Cats* Now and Forever". How did I know that *Cats* was not going to last forever? Because if *Cats* lasted forever then nearly all the observers of *Cats* would live more than a trillion years in the future and nearly all of the observers of Cats would see that it was nearly as old as the universe: Age (*Cats*)/Age of Universe ≈ 1.0, but in 1993 we observed Age (*Cats*)/Age of Universe << 1, and that would make us very special. So that tells us that *Cats* is not likely to last forever, and if it has an end, its end is given by 95% certainty by formula (1).

At a talk I gave, someone in the audience asked: What did the Copernican argument predict about your future longevity? Answer: At the time my paper was published on May 27, 1993, I was 46.3 years old, so the 95% delta-t argument predicted that my future longevity would be at least 1.2 years but less than 1,806 years. I have survived past the lower limit already and so if I don't make it past the upper limit, then that prediction will indeed prove correct for me! According to world-wide actuarial and population distribution tables, of all the people alive when my paper was published, the 95% delta-t argument should predict the future longevity accurately in 96% of the cases, as I described in Gott (1996). The success fraction is largest for middle-aged people and smaller for very young and very old people. The overall fraction for all people alive in 1993 is 96%, so the argument performs as advertised.

Carlton Caves (2000) proposed testing the Copernican formula on the longevity of dogs. He discovered that members of his department owned 24 dogs and he found each of the dogs' ages as of December 2, 1999. How has the 95% Copernican formula done? When I checked with him some four months later (on April 24, 2000), all the dogs were still alive, meaning that all 24 had survived for at least 1/39th of their original age. If none break the Guinness World Record for dog longevity (29.4 years), then only two dogs, the puppies Brandy and Koko, have a shot at surviving longer than 39 times their original age. Thus, I expect the 95% Copernican formula will have a success rate of 92% (22/24) or 96% (23/24) or 100% (24/24), depending on how well Brandy and Koko do. Thus, the 95% formula should do well in predicting the future longevity of the 24 dogs in the sample. The formula should not be applied to a subset of just the youngest or oldest dogs in the sample, for these are special by definition. My formula should work if applied to a random dog, or equivalently to all dogs in the sample as shown above. It should also work for your dog—if you had one on the prediction date, December 2, 1999—because your dog is not likely to be special. So the formula works for dogs as well as *Cats*! (For a discussion see Monton & Kierland [2006].)

The *New York Times* (February 8, 2000, p. F5) reported a prediction I had made in 1996 about the Chicago White Sox's World Series prospects, a team which had not won the World Series since 1917. I said "there was a 95% chance that the following statement was true: the White Sox would not win a World Series in the following two years, but they would win one before the year 5077, if the team still existed then." The White Sox won the World Series in 2005 in agreement with the prediction.

The *Wall Street Journal* asked me to predict the future longevities of 14 famous things: Stonehenge, Pantheon, Humans (*Homo sapiens*), Great Wall of China, Internet, Microsoft, General Motors, Christianity, United States, New York Stock Exchange, Manhattan (i.e., a city on Manhattan island), *Wall Street Journal*, *New York Times*, Oxford University. All are still in existence. This was published Jan. 1, 2000. Several are now past their lower (1/39th past longevity) limits: (Internet, Microsoft, General Motors, United States, New York Stock Exchange, *Wall Street Journal*, *New York Times*). I did the interview for this article on Oct. 20, 1999. The reporter, Rachel Silverman, asked if I could estimate how long it would be until the next record-breaking drop in the Dow Jones average. At the time of the interview I told her that we had been without a record-breaking drop in the Dow for 723 days. Thus, I told her to expect with 95% confidence that sometime between Nov. 7, 1999 and Dec. 31, 2076, either the one-day drop of 554 points would be exceeded, or we will quit recording the Dow Jones average. On April 16, 2000 I sent her an e-mail noting that on April 14, 2000 there was a new record-breaking drop in the Dow Jones Average—617 points. She sent me back a one word reply: "Cool!"

World Leaders

As of May 27, 1993 there were 313 world leaders in power—heads of state and heads of government of independent countries. How did the 95% Copernican Principle argument do? It predicts with 95% confidence the future longevity in office: $(1/39)t_{past} < t_{future} < 39\, t_{past}$. As of July 2003, 312 of these cases have been decided, assuming none of those world leaders still in office stays in office past age 100 (data from www.worldstatesmen.org, and Wikipedia).

The 95% Copernican Formula has been right in 295 cases, wrong in 17 cases, with 1 still undecided, for a success rate so far of 94.55%.

The Copernican formula applies to a random world leader, but it also applies to the leader of *your* country, because it points to you and says you are not likely to be special. In this case, my paper was submitted from the United States and was published in the United Kingdom. So how did the predictions for the leaders (Head of State, Head of Government) in those two countries turn out?

<u>United States</u>

President Bill Clinton had been in office for 127 days. The Copernican Principle 95% confidence prediction for the future longevity in office of Bill Clinton was:

<u>Clinton--Copernican Principle 95%:</u> 3days < t_{future} < 4,953days

An *actuarial* estimate of future longevity in office of Bill Clinton (as of May 27, 1993) could be made based on the Copernican assumption that he will not be special among U.S. Presidents. This is based on the total longevities in office of all the preceding presidents. There were 41 previous presidents (Taft counts twice since he had two separate terms of office and we are only predicting the length of the current president's current term of office--how long it will be until the current president goes out of office.) On May 27, 1993 Clinton had served 127 days in office, already longer than Harrison (who only served 30 days), so that leaves 40 prior presidents to consider. At the 95% confidence level, Clinton should serve longer in the future than Garfield who served a total of 199 days (=127 days + 72 days) but not as long as Franklin Roosevelt who served 4,422 days (= 127 days + 4,295 days), yielding:

<u>Clinton--Actuarial 95%:</u> 72 days < t_{future} < 4,295 days

Using Constitutional rules (the date the President goes out of office [January 20th], the 22nd amendment limiting a President to two terms, the probability of rescinding such a constitutional amendment [which occurred once for prohibition]), and the actuarial probabilities of assassination, resignation, impeachment, and natural death starting with a first-term elected president based on past presidents, and the probability of being re-elected, also based on previous presidents, one finds:

<u>Clinton—Constitutional Rules & Actuarial estimates 95%:</u> 226 days < t_{future} < 2,796 days

<u>Clinton left office 2795 days later, so all three predictions worked.</u>

The Copernican estimate based on the past longevity is like having an X-ray telescope that tells you there is a 95% chance that the X-ray source lies within a 1^{o}x1^o box. If later you have another more accurate telescope that with 95% probability locates the X-ray source inside a 30'x30' box, that does not mean that the earlier estimate was wrong. In fact, the earlier telescope may have correctly located 95% of the X-ray sources within 1^{o}x1^o boxes. And the 30'x30' new error box should be expected (often) to lie inside the original 1^{o}x1^o box. That is the case here. The actuarial estimate based on the past longevities of 41 presidents at the 95% level has a smaller range than the Copernican estimate and both proved to be right. I have always noted that actuarial estimates may be more accurate (have smaller 95% confidence ranges) than ones from the Copernican formula because they use more data and still use the Copernican idea that your leader is not special among previous leaders (cf. Gott 1996). Each of these estimates will be true approximately the correct percentage of the time if the hypotheses on which they are based are correct. But we do not have actuarial data on the longevities of other intelligent species or on the longevity of other species' spaceflight programs; therefore, for these questions the Copernican principle estimate may be the best one we can make (cf. Gott 1993). The tests presented here are meant support the Copernican formula's usefulness--that it predicts the future longevity based on the past longevity alone—with 95% confidence within the prescribed limits, as advertised. This means that you can apply it with confidence within its limits knowing only the past longevity.

United Kingdom

The head of state was Queen Elizabeth II who had been in office for 15,086 days. The Copernican prediction was:

Elizabeth II--Copernican Principle 95%: 386 days $< t_{future} <$ 588,354days

She is still in office today, well over the lower limit, and unlikely to live past the upper limit, so this is a win for the formula. The Head of Government was Prime Minister John Major who had been in office for 938 days, so the prediction was:

John Major--Copernican Principle 95%: 24 days $< t_{future} <$ 36, 582 days.

He left office 1,435 days later so the formula was correct.

The Copernican 95% formula was correct for all three leaders in the United States and the United Kingdom. In other countries where there is no track record of 40 or more previous equivalent office holders, actuarial and "Constitutional rules and Actuarial estimates" calculations at the 95% confidence level are not so easy. But the Copernican formula still works in approximately 95% of the cases. For example, in Iraq as of May 27, 1993, Saddam Hussein had been President for 5,064 days and went out of power 3,604 days later, within the 95% limits.

After I published my Copernican Formula in 1993, I received a nice note from Henry Bienen (co-author with Nicolas van de Walle of the book *Of Time and Power*). After a detailed statistical study of 2,256 world leaders they concluded:

"The length of time that a leader has been in power is a very good predictor of how long that leader will continue to hold power. Indeed, of all the variables examined, it is the predictor that gives the most confidence" (*Of Time and Power*, p. 106)

The Copernican formula also works for things without limits set by individual human lifetimes. As of May 27, 1993 in the United States, the Democrats had been in control of the House of Representatives for 14, 024 days, so the prediction was:

Democratic House--Copernican Principle 95%: 359 days $< t_{future} <$ 546,936 days

The Democrats lost control of the House 586 days later so the formula was correct.

The Democrats had been in control of the U.S. Senate for 2,336 days so the prediction was

<u>Democratic Senate--Copernican Principle 95%:</u> 59 days < t_{future} < 91,104 days

The Democrats lost control of the Senate 586 days later so the formula was correct. The Democrats could have retained control of these two houses of Congress indefinitely, but the Copernican formula suggested correctly that their future control was likely to be limited and of the order of their time of past control.

In my article for *New Scientist* (Gott 1997b), I noted a number of situations where I would not apply my formula. I noted that I would not use my formula at weddings to predict the future of the marriage. Why? Because one has been invited to a wedding precisely to witness a special period, namely, its beginning. However, it could be used on May 27, 1993, to predict the future of your marriage, if you were already married at that time. (For example, the most famous married couple in the world on May 27, 1993, the day my paper was published, was Prince Charles and Princess Diana--at that time they had been married for 11.8 years. They were divorced 3.26 years after the publication of my paper. Thus, the future longevity of their marriage turned out to be (1/3.6) times as long as its past longevity [within a factor of 39]).

BAYESIAN FORMULATION

Any probability problem can be given a Bayesian formulation. Bayes's theorem says that if you have a prior probability for two hypotheses P(H1) and P(H2), after making an observation X, your posterior probability of each is proportional to the prior probability multiplied by the likelihood of observing X given H1 or given H2. Suppose you have two urns: Urn 1 has balls numbered from 1 to 10. Urn 2 has balls numbered from 1 to 1000. You pick an urn at random. So your prior probability is $P_{prior}(H1)/P_{prior}(H2) = 1$. Now you pick a ball at random from the urn you have chosen: you find it is number 7. The likelihood L1 of picking number 7 from Urn 1 is 1/10; the likelihood L2 of picking number 7 from Urn 2 is 1/1000. Thus your posterior probability after observing number 7 is $P_{posterior}(H1)/ P_{posterior}(H2) = P_{prior}(H1)L1/P_{prior}(H2)L2 = 100$. Thus, you are much more likely to be holding Urn 1. (Adapted from a similar example by Leslie [1996, p. 199].) Try it.

Consider Jeffreys's (1939) Tram Problem. A man traveling in a foreign country has to change trains in a junction, and goes into town. He has no idea of its size. The first thing he sees is a tram numbered 100 and he steps aboard. What can he infer about the number of tramcars in the town? Assume they are numbered consecutively from 1 upwards. Jeffreys adopts a vague prior appropriate for a positive unbounded number: $P(n)dn \propto dn/n$, where n is the number of trams. The likelihood of observing tram number 100 is zero if $n < 100$ and equal to $1/n$ if $n \geq 100$. Thus, the posterior probability is $P(n)dn \propto dn/n^2$ for $n \geq 100$ and zero otherwise. After integration, and normalization one finds $P(n \geq N) = 100/N$. Thus, Jeffreys concludes there is a 50% chance that the number of trams in the town is 200 or greater (and a 10% chance that it is 1000 or greater). This agrees exactly with what I would calculate from the Copernican principle--namely that as a random observer there should be a 50% chance that the traveler would step onto one of the trams in the first half of the numbered trams in town (and a 10% chance that the traveler is on one of the first $1/10^{th}$ of the trams in town). A *vague prior* is sometimes called a *public policy prior* because anyone can use it and it can be used for weighing the merits of public policy (Press 1989).

What if the traveler jumped on the first tram he saw in his hometown? Some authors (Buch 1994, Caves 2001) have suggested that the Jeffreys prior should be revised due to the anthropic weighting proportional to n that occurs because hometowns are likely to be larger than random towns. They claim this would balance the $1/n$ likelihood function to leave the prior unchanged, and the *only* new information obtained by knowing that you were on tram 100 was that $n \geq 100$. That would be true if you had a data-based actuarial prior, but it is not true if you use the Jeffreys vague prior (Gott 1994). Suppose that towns have an exponential distribution for example: $P(n)dn \propto \exp(-\lambda n)dn$ and suppose that I *know* λ. This is an actuarial prior. Hometowns would have a prior weighted by population so $P(n)dn \propto n\exp(-\lambda n)dn$ (because the probability of your observing a town to be your hometown is proportional to its population); and multiplying by the likelihood ($L = 0$ if $n < 100$ and $L = 1/n$ if $n \geq 100$), we find a posterior probability $P(n)dn = 0$ if $n < 100$ and $P(n)dn \propto \exp(-\lambda n)dn$ if $n \geq 100$. This is the procedure one would use if you had an actuarial prior such as that used to estimate President Clinton's future longevity in office based on prior presidents' terms of office. But it is not the correct procedure when using the Jeffreys vague prior as I described in Gott (1994). Suppose that towns have an exponential distribution as before: $P(n)dn \propto \exp(-\lambda n)dn$, but now suppose that I *don't know* λ. Since λ is a positive number unbounded above, my appropriate Jeffreys prior for λ would be $P(\lambda)d\lambda \propto d\lambda/\lambda$. It's true that hometowns would have a prior weighted by population $P(n)dn \propto n\exp(-\lambda n)dn$, but I still don't know λ. So using the Jeffreys prior for λ ($P(\lambda)d\lambda \propto d\lambda/\lambda$) and integrating over λ I would still get a Jeffreys prior for *hometowns* of $P(n)dn \propto dn/n$, and I would multiply by the likelihood as before. The Copernican Principle tells you that the answer to the Jeffreys tram problem is the same regardless of whether you are in a random town or your hometown. Even in your hometown there is a 50% chance that you will be on a tram in the first half of all the trams in town and there is a 50% chance that if you are on tram 100, the number of trams in the town is greater than or equal to 200. If you are in your hometown, however, it is likely that the tram you are on will have a *higher number* than if you visited a random town. I discuss this in Gott (1993)--the country in which you are born is likely to have a larger population than the median country. In Gott (1996) I pointed out that the reason I'm using the Jeffreys prior is not that I think there is no scale in the problem but that I don't know what it is.

The fact that the Copernican principle gives exactly the same answer to the tram problem as Jeffreys got shows that in fact Jeffreys' prior can be used by everyone (take a poll of all observers, the result must agree with the Copernican Principle), so the Jeffreys vague prior is the correct one to use in this problem. And using the Jeffreys prior for longevity gives exactly the same 95% confidence limits for longevity as the Copernican Principle argument. Using the Jeffreys prior, if the past longevity is t_p, the posterior total longevity ($L = t_p + t_f$) is $P(L > [1 + Y]t_p) = 1/(1 + Y)$ where $Y = t_f/t_p$ and $Y > 0$. Thus $P(Y > 39) = 1/40 = 2.5\%$ and $P(Y > 1/39) = 39/40 = 97.5\%$, so $P(1/39 < t_f/t_p < 39) = 95\%$, which is exactly the Copernican Principle result (cf. Equation 1)

The human race, because it exists now, should have a longer longevity than the median intelligent species (i.e. a species able to reason abstractly and ask questions such as how long will my species last). This anthropic weighting, which is proportional to the total longevity of the species, is just like the hometown weighting proportional to n). If one produces a *subjective* prior for the longevity of the human race based on examining *its* properties—since it is the only intelligent species we know—one will have implicitly already included the anthropic weighting in one's estimate, for the human race is likely to be more successful than the median intelligent species. When one then multiplies by the likelihood of observing that we live 200,000 years after its beginning (which is proportional to 1/(total longevity)--like the 1/n likelihood weighting in the tram problem) one will be more pessimistic about its future than if one had not considered this effect, as argued by Leslie and Carter (cf. Leslie 1996). *Subjective priors* made by different people may differ, however. Since we have no actuarial data on the longevities of other intelligent species or their space programs, and any subjective priors would be based on speculation alone, the Jeffreys vague prior is arguably the best we can do. That leads directly to the Copernican 95% limits in equation 1, as I explained in (Gott 1994).

See also the discussion of this by Monton & Kierland (2001) who support the Copernican view against the Caves-Buch position: they give the nice example of an astronaut who visits a planet of geysers. He knows nothing about them but there is a running clock in front of each geyser showing how long it has been erupting. They agree with applying the Copernican Principle here, arguing that one should forecast a shorter future longevity for a geyser that had been erupting for only 10 minutes than for one that had been erupting for 10 years.

Now consider the fact that we are having this conversation on the earth. You were born on Planet number 1, out of all the planets that humans shall be born on. It's like jumping on a tram in your hometown and finding that it is Tram number 1. How many hometown trams (planets that humans will be born on) are there? Jeffreys's argument and the Copernican Principle would suggest that there is a 50% chance that there will be 2 or more such trams (or planets). For there is a 50% chance that you will be born in the first half of the planets ever to have humans born on them, and you will be in the first half if the total number is 2 or more (i.e. we colonize other planets). But this also means that there is a 50% chance that we will not colonize and that we will be stranded on the earth where we will eventually go extinct. The Copernican Principle at the 95% confidence level does not say that we will be trapped on earth or that we will colonize. It could happen or not and still you would not be special. It suggests that colonization is something that would be not too unlikely, but also provides a warning that we may fail to do it, a warning that we should take seriously.

A PLAN FOR THE FUTURE

Given the results of the Copernican Principle, what would be a wise strategy to adopt? First of all we should realize that since the human race has only been around for 200,000 years it is in danger of going extinct on a timescale of 200,000 years ($x39^{\pm 1}$). This timescale is similar to the extinction timescale for mammal species. As long as we stay on the earth we are subject to the same kind of extinction events that have made mammal species go extinct on timescales of 2 million years on average. Also, since we are still on the earth, we should realize that there is a significant chance that we will never colonize off the earth (50%) and that if we are stranded on earth we will indeed be subject to all the extinction events that cause mammal species to go extinct--plus those we provide ourselves. Planting even one colony in space might as much as double our long term survival prospects giving us two chances instead of one. Colonies off the earth serve as a life insurance policy against whatever (perhaps unexpected) catastrophes might occur to us on the earth. The fossil record provides ample evidence that such catastrophes occur.

The goal of the human spaceflight program should be to improve our survival prospects by colonizing space.

That is a goal worth spending hundreds of billions of dollars to achieve. Stephen Hawking has recently echoed this thought, saying "It is important for the human race to spread out into space for the survival of the species." Colonies are in fact a great bargain. A small group of astronauts who establish a permanent home off the Earth can expand their numbers and sustain a growing population with indigenous materials. Colonies can also found other colonies. The first words spoken on the Moon were in English, not because England sent astronauts to the Moon but because it planted a colony in North America that did. Planting a self-supporting colony on Mars might double our chances of eventually going to Alpha Centauri, because it might just as well be people on Mars that sent the expedition as people from Earth. The Copernican Principle warns us that today the human spaceflight program is only 45 years old and may itself go extinct on a timescale of 45 years ($x39^{\pm 1}$). The human spaceflight program is in much greater danger of going extinct in the near future than the human race. But if it goes extinct in the near future, before we have colonized, this will leave us stranded on the earth—to the detriment of our survival prospects (Gott 1999, 2001b, 2001c).

How much time do we have left to get off the earth? The Copernican Principle suggests, today in 2006, that there is a 50% chance that the human spaceflight program will last at least another 45 years (for if today is not special there is a 50% chance that we are in the first half of the human spaceflight program now). Jeffreys's tram example suggests a 50% chance that we will colonize at least one other planet, so this is a realistic goal. I would say that the most important goal that we could set for ourselves in the next 45 years would be to plant a self-supporting colony off the earth. Mars seems like the most likely place on which to plant such a colony. It has an atmosphere, water-ice, and all the chemicals needed for life. Over a long timescale there has been discussion of how it could be terraformed to be more like the Earth (McKay, Toon, & Kasting 1991). It is important that the colony should be self-supporting because the danger is that we will shortsightedly cut off funding to the space program at some point. History shows that expensive projects (such as ancient Egyptian pyramid building, or the Chinese epoch of exploration, which extended as far as Africa under Cheng Ho) can be abandoned after awhile. But even if funding from the earth were to stop, a self-supporting colony could continue its existence. The real space race is whether we will succeed in colonizing off the earth before the funding for space travel ends.

It is on Mars that astronauts would enhance our survival chances, so it is advantageous to send astronauts to Mars and let them remain there, with ample supplies to continue and grow a colony, rather than bring them back to Earth. A minimum of 8 people who are willing to emigrate to Mars and stay there and have children could found a Martian civilization. One can find such people. Any such people who volunteered would be doing something very important, changing the course of world history—in fact it could not even be called "world" history anymore. Making us a two-planet species would be a watershed moment. In 300 years (with a fertility rate of 4 children per couple—lower than that in 49 countries today) a self-supporting colony of 8 people could grow to 8,000; in 600 years it could grow to 8 million people. On longer timescales terraforming could make Mars more habitable (McKay, Toon, & Kasting 1991).

So we should try to make a plan to plant a self-supporting colony on Mars in the next 45 years. Further, we should conservatively assume that we might have no more money for this in the next 45 years than we have had in the last 45 years. Again, conservatively, we should assume that we would be able to send into low earth orbit (LEO) in the next 45 years no more weight than we have sent in the last 45 years. The Copernican Principle might suggest we have a 50% chance of achieving that.

What have we done in manned spaceflight in the last 45 years? Well, a *lower* limit would be to consider just what NASA has done (adding in the contribution of the Soviet Union, later Russia, and China would just make the total larger):

NASA tons to LEO in last 45 years (leaving out smaller payloads prior to Apollo):

13 Saturn V rockets (127 tons each to LEO)	=	1,651 tons
115 Shuttles (77 tons each to LEO)	=	<u>8,855 tons</u>
Total	=	10,506 tons

Now according to calculations by Zubrin (1996):

<u>Zubrin</u>: 140 tons in LEO $\Rightarrow$ 28.6 tons delivered to surface of Mars

So 10,506 tons in LEO $\Rightarrow$ 2,146 tons delivered to surface of Mars

Thus, if we are able to do as well in the next 45 years as we have done in the last 45 years, we should be able to deliver 2,146 tons to the surface of Mars if we made that the priority.

Suppose we wanted to establish a self-supporting colony of 8 men and women on Mars. That would seem to be the minimum number. The astronauts could take with them frozen egg and sperm cells to add to the genetic diversity. O'Neill (1977) has calculated the mass required (including biomass and shielding) required per person to establish life in a closed system in space.

<u>O'Neill</u>: self-supporting space colony 50 tons/person

On Mars, we would have access to additional water and oxygen [from the CO_2 in the atmosphere], and shielding could be provided by Mars material, so 50 tons per person should be sufficient.

Thus, conservatively we could say:
An 8-person colony on Mars ⇒ 400 tons on Mars

2 crew transports + 2 emergency return vehicles (hopefully not used) ⇒ 101 tons on Mars
(From calculations by Zubrin)
Total: 501 tons on Mars

What about the radiation hazard? Fortunately, on Mars, local material can provide shielding. Data from MARIE, a radiation detector on the Mars Odyssey orbiter can be used to estimate the risk from exposure to solar particle events and cosmic ray particles both on the surface of Mars and on the trip there (http://marie.jsc.nasa.gov). On an 8-month trip to Mars the dose would be about 0.4 severts. (By comparison, a round trip to Mars with an 18 month stay at a random location on the surface with no protection would have a total dose of approximately 1.2 severts.) There has been some discussion of magnetic shielding for spacecraft [5 tesla toroidal fields confined with a torus] (c.f. Atkinson 2005) but the total dose for a one way trip is not large in any case, particularly if a small shelter inside the spacecraft with shielding for solar flare events is provided. Also one could go during solar minimum where solar flares would be rare. On the surface of Mars some shielding is supplied by Mars itself and its atmosphere. During solar flares, colonists can take shelter underground. Galactic cosmic rays are a more constant threat. Six meters of water ice above you should be sufficient protection against both solar flares and galactic cosmic rays (Parker 2006), and 5 meters of soil should offer similar protection (Schmidt 2006). Ten meters of material (1 kilogram of shielding material per square centimeter) should provide the same protection as one finds at sea level on earth (Parker 2006). Some excavation for building and shielding a base could be done robotically before colonists arrived. If one wants to minimize the danger from galactic cosmic rays and solar particle events one would choose a low altitude location on Mars (like Hellas) where the atmospheric shielding is greatest. The galactic cosmic ray dose at Hellas is about 0.1-0.2 severts/yr from solar maximum to solar minimum (http://marie.jsc.nasa.gov). This would be an average of about 0.15 severts/yr. For colonists born on Mars, living 10 meters underground (like some of our ancestors who lived in caves) and going out on the surface on average less than 31 hours a week, this dose could be lowered to 0.03 severts/yr. If a dose of 1 person-severt leads to a 3 year loss of life on average due to premature deaths (Jackson, Stone, Butler, and McGlynn 2005), then this could reduce the average life expectancy of Mars colonists (from a US value of 77.1 years) to 70.7 years. This might seem a high price to pay but it would be a worthy sacrifice if the result was longer species survival. Also, in the future, we may be able to develop drugs to treat radiation damage more successfully.

President Bush's program to go back to the Moon and on to Mars has caused NASA engineers to propose a very clever space transportation system to replace the shuttle. There would be an Ares I rocket made of a first-stage solid booster (like one of the two on each shuttle) with a second liquid fueled stage to take a crew (of say 4) up into orbit. Most importantly, there would be an Ares V rocket consisting of a shuttle center tank, with F1 engines at the bottom, two solid boosters, and a second-stage liquid fueled stage. The Ares V has the following capability:

Ares V: 130 tons to LEO ⇒ 26.6 tons to Mars

Suppose that, conservatively, it took 11 years to develop (longer than it took to develop the Saturn V) and be ready to launch for Mars. In our next 45 years that would leave:

34 years (4 launches/2 year cycle) = 68 launches ⇒ 1,808 tons to Mars

Four Ares V rockets could be assembled at once in the vertical assembly building at Cape Canaveral to be ready for each 2-year launch cycle for Mars. Remember, the first payloads could deliver supplies the colony would need with robots for assembly, and the astronauts could be sent on one of the later expeditions. If we adopted this plan, we could send 1,808 tons to Mars in the next 45 years. Notice that this is less than the 2,130 tons we could deliver if we just matched the tons delivered to LEO that we did in the last 45 years. Also notice that it is greater than the 501 tons needed to establish a self-supporting Mars colony.

501 tons (Mars Colony) < 1,808 tons (Ares V capability) < 2,146 tons (last 45 yrs. equivalent)

There is over a factor of 3 between the 501 tons needed and the 1,808 tons we might reasonably deliver, leaving more than enough slack for other programs such as sending as many astronauts back to the moon as we did in the Apollo program (which was the equivalent to sending 311 tons to Mars).

Thus, I conclude that we can establish a self-supporting colony on Mars in the next 45 years if we can muster the will to do it. That is the big question. Will we be smart enough to do this? If we fail to establish a self-supporting colony on Mars in the next 45 years while we have the chance, it would be a tragedy. The dimensions of that tragedy may not be apparent to us until such a time, perhaps many thousands of years from now, when we find ourselves trapped on earth with no space program and our extinction as a species looms near. If we spend on the human spaceflight program over the next 45 years as much money in real terms (and send as much weight into low earth orbit) as in the last 45 years and still fail to establish a self-supporting Mars colony, it would be a double tragedy. I do not say this would be easy, but it is what we should be doing. No project we could attempt in the next 45 years would be likely to be as challenging or as important for the future history and survival prospects of our species. Because the human spaceflight program is not very old relative to our species and because our species is not very old relative to the universe, and because our habitat is tiny relative to the universe, we should be colonizing off the earth as soon as possible, while we still can. In 1961 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 and unwilling to postpone.”

Space colonization is a challenge we should be willing to accept and unwilling to postpone.

Thanks to Wes Colley for helpful conversations on the future plan for the space program. Supported by JRG's NSF Grant AST04-06713.

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