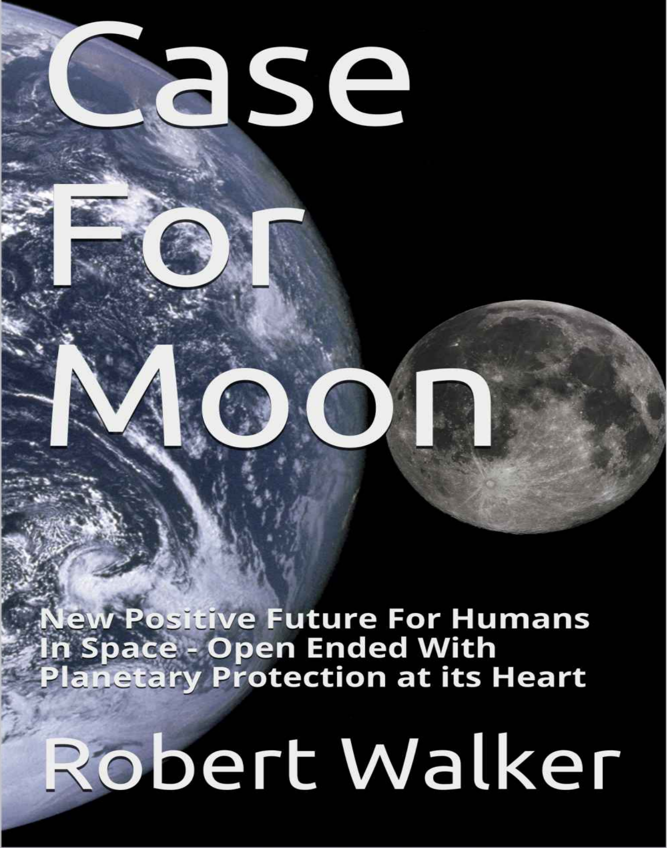
Case
For
Moon
New Positive Future For Humans
In Space - Open Ended With
Planetary Protection at its Heart
Robert Walker

Case For Moon

Positive Future For Humans In Space - Open Ended With Planetary Protection at its Heart

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Cover picture shows Moon Earth comparison (from wikipedia, public domain).

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You can also read this online (free) - published 2016 on my Science20 blog. (Online version is identical except for formatting, cover picture, and table of contents).

For my other kindle booklets, see my author page on Amazon.com.

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EXECUTIVE SUMMARY

(Most of the links in this section take you to appropriate sections of this booklet)

If you prefer to listen to it, here I am reading out the executive summary:

(click to watch on Youtube)

The Moon is our nearest unexplored territory outside Earth. To ignore it is like ignoring Antarctica after the first few landings in the nineteenth century. Why rush humans as quickly as possible to distant Mars, the one place in the inner solar system most vulnerable to Earth microbes?

- **The Moon is resource rich**, with volatiles at the poles, possibly hundreds of millions or a billion tons of them, with water, ammonia and carbon dioxide. It has many metals and nanophase pure iron in the regolith, also easily made into glass. It has a high grade vacuum for chip manufacture.
- **It has many advantages for a human base**, including the peaks of eternal light, and possibly enormous lunar caves.
- **It is of great interest for science,** with many new discoveries to be made.
- **It is far safer than Mars** as a first destination for humans.
- **There are many places other than Mars** to settle and perhaps colonize.
- **We don't know which gravity levels humans need for health**, or what spin rates we can tolerate. You can’t draw a straight line between the effects of zero g and full g based on two data points.
- **Everything humans need in space is available in the asteroid belt**, sufficient to build full g spinning habitats with a thousand times the land area of Earth.
- **Terraforming Mars is a far off dream**. We are not yet mature enough as a civilization to see this thousands of

years long megatechnology project through to completion. Failed attempts would introduce new lifeforms to Mars which may get in the way of future goals.

- **Earth is the best place for a backup and to rebuild civilization**. We live in a quiet galactic region, at a quiet time in our solar system. None of the proposed disasters could make Earth as uninhabitable as Mars, leaving Earth as the best place to rebuild. While if our technology is the problem, surely the solution can't be to set up one of the most highly technological societies ever, in space.
- **As a young technological civilization, we should have protection and sustenance of our home planet as first priority**, A trillions of dollars megatechnology "backup" attempt could distract from this. We can use our space technology to protect Earth against asteroids, to move damaging mining operations into space, for solar power, and for scientific discovery.
- **Mars has much more potential for surface and near surface habitats for indigenous life than realized before**. These habitats could host lifeforms that are vulnerable, for instance early life based on RNA and ribozymes instead of ribosomes, out evolved on Earth by DNA based life.
- **We have protection guidelines on Earth to stop microbial contamination of vulnerable habitats** such

as lake Vostok (an isolated lake below 3.5 kilometers of ice in Antarctica). Humans would not be permitted to descend into this lake at present.

- **Mars can be explored from orbit more effectively** than from the surface, using telerobotics.
- **Humans in clumsy spacesuits don't have special advantages over telerobots** on the Mars surface
- **From orbit, you can "teleport" via telepresence to anywhere on Mars** with immersive virtual reality experience of the surface.
- **We have miniaturized life detection instruments on a chip**, that just a decade ago filled an entire laboratory

> *"If such capabilities were to become available, one advantage is that the experiment would not be limited by the small amount of material that a Mars sample return mission would provide. What is more, with the use of rovers, an in situ experiment could be conducted over a wide range of locations."* (Page 41 of Safe on Mars)

These are now the most effective way to search for Mars life, past and present (as eight exobiologists said in a white paper for the decadal review). With our recent complex understanding of Mars processes, a sample return will not prove that Mars is safe for humans, or that humans are safe for Mars. Find out more

- **We should return samples from Mars either sterilized or to above GEO, or both**, at least for preliminary investigation. It is far easier, both physically and legally, to return them to Earth after we know what is in them. Otherwise we are left with the daunting task to design for safe handling of any conceivable Mars exobiology, based only on knowledge of DNA based life.
- **If we show that human exploration of the Moon is of value to Earth**, this will help human exploration of the rest of the solar system, not hinder it.
- **The same open ended principle should be used for all our explorations in space** . Rather than grand overarching plans - we need an open step by step approach. At each stage we learn from what we have found so far, and can adapt and change our goals rapidly.
- **Until we know a lot more than we do now, we should not close off future possibilities** for ourselves, our descendants and all future civilizations on Earth, but should keep all options open.
- **In this approach, planetary protection and biological reversibility are core principles**.

The Moon in this vision is a gateway to the solar system, a place to develop new techniques and explore a celestial body that is proving much more interesting than expected.

Along the way, we are bound to get human outposts in space, and colonization may happen also.

However, settlement in space doesn't need to be the driving force, any more than it is the driving force behind the study and exploration of Antarctica. If we try to turn Mars and other places in space into the closest possible imitations of Earth as quickly as possible, this may close off other futures, like the discovery of vulnerable early life on Mars, or better future ways to transform Mars.

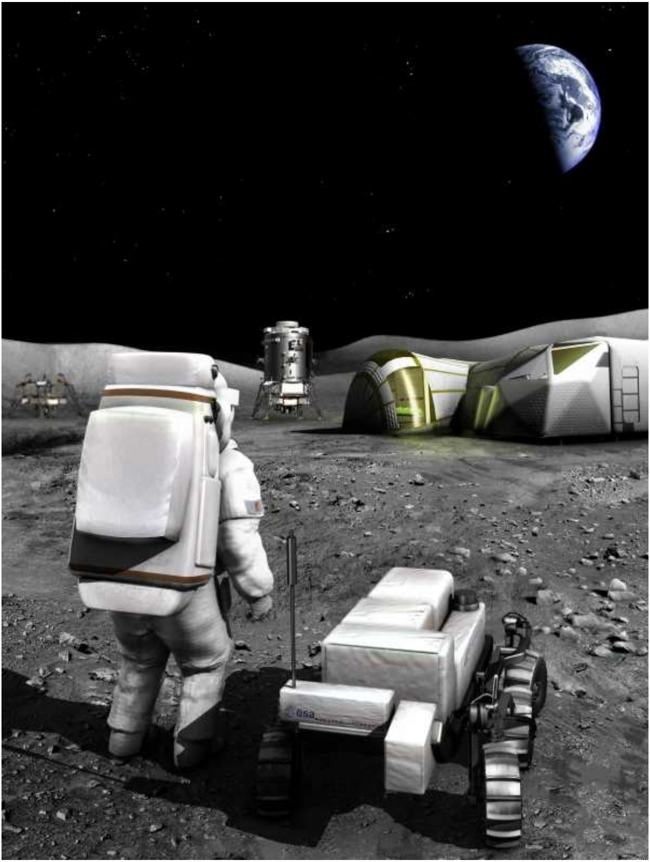
Once we develop the ability to live in space for years at a time, the whole solar system will open out to us. While keeping future options open on Mars we can explore Venus, Mercury, asteroids, Jupiter's Callisto and further afield, and Mars itself via telepresence. We also have many experiments in human settlement to try closer to hand on the Moon. This can be an exciting future, with humans working together with robots for remote exploration, as our mobile sense organs and hands in the solar system and galaxy.

SEARCH FOR INSPIRATION

If you are keen on Mars colonization, it is not hard to find a future vision to inspire you. Elon Musk has plans to send a hundred people at a time in his proposed "Mars Colonial Transporter" and found a city of 80,000, and eventually a million. He is due to reveal these plans at the IAC conference this September. And NASA, though they don't have such a large scale vision, aim to land human boots on Mars, with an eye to permanent Mars settlement in the future. You can also join the Mars society and read the books of Robert Zubrin.

But what if you are keen on humans in space, but don't think we have any realistic chance of colonizing the planet? What if you love science, and think "boots on Mars" has significant planetary protection issues? What can your future vision be? You have to go back perhaps to O'Neil's "Colonies in Space" vision of the 1970s to find an alternative that has the same level of positive inspiration as this Mars colonization idea.

Now though, some of us are discovering a gradually evolving alternative that I think will be a positive future inspiration, based on the Moon as our next place to visit and start permanent settlement rather than Mars. This new vision is open ended, with new goals that we discover along the way, and has planetary protection as a core principle.


esa

ESA image from blog post: Lunar Surprises - ESA rocket science blog

WHO THIS IS FOR

Are you keen on humans in space, but think Mars could be a step too far right now, and are skeptical about Mars colonization? Do you think we are bound to need to support our space settlements from Earth for a fair while into the future, just as we do for inhospitable places such as Antarctica? Do you think our exploration should be open ended with science as a core objective, and planetary protection and reversible biological exploration as core principles?

Do you see the Moon as an exciting first place to visit and explore, and see robots as our mobile sense organs in the solar system? Do you think that it's not quite yet the right time to relax planetary protection guidelines, and don't want to make Mars more vulnerable to Earth life?

Then this may be a vision for you.

The Moon is interesting in its own right. To ignore the Moon is like ignoring Antarctica because someone landed there in the nineteenth century, saying that Antarctica is already "done". It's the closest place to us in space which we can explore on the ground, and also the easiest, and safest to explore. If we can't explore our Moon, how can we have a chance of exploring Mars?

Also - why rush humans as quickly as possible to the one place in the inner solar system most vulnerable to Earth microbes? We want to find native Mars life there, if it exists. It is easy to find life if you bring it with you yourself. That would be the worst possible anticlimax of our searches for life in the solar system. Imagine, for instance, if we found that right up to the first human visits, present day Mars was the home to an RNA based lifeform, or many species of RNA life, which on Earth got made extinct by DNA life. Imagine if we discovered this just too late to study it, because our accidentally introduced microbes had made it extinct on Mars already, or we discovered it too late to stop the spread of Earth life and the inevitable extinction of Mars life? There may be many other ways Mars life could be vulnerable to Earth microbes. We must make sure this sort of thing just can't happen.

The Moon meanwhile is also resource rich. Many of the resource advantages listed for Mars apply to the Moon also. It also has some resources that Mars doesn't have, as we'll see.

This is the ESA video about ideas for small robotic missions first, followed by Antarctic base type settlements on the peaks of eternal light at the lunar poles

(click to watch on Youtube)

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In the process we find out what humans do best, and what robots do best, starting off with humans on the Moon. Then we can continue outwards in an open fashion, building on what we've learnt.

Meanwhile, we continue to explore Mars robotically from Earth, as well as many other interesting places in our solar system, including Venus, Mercury, Europa, Enceladus, Titan, comets, asteroids and so on. Later, once we have the capability, we can send humans to explore Mars telerobotically, perhaps first though "free return" flyby missions, then from orbit, then perhaps explore Mars from bases on its two moons Phobos and Deimos, and explore its moons themselves. These would be only some of many future human based missions, eventually spanning the entire solar system.

In this approach, science and planetary protection is central. Space settlement happens because you are there for a purpose. As with the Antarctic bases - once we are there with good science as the motivation, it would naturally become a permanent outpost and a first step into space.

Missions motivated by science continue to grow, and engage the public. There is no suggestion that we should stop exploring Antarctica because of the cost of doing science there. What's more, scientifically motivated missions can have overwhelmingly positive outcomes too, especially if we make new discoveries about biology and evolution.

However it's not enough to just say this. We need to try to provide a much more detailed vision. It needs to address the idea that Mars is the obvious next place to go, and somehow provide an alternative vision that is as compelling as that to the human imagination. That's quite a tough task.

SCEPTICISM ABOUT A VIABLE COLONY IN A COLD DESERT WITH A NEAR VACUUM FOR AN "ATMOSPHERE"

If you don't think we have a realistic chance of colonizing Mars, you can present your reasons for skepticism. You can say that it is sure to be much harder to live on Mars than to set up home in Antarctica, the Atacama desert, or the top of Mount Everest. You can point out that Mars is currently far more like the Moon than it is like Earth in terms of habitability, with its laboratory vacuum for an atmosphere (similar to Earth's atmosphere at 30 kilometers upwards), with hard radiation, and extremes of cold.

You can mention that (though it can get warm in the daytime), it gets so cold at night that carbon dioxide freezes out in dry ice / water ice frosts for 200 nights of the year even at the equator. You can point to the additional issues of the global dust storms that can sometimes blank out the sun for weeks on end, and harmful perchlorates in the dust.

I think everyone agrees with all those points. The difference is that prospective colonists see them all as challenges to be overcome, rather than as reasons not to colonize the place. They will point you in the direction of Robert Zubrin's books explaining how it would be done.

You can go on to ask, would that really work as a place where a million people, or even a thousand people could live and be self sufficient without constant expensive resupply from Earth? When we don't even colonize deserts on Earth, would we really colonize the near vacuum extreme conditions of Mars? However, a keen Mars colonization enthusiast will answer "Yes!" emphatically. Somehow all these problems will be solved, they say, and we will have colonies on Mars.

EARTH BEST FOR A "BACKUP"

I'll go into other aspects of this later on, but perhaps we should address this right away as it's become the top reason to attempt to colonize Mars for many people. Elon Musk has been promoting it strongly. Stephen Hawking has also said this is an important reason to go multiplanetary. In this account of an interview with Elon Musk, the author Ross Anderson presents it as:

> *"A billion years will give us four more orbits of the Milky Way galaxy, any one of which could bring us into collision with another star, or a supernova shockwave, or the incinerating beam of a gamma ray burst. We could swing into the path of a rogue planet,*

one of the billions that roam our galaxy darkly, like cosmic wrecking balls. Planet Earth could be edging up to the end of an unusually fortunate run."

But there are no figures here. So let's supply them. Calculation indented, and coloured purple, to make it easy to skip:

> *There's a formula, we can use here, from Perturbation of the Oort Cloud by Close Stellar Approaches. Our sun has approximately $4.2*D^2$ encounters with other stars every million years where D is the diameter in parsecs of the region. Neptune's semi major axis is 4.49506 billion kilometers so it's diameter is around 0.00029135 parsecs. So every million years there is 1 chance in $1/(4.2*0.0002913^2)$ of a star passing closer to the sun than Neptune.*

That makes it about one chance in 2.8 million of a star passing closer to the sun than Neptune every million years. There may be twice as many rogue planets as stars, so that means one chance in 1.4 million of one of those passing closer to the sun than Neptune every million years. Neutron stars are even more unlikely. So we don't need to worry about any of these on the millions of years timescale.

Gamma ray bursts are possible also, but would not make humans extinct, even if very close, because they only affect one side of the planet straight away and are over by the time the other side comes around. They would have long term effects on the ozone layer and such like, but if there were humans, or other beings here, with technology, the ones on the other side could survive and could then rebuild Earth much more easily than Mars.

It's the same also for a nearby supernova. They are very short, violent events, and only one hemisphere of the Earth would be impacted by the immediate effects of the sudden burst of gamma rays and extra cosmic radiation. A supernova within 33 light years, which should happen every few hundred million years, would also damage the ozone layer, but unlike animals, humans can protect themselves against the extra UV radiation. The population of the other side of the Earth could then rebuild civilization. So Earth is its own backup again. For those that worry about such things, I'd like to just add, that both of these are extremely unlikely events, and there are no known stars likely to go supernova close enough to be a hazard right now. The next supernova is most likely to be thousands of light years away. They are rare events that happen occasionally in an entire galaxy, and can be seen from an immense distance, and are most often spotted in distant galaxies.

The important thing is, that none of these, apart from a direct collision, or sending Earth out of its orbit, would make Earth less habitable than Mars. It would still have its oceans, its oxygen rich atmosphere, its protection from cosmic radiation, it's land, it's plants and surely fish and shellfish and animals also (even after the extinction of the dinosaurs, birds, dawn sequoia, river turtles, small mammals and many other plants and creatures survived). Many species would go extinct after a gamma ray burst or a large asteroid impact, but humans are great survivors and can survive anywhere from the Arctic to the hottest of deserts with only neolithic technology. So some of us, surely, would survive. And there is no realistic chance of a significantly larger asteroid, as there have been no impact craters that large anywhere in the inner solar system for over 3 billion years.

And you could do a much simpler backup, if you think it's necessary, by simply setting up your Mars base on Earth, in three different locations, say, in order to make sure they aren't all destroyed at once. By putting your backups on Earth, the inhabitants don't need to worry about the need to maintain a breathable atmosphere, and can go outside and repair their habitats without spacesuits, and don't need to cover the habitats with meters of regolith to protect from cosmic radiation. And if your "backup" is on Mars, it's not much use if the best place to rebuild in the solar system is on Earth.

So, it just doesn't seem to add up. Extinctions are happening, and will surely continue, many of them human caused. But humans themselves going extinct? I can't see it.

That is, unless we go extinct through misuse of technology. Nick Bostrom is a philosopher who thinks we have a high risk of going extinct from use of our own technology, perhaps as high as 25%. But that's partly because he is one of those who think the "singularity" is a possible future scenario, complete with mind uploading and boot strapping super intelligences who might take over the world, or that we might be living in a simulation which gets switched off. Elon Musk also thinks those are possible, as you can tell from the interview. Myself, I think those are science fiction scenarios that probably don't correspond to anything in reality. I see the greatest potential risks as from synthetic biology, for instance experiments to modify living cells to use something else in place of DNA, or from return of an extraterrestrial biology to Earth. See my Could Anything Make Humans Extinct In The Near Future? for the reasoning there.

In any case, if the main risk of extinction is from our own technology, then how can the solution be to set up a new society in space that is more dependent on technology than any other society that there's ever been? This could even increase the risk, by deflecting attention and money away from preserving Earth, and if done rapidly, even by causing conflict situations in space. And as for quarantine ideas - if it is quarantine that is the safety net, it would be easy to set up our "backups" on Earth with quarantine periods. And the six months voyage to Mars would surely get shorter, maybe even go down to days, as transport gets better.

So, I don't see this as a good motivation for sending humans into space. Rather, it's a motivation for setting up backups on Earth, if you think this is a serious risk. Plus taking great care about new technological developments that could lead to any kind of an extinction risk, such as synthetic biology, or return of extraterrestrial life to Earth.

Maybe half a billion years from now it will be a priority to set up habitats elsewhere, for whatever intelligent creatures have evolved on Earth by then, or they might have other solutions to the future hotter sun, but it's not urgent right now.

To be clear, this is not at all an argument against settlement. I think settlement in space is likely to happen, and can be beneficial if done well. But I think the motivation for it matters. More on this below under [Earth is the best place for a backup], where I link to some of my other articles as well.

WHY DO MICROBES ON HUMAN OCCUPIED SPACECRAFT GET A "SPECIAL PASS" TO MARS?

You can also ask, why land trillions of Earth microbes with every human occupied spaceship to Mars, while searching for Mars life? With our robotic missions, we continue to sterilize as carefully as before, with no sign of any suggestion that we can relax the planetary protection requirements. Indeed the trend is towards more rather than less by way of planetary protection for robots.

So, what is special about all the microbes that hitch a lift in human occupied spacecraft? Why give them special treatment? Would it not be more sensible to keep them well away from the planet too, until we know what effect they will have?

But all this so far is negative vision. It's not going to inspire people. Again the colonization enthusiasts will agree that this would be the ideal way to proceed. However they will say that colonizing Mars is so important, that they have to go ahead anyway. They will assure you they will take the best precautions they can to protect the planet given the requirement that they have to land humans on Mars. They may go on to say that some irreversible contamination of Mars with Earth life is inevitable, so we just have to find a way to cope with that.

NEED FOR VISION AND INSPIRATION

Humans need vision and inspiration, I agree. If you just say "can't do this, don't do that" that's a negative vision that can't inspire anyone. We need a positive vision if we are going to have any alternatives to this Mars colonization idea for the future.

So, I think I'm trying to develop an alternative positive vision here. Whether it works or not is something I'm finding out. It's getting enough favourable attention to be encouraging. In the process I've also come across others with alternative visions of their own. So perhaps it might encourage them too to continue to develop their visions.

The more visions we have, the more options we have for the future.

It is hard to present a vision like this in a short period of time. Remember that the positive vision of Mars colonization is has many details to support it, built up by its advocates over books, talks, television programs and so on. So an alternative positive vision also has to be quite detailed. This booklet, though it is quite long, is a rapid summary of just the main ideas.

Also, I'd also just like to say at the outset to humans on Mars enthusiasts, that **"This approach doesn’t mean that humans can never land on Mars ever".** It's the microbes that are the planetary protection issue here, not humans. And the microbes are an issue right now because we don't know what is on Mars, or what effects our microbes will have on the planet. I will suggest that whether microbes continue to be an issue in the future, or whether we can relax planetary protection measures for Mars, is something we can only find out by studying the planet in much more detail than we have so far.

THIS BOOKLET OUTLINES ONE PARTICULAR VISION OF MANY

The main new thing about this booklet compared to other treatments of the subject is that I put planetary protection, the value of science, and reversible biological exploration as central core principles from the outset. Often these topics, especially planetary protection, are barely mentioned.

I outline one particular vision here and present my own views unashamedly. I expect most readers will agree with me on some points and disagree on others. My main aim here is to present a vision in enough detail to stimulate discussion about other possibilities for future alternative visions. There could be many other ways to develop such a vision.

POSITIVE VISION FOR HUMANS IN SPACE

The key point here is, that while we continue to explore other places in the solar system with robots, we start with the Moon, for humans, as a place of great interest in its own right, and not just as a step on the way to Mars.

This is an important part of the vision, so I'll open out by talking about how interesting the Moon is, in some detail. It's our first place to explore on foot outside of Earth, and a gateway for humans to Mars, Venus, Mercury, the asteroids, Jupiter's moon Callisto, and further afield. If we develop the ability to live in space for years at a time on the Moon, then the whole of the solar system will open out to us, and we won't need to be focused on humans to Mars as the only option.

Artist's concept of a permanent lunar base, credit ESA.

Screenshot from ESA Destination Moon video.

In this article I use "space settlement" as the more general term, to refer to any humans living in space in permanent or semi-permanent bases, as they do in Antarctica - and space colonization for some later stage when they may become more self sufficient and also have children born in space.

It is likely to be a progression, first with outposts only temporarily inhabited. Then bases, like an Antarctic base. At some point, perhaps quite early, these become materially self sufficient in many things, able to produce all their own food, recycle their water, and produce power and even fuel for their rockets in situ. But they would be dependent on Earth for other things like spacesuits, computer chips, clothes, experimental apparatus, and any other complex machines and hard to manufacture materials. At some point we get the first children born in space, and then we may get the beginnings of true colonization.

But, I argue, colonization is perhaps not the best goal to have in the early stages. We may miss many opportunities if we make this our main aim, rather in the same way that if the early Antarctic explorers had had as their main aim to colonize Antarctica, they would surely never have succeeded in this, and would have missed out on the many discoveries and advances in science that came from a more open ended approach.

THE MOON IS RESOURCE RICH

Mars colonization advocates often contrast Mars with the Moon. The Moon may be described as being as uninteresting for human colonization as a lump of concrete. But actually it turns out that the Moon is very rich in resources. We need a "Case for the Moon" here like Robert Zubrin's "Case for Mars".

Moon advocates perhaps don't hit the news as much as the Mars advocates but are just as enthusiastic about their vision. Paul Spudis is one, with his most recent book, The Value of the Moon: How to Explore, Live, and Prosper in Space Using the Moon's Resources. Another is Dennis Wingo, CEO of Skycorp, see his recent paper, and appearance on the Space Show. It was also the policy of the US too during the Bush administration, with his Vision for Space Exploration program. And the ESA and Russia are strongly behind the idea of sending humans to the Moon first.

So, let's look at some of the suggested lunar resources for this Moon first approach.

CO_2 ON THE MOON

The Moon has CO_2 too, like Mars. At the poles - it has an estimated at least 600 million metric tons of ice (based on the mini SAR and lunar prospector data, indirectly detected through radar), and possibly much more. If those figures are correct (which needs more confirmation), and if the proportion is the same as for the LCROSS measurements, 2.12% of that may be CO_2, so that could be more than twelve million metric tons of CO_2 on the Moon by that estimate - in the form of dry ice.

Also CO_2 is not actually needed as a constant input into greenhouses, as many may think. In a closed system, then humans who eat the food breathe out just the exact amount of CO_2 that the plants need to grow the food they just ate (minus a small amount for feces but actually, this may surprise you, most of the carbon we eat is breathed out as CO_2, about 1 kg of carbon dioxide is exhaled every day, compared to only 30 grams of dry weight in feces).

Usually half of the plants grown for crops consist of plant wastes, but that also doesn't really change anything. The CO_2 you get from burning the wastes or composting it, added to the CO_2 breathed out by humans, is almost exactly the amount the plants need to grow the next generation of crops.

And to close the cycle, the plants produce almost exactly the amount of oxygen that humans need to breathe, indeed that's the main advantage of growing your food, that it saves on the 0.84 kg of oxygen you need to supply every day. Oxygen supply is the main issue here, and after that, food. It's not too likely that you will have a shortage of CO_2 in space.

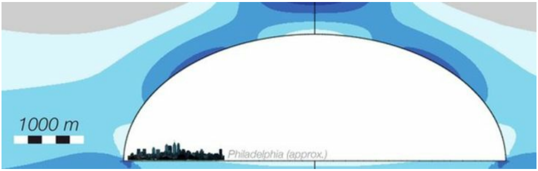
If you don't have a closed system greenhouse like that, if you have to import food, then you have a problem of an excess of CO_2 which has to be dealt with somehow. On the ISS it used to be vented into space. Nowadays they react it with the hydrogen got from splitting water to generate oxygen, in the Sabatier reaction - and so convert it to methane which is then vented into space. That's still not a closed system as it depends on constant input of water and food to provide the carbon and hydrogen that's lost to space in the methane.

One way or another, if you import food, you will have an excess of carbon in the system which has to be scrubbed and got rid of somehow, usually as carbon dioxide or methane. While if you manage a nearly biologically closed system, you need hardly any materials supplied from outside to keep it going, just need to deal with leaks. The water in urine, sweat and grey water can be recycled, something that is already done in the ISS. For techy details: upgrades to the ISS water recovery systems. And the feces can be dealt with also, without need to build a sewage plant in space, for instance oxidized at high temperatures 400 C and high pressures using supercritical water.

For more about all this see my Could Astronauts Get All Their Oxygen From Algae Or Plants? And Their Food Also?

LUNAR CAVES

It has lunar caves to explore, which could be large enough to fit an entire city within, in the low lunar gravity.



Lava tube caves on the Moon could be stable up to five kilometers wide in the lower gravity. The black silhouette here shows the city of Philadelphia superimposed in one of these suggested tubes. We know there are rills on Mars this wide and can see cave entrances into them on the surface, in photographs taken from orbit, but we can't see far into them so don't know how large the caves are yet. These huge lava tube caves may have been detected indirectly though, through gravitational anomalies in the Grail spacecraft measurements: [Scientists May Have Spotted Buried Lava Tubes on the Moon] - see also [Grail data points to possible lava tubes on the moon].

This is only possible because of the low lunar gravity, similar caves on Earth would be far smaller as would be any similar caves on Mars. We don't know for sure if such large caves do exist, but it does have many cave entrances photographed from orbit, which proves that at the least, it has caves similar in size to Earth caves. And the extensive systems of rills and the [Grail data] are suggestive of larger caves to be discovered.

VOLATILE RESOURCES

We have pretty good evidence now of ice at the poles, in permanently shadowed craters, thought to be [relatively pure and at least a couple of meters thick] according to radar data from a NASA instrument flying on India's Chandrayaan-1 lunar orbiter.

It's not a direct detection however, so there is still room for scepticism about it, as rough material would have the same radar signature as radar transparent ice. But craters that are rough when new, are rough both inside and outside the crater rim. While these signatures are found only inside the craters and not outside the rims, which they interpret as meaning that they are caused by ice. The temperatures are also right for ice.

If it is ice, it could be "fluffy ice".

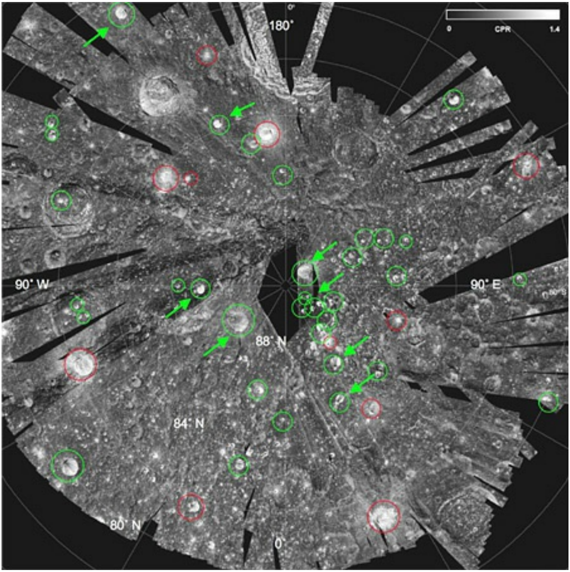
> *"We do not know the physical characteristics of this ice—solid, dense ice, or “fairy castle”—snow-like ice would have similar radar properties. In possible support of the latter, the low radar albedo and lower than typical CPR values for nonanomalous terrain near the polar craters are 0.2–0.3, somewhat lower than normal for the nonpolar highlands terrain of the Moon and are suggesting the presence of a low density, “fluffy” surface."*
> (page 13 of Evidence for water ice on the moon: Results for anomalous polar)

In either case, it is not just a little ice; if this is what they detected, there's estimated to be at least 600 million metric tons of this, and possibly much more.

It also contains other volatiles. We know for sure that there is some ice on the Moon, by the LCROSS impact experiment. Relative to H_2O at 100% they found H_2S at 16.75%, NH_3 at 6.03% SO_2 at 3.19%, C_2H_4 at 3.12%, CO_2 at 2.17%.

So, if the rest of the ice at the poles has a similar constitution to the impact site that's a lot of nitrogen (in the ammonia) and

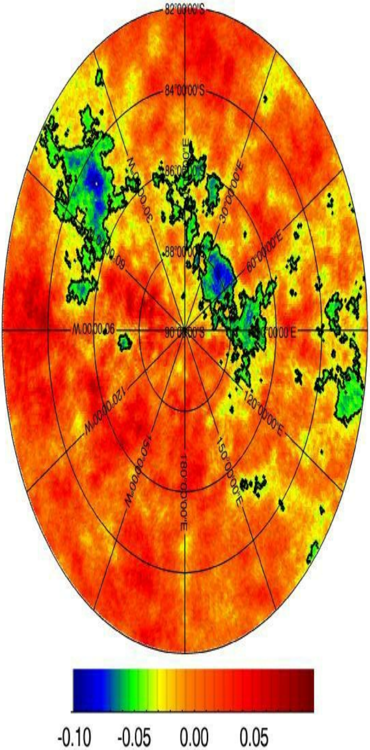
CO_2 on the Moon at the poles.



The green circles here surround craters at the lunar north pole thought to have layers of ice, [with an estimated total of at least 600 million metric tons of water.]
(0 degrees longitude at bottom)

On the other hand, caution is needed as this is not direct detection. The LEND results (searching for hydrogen through reduced emissions of neutrons of a particular type) are particularly puzzling, as there is almost no resemblance between their map and the miniSAR map.

LEND DLD South Polar diffCPS map contours at -0.04



LEND map - in this picture blue is reduced neutron emission and shows likely locations of hydrogen. 0 degrees longitude is at the top.

They did detect hydrogen, but puzzlingly, it was not correlated with the permanently shadowed regions - there was some hydrogen in permanently shadowed regions, and some also in illuminated regions. A recent paper suggests that ice mixed in the regolith in illuminated regions may be ancient ice that survived a minor shift of the lunar axis. According to one hypothesis, this may be ancient deposits from over three billion years ago before volcanic activity, which changed the polar axis slightly by shifting material.

A new LEND mission has been proposed involving low passes over the poles at altitudes as low as a few kilometers, for higher resolution results.

The Moon may also have ice at lower latitudes too, as there are permanently shaded regions up to 58 degrees from the poles (only 32 degrees from the equator). Though these regions are too warm to have ice on the surface, there may be ice there underground. See Ice may lurk in shadows beyond Moon's poles (Nature, 2012).

At any rate, the Moon does seem to have resources of ice at the poles (though memorably, Patrick Moore in one of the last Sky at Night programs that he did said that he'd believe there is ice at the poles when someone brought him a glass of water from the Moon). More research is needed to find out how much there is and where it is.

METALS

As for metals, the Moon has many valuable ores. For instance, the highland regions (probably the original crust of th Moon) consists mainly of Anorthite (a form of feldspar, formula $CaAl_2Si_2O_8$) which is 20% Aluminium, compared with 25% Aluminium for Bauxite on Earth. So aluminium ores are abundant on the Moon, indeed orders of magnitude more abundant than they are in typical asteroids, but it does require a lot of energy to extract the aluminium from the ore. Either a nuclear power plant or large areas of solar panels. Crawford, in his "Lunar Resources: a Review", says this about aluminium on the Moon:

> *"Aluminium (Al) is another potentially useful metal, with a concentration in lunar highland regoliths (typically10-18 wt%) that is orders of magnitude higher than occurs in likely asteroidal sources (i.e. ~1 wt% in carbonaceous and ordinary chondtites, and <0.01 wt% in iron meteorites; . It follows that, as for Ti, the Moon may become the preferred source for Al in cis-lunar space. Extraction of Al will require*

*breaking down anorthitic plagioclase (CaAl2Si2O8), which is ubiquitous in the lunar highlands, but this will be energy intensive (e.g. via magma electrolysis or carbothermal reduction; Alternative, possibly less energy intensive, processes include the fluoridation process proposed by Landis , acid digestion of regolith to produce pure oxides followed by reduction of Al2O3 (Duke et al.), or a variant of the molten salt electrochemical process described by Schwandt et a*l."

Mining this for the aluminium would create calcium as a byproduct, which is useful as a conductor in vacuum conditions, a better conductor than copper weight for weight - you need half the mass for the same amount of electricity. (Copper does better than calcium on a per volume basis because it is 5.8 times denser, it is also of course much more practical in an atmosphere because calcium reacts vigorously with air, but that's not a problem for conductors that operate in a lunar vacuum, and in space applications the reduced mass may be an advantage).

"Calcium metal is not used as a conductor on Earth simply because calcium burns spontaneously when it comes in contact with oxygen (much like the pure magnesium metal in camera flashbulbs). But in vacuum environments in space, calcium becomes attractive.

"Calcium is a better electrical conductor than both aluminum and copper. Calcium's conductivity also holds up better against heating. A couple of figures mining engineer David Kuck pulled out of the scientific literature: "At [20C, 68F], calcium will conduct 16.7% more electricity than aluminum, and at [100C, 212F] it will conduct 21.6% more electricity through one centimeter length and one gram mass of the respective metal." Compared to copper, calcium will conduct two and a half times as much electricity at 20C, 68F, and 297% as much at 100C, 212F.

"Like copper, calcium metal is easy to work with. It is easily shaped and molded, machined, extruded into wire, pressed, and hammered.

"As would be expected of a highland element, calcium is lightweight, roughly half the density of aluminum. However, calcium is not a good construction material because it is not strong. Calcium also sublimes (evaporates) slowly in vacuum, so it may be necessary to coat calcium parts to prevent the calcium from slowly coating other important surfaces like mirrors. In fact, calcium is sometimes used to deoxidize some metal surfaces. Calcium doesn't melt until 845C (1553F).

"Utilization of lunar materials will see the

introduction of industrial applications of calcium metal in space."

From the section on Mining the Moon in Permanent - by Mark Evan Prado, a physicist in the Washington, D.C., region working for the Pentagon in advanced planning in the space program.

The Moon is deficient in copper, at least on the basis of what is known so far, but as well as calcium, aluminium is a good conductor.

The LCROSS experiment found silver (a superb conductor) and mercury at the impact site, but the concentration is not known, except that it is far higher than the levels in the Apollo samples, and is probably in a layer below the surface, as the signal was delayed. See LCROSS mission may have struck silver on the moon.

It has abundant iron - in addition to ores (which would need a lot of power to extract), it actually has free iron metal

- From meteorite impacts
- Nanometer sized "blebs" released from the rock by the hydrogen in the solar wind reacting with iron oxides
- Particles of iron concentrated from the source materials for the regolith.

It's in powder form already, and naturally alloyed with nickel and cobalt. The blebs, or "nanophase iron" are found inside impact glass particles, so would be hard to extract. The rest though is made up of tiny particles of pure iron, so the obvious thing to try to do is to separate them out using powerful magnets. They are rather small though, most are less than a micron in diameter which could be a challenge. If we can separate them out, we can get five kilograms of iron, 300 grams of nickel and about half a gram of platinum, gold etc (platinum group metals) in every cubic meter of regolith - as pure metal what's more.

The iron is valuable for steel, and is also a conductor, though not nearly as good as Aluminium or Calcium. It would be useful for some applications such as electric railroads on Mars, and is a conductor easy to access in the early stages.

Also nickel and iron are useful for making nickel / iron batteries. These could be useful for making batteries on the Moon with in situ resources, for instance to help last through the lunar night.

> *"Iron-nickel batteries are very rugged. Their lifetimes which can exceed 20 years are not affected by heat, cold or deep cycling. They are not easily damaged by rapid discharging or over-charging. On the downside, they have poor performance at low temperatures but they can be kept warm with insulation (e.g. simple*

regolith) and thermal wadis. Also, they only have a charge to discharge efficiency of 65% and will self discharge at the rate of 20% to 40% per month. Despite these shortcomings, they might be the Moon-made power storage systems of choice due to their simplicity and the availability of their component materials on the Moon. Moreover, these materials are among the easiest of materials to produce on the Moon."

See Electrical Energy Storage Using Only Lunar Materials.

Then, you also have titanium. This is especially interesting as it is rare in asteroids. Apollo 17 samples are 20% high purity Ilmenite, a Titanium ore which is found in the lunar mare. And better than that, the Lunar Reconnaissance Orbiter, with its spectral mapping of the Moon, discovered deposits that are up to 10% titanium, more than ten times higher than titanium ores on Earth. (Phys.org report, NASA image). Titanium is an industrially desirable metal, stronger per unit weight than Aluminium (though it is a poor conductor).

Crawford writes (page 17):

"Therefore, in the context of a future space economy, the Moon may have a significant advantage over asteroids as a source of Ti. The fact that oxygen is also produced as a result of Ti production from

ilmenite could make combined Ti/O2 production one of the more economically attractive future industries on the Moon.

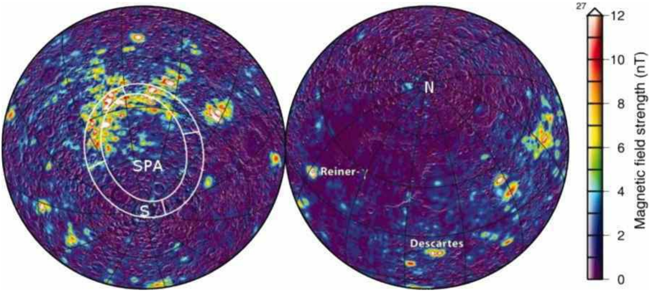
For more on this, see major lunar minerals. And for an in depth study, read Crawford's review.

So, yes, there are plenty of metals on the Moon, but it might take a lot of power to extract them, apart from the iron, if that can be separated out using magnets.

And that's mainly based on the Apollo results which explored a small region of the lunar surface which has been found to be in some ways unrepresentative. The Moon may have many other surprises in store. Many ores on Earth would not be detected from orbit, and it seems the Moon has a fairly complex geology as well.

As an example of one way the Moon could surprise us - Earth is often hit by iron meteorites, so the Moon should be also. The main question is, how Dennis Wingo has hypothesized in his Moonrush book, that the Moon may also have valuable platinum group metals which could be mined, the result of the impacts of these iron meteorites.

Taking this further, there's a hypothesis by Wieczorek et al that magnetic anomalies on the Moon around the south pole Aitken basin may be from the remains of the metal core of a large 110 km diameter differentiated asteroid that hit the Moon to form the basin. If so, they could be useful sources for platinum, gold, etc.



From Wieczorek et al, the North and South poles are marked N and S. Notice the magnetic anomalies clustered around part of the rim of the South Pole Aitken Basin. This is thought to be the result of an impact by a 110 km diameter asteroid. Wieczorek et al hypothesize that the magnetic anomalies trace out the remains of the metal core of this asteroid. If so these could be rich ores, including iron, nickel, also platinum and other platinum group metals (gold, rhodium etc). See page 16 of Crawford's Lunar Resources: A Review

Then, although the Moon doesn't have any liquid water so all the processes involving concentration of resources through water erosion won't work, it still has many processes that can concentrate ores. Including:

- Fractional crystallization - as a melt cools down, some minerals crystallize out at a higher temperature than others so form first. They then settle or float, so remove the chemical components that make them up from the mix, so changing its formula, leading to new crystals to form in a sequence.
- Gravitational settling, lower mass material floats to the top.
- Volcanic outgassing can concentrate materials such as iron, sulfur, chlorine, zinc, cadmium, gold, silver and lead.
- The processes that lead to volatiles condensing at the poles - which it seems can also concentrate silver too
- Processes unique to the Moon (perhaps electrostatic levitation may concentrate materials)?
- Volatiles brought in as part of the solar wind

Probably only the platinum group metals would be worth returning to Earth, since it's going to be easier to mine the Near Earth Asteroids, especially the ones that consist almost entirely of pure metal. However, whether or not they are useful for Earth, they are well worth using on the lunar surface once you have industry there.

The Moon has some advantages over Mars indeed for metals, such as the pure nanophase iron mixed in with the regolith.

LUNAR GLASS

This is a beneficial side effect of all the micrometeorite impacts on the Moon (which you don't get so much on Mars with its thin atmosphere, just enough to filter out micrometeorites). The Moon's "soil" or regolith contains large quantities of glass, created during the impacts. It also has free iron, as we saw, at half of one percent of the soil, in tiny micro beads of iron (nanophase iron) which concentrate the microwave energy. Again, you don't have this on Mars.

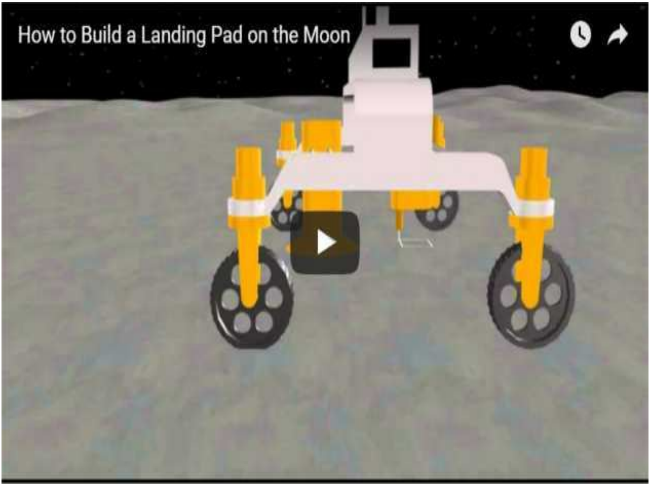
As a result, it is really fast to melt the regolith using microwaves. It took only 30 seconds to melt small lunar sample at 250 watts (typical of a domestic microwave). You can melt the soil to glass as easily as you can boil water using the microwave in your kitchen. See lunar lawnmower. This only works with genuine lunar soil and not the simulants. We have nothing analogous to lunar soil on Earth, as Larry Taylor, principle author of this paper found: Microwave Sintering of Lunar Soil: Properties, Theory, and Practice. He says the microstructure of the genuine lunar regolith, with nanophase iron beads scattered throughout, would be almost impossible to simulate.

His idea (see Products from Microwave Processing of Lunar

Soil in that paper) is to run a "lunar lawnmower" over the soil with two rows of magnetrons (such as generate microwaves in a microwave cooker). The first row would sinter it to a depth of half a meter using microwaves. Then the second row completely melts the top 3-5 cm of the soil, which then crystallizes to glass. As it does this, it will heat up and release most of the solar wind particles notably hydrogen, helium, carbon and nitrogen. So it could also capture these assets as it goes along, including the Helium 3, if this turns out to be of economic value.

See also The Lunar Dust Problem: From Liability to Asset. This could also be useful, for instance, for making solar panels and other applications.

Then, there's Behrokh Khoshnevis' idea for making a landing pad on the Moon using tiles made of lunar glass in situ. The idea is to make the surface into lots of tiles by injecting a material that can't be sintered easily using microwaves into the soil first to outline the edges of the tiles, then use microwaves to melt the soil in between.



(click to watch on youtube)

This would make a tiled flat surface for supply vessels to land on. It would also help with the problem of lunar dust by removing dust from the landing area. You can read the details here. He used lunar regolith simulant, so presumably by Larry Taylor's results, it would work even better with genuine lunar samples.

LUNAR DUST INHALATION COMPARED WITH MARS DUST

Both the Moon and Mars have dust, and in both cases also, it's a fine dust much finer than you normally encounter on Earth, so fine that it can't be expelled from our lungs by the cilia, the hairs on the cells that line the airways. The lunar dust is sharper edged, on the other hand the Mars dust is oxidizing, and may also burn your skin.

The Mars dust also has perchlorates in it, at levels 10,000 times higher than on Earth. These are food for some microbes, but harmful to humans as they impair uptake of iodine which is needed for functioning of our thyroid glands, which regulate our metabolism. They may also have other effects. See This chemical might make Mars more dangerous.

Mars perchlorates are also likely to be decomposed by ionizing radiation into the reactive ClO_3 and ClO_2 which have more serious and immediate effects *"such as respiratory difficulties, headaches, skin burns, loss of consciousness and vomiting"* (quote from page 3 of this paper). Mars also has dust storms, which the Moon doesn't have - and it's likely to be harder to keep dust out of a habitat on Mars if you have to go out during a dust storm.

Mars and the Moon are rather similar here. In both cases the dust is both a hazard and a resource. For Mars, see Perchlorate on Mars: A chemical hazard and a resource for humans. For more on the Moon, see *"Risk of Adverse Health Effects from Lunar Dust Exposure"* (Chapter 13, page 317 of *Human Health and Performance Risks of Space Exploration Missions* from the NASA Human Research Program, 2009). In the case of the Moon we also have actual experience of humans inhaling the lunar dust, and can also examine and test the dust returned to Earth. Some of the astronauts found it a sensory irritant, but they did tolerate it fine short term. That's just for a few days however.

In both cases, steps would need to be taken to keep the dust out of habitats and spacesuits, for instance using the SuitPort which has been developed to keep dust out of habitats for either Mars or the Moon.

HELIUM 3

I should mention this, since the topic is brought up so often in discussions of lunar settlement. However I don't see this as a major plus point for the Moon at present.

The Moon is a source for helium 3, deposited in the regolith by the solar wind, and some say that helium 3 will be of value for fusion power in the future because it is not radioactive and doesn't produce radioactive waste products. If so, small amounts of helium 3 from the Moon could be worth a lot on Earth and be a useful commodity to export. Apollo 17's Harrison Schmidt is a keen advocate of helium 3 mining on the Moon.

However, we don't yet have fusion power plants at all, and one able to use helium 3 is a tougher challenge. Frank Close wrote an article in 2007 describing this idea as "moonshine" saying it wouldn't work anyway. For a critical discussion see also the Space Review article The helium-3 incantation

Crawford says (page 25) that to supply all of our energy from Helium 3 would mean mining 5000 square kilometers a year on the Moon, which seems ambitious (and would mean the whole Moon would only last 200 years). So, even if we develop Helium 3 based fusion, and it turns out to be a valuable export, it's probably not going to be a major part of the energy mix. He also calculates that covering a given area of the Moon with solar panels would generate as much energy in 7 years as you'd get from extracting all the Helium 3 from that region to a depth of three meters.

Also - there are many other ideas being developed for nuclear fusion, such as laser fusion, and the polywell which has the same advantage that no significant radiation is produced when it uses fusion of boron and hydrogen. I think it is far too soon to know whether or not the helium 3 on the Moon will be an asset in the future when we achieve nuclear fusion power. For a summary, see ESA: Helium-3 mining on the lunar surface.

However (as Crawford suggests page 26), Helium 3 is useful for other things, not just for fusion power. for instance for cryogenics, neutron detection, MRI scanners, so some Helium 3 from the Moon could be a valuable export right away, even if it doesn't scale up to the huge quantities you'd need for Helium 3 based power generation on Earth. You'd get it automatically as a byproduct while extracting the more abundant volatiles from the solar wind in the regolith, so it might well be a useful side-line to help support lunar manufacturing economically.

THORIUM

The Moon may not have much uranium, but it is rich in Thorium, in the lunar Mare. This is useful as a fuel for nuclear fission reactors, which have to be designed to burn thorium instead of uranium to use it. It's not likely to be worth returning to Earth as thorium is abundant here. But it could be very useful in space, at some point in the future.

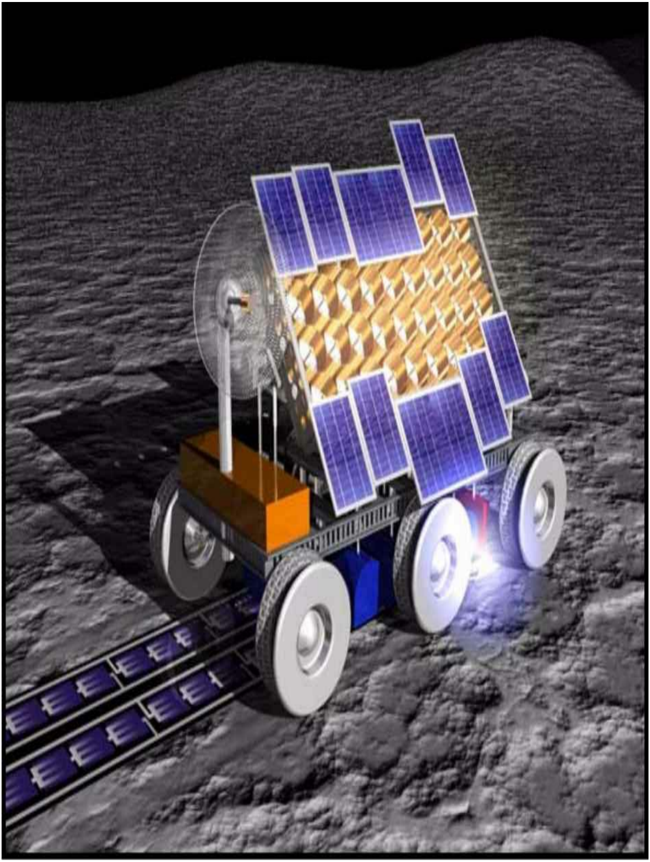
Nuclear power stations built on the Moon wouldn't have the same pollution hazards and hazardous waste issues as stations on the Earth. Perhaps this may be a way to power space colonies, and interplanetary ships fueled from the Moon, so avoiding the need to launch nuclear power plants from Earth to orbit.

SOLAR CELLS FROM LUNAR

MATERIALS

Once you have glass, it might not be such a big step to make photovoltaic cells on the Moon. And here the Moon has one big advantage, the high grade vacuum so you could use vacuum deposition to make the cells in situ. To start with you'd make the cells themselves from materials sent from Earth, later on mine them on the Moon.

This is a report from the Center for Advanced Materials at the University of Houston, suggesting the possibility of an autonomous solar powered lunar photovoltaic cell production rover



It would use silicon extracted from lunar materials to make the cells themselves. Of the various methods you could use, magma electrolysis may be best. He uses low efficiency silicon cells which are vacuum deposited on glass, something that is not easy to do on Earth but would be possible in the ultra high vacuum conditions on the Moon. Techy details of this suggestion are here.

EARTH LENGTH DAY ON MARS VERSUS ADVANTAGES OF CLOSE TO 24/7 SOLAR POWER AT THE LUNAR POLES

Yes the Mars near to 24 hours day is a remarkable coincidence. But - it's not so much of an advantage over the Moon as you might perhaps think. The 24 hour day of Mars actually leads to huge differences of temperature between day and night in Mars' very thin atmosphere. At night in the Martian "tropics" the air gets so cold that carbon dioxide freezes out as dry ice, carrying water with it to form the Martian frosts photographed by Viking. While in the day time the temperatures can get well above zero at times.

You might think the Moon is even worse with its 14 Earth day long night. But there's one other big difference between the Moon and Earth, that turns out to be very important. Unlike Earth and Mars which have an axial tilt of over twenty degrees, the Moon has a tilt of only a bit over 1 degree.

This means it has no seasons, and as a result, you get points at the poles that are in almost constant sunlight, the peaks of eternal night, and just next to them, permanently shaded craters.

So, yes, the lunar night is a major challenge. But it does have the advantage of these peaks of eternal light at its poles where the temperatures are much more even, neither too hot nor too cold. (The average temperature may seem rather chilly at -50° C, but it varies by only 10° C in either direction and that's warm enough that a habitat there can be kept at a comfortable temperature of 20° C with the aid of a solar collector. See Peaks of Eternal Light in the online NASA astrobiology magazine). Compare that with Mars, where for for 200 days of the year, even at the equator, it gets so cold at night that dry ice condenses out as frost (mixed with water ice), while in the day time the temperatures can get well above 0 C and you can see that thermal regulation would be far easier at the lunar poles.

The best place for long term settlement on the Moon as they explain in the ESA video also, may be these peaks of almost eternal light. They are best for power too, as they get solar power almost 24/7. There are a few hours and occasional days in the year (Earth days there) when they don't get solar power but for most of the time there is just sun 24/7. So they do much better than Mars in that respect. See also the section lunar poles (below).

So, when you are at the lunar poles, it's like a perpetual Arctic or Antarctic equinox with the sun skimming the horizon, seeming to circle around you once every 28 days. If you have solar panels mounted upright, which rotate once every 28 days,they can then follow the sun and get maximum solar power. The reason that can happen is because the Moon has an axial tilt of only 1.5424°. Basically, the Moon doesn't have seasons like Earth. Earth has seasons because of its axial tilt of around 23.4° at present (varies slightly by around one degree or so between 22° 2′ 33″ and 24° 30′ 16″ with a period of 41.040 years).

For a detailed working out of power available and requirements for various stages of a lunar polar base (with Shackleton crater at the south pole as an example site for the base), including methods of transmission of the power, and storage on the Moon, see Power System Concepts for the Lunar Outpost

The Moon also has the lunar caves. These would shield from radiation, lead to a more even temperature again, may be possible to be made air tight, and as we saw, are thought to be possibly as much as several kilometers in diameter (only the Moon with its low gravity can have caves as large as that).

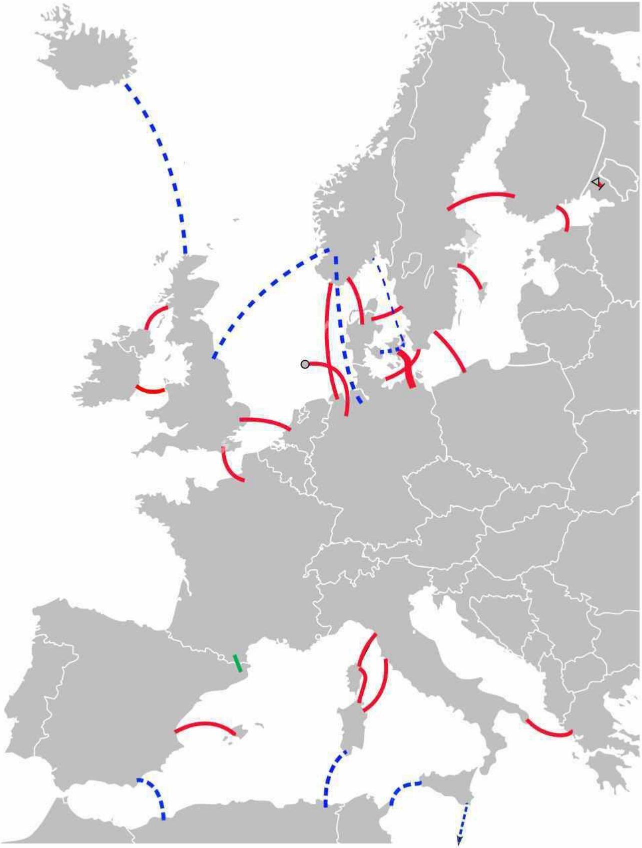
So, what happens to plants, won't the caves be too dark, for them? Well, yes, lights would be needed in the caves or anywhere on the Moon except the poles, during the long 14 day lunar nights. But they would be needed for plants on Mars too, during the dust storms, which block out 99% of the sunlight, often for weeks on end.

This used to be a major issue, because the lights for growing plants would consume a lot of the power of a space habitat with a greenhouse. But it's not a big issue any more. This is something that has changed a lot recently with the invention of LED lights. Even if you have to produce all the lighting for your plants through electric power, that's feasible. You need about 100 watts of supplied power for lighting for one square meter. With only 13 square meters needed for most of the food per person - then that amount of power is actually within the range of RTGs if you had a few of those, for times when solar power is not available. Or you could generate power from fuel, or use batteries which are topped up when you have an excess of solar power. So,power for the LEDs for your greenhouses doesn't seem likely to be a major issue.

Longer term, perhaps you could start by just putting panels on all sides of one of the lunar poles of sunlight. Then the only periods without any solar power would be during the rare total lunar eclipses. You could use cables to transmit the power over a short range, and then microwaves for longer distances, and perhaps eventually HVDC for transmission as is often done on Earth. Eventually perhaps have solar panels at various latitudes on the Moon, right down to the equator, and positioned so that there are always some panels in sunlight, and then you could have a power grid on the Moon which supplies solar power 24/7.

We can do similar things on Earth. Not from the other side of the planet - but actually you can get abundant power even at night in the Sahara if you use the sun to store the heat as molten salt in the daytime to use to supply power at night.

Desertec was a project to supply pretty much all of Europe with solar electric power from the Sahara desert. The reason they never did that is mainly political, and the cost of setting it up in the first place. Desertec would have supplied power from Sahara to the whole of Europe including Germany, even up to Norway and Sweden. They would have used HVDC cables, including existing cables that connect the countries to each other already plus new ones for the project.



In this map, the existing HVDC cables are shown in red, and proposed ones, which would be used to connect Europe together to the power generating facilities in the Sahara desert are in blue.

The longest existing HVDC link in the world is 2000 km in China.from Xiangjiaba–Shanghai transmits 6400 MW of power over that distance according to the [details here (see page 8)]. (would need to check but probably accurate). A quarter of the circumference of the Moon is 2728.5 km which is the furthest you'd have to send power to get it to the middle of the night side from the day side of the Moon. It's not much more than the Chinese grid system - and probably have less transmission loss in a vacuum.

With any of these approaches, even if you have cables spanning the Moon, you can't do anything about the times when the moon is eclipsed by the Earth. However, that would only be for a few hours per year for the partial eclipse stages, and [totality for the longest duration total lunar eclipses lasts a little over 100 minutes].

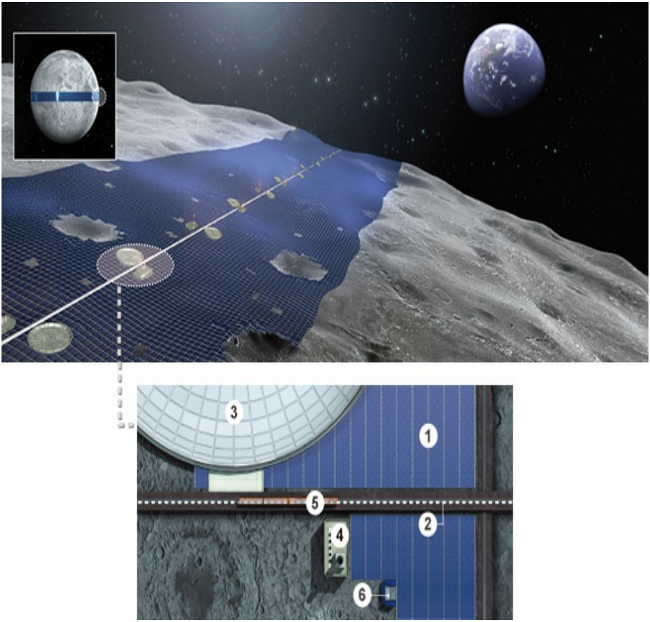
So you would need some form of power storage. But that's not likely to be a major issue with lots of ways to do it. If you are mining water and splitting it for fuel, then a natural way to store power is simply to use hydrogen fuel cells. But there are many other possible solutions.

POSSIBILITY OF USING LUNAR SOLAR POWER FOR EARTH

This is a bit more far out, but it is worth thinking about, whether solar power for the Moon could actually be useful for Earth also. Some scientists think it could be.

It's easy to see this working on the Moon, but some have suggested it could also be used to generate power on Earth. So, taking this even further, with a large scale operation of this type, using only 1% of the surface area of the Moon, you could supply 2 kilowatts of continuous power per person to a population of 10 billion on the Earth. See Solar Power via the Moon. More details here.

Or, further ahead, maybe this is more interesting as a talking point than a likely near future concept, the Japanese Shingzu corporation has suggested we could build solar panels in a band around the Moon - at the equator



See [Shimizu dream - Lunar Solar Power Generation - Luna Ring.]()

(click to watch on Youtube)

Earth would get solar power only half the day, so they send the power to satellites in orbit around Earth, which then beam it down to the other side of Earth. Of course they need large receivers to collect the power from the Moon, but only 1% of what they'd need to collect it directly from the sun - that could be worth doing if it is significantly easier to make solar panels on the Moon.

On the other hand there are ideas to use large thin film solar panels in space or large thin film mirrors to concentrate the light onto solar panels or furnaces, launched from Earth to LEO. So would the lunar solar plants be a major saving compared to those?

Another way that the Moon could help the Earth though, with solar power, is to make the solar cells from lunar materials, and then ship them to GEO or lower orbit. The idea of using lunar materials to make solar power satellites goes back at least to the 1970s, see Construction of Satellite Solar Power Stations from Nonterrestrial Materials

GREENHOUSE CONSTRUCTION - COMPARISON OF THE MOON AND MARS

Mars does have an atmosphere, but it is a near vacuum. Less than 1% of Earth's atmosphere. This is not enough pressure to be a significant advantage over the Moon for greenhouse construction, as the lowest pressure greenhouses typically would be pressurized to around 10% of Earth's atmospheric pressure.

> **Example:** if you have a greenhouse on the Moon at 10% of Earth' pressures, the atmosphere exerts an outwards pressure of one ton per square meter of the greenhouse. On Mars, on average, the outwards pressure on your

greenhouse would be 0.93 tons per square meter. (assuming 0.7% of Earth's atmospheric pressure). It depends where you site it - at the bottom of the Hellas basin it is a little more, but remember you have to engineer for the lowest rather than the highest pressure there and it varies seasonally. The maximum pressure is 12.4 mbars for Hellas Planitia which means it requires at least 0.876 tons per square meter for the greenhouse though it is likely to be more than that to allow for the lower pressures in winter. At any rate it's a lot of outward pressure, not that different from the Moon.

The 10% figure here is nearly the lowest pressure greenhouse you can have and still have humans able to visit it using only an oxygen mask and not a full body pressurized spacesuit. If you go all the way down to 6.18%, right at the limit of tolerance with just an oxygen mask, then the figures are a pressure of 0.618 tons per square meter for the Moon and 0.548 tons per square meter for Mars average pressures. At lower pressures than that, the moisture lining your lungs, on your skin, in your mouth etc will boil at blood temperature, so you can't survive without a pressurizes spacesuit.

LANDING AND TAKING OFF - COMPARISON OF THE MOON AND

MARS

The atmosphere does help with aerobraking on Mars, but at a price of a much trickier landing. Typically you have to reduce speed from Mach 5 to Mach 1 and then convert to a lander, and land it on the surface all within 90 seconds. Then typically the parachutes only reduce the impact velocity to around 200 mph, so for the final few meters of the landing you need retropropulsion.

The lunar gravity is only a little under a half of the Mars gravity, so you might think there wouldn't be much difference, but there's a huge difference because of the rocket equation. You can see this difference with the Apollo lunar landers. Their small rocket motors were not only able to land two humans and their supplies on the Moon, but take off as well, and all with no use of atmospheric braking.

OTHER MOON MARS COMPARISIONS

Much is made of the value of CO_2 for fuel generation on Mars from a hydrogen feed stock. However, Mars needs much more fuel for take-off than Earth. The volatiles at the poles of the Moon might be a source for rocket fuel to LEO, and the solar power, which is more than double on the Moon and even more so at the poles where it is not only double the intensity of Mars sunlight, but also present nearly 24/7.

As for the extreme cold - yes the Moon has the coldest temperatures of the entire inner solar system in the polar craters of eternal night. But that's actually an asset, it can be used for passive cooling of infrared telescopes for instance. Especially since it is right next to areas where the temperatures are much warmer, for habitats, and again, pretty much the same year round.

Much is made of the coincidence of the Mars 24 hour day. But it is easy to create night, for plants to grow in darkness, you don't need a lot of shielding. Just a thin sheet of any opaque material is all you need to shield out the midday sun and create a shadow on the Moon. And you need light for the plants during the lunar night - well you need light for plants on Mars during the Martian storms so you would need the capability to supply plants with LED lighting for several weeks on end anyway.

And the 24 hour day of Mars actually leads to huge differences of temperature between day and night in Mars' very thin atmosphere. At night in the Martian "tropics" the air gets so cold that carbon dioxide freezes out as dry ice, carrying water with it to form the Martian frosts photographed by Viking. While in the day time the temperatures can get well above zero at times. The steady temperatures of the lunar poles of the Moon would be much easier to engineer for.

So none of those seem particularly to be advantages for Mars over the Moon. Indeed, I think you could say that, despite appearances, the Moon is actually more habitable than Mars in many ways, for the first settlers to get there at least. Especially so if it has volatiles at its poles.

The one possible advantage Mars might have is its somewhat higher gravity level. But we know so little about human tolerance of gravity, that you can't really assess this, or even say for sure that it is an advantage. You can't extrapolate a straight line based on only two data points, Earth gravity and zero gravity. We don't even know if lunar gravity is bad for health yet (it might be beneficial, or beneficial for some people or health conditions or ages), or what the gravity health prescription is for humans, or what human spin tolerances might be for artificial gravity on the Moon (e.g. when asleep), or whether a steady gravity level is best or one that varies (e.g. higher gravity when asleep or while eating or exercising).

LUNAR VACUUM AS AN ASSET

The vacuum of the Moon is also actually an asset, so much so that we might need to take special precautions to preserve it.

> *"It seems absurd to expect that the lunar vacuum could be lost by small-scale operations on the moon. However, high-vacuum and ultra-high vacuum is needed for many industrial processes, some of which may be accomplished on the moon. Some processes which require vacuum and thus would be simpler to manufacture or use on the moon include vacuum tubes, semiconductor manufacture, solar cell manufacture, and particle accelerators."*
>
> Degradation of the Lunar Vacuum by a Moon Base - Geoffrey A. Landis

The carbon dioxide atmosphere of Mars ia so thin it counts as a laboratory vacuum, you would need a pressurized spacesuit or you'd die quickly because the water lining your lungs would boil. But it's not thin enough to be a useful vacuum. And as we've seen, carbon dioxide is not needed as an input for greenhouses - in a closed system it just circulates around to food and back again. The Moon would seem to have the advantage here, too.

MARS OR MOON SPECTACLES AND THE OLD WOMAN YOUNG WOMAN ILLUSION

One of the things I've discovered as a result of writing this book, is that the Moon is not only much closer, and a safer place to send humans - it's probably also in many ways more habitable than Mars! That will probably surprise you if you come to it after reading Robert Zubrin's "Case for Mars". Probably you will say: it's got no 24 hour day, no CO_2 atmosphere - it seems dull as concrete - and some of the ideas for colonizing Mars will work, but others will not. It's no longer easy to make methane from a hydrogen feedstock without a CO_2 atmosphere for instance. So how can the Moon possibly be an easier place for humans to live than Mars, when only some of Robert Zubrin's ideas will work there?

But if you look at it on its own merits, then things suddenly turn around, like those images of a young girl and an old lady

One of the early versions of the Young Girl Old Lady Illusion.

The 24 hour day of Mars actually turns into a disadvantage of Mars because of the huge day to night temperature changes. Similarly we've seen that on the Moon you won't miss the low grade laboratory vacuum levels of carbon dioxide, which is not needed in a closed system greenhouse. And instead the hard vacuum becomes a major advantage of the Moon over Mars. Instead of methane fuel, you use the abundant solar power to split the water ice into hydrogen and oxygen, a much better rocket fuel, and you can also use the hydrogen to make fuel cells. We've seen several examples like this.

I think the general point here is that if you try to analyse the Moon as if it was Mars, then it seems like it has little by way of resources. But when you analyse it on its own terms, it is rich in resources. It also has several unique resources not available on Mars. You need to look at the Moon with "moon spectacles" to see its advantages.

WHERE TO BUILD OUR FIRST LUNAR BASE FOR HUMANS

We have two choices for a lunar base, well on the basis of what we know so far: the poles, or lunar caves.

LUNAR POLES

The lunar poles seem very attractive for our first base, after discovery of volatiles at the poles, as well as confirmation of the peaks of almost eternal light As we've seen, the temperature at the poles hardly varies, and it gets solar power nearly 24/7. Our base needs to be protected from solar storms and cosmic radiation, but that should be easy, with regolith piled over the habitats. See for instance Lunar Station: The Next Logical Step in Space Development (from 2015)

This is the the choice for both ESA and ROSCOSMOS, as well as many others.

LUNAR CAVES

However the poles aren't our only option by any means. One other place to build a base is in the lunar caves. See for instance, Technologies Enabling Exploration of Skylights, Lava Tubes and Caves (from 2011). One big advantage of the caves is that they give natural protection from cosmic radiation and solar storms. The temperature is lower, but constant and the base would be easy to insulate and keep warm.

The basic idea is to send robots first to scout it out before you send humans - for science reasons and for safety reasons. First, a lander flies over the cave entrance before it lands, to image it close up. It then drops a line into the cave entrance which is used to supply power to the bots underground, and for them to communicate to the surface.

The bots themselves can be lowered down on tethers, or just be dropped in, in the low lunar gravity and drive, hop or crawl. or move like a snake, or like a spider crawling over the walls - or they can have little rocket engines and fly about inside.

For more on this, see the various cave bots on page 21 of the paper. The bots discussed include:

- **Spherical hopping microbots** - an idea from Penelope Boston - launch many into the cave, each with a small instrument package. Many will not survive but the ones that do can be used to explore, for communications links to the surface and data return.

- **Multi-segment tethered robot** - the tether is used to lower it down, and then for communication with the surface and recharging.
- **Legged tethered robot** - the same idea but with legs so it can navigate rough terrain more easily.
- **Snake tethered robot** - the same idea but it moves like a snake
- **Cave hopper** - combines hopping with wheels
- **Climbot** - future robot able to climb walls with a high level of autonomy
- **Elevator** - large tethered platform used to lower multiple robots at once into the cave, with wheels to allow it to maneuver over debris once down.
- **Propulsive flying bot** - uses small thrusters to navigate, so it can get to parts that may be unreachable by the other bots
- **Telescoping ball robot** - has two modes: enclosed in a ball, for launching into the cave and rolling down slopes inside the cave, and then the two halves of the sphere can separate to be used as wheels, with extending tail for balance.
- **Prismbot** - the bot can move by tipping from one side to another.
- **Rope climbing** - a fixed tether and the robots can climb up and down it.

POWER STORAGE

Unless we find a cave close to the peaks of eternal light then a base in a cave only has access to nearby solar power for 14 days of a lunar month. Some power storage would also be needed for the lunar poles, to deal with the short periods of night they get, including lunar eclipses. This could be fixed with the use of batteries capable of storing power for 14 days, or through nuclear power. Some power could be supplied for the lunar night through radioisotope thermonuclear generators. We've also seen the possibility of making nickel iron batteries using lunar materials Electrical Energy Storage Using Only Lunar Materials

One method that's been suggested for storing energy for the lunar night is to use the reversible reaction of CaO with H_2O to produce $Ca(OH)_2$ which liberates large amounts of heat. The CaO can be obtained from the lunar soil as a byproduct of aluminium extraction from anorthite. During the day, the CaO and H_2O are dissociated again at high temperatures (550 °C) using sunlight for heat. This reaction is tricky to use for power storage on the Earth because of the presence of CO_2 which leads to formation of calcium carbonate, steadily removing calcium oxide from the system. But on the Moon there is no CO_2 naturally present so it would be easy to keep carbon dioxide excluded from the power generation and storage system, and the system could be cycled over and over.

Other systems that could be used include flywheels, hydrogen / oxygen fuel cells, beamed power, or indeed long range cables connecting solar panels on the day side of the Moon to the night side. With modern LED light with only 100 watts per square meter to supply light for photosynthesis, greenhouses in lunar caves could work with reasonable levels of power.

ROBOTS FIRST

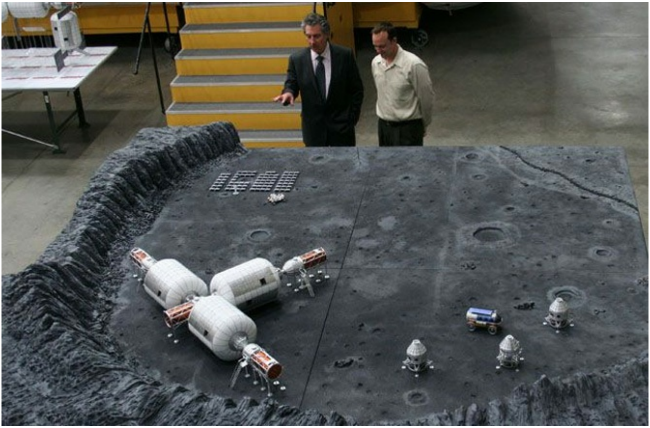
In both cases, we would explore using robots first.

- **They need to check conditions on the ground** to find the safest place to set up a base for the humans
- **They need to do scientific study before the humans arrive** - because of the possibility of contaminating scientifically important sites such as volatiles in the dark areas close to the proposed sites at the lunar poles or perhaps deep underground in permanently shadowed regions at lower latitudes.
- **The robots can also be used to start construction of the bases via telerobotics** from Earth, so that there are shelters for the humans already ready for them when they arrive.

[Luna 27 - robotic prospector to the lunar south pole Aitken crater, planned mission for ESA and Russia for 2020].

HUMAN HABITATS

We would probably use the Bigelow inflatable modules to reduce weight.



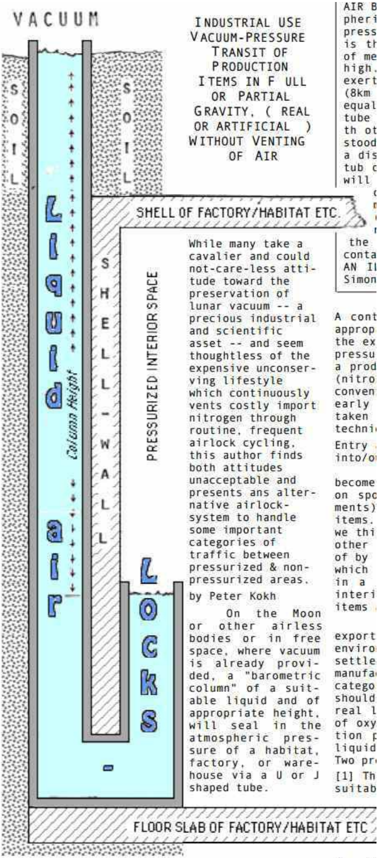
Robert Bigelow with a model of a Bigelow Aerospace lunar outpost
BIGELOW AEROSPACE

We could get started quite soon if the Falcon Heavy is a success, with its 53 tons payload, perhaps using the Dragon V2 for humans.

LIQUID AIRLOCK

This is a rather fun idea originally suggested in the Moon Miner's Manifest Classics - 1987-1988 (see page 31).

Though not so likely in the early stages, it may perhaps be useful at a later stage, especially for bases that have a lot of traffic in and out.



INDUSTRIAL USE VACUUM-PRESSURE TRANSIT OF PRODUCTION ITEMS IN FULL OR PARTIAL GRAVITY, (REAL OR ARTIFICIAL) WITHOUT VENTING OF AIR

While many take a cavalier and could not-care-less attitude toward the preservation of lunar vacuum -- a precious industrial and scientific asset -- and seem thoughtless of the expensive unconserving lifestyle which continuously vents costly import nitrogen through routine, frequent airlock cycling, this author finds both attitudes unacceptable and presents ans alternative airlock-system to handle some important categories of traffic between pressurized & non-pressurized areas.

by Peter Kokh

On the Moon or other airless bodies or in free space, where vacuum is already provided, a "barometric column" of a suitable liquid and of appropriate height, will seal in the atmospheric pressure of a habitat, factory, or warehouse via a U or J shaped tube.

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It's a liquid airlock for the Moon. You need to look carefully at the picture. How it works is that you have a sump, like the sumps that cave divers dive into. But on the inside, it is kept in position by the pressure of the air inside the habitat. On the outside is a vacuum.

The interesting thing about it is that you could dive through it in a spacesuit, if your suit is capable of being submersed, and come out onto the surface with no loss of air at all from the habitat. There is no need to evacuate the airlock, or anything. Just there available as an airlock all the time. Any time to get out of the base you just dive through the sump. This could be quite a saving if the airlock is in regular use.

The liquid needs to have a very low vapour pressure. The original author suggests NaK. Kim Holder suggests water glass in this stack exchange conversation about it. And I've just suggested you could use ionic fluids - water glass is basically half salts, half water - and an ionic fluid is just a salt, like sodium chloride but that's liquid only at very high temperatures. If it is liquid at room temperature or below, you call it an ionic fluid.

There, a salt in chemistry is a general term for the result of combining any acid with any base. It has positive and negative ions, when in solution, and when you melt the solid salt, if you can do that without it decomposing or vaporizing, it also usually consist of positive and negative ions (cations and anions).

Anyway, so it turns out that if they have high molecular weight, salts are often liquid at room temperature and even at very low temperatures such as you'd get on the lunar surface, so those are all ionic fluids. And they have a very low vapour pressure, so wouldn't boil away in a vacuum. For this reason they have been suggested for liquid mirror telescopes on the Moon.

The only thing is, that most are high viscosity, but there is research into low viscosity ionic fluids. You'd probably also want a high density fluid to reduce the height of the outside part of the sump.

Perhaps it might also be useful for moving cargo in and out. Instead of those big hanger like airlocks you get in science fiction movies, maybe you'd just have a truck that drives through a sump filled with ionic fluid - or even - a funicular railway type carriage gets pulled through it? You could have trains that run out of the base onto the lunar surface directly with no need for an airlock so long as they can withstand being submerged. This doesn't seem to be beyond future high tech. The more I think of it, the more possibility it seems to have for future tech.

One thing that makes it harder on the Moon is that with a sixth of the gravity, the column is six times higher. So a water column would have a height of (9.807/1.622)*10.3 or 62.3 meters which is quite a lot. The author talks about higher density fluids to keep the height difference down. Some ionic fluids are high density so that would help.

There's a plus there, however as the height difference is comparable to the depths below the surface of the floors of the lunar cave entrances. So when you dive into the sump at the bottom of the cave, your buoyancy will take you to the surface. A sump that goes all the way from the cave floor to the surface would make it easier to move goods up and down using weights, or floats.

It would also help keep out dust. A lot of the dust in the Apollo lunar module came in on the outside of the suits. So it would surely also come in on the outside of vehicles and their wheels, and there'd be a chance of it getting scattered in through an open airlock too from the outside. None of this would happen with a liquid airlock.

THE MOON IS TURNING OUT TO BE MUCH MORE INTERESTING THAN EXPECTED

We are at the same stage here as the very first Antarctica explorers, setting foot on a continent sized land mass that we know little about first hand. Indeed, far larger than Antarctica; the Moon is as large as Russia, the USA and China put together.

The ice at the poles of the Moon could be the "Record keepers of the early solar system" as Greg Delory put it.Then there is more ice offset from the north and south pole. As mentioned already, this may be ancient deposits from over three billion years ago before the volcanic activity, which changed the polar axis slightly by shifting material.

Then there are ancient regolith layers covered with lava which preserve a record of surface lunar conditions and solar activity over billions of years.

There are other surfaces on the Moon recently formed with few craters - changed by some activity, perhaps emissions of gas, in the very recent geological past Some think it may still have ice, deep down, or even trapped water, from a layer of water rich material that might have accumulated on the early Moon at the same time our oceans formed soon after the original impact of the Mars sized protoplanet with early Earth - Water on the Moon, Yvonne Pendleton, page 3.

We don't yet know the age of the ancient South Pole - Aitken basin, a huge 2,500 km diameter crater which extends over the far side, the "oldest, deepest and largest basin recognized" on the Moon. Just a few samples of rocks returned from it would establish this.

The Moon might also be of interest for evolution and exobiology. That's because meteorites from Earth must hit the Moon in large numbers, after the largest impacts on Earth such as the dinosaur extinction Chicxulub event, (perhaps a million fragments around a cm in size, in that case). Though there is no atmosphere, the gravity is so low that meteorites from Earth can hit the surface at quite slow speeds (comparatively). This has lead to many ideas in the literature of ways that organics from life on Earth or other sources of interest to biology may be there for us to discover. We can only find out for sure by exploring the Moon on the surface:

- **Possibility of an ancient regolith layer** buried beneath later lava preserving actual organics from the first few hundred million years of Earth evolution.

- **Suggestion that the lunar ice at the poles could preserve ancient biogenic organics**.
- **Suggestion that effects of cosmic radiation on the ices and other chemicals** at the poles of the Moon may be creating complex organics - not quite life probably but the ingredients for life.

- **Possibility of meteorites from Earth on the Moon** - which again, if they landed in frozen areas of the Moon, may preserve organics from millions or even billions of years. They could also preserve fossils as fossil diatoms are still recognizable, and the smallest ones intact after a simulated impact on the Moon. There may be as much as 200 kilograms of material from Earth per square kilometer of the lunar surface.
- **It may also have early rocks from Mars and Venus**. See section 3.1.1 of Back to the Moon: The Scientific Rationale for Resuming Lunar Surface Exploration
- **Must have organics from meteorite and comet impacts** at least and probably from the solar wind too which brings not just hydrogen but also heavier elements to the Moon.

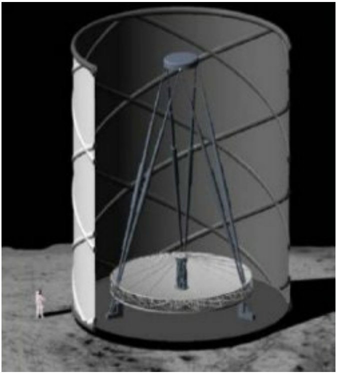
The Apollo samples were recently re-analysed and the composition of amino acids suggests some extraterrestrial sources, The analysis was a tricky one due to contaminants from Earth in the form of rocket fuel, organics taken to the Moon by the astronauts, and organics introduced while handling them on Earth, which suggests we need to take care to avoid this sort of thing as we explore the Moon.

So, another thing we can do on the Moon is to find out how much organic contamination accompanies human explorations. E.g. before we send humans to Phobos or Deimos or wherever they go next, we'd better know what humans will do to a celestial body when they set up a settlement there. Especially if the aim is to study ice deposits in craters and such like. Organic Measurements on the Lunar Surface: Planned and Unplanned Experiments

The far side is the best place to build radio telescopes anywhere near to Earth because it is radio dark, shielded from Earth by the Moon. Long wave telescopes could be built simply by rolling out lines of cable across the surface. It is a particularly good site for frequencies below 100 MHz, as these are blocked by the ionosphere on Earth. This would open up the last unexplored frequency regime in our radio observations of the universe.

Further into the future, we could build Arecibo dish type radio telescopes in natural craters on the Moon. Frank Drake once calculated that it should be possible to create Arecibo type telescopes with a diameter of 30 km or more on the Moon (see abstract on page 91) - Arecibo is 305 meters in diameter.

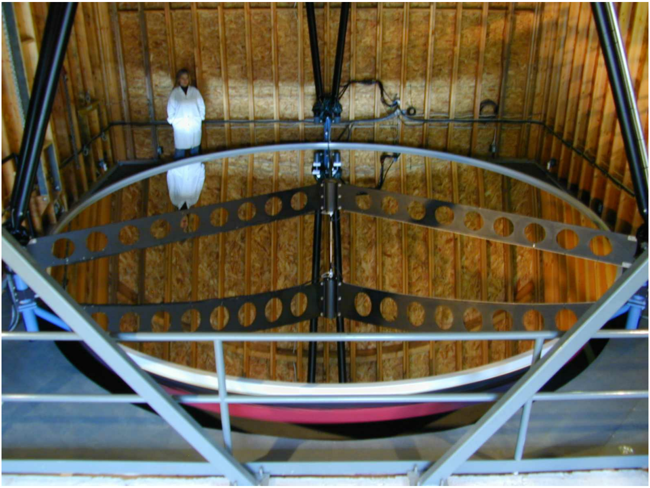
We can also construct infrared passively cooled telescopes at the poles, for instance using liquid mirrors



Artist's impression of a large liquid mirror infrared telescope on the Moon, passively cooled near the lunar poles. The dish rotates to make a natural parabolic shape.

Because the Moon librates so much - rocks up and down and back and forth relative to Earth as it orbits us - a telescope like this would see much more of the sky than a comparable telescope on Earth. See Liquid Mirror Telescopes on the Moon (NASA news, 2008). This infrared telescope could detect objects a hundred times fainter than the ones visible to the planned James Web Space Telescope.

A lunar infrared liquid mirror telescope would have a mirror like this

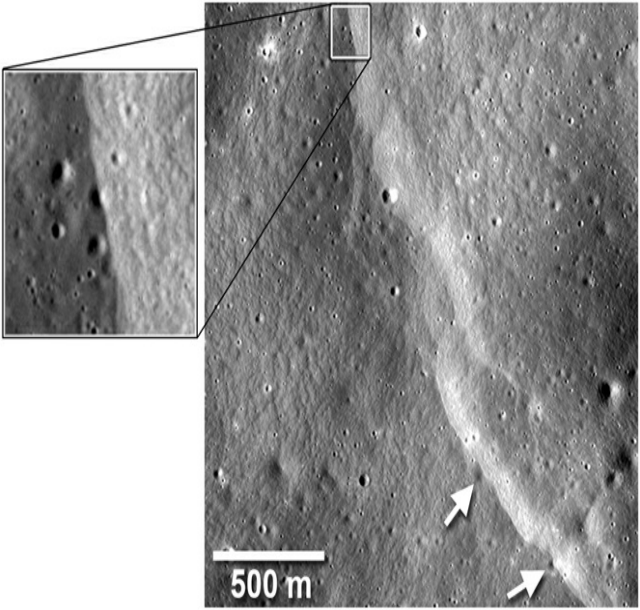


which keeps its natural perfect parabolic shape through rotating the disk slowly. The photo shows the six meter diameter Large Zenith Telescope in Canada. On the Moon, this mirror would be made of ionic fluids (salts in a liquid state) rather than mercury, due to their very low vapour pressure which would let them work in the vacuum conditions of the Moon.

GEOLOGICALLY ACTIVE MOON

Another big surprise recently is that the Moon was recently geologically active, over the timescale of millions rather than billions of years. It might even be active today.

First there are the lobate scarps, fault lines that cut across small craters on the Moon. Small craters tend to be geologically young as they get obliterated by later craters. So these faults are thought to be young, possibly as young as a few hundred million years.



The Apollo seismometers recorded moon quakes, and though most are probably due to impacts, tides, and day / night temperature changes on the Moon, it leaves the possibility open that perhaps the Moon is still active today. These scarps may be a sign of it.

See [NASA's LRO Reveals 'Incredible Shrinking Moon']

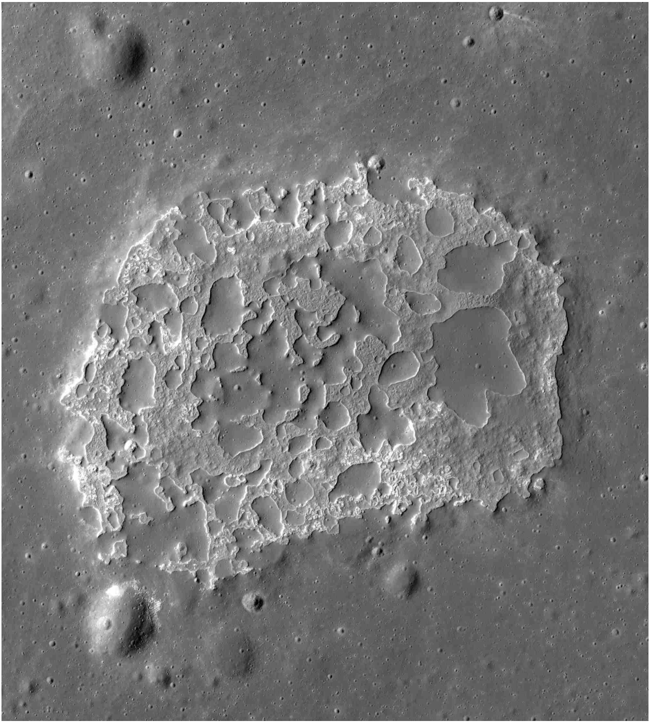
Then, they also found graben - trenches formed when the crust pulls apart. And these are as young as 50 million years old. That is so young that it suggests the Moon is still active.

[Graben on far side of the Moon found by Lunar Reconnaissance Orbiter]

This was a big surprise as the lobate scarps suggested that the Moon was shrinking. So how can it be expanding as well?

[(click to watch on Youtube)]

Then, there's this strange feature on the Moon, unlike most of the terrain there, the Ina depression.



Ina depression as imaged by LRO. It's 2.9×1.9 km and 64 m deep. Higher resolution available here. It is one of four similar features around the Imbrium basin.

Whatever it is, it seems to be geologically recent, as there are few really small craters, and larger features have sharp edges and haven't been degraded. This suggests an age of only millions, rather than billions of years. It's spectra shows it to be bluer than the surrounding terrain (slightly) - a spectral signature consistent with freshly exposed Mare materials. Schultz et al interpret it as mare exposed by a sudden outgassing from the interior blowing away more than 12 meters thickness of overlying an regolith or pyrolastic material (rubble like in texture, result of fountaining lava in the past).

The Moon's surface layers are not just depleted in water compared to Earth, it's also depleted in the more volatile metals potassium and sodium too (by comparison with the less volatile zinc). One recent idea is that when two protoplanets collided to form the early Earth, and the debris condensed to form the Moon, volatile rich layers may have condensed first, then dry layers accumulated on top of them (links also to the original Nature paper) . That paper is mainly used to explain why the surface layers are so dry. They weren't able to determine if the interior would have volatiles in it, but it's possible.

So, it's not necessarily as dry all the way to the center as it is on the surface. Perhaps it has water and other volatiles deep down. If so, these outgassing ideas may be easier to accept.

Then you have the Transient Lunar Phenomena. Moon observers over the years have often noticed short term brightening of the Moon's surface, especially in the Aristarchus plateau. A small bright patch will appear, then disappear, just a bit too slowly to be just a flash from an impact on the Moon. Our eyes are very good at picking up such things, but also easily fooled. So it's a controversial observation. But they may be the result of outgassing, again, if they are real.

So anyway, Arlin Crotts of Columbia University noticed a correlation of the TLPs with sites where argon and radon gas is detected. This can't come from the solar wind and must be outgassing from below the surface. The usual explanation is that it's the result of slow leaks from radioactive decay from below the surface. He thinks that there may also be explosive outbursts of gas which may lead to the TLPs.

He developed these ideas in a series of papers called "Lunar outgassing, transient phenomena, and the return to the Moon", where he also suggests that the Moon may have ice some meters below the surface replenished from below

- I: Existing data
- II: Predictions and Tests for Outgassing/Regolith Interactions
- III: Observational and Experimental Techniques

In the third paper he proposes using ground penetrating radar in orbit around the Moon to search for subsurface ice. He also suggests various ways to monitor the Moon from orbit searching for outflowing gas as well as attempting to observe the TLPs directly.

EXPECT THE UNEXPECTED

On top of that you also have the unexpected. What I've described so far are things we can expect, or know to search for and investigate, on basis of what we know so far. But usually we get surprises when we explore new places in the solar system. And though in some ways the Moon is well understood, in other ways it is barely explored at all on the surface, never mind below the surface. It wasn't that long ago that ice on the Moon was a big surprise to many astronomers. It may have many other surprises in store too. We have spent hardly any time exploring the Moon so far, with only one expedition with a geologist on it. Imagine if we had given up on Antarctica as "done" after the first few expeditions that succeeded in landing a human on the continent?

USING THE MOON TO BUILD HABITATS IN FREE SPACE

The Moon may be the key not just to lunar habitats, but also habitats in free space. The original plan for space habitats in the 1970s was to use a rail gun on the Moon to fire material away from the surface for the radiation shielding of the Torus. This is the most heavy part of the structure. The idea was to land a small bulldozer on the Moon, and then bulldoze the regolith, load into a railgun, and fire it to the construction site for the habitat. This then would be used for the 4.5 tons per square meter cosmic radiation shielding; the heaviest part of the structure.

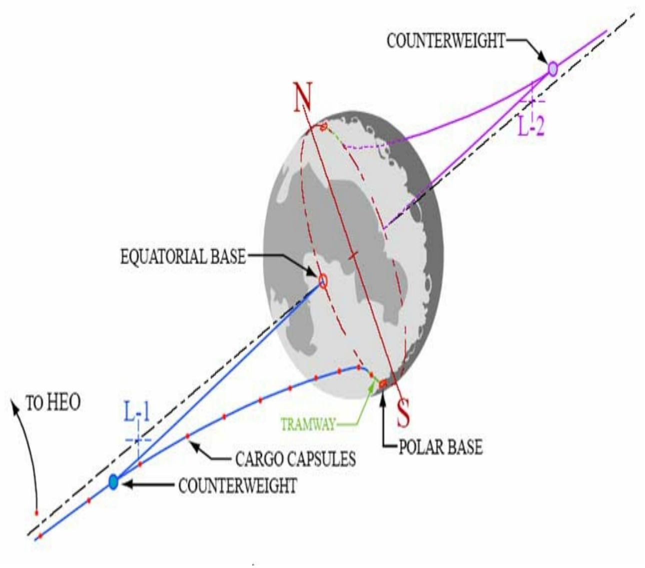
As O'Neil put it in his testimony to the US house of representatives (subcommittee on space science and applications) in 1975,

> *"The removal of half a million tons of material from the surface of the moon sounds like a large-scale mining operation, but it is not. The excavation left on the moon would be only 5 yards deep, and 200 yards long and wide: not even enough to keep one small bulldozer occupied for a five-year period."*

With the low lunar gravity, and escape velocity of only 2.3 km / sec, then this could be done with solar powered or nuclear powered rail guns on the Moon capable of sending material to orbit. This is something we could test on the Moon.

There are other ideas also for exporting materials from the

Moon, such as the lunar space elevator. which was promoted in a successful kickstarter by the Liftport group. Though we don't yet have the technology to build a space elevator on Earth, we could in principle build one on the Moon. It would extend from the surface through the Earth Lunar L1 point,



Then, there's the possibility of generating fuel using the ice at the lunar poles. With 600 million metric tons at least, if those figures are correct, then it seems that we could make fuel without significantly impacting on the amount of ice there.

Agreed, if you want to go to Mars and it's your only destination you are interested in for humans outside of Earth, and for a short visit only, then perhaps it wouldn't make sense to set up all that infrastructure to mine lunar water just for a single mission to Mars, or a couple of missions there with humans.

But if you are visiting the Moon because it is interesting in its own right, then the fuel on the Moon could then easily become a key towards opening the rest of the solar system to easier spaceflight, as well as supplying fuel and water to LEO as well. Perhaps just for a few decades, until we find an easy way to access other sources in the asteroid belt or find easy ways to lift it from Earth.

MOON FIRSTERS - ESA, RUSSIA, MANY ASTRONAUTS, FORMER US VISION FOR SPACE EXPLORATION ETC

So far this vision is the same as the vision of the ESA and many others. The ESA has come out firmly in favour of sending humans to the Moon first.

(click to show on Youtube)

ROSCOSMOS (Russian space agency) are of the same opinion. They plan a mission Luna 27 to the south pole Aitken basin in 2020 in partnership with Europe.

President Bush also favoured this approach, when the Vision for Space Exploration Program was announced, though now, of course, US favours a "Mars first" approach.

The Canadian astronaut and former ISS commander Chris Hadfield has also come out firmly in favour of Moon first, as reported by Wired Magazine: *"I expect we'll treat the Moon, for the next 100 years, like we've treated Antarctica for the last 100 years. With an initial outpost briefly and then longer stays and people staying through the entire winter, and eventually we will have permanent habitation on the Moon."* Then, he says, humans will go as far as Mars. This is also the message of former ISS commander Leroy Chiao who wrote an article about it for Space.com

Buzz Aldrin also, a keen advocate for Mars colonization, and inventor of the idea of the Adler cyclers for transport to Mars, now says we should go to the Moon first, with a quote from his own website:

> *"Aldrin and other experts believe Nasa is overlooking an important part of space exploration: a permanent,*

> *manned base on the moon that would prepare us for the mission to Mars."*

and in more detail here (he used to say to leave the Moon alone), perhaps his views were changed by the more recent discoveries of ice on the poles.

In his Mission to Mars, he says

> *"The moon is a different place since I traveled there in 1969.*
>
> *"... Thanks to a fleet of robotic probes recently sent to the moon by several countries, there's verification that the moon is a mother lode of useful materials. Furthermore, the moon appears to be chemically active and has a full-fledged water cycle. Simply put, it's a wet moon.*
>
> *"New data on our old, time-weathered moon points to water there in the form of mostly pure ice crystals in some places. For example, sunlight-starved craters at the poles of the moon — called 'cold traps' — have a unique environment that can harbor water ice deposits. Gaining access to this resource of water is a step toward using it for life support to sustain human explorers. Similarly, the moon is rife with hydrogen gas, ammonia, and methane, all of which can be*

converted to rocket propellant."

"Fresh findings about the moon from spacecraft have revealed the lunar poles to be lively, exciting places filled with complex volatiles, unique physics, and odd chemistry, all available at supercold temperatures ...

"In short, our celestial neighbour in gravitational lock, the moon, can be tapped to help create a sustainable, economic, industrial, and science-generating expansion into space. The question is, What should America's role be in replanting footprints on the moon?"

Jeffrey Hoffman is another astronaut who says we should go to the Moon first. The US non profit organization Space Foundation also say the same. As also mentioned, Paul Spudis is a keen Moon first advocate, author of several books, most recently, The Value of the Moon, as is Dennis Wingo.

More about some of this in Human Spaceflight At "Coastline Hugging Phase" - Lunar Villages Not Interplanetary Voyages - Op. Ed.

So far this is a "Moon first" argument. There's endless discussion between the Moon firsters and the Mars firsters about where humans should go first. See for instance the The

Case for the Moon: Why We Should Go Back Now, and The Case Against the Moon: Why We Shouldn't Go Straight Back published in Space.com in 2011. These discussions rarely mention planetary protection.

Where this new vision differs is that planetary protection is a core principle which guides the vision. It's also an open ended vision where what we do next depends on what we discover along the way. It's a vision for human spaceflight enthusiasts with a deep love of science.

ALTERNATIVE POSITIVE VISION FOR EXPLORATION OF OUR SOLAR SYSTEM - MAIN POINTS

With the Moon as our starting point, we can then explore Mars as well. I totally agree that Mars is a great place to explore and that we can learn much about exobiology from studying it. But I think this is best done with robots initially, with humans first controlling them from Earth, and then later on, from Mars orbit.

The Mars colonization advocates say that we need to send humans to the Mars surface to explore it. But I don't think this argument stacks up if you look at it in detail, as you will see. In this alternative vision, humans work together with robots to explore the entire solar system, not just Mars. It uses humans and robots each to their best advantage, where they are most needed.

I've added links to my other online articles in this section, which you can read to find out more details about some of the ideas outlined here. Some of them have book cover images - these are ones that have been made into kindle books. Click on the book covers to go through to kindle booklet. These have the same content as the articles with addition of a table of contents and a cover image, and of course, formatted for kindle.

So the main points are (with links to other articles and booklets to find out more)

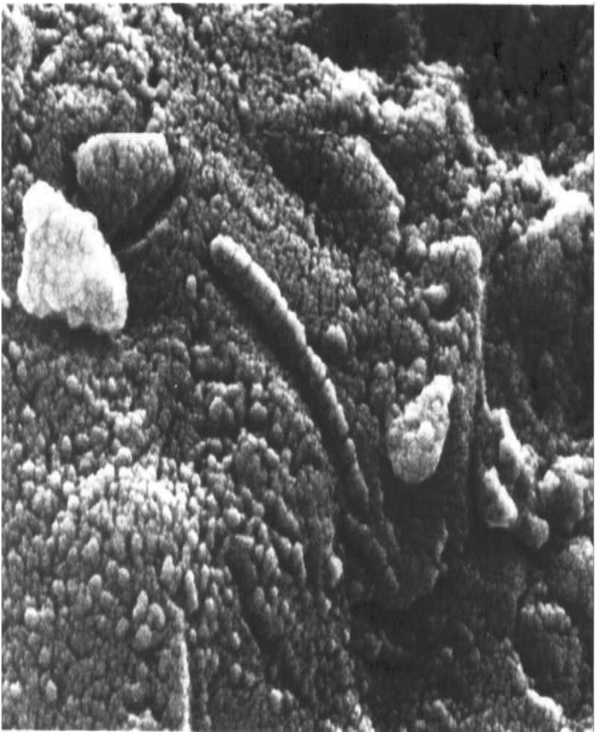
- **Robots and humans work well together**. Our robots are our collective sense organs in the universe, and they can go to places humans can't . On Earth they can explore active volcanoes, the sea bed etc. In space they can explore places that are either too dangerous to go to, too remote, or places where we don't want to introduce Earth life quite yet.
- **We have potential for superpositive outcomes of great value for humanity from the search for life in our solar system** from discoveries of origins of life, earlier forms of life, or alternative exobiology. And life on Mars can be vulnerable to Earth life. These are exciting prospects for the future. For more on this : "Super Positive" Outcomes For Search For Life In Hidden Extra Terrestrial Oceans Of Europa And Enceladus
and
Why Mars Microbes Matter - Like Tigers - And More So? - Microbial ETs
- **One example of what we might find on Mars is some**

early form of life that's been made extinct on Earth by DNA based life - I like this example because it makes it clear that what we search for on Mars can be vulnerable to Earth life. You often get the argument that anything we find there has to be better adapted to Mars, and Earth life can do it no harm - this just blows through that argument in one go.

This could for instance be RNA life using the small ribozymes (made up of many fragments of RNA) in place of the much larger ribosomes (which are a mix of RNA with proteins),

The 2.2 a structure of a full-length catalytically active hammerhead ribozyme, much smaller than a ribosome

This early RNA based life could be similar in size to the contested microbe "fossils" in ALH 84001.



If life evolved independently on Mars, and if it went through similar stages to the ones hypothesized for Earth life, but with a different timeline, there is a chance that earlier forms of life may still be there.

- **Yes Earth could have shared microbes with Mars. But if so, we don't know which microbes got there, if any. Mars life could still be vulnerable to the ones that didn't make the trip.** As an analogy from Earth, some Arctic terns fly over both Europe and Australia on their yearly migrations from the Arctic to Antarctica and back again, but that doesn't make the European rabbits safe for the wildlife of Australia, because, of course, rabbits can't make the same trip.

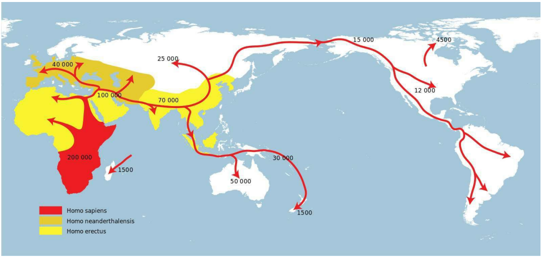
  We don't know if any life has been transferred to Mars, though it's possible in theory. There are formidable barriers in the way. These include the century long passage in the vacuum of space (that's the fastest transit from a giant asteroid impact on Earth), the cosmic radiation, and harsh conditions that only a few Earth species could survive.

  They have to be anaerobes (survive without oxygen), be able to grow in a place with a near vacuum for an atmospheric and tolerate high levels of UV light and cosmic radiation. They probably need to be tolerant of perchlorates, and probably salt loving, and also to be autotrophs capable of forming single species ecosystems, at least for the first ones to get there, amongst a few of the capabilities needed for a pioneer microbe from Earth to survive on Mars. There are microbes with all those qualities but did they got to Mars on meteorites? And did they find a habitat when they got there, given that the most hospitable places on Mars are also probably very rare? At present, nobody knows.

Perhaps one of the best candidates for a microbe to get from Earth to Mars might be Chroococcidiopsis, a photosynthesizing polyextremophile, one of the oldest microbes on Earth, able to handle almost anything you throw at it, and it can form a single species ecosystem. It doesn't eat other lifeforms (is a "primary producer autotroph"). If it did get to Mars, it might cause no problems, it might be useful food. This wouldn't mean that all Earth microbes are okay for Mars.
Does Earth Share Microbes With Mars Via Meteorites - Or Are They Interestingly Different For Life?
Could Microbes Transferred On Spacecraft Harm Mars Or Earth - Zubrin's Argument Revisited
No Simple Genetic Test To Separate Earth From Mars Life - Zubrin's Argument Examined

- **So we have to be careful when exploring Mars,** also Europa and Enceladus, and anywhere likely to have an alternative exobiology. Why start our new phase of human exploration in space by sending humans with our microbe hitchhikers to the one place in the inner solar system that is most vulnerable to introduction of Earth microbes?

- **Space development can be of great benefit to Earth** through new discoveries, also moving heavy industry into space, providing solar power from space etc.
- **Most successful colonization has been of places already occupied by humans**, for thousands of years. We don't have any examples of large scale colonization of Earth deserts, or ice fields, or mountain tops or other uninhabited regions, not since neolithic times.



Overview of [Pre-modern human migration]() - there is debate and controversy about the details, but generally agreed that humans were already present world-wide by the end of the [neolithic period]() (which ends around 2,000 BC) or shortly after. Large scale colonization since then has always been of areas where humans can survive with stone age technology. More hostile places such as Antarctica, the highest mountain summits, and the sea floor, have not been colonized.

So the analogy of colonization on Earth is of limited relevance to space exploration. That doesn't mean it is impossible, but it's a new kind of thing that we have never done before, like colonizing the sea floor, and analogies with the past can't really tell us if it can be done or not, or how successful it is likely to be.

- **There have also been many failed colonizations** such as the attempt of the Vikings to colonize America, and the attempt by the Scottish to colonize Panama, which was so disastrous it lead much of the lowland population of Scotland to bankruptcy, and resulted in an urgent need for unification with England to save them.

Flag of the Company of Scotland Trading to Africa and the Indies. Their "Darien Scheme" an attempt to colonize Panama, lead to the death of nearly all the colonists, and it also drained Scotland of an estimated a quarter of all its liquid assets. Scotland was saved from bankruptcy by England, in exchange for unification with England, higher taxes, and an agreement to service the English national debt.

If you focus just on the colonization attempts that succeed, you get only a partial picture, which may be over optimistic.

- **Mars is far more like the Moon than it is like the regions humans colonize on Earth**. It's more inhospitable than deserts and Antarctica and we don't colonize those places. Indeed even the top of Mount Everest (at 8.848 km above sea level) is far more hospitable than Mars. You need to go to an altitude of 30 kilometers on Earth, to have the same atmospheric pressure as the lowest points on the Mars surface, and the average temperatures on Mars in its equatorial regions are similar to Antarctica.
- **So, I think that space settlement in the early stages at least would be like an Antarctic base** - where you are there because you are doing something of value. I suggest our focus should be on creating settlements that are of value for Earth rather than colonization for its own sake.
- **Yes we might get future tech that lets us build self**

sufficient habitats on Mars. But before then we'd be able to build self sufficient colonies in deserts, and do many other things. We don't have that technology yet. Perhaps we can consider colonizing places with a laboratory vacuum for an atmosphere, once we have learnt to make a self sufficient floating sea colony - that is to say one that only uses sea water and the atmosphere, and maybe a few rocks, and no other resources from Earth. That would be a far easier task to achieve.
Can You Suggest A Second Earth Apart From Mars?

- **Other places in space may be better for exploiting in situ resources than Mars.** Using materials from the asteroids, and the moon has many advantages. You don't need to build a Mars surface rated human lander. Mars is the hardest place to land on in the inner solar system without crashing, with automatic systems needed to respond in 90 seconds to land safely, way beyond any possibility of human recovery in case of error. There would be no last minute Neil Armstrong type course corrections for a Mars landing.

> *".. with current EDL (Entry Descent Landing) capability, a large vehicle plunging through the tenuous Martian atmosphere has about 90 seconds to decelerate from Mach 5 to Mach 1, flip over from being a spacecraft to being a*

> *lander, open the chutes to decelerate some more, then fire those thrusters to navigate to the landing site before touching down"*. - page 137 of SpaceX's Dragon: America's Next Generation Spacecraft, by Eric Seedhouse
>
> It may well be possible to solve this for humans. For instance SpaceX hope to use supersonic retropropulsion, which removes one of the stages, no need for the parachutes. But if you send humans to the Moon or asteroids, you don't have these problems in the first place. One less thing to deal with.

All the resources you can find on Mars are also available on the Moon or in asteroids. The Moon has a shortage of nitrogen, but is not as thoroughly explored as Mars in many ways, and may still have it, e.g. it does have some ammonia in the polar ices from the LCross results . Nitrates are rare on the Mars surface also.

Then, perhaps surprisingly, Venus cloud colonies have advantages over Mars too. This is the NASA scientist Geoffrey Landis' proposal, though first explored by the Russians in the 1970s. These "aerostats" have the lowest level of technology requirements of all the space habitats for their inhabitants. You could maintain them with almost a nineteenth century level of technology, especially if we can achieve closed system biological recycling. You might wonder how it is possible, on hostile Venus, but these are habitats that float just above the Venus cloud tops, where the temperature and atmospheric pressure is comfortably in the habitable range for humans.

There's the sulfuric acid in the Venus clouds to deal with of course. But there's no vacuum, and acid is far easier to deal with than a vacuum. To go outside your floating Venusian aerostat you would need an acid resistant suit and a closed system air breather like an aqualung. But you wouldn't need the millions of dollars spacesuit like a mini spaceship, which you need for any of the other suggested habitats in space.

The Earth's atmosphere of nitrogen and oxygen has a lifting capability about half that of helium in our atmosphere.
The first habitats there would be lightweight and inflatable, and would surely require less mass launched from Earth per person than anywhere else in the solar system outside Earth, and much more habitable volume per person. There are no detailed plans for these yet (at least I can't find one). But you can get some idea from airship designs on Earth.

An airship such as the Airlander 10, which has mass 20 tons and lifting capacity of 50 tons, if transferred to Mars with the helium replaced by breathable air, would have a lifting capacity of 15 tons in the Venus atmosphere. The ratio goes up with larger airships. A one kilometer diameter Buckminster fuller Cloud Nine type tensegrity sphere city in the Venus atmosphere could carry a weight of 700,000 tons. Since your lifting gas is breathable air, you can live inside the lifting envelope itself, so the interior is very spacious.

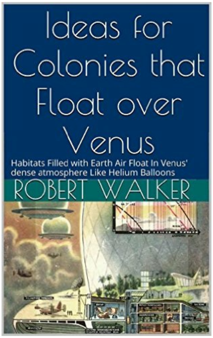
It's also safer than a Mars or Lunar colony in some ways, because the pressure is the same inside and out, like a hot air balloon or an airship. You can see this equalizing of pressure clearly with weather balloons destined for the stratosphere, which leave Earth's surface only partially inflated. So, if the aerostat outer cover has a hole in it, the air inside will escape only very slowly and the hole will be easy to patch. And the atmosphere would protect you from micrometeorites and even quite large meteorites as for Earth.

You also have shielding from cosmic radiation and solar storms by the atmosphere. The aerostat would float at a level with internal and external pressure equal to one bar, so you'd have around ten tons of carbon dioxide atmosphere above every square meter. And since it floats just above the cloud tops, it's in a clear atmosphere, with sunshine, and vast vistas over the cloud tops, like flying in a jet airliner on Earth.

Getting there is easier too. There is no hard surface to crash on, as your target altitude is many kilometers above the surface. Russia had ideas for sending humans to Venus in the 1970s, and NASA has considered sending robotic missions there first followed by humans exploring the atmosphere using airships in its HAVOC program. See project home page. This is an internal study, so it's at an early stage at present.

Returning to Earth of course is harder, the hardest return of any in the inner solar system apart from Earth. But it's possible - the NASA HAVOC proposal has the crew return to Earth of course.

Right now, I think this of most interest for outposts and temporary bases supported from Earth and eventually research stations rather than colonization. I think, though, that the comparison helps highlight how high tech and difficult Mars colonization would be and the level of support it would need from Earth with present day technology - rather than practicality of Venus colonization in the near future. Again, self sufficient floating sea cities on Earth using only sea water and the air from the atmosphere and a few rocks would be far easier to build than either of these, and we don't have them yet.



[Will We Build Colonies That Float Over Venus Like Buckminster Fuller's "Cloud Nine"?]

- **Yes, we can build human settlements using resources from space.** But the reasoning of the 1970s is still valid - that we don't need to look any further than materials from the asteroids and the Moon.

  Some asteroids consist almost entirely of pure metals including iron, nickel, and heavier metals such as the industrially useful platinum, and gold ([a small asteroid 452 by 1011 meters across, to take an example, was estimated to contain 90 million tons of platinum)]. These metals may also be capable of being extracted without physical mining using carbon monoxide at low temperatures to convert metals to gas (second half of the Mond process with no need to extract the pure metal first), and perhaps directly converted back to metal parts again from the extracted metal carbonyls in 3D printers.

Other asteroids have organics, volatiles, and everything that we need. The conclusions of the 1970s are still valid, that there is enough material in the asteroid belt to eventually build the equivalent of a thousand times the surface area of the Earth. So there's far more potential for settlement in the asteroid belt than there is on either Earth or Mars, measured according to the available land area. And what's more, you can choose whatever climate and even atmosphere, and gravity level that you like for the habitats.

(I find this is often the most telling point in the argument).

[Asteroid Resources Could Create Space Habs For Trillions; Land Area Of A Thousand Earths]

- **The Moon is far safer at this stage**, as we can resupply the astronauts from Earth within days, they can return in an emergency within days, and experts on Earth can trouble shoot problems with just a 2.6 second round trip delay. A base on the Moon could also have "lifeboats" for all the crew on standby ready to take them back to Earth within three days in the case of any emergency.

  While ***a mission to Mars is like a long sea voyage without lifeboats***. The only way to get back takes at least six months, and could be much longer. If there is some problem soon after you do the final burn to leave Earth, and you are already on your way to Mars, then an

Apollo 13 type rescue would involve trying to figure out how to survive for two years, to get back safely, not 87 hours.

This is something we can learn to on the Moon first, how to keep humans alive in space with minimal resupply from Earth, ideally for years on end. Until we can achieve that, I think it is just not safe to send humans to Mars.

Then trouble shooting at the distance of Mars with a 48 minutes maximum round trip time is bound to be harder than for the Moon. A situation like the Apollo 13 "Okay, Houston, we've had a problem here." if it developed as far away as Mars, would find the astronauts having to make many decisions on the spot, with Earth only able to advise them based on things they told had Earth 48 minutes earlier. (See the transcripts, and imagine how it would play out with a 48 minute delay).

- **Settlements on the Moon, or in space, using materials from asteroids, are likely to be easier to support economically** - as it's much easier to export materials, to LEO, cislunar space or to Earth itself. It's not yet clear whether settlement in space can be supported in this way. But if this is possible, the launch costs from an asteroid or the Moon are far lower than from Mars. They could use ballutes, large parachutes,

or similar, to land the materials on Earth.
~

- **We don't yet know how well humans can cope with artificial gravity, or what level of gravity we need for health** . The problem is that though we can simulate the physics easily, we can't simulate the human body. We can only find out human tolerances for spin rates, and the "gravity prescription" for health with experiments in space. The best we can do at present is to simulate zero g using bed rest subjects on Earth with their heads lowered, then spin them to try to simulate artificial gravity. The only way to tell how well this simulates the health effects of artificial gravity is to get some ground truth from space.

  There are many experiments we could do in space to resolve this. But until then, it's not really possible to say for sure whether humans will do best in lunar gravity, Mars gravity or spinning habitats in space, and which are easiest to build and what spin rate is needed.

  We don't know the optimal artificial gravity or real gravity level for health. Indeed the optimum could also be a mix of different levels during the day. It might even be that the optimal design for humans is a zero gravity module with a rotating sleep habitat at night as in the Nautilus X design - as this has never been tested. We know that humans are not healthy long term in zero g unless they do at least two hours of exercise a day and even that still keeps you less healthy than someone confined to a bed on Earth. We also know that a few days of lunar gravity can be tolerated with no apparent ill effects. Apart from that, we know almost nothing about the gravity prescription for human health.

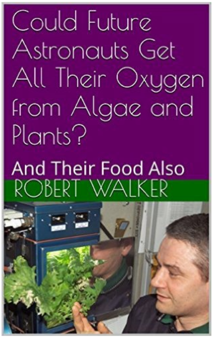
I'd argue that it is far too soon to say what is the optimal type of habitat to build for humans in space, or where is the best place to build them, for human health.
Can Spinning Habitats Solve Zero g Problem? And Answer Low g Questions?
Could Spinning Hammocks Keep Astronauts Healthy in Zero g?
Ingenious Idea: Soyuz Crew in Tether Spin On Way to ISS - For Artificial Gravity - Almost No Extra Fuel
Crew Tether Spin - With Final Stage - On Routine Mission To ISS - First Human Test Of Artificial Gravity?
Crew Tether Spin For Artificial Gravity On Way To ISS - Stunning New Videos - Space Show Webinar - Sunday

- **We haven't yet attempted a self sufficient habitat in space.** Several ground experiments suggest it may be possible, and that we could produce all our own food and oxygen from plants in a closed system with minimal supply of materials. It's surprisingly small also, only 13 square meters of growing area per person to produce most of their food and all their oxygen. But though this works on the ground, this has not yet been tested in space.

The food by itself isn't such a big thing, even the food for a multi-year mission, in dried form, is not so much by wy of mass. But growing food in space really comes into its own when you combine it with purging the CO2 and providing oxygen.

Then, if you use algae for that, e.g. the spirulina algae – I think you can say that arguably that’s a more robust system than any complex mechanical way of doing it. Even if nearly all the algae die, through some problem of maintenance, you just need a few left, clean the container, and you are ready to go again. While if a mechanical CO2 scrubber or the equipment to make oxygen from water fails, you need mechanical part spares, and if you don’t have those or can’t produce them, you are sunk.

You could have algae as a backup, for CO2 scrubbing and oxygen, plus extra dried food in case of a disaster in the hydroponics. But the BIOS-3 experiments managed fine for months without problems and I think once we get over the early teething issues in space same will be true in space. They would use easy to grow plants, that grow quickly, and there would be no plant diseases or insect pests, and very controlled conditions with hydroponics or aeroponics. And especially so if we have artificial gravity as a lot of the issues in the ISS and earlier experiments in MIR etc were to do with growing the plants in zero g.



See [Could Astronauts Get All Their Oxygen From Algae Or Plants? And Their Food Also?]
[Beautiful Edible Orange Zinnia - First Zinnia But Not First Flower In Space - And Astronaut Choices]

- **So before developing grand visions of the future of humans in space, we need to look closely at those two points**. And do them in a location where we can do it safely. In my view, it's not the time to send humans on deep space missions until we know how to send them safely, say, as far as the Moon, and to live there for years on end. It's neither safe, nor is it sensible. We have been sending humans back and forth to LEO with a lifeboat always attached to the space stations so that they can get back to Earth within hours. From the Moon, they can get back within a couple of days. That is already a demanding step up from what we had before. From Mars, with present day rockets, they might find that they can't get back in less than a year.

The key to Apollo was to do things on a step by step fashion, first showing that humans can survive a few days in zero g, which was not known at the start of the program, then building up to longer and more demanding missions. What we do next may depend on what we find out in the process.
Human Spaceflight At "Coastline Hugging Phase" - Lunar Villages Not Interplanetary Voyages - Op. Ed.
Flags On The Moon - Like A Space Exploration Olympics - And Olympics Style World Flag

- **We are bound to have fewer people in space than on Earth** in the near future. Just as Antarctic settlements are not self sufficient, but are supported by many people not in Antarctica - same will be true for space settlements, in the near future at least. Whatever the ratio is - if you need a hundred people on Earth to support each space settler, for instance - it doesn't matter how valuable the materials are that are returned from space, what matters is how many people on Earth are needed to support you there. So, that would be a limit of 7.5 million people in space. Or 750,000 if you have 1000 on Earth for each in space, or could be a higher ratio as unless space settlers have some big hold over Earth dwellers, we might not get everyone on Earth just involved in supporting them. I think therefore in the near future that we will have possibly tens, even hundreds of thousands in space but not billions. This would change if we can make self sufficient colonies in space - but before that, we would have self sufficient sea colonies etc.

- **Earth is the best place for a backup** and to rebuild civilization for those that worry about end of the world disasters. That's because no disaster could make Earth as uninhabitable as Mars and some humans would survive anything that is likely to happen. Because we live in a relatively quiet time in our solar system and relatively quiet region of the galaxy.

  For asteroids, then the large impacts in our solar system all date back to well over three billion years ago. There is no risk of an asteroid large enough to make such an adaptable species as tool using homo sapiens extinct. With just the most primitive of tools we can survive anywhere from the Kalahari to the Arctic. Turtles, crocodiles, alligators, flying dinosaurs (birds), dawn redwood, pine trees, all survived the Chicxulub impact event. We would also.

And Mars is already far more inhospitable than Earth could possibly be even after the very worst asteroid impact - we'd have a nuclear winter - darkness - but still, air to breathe, cosmic radiation protection, water, seas, and surely a fair bit of food also available. Those left on Earth after such an event would be way ahead of the curve compared to anyone trying to survive on Mars.

Giant Asteroid Headed Your Way? - How We Can Detect And Deflect Them

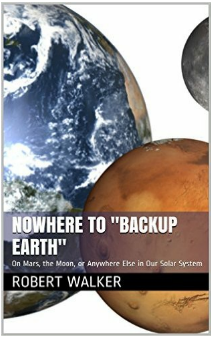
And for the cosmological disasters like a gamma ray burst - why go to Mars? Here on Earth at least we are protected by the 10 tons per square meter Earth atmosphere. On Mars only protected if you dig deep underground. This motive just doesn't add up in my view. And wherever you had your backup, Earth is the obvious planet to rebuild, no matter what happens of the possible disasters.

At the very least, anyone in a nuclear sub deep under the sea would survive nearly all those disasters. Most would be survived by anyone who happens to be on the other side of Earth at the time. So why go to Mars?

[Could Anything Make Humans Extinct In The Near Future?]

[Why Elon Musk's Colony on Mars in 2020s is Unfeasible - What Could We Do - Really?]

[No Escape From Problems in Space Colonies - Earth is Des Res - Even After Nuclear War or Asteroid Impact]



[Why We Can't "Backup Earth" On Mars, The Moon, Or Anywhere Else In Our Solar System]

End Of All Life On Earth - A Billion Years From Now - Can It Be Avoided - And Who Will Be Here Then?

- **As for self created problems, again we can't escape from them in space**. A future with many humans in space will have much communication back and forth, so we don't achieve a significant level of quarantine that way. And the high tech space colonies would be the most likely places to create and use the most advanced technology - in my view again, if technology is our problem, escaping into space to set up an even more highly technological society is not likely to be our solution.
- **A future with large numbers of humans in space with high technology is not necessarily the best thing to aim for**. If you have millions of people in space, you will certainly have ISIS and North Korea in space also,

with the technology greater than that of ICBMs at their disposal. Rushing into space could create the very problems we would want to run away from. You can't restrict it to just the "good guys" whoever you think they are if you have millions in space. There is a chance we can achieve millions in space peacefully, but exactly how we do it surely matters.

Projects To Get To Space As Easily As We Cross Oceans - A Billion Flights A Year Perhaps - Will We Be Ready?
Will Anyone Ever Own Their Own Land In Space - And May We Get Wars In Space In The Future?

- **Space settlement is neutral just like settlement anywhere - could be good or bad.** I don't think settlement and colonization is an "intrinsic good" in the sense of philosophy and ethics, but rather an extrinsic or instrumental good, good only because of its benefits (Intrinsic versus extrinsic good in Stanford online Encyclopedia of ethics).

  It could be hugely positive if done well. It could be very harmful if it goes wrong. And the details of how we do it could swing it either way.

  It seems likely to be more healthy if the main aim is to help and protect Earth or to expand our understanding.

For instance to go into space to explore and discover new things, as we do in Antarctica, or to build solar panels to supply electricity to Earth, or to mine resources from asteroids, which can help move heavy industry into space, or if low g turns out to be beneficial to human health for some sick people e.g. with heart conditions, or for tourism, or adventure, or to discover asteroids and to protect against them. All of these could make space settlement positive in its effect, if done well, and with consideration of the effects on Earth.

- **It's not likely to be a "new form of society" in space in the near future.** This is an argument given by some space colonization enthusiasts. The idea is that we can make a fresh start, perhaps a more anarchic (in the good sense), or more fluid society in space.

  But the space environment seems the least likely of all places to achieve this, in the near future at least. It would make more sense, I think, to try such things on islands on Earth. There are many remote islands, uninhabited, where you could attempt to start up such a society.

  The reason this seems unlikely in space is that you have to be extremely disciplined in space. Astronauts for the ISS are evaluated for their ability to fit into a team, and follow orders. They are relaxed and happy on the ISS because they are people that are content in such a situation. But if the commander says they have to evacuate to the Soyuz, for instance, that is what they have to do, following a detailed procedure that they have trained extensively to be able to do without error and quickly.

It is like living in a nuclear submarine, you have to be able to follow orders and have someone in charge, for safety reasons, since life threatening situations can arise quickly. You also have to follow careful procedures to put on your spacesuit, takes a long time, then during space walks each movement you make needs care and attention. And if mission control say you have to end the space walk, then there is no arguing, you just go back in right away. There is room for improvisation by the individual astronauts, and finding new solutions and creative approaches, but for safety reasons this is done within a framework of a clear chain of command.

It may get easier as time goes on, but it would still be the most regulated modern society of any, just for safety reasons and because you are surrounded by very dangerous high technology if misused, and with the vacuum of space separated from you by a few cms of metal.

The same is also true of other hazardous environments on Earth. In Antarctica, then inhabitants of the settlements have to be able to follow rules and guidelines carefully, especially in the Antarctic winter when it gets extremely cold outside the habitats and dangerous if you don't follow proper procedures.

This may change in the future, but I suggest that currently this is the situation for space settlements or attempts at colonization.

- **As a young technological society, our priority should be to protect and sustain the Earth**. Attempts at terraforming Mars, or any attempt for large scale human occupation would cost trillions of dollars. The resources used to construct the large space mirrors to warm the planet, or the hundreds of greenhouse gas manufacturing plants on the surface could instead be used to provide solar power for Earth from space, to deflect asteroids and protect Earth from other hazards, and to move heavy industry into space.

  Sometimes the idea of creating colonies on other planets is motivated by the idea that it will make us a multi-planetary civilization, type II in the Kardashev scale. But creating settlements in space, and on other planets, doesn't really turn us into a multi-planetary society. In the Kardashev scale, a Type I civilization is one that uses just about all the power available to it on its home planet. We are nowhere near achieving that. A type II civilization is one that uses nearly all the power from its sun. Putting a few bases on the Moon, or Mars or the asteroids will not take us to a type II civilization, or even the beginnings of one. Indeed if it has the effect of diverting resources away from Earth it could be a set back preventing us from getting to the type I civilization level.

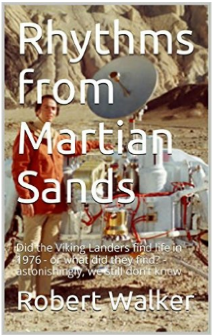
(You can of course question the whole premise here - is a society with more consumption of energy necessarily better? But if you measure progress by the Kardashev scale, then going multi-planetary before you are ready for it is not necessarily a step forward in this scale and doesn't necessarily mean you are in a more robust position to deal with future crises).

For deflecting asteroids see Giant Asteroid Headed Your Way? - How We Can Detect And Deflect Them

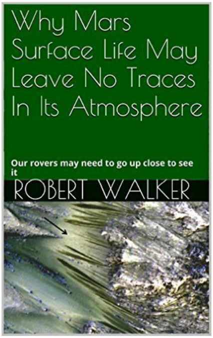
- **Mars has turned out to be a much more likely habitat for present day indigenous life than previously thought**, as are some other places in the solar system.

  Though it is so cold and inhospitable for humans, and extremely dry, yet it may have habitats for microbes and even lichens capable of surviving in extreme conditions.

There are seasonal changes when observed close up not caused by dust storms, winds, or by dry ice, that may be due to liquid water. And, since Phoenix in 2008, many independent lines of evidence suggest potential present day surface habitats on Mars. Liquid water has been confirmed by Curiosity, though most think that the particular liquid water layer it discovered indirectly is not habitable. Other liquid water layers on Mars may be habitable, and it is possible that life could even use the 100% night time humidity. This is great news for exobiology, if it turns out that there is some form of life still existing on Mars. It will mean however that we need to take great care with human exploration because of the microbial hitchhikers that accompany us everywhere.
Might there be Microbes on the Surface of Mars?
Our Spacecraft Could Look Straight At an Extraterrestrial Microbe - And Not See a Thing!

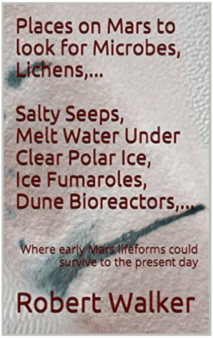


[Rhythms From Martian Sands - What Did Our Viking Landers Find in 1976? Astonishingly, We Don't Know]
[UV&Cosmic Radiation On Mars - Why They Aren't Lethal For The "Swimming Pools For Bacteria"]



[Why Mars Surface Life May Leave No Traces In Its

Atmosphere: Our Rovers May Need To Go Up Close To See It



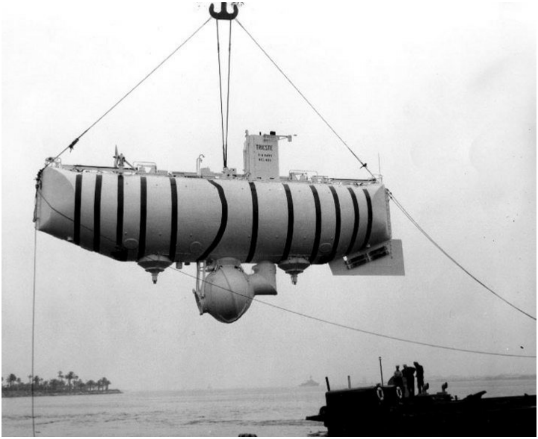
Where To Search On Mars For Droplets,&Shallow Flows Of Liquid Water - Where Microbial Life May Flourish
Will We Meet ET Microbes On Mars? Why We Should Care Deeply About Them - Like Tigers
Are There Habitats For Life On Mars? - Salty Seeps, Clear Ice Greenhouses, Ice Fumaroles, Dune Bioreactors,... (long detailed survey article with many cites)
As Philae Awakes - Where Might Life Hide In Our Solar System?
NASA Says Mars Mystery Solved - What Is It? - Three Mysteries About Recursive Slope Lineae
Why Are Hydrated Salts A Slam Dunk Case For

Flowing Water On Mars? And What Next?

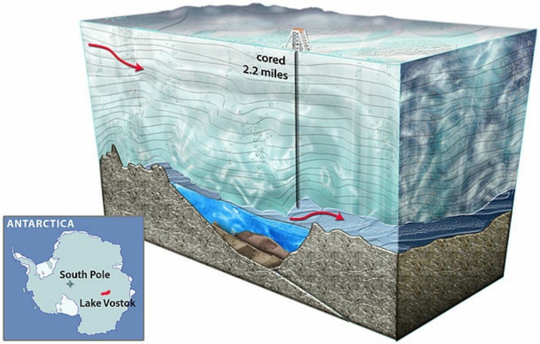
- **It is tricky to explore places with life without introducing Earth life.** We are still figuring out how to explore the subglacial lakes in Antarctica.

  We shouldn't just assume we know how to do this on other planets, yet. Some places, like Europa's oceans may be currently unreachable with our technology, until we can manage 100% sterile robots. Perhaps the same might be true for liquid water habitats on Mars also for similar reasons.

  Lake Vostok is only 4 km below the surface, 0.5 km above sea level. Less than half the depth reached by the Trieste bathyscaphe, in 1960, yet the Russians wouldn't think of sending a bathyscaphe down there. They stopped drilling for several years, mainly to avoid contaminating the lake with drilling fluid. However another concern is not to contaminate it with surface life to avoid confusing the results.



The bathyscaphe Trieste reached a depth of over 10 km in the Challenger deep in the 1960s, with Jacques Piccard and Don Walsh on board. But we don't send even a robotic sub into Lake Vostok to avoid contaminating it with surface life.



The Russians drilled down nearly all the way to lake Vostock, but then stopped until they figured out how to do it safely, preserving the science value.

Scientists at the National Research Council have prepared guidelines to protect the lakes, similar to planetary protection guidelines. So, nobody would think of sending humans down there quite yet.

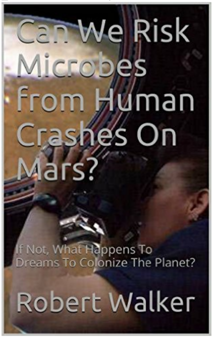
It's not an exact analogy. In some ways Mars is less vulnerable than lake Vostok, because of the harsh conditions there. In other ways it is potentially more vulnerable because of the wider range of possibilities including some vulnerable form of early life, and whatever is there has been isolated from Earth for a lot longer than lake Vostok.

However, I suggest that it shows that we can sometimes halt exploration because we don't yet have the technology to do it successfully, without impacting on the science - and may need to wait until the technology is developed until we can continue further. And that there are places we wouldn't send humans to, even on Earth, to protect them from introduced microbial life. So why not have the same situation in space?

Can Human Explorers Keep Mars Clean, For Science?

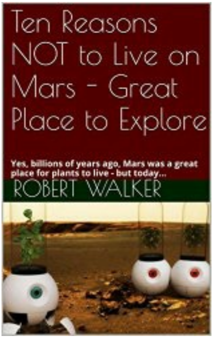
- **100% sterile robots are possible in principle**. You just need to build the robots without organics, and then sterilize them of all organics. But we don't yet have a 100% reliable way to do this. Heat sterilization to a high enough temperature works, but destroys the robot also. Ionizing radiation is similar as electronic circuits are vulnerable to ionizing radiation. Supercritical CO_2 snow is promising and being investigated by ESA, it's interesting as it not only sterilizes at low temperatures, and has no effect on electronics, but also removes the organics completely if the robot is already reasonably clean. So if something along those lines could some day be made 100% effective, you not only get no life on the spacecraft, but no DNA fragments or GTAs or anything organic at all.
- **A human crash on Mars putting debris all over the**

planet would introduce Earth microbes and has to be avoided. We don't yet have the technology to build 100% reliable spacecraft, and even a 1 in 100 chance of a crash, which some volunteers might be willing to take on as a personal risk, is far higher than the 1 in 10,000 probability that's often used for planetary protection.



[Can We Risk Microbes From Human Crashes - On Mars? If Not, What Happens To Dreams To Colonize The Planet?]

- **There is no urgency to send humans to the Mars surface**. Even if we send humans there, it is best to understand Mars better first. The best way to do it for planetary protection is to send robots, either controlled from Earth or from Mars orbit.



Ten Reasons NOT To Live On Mars - Great Place To Explore
Mars, Planet Of Surprises, Great To Explore Not So Great To Colonize - 1. Is It As Good A Place To Live As A Desert?
"Ten Reasons Not To Live On Mars, Great Place To Explore" - On The Space Show
Life On the Edge In Cold Dry Deserts Of Mars - Dust Storms, And Contamination By Microbes From Leaky Spacesuits
If Mars Is For Hardy Explorers Only, Where Is The Best Place In The Solar System For First Time Colonists?
Space Habitats For Colonists - And Contamination Free Boots On Mars - With Telerobotic Avatars
Would Microbes From This Astronaut Make It

[Impossible For Anyone To Terraform Mars - Ever? Telerobotic Avatars On Mars With Super-Powers ("Teleporting" from orbit) - Search For Life - And Long Term Exploitation]

- **It is not at all clear that we can terraform Mars**, and if it is possible, with current technology, it's a thousands of years, or perhaps a 100,000 year megatechnology project. There are so many questions. How sure can we be that we will continue such a project, when it is likely to cost billions of dollars a year and need support from Earth for thousands of years?

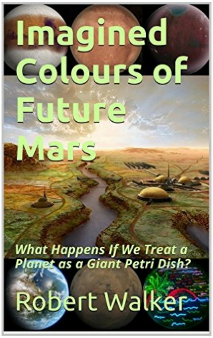
  The Mars trilogy is science fiction and the optimistic real world estimate from the Mars Society takes a thousand years to a stage where trees can grow but no animals or birds yet, and humans need aqualung like closed system breathing kits to get around. And is based on assumptions about the amount of dry ice on Mars which are not yet confirmed, and doubts have been cast about how much dry ice still remains there.

  Do we have the scientific understanding needed for it? We have never terraformed a planet, and with all our technology on Earth, we find it hard to just keep the CO_2 levels on Earth from rising by tens of parts per million. Would it unterraform as easily as it terraformed or go to some undesirable end state. Is it possible at all?

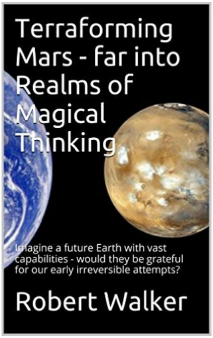
What about accidental planet transformations, where lifeforms we didn't mean to introduce change the climate in unexpected ways? And Mars gets much less light than Earth, so an Earth atmosphere would not be warm enough for Mars without planet scale thin film mirrors to double the amount of light reaching Mars, or industrial levels of production of artificial greenhouse gases (200 half gigawatt nuclear power stations to supply power, and 11 kilometers of fluorite ore mined per century to make the gases).

Are we confident that this is what our descendants a thousand years from now will want us to do for them? Will they be pleased that we started the project so soon and made Mars just as they wanted it, or will they be frustrated by our failed projects, and lament the pristine Mars they would wish to be able to study and possibly transform for themselves?

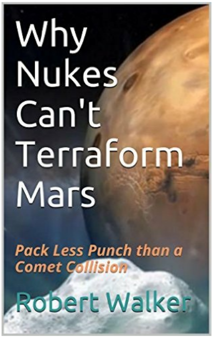
Trouble With Terraforming Mars



Imagined Colours Of Future Mars - What Happens If We Treat A Planet As A Giant Petri Dish?



[To Terraform Mars with Present Technology - Far into Realms of Magical Thinking - Opinion Piece]



[Why Nukes Can't Terraform Mars - Pack Less Punch Than A Comet Collision]

[Our Ethical Responsibilities To Baby Terraformed]

[Worlds - Like Parents]
[How Valuable is Pristine Mars for Humanity - Opinion Piece?]

- **Introducing life to Mars as a result of a human crash or landing on Mars is likely to be biologically irreversible.** As a result, the situation is asymmetrical here.

  If you hold off from landing humans on Mars to protect it from our microbial hitchhikers while you study it carefully for the science and to learn about exobiology and the origins of life, you still have the option to introduce Earth life in the future at any time.

  But if you introduce Earth life to Mars right away in a biologically irreversible fashion, then you never in the future have any chance of studying a Mars without Earth life on it. For the scientists, it might then become a race to try to find and study habitats on Mars before Earth life got to them through spores transported via the dust storms. You could create a new geological era on Mars, marked by the presence of Earth lifeforms brought to the planet by twenty first century humans.

  If there is no life there. Mars is still of interest as a planet without life. Indeed it would be of a fair bit of interest to study what happens on a planet like Earth without life, especially if it has complex organics, and habitats for life but with no life in them - what happens in those situations, and why didn't life evolve there? We might learn a lot about exoplanets and the origins of life.

It's the same also with terraforming. Life introduced to Mars by mistake could send it on unexpected paths and interfere with your intended end state. E.g. methanogens producing methane which you might not want, or it might be you want the methane but methanotrophs eat it, or aerobes consuming the oxygen, or primary consumers eating algae that you are trying to use to transform the planet etc etc.

So again introducing Earth life before you study Mars in depth is closing off options for the future. While keeping it free of Earth life leaves all your future options open.

It seems a situation where we need to think about future consequences quite carefully before we act. Otherwise we may find we close of valuable potential futures before we know that they are possible.

- **Perhaps we can send humans to Mars in a biologically reversible way - but if so - with this vision - we need to be really sure that it is reversible**

The only way I can see that could be given some reasonable guarantee of planetary protection in the near future would be a metal sphere - that enters the Mars atmosphere at a shallow angle, so slows down to terminal velocity before hitting, with a human inside. Then even if all systems fail, it would hit the surface at at most a few hundred miles per hour - in that case the human would not survive - but hollow spheres (rocket parts) that re-enter in the much thicker Earth atmosphere survive intact to the surface - so perhaps a sphere could be guaranteed to remain intact, or at least, not breached, after a crash on the surface?

If all goes well, the human would land on Mars and then could be lifted off again - but of course can never leave the sphere or even look outside directly (as it is opaque), so I'm not sure if this would be thought worth doing.

Another suggestion is to send humans to Olympus Mons.

Olympus Mons Caldera Region This might be the area on Mars most biologically isolated from the rest of Mars of anywhere, due to the thin air, high altitude, and the caldera walls. But it is also a difficult place to land technically, and - would even this be a biologically reversible place for a human base on Mars? The idea is that it is so high above the surface that the air is very thin and there is almost no dust. This was suggested as a planetary protection measure in an article in The Space Review. It's a major challenge to do this with present day technology though, see Rob Manning's talk on the Space Show. In the space settlement article, they are suggesting a future with new technology with human bases already on Deimos. Some of the technologies Rob Manning mentions could be relevant such as deployable extending heat shields, or using larger parachutes than any of the ones tested supersonically to date.

In any case, there's the same problem as with other human landings - that we are unlikely to have 100% reliable landing systems and even with your target the caldera at the summit of Olympus Mons, a failure during approach to Mars, entry, descend or landing could easily land you somewhere else. And would a human party - say inside the Olympus Mons caldera - really be biologically insulated from the rest of Mars? Also after a crash there? And would such a landing be biologically reversible in the future?

Yes if there is anywhere on Mars where humans can land in a biologically reversible way - or at least in a way that keeps the landing site separate from the rest of Mars so only one area is contaminated - then this might be it.

I think though, it would take a lot of research to be sure of this. If not biologically reversible, you have the possibility of an "oops" moment where you realize you have introduced Earth life to Mars, can't remove it, and have found a lifeform there you want to preserve or a biology such as ancient RNA based life, and can't do anything to prevent its eventual extinction.

- **We can do a lot more in situ exploration of Mars from Earth than we can currently.** The main bottleneck at present is not the light speed time delay, but the bandwidth. If we could communicate back and forth every 40 minutes, decreasing sometimes to 8 minutes we could do a lot more much more quickly than the present situation where we communicate back and forth every day. We could probably complete Opportunity's ten year mission in a matter of months. Perhaps even faster with rovers with more autonomy and use of artificial real time (technique from computer gaming that builds up a model of the landscape on Earth, and then you drive around and explore the virtual model at the same time the rover explores it on Mars, with warning colours to indicate regions that are imperfectly modeled).

- **The search for life on Mars is also best done in situ at present.** It is more practical, can study many different regions at different depths over the rover's exploration region, and we do have many space capable instruments now for sensitive searches for life in situ, which we didn't have as recently as a decade ago.

  Mars has organics from meteorites which are easily confused with life unless we have in situ life detection. The organics found so far are thought to be from meteorites. As a result, early sample returns are unlikely to contain present day life unless it is already identified as life in situ, or unless life is abundant on Mars.

  The situation is similar for past life because of the difficulty of preservation in Mars conditions, with surface radiation which removes organics completely over a billions of years timescale. There is an excellent possibility of interesting fossil organics from early Mars in ideal conditions in which the material is rich in life based organics originally, buried quickly to depths of ten meters or more, preserved from leaching by flooding, and returned to the surface rapidly soon before discovery (or discovered by drilling). But it seems likely that it will take in situ life detection searches to find these organics, and to distinguish them from the meteorite organics.

> As eight exobiologists wrote in in a white paper submitted to the 2012 decadal survey,
>
> *"In the worst scenario, we would mortgage the exploration program to return an arbitrary sample that proves to be as ambiguous with respect to the search for life as ALH84001."*

Colonization enthusiasts often cite the "Safe on Mars" report as a reason to get a sample from Mars as soon as possible to prove that it is safe for humans. But actually, "Safe on Mars" recommends in situ exploration as the best way to find out about Mars and prove that it is safe for humans. It only recommends a sample return because it concluded that the technology of the day was not good enough for an in situ search.

> *"As stated above, there are currently no measurement techniques or capabilities available for such in situ testing. If such capabilities were to become available, one advantage is that the experiment would not be limited by the small*

amount of material that a Mars sample return mission would provide. What is more, with the use of rovers, an in situ experiment could be conducted over a wide range of locations." (Page 41 of Safe on Mars)

More than ten years later, we can now miniaturize many of the machines that required entire labs back then to small chips that require minimal power and weigh hardly anything. These include DNA sequencers, electron microscopes, ultra sensitive biosignature detectors able to detect a single amino acid in a sample, and updated versions of the Viking Labeled release using chirality to eliminate false positives. Our instruments also include the exquisitely sensitive electrophoresis "lab on a chip" methods mentioned by Bada et al. Another new idea is the Solid3 approach of using polyclonal antibodies - which can detect, not just the organics you find in animal bodies, but a wide range of organics, again with exquisite sensitivity, and a "lab on a chip".

Mars has also turned out to be much more complex on its surface than was realized back then, with many seasonal and daily surface processes, with some of them now confirmed to involve salty but potentially habitable liquid water. So this is no longer the situation. With our current understanding, a sample return can at best just prove that there are some rocks on Mars that are safe for humans. I think the authors of "Safe on Mars" would surely recommend in situ searches over a sample return, if it was written again from scratch today.

Returning exobiology in a sample return is one of the few things we could do that could potentially make us extinct or severely reduce future human life prospects on Earth. It has similar risks to creating artificial lifeforms in a laboratory. It is also potentially tremendously positive, especially if we do find some other form of life on Mars or in the Europa oceans etc, but we have to take care.

This is not something we "know how to do" as we have never had to return biology from another planet before.

It seems easy when you first think about it, but when you look at it in more detail there is much more involved than you might think and the expert studies of this topic by the ESF and NRC conclude that methods used to contain DNA based life in biohazard level 4 laboratories can't be guaranteed to work for all possible forms of non terrestrial biology.

For instance cells based on another biology may be smaller even than ultramicrobacteria, impossible to see except with an electron microscope, only 50 nanometers across or less. You also have the unusual requirement to exclude all Earth biology and organics from the sample requiring a double wall technology never used before.

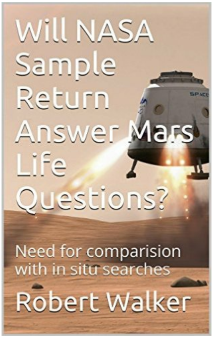
The main problem here is the need to contain any conceivable exobiology when we have no empirical data to work on except Earth biology.

It would be much easier to contain a known exobiology once we have a chance to study it for a while. For instance if Mars only had early life, made extinct on Earth by DNA, then after some careful study, we might decide there is no way it could survive on Earth and it might not need any special precautions to return it.

Other forms of exobiology might need elaborate precautions or we might decide it is simpler to just return it to telerobotic facilities above GEO. Bear in mind that by the time we can do a sample return, it is probably going to be easy to send hundreds of tons to above GEO, that our telerobotic capabilities which are already impressive will be advanced much further by then, that one of the ways to return it to Earth involves a rendezvous spacecraft anyway, that we can return sterilized material right away, and that if we become totally sure it is safe to return unsterilized samples, we can still do so after examining it in orbit first telerobotically.

The key, I think, is to study it in situ on Mars first. Which is also what some exobiologists recommend as the best and fastest way to discover either past or present life on Mars and find out the most we can about it most quickly in the initial stages of the direct search for exobiology on Mars.

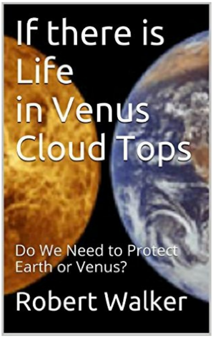
See my



[Will NASA's Sample Return Answer Mars Life Questions? Need For Comparison With In Situ Search]

[How To Keep Earth Safe - Samples From Mars Sterilized Or Returned To Above Geostationary Orbit - Op Ed]

Need For Caution For An Early Mars Sample Return - Opinion Piece
Concerns for an Early Mars Sample Return - background material
Mars Sample Receiving Facility and sample containment
Mars Sample Return - Legal Issues and Need for International Public Debate



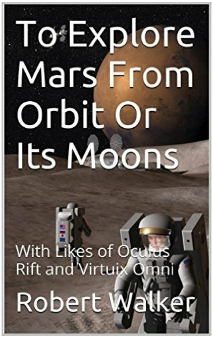
If there is Life in Venus Cloud Tops - Do we Need to Protect Earth - or Venus - Could Returned XNA mean Goodbye DNA for Instance?

- **Broadband communication would need to be set up to send humans to Mars.** Why not prioritize this and use it for our robots first, and see what we can do with robots with broadband to Mars?

- **Humans don't have special advantages for Mars surface missions.** A robot can sit in one place for years if needed, with only a trickle of sunlight. Robots can explore caves and cliffs far too dangerous for humans. Even small robots can be light enough to fly in the near vacuum atmosphere. Humans in spacesuits are clumsy, and it takes a long time to put them on, and they are vulnerable to danger in a spacesuit. And robots can drill as easily as humans and probably more so. Humans have great advantages for on the spot decision making, fine control and creative approaches to problems - but this can be done as easily from orbit, and more safely. Soaring, Buzzing, Floating, Hopping, Crawling And Inflatable Mars Rovers - Suggestions For UAE Mars Lander
- **Methods designed for human missions to the surface can be used for our robots also, so that they can travel faster, and explore more in each day.** We can generate fuel in situ using hydrogen feedstock from Earth just as for human mission proposals. Or we can use solar power and batteries, adapting the Mars One idea to spread a large area of thin film solar photovoltaics over the Mars surface for power. The Apollo lunar roving vehicle had a rated top speed of 8 km / hour (though it could go faster), weighed 210 kg, for the entire vehicle, and had a range of 92 km, nearly twice the total distance Opportunity covered in ten

years. So it's not lack of power that limits our rovers - they could go much faster if there was the need to design them to do so.

- **Then humans in Mars orbit would be an exciting mission**, psychologically good for the crew, like orbiting in the ISS but above another world. Controlling avatars on the surface via telepresence, with binocular vision, binaural sound if you like, haptic feedback, and digitally transformed vision so you can experience the surface with bright colours as if lit by a midday sun, even a blue sky if you like.



Exploring Mars By Telepresence From Orbit Or Phobos And Deimos

- **As for exploring a galaxy, robots are far safer.** We should start with robots and think very carefully before considering setting up new colonies of humans around other stars. Because uncontrolled self replication is an issue in the galaxy whether the self replicators are robots or humans. We could make ourselves extinct indeed in this way, out evolved, maybe by something that we would consider to be worse than ourselves. Or maybe it can be done in a way that is safe for ourselves and the galaxy - but it probably depends how it is done.

While robots can either be mass produced with identical copies sent to many destinations - or if we can make self replicating machines, designed with many replication safety restrictions so that they can't be a nuisance to the galaxy (e.g. telomere style maximum number of generations, and a "keep alive" signal from Earth so that they stop functioning if they no longer get it). This is surely the safest way to start galactic exploration, and may explain why we don't find our solar system already filled to the brim with ETs along with the rest of the galaxy.
Self Replicating Robots - Safer For Galaxy (and Earth) Than Human Colonists - Is This Why ETs Didn't Colonize Earth?

- **Generally, sending humans into space is something new, that humans have never done before.** We are capable of making mistakes, even huge ones, and this could even cause our extinction. Or it could have hugely beneficial consequences. The universe is not set up in

such a way as to make it impossible for us to make mistakes. We need to think things through, and consider the long term future consequences of our actions.
Why ET Populations Can't Continue To Expand For More Than A Few Millennia
Why Only Very Young ET Civilizations Will Have Expanding Populations - Opinion Piece

- **Grand plans such as terraforming ideas, and ideas for ways that humans might be able to survive on Mars etc are well worth studying.** Not at all suggesting that we should stop studying such ideas. As we study how to terraform Mars for instance, maybe we find a way to terraform the planet easily, and gradually gather the technology and knowledge to do it safely. Or maybe we don't. But either way we find out more about how planets work, learn about other potential futures for Mars, may help with studies of exoplanets, and help us understand how Earth works, and it may have many other benefits.

  And whether or not they are eventually used for humans on Mars, all these studies could have many other spin off benefits. Studies for in situ resource utilization on Mars for humans could be directly useful for robotic exploration, e.g. methods to create fuel for human rovers could help robots to travel faster, return materials to orbit and so on. Studies for ways to grow plants on Mars could be used for sterile hydroponics on Mars which might even in the future be useful for astronauts in orbit around the planet - plants can be grown safely on Mars in principle without any planetary protection issues as seeds can be sterilized. And many of those ideas can be applied directly to other places with no planetary protection issues such as the Moon, asteroid belt, or even Jupiter's outer moon Callisto orbiting outside its harmful radiation zone (which is currently thought to not need planetary protection as though it has a deep subsurface ocean, there is thought to be no communication with the surface).

- **For all these reasons our human and robotic space exploration strategies should be open ended and capable of being changed quickly and easily based on new discoveries.** They should also involve long term future thinking to
avoid mistakes that we could make by rushing in "where angels fear to tread".
- **If we show that it can be done on the Moon, this will actually help human exploration of the rest of the solar system, not hinder it.** The amount we spend on human spaceflight is actually tiny when you work it out per person. The ISS cost a little over $8 per year per person for the US, and the ESA estimates its contribution as one euro for the entire project - less than the price of a single cup of coffee per person.

For more on this see [Is The International Space Station The Most Expensive Single Item Ever Built?](#) (I argue that it probably is, but that's because it is built by a larger population. Per capita it is comparable to earlier mega projects).

Saying that we have to choose between sending humans to the Moon, or to Mars or Jupiter or Venus or Mercury or the asteroid belt is a bit like saying we have to choose between sending satellites to LEO or GEO. It's a false dilemma. We send satellites to both, and can do so because everyone can see the value of both to Earth. Once people see the value of human exploration, the finance will be easy to find. It will be easier and safer to demonstrate the value of humans in space on the Moon and in the Earth Moon system first.

In this vision we continue with robotic exploration of the solar system, and send humans to other places once it is safe and worthwhile to do so.

- **The best place to start surely is the Moon and the Earth Moon system** - where we know that we can do it, with minimal risk of contamination, and the maximum of safety for humans.

In the process we can discover what role humans have in space alongside the robots that are already exploring the solar system as our remote sense organs in space. We can also get some ground truth about how much contamination human missions cause in a pristine extraterrestrial environment where it doesn't matter so much, as there are no global processes to move the materials around the surface.

The few square kilometers around our first base on the Moon might get so contaminated with Earth organics that it is hard to study the faint traces of lunar organics in the regolith. That seems likely from the experience of the lunar sample studies (as we saw above with the analysis of the Apollo samples). Well it doesn't matter on the Moon, as there's always another cleaner square kilometer further away. There's no risk at all that our microbes could grow exponentially and colonize some habitat or other on the Moon. They just lie where they fell, except maybe for the levitating dust.

We can also develop the technologies needed to permit safe deep space missions and appropriate and safe space settlement in the solar system. These settlements would surely continue to be more like an Antarctic base than a pioneer's log cabin in the near future.
Let's Plan For Exploration and Discovery of Space with no End Date - NOT Escape from Earth - Opinion Piece

MOON AS OUR GATEWAY

So, the Moon in this vision is a gateway to the solar system, where we can develop techniques we need, and also at the same time explore a celestial body that is proving much more interesting than expected.

By the time I get to the end of that, then it comes over as an interesting and positive alternative. But there are many steps to it before readers can see the vision.

It's a matter of familiarity. We've had decades to get used to the Mars colonization ideas. These ideas may seem unfamiliar, even unlikely and implausible, but give them some time, to think them over, and perhaps you too will find this an exciting and interesting future too?

Perhaps this can help towards a future where humans in space is not all about colonization and making the universe into a place for humans to live in, but one where we can find out and explore and learn from this amazing universe we live in.

Along the way, settlement is sure to happen. Eventually colonization may happen also.

But I'd like to suggest, it doesn't need to be the main driving force behind our space exploration, no more than it is the driving force behind Antarctic study and exploration, or exploration of the sea bed and so forth. And that this future with scientific exploration, and humans working together with robots for remote exploration, our mobile eyes on the solar system and galaxy, is an equally exciting one. And one that is likely to lead to be much more interesting in many ways than a future where we try to turn all the planets and everything else into the closest possible copies of Earth that we can manage, or at least, habitats for humans, as quickly as possible, as our main motivation.

And also I'd suggest it is more practical, and less likely to lead to disappointment. When you look at Mars and your main thought is "how can I turn this into something like Earth?" you may miss many other possible futures that may be far easier to achieve and may perhaps be of great benefit for humanity in ways you can't anticipate.

If you plan everything out and set a goal to achieve before you know what is there, then your plans may not match the reality, and you may miss out on things that you couldn't plan for because there was no way for anyone to know about them in advance.

So, rather than a grand overarching plan, I think human space exploration has to be flexible, continually adjusted based on new discoveries. And that at each stage we plan carefully for the near future, but also do many tests and experiments and explore different avenues, because the most likely thing is that we don't know everything yet that needs to be known, so can't plan for the future in detail in space.

THE ROMANCE OF SPACE ELEMENT

Whatever the commercial or science value of humans in space, it's also a great adventure for humans. We don't need to be ashamed of this, as it is a motive that can lead to us exploring ideas that might be of great value in the future. It's one of the things that help humans to venture into the unknown and to try out new things which may be risky and with no clear immediate value.

As to how much money to spend to finance such things, I don't know, that's for politicians, but even the ISS cost very little when spread over the populations that supported it on Earth. $8 per person per year. Think how much we spend on movies, and computer games by comparison. The ESA spent only one euro per person for the entire ISS project (for more on this see my "Is the ISS the most expensive single item ever built?"). I think the romance of space is a lot of the reason for the ISS, which would be designed differently if it was purely a zero g research lab in orbit (no need to have humans there 24/7), and differently also if it was a human factors research lab.

Acknowledging this as a motive for ourselves, and also for other space organizations, could make it easier to have more realistic plans. Because then it means we don't have to do grand plans where details are spelt out for decades, to explain why the humans are going there. The early Antarctic explorers didn't have a detailed plan to show how their exploration would benefit humanity in the future. It did, in surprising ways, but they had no way of anticipating that.

Let's acknowledge that we don't know for a certainty if human exploration is the best way to find out about the Moon, or whatever the objective is right now, and that we don't know for sure what the future of humans will be in space, but it's a great adventure. Also, as with almost any adventure into the unknown, it may be the best way ahead into a future we can't quite see yet. And if we don't do this, we'll never find out what the role is for humans in space exploration and how they can work with the robots in space.

I say this because it will permit much more open and flexible exploration if we are not required to explain what the humans are doing there and why they are there as part of some plan with every step mapped out for a decade or two into the future. I think the end result of a more flexible adventurous approach like this would be that we find new ways for humans to explore space and may avoid blind alleys that could lead to space exploration stagnating, just because of the lack of some new idea that may make all the difference.

INTERNATIONAL CO-OPERATION AND ROLE FOR CHINA - USA POLICY

It's impossible for the USA to co-operate with China in space in missions lead by NASA, because of a 2011 bill that prohibits the US from co-operating with China in space, and prohibits NASA facilities from hosting official Chinese visitors. This is due to fears of espionage and China getting an advantage from learning about US technology.

> *"None of the funds made available by this Act may be used for the National Aeronautics and Space Administration (NASA) or the Office of Science and Technology Policy (OSTP) to develop, design, plan, promulgate, implement, or execute a bilateral policy, program, order, or contract of any kind to participate, collaborate, or coordinate bilaterally in any way with China"*

That's why no Chinese taikonauts have ever been to the International Space Station, because NASA are prohibited from inviting them. As a result, it is building its own space station.

There are calls for the US to change its policy towards China, but this may be a long process. John Logsdon of the George Washington University's Space Policy Institute told

Space.com:

> *"It will take presidential leadership to get started on enhanced U.S.-Chinese space cooperation . The first step is the White House working with congressional leadership to get current, unwise restrictions on such cooperation revoked, Then, the United States can invite China to work together with the United States and other spacefaring countries on a wide variety of space activities and, most dramatically, human spaceflight."*

The report "China Dream, Space Dream China's Progress in Space Technologies and Implications for the United States" mentions many of the concerns that were behind the US non co-operation with China in space law, but also says that as China increases in space capabilities and uses space more, it also increases in vulnerability too, the more it relies on space assets:

> *"Although China is probably truthful when it says that it is not in a space race, such statements mask the true intent of its space program: to become militarily, diplomatically, commercially, and economically as competitive as the United States is in space.... As China's space program increases in capability, it can be expected to wield this power in ways that, according to Bonnie Glaser, not only "persuade its*

neighbors that there is more to gain from accommodating Chinese interests" but also "deter countries from pursuing policies that inflict damage on Chinese interests."

"Nevertheless, although China's space program may pose challenges for the United States and its space power neighbors, it may also present opportunities for scientific collaboration on the Earth's environment and outer space. In addition, it may make human spaceflight safer by providing additional capabilities to rescue stranded or imperiled astronauts through the use of common docking apparatus. Moreover, what is unwritten in Chinese analyses is that as China becomes more invested in space capabilities it takes on the same vulnerabilities as the United States. Although China would not have the same asymmetries as the United States in a conflict in the Western Pacific, the goal of having a global, 24- hour, all-weather remote sensing capability and spending nearly $1 billion per year until 2020 to establish a global satellite navigation system and associated technologies indicates that China is devoting significant effort and resources to establish a system that is similar in architecture to that of the U.S. military's space program. With this trajectory, China will have as much to lose as it has to gain from the management or mismanagement of the outer space

global commons. It is in this vein that some sort of strategic accommodation that ameliorates the worst effects of competition could be achieved. "

China does have plans to send humans to the Moon eventually. As with the US and Russia in the 1960s and 1970s, its main reasons for doing this seem to be similar to other nations, reasons of national prestige, to show their technical prowess, as advertising for the space technology capabilities and to achieve results of scientific value.

Emily Lakdawalla has a useful summary of past and future robotic Chinese missions to the Moon. Plans include a robotic sample return in 2017 and a mission to the far side (probably) in 2020 (according to Weiren Wu, their chief lunar exploration engineer). That last would be a particularly impressive and prestigious feat for them, as nobody has achieved it before.

Paul Spudis says in his new book (chapter 8, If Not Now, When, If Not Us, Who?) writes that he considers that the developing Chinese deep space capabilities, to send robotic spacecraft and eventually humans to the Moon and further afield, are a defense issue for the US.

I like much of what he says in the book. But I can't follow his reasoning here. Anything that China can do, the US and Russia could do forty to fifty years ago. If it was a military advantage for China to be able to send it's Chang'e 2 to the L2 position for instance, as he says in this chapter, why doesn't the US have spacecraft there already, to swoop down on geostationary satellites from an unexpected direction in a war situation? So I don't find it very plausible myself that the Chinese deep space lunar and asteroid encounter robotic missions have a military purpose behind them.

We have several civilian spacecraft at the EML1 position at present, including Advanced Composition Explorer, Deep Space Climate Observatory, and the Gaia spacecraft. EML2 isn't used so much, since after all, though as close to the Moon as EML1, there is no direct communication with Earth. I don't think we have any spacecraft there at present?

But Chang'e actually went to the Sun Earth L2. That's a natural spot for any spacecraft to go on its way to an interplanetary target, as it is a waypoint on the "interplanetary super highway" - from which it is easy to go to a further away deep space target, such as an asteroid, which is what it did next. I think this just shows that China has an interest in deep space exploration. Similarly India has just sent a spacecraft to Mars, more of a technological challenge than a mission to L2 and an asteroid, but nobody sees this as a military issue.

Some of what they do in space is of course of military significance. Their ASAT test in LEO in 2007 was, definitely. However, [the US did an ASAT test in 1985](), destroying a defunct weather satellite using a portable missile launched from an F-15 fighter. The US was way ahead of the present day China in these capabilities back in 1985.

I think their motives for deep space missions must surely be the same as everyone else. Nobody else seems to think that their own deep space missions, currently, are of any military significance. Neither the US, nor Russia nor the ESA, nor any of the other space agencies think deep space is of any military value at all. We don't get secret defense payloads launched to deep space (and we'd know about it if there were any, as it is easy to track spacecraft after launch from Earth, by following their trajectory, and even into deep space from monitoring their radio communications with Earth). So why should China?

We do many things that have no immediate economic or practical or defence value. One nice parallel with our space activities I think are the Olympics. These also bring together nations from many different countries in friendly co-operation and competition. Just as China takes part in the Olympics, despite many differences of opinion and concerns about human rights, and so on, let's encourage it to take part in international space ventures too.

The Chinese are interested in collaborating from their side.

Yang Liwei, China's first astronaut said:

“China will not rule out cooperating with any country, and that includes the United States,” said Yang Liwei, China’s first astronaut. “The future of space exploration lies in international cooperation. It’s true for us, and for the United States, too.”

Similarly, Zhou Jianping, chief engineer of China's manned space program, said:

"It is well understood that the United States is a global leader in space technology. But China is no less ambitious in contributing to human development ... Cooperation between major space players will be conducive to the development of all mankind,"

from: China open to Sino-US space cooperation

ESA, RUSSIA AND CHINA

Though the US can't collaborate with China, without a major political change of direction, Europe and Russia are able to co-operate. and indeed are keen to do so. They already co-operate in many ways.

Johann-Dietrich Woerner, Director General of ESA outlining his vision for the ESA village and Space 4.0 in [his visit to China in April 2016 said:]

> *"Let's open space. Space is beyond all borders so let's also have the cooperation beyond borders, When you ask astronauts, and I'm sure also the Chinese astronauts will tell you the same: they cannot see any border from space. So this is a very nice vision. We should use this and cooperate worldwide on different schemes, and I think Moon Village has its value for that."*

The ESA village idea is based on many different habitats from different countries in single village on the Moon. Unlike the ISS which is a single facility, it would be possible for China to have its own separate habitat in the village.

For these reasons I think that actually it would be good for the ESA to lead the Moon initiative, at least for as long as the US has this stance on China. It has this capability and also willingness to collaborate with all of the US, Russia, and China. With the ESA leading, then US could, I think, be part of a moon village with China also taking part. That could be an interesting future.

Chinese taikonauts, crew of Shenzhou-10 after 15 days in space. (Credit: CNSA)

Meanwhile, the ESA has put an experiment on the Shijan 10 Chinese satellite, has sent personal to visit Chinese facilities, plans to send an astronaut to the Chinese space station in 2022, and several ESA astronauts are learning Chinese. It can't invite the Chinese back to the ISS of course because of the US law. But it's a starting point towards greater collaboration in space in the future. Also Sweden (a member state of the EU) will put an experiment on the Chang'e 4 mission to the lunar far side, to measure the solar wind and look at what its role cold be in the formation of water at the lunar poles.

For these reasons, unless the US change their policy, I think the ESA is the natural leader for future human Moon space initiatives. That's just because if they lead, then both US and China can take part, but if the US lead, China will be excluded. I think that it will help future international relations between countries in space if China can be part of the initiative. Which in turn may make it easier to achieve a peaceful future in space longer term.

SPACE ASSETS AND STRATEGIC, ECONOMIC AND MILITARY SIGNIFICANCE OF SPACE

I agree with Paul Spudis's later point in his book, that if we have a large presence on the Moon, then at some point, it may become of military significance, especially once spacecraft can be supplied with fuel from the Moon and once we build deep space spacecraft using materials from the Moon, even nuclear reactors fueled with thorium from the Moon. But this is for the future, and I don't think we need to worry about the consequences quite yet. The provisions in the OST to prevent militarization of space, particularly setting up military bases in space, may help there when the time comes when we need to legislate and have international agreements about such issues and so forth.

If we can co-operate in the early stages, much as we do in Antarctica, not necessarily doing everything together, but in a spirit of collaboration and friendly competition, I think this is the best way to set us on course towards a peaceful future in space. Also, though the peaks of eternal light are geographically quite small, still, there is plenty of space for an ESA type village and many habitats at each one. If there are hundreds of millions of tons of ice at the poles, there is plenty there for everyone for the foreseeable future, at least until we get large scale mining of ice from asteroids.

I also think that we have to head towards peace in space, because even a minor war in space, anything that involved firing weapons to destroy habitats, would be a disaster. It doesn't require powerful weapons of mass destruction. Most space habitats, including surface facilities would be easily destroyed just through kinetic impact of a small mass at a few kilometers per second, easily achieved with space technology. Settlements in deep lunar caves might be immune to this, but they would still have vulnerable surface facilities as well. Unlike wars on Earth, humans would have nowhere to go as a refuge, even if they survive destruction of their space habitat.

So our future in space has to be peaceful, or we simply won't survive in space and will have to go back to a non space technology based civilization. Luckily we have made a good start on this with the Outer Space Treaty. And all members of the treaty have much to lose if the treaty is broken, so I think it will stand for a long period into the future.

Luckily the Outer Space Treaty is also flexible enough to incorporate many future developments of space law. It rules out any possibility of "stake holding" where countries claim ownership of territories in space, or individuals do so supported by their country. But that's a plus as it means we don't need to be concerned that China, or anyone else, will try to lay stake to some region of the Moon. There are many ideas for adding some form of "space ownership" of assets in space, which are compatible with it, based for instance on the ownership of habitats you build in space already included in the treaty, maybe accompanied by extra provisions for functional ownership, or based on a controlled safety zone etc.

The details need to be worked out by space lawyers. One likely point of contention is based on the provision in the Outer Space Treaty that we are going into space for the benefit of all mankind. Broadly speaking, then in the US this is interpreted as free market capitalism in space, where companies compete, and are taxed only by their host country and are free to sell whatever they want at whatever price back on Earth.

While in Europe and in other places, there's more support for the idea that all of humanity should share in the space mining boom, an idea that's called the "common heritage of mankind" in the Moon treaty. One idea discussed recently on "the conversation" is the idea that space industry could be a basis for a sovereign wealth fund, which could then be used to guarantee a minimum wage world wide, similar to the Alaska sovereign wealth fund, but applied globally rather than to a single country. Which could eliminate the worst of poverty, hunger, access to clean water and sanitation, education etc world wide.

Other similar ideas include support for nations to go into space who can't afford to do it themselves. That they can use assets such as space launches, and facilities in space to do their own space mining.

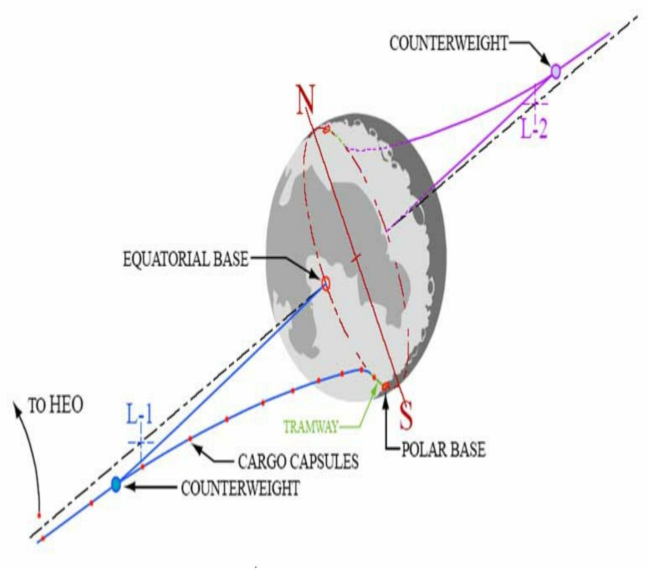
As someone who lives in Europe, perhaps I'm naturally biased towards the "share with all humanity" approach. Of course, recognizing risks in the early stages, a company that is attempting something that is just on the border of possible should be given all the encouragement it needs, and the last thing you would want to do at that point is request them to divert funds elsewhere. But once they are up and running and have a healthy balance sheet, then why not tax them, like everyone else, and if so, why not have an element of that tax used for a global sovereign wealth fund? Or similar, maybe a fund used to combat world poverty, or one way or another, to recognize that the assets in space are the heritage of all mankind. That would certainly have my vote.

As for the importance of it, I think it depends how much of a space economy there is. If the optimists are right and there is a potential economy that could lead to the world's first trillionaires, maybe even individuals able to pay off the national debt of the US, then I think that we do need some kind of a provision to balance this, to make sure that others on Earth don't suffer and to make sure we all benefit from the space assets, not just their share holders and the country that they are citizens of. I think it would be too risky and unstable to rely on their benevolence, and there could be other issues too, such as artificially high prices for materials such as platinum that could be supplied at low cost, just to increase profits for their share holders, and also collapse of many Earth based industries due to imports from space.

But if it is just another industry, billion dollars type companies, similar in size to Microsoft or SpaceX, I don't see it as a huge issue either way. For more on this, see Will Anyone Ever Own Their Own Land In Space - And May We Get Wars In Space In The Future?

One way or another this will need to be addressed and an attempt made to find a solution that all nations can agree on, that clarifies some of the more ambiguous elements of the Outer Space Treaty. And I don't think an attempt for one country to deny access to assets by another country is a good way ahead. We have to find some other solution.

Another example of a space asset here is the lunar space elevator, if this gets built. We could have multiple space elevators from the lunar surface headed up to EML1 and EML2. But only one hub at the L1 and L2 positions, and then only one counterweight tether section leading outwards towards the Earth.



This seems to be a project where we will have to have international co-operation. Though how it works out I don't know. But we manage such things on Earth one way and another, for instance the Suez and Panama canals. Would it be "owned" by one country or company, or would it be an asset that is jointly developed and owned internationally? I think we will find a solution somehow.

I'm sure there will be much here to occupy space lawyers and politicians for decades to come. This is an article I wrote about: Will Anyone Ever Own Their Own Land In Space - And May We Get Wars In Space In The Future? It is a very technical subject and I'm no expert, so perhaps that article is most useful for the links to expert opinion and the questions it raises.

ROBOTS AND HUMANS TOGETHER

Paul Spudis and Dennis Wingo have presented detailed plans leading up to a human outpost on the Moon and then to a base with a more or less continual presence of humans there. Though they have differences of detail in their visions, they both have the same basic idea, to send robots first to scout out the Moon, and then to set up a human base at one or other of the lunar poles, with much of the early work of constructing the base done telerobotically from Earth.

Both of their visions are based around the idea that it will be easy to extract volatiles from ice deposits in the perpetually dark craters at the poles. And both think that this water will not only be useful for humans in situ, but also help to fuel spacecraft shuttling back and forth between the Moon and Earth, and start a lunar economy based on exports of water and fuel to LEO and to other spacecraft. The main idea here is that it would be much easier to supply the water from the

Moon than from Earth.

Dennis Wingo outlines their similarities and differences here in this review of Paul Spudis's book, "The Value of the Moon". BTW do check out Paul Spudis' beautiful graphic, showing the outline of his vision. He reproduces part way down the page in that review .

I'm presenting a more fluid approach here though. The main idea here is to increase the emphasis on the initial scouting phase, and de-emphasizes the later plans, for the time being, until we find out a little more. Their plans may well describe exactly what we do. They are worked out in detail and if the assumptions they make are correct, and we make no new surprising discoveries on the Moon, then one or the other of these plans may well be the best way we can possibly explore the Moon. It's great to have them worked out in such detail already.

However, we have had so many surprising discoveries about the Moon in the last few years, just from orbit. Given how little explored it is on the ground, I think that it's just a little too soon to commit to detailed plans like that about how exactly humans will return to the Moon.

I think that we should do open ended research with robots on the surface for a few years first before we commit to detailed plans for the later stages. They both have plans for robots that explore the lunar poles to look for the best deposits of volatiles. Of course we need to do that. But I'm talking here about a more open ended and extensive exploration, not focused only on the places that seem the best places for humans right now. Because we should "expect the unexpected", I think, at this stage. For instance, to check out to see if Arwin Crotts' deposits of ice exist a few meters below the surface. It may be a long shot, but they would be revolutionary if they exist. To explore the caves, see how large they are and what's in them. Take a look at the In depression, and see if it is a result of volatiles carrying away meters of the surface layers. Test to see if Wieczorek et al are right, that the magnetic anomalies beyond the rim of the Aitken crater are deposits of high purity valuable metals.

This might not be a long period of exploration, and the more robots, the quicker it would be. But we have done so little direct exploring of the Moon on the surface to date, that surely open ended exploration may still turn up many surprises. The Moon has roughly the same surface area as the US, China and Russia put together, with a varied terrain and many geological features to explore on the ground that we can't study easily from orbit. The volatiles were a relatively recent discovery after all, which changed everyone's ideas about how best to explore the Moon. Perhaps future discoveries may change those ideas again, in detail or dramatically.

This could be done with humans, as with Apollo, but nowadays robots are a much more cost effective way of doing it. They'd be doing open ended scientific research, and along the way also checking out resources for humans, and getting a fuller picture of the Moon. It would also give us an opportunity to study the Moon with the less intrusive robots, before humans arrive with their large rockets, the fuel from those rockets, and the extra organics that will accompany them to all the landing sites they visit. This can give us a baseline, and we can take this golden opportunity of a few years, to study things that we won't be able to study later once the lunar "atmosphere" is augmented by human activities on the Moon - such as water transport in the thin lunar atmosphere.

Perhaps with a thorough understanding as a result of these studies, we position a human base a few tens, or hundreds of kilometers away from what seems the most obvious place, based on our knowledge to date. Perhaps the best place for a base is indeed on one of the peaks of almost eternal light as Dennis Wingo and Paul Spudis both suggest. However, there are quite a few of those peaks at both poles, and the best one in terms of light might not be the best for humans in other ways.

For an example, we don't know yet, but there might be deposits with 100% pure ice or other volatiles, who knows, if we explore enough. Perhaps on the surface in some unexpected place, or perhaps below the surface. These might be much better for in situ resource utilization than the obvious first choices. But perhaps we would need a better scientific understanding of the Moon before we can find them. This is just one possibility.

We may also find sites of exceptional scientific interest that need to be protected. Dennis Wingo spoke about developing the North pole for industrial work, so separated by a lunar diameter from the South pole which is for scientific research. That makes sense on present day understanding, but what if there is some uniquely interesting scientific site at the North pole? Perhaps it might even be the other way around, after we've done the preliminary studies?

So we need to know not just where to locate the base, but where not to put it also. And generally explore anything that's unusual and interesting, as you don't know what it will turn up.

Or we may get surprising discoveries about the lunar caves which make them go to the top of the list. The caves have an even temperature just as for the poles. It's true that the lunar poles are dramatically better sites for solar panels, when you work out the average power generated, as Dennis Wingo shows in his recent paper. But should the amount of solar power available be the main factor for choosing a landing site? It is a factor of course, but solar panels are quite lightweight. When you have a stable surface to spread them out on, as for the Moon, and no weather to disturb them, they can even be thin film, spread over a large area. They can also perhaps be made on the Moon itself.

You can compensate for less power by having more panels - and adding facilities to store the power for the 14 day lunar night. That is definitely possible, using hydrogen fuel cells, or good batteries, or in many other ways. Suppose for instance that some of the lava tube based lunar caves are large enough to fit an entire city inside, with smooth, close to airtight walls, easy to turn into large habitats with natural cosmic radiation protection? That by itself might outweigh the solar power advantages of the peaks of eternal light. Or there may be resources in the caves that we don't know about yet, or in some of them only, available nowhere else. Also, if there is ice near to a cave, a cave close to the poles say, that would combine the best of both worlds. Or they may have other advantages including ones that nobody has thought of yet.

Also, if we have biologically closed systems, nearly all the water can be recovered and used again just as water. So it might not be so important to have the main human base close to the ice. It might be that the best place for the humans is close to the ice, especially if the ice is the basis for an industrial operation that they have to oversee. But again, maybe that's not the best place for them. Maybe the ice has to be kept free of organics for scientific reasons, and that it's best if the humans are some way away from it. Just as a "for instance". Or perhaps, the main base is somewhere else and there is an outpost, only visited occasionally, near the ice deposits.

Or it might be that Dennis Wingo and Paul Spudis are right and that the peak of "eternal light" with the most solar power is the best place to send humans, and that this also is a place so rich in ice that it will be a source of fuel not just for the Moon but for cislunar space as well. If so we might find this out early on. We might find a place that is so good as a base, that we feel there is no need to look any further.

But if we base our entire strategy on this, before we know for sure, and then it turns out to be wrong, that could be a huge setback. Also, if it is more or less right but less than optimal, we might miss some opportunity that could have reduced the cost of the human mission considerably.

You could probably go on almost for ever looking for better and better sites for a base. I'm not suggesting that. But I think perhaps a few extra years searching in a more open ended way early on could bring dividends later.

MEANWHILE IN LEO - SUSTAINED RESEARCH INTO HUMAN FACTORS

As well as that I think that we need to start working on human factors research. The ISS is not really a human factors research facility. First - why is there so much emphasis on growing food for astronauts in zero g? It's interesting pure research to discover that some plants manage fine in zero g. But as for practical applications, we don't really know whether or not astronauts will typically need to grow food in zero g in the future.

I think this is more a case of "we have a facility in zero g, and astronauts in it, so let's see if we can grow food there for the astronauts?" Even a very slow spin can give you a hundredth of a g for the plants, which is enough to change the gene expression of every cell in the plant, turning many genes on or off. In future interplanetary missions, we may spin the habitats and greenhouses with a counter balance using tethers to achieve whatever g we want for the plants. Or we might just spin the plants themselves in centrifuges.

For the Moon we are particularly interested in how well plants grow at lunar levels of gravity. And also of course, how humans manage at lunar g. Again, there is very little data, just the few days of astronaut EVAs on the Moon, with 1960s and 1970s monitoring equipment. Also, there has been no attempt to achieve almost biologically closed systems in space, where nearly all the food and oxygen for humans comes from plants, even though it has been achieved on the Earth already by the Russians with BIOS-3.

For a lunar base, I think we need experiments in growing plants at lunar g. The obvious place to do that is on the Moon of course, but we can speed things up by testing this right away in LEO, testing long term adaptation of plants and humans in lunar gravity. We will need some kind of base in LEO anyway at some point, surely.

We could have humans in LEO in artificial lunar gravity right now, for days. We could set that up probably within a year (it didn't take long to get the Gemini tether experiment together back in the 1960s and we know much more now than they did then). Then we could do more experiments like that for weeks, then longer periods, using existing technology. We seem to have lost our sense of exploration and adventure in space. We are no longer doing bold new tests of things that nobody has done before, as they did with the Gemini program - the first EVA, the first tether, the first docking in space etc. It's mainly repeats now, of things done before. Yet there is so much we have hardly even looked at yet. Let's start exploring new territory, which we can do right away, in LEO.

Even with future advances, it's probably safer to do preliminary experimental work of this sort in LEO rather than on the Moon. It's easier also, with a faster turn around time for the experiments, and it's less expensive to do these experiments in LEO rather than to have to go to the Moon to do them. Especially right now when we are still at an early stage of research, and may have many false starts. Doing these experiments in LEO will also mean we can try many other gravity levels, and also learn how to achieve artificial gravity for interplanetary missions. This can go on at the same time as the early robotic exploration of the Moon.

This is open research, so we don't know where it is headed. So we should certainly also try small scale centrifuges as well, such as the MIT researchers recommended. We don't know what any of this will be useful for. Perhaps it turns out to be a vital capability for human health for deep space missions, perhaps it's the key to health for lunar habitats, or maybe it makes exercise in space much more effective, or maybe it just makes it more comfortable for astronauts in zero g to eat their meals or use a toilet with brief periods of artificial gravity. As basic research, we don't know until we try it.

We can also do biological closed system research in LEO. See if we can duplicate the BIOS-3 results in space.

So, I'd follow Joe Carroll's idea of an artificial gravity research gravity in LEO myself. It's not a zero gravity lab - though you could add one to the hub later on. It can start off as simple as just one module with a counterweight.

Before that, just the Soyuz TMA or any other spacecraft can do Joe Carroll's tether spin on the way to the ISS, deliberately use the longer two day phasing approach to get to the ISS and do your first experiments on the way. I don't know what the cost would be, but not much, just to add a tether to a Soyuz TMA mission that is going to the ISS anyway, and to use the older two day approach path, which they still have as an option.

This video shows a 600 meter tether at 1 rpm joining a Soyuz TMA to its final stage to achieve lunar gravity. Even the most highly susceptible people have no problems with 1 rpm in rotating rooms on the Earth long term. So probably this would be fine for everyone in space also - that is if the Earth experiments are a reasonable guideline, which nobody knows of course (that's why we do the experiment). There are some indications that in space, with spins around a horizontal axis (above your head) and no gravity pulling sideways along the rotation axis, that we can tolerate spins better than on Earth. Though the data is very limited so far.

(click to watch on Youtube)

All these videos are done in Orbiter, a remarkable space mission simulator by Dr. Martin Schweiger with lots of add ons contributed by enthusiasts.

Thanks to Gattispilot, for making the tethers for these animations and for techy advice about how to attach everything together.

Note that the video shows an "eyeballs out" configuration. The tests would only go from low g up to full g, but still, this is not the most comfortable orientation for the crew. Joe Carroll's plan is for an "eyeballs in" configuration, it's just that for techy reasons I found it much easier to position the Soyuz in the simulator for "eyeballs out". The tether would be brighter than this, and you may notice a cube at the center of gravity of the tether - this is just to indicate where the center of gravity is and would not be there in reality.

Based on these very early tether spin experiments, we can answer basic questions such as, can humans tolerate spinning for two days, and if so what tether length and spin rate is tolerated? (The experiment is designed so it is easy to abort from it at any time by just cutting the tether, then continue to the ISS). And what are the immediate effects on the human body of artificial gravity? What is the gravity prescription for health (what g level, how many hours a day or do we need it full time) and how easy is it to apply the desired levels using AG?

Based on those preliminary results from the Soyuz TMA, or any other crewed capsule that goes to orbit with a third stage which you can use as a counterweight, you'd work towards designing a larger AG research lab in the future for longer duration studies. It might be based around using the newer modules from the ISS when it is decommissioned, for a hub for spacecraft to dock to and for zero g research, and then tethered habitats for the crew going round it. If it gets more elaborate, perhaps it would also use spent final stages, fitted out in advance as "wet workshops" like the early ideas for Skylab.

This then would create a small facility in orbit. It doesn't need to be a big multibillion dollar facility like the ISS, just a small space station to start with, which can also be a basis for a staging post in LEO later on. It could also be a facility for research into closed systems, growing plants and so on. It would have a science component of course, like the ISS, but the main objective would be human factors. It would be forward looking, helping us to find out what role humans can play in space in the future. Which of course would have science benefits in turn. Once we know more about what humans can do and how best to support them, we can then send them on science expeditions further and further afield into our solar system.

It would start small, based on this idea that we are still experimenting, and are not yet very experienced in space travel. At this stage, I think we need to try out ideas, and lots of them, to see what works. This could lead to advances that we would never get if we proceed in a linear planned out way with some grand plan for the future, based only on the knowledge we have so far.

So, it is open ended, and low cost (as human spaceflight programs go). It doesn't have to have a continual human presence, unlike the ISS, which is one of the things that makes the ISS so expensive. There's a strong emphasis on closed systems, doing our best to get biological closed systems working in space, which are, after all, a central part of nearly all human space exploration plans further afield, So let's get started on those right away in LEO. If this closed systems research pans out, and if astronauts stay healthy in some level of artificial gravity, then you could send them supplies only once a year, perhaps, or less, and then you could start to occupy it continuously. So then the costs would go right down, and typically at least some of the astronauts would stay up there for several years at a time. If you can achieve this much, then you would get a lot of confidence and experience for long duration missions further afield, not just to Mars or Venus, perhaps eventually also to Jupiter's Callisto, and beyond.

Once the lunar mapping and research phase with robots is done, which might be only a few years, then you start thinking about where humans would go on the Moon and what their role would be. You could wind down the AG lab at this stage, if we know the answers to the main questions already. Or it could be retained as a staging post for missions to higher orbits. and the Moon when needed, or for continued AG research.

I'd see all this as costing less than the ISS to keep going, once the ISS ends, so it shouldn't impact at all on robotic exploration of the solar system. So, meanwhile we continue robotic missions to Mars, but also to many other places. The robotic exploration perhaps can step up even, since now it would be seen as part of the human exploration, on the Moon, and further afield. It might start to pay for itself as well on the Moon.

And if the humans on the Moon only need supplies once a year or less frequently, again it would probably cost less than the ISS to keep a lunar facility going, as it's the supply missions that are the biggest ongoing cost. We could run both the lunar base and the AG lab together for less cost, perhaps, than the ISS alone. So this period of time in LEO refining biologically closed systems and working on Artificial Gravity would lead to dividends later on as we design habitats for the Moon and then further afield.

Then building the lunar base would involve ISRU so again it might be easier to build than the ISS was. Meanwhile you have the private space industry, tourism etc developing which could lead to many facilities in space that are designed for tourists but can also be used by astronauts or are jointly run by tourist companies and space exploration companies / government entities funded as basic research.

And maybe already commercial resource utilization too. If along the way you find that there are those resources on the Moon of commercial value, then it might be that humans on the spot are useful, so that could happen naturally that humans are sent there. But if it costs less to extract the ice with a purely robotic facility, that might undercut a facility manned by humans. I think we might end up with some optimal mix of humans and robots at this stage.

So then, after a few years of exploration from Earth, when humans go to the Moon, they would have a whole network of robots on the surface that they can control via close telepresence and lunar communications satellites as well. This would also give us valuable experience for exploration of the solar system further afield. As well as that, the work on sending many robots to the Moon would mean that we have learnt a lot about the best and most mobile designs, and dealt with bugs such as the Chinese rover that couldn't furl its panels at night. By then, these lunar robots will be robust, mobile, semi autonomous and easily controlled. So it will then be much easier to build the human base from Earth via telepresence, and the robots will be much more capable tools for the humans on the Moon to control.

There are many dangers in any space walk on the Moon, including hazards of falling over and damaging your spacesuit (which could kill you), also the solar storms and cosmic radiation. So, I expect that most future exploration will involve controlling rovers on the surface via telepresence, or exploring the surface in enclosed rovers. There wouldn't be so much by way of EVAs by humans on the surface of the Moon as in Apollo, though of course there would still be some of that.

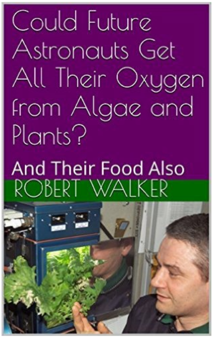
In this vision, one advantage of the caves idea (if those large lunar caves exist) is that you'd end up with a much more spacious habitat for humans to live in, easier to "build" than a city dome, which could be a plus if it turns out that they don't spend that much time on the surface. They could enjoy the lunar gravity inside the caves. Indeed, eventually, with kilometer scale caves filled with breathable air, they could explore the dream of human powered flight and lunar gravity athletics etc as well :). And as with the Stanford Torus ideas, have habitats with plants and so on inside the caves.

So, this is just a draft idea of how it might continue. In the spirit of this approach, we'd need to be ready to adapt it quickly and change plans depending on what we discover along the way.

For more about the ideas for artificial gravity research in this section see my

- [Can Spinning Habitats Solve Zero g Problem? And Answer Low g Questions?]()
- [Could Spinning Hammocks Keep Astronauts Healthy in Zero g?]()
- [Ingenious Idea: Soyuz Crew in Tether Spin On Way to ISS - For Artificial Gravity - Almost No Extra Fuel]()
- [Crew Tether Spin - With Final Stage - On Routine Mission To ISS - First Human Test Of Artificial Gravity?]()
- [Crew Tether Spin For Artificial Gravity On Way To ISS - Stunning New Videos - Space Show Webinar - Sunday]()

For more about the BIOS-3 results and other ideas for ways we can achieve biological closed systems in space, see



- [Could Astronauts Get All Their Oxygen From Algae Or]()

Plants? And Their Food Also?
- Beautiful Edible Orange Zinnia - First Zinnia But Not First Flower In Space - And Astronaut Choices

WE ARE LIKE THE EARLY ANTARCTIC EXPLORERS

I've touched on this comparison a few times already but let's follow it through bit further this time. We are like the first explorers to get to Antarctica. They didn't set off to colonize the continent.

If they had had that as their main objective, to "live off the land" they might well have succeeded for a while, killing seals and penguins for food and using their fat for fuel to keep warm, a bit like high tech inuit. After all Shackleton's party did survive an Antarctic winter while he and a couple of companions set off to find rescue for them in a small open boat. But I can't see a colony on Antarctica with nineteenth century technology surviving for long. However enthusiastic the first settlers were; soon their children would decide they'd had enough, and want to come home, and not continue with the harsh difficult way of life their parents had chosen.

Instead of attempting this, the early Antarctic explorers did their exploring, and scientific study, and then came back to their warm comfortable homes at the end of each expedition.

And then for year after year they continued to explore, built temporary bases, then more comfortable ones, then now we have many bases in Antarctica that are occupied all the year round (though with fewer people there in the Antarctic winter). There is no sign at all that we have come to an end of the science we can do in Antarctica, or that people will lose interest in going there as tourists, or going on adventures there. Yet, we are nowhere near to starting up a true colony there, and nobody has that as an objective at present.

So, I think it's the same with space. That if we go into space to try to colonize right now, we will never succeed. It is just too hard. Would you colonize a mountain plateau 30 kilometers into the atmosphere, more than three times the height of Mount Everest? At that height you'd have the same atmospheric pressure as Mars, but it would be much more hospitable in other ways. Perhaps it could be done, but why live in a place where everything is so difficult to do? Unless you have some very strong reason for living there, people just wouldn't set up home in a place like that, Not once the novelty wore off.

But you'd go there for adventures, you'd have scientists studying, and so on.

Maybe eventually we will find a way to live in such harsh conditions as the Moon easily. Maybe we can do this with 3D printers, and biologically closed systems. Maybe this will lead us to find a way towards a more sustainable future here on Earth as well.

But even so, if we achieve the ability to do this easily, the technology would still work much better on Earth than in space. You can use much the same design for your colony - except that you can drop all the cosmic radiation shielding, forget about airlocks and spacesuits, and just have windows and doors, instead, which you can walk out of, into a breathable atmosphere. And then put that habitat almost anywhere on Earth, in a desert, or floating on the sea - and that would be a far easier place to live than any space habitat. So if those types of habitats became possible in the future, even as a spinoff from space habitat research, I think most of them would be built on Earth rather than in space, at least to start with.

So, in this vision of the future, we have humans in space, but they aren't there to colonize. They are there rather to explore and study, and for adventure and so on, for many of the same reasons we have people in Antarctica. In the near future anyway. I think this is just being realistic; choosing a future that is within our reach rather than a rather beguiling far future science fiction fantasy that is probably centuries or even thousands of years out of reach, such as a terraformed Mars.

In this way, without that imperative that we have to colonize as quickly as possible, and turn everything into the nearest to a pale imitation of Earth as we can manage - then we can have a more open ended future. It gives us space to consider other possibilities; or at least, to look at them. For instance, in one possible future we ***could*** introduce Earth life to Mars, accidentally and irreversibly, perhaps from a crashed human occupied spaceship, creating a new geological era on Mars. But we don't ***have*** to do that. There is no need quite yet to make such an irrevocable decision for ourselves and all future civilizations on Earth.

Let's study Mars carefully from orbit first. There is no hurry, and this would be a fascinating exploration using telepresence, once we can get humans there. Maybe we will know enough in the future to make such far reaching decisions, but meanwhile, let's keep our options open for the future.

This next video is not telepresence as such; rather, it's a new way to explore the Mars landscape to help with controlling the rovers from Earth. However, I think it gives as good idea of what telepresence might be like for those operating rovers on Mars in real time from orbit, some time in the future with this vision.

(click to watch on Youtube)

See Scientists Can Virtually Wander Around Mars for Miles with HoloLens

THIS APPROACH DOESN'T MEAN THAT HUMANS CAN NEVER LAND ON MARS EVER

The idea isn't at all to prohibit humans on Mars. The humans are not the problem; it's only their microbes that are. And the idea is to do it step by step and to make sure we understand Mars and understand the implications of our actions before making a decision about whether it is okay to have human boots on Mars.

I'm a spaceflight and science fiction enthusiast myself and I'd love to be able to cheer on humans on an expedition to Mars. Just for the childlike wonder of seeing humans doing things like that in space. So it would be fun to see humans go to Mars. And at least we can send them to Mars orbit whatever we might discover about the surface - so long as it is done with care to make sure that they can't crash on Mars.

SAFE WAYS TO GET HUMANS TO MARS ORBIT OR ITS MOONS TO AVOID ANY RISK OF CRASHES ON THE SURFACE

You couldn't do aerocapture in the Mars atmosphere as a way to get into orbit. It would be far too risky. Also Hohmann transfer with insertion burns are too risky also, as the insertion burn is done as close to Mars as possible to reduce the amount of fuel needed due to the Oberth effect. So you would need to be very sure that the insertion burn can't go on too long and end up on an impact trajectory with Mars.

I suggest ballistic capture is a far better method for human missions to Mars. The idea is that you launch the spacecraft to arrive ahead of Mars at just the right point for it to capture you as a temporary satellite. Once you leave Earth, you are already on a trajectory that ends up with your spaceship getting captured temporarily in a distant Mars orbit when it gets there, with no need for an insertion burn. Then once you are in that orbit, you use ion thrusters to spiral down to lower permanent orbits around Mars.

This is surely the safest of all the ways proposed to get into a Mars orbit, and the best way to prevent a crash of a human occupied spaceship on Mars.

Then you also have the flybys. Flybys are safe because although they involve precision targeting, you have months to set the target up. Also, the ones that are of most interest for Mars are free return, so even if your rocket fails, you are still on an orbit that will take you back to Earth again. You would use trajectory biasing of course, so that as you leave Earth you are biased away from Mars rather than towards it and use fine adjustment then to target the flyby orbit.

We have done many flybys, delicate ones, repeatedly for Saturn's moons with Cassini, and get them right every time, so it is obviously one thing we know how to do reliably. This has no time critical insertion burns. Just gentle thrusts nudging until you are in the right trajectory, which you set up long in advance of the actual flyby.

So, especially Robert Zubrin's double Athena flyby - a very interesting mission - is safe for humans to Mars. This has two flybys of Mars. The first diverts you into an orbit that closely parallels Mars for half of its year, so a full Earth year. The second flyby takes you back to Earth 700 days after the launch. It's free return - once you leave Earth you are already on a trajectory that will take you back to Earth 700 days later even if your rocket motors fail completely.

It's a great orbit for telerobotics as you spend several hours close enough to Mars for direct telepresence with each flyby, and days close enough for significant advantages relative to Earth, and over the entire one year period when you are almost paralleling Mars in its orbit, your crew are much closer to it for controlling robots on the surface than anyone on Earth.

TELEROBOTICS

Telerobotics lets us explore Mars much more quickly with humans in the loop. And you'd use an exciting and spectacular orbit for early stages of telerobotic exploration of Mars, following the HERRO plans. It comes in close to the poles of Mars, swings around over the sunny side in the equatorial regions and then out again close to the other pole, until Mars dwindles again into a small distant planet - and does this twice every day.

Imagine the view! From space Mars looks quite home-like, and the telerobotics will let you experience the Martian surface more directly than you could with spacecraft, actually touch and see things on the surface without the spacesuit in your way and with enhanced vision, blue sky also if you like. It's like being in the ISS, but orbiting another planet.

12th April 2011: International Space Station astronaut Cady Coleman takes pictures of the Earth from inside the cupola viewing window.- I've "photoshopped" in Hubble's photograph of Mars from 2003 to give an impression of the view of an astronaut exploring Mars from orbit.

This is a video I did which simulates the orbit they would use - in orbiter. I use a futuristic spacecraft as that was the easiest way to do it. Apart from that, it is the same as the orbit suggested for HERRO.

(click to watch on Youtube)

It would be a spectacular orbit and a tremendously humanly interesting and exciting mission to explore Mars this way. The study for HERRO found that a single mission to explore Mars by telepresence from orbit would achieve more science return than three missions by the same number of crew to the surface - which of course would cost vastly more. Here is a powerpoint presentation from the HERRO team, with details of the comparison.

TELEROBOTICS WITH HUMANS IN ORBIT COMPARED TO ROBOTS CONTROLLED FROM EARTH

That's not to say that humans to orbit would be better than robots. I don't know if anyone has done a comparison study there.

You might be able to compensate for the advantage of humans in orbit by having many more robots on the surface for the same cost, especially if broadband communication is possible, better robotic autonomy, and techniques from gaming such as artificial real time (building up a copy of the Mars surface explored by your robot in your computer on Earth and navigating that to help speed up movement from a to b on Mars).

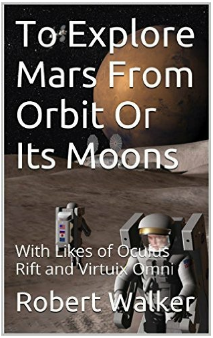
But a human expedition might well capture the public imagination and so permit a much faster exploration of Mars from orbit. And would be an exciting and fun expedition to follow, and interesting for the crew too.

As a later mission you could then go on to explore Phobos and Deimos. They have many advantages for exploration. For instance Phobos has meteorites and micrometeorites throughout its surface layer of regolith, from the entire history of Mars, back to when Phobos first formed or was captured. This probably includes meteorites from the time when Mars had global oceans and then later on, lakes. Our Mars meteorites on Earth all left Mars no more than twenty million years ago (because the terrestrial planets clear their orbits so NEOs have to be replenished over a twenty million year time period).

Deimos also has a Mars facing crater which helps protect it from cosmic radiation, and solar storms - Mars obscures it from the sun in its local daytime, except for a few hours a day. Deimos may well have ice too, as it is related to a type of asteroid that often does have ice in its constitution.

There are many other advantages and points of interest of Mars' two moons.

For more on this, see my:



[Exploring Mars By Telepresence From Orbit Or Phobos And Deimos]

WHAT ABOUT HUMANS ON MARS LATER ON?

We could decide what to do later on, based on what we find out. If we find that there is some vulnerable early RNA based life on Mars for instance, I think that public opinion might well swing in the direction of saying we need to go slow here, and study it first before doing anything that could make it extinct on Mars. The scientists would be on the TV talking about how exciting it is, and I think nearly everyone would soon understand the importance of what we had found.

In the other direction, there might be other findings that show that microbes would have minimal impact on Mars. For one example, suppose that none of the proposed habitats turn out to be habitable for Earth life? I think that's an unlikely scenario myself, and it would be a disappointment for exobiologists, but it's a possible future as of writing this.

Or maybe new technology gives us the capability to send humans to Mars in a biologically reversible way. Again, it's hard to see that with present day technology, at least not for an interesting mission for the humans involved. But the human in a metal sphere idea shows that it is at least possible in a minimal rather uninteresting way.

Could there be some other more flexible and more interesting ways to achieve the same thing? I can't imagine how that would happen but there are many technologies today that I couldn't even imagined in the 1960s when I watched the Apollo landing on the moon on TV as a child of 14. Indeed right up to not long before the landing, the science fiction writers never imagined that it would be watched on global TV as it happened. So sometimes your ideas about the future can be upturned like that, suddenly, in just a couple of years.

If you have any other ideas for biologically reversible human exploration of Mars, do share in the comments!

WHEN WILL WE KNOW ENOUGH ABOUT MARS?

I don't think we can answer this at this stage. It's asking us to predict future science. You can't know what direction it will go and what we will learn about Mars. So it can't be timetabled.

Let's take it step by step, and send humans to the Moon and asteroids and Mars orbit first, and make the next decision based on what we find out from that first phase.

The main thing right now should be not to close off future possibilities. If we make that decision in the future, it will be an informed decision.

We wouldn't know Mars completely, as that would take for ever. We don't understand Earth completely yet. But we'd know a lot more about Mars than we do today.

We need to leave it to our future selves or descendants to evaluate what they know then, and to decide whether they know enough yet to make this decision. I think that with the rapid pace of science, you can only foresee the future perhaps 10 or 20 years ahead in detail, and even on that timescale, surprises are likely.

PRECAUTIONARY PRINCIPLE AND SUPER POSITIVE OUTCOMES

The main principle here is that we should advance by increases of knowledge until we have sufficient to make informed decisions, rather than use ignorance of conditions on Mars, in the Europan ocean or anywhere else to justify sending humans there. For me that's not a strong enough justification for landing on Mars if there are significant unanswered questions about whether it could cause problems.

It's similar to the Precautionary principle guideline in International Law

> "When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically.
>
> "In this context the proponent of an activity, rather than the public, should bear the burden of proof.
>
> "The process of applying the Precautionary Principle must be open, informed and democratic and must

include potentially affected parties. It must also involve an examination of the full range of alternatives, including no action."

I suggest we should have similar guidelines for super positive outcomes - things of overwhelming positive value that we could discover:

"When an activity impacts on a super positive outcome, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically.

"In this context the proponent of an activity, rather than the public, should bear the burden of proof.

"The process of applying the Precautionary Principle must be open, informed and democratic and must include potentially affected parties. It must also involve an examination of the full range of alternatives, including no action."

So I'm not saying we should never land there. But that if we do, it has to be on the basis of knowing clearly the consequences of our actions and public debate and open and informed democratic discussion of whether we should do it.

But to have informed public discussion, first we have to know what is there. For that we need an explore and discover first approach before making any irreversible decisions such as whether to introduce Earth life to a planet.

For more about this see my "Super Positive" Outcomes For Search For Life In Hidden Extra Terrestrial Oceans Of Europa And Enceladus

SUMMARY OF THE VISION

Here are some of the main points again, to review some of the material covered above:

- **The Moon is turning out to be far more interesting than most realized**. We are at the same stage there as the very first Antarctica explorers, setting foot on a continents sized land mass that we know little about first hand.
- **So we have to be careful when exploring Mars,** also Europa and Enceladus and anywhere likely to have alternative exobiology. Why start our new phase of human exploration in space by sending humans with our microbe hitchhikers to the one place in the inner solar system that is most vulnerable to introduction of Earth microbes?
- **Robots and humans work well together**. Our robots are our collective sense organs in the universe, and they can go to places humans can't go.
- **We have potential for superpositive outcomes of great value for humanity from the search for life in our solar system** from discoveries of origins of life, earlier forms of life, or alternative exobiology. And life on Mars can be vulnerable to Earth life.
- **So we have to be careful when exploring Mars,** also

Europa and Enceladus and anywhere likely to have alternative exobiology. Why prioritize a mission with our microbe hitchhikers to the one place in the inner solar system that is most vulnerable to them?

- **Space development can be of great benefit to Earth** through new discoveries, also moving heavy industry into space, providing solar power from space etc.
- **Most successful colonization of Earth has been of places already occupied by humans**, for the last thousands of years and there have been many failed colonizations. If you focus just on the ones that succeed you get only a partial picture, which may be over optimistic.
- **Mars is far more like the Moon than it is like Earth**. It's more inhospitable than deserts and Antarctica and we don't colonize those places.
- **So, I think that space settlement in early stages at least would be like an Antarctic base** - where you are there because you are doing something of value to Earth.
- **Yes we might get future tech that lets us build self sufficient habitats on Mars.** But before then we'd be able to reverse desertification, build self sufficient sea colonies far more easily than on Mars, and do many other things.
- **Yes, we can build human settlements in space using resources from space.** But the reasoning of the 1970s

is still valid - that the most abundant and easiest resources to access in space, are those on the Moon and in the asteroids.

- **Settlements on the Moon or using materials from the asteroid are likely to be easier to support economically** - it's much easier to export materials, to sell on Earth.
- **We don't yet know how humans tolerate artificial gravity, or what the gravity prescription is** . The problem is that though we can simulate the physics easily, we can't simulate the human body, but can only find out with experiments in space.
- **We haven't yet attempted a self sufficient habitat in space.** Several ground experiments suggest it may be possible, but though this works on the ground, this has not yet been tested in space.
- **So before developing grand visions of the future of humans in space, we need to look closely at those two points**. And do them in a location where we can do it safely. The key to Apollo was to do things on a step by step fashion, first showing that humans can survive a few days in zero g, which was not known at the start of the program, then building up to longer and more demanding missions. What we do next may depend on what we find out in the process.
- **We are bound to have fewer people in space than on Earth** in the near future. It doesn't matter how valuable

the materials are that are returned from space, what matters is how many people on Earth are needed to support you there.

- **Earth is the best place for a backup** and to rebuild civilization for those that worry about end of the world disasters. That's because no disaster could make Earth as uninhabitable as Mars, the Earth surface is much better protected from cosmic disasters than Mars, and some humans would survive anything that is likely to happen.
- **As for self created problems, again we can't escape from them in space**. In my view again, if technology is our problem, escaping into space to set up an even more highly technological society is not likely to be our solution.
- **A future with large numbers of humans in space with high technology is not necessarily the best thing to aim for**. You can't restrict it to just the "good guys" whoever you think they are if you have millions in space.
- **Space settlement is neutral just like settlement anywhere - could be good or bad.** It could be hugely positive if done well. It could be very harmful if it goes wrong. And the details of how we do it could swing it either way.
- **Mars has turned out to be a much more likely habitat for present day life than previously thought** Though it

is so cold and inhospitable for humans, and extremely dry, yet it may have habitats for microbes and even lichens capable of surviving in extreme conditions.

- **It is tricky to explore places with life without introducing Earth life.** We are still figuring out how to explore the subglacial lakes in Antarctica, and wouldn't send humans there.
- **A human crash on Mars putting debris all over the planet would introduce Earth microbes and has to be avoided**. We don't yet have the technology to build 100% reliable spacecraft, and even a 1 in 100 chance of a crash, which some volunteers might be willing to take on as a personal risk, is far higher than the 1 in 10,000 probability that's often used for planetary protection.
- **There is no urgency to send humans to the Mars surface**. Even if we send humans there, it is best to understand Mars better first. The best way to do it for planetary protection is to send robots, either controlled from Earth or from Mars orbit.
- **It is not at all clear that we can terraform Mars**, and if it is possible, with current technology, it's a thousands of years, or perhaps a 100,000 year megatechnology project. Are we confident that this is what our descendants a thousand years from now will want us to do for them? With our clumsy early attempts, we may close off future options for Mars that our descendents would prefer.

- **Introducing life to Mars as a result of a human crash or landing on Mars is likely to be biologically irreversible.** You could create a new geological era on Mars, marked by the presence of Earth lifeforms brought to the planet by twenty first century humans. Introducing Earth life before you study Mars in depth is closing off options for the future. While keeping it free of Earth life leaves all your future options open.
- **We can do a lot more in situ exploration of Mars from Earth than we can currently.** The main bottleneck at present is not the light speed time delay, but the bandwidth.
- **The search for life on Mars is also best done in situ at present.** It is more practical, can study many different regions at different depths over the rover's exploration region, and we do have many space capable instruments now for sensitive searches for life in situ, which we didn't have as recently as a decade ago.

  We don't have any prior experience of containing exobiology returned from another planet in our labs. It will be much easier to do this safely if we know what is there first, at least in a preliminary way.
- **Then humans in Mars orbit would be an exciting mission**, psychologically good for the crew, like orbiting in the ISS but above another world. Controlling avatars on the surface via telepresence, with binocular

vision, binaural sound if you like, haptic feedback, and digitally transformed vision so you can experience the surface with bright colours as if lit by a midday sun, even a blue sky if you like.

- **As for exploring a galaxy, robots are far safer.** We should start with robots and think very carefully before considering setting up new colonies of humans. Because uncontrolled self replication is an issue in the galaxy whether the self replicators are robots or humans.
- **Generally, sending humans into space is something new, that humans have never done before.** We are capable of making mistakes, even huge ones, and this could even cause our extinction. Or it could have hugely beneficial consequences. We need to be able to look ahead and need to be adaptable.
- **Grand plans such as terraforming ideas, and ideas for ways that humans might be able to survive on Mars long term are well worth studying** as we find out more about how planets work, learn about other potential futures for Mars, may help with studies of exoplanets, and help us understand how Earth works, and it may have many other benefits. Many of the ideas will be of benefit early on for robotic exploration and human missions closer to Earth. But anything that closes off other options for all future time needs to be approached with caution at this stage, until we know more about Mars.

- **For all these reasons our human and robotic space exploration strategies should be open ended and capable of being changed quickly and easily based on new discoveries.** They should also involve long term future thinking to avoid mistakes that we could make by rushing in "where angels fear to tread".
- **The best place to start surely is the Moon and the Earth Moon system** - where we know that we can do it, with minimal risk of contamination, and the maximum of safety for humans.

SO MANY EXCITING NEW THINGS TO DO IN SPACE WITH THIS VISION

We have so many other things humans can do in our solar system, apart from the usual objective of colonization and boots on Mars. Including exploring the Moon, asteroids, Venus, Mercury, Jupiter's Callisto, Mars from orbit and its two moons, maybe even further afield. Plenty to sustain interest.

If the aim is just to "land boots on Mars / Moon / Venus / Mercury / Callisto" I think our space explorations will be short lived as they were for the Moon. And I happen to think that attempts at colonization would be short lived also, as they run out of funds, and can no longer get people from Earth to support their expensive attempts to live in places with a near vacuum, where they have to create all their own oxygen to breathe, etc etc, and many of their needs, can only be met by supplies sent to them on rockets.

While settlement in space supported because of their benefits to Earth, and accompanied by robotic explorers finding out new things about our solar system, would grow and grow. Look at how much interest there is in Curiosity, the Dawn mission, Philae the comet lander, and the New Horizons mission to Pluto? And there's no sign that any country wants to pull out of scientific exploration of Antarctica.

We need some longer term positive vision, and what I outlined here is a suggestion for first steps towards an alternative to the usual colonization motivation.

GOING INTO THIS WITH OPEN EYES

The main message is that whatever we do, with Mars, we should do it as a choice, not as an accident. We shouldn't just have a human occupied ship crash on Mars, and then say *"Oops, we have now introduced Earth life to the planet"*. The main thing is not to just jump off a cliff into the sea with our eyes shut and hope for the best. We need to understand what we are doing and to go in with open eyes.

So, then if we hold back from sending humans to Mars, this leaves all our options open. We can always send them next year, or ten years later, or fifty years or a century later. Mars will still be there. But if we send microbes to Mars in an irreversible way, this closes off many futures. For instance, maybe we want to introduce particular microbes to Mars only, maybe only methanogens, or methanotrophs, or photosynthetic life. Maybe we want to keep the predatory secondary consumers away from Mars until much later.

Or maybe we have an opportunity to set aside Mars for the Martians. There's plenty of material in the asteroid belt for human habitats. But perhaps on Mars we have the opportunity to restore an early Mars like early Earth, with pre-DNA life on it. Imagine how wonderful that would be. Or some alternative biology not based on DNA at all. Maybe that is one of the futures we would be closing off - to have an exoplanet in our own solar system, which has ETs on it, even if they are just microbial or lichen like ETs, with a totally different biology from Earth life.

When we have a choice that closes off futures for an entire planet, or for some vulnerable habitat, or unique form of life, I think we need to look long and hard at that choice. And whatever we do, we shouldn't do it just through carelessness, by accident, or without thinking through the consequences.

While when our choices are open ended and open out more and more future possibilities, as exploring the Moon seems to do, then that's a way forward that we should encourage and walk into with open eyes. We can follow a path like that with a sense of wonder indeed!

IS THIS A POSITIVE VISION?

This is work in progress, and I'm interested to hear whether you think it is a positive vision for the future. Or is there anything else that could make it more positive? It might well be missing something that I just haven't seen yet.

Also do share your own visions for the future too.

And - what do you think about "boots on Mars"? Do you think there's a chance we will find a way to land humans on Mars compatible with planetary protection and preserving its interest for science? Or is this likely to be impossible? What about a crash on Mars, how does the potential for that change the situation?

Should we explore Mars in a biologically reversible way until we understand it better? If so, can you think of any way that could be done with humans on the surface, or should they remain in orbit?

Some think we should just land humans on Mars anyway. That we should do our best we can to study it scientifically first, and then, whatever the state of science, once the technology is there to land humans, forget about planetary protection and just land humans, taking the best precautions we can in the circumstances.

Is that your view? If so do say so. Don't be shy. I'm interested to hear all views on the topic.

AIM TO STIMULATE DEBATE

The main reason for writing this is to stimulate debate on these topics, and to help make sure the debate is done with an informed background.

What do you think about these ideas? Do say in the [comments on the online article]() - or you can start a discussion on the kindle booklet page.

Also if you see any errors at all, whether typos, or more fundamental errors, please don't hesitate to let me know or say so in the comments. Thanks!

SEE ALSO

- TheSpaceShow Broadcast 2663 Dr. Catharine (Cassie) Conley: Topics: Planetary protection
- TheSpaceShow Broadcast 2660 Robert Walker: Topics: Planetary protection and human spaceflight to Mars
- Why We Can't "Backup Earth" On Mars, The Moon, Or Anywhere Else In Our Solar System
- Will We Meet ET Microbes On Mars? Why We Should Care Deeply About Them - Like Tigers
- No Simple Genetic Test To Separate Earth From Mars Life - Zubrin's Argument Examined
- Can You Suggest A Second Earth Apart From Mars?
- Does Earth Share Microbes With Mars Via Meteorites - Or Are They Interestingly Different For Life?
- Are There Habitats For Life On Mars? - Salty Seeps, Clear Ice Greenhouses, Ice Fumaroles, Dune Bioreactors,...
- Could Microbes Transferred On Spacecraft Harm Mars Or Earth - Zubrin's Argument Revisited
- Asteroid Resources Could Create Space Habs For Trillions; Land Area Of A Thousand Earths
- To Explore Mars With Likes Of Occulus Rift&Virtuix Omni - From Mars Capture Orbit, Phobos Or Deimos
- "Super Positive" Outcomes For Search For Life In Hidden Extra Terrestrial Oceans Of Europa And Enceladus

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CASE FOR MOON - FACEBOOK GROUP

I've made a new facebook group which you can join to discuss this and other visions for human exploration with the Moon first, and with planetary protection and biological reversibility as core principles.

When I founded it, to discuss the approaches outlined in Case for Moon, I was so surprised that I couldn't find any other group on facebook for discussing Moon first approaches to humans in space, although it's easy to find groups for discussing colonizing Mars.

So, as the group description says, it's for anyone interested in a Moon first approach. With the vision in Case for Moon as one of many.

[Case for Moon for Humans - Open Ended with Planetary Protection at its Core]

OTHER RESOURCES

You may also be interested in [Moonwards], Kim Holder's Virtual Moon Colony project, to explore a vision of what a focused drive to settle the Moon could create. [Listen to her] talk about it on the Space Show.

If you know of any other good groups or websites focused on Moon first ideas, or on exploration of our solar system with planetary protection as one of the core values behind the exploration, do say and I'll add them in.

CHANGE LOG

16th April

- Added new section ***WHERE TO BUILD OUR FIRST LUNAR BASE FOR HUMAN***S. covering bases in the lunar caves and the poles.
- Added image of the ESA lunar village in the ***POSITIVE VISION FOR HUMANS IN SPACE*** section.
- Added launching pad robot idea to the Lunar Glass section.
- Added mention of Buzz Aldrin's 2009 Mars first views, and the views of the Space foundation and ROSCOSMOS to ***THE MOON IS TURNING OUT TO BE MUCH MORE INTERESTING THAN EXPECTED*** section.
- Added information about the LEND results and caution about the indirect detection for the 600 million metric tons figure to the section ***VOLATILE RESOURCES***

17th April

- Added Buzz Aldrin quote from Mission to Mars. I'm not sure though what to make of this article about his latest "No dream is too high"? I've ordered the book and will update the article if he has changed his views again. If anyone knows for sure do say!

18th April

- Added link to Ice may lurk in shadows beyond Moon's poles (Nature, 2012) about the possibility of regions of permanent shade with ice below the surface down to 58 degrees from the poles to the section ***VOLATILE RESOURCES***. Replaces statement suggesting ice may be possible in caves at lower latitudes. I think that was just a mistake - as the temperatures inside the caves seem to be far too high for ice - unless perhaps below those permanently shaded regions? Also added link to the article Peaks of Eternal Light in the online NASA astrobiology magazine. for information about the temperatures of the peaks of eternal light, to ***EARTH LENGTH DAY ON MARS VERSUS ADVANTAGES OF CLOSE TO 24/7 SOLAR POWER AT THE LUNAR POLES***

19th May

- Added executive summary
- General copy editing.
- Changed some section titles
- Added sections on Thorium, The romance of space, Robots and humans together, Meanwhile in LEO - sustained research into human factors

20th May

- More copy editing
- Added video with 600 meter tether for lunar gravity to Meanwhile in LEO - sustained research into human factors
- Added two new sections: International co-operation and role for China - USA policy and ESA, Russia and China

21st May

- More copy editing
- New quote for the section International co-operation and role for China - USA policy
- New sections Space assets and strategic, economic and military significance of space and This booklet outlines one particular vision of many

22nd May

- More copy editing
- New section Earth best for a "backup"

23rd May

- More copy editing, with some more cites and a bit of new material also
- Added a new section Solar cells from lunar materials, Possibility of using lunar solar power for Earth, and Other Moon - Mars comparison

24th May

- More copy editing
- Added Geologically active moon, Using the Moon to build habitats in free space, Expect the unexpected, Mars or Moon spectacles and the old woman young woman illusion, Going into this with open eyes, and We are like the early Antarctic explorers.