A Radically Easier Path to Space Settlement

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Very smart and capable people have been dreaming about space settlement for decades, but these dreams have not come to fruition. Why? Because building space settlements is extraordinarily difficult. There are two ways to overcome this: a lot of money or an easier way. An enormous pile of government money doesn't seem to be headed our way, but it turns out there is a much easier way.

The location of the usual space settlement suspects includes the Moon, Mars, asteroids, and the Earth-Moon L5 point (or other high Earth orbit). They all suffer from one very serious problem: they are very far away, anywhere from 363,000 to 400,000,000 km from Earth. This makes everything we want to do extremely difficult.

All space settlements need pressurized habitat, power systems, thermal control, communications, life support, materials recycling, and radiation shielding. As radiation levels in space are high compared with Earth, the mass of the radiation shielding completely dominates the mass of most space settlement designs because inadequate shielding can lead to cancer, cataracts, and sterility. In orbits beyond Earth's magnetic field, radiation protection requires about seven tons of water, or eleven tons of lunar regolith, per square meter of hull and a little bit less on the surface of Mars or the Moon[1]. This amounts to millions of tons of material for a settlement big enough that people might actually enjoy living in it once the excitement of moving to space wears off, perhaps 100 m across at least. If the radiation shielding was not needed space settlement would be a vastly easier.

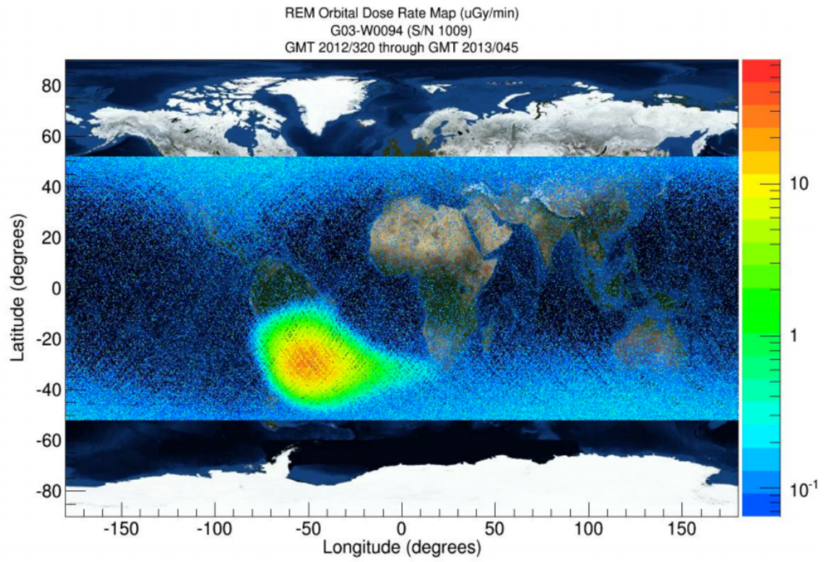

Figure 1. Radiation measurements taken on the ISS (International Space Station). Note the very low levels (blue) near the equator, which is on the horizontal line starting at 0 on Latitude scale. Image credit NASA.

It is our incredibly good luck that there is a region of space, very close to Earth, where radiation levels are much, much lower than at the usual suspects. This is Low Earth Orbit (LEO) directly over the equator (or ELEO) see figure 1. The Earth's magnetic field protects this region from all but a small fraction of space radiation, albeit the most energetic part. Radiation levels are so low that below about 500 km it is possible, even likely, that no dedicated radiation shielding will be necessary[1]. This means that a 100 m diameter cylindrical settlement in ELEO might have a mass of around 8.5 kTons[2], hundreds of times less than above the Earth's magnetic field. This entire mass could be launch by about 160 Falcon Heavy launches. This is not for a few capsules connected by tunnels, but an open living area comparable in size to a large cruise ship with zero-g recreation at the axis of rotation, full 1g pseudo-gravity just inside the hull, and recreational space walks.

Figure 2. Artist concept of a small early space settlement. Note the curvature necessary to generate pseudo-gravity by rotation. Image credit Bryan Versteeg.

If you are familiar with free space settlement issues you might object that to get Earth-normal pseudo-gravity with a 100 m diameter you need to rotate a settlement at about four rpm (revolutions per minute), which will make many people sick. That is true, but it is also true that people adapt to rotation at four rpm within a few hours or days and are subsequently

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[1] "Orbital Space Settlement Radiation Shielding," Al Globus and Joe Strout, preprint, June 2016. http://space.alglobus.net/papers/RadiationPaper.pdf This contains data and references for radiation related claims in this article.

[2] "Space Settlement: an Easier Way," by Al Globus, Stephen Covey, and Daniel Faber, June 2016. http://space.alglobus.net/papers/Easy.pdf This contains data and references for settlement related claims in this article.

just fine[3]. If you were to move to Nepal you would be altitude sick for a few days, but Nepal is still a beautiful place to live.

You might also note that most Mars/Lunar settlement schemes involve putting a module on the Martian/Lunar surface with far less than 160 launches. But that's for a module a few meters across, similar to vehicles that have been in LEO off and on since the 1960s and much smaller than the ISS which has been continuously inhabited since 2000. For a given size, the total mass of the material needed from Earth for early ELEO vs Mars/Lunar settlements is about the same. Low radiation levels in ELEO mean settlements there require little or no radiation shielding. Although radiation levels on the Martian/Lunar surface are high, about half that in free-space, local materials can be used for radiation shielding. However, Mars/Lunar residents will rarely leave their habitat due to the radiation and LEO development will continue to be far ahead because LEO is at least 100,000 times closer than Mars and 720 times closer than the Moon giving ELEO a massive logistical advantage.

While space settlement may be vastly easier to get started in ELEO than anywhere else, it is still a massive task. Launch vehicle prices need to come down by a factor of perhaps 50[1], reliable nearly-closed large-scale life support must be developed, and a million engineering problems must be solved so that people can live comfortably, safely, and enjoyably in space. Absent a gigantic pile of government money, how can this been done? One word: tourism.

Tourism can supply the two things essential to market-driven equatorial LEO settlement development:

1. A very high flight-rate to make fully reusable launchers economically viable. We estimate at least > 10,000 flights per year is needed, compared to < 100 today.
2. A market for ever larger and more sophisticated space hotels starting with the ISS.

Seven paying tourists have flown to the ISS (one twice) on a 7-10 day trip, but right now no seats are for sale. Rumour has it that the first few space tourists paid about $20 million and the most recent flight was on the market for $50 million. While this is discouraging (the price is absurdly high and headed in the wrong direction) surveys suggest that if someone could drop the price a bit, much larger numbers of people would want to go.

The good news is that the best advertised price to fly to LEO so far is $26.25 million, although the vehicle is still in development. If this is successful and makes a profit, as more flights are booked economies of scale can reduce the price, which in turn increases the size of the market, which enables a reduction in price, which increases the size of the market … and so on. We need to get on this virtuous spiral of dropping costs leading to bigger markets leading to lower cost. If the cost is low enough the market is measured in millions of customers per year[2], which is the sort of market needed for the kind of low-cost high-flight-rate transportation system necessary to settle space regardless of destination.

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[3] "Space Settlement Population Rotation Tolerance," Al Globus and Theodore Hall, preprint, June 2015. http://space.alglobus.net/papers/RotationPaper.pdf This contains data and references for human response to rotation claims in this article.

All those tourists need somewhere to go, meaning we will need space hotels. The first ones may be small to keep up-front costs down but if space tourism is successful the desire for bigger, more sophisticated, and more comfortable hotels could drive constant improvement.

As luck would have it, most of what is needed for ELEO settlements is also important for hotels: recycled air, water, and food, power systems, communications with Earth, etc. Hotels may even want artificial gravity, achieved by rotation, so that guests need not learn how to use a 0g toilet -- which is difficult and, when you screw up, disgusting as everything floats around and gets into places you would rather it not. Also, staff can have longer tours of duty, reducing transportation costs, as their bodies will not be continuously subject to weightlessness, which can cause a number of problems[3]. Once hotels have developed most of the necessary technology and supporting infrastructure, building the first space settlement should be not much more difficult than building another hotel.

The first settlement in ELEO might look something like Kalpana Two:

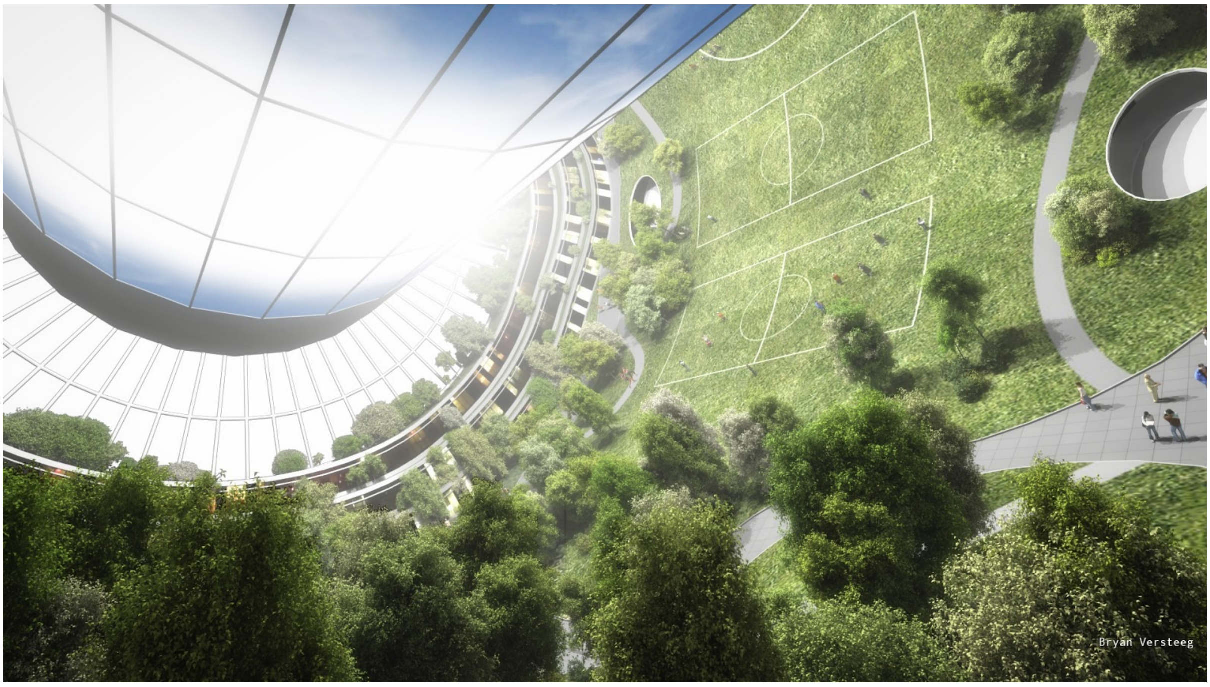

Image credit: Bryan Versteeg.

In an internet survey of space enthusiasts, 30% of respondents said they would very much like to live in Kalpana Two in ELEO, including raising their children, and are willing to spend 75% of their wealth and lifetime income to do so. That’s enough to get space settlement started.

Although building Kalpana Two after a few decades of space tourism development may be much easier than starting from scratch, it is still a monumental effort requiring a great deal of money and those funds will be easier to raise if Kaplana Two and later settlements have a mass-market product to sell to Earth.

Kalpana Two residents could assemble and test extremely large communication satellites, much larger than those launched today. Large comsats are attractive because the larger the spacecraft antenna and the larger the power-producing solar arrays the smaller the antenna on the ground must be and the less battery power is needed, two things for which there is a large and growing market. ELEO is also a good place to manufacture ultra-light solar sails, as the sails need not be folded into a fairing, launched and unfolded. While the market for solar sails is small, if you cover one side of the sail with power-producing electronics you have extremely light power arrays[4] which can be used for large comsats. Put fiber lasers on the other side of the sail and you can beam power[4], first for in-space applications, such as power for Kalpana Two, and later to deliver power to Earth -- a gigantic market.

The first equatorial LEO settlement is the hardest to build. The second and subsequent ones will be easier because lessons will be learned and infrastructure developed. We estimate there is room for at least a few million people spread out in a few hundred settlements in equatorial LEO[2]. This can provide the key requirement for commercially viable lunar and asteroid mining: a decent sized market in space. It is hard for extraterrestrial materials to compete on Earth due to transportation costs. However, in space lunar and asteroidal materials have the edge due to high launch costs from Earth. The problem today is that the in-space market is a single satellite designed for in-space refurbishment (the Hubble Space Telescope) and six people on the ISS, which is tiny. Equatorial LEO settlement is a game changer for lunar and asteroidal mining.

Once the mining infrastructure to deliver substantial materials to equatorial LEO is in operation and ELEO fills up with settlements, it will be time for the next step: settlements in orbit beyond the Earth's protective magnetic field. These settlements will require millions of tons of radiation shielding, which can provide a market for a huge expansion of lunar and asteroidal mining. This, in turn, can provide economic support for mining settlements on the Moon and co-orbiting with asteroids. This network of settlements can then expand to Mars and the asteroid belt. Of course, for Mars and the Moon the problems associated with raising children in partial-g -- including but not limited to growing up with weak muscles and bones -- will have to be addressed.

At this point we will be well on our way to turning the resources of this solar system into living, breathing settlements in huge numbers. The next step, of course, is to send groups of settlements to Alpha Proxima and start the billion-year project of greening our galaxy. After all, if you have lived for 50 generations in orbital space settlements does it matter much if you are close to Sol or on the way to the nearest star? Probably not, at least for some, but that is a task for future generations. Our mission, should we decide to accept it, is to get space tourism on track to develop the technology and infrastructure necessary to build Kalpana Two in equatorial LEO. This tape will not self-destruct.

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[4] "Towards an Early Profitable PowerSat," Al Globus, Space Manufacturing 14: Critical Technologies for Space Settlement, NASA Ames Research Center, Mountain View, CA, October 29-31, 2010. and "Towards an Early Profitable PowerSat, Part II" Al Globus, Ion Bararu, and Mihai Radu Popescu, International Space Development Conference 2011, National Space Society, Huntsville, Alabama, 18-22 May, 2011. http://space.alglobus.net/papers/TowardsAnEarlyProfitablePowerSatPartII.pdf