Storytelling with Uniview #06:
What Makes the Earth Habitable?

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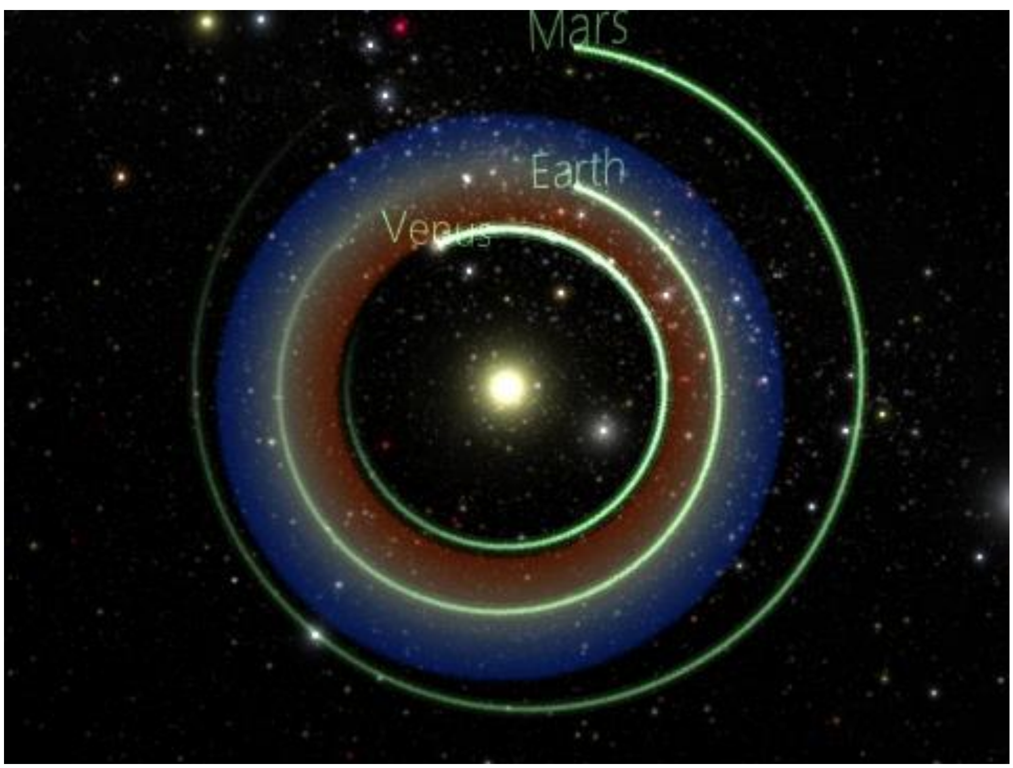
Earth is the only place in the entire universe that we know to have a biosphere. Researchers are interested in whether Mars might have been wet and warm enough to support life in its distant past. Europa and Enceladus, orbiting Jupiter and Saturn, respectively, are cited as interesting places for future exploration because of the strong evidence for subsurface water below their icy crusts. However even if we find evidence that some of these remote worlds are hospitable to some form of extreme microbial life, they are still extremely inhospitable environments to complex life like us. Except for small exploratory expeditions, our home planet is where we are to stay for the foreseeable future.

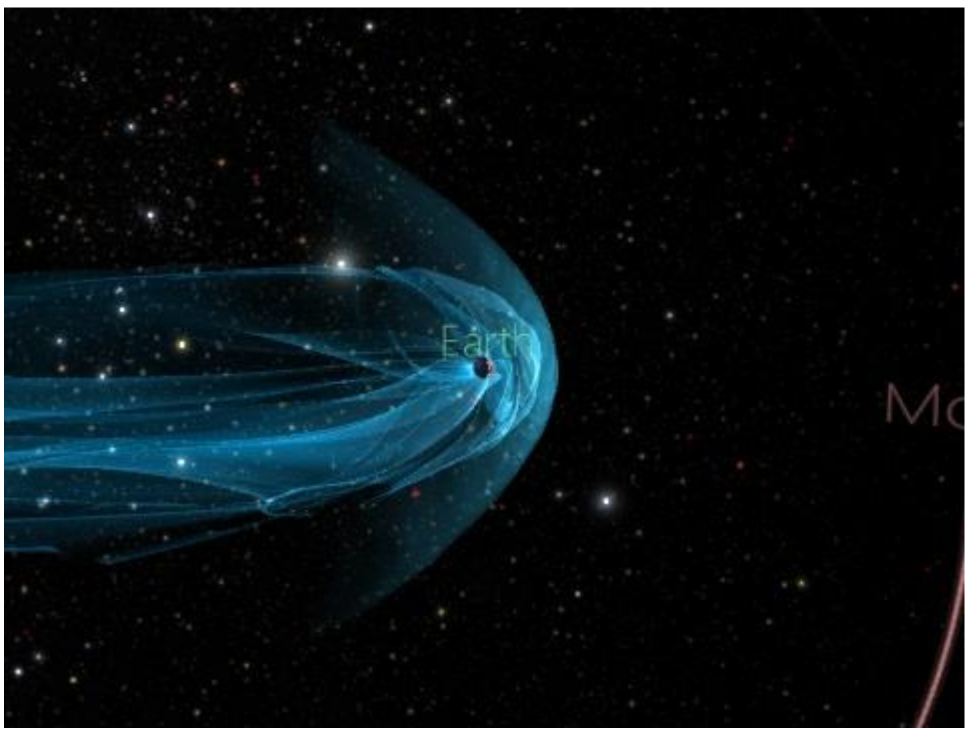
The Earth's biosphere is extremely thin, and is entirely contained within the Earth's atmosphere and hydrosphere. You can point out the thin edge of Earth's atmosphere when you are either close to the surface (with the camera attached to the ISS), or when you are not too far from its surface while the entire disk of the Earth is still visible. To give some perspective about the thickness of the atmosphere, we can use the 6-foot diameter Science On a Sphere as an prop for demonstration. The tropopause—below which all weather on Earth occurs, and which contains 80% of the mass of the atmosphere—is 10 km above the surface. If the Science On a Sphere represents the Earth, that amounts to about 1.2 mm, or the thickness of a dime. The average depth of the oceans is 14,000 feet, or 4.3 km, or half a millimeter at the scale of Science On a Sphere. Since the majority of life on Earth is on the surface of the land (and not high in the air), and near the sea surface, most of the biosphere is crammed into an even thinner veneer.



The water at or just above the surface makes Earth's appearance unique amongst the planets and moons of the Solar System. When you view it in Uniview or Science On a Sphere, the white clouds and blue oceans immediately stand out. Seventy percent of the Earth's surface is covered by water, which is essential to life as we know it. And although the total amount of water pales in comparison to the amounts locked up in the icy moons of the outer planets (or that contained within cometary bodies in the Kuiper Belt and Oort Cloud), it is much more easily accessible. Water falls out of the sky on Earth in liquid and solid form. It pools and collects in rivers and lakes, before running out into the oceans where it becomes less available to us because of the salinity.

The abundance of liquid water is due in part to our planet's distance from the Sun. It is neither too close nor too far; neither too hot nor too cold for liquid water to exist on the surface of a rocky terrestrial planet. If you turn on Solar System→Habitable Zone in the Object Tree in Uniview, you can see Earth orbiting in the center of the habitable zone, while Venus and Mars lie on the outskirts. We have good evidence to suggest that all three worlds were more similar early in the history of the Solar System. However for different reasons, the other worlds dried out, with Venus becoming hellishly hot, while Mars' surface has turned into a cold desert landscape. Only Earth has remained habitable in the past 4 billion years.

The Earth's atmosphere is also crucial for its habitability. It is thick enough that the atmospheric pressure keeps liquid water from sublimating, like it does from the surface of Mars. In addition to being a resource for life's metabolic processes, some of the oxygen high up in the stratosphere is converted into ozone by the Sun's UV radiation. This thin ozone layer protects life below from that same radiation. Since oxygen did not exist before the advent of photosynthesizing organisms, this is an example where later life has taken advantage of a drastic change in the environment by earlier life.



If you turn on the magnetosphere with Earth→Magneto Sphere and Earth→Magneto Bow Shock, you find a protective shield that funnels or deflects charged solar wind particles and cosmic rays from life on Earth. Over the history of the Solar System, Earth's magnetic field has also shielded the molecules making up the atmosphere from collisions with these high velocity particles from space. It is thought that one reason Mars has lost much of its atmosphere (and water) through sputtering interactions with the solar wind over the history of the Solar System is because it lacks a strong magnetic field.

Although not something that can be shown in Uniview on the Orbits Table (but it is possible with Science On a Sphere), Earth's tectonic activity is important for habitability. Its interior heat drives the currents in the outer core to generate the magnetic field. This heat also propels the mantle motions that lead to plate tectonics on the surface. (Small amounts of water locked up in the rock is also theorized to help keep the mantle pliable enough to allow for convective motions. Venus is thought to have dried out so much that plate tectonics is not possible even though it is the same size as the Earth.) Plate tectonics recycle surface crust, and keeps a long-term carbon cycle going over tens to hundreds of millions of years. It is this cycle—where carbon is drawn into subduction zones and re-emitted as carbon dioxide by volcanoes—that has been hypothesized as one way around the "Faint Sun Problem." Early in the history of the Solar System, the Sun was only 70% as bright as it is today, which is not enough to keep the oceans from completely freezing, unless there was much more greenhouse gases in the atmosphere. Back then the habitable zone would have been closer to the Sun than it is today, but we have fossil evidence that water was still liquid on Earth's surface. A long-term carbon cycle might have regulated the atmosphere's greenhouse effect, strengthening it and keeping Earth habitable despite the fainter Sun.

Finally there are a few more esoteric (at least as far as Uniview's ability to show such processes) reasons that have kept Earth's habitability stable over the history of the Solar System. They have to do with gravitational effects of all of the Solar System bodies on each other, with the effects of the largest planet Jupiter dominating. Numerical simulations show that at very long time scales, the orbital parameters of the planets may not be stable, but could change chaotically. Mars' tilt with respect to its orbital plane (its obliquity) can vary due to gravitational interactions with Jupiter and the other planets. Such drastic alterations to the amount of sunlight reaching the surface seasonally could have played havoc on developing life. However Earth was spared this fate because of its large Moon. The combined Earth-Moon system is much more stable to gravitational perturbations.

Do the conditions that make Earth uniquely habitable in our Solar System also make life uncommon in the universe? This is the thesis expounded by Peter Ward and Donald Brownlee in their 2004 book *Rare Earth*, where they cite the conditions outlined here along with many others to show why they think complex (but not microbial) life in the galaxy is rare. Although I am not an astrobiologist, I feel skeptical about broad conclusions about life in the universe based on the single example of life on Earth. We are only just beginning to discover the diversity of planets and the character of solar systems outside of our own. Not only do we not fully understand the evolution of these myriad worlds (which currently outnumber the planets in our own Solar System by more than a factor of 100), but also the particulars of the habitable zones that they may offer to Earth-like as well as completely alien life forms. One lesson that I've learned from the history of astronomy is that nature has consistently found ways to surprise us. We may think it improbable for complex life to evolve on a planet without vibrant plate tectonics, a large Moon, and other factors, but such a conclusion may be based more on the paucity of our own imaginations than having complete scientific information.

Reference

Kasting, J. 2010, *How to Find a Habitable Planet*, Princeton, NJ: Princeton University Press.