OpenSpace

Getting started

System Requirements

OpenSpace is developed to run on multiple platforms, from laptops to Virtual Reality headsets to planetarium domes. Machines with stronger graphics cards and processors have the most success with the software. OpenSpace cannot be run on smaller devices, including smartphones, tablets, and Google Chromebooks.

Basic requirements

- **Internet connection:** Required to download the software
- **Processor:** i5 processor or newer
- **Graphics:** Support for OpenGL 3.3
- **Disk space:** 6 GB
- **Operating System (OS):** MacOS 10.12 or later, Windows 7 or later

For optimum performance

- **Continuous Internet connection:** For updated datasets, additional scenes including globe browsing, and an option of servers
- **Processor:** i9 3+ GHZ or latest intel processor
- **Graphics:** 1080/1080Ti or 2080/2080Ti
- **Disk space**: 50 GB
- **Mouse and keyboard or other controller:** For easiest navigation, we recommend using a keyboard and a mouse with a middle mouse button. OpenSpace also supports game controllers.

Installation

MacOS

1. **For most uses of OpenSpace, download the software from our website.** You can choose to download the application with just the core Digital Universe Atlas content or with additional scenes. Make sure to choose the download link for Mac.

2. **After downloading, run the installer. OpenSpace will be installed in your applications folder.** The installed OpenSpace folder contains everything you need to get started. Make sure you have permission to read and write files in all of the subfolders, or some features of OpenSpace will not work.

Windows OS

1. **For most uses of OpenSpace, download the software from our website.** You can choose to download the application with just the core Digital Universe Atlas content or with additional scenes. Make sure to choose the download link for Windows.

2. **After downloading, unzip the OpenSpace folder and choose where you would like to install.** The installed OpenSpace folder contains everything you need to get started. Make sure you have permission to read and write files in all of the subfolders, or some features of OpenSpace will not work.

Other systems

Users who wish to use OpenSpace for a different platform or who wish to do more with the software can access the source code on our GitHub.

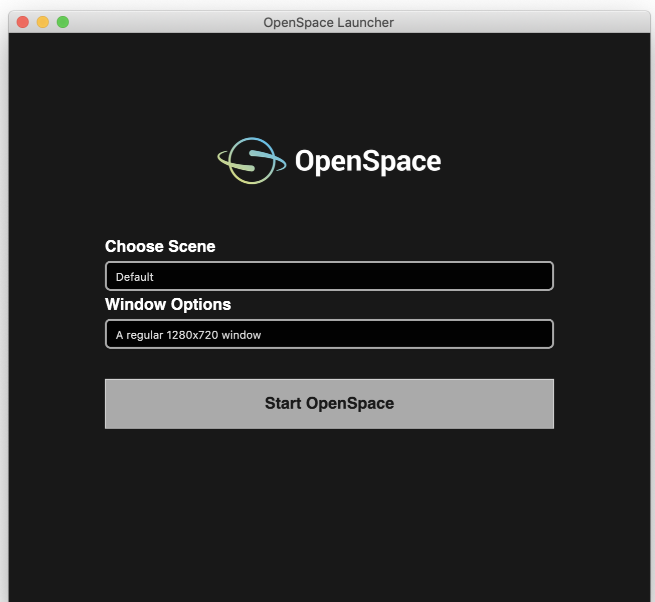
Launching OpenSpace

New with 0.15.0, Windows, Mac, and Linux OS users can open OpenSpace with the OpenSpace Launcher.

1. Within the OpenSpace folder, open OpenSpace Launcher.

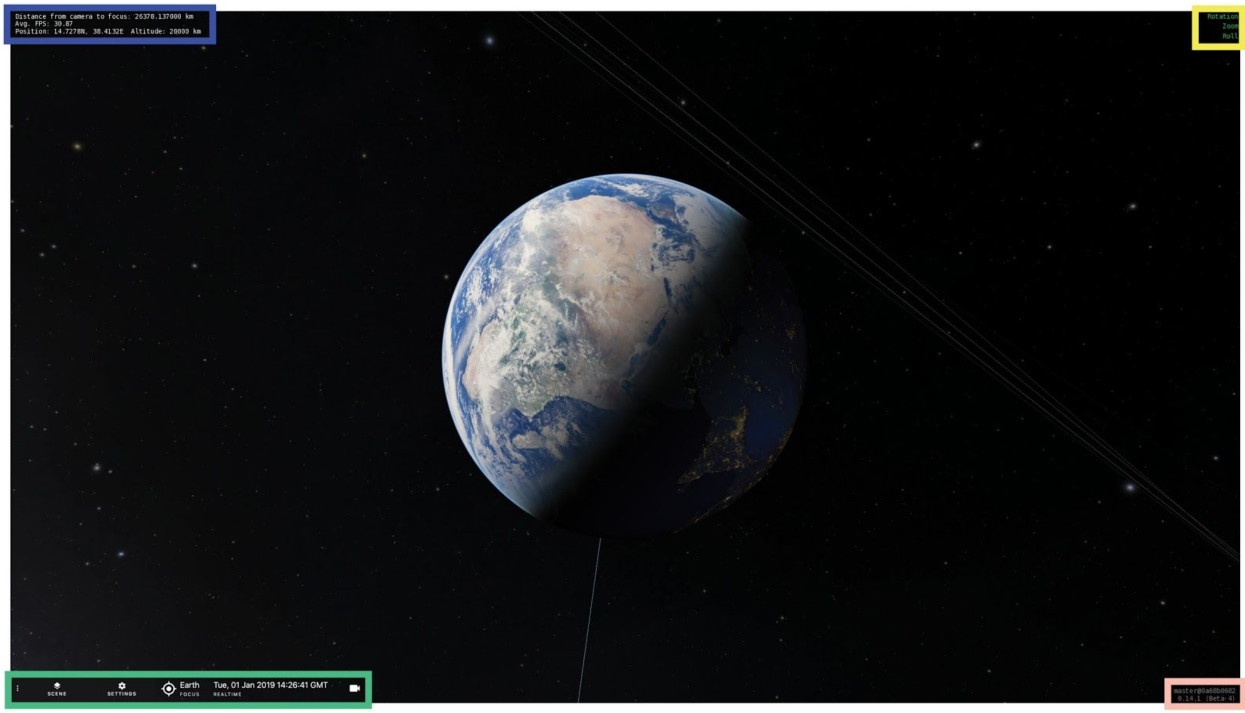
2. A window will open with options for the scene and display output. This will default to your last used selections.

3. Click to select your preferences, and click "Start OpenSpace" to open the software. (This could take several minutes, depending on the speed of your processor and the size of the scene.)



OpenSpace

Interface



When you first launch the default scene in OpenSpace, you will be focused on Earth at the current time and date.

In the top left corner of your window is your **Dashboard.** Hide with Shift + Tab.

By default, this displays:

- **Distance to focus in kilometers**
- **Avg. FPS**: Average frames per second
- **Position**: Latitudinal and longitudinal coordinates of the object in focus, followed by altitude from the object in focus

You can modify this information (including the display font and size) in Settings > Dashboard.

In the top right corner of your window are **Friction Toggles.** Hide with Shift + Tab.

Movements can either stop naturally (with friction) or continue indefinitely (frictionless). This is toggled by clicking on these words or using these shortcuts:

Rotation	f
Zoom	Shift + f
Roll	Control + f

In the bottom right corner of your window is **Version information**. Hide with Shift + Tab.

This information is the current build and version number of OpenSpace you are using.

In the bottom left corner of your window are your **Menus** (also known as Graphical User Interface, or GUI). Hide these with Tab.

These menus, from left to right, will be explored in guides that follow:

- System
- Scene
- Settings
- Navigation
- Time
- Record
- Slides

The basics of flying

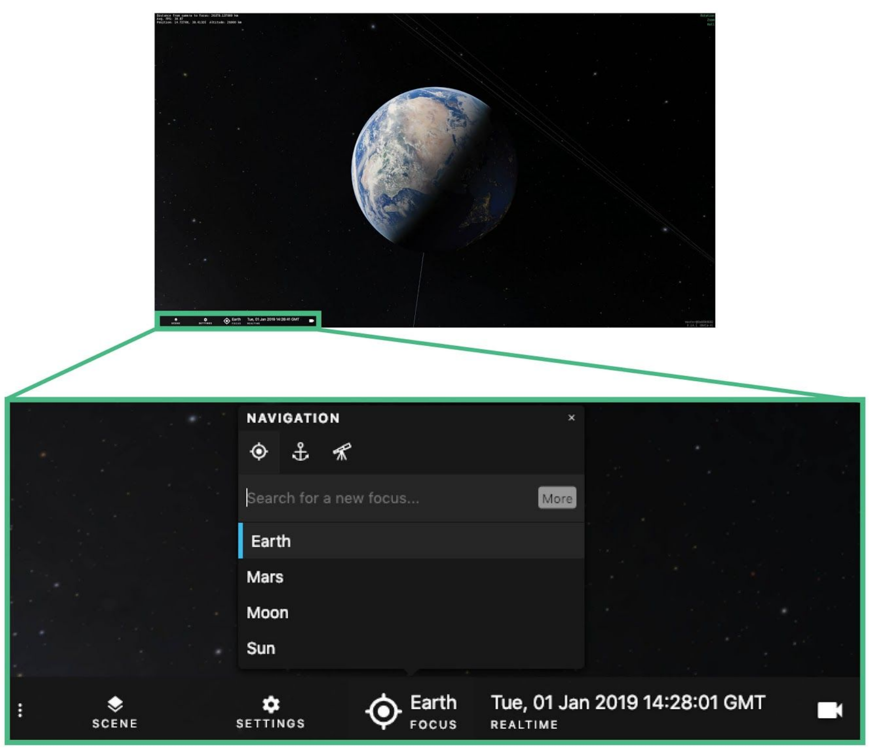
To fly around the universe in OpenSpace, you will focus on an object, such as a planet, moon, star, trail, or satellite. Using a mouse, you move through space with that object as your anchor.

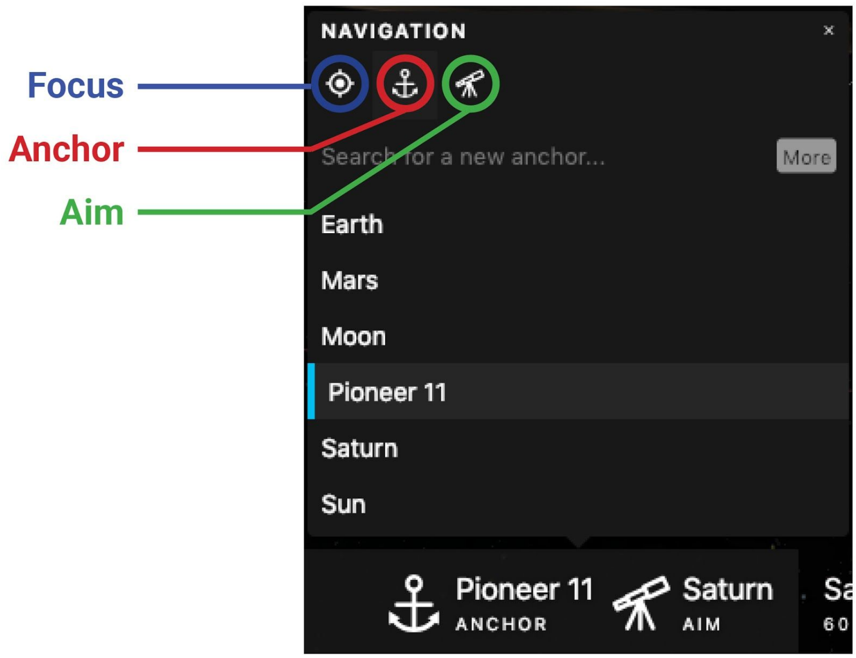
Navigation menu

The Navigation menu in the lower left corner of your screen consists of **Focus**, **Anchor**, and **Aim**, which you can use to change the object in focus. This allows you to set your destination which you can then fly to with Zoom. You can also use these options to set up your view.

When the Navigation menu is closed, it will appear as it does here, with the object name and whether it is the Focus, Anchor, or Aim.

Click on Navigation to open the menu, as shown below. This will bring up options for your Focus, Anchor, and Aim which you can select by clicking on the object name. More options can be accessed with the gray “More” button or by using the search bar, which you click to type into.





Focus

The object in Focus will be at the center of your movement and view. Click on the crosshair icon (circled in blue above) to select your focus.

Anchor and Aim

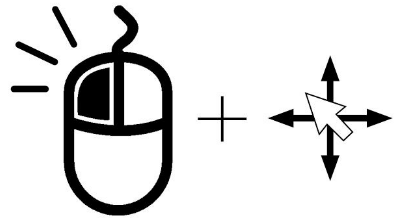
Anchor and Aim are used together. Anchor locks you onto one object, while Aim will direct your view at another object. By selecting an object to Aim at, you will remain locked on your Anchored object while looking at the Aimed object, keeping them both in view. This presents a view that shows the objects in relation to each other, often for dramatic results.

In the Navigation menu, select the anchor icon (in red above) and telescope icon (in green above) to choose the objects to Anchor and Aim.

Moving with your mouse

Rotate

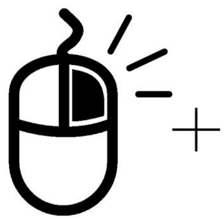
hold the left mouse button
+
move the mouse



Zoom

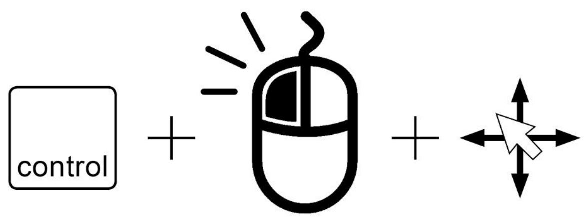
hold the right mouse button
+
move the mouse up or down

To zoom quickly, also hold z.



Pan

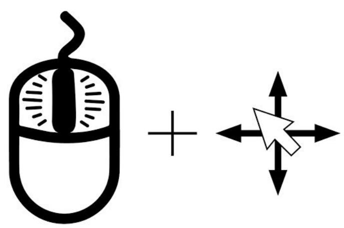
hold control
+
hold the left mouse button
+
move the mouse



Roll

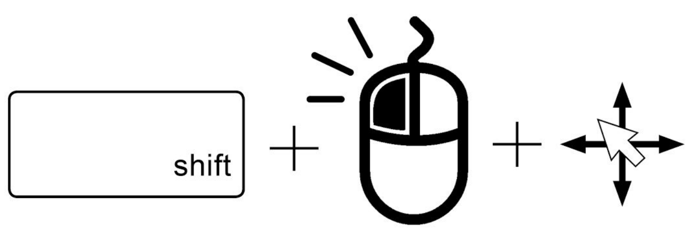
If you have a middle mouse button:

hold middle mouse button
+
move the mouse



If you do not have a middle mouse button:

hold shift
+
hold the left mouse button
+
move the mouse



ASTROBIOLOGY with *OpenSpace*
Public Program Guide

The Search for life in the Solar System and the Search for Extraterrestrial Intelligence (SETI)

using *OpenSpace*

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OpenSpace

NASA

Introduction: This is a general guide for the astrobiology-themed facilitated program using OpenSpace that we have presented at the NC Museum of Natural Sciences. This is not a script or intended as a comprehensive overview of every site, but rather it is a guide to provide some interesting facts on locations that tie together into an interesting and relatable story of how scientists are searching for life beyond Earth. This program illustrates how we can use OpenSpace to explore real mission targets beyond Earth, and shows how our own planet fits into this narrative. I like to emphasize how exploring space, in particular astrobiology-related research, teaches us more about our own planet, the evolution of life, and our place in the Universe.

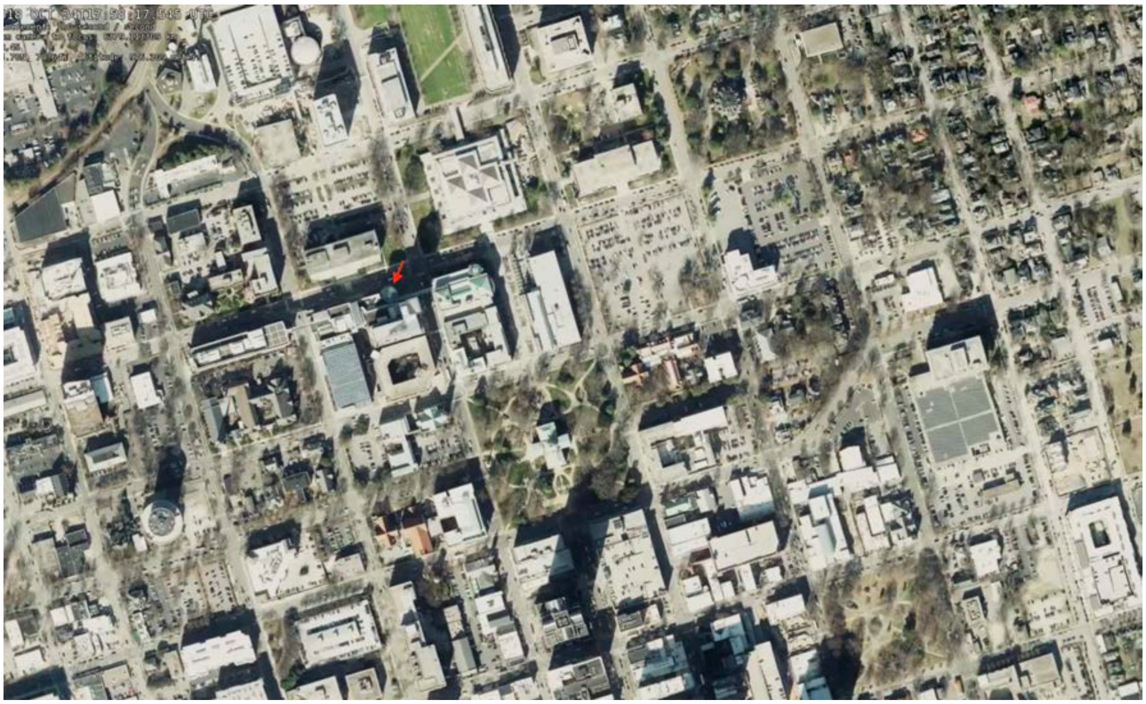
The theme of the first part of the program follows NASA's search for life beyond Earth and "follow the water", i.e. where are the environments where liquid water can exist, and where microbial life survives in "extreme" conditions (termed "extremophiles" or "lovers of the extreme") similar to various locations in the solar system? All life as we know it contains carbon and needs liquid water at some point in its life cycle, so as scientists starting with *what we know*, we consider these two aspects in the search for life. Themes for programs like this can certainly evolve as OpenSpace adds more assets, modules, and functionality, and there are many stories and programs that can currently be created with the software. Any part of this guide can be removed to shorten the program, and for us all of the sites can be done in ~35-40 minutes.

One important note is with OpenSpace we cannot show all regions on Earth that are considered key analogues for searching for life in space, including undersea hydrothermal vents and deep underground mines, both of which are key environments in which extremophiles thrive. However, we can still showcase several sites as examples relevant to current science and NASA missions.

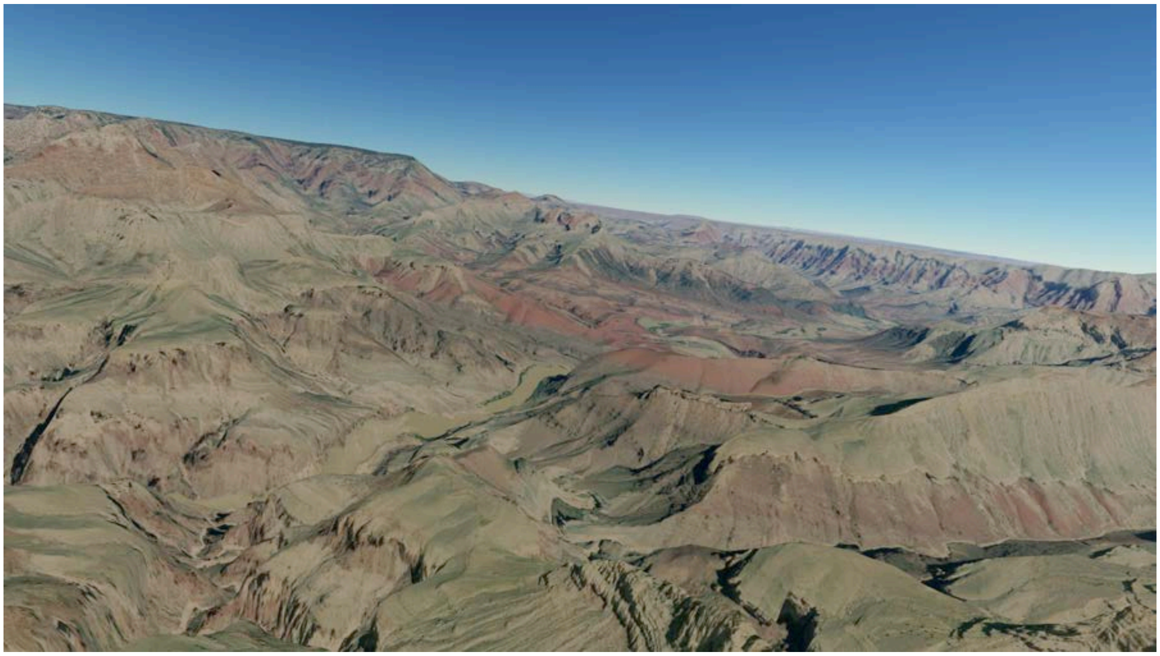
Some general notes and "fun facts" are included for each stop, and with more or less detail included and tailored for the audience or timing. Screenshots from OpenSpace are found within or below each description. A few stops are relatively small and can be hard to find (i.e. Grand Prismatic Spring and Meteor Crater, perhaps), so one way to find them is with Google Maps in satellite view, and then using these maps as a guide for the OpenSpace locations. Also, any location can now be "bookmarked" within OpenSpace for future programs.

Part I: How is Earth an analogue for the search for life in space?

1. **NC Museum of Natural Sciences**: Before launching into astrobiology, I like to start with where we are, which for us has so far been our museum in downtown Raleigh. We can see our Daily Planet theater (Earth globe from the outside) on West Jones Street (noted with red arrow in figure below) with OpenSpace, and from here (or wherever this program is taking place) drive directly to selected locations on Earth.



2. **The Grand Canyon**: Since the program contains various aspects of comparative planetary geology as well as astrobiology, I include a few locations that are both interesting in their own right and can be later compared to other planets; for this program that would be Mars. The first stop is the Grand Canyon, a river valley carved by the Colorado River in the Colorado Plateau. It records the past ~70 million years (exact age is still a subject of debate), and much of the early geological history in North America. The Canyon is 277 miles (446 km) long and 18 miles (29 km) wide. While not the deepest canyon on Earth, it is arguably one of the most spectacular both in visual scale and colorful landscape; compare to Valles Marineris on Mars.



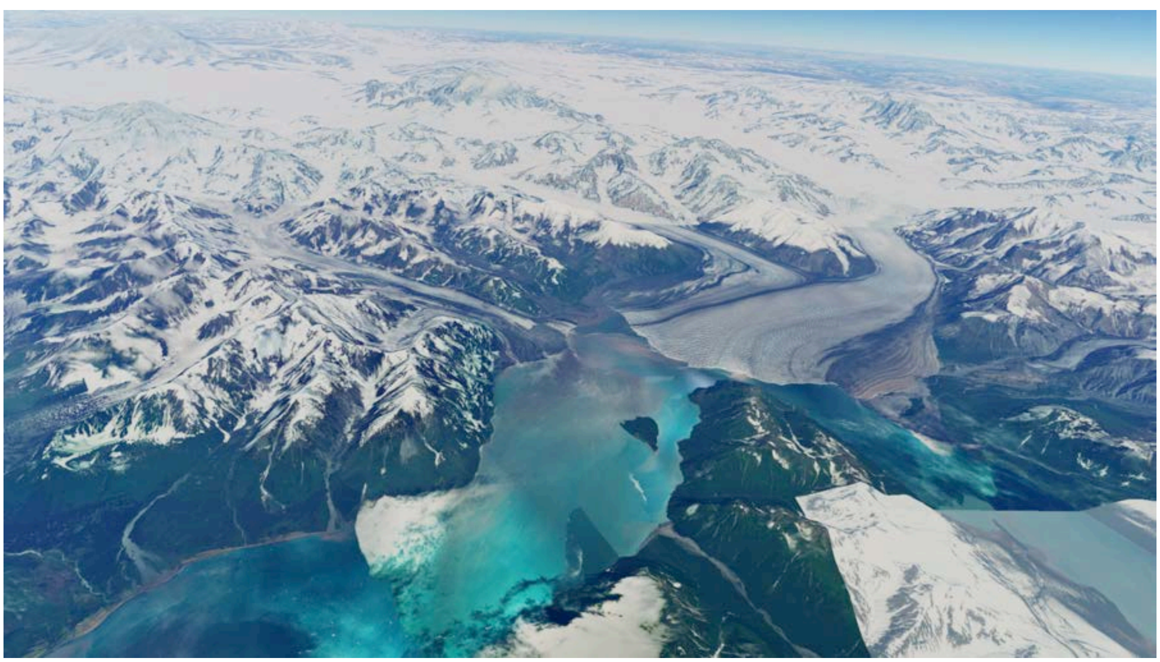
3. **Meteor Crater**: This crater is one of the most famous preserved craters on Earth and is located outside of Flagstaff, AZ. It is about 1200 meters in diameter and 170 meters deep, and formed ~50,000 years ago (during the Pleistocene epoch) when a ~50 meter-diameter piece of a nickel-iron asteroid exploded over the region, creating the crater we

see today. In the Pleistocene, this region was much cooler and wetter, and such animals as giant sloths and mammoths roamed. This crater was used to train the Apollo astronauts so that they could learn to differentiate impact from volcanic lunar craters. Related to astrobiology, we still do not have a complete story as to how Earth got its oceans, or how life started on this planet, and water-laden asteroids might have delivered water and/or the ingredients for life to Earth. Further, asteroids could easily deliver these ingredients to other habitable worlds. Asteroids are also not so positive for life in that they are likely at least partially responsible for several extinction events, the most famous of which was that of the dinosaurs ~65 million years ago (related crater is Chicxulub Crater in the Yucatán Peninsula, Mexico).

4. **Grand Prismatic Spring**: This is a vividly colorful thermal hot spring in Yellowstone National Park, and the largest (110-meter diameter; 50-meter depth) hot spring in the US. The colors in the spring are due to mats of extremophile microbes that live and thrive in the ~160-degree F pool. It is hypothesized that such extremophiles (specifically *thermophiles*, or “heat-loving” organisms) could be analogues to potential life in extreme temperatures beyond Earth, possibly in hydrothermal vent systems on Europa.

5. **San Francisco Bay Salt Ponds**: These artificial salt pans lie along San Francisco Bay, and are evaporation ponds that are home to *halophiles* – “salt-loving” extremophiles. The 8,000-acre ponds were engineered to harvest salt from the Bay, and the varying colors of the ponds, which can be seen out airplane windows while landing at SFO airport, are produced by the microbes living in the salt. Interestingly, conservation efforts in the Bay area have changed the colors of the pans from vibrant green, blue, and orange hues to more natural tones as some of the pond area is restored back to marshland.

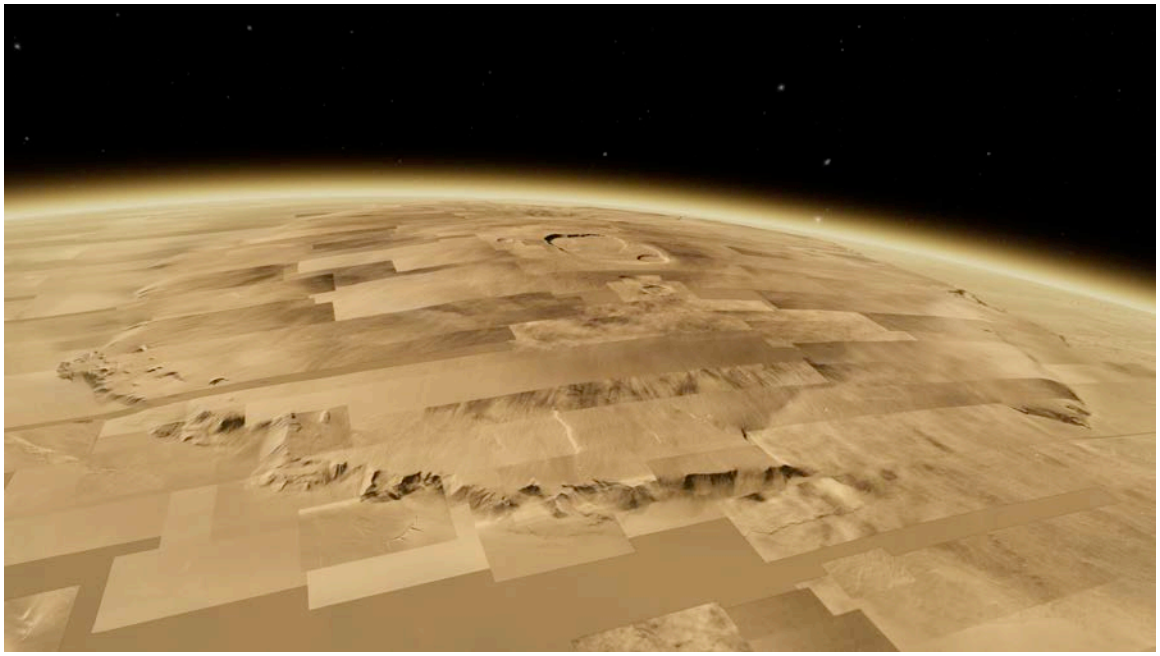
6. **Alaskan Glaciers**: Any ice sheets could be chosen to showcase *psychrophiles* – "ice-loving" extremophiles that live in permanent frozen regions, such as Greenland, Antarctica, and other regions with ice sheets and glaciers. I chose the Alaskan glaciers since they are visually striking with their blue ice floes. Microbes that can survive inside ice, often well below zero-degrees C, are potential analogues for possible life on icy moons (like Europa) and planets.



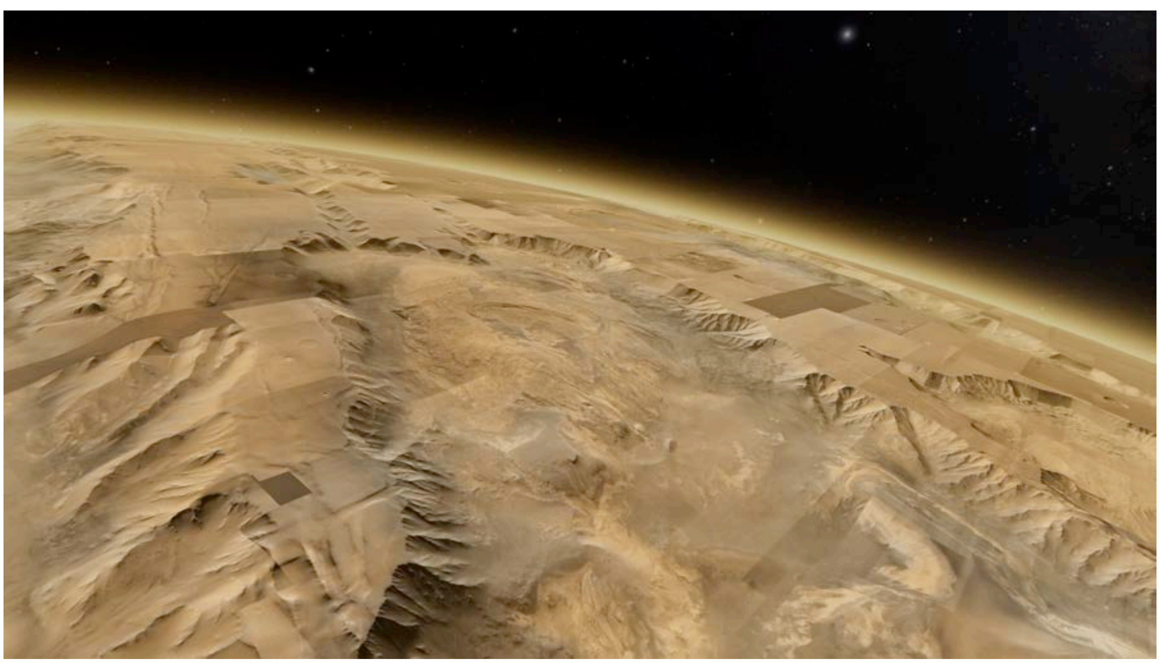
7**. Telescopes on Mauna Kea, Big Island, Hawaii**. I like to end on Earth with Mauna Kea, a spectacular mountain (and the tallest on Earth when measured from its oceanic base) of 13 working observatories for ground-based astronomy, including the Keck and Infrared Telescope Facility telescopes which I currently use for my research. This mountain is widely considered in the astronomy community to be the best site on Earth for ground-based observations, being both high (nearly 14,000 feet; ~4200 meters) and dry, and with the most “good weather” days. Mauna Kea is a shield volcano and can be directly compared to Olympus Mons – a dormant shield volcano on Mars (comparative planetology). With OpenSpace you can also see the observatories and cinder cones (reddish mounts that resemble anthills from above) on the summit of Mauna Kea.

Journey to MARS – this planet is the site of currently most of the robotic missions in the solar system, and where scientists are searching for signs of past and possibly current life. Water flowed in Mars’ past, and it may have had an ocean in its northern hemisphere. Water may even be flowing intermittently on the surface today.

8**. Olympus Mons**: One of the most striking features of Mars, Olympus Mons, is ~624 km (374 miles) in diameter, and ~25 km (16 miles or 72,000 feet) high, about 2.5 times the height of Mount Everest. It is the largest volcano and planetary mountain in the solar system; the largest mountain anywhere in the solar system is on the asteroid Vesta. It is a shield volcano, similar to Mauna Kea in Hawaii and other shield volcanoes on Earth. This stop and the next are more opportunities for comparative planetology, and one can add that the terrestrial planets all formed from the same materials in the solar nebula and we thus see distinct similarities in their composition and surface features. I like to also remind audiences here that all the ingredients for terrestrial planets and for life are in space, and this fact is a key driver for searching for life beyond Earth.

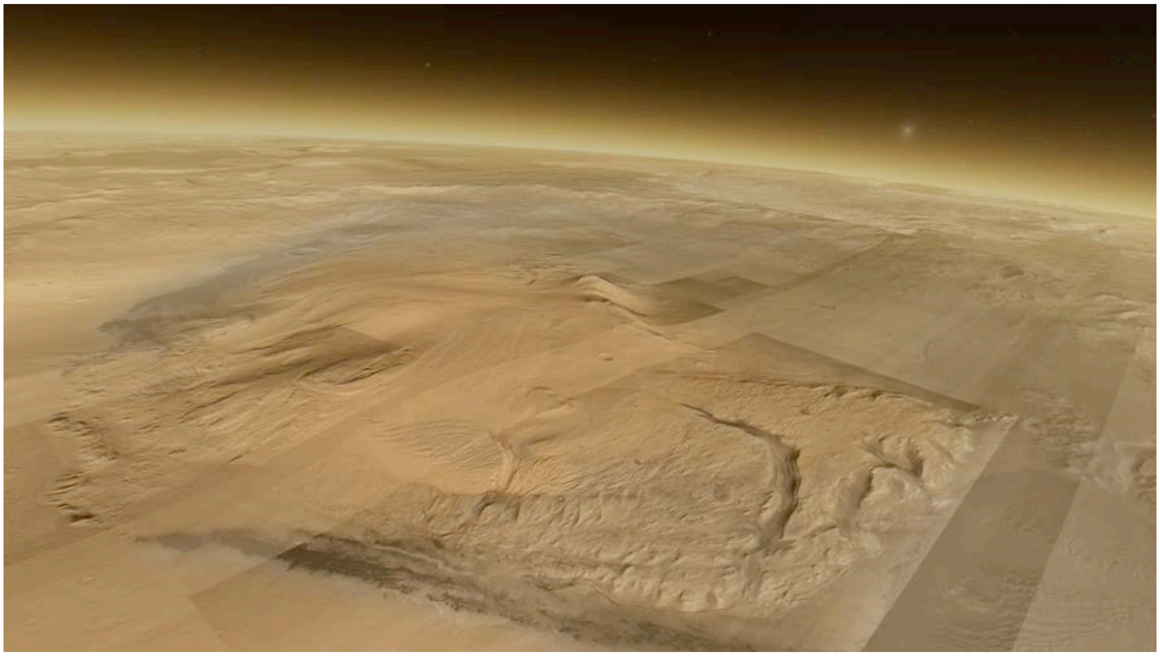


9. **Valles Marineris**: At ~2,500 miles (4,000 km) long, 120 miles (200 km) wide, and ~23,000 feet (7 km) deep, this is one of the largest canyons in the solar system. It extends nearly one-quarter the circumference of Mars, and theories on its formation include volcanism, landslides, and/or asteroid impacts. These processes can be compared to the understanding of the Grand Canyon, a valley carved by the Colorado River (we don't think that Valles Marineris formed from river carving). One can mention



again here that water likely flowed on Mars in the past and may still flow on the surface intermittently as well as underground, which still makes Mars an ideal candidate for searching for past and/or present life.

10. **Gale Crater**: This is a supposed dry lakebed, and the landing site for the Curiosity rover which is still actively exploring the chemistry of the region. At the center of Gale Crater is the mountain Aeolis Mons, and there is a nearby outflow channel that likely contained flowing water in Mars' past. It is thought that a lake formed in the crater shortly after its formation. This is an ideal site for searching for past/present life give that water likely existed in this location. A bird's-eye followed by zoomed-in view of the crater are shown below.



Journey to MOONS

11**. Europa**: the smallest of the Galilean moons of Jupiter. This is one of the most intriguing sites for astrobiology since it likely has a global salty liquid water ocean beneath its ~100 km-thick surface of ice. Observations have also shown liquid water geysers spewing from the surface. The ocean is thought be kept liquid from the tidal flexing by Jupiter, and future missions, such as the planned Europa Clipper, will help confirm its presence. If there is indeed liquid water, it is thought that the rock-water interface at its base could be analogous to those interfaces found in Earth's hydrothermal vent systems which provide rich chemical environments for organic chemistry and habitability. Further, a leading hypothesis for the origin of life on Earth several billion years ago (possibly even within the first billion years of Earth's formation) is that it started within rock-water interfaces far below the surface of an early ocean. Another interesting feature of Europa is its crisscrossed surface of bands and ridges that are seen in images from various space missions. These "lineae" may be the result of periodic eruptions of warm ice when the surface crust spreads, also possibly due to tidal flexing from Jupiter.

12. **Titan**: the largest moon of Saturn and the only moon known to have a dense atmosphere. Titan is interesting from an astrobiological standpoint for two main reasons: it has liquid hydrocarbon (methane and ethane) lakes and seas (carbon-rich environments that could possibly harbor life that may not need liquid water, but could potentially survive in liquid methane or ethane), and its thick nitrogen-rich atmosphere is thought to be analogous to that of the primordial Earth, with the exception that there is no water vapor on Titan. Any life existing in Titan's hydrocarbon seas would have to metabolize at (–290 C/94 F), which could hinder complexity and functionality.

While the habitability of Titan is still debated, it is nevertheless an intriguing site for exploration, and was recently selected for the robotic mission, *Dragonfly*, currently scheduled to launch in 2026 and reach Titan in 2034. A theoretical cell membrane made of phospholipids including carbon, hydrogen, oxygen and phosphorous which could survive this extreme environment was also modeled in 2015, lending some theoretical robustness to the idea that life could persist in this harsh environment.

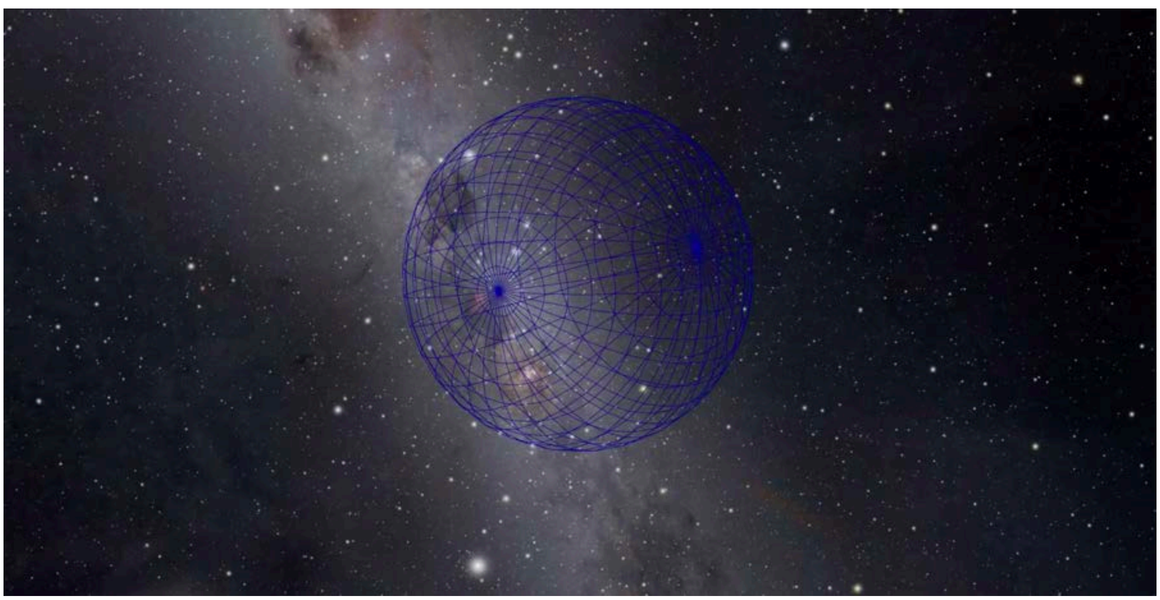
13. **Enceladus**: This moon of Saturn is yet another solar system body that likely has a subsurface water ocean and thus could be habitable for “extreme” life similar to what could be found on Europa. Water geysers and silicates (tiny rock particles) have also been observed spewing from its interior. Enceladus has surface fissures, plains and corrugated terrain that provides additional evidence for an undersurface ocean. As with Europa and other under-ocean environments that have potential rock-water interfaces (substrates for organic chemistry) observing silicate particles was exciting supporting evidence for such an environment on Titan. Below is a screenshot of Enceladus with Saturn in the background.

Part II: SETI, the Search for ExtraTerrestrial Intelligence (SETI). I like to include a short section on SETI since the public is typically interested in the possibility for intelligent life (“aliens”) beyond Earth, and SETI provides an opportunity to compare science fiction to the work of real SETI astronomers. If a shorter program time is desired, I suggest shortening some of the stops in Part I. Two datasets related to SETI that are found in OpenSpace are the radiosphere and exoplanets.

14. **Radiosphere**: With OpenSpace we can travel from Earth to the cosmic microwave background in a handful of seconds, rapidly and non-physically traversing the vast

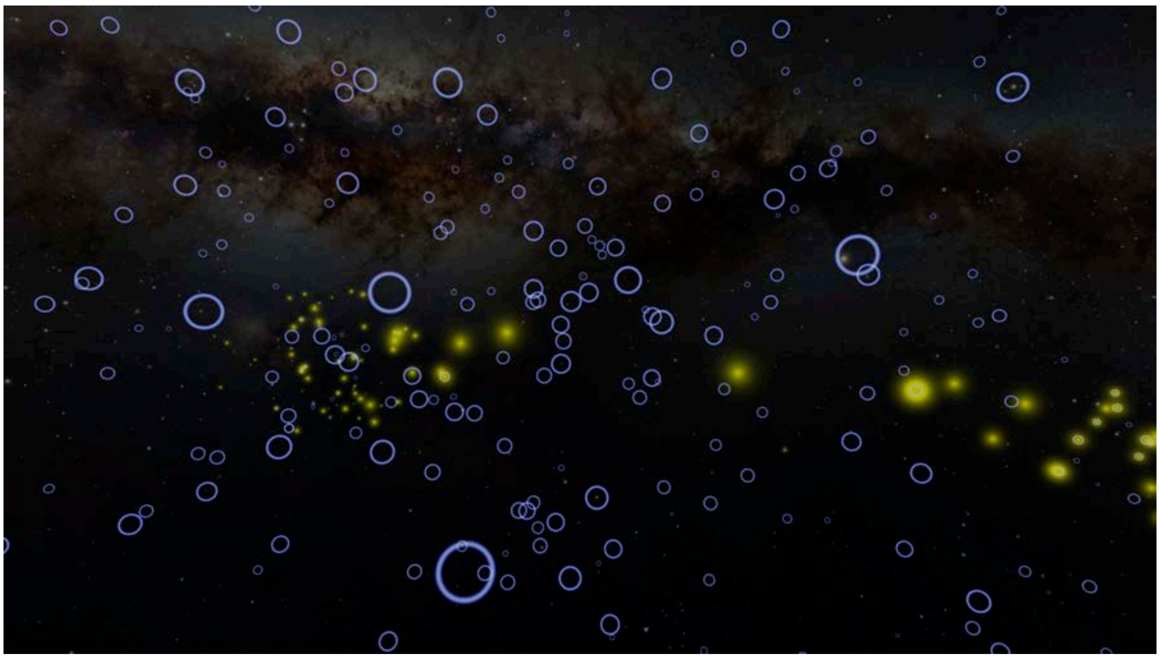
emptiness of space. The edge of Earth's radiosphere – the distance radio signals have thus far traveled from our planet – is ~ 110 light years; i.e. humans have been sending signals out to space for a mere 110 years. This is next to no time at all compared to the age of the Universe. We can turn the radiosphere on shortly after leaving the solar system, and then zoom out to see this distance in context with enormity of the Galaxy and Universe. The take-away from this visual is that we haven't sent signals out to space for long, and so far it seems rather unlikely that there is intelligent life anywhere near Earth, or at least close enough that we could hope to receive a signal within many lifetimes. Even if intelligent life were relatively close to Earth this could still be thousands of light years from us, and therefore it would take an equivalent time to reach them, and then then another equal time frame to return a signal. Further, humans as a civilization are "growing dark" as technology moves from radio and television broadcasting digital platforms. Therefore we might have to intentionally beam signals toward potential areas of civilizations (i.e. where there are "Earth-like" planets) if we hope to ever make our presence known.

As Carl Sagan famously said, "Space is vast, and the stars are far apart", so even if life were out there, we may, likely, never know. Yet, many scientists remain hopeful that we are not alone.



15. **Exoplanets**. Showing the exoplanets in OpenSpace offers the opportunity to talk about the ongoing search for potentially habitable, "Earth-like" worlds, and how we use various datasets to determine these characteristics. Currently, we can really only know if a planet is terrestrial (has a solid surface rather than just a being gaseous) and within the habitable zone of its host star(s), as well as certain basic characteristics of the planet's orbit, but we are still not sure how to define biosignatures – the tell-tale atmospheric molecules for an inhabited world. Further, we are far from having the ability to travel great distances from Earth, as we currently still use chemical rockets.

Even if we could go as fast as the Voyager probes – the fastest spacecraft sent by humans to date – traveling ~one million miles per day, it would take ~70,000 years to reach our closest star system, Proxima Centauri. We clearly need to develop new technologies to take us to the stars. Another point to bring in while visualizing the exoplanets is how we "show" data, i.e. these are two-dimensional visualizations of the positions of the exoplanets, which is all the information we have for objects to which we cannot yet travel. We have many such data sets in OpenSpace (e.g. galaxies, quasars, cosmic microwave background). Until we sent spacecraft to the exoplanets we will have only markers for them in space, as well as artistic renderings or models of their surfaces and atmospheres. This is why we only see the exoplanets as circles.



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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.

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OpenSpace

Tour of the Solar System

9/3/19

Description: Do you love space? Come and join our Planetarium Presenter on a wander through the worlds of our Solar System. Explore with us in this live 20-minute show using NASA's OpenSpace software.

Note: This guide references custom-made html buttons. The tour can be completed without these buttons, by bookmarking or flying manually.

Section of Show	**Button** (and description of visual)	**Talking points**
1. System		
	Setup Solar System (***be sure to press this before any show when you first launch OpenSpace***)	● These buttons are for setting up the show before your intro and before you load guests into the dome
	Welcome (could do a welcome like this either during your intro in front of the audience or at the beginning of the show)	● We're going to be explorers today — explorers of the Solar System! ● In the past, people explored the night skies with the only tools they had — their eyes. We can still do that today, and it's one of the things I love to do most. What kinds of things have you seen in the sky? ● Has anyone here ever seen a planet in the sky? Which one? ● The invention of the telescope changed the way we look at the sky. Have any of you ever looked through a telescope? What did you see? ● There is of course one planet we can almost always see — but it's not in the sky… It is Earth!
2. Visual		
		● These buttons can be used throughout the show to turn the planet trails/orbits on or off
	Start show: will start out looking at Earth, before starting the show be	● Our home world is the only spot in the Universe where we know life exists — that makes us pretty special by default.

	sure to position yourself where you'd like	● When we look at Earth, we see it as it was today using images taken by the SUOMI spacecraft — provided by NOAA and NASA — these images are brand new, was it a sunny day outside the Museum? ● Those bright bands show us where the glare from the sun was when each "strip" of earth was imaged.
	Fly manually to night side of Earth	● Something else special about Earth — we shine light from our night side. Most other planets don't do that — maybe that would help an alien civilization locate us?
	Zoom out from Earth	● Let's zoom out to see the planets of our solar system, Earth is one of them. How do these planets compare to the planet we know best, Earth? We're going to get a closer look to find out in a second!
	Show Planet Trails	● First, let's see how the Earth moves around the Sun. We're now high above the Earth and we'll put in an imaginary line showing Earth's path around the Sun — its orbit. ● How long does it take the Earth to complete one orbit of the Sun? ● We define our year by how long it takes the Earth to orbit the Sun once. The ancient calendar-makers didn't have the benefit of this view, though — they figured it out by looking at the sky!
	Adjust Speed Menu (on the left/GUI screen click where it says the date and time, this brings up a menu to change time)	● What about the other planets? We know that Earth is the third planet from the Sun. Let's see how these planets move in their orbits. You see the one closest to the Sun is moving the fastest — in fact, it would orbit the Sun 4 times before we even complete one orbit. The next one out is a bit slower, and the one out beyond the Earth takes about twice as long. Why is that? Why would the planets closer to the Sun move faster than those farther away? ● The Sun is by far the most massive object in the solar system — more than 99% of all the stuff in the solar system is inside our star. And the more massive something is, and the closer you are to it, the more powerful the pull of gravity is. The closer planets

		have to orbit faster to counteract the Sun's stronger gravity. The planets are moving at just the right speed to keep them safely in their orbits.
3. Mercury		
	Focus on Mercury	• The planet names come from Greek and Roman mythology, and they named the fastest moving planet after the Roman messenger god, Mercury – it only takes 88 Earth days to complete one orbit. • Mercury is the smallest planet. As we fly over to Mercury I want you to think about what else you've seen that looks similar. Mercury is very rocky, and looks pretty Moon-like. • Mercury is very close to the Sun compared to the other planets, which makes it very hot, over 800 degrees F! On sunlit side that is. Mercury has no atmosphere to hold in heat, so the nighttime side is very cold (-280 degrees F) • Mercury rotates 3 times for every 2 orbits – a day on Mercury is about 176 Earth days – that's 2 Mercury years! You'd have a lot more birthdays on Mercury, but the school day or work day would be VERY long. • Mercury is so close to the Sun that you can only see it in the sky (from Earth) just before sunrise or after sunset, and only at certain times. Lots of people have never seen Mercury – it's a good challenge!
4. Venus		
	Focus on Venus	• The next planet, Venus, though, is much easier to see – in fact, it's the third brightest thing in the sky after the Sun and the moon. Sometimes people think it's a UFO, it's so bright! Have you seen it in the morning or evening sky?

		● Venus is so bright because it's cloud-covered – reflects a lot of sunlight. ● Venus is similar to Earth in a couple of ways, it's rocky like the Earth and it's almost the same size, just a little bit smaller ● It orbits the Sun a bit faster than Earth, in about 225 Earth days ● Its rotation and day however are very different from Earth and pretty unusual. Venus rotates backward compared to most of the other planets, and it takes about 243 Earth days to do so. So its day is also longer than its years! And since it's rotating "backwards" if you could see the Sun from the surface it would rise in the west and set in the east!
	Venus Atmosphere Toggle	● But I say "if" you could see the Sun from the surface, since that's hard to do. The clouds on Venus are extremely thick, so what we're seeing here isn't the surface at all, it's only the atmosphere ● Some of our orbiting spacecraft have used radar to penetrate the clouds and map the surface. Places that are flat reflect the radar and are brighter/lighter. The spots that are dark are less flat ● This atmosphere also causes a lot of pressure on Venus. If you were to stand on the surface of Venus it would be like being a kilometer below the ocean – that's 90 times the pressure on Earth's surface ● And if all that wasn't enough to make you not want to visit Venus, the atmosphere is also made of gas that traps the Sun's heat really well, mostly CO_2, which makes the surface reach almost 900°F, hotter than Mercury! ● Plus there is often acid rain falling from the sky here. Not too pleasant, that's for sure.
5. Earth/Moon		
	Focus on Moon	● Since we already stopped by Earth, let's swing by the Moon. ● The Moon is much smaller than Earth, with less gravity. When the astronauts walked on the surface just over 50 years ago they

		more bunny-hopped rather than "walked" since the gravity is so low ● The Moon is plainly visible from Earth and one of the easiest/best astronomical things to observe from Earth using your own eyes. ● On the moon we can see the ancient cratered highlands, the oldest parts of the Moon's surface, and the slightly less ancient mare (maria comes from the word for "oceans" in Latin). The mare are where lava flowed across the surface long ago, covering up older features. ● The Moon might be a place that humans return to soon, especially as a place that helps us get to our next planet - MARS!
6. Mars		
	Focus on Mars **Mars CTX Toggle** (this loads in strip of high resolution images of Mars' surface. Note that it looks VERY odd if you're looking at Mars as a whole, might be best to use this for certain areas you want to see up close)	● People often talk about Mars being a planet similar to Earth, but it's also different in a lot of ways. For one thing it's pretty small, about 1/2 Earth's diameter, ● But it also has some of the most interesting features in the Solar System. It has the largest mountain in the Solar System (Olympus Mons 15 mi. high, base as big as Arizona), the biggest canyon too (Valles Marineras 2500 miles long, would stretch from SF to NY). ● Humans have sent a lot of robotic explorers to Mars – orbiters, landers and rovers, so it's probably the planet we know the best other than Earth ● Why do you think we've been so interested in Mars? ● Mars has a thin atmosphere compared to Earth. It's a cold place now, but it was probably warmer in the past with a thicker atmosphere. ● The reason Mars is the planet that seems most like Earth is that it's got a rocky surface, it does have an atmosphere (and not a crazy one like Venus), it has a lot of frozen water, it may have had conditions a lot more like Earth millions of years ago, and it's the only one we're talking about visiting in person. ● OPTIONAL TALKING POINTS:

		• *Water features – evidence of liquid water in the past, but now cold and dry – most of the water we've detected is now frozen beneath the surface* • *Gale Crater – landing location of Curiosity rover, chosen because of suspicion of water in the past, Curiosity looking for evidence*
	Zoom out to see orbits	• Beyond the orbit of Mars we find a very different part of our solar system, filled with small rocky objects. Anybody know what this region is called? We've brightened them up so we can see them, but they're really much smaller and farther apart than this.
7. Ceres		
	Focus on Ceres (Optional)	• *There is one object in the asteroid belt that's big enough to be round like a planet. We have a spacecraft called Dawn that's orbiting it now – anyone know its name? Ceres once was called a planet, but when all these other objects were detected it was dropped from the planet list. Now we consider it a dwarf planet, like another object you may have heard of….*
	Zoom back to overview Jovian	• To see the orbits of the rest of the planets, we'll need to fly even farther away from the Sun. • We've reached the end of the small, rocky worlds like Earth. What do you think the rest of the planets will be like? Let's go see!
8. Jupiter		
	Focus on Jupiter	• We'll start with the largest planet – what's its name? • Jupiter is really far away from the Sun, 5 times farther from the Sun than Earth. And the years for planets here on out are going to get longer and longer. Jupiter takes about 12 Earth years to orbit the Sun once • As we get closer, you can see that Jupiter doesn't look anything like the planets we've seen so far. In fact, Jupiter is largely made

		elements that are gas here on the surface of Earth – hydrogen and helium, like the Sun. And while those elements are nearly always gas here on Earth, and are gas in the thick atmosphere of Jupiter, if we were able to see deep into Jupiter the pressure would build to be so great that the hydrogen would be liquid and we even think it may be solid very, very deep inside Jupiter. ● And it's no wonder that things would be a bit extreme and odd at a gas giant, after all, they are GIANT. Jupiter is 11 Earths wide — it's hard to imagine just how big Jupiter is. And it's incredibly massive (can kind of think of it as heavy) — it's more massive than all the other planets put together! ● You might have noticed some other objects coming into view – some of the many moons of Jupiter. We didn't talk much about moons with the other planets, since there aren't many. Mercury and Venus don't have any moons while Mars has only two and we only have one. The outer planets on the other hand have lots! Jupiter has nearly 80 moons, and that number bumped up by a dozen just a year ago (July 2018) when we found more! ● Another part of Jupiter that is way more extreme than on Earth is its storms. The Great Red Spot for example is very similar to a hurricane, but WAY larger. This spot is bigger than Earth! But it has been shrinking in the last century or so (and is getting taller as it shrinks, weird) ● 4 large moons are called the Galilean moons - almost like planets themselves.
	Focus on Io (Optional)	● *Io is the most volcanic place we have ever observed, with more actively erupting volcanoes at any given moment than Earth - even though Earth is much bigger!* ● *The source of Energy for Io is likely Jupiter itself, imparting energy to the small moon through tidal forces.*
	Focus on Europa (Optional)	● *Europa is the spot in the solar system with the most liquid water closest to the surface, according to current models, more than twice what we have in all of Earth's oceans.*

		• *The source of Energy for Europa is likely Jupiter itself, imparting energy to the small moon through tidal forces.*
	Focus on Ganymede (Optional)	• *Ganymede is the largest moon in the Solar System - bigger than the planet Mercury!* • *The surface has both dark and light regions, but is strange when compared to our moon - dark features are older, light features are younger!*
	Focus on Saturn	• Almost twice as far out as Jupiter – 9.5 AU, 29-year orbit, 9.5 Earths wide • Cassini there since 2004 - but its mission ended in 2017. • Famous for its rings, the surface is similar to Jupiter's but a bit less dramatic. The rings are ice and a little bit of rock, likely from a former moon.
	Focus on Titan	• The second largest moon in the SS, just behind Ganymede, but much more like Earth. • Titan has a thick atmosphere made of mostly Nitrogen, a bit like the one we are breathing right now!, but we are seeing the surface that is normally hidden. • Cassini was able to observe through the haze to make this map using radar, much like Venus's map we saw earlier. • It also dropped a probe called Huygens down to the surface, helping us understand Titan a little better. • Titan is covered with lakes and oceans made of not water, but ethane, methane and dissolved nitrogen. • While not a good place for life as we know it here on Earth, Titan is proof that Earthlike worlds exist beyond our own.
	Focus on Enceladus (Optional)	• *Enceladus might be a good place for life though! Much like Europa, a moon of Jupiter, Enceladus has an ice crust with liquid water underneath.* • *While the moon is small, it has hotspots of activity and liquid water that were located by Cassini and other observatories.*

		• *Cassini even flew through some geysers erupting from the surface and was able to analyze the water that came out. While Cassini was not designed to find life that way, it did detect some of the elemental signatures that indicate the potential for life there. (organics, hydrocarbons)*
	Focus on Iapetus (Optional)	• *Iapetus is an EXTRA WEIRD moon of Saturn, it isn't quite round, but it's the biggest not-round thing in the Solar System.* • *It has a dark smear across its surface, likely from being dusted with dark material coming from another moon, Phoebe.* • *It also has a long ridge running across ¾ of its mottled surface. A very unusual place!*
	Focus on Uranus	• All of the planets we've seen so far you can see yourself in the sky – they're the ones that humans have seen all throughout history. The remaining planets weren't known until the invention of the telescope. • Uranus was discovered by the great astronomer, William Herschel, in 1781 • Twice as far as Saturn – 19AU, 84-year orbit, 27 known moons, rings • Only one spacecraft has visited Uranus & Neptune – Voyager 2, 1986 • Tilted over on its side – why? • Methane high in atmosphere absorbs red light, so blue-green color • *4 earths (optional)*
	Focus on Neptune	• Last of the giant planets – 30 AU, 164-year orbit, 13 known moons • Voyager 2 visited in 1989 • 4 earths (optional) • Very faint dust rings - (not visible in OS yet!) • The windiest planet in the solar system • Possible that Neptune has liquid water deep inside it because of the high pressure

		• Only planet found predicted to exist based on calculations before it was observed, *so far...*
	Focus on Triton	• Only major moon to orbit in the opposite direction to its planet's rotation • Has a pretty smooth surface with icy lava-like flows. • Once New Horizons visited Pluto, many features of Triton started to look more familiar - penitente mountains are carved out of ice by sunlight causing sublimation of the ice. Also - nitrogen slush ocean. • Green is based on data but is a very strange feature. Not "scientific visual" or colorized data, just green. Weird!
	Focus on Pluto **Focus on Charon**	• Surprisingly, New horizons discovered Pluto's has a thin atmosphere surrounding it (can see it well when looking at the night side). During Plutonian winter atmosphere 'freezes away' and falls back to the surface. Nitrogen snow! • The western lobe of Pluto's "heart" (left side when looking at it with the heart shape right-side-up) • Made mostly of nitrogen ice and has glaciers • Underneath this area is a subsurface ocean • Another surprise that was discovered by the New Horizons spacecraft were huge water-ice mountains. Some we can see on the right side of the "heart" • Pluto and Charon are tidally locked to each other, so if you were to stand on either one the other would never move in the sky • The two are also orbiting a mutual center of gravity that is outside Pluto, so Charon technically doesn't orbit Pluto, they both orbit each other
	Focus on Sun **Show planet trails** **Zoom out of SS**	• All the worlds we have seen are still part of our own Solar System, sort of like siblings to our own Earth. • As we zoom back, we can see our own sun in relation to the nearby stars
	Exoplanets	• We are now discovering solar systems in some of those locations,

		orbiting other stars - who knows what other amazing things might be awaiting discovery in those ● These places are called exoplanets and today we are just beginning to build the first generation of telescopes that will allow us to understand them a little better.
	Back to SS view	● For now though, let's return to our own Solar System, the one we know best and our place in space. It is here that we are stuck for now, so take care of each other and the planet we reside upon!

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