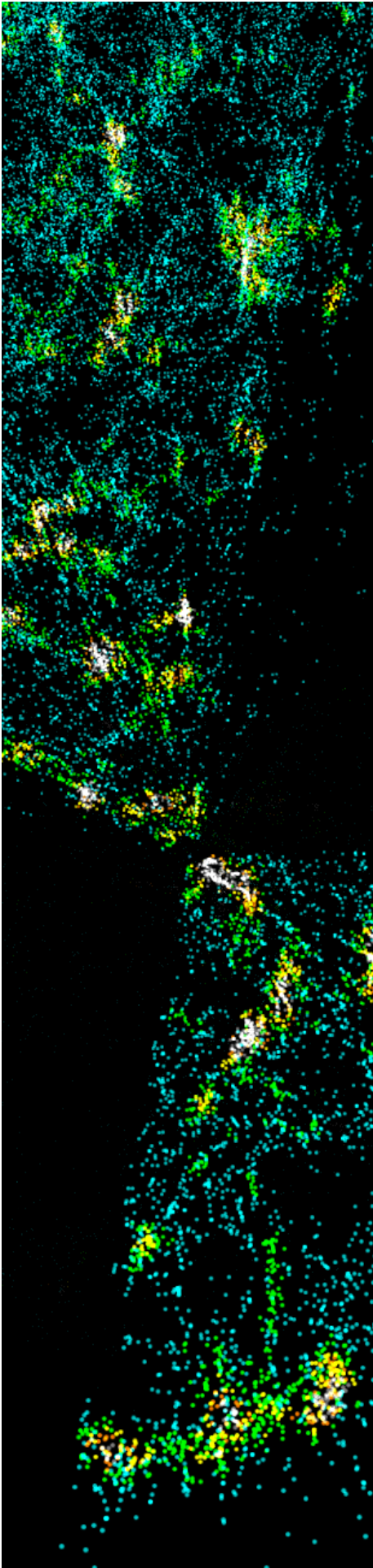


Digital Universe Atlas

1. The Grand Tour



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American Museum of Natural History



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See the [Digital Universe website](#) for more information.

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About This Guide

These guides are designed to explain the Digital Universe Atlas. They will take you through these data sets in a logical progression, and with navigation instructions and cues for turning data sets on and off. They are software-independent, so be sure to know the basics of the program you're using before reading this guide.

While the information here can never be completely comprehensive, we aim to offer a broad view of the universe in these guides, but with compelling detail when appropriate.

The Grand Tour

The Grand Tour is designed to be an overview of the entire universe and is modeled after the tours we give in the Hayden Planetarium. Its aim is to give one a sense of the overall landscape, from Earth to the farthest reaches of the observable universe. We typically give this tour in about an hour, but it may be condensed down to any length of time.

Because we attempt to describe the entire universe in one sitting, the discussion necessarily remains at the surface, and without too much depth on any one topic. Subsequent, more specialized guides will offer greater detail on the realms discussed here.

Conventions



The light bulb signifies a tip or recommendation.



The rocket indicates navigation suggestions and directions.



The wrench signals when to adjust and activate data sets.



The asterisk provides definitions and information.

About the Digital Universe Atlas

The Digital Universe, developed by the American Museum of Natural History, incorporates data from dozens of organizations and scientists worldwide to create the most complete and accurate 3-D atlas of the universe from the local solar neighborhood out to the edge of the observable universe.

Founded in 1998 as the Digital Galaxy Project, and renamed Digital Universe in 2000, the atlas grew out of a convergence of two great streams of technical achievement: celestial map making, which incorporates centuries of observation and scientific breakthroughs, combined with hardware and software engineering, which enables sophisticated data visualization. As new data are gathered, and new tools developed, the Digital Universe will continue to expand as our understanding evolves.

Available Viewers

The Digital Universe is available in a number of applications.

Open Source Applications

[Partiview](#) is an application developed by the National Center for Supercomputing Applications with strengths in data visualization and analysis. See [Partiview Quick Start Guide](#) for a primer on using Partiview with the Digital Universe (does not include the Solar System).

[OpenSpace](#) is a NASA-funded, open-source software that breaks new ground by supporting real-time interaction with visualizations of space exploration, observations, and computer simulations of nature's dynamic behavior. The software is being developed by AMNH in collaboration with Sweden's Linköping University, New York University, University of Utah, and NASA's Community Coordinated Modeling Center at the Goddard Space Flight Center.

Commercial Software

Commercial software is available from these companies, primarily for institutional use.

[Uniview](#) by SCISS

[Digistar](#) by Evans & Sutherland

[DigitalSky](#) by Sky-Skan




Consult the guides for your application to learn how to start Digital Universe and explore the atlas.

Earth & Moon

We always begin our exploration of the universe from where we are most familiar—Earth, our home.




 *Start a slow orbit around Earth.*

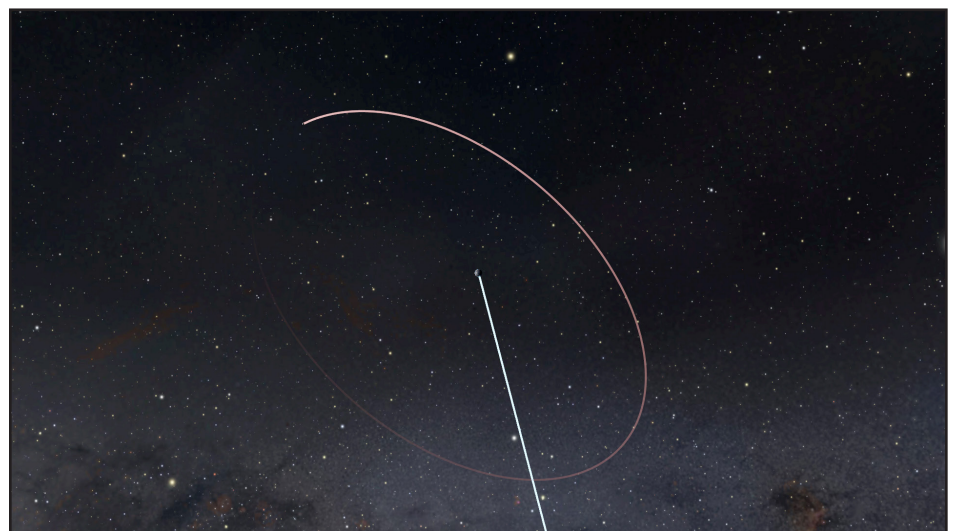
Earth is, of course, home to everyone you know, and we're all huddled on those parts of the planet that are above present sea level—about 30% of the planet's surface. Earth remains a dynamic planet, with plate tectonics, active volcanoes, and crust formation.

Earth formed about 4.6 billion years ago, but our modern species appeared only about 200,000 years ago. In that time, we have populated all corners of the planet, developed agriculture circa 10,000 years ago, and produce enough food to be able to think beyond our own survival and about things that enrich our lives and advance civilization.

We did not have the first accurate distance to a nearby star until the year 1839, so most of what you're about to see is very recent in the grand scheme of things. And, a lot remains to be discovered.

 *Pull away from Earth so that the Moon's orbit is in full view, and continue orbiting Earth.*

The Moon is Earth's only natural satellite. Its average distance is 384,400 km (almost 239,000 miles), but it ranges from 362,000 km

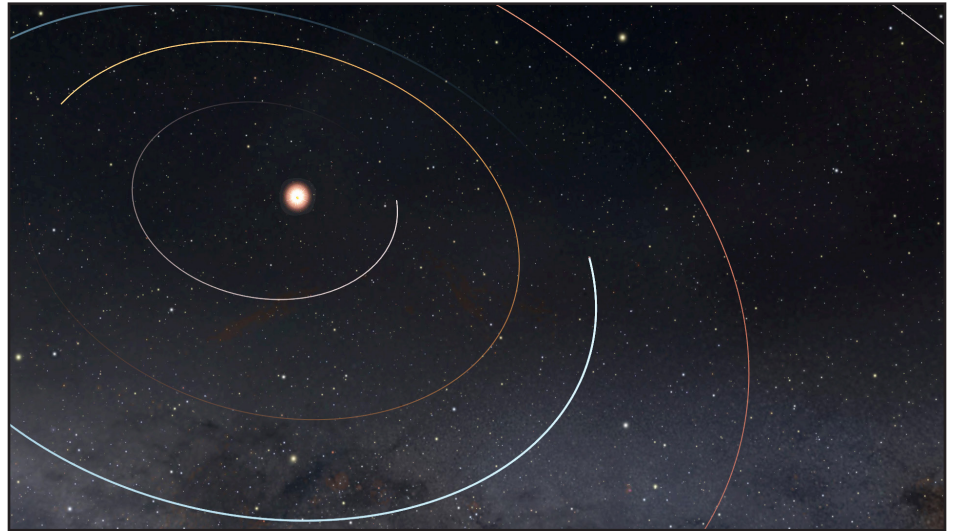


at its nearest to 405,000 km at its most distant (that's 225,000 miles to 251,600 miles).

❁ *A light year is the distance over which light travels in one year. Light speed is 300,000 km/s (186,000 miles/sec). So, 1 light second is just 300,000 km (186,000 miles), 1 light day is 26 billion km (16 billion miles) and 1 light year is 9.5 trillion km (6 trillion miles).*


We can also express this distance in terms of light travel time. You may be familiar with the term *light year*,* which is the distance over which light travels in one year. The Moon is so close, we need to talk about the light travel time in *light seconds*. Its average distance is equal to about 1.3 light seconds, so it takes 1.3 seconds for light to travel from Earth to the Moon. When the astronauts were walking on the Moon, it took 1.3 seconds for Houston to relay a message to them, and another 1.3 seconds for their response to reach Houston.

The Sun is, on average, 150 million km (93 million miles) from Earth, which we can also state as 8 light minutes—it takes 8 minutes for the Sun's light to reach your eyes on Earth. In that sense, when we look at the Sun (which we should never do directly), we're seeing it as it was 8 minutes ago. In this way, we're looking back in time as we look out into the universe.

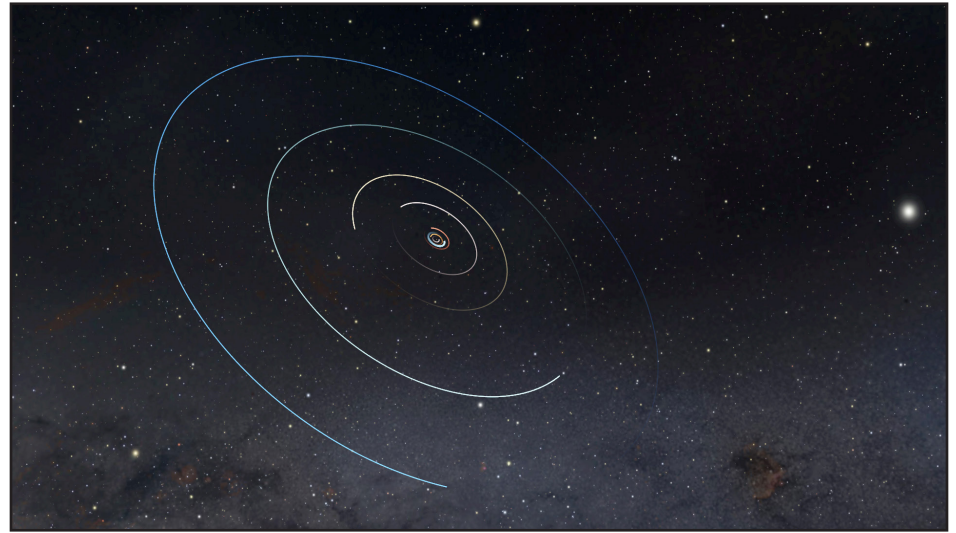


The Moon remains the farthest we've traveled as a species. We have sent probes farther into space, but we have not set foot on any other world beyond the Moon. We last left the Moon on December 14, 1972, nearly fifty years ago.

Solar System

 Fly away from Earth so that the entire Solar System is in view. Orbit about the system so that you see the planet's orbits from above and from the side.


From outside the orbit of Neptune, we see the eight planets of the Solar System. The inner, rocky planets are huddled near the Sun, the star at the center of the Solar System. The outer, gaseous planets are far larger and each harbor a complex system of moons.



The planets align very well with the plane of the Solar System. Mercury is inclined about 7° to this plane, but the other seven planets are all within two degrees of the plane.

 Turn on Pluto and show its orbit.

In contrast to these planets, Pluto is inclined 17° to this plane, clearly demonstrating it's different from the planets. When viewed from above the plane, you can see that the trajectory of Pluto is interior to Neptune's orbit for a portion of its journey around the Sun.

 The Kuiper Belt is a region of small bodies that orbit the Sun beyond Neptune. These objects were discovered in 1992, and we now know of over 1,000 such objects. Pluto, and other similarly sized objects exist in the Kuiper Belt, along with two other dwarf planets, Makemake and Haumea.

Once we discovered Kuiper Belt* objects—small, rock-ice worlds beyond Neptune—astronomers understood that Pluto resembles these objects, and belongs with its Kuiper Belt brethren. Pluto is now one of a few dwarf planets in the Solar System.

The Solar System is composed of an exotic variety of objects that orbit the Sun. The Sun, a rather average star, contains the vast majority of the mass of the Solar System (99.85%). Jupiter, the largest planet, is 317 times the mass of Earth, but all the planets account for only 0.135% of the Solar System's mass. The remaining 0.015% is made up of asteroids, dwarf planets, meteoroids, and smaller objects.

 Turn on the Voyager Spacecraft.

From this perspective, and with the Voyager spacecraft on, we see the trajectories of Voyager 1 and Voyager 2 from launch to the year 2050. Launched in 1977, they were sent to explore the outer Solar System. They arrived at Jupiter in 1979, Saturn in 1980, and Voyager 2 visited Uranus and Neptune for the first time in 1986 and 1989, respectively.

After 40 years, the Voyager spacecraft continue to traverse the outer Solar System into the gas that exists between stars. Voyager 1 is, and


always will be, the farthest object we've sent out into the universe. Currently, it's over 21 billion km (13 billion miles), or 19.5 light hours, from Earth.

In 296,000 years, Voyager 2 will pass within five light years of the bright star Sirius, which is currently about 9 light years from Earth. But, between the years 2025 and 2030, both probes will cease to function, having depleted their power sources. At that point, they will be lifeless ambassadors as they continue to press into the Milky Way Galaxy.


Constellations & Stars

Even from this great distance, we still see the same star patterns traced in the starry sky. The familiar Ursa Major (the "Big Dipper"), Orion, Scorpius, and the other constellations remain the same from this perspective because the stars are very far away. We also see the band of light we call the Milky Way.



 Turn on the constellation lines.

The constellation lines connect stars that trace the figures outlined in the night sky. The sky is divided into eighty-eight constellations, each claiming a region of the sky as a country's borders claim part of a continent.

 Fly away from Earth until you begin to see the nearby stars move.

As you fly away from the Sun and Earth, you will begin to see some of the nearby stars move. The constellation lines will become distorted as the two-dimensional sky transforms into three-dimensional space.

Some of the nearby stars are easily distinguished. In particular, Sirius, the brightest star in the sky (due to its intrinsic brightness and its distance), is about 9 light years from the Sun. Nearby is Procyon, about 11.5 light years from us. Opposite the Sun is Vega, 25 light years away, and Altair, around 16 light years from Earth. Several dimmer stars also populate the solar neighborhood.




As you fly farther from the Sun, it quickly becomes clear that the constellations are only practical from our perspective in the Galaxy. Once we're a few light years out, they begin to distort. Farther still, and they only serve to visually distract, and should be turned off to explore this part of the Galaxy.

 Turn off the constellation lines.

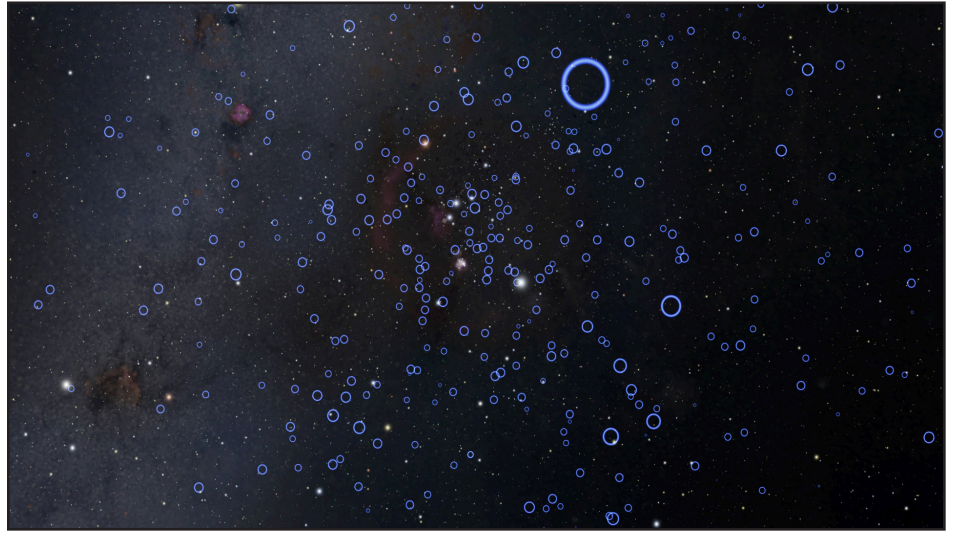
From this location, you may notice that the stars exhibit various brightnesses and colors, as they do in the night sky. Stars come in a variety of masses, which determine their temperatures, colors, and luminosities. Bluer stars are more massive and hotter. These stars have short lifetimes and there are far fewer of them in the Galaxy. Redder stars, on the other hand, are less massive and cooler, and are abundant throughout the Milky Way. The Sun is generally average in terms of brightness and will remain a star for another five billion years.

Exoplanets

It may appear we are now lost in a sea of stars, but we can now explore objects on larger scales in and beyond the solar neighborhood. For example, let's look at the exoplanets.

 Turn on the exoplanets.

 Continue flying away to examine the exoplanet data.





Each marker in this data set indicates the stars that we know have planets. None of these were confirmed before 1995, so this is a relatively new branch of astrophysics, and a burgeoning one at that.


We now know of thousands of planets outside our Solar System, and some of these systems have multiple planets, indicated by the number in their label (no number signifies only one planet).

We detect the bulk of these by the so-called transit method, where the light from the host star dims ever so slightly as the planet passes in front of it. That, of course, will only be effective for systems which are edge-on* to us. Astronomers also use the gravitational “wobble” of the host star that occurs when a large planet revolves around that star.

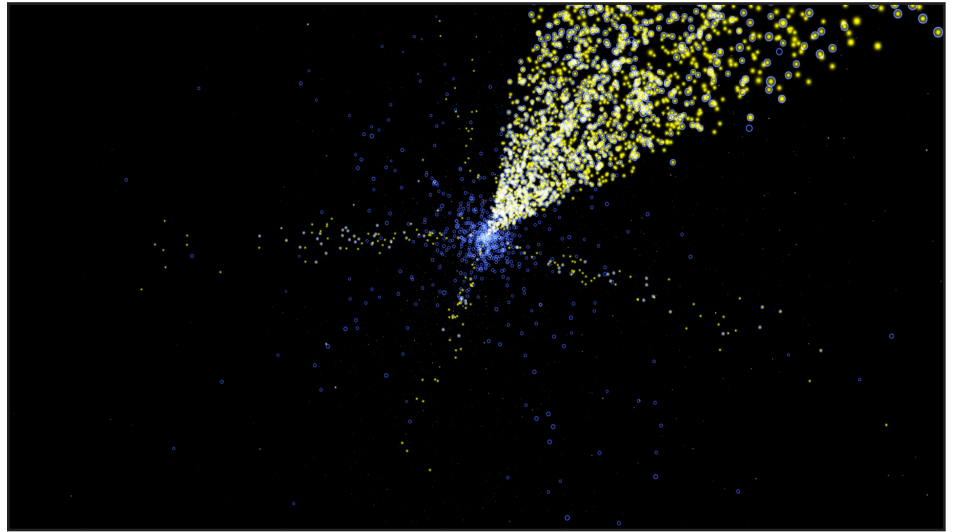
Initially, we observed large planets in nearby stars—all the known planets were relatively close to the Sun. In 2009, the Kepler Telescope was launched into space. Its mission was to stare at one patch of sky near the constellation Cygnus, and find all the planets in that patch. The spacecraft was optimized to detect planetary transits, and was extremely successful in doing so.


 When we say “edge-on” we refer to looking along the thin side, as if looking at the side of your cellphone, where the charging connection is. Conversely, when we look down on the phone’s screen, we are looking “face-on.”


 Turn on the Kepler Planetary Candidates.

 Push out farther to see the Kepler data.

The Kepler Candidates are stars, arbitrarily colored yellow, that are thought to be strong candidates for hosting planets. If you increase the size of the exoplanets, you will see an exoplanet marker on many of the Kepler stars that have been confirmed to host planets.

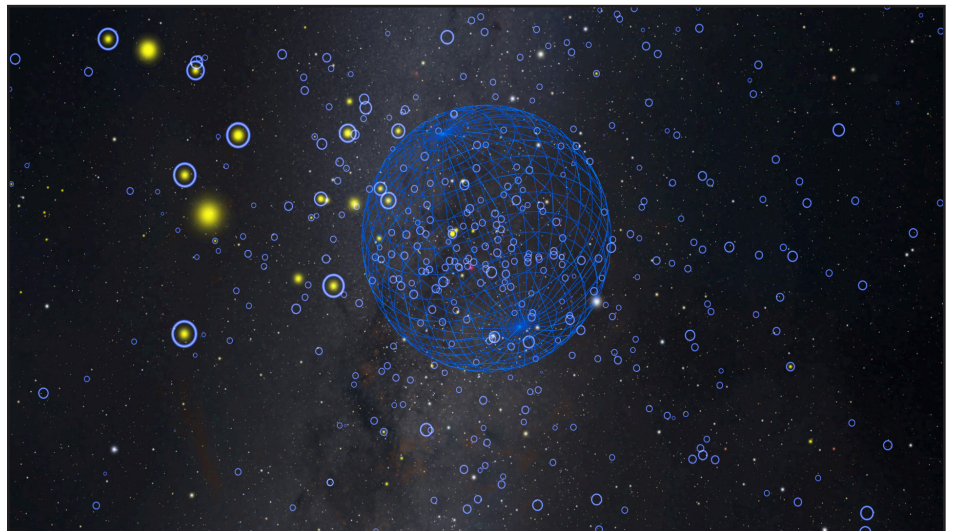



 Increase the size of the exoplanets to see those that are farther from the Sun.

 Turn on the Radio Sphere.

The takeaway with Kepler is that within this narrow cone we see thousands of planetary systems. If we imagine viewing the entire sky with a telescope that possesses Kepler's capabilities, we would see tens or hundreds of thousands of planets in the neighborhood.

From this vantage point, turn on the Radio Sphere. The Radio Sphere is a hypothetical boundary that traces the extent of Earth's radio signals.



 Fly back toward the Sun to explore the Radio Sphere.

Earth began broadcasting to the universe around 1940. Before that, signals did not escape the atmosphere. But, in 1940, stronger signals were able to pass through the atmosphere and travel into space at one light year per year—as all light does. This results in an ever-expanding bubble we call the Radio Sphere.

At the boundary, roughly 80 light years away, are Earth's oldest signals, like the initial broadcast of *I Love Lucy*. As we look closer to Earth, we see more recent signals, until we arrive at Earth, where today's signals are being emitted.


We mentioned earlier that this is a hypothetical boundary because these signals lose strength as they travel out into space—as all light does. The intensity of light falls off as the radius increases—the farther you are from a candle, the dimmer it appears—and Earth's signals are no different.


In reality, by the time our radio signals reach the outer Solar System, their strength is equal to that of the cosmic noise, the background signals that randomly float throughout the Galaxy.

The radio sphere remains a hypothetical boundary, but exemplifies our farthest reach into the universe, not by humans or machines, but by light produced by humans on Earth.

Milky Way Galaxy

 Turn on the Milky Way Galaxy.

 Move away from the Sun so that the entire Galaxy is in view.


 Turn on the constellation lines for a more conspicuous marker of the Sun's position in the Galaxy.


As we explore the edge of the Kepler and exoplanet data, let's look at the Milky Way Galaxy. As you move away from the Sun, keep your eye on the Radio Sphere and Kepler stars as they become smaller and smaller.

Just as we went from the two-dimensional sky into the three-dimensional stars, we now see how that band of light in the night sky we call the Milky Way is actually a large complex of stars, gas, and dust.



Taking in the entire Galaxy, we now see that we're located in a far-off part of the Galaxy, about 26,000 light years from its center. The faint Kepler stars point to the location of Earth.

 Turn off the Kepler stars and Exoplanets.

 Astronomers use the term “dust” to refer to microscopic rocks that can be anywhere from a few molecules up to about one millionth of a meter, or 0.00004 inches.

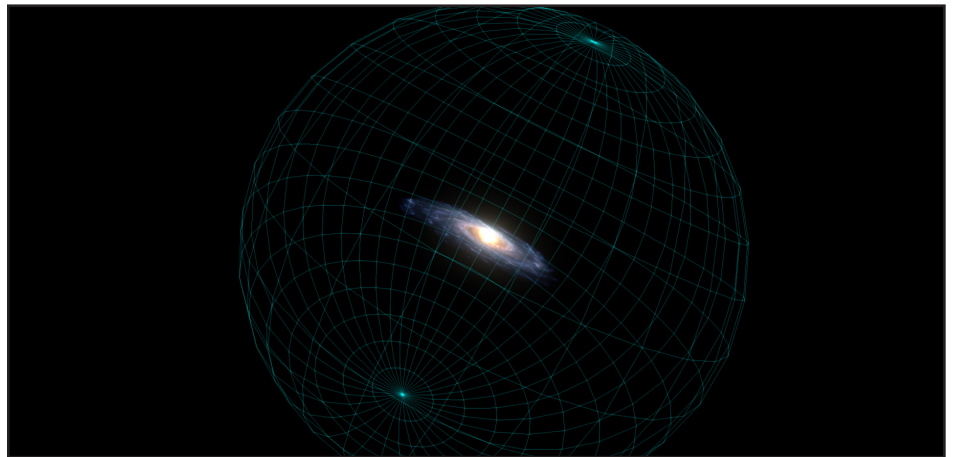
A white dwarf is the remnant of a stellar core. It is very dense and far dimmer than a normal star. It is the final evolutionary state for stars like the Sun.

 Turn on the Milky Way Halo.

The Galaxy is composed of over 100 billion stars, and contains gas and dust* (microscopic, rocky particles). The Milky Way is a spiral galaxy, with a bright center rife with young stars and a supermassive black hole, and arms that emanate from its center. The Galaxy is about 100,000 light years across, but the disk is very thin.


Stars are born from gas that condenses due to gravitational perturbations (from shock waves from a nearby supernova explosion, for example). Galaxies, generally, are star-making machines, where stars are born from this gas and provide light in the otherwise dark universe. When stars die, they return some fraction of their gas back into the Galaxy to form a new star one day. The Sun formed about five billion years ago from such a cloud, and has about five billion years left before it evolves into a white dwarf*—a small, dim object that will ultimately fade away.

Stars form in the disk of the Milky Way—the part we’re viewing now—but, the Galaxy has a spherical component called the *halo*. The spherical halo stretches beyond the disk and is filled with cool, dim stars. Cooler stars have much longer lifetimes (they burn their fuel more slowly), and live long enough to be sent on a trajectory out of the disk of the Galaxy, where they formed. Over time, the halo has been populated with such stars.



All of the stars we see in the night sky with our eye (about 9,000 total, and 6,000 over the course of one night) are very close to the Sun. We cannot see stars this far away from the Sun without sophisticated telescopes.

Given that the Milky Way has hundreds of billions of stars, it’s compelling to wonder just how many planets might be in our own Galaxy. Not all stars will necessarily have planets, but astronomers estimate that the number could be over 500 billion planets.


 *Turn on the Sun's orbit.*

Everything moves in and around the Galaxy. We can see the trajectory of the Sun over the next billion years by turning on the Sun's orbit. The Sun, and its accompanying planets, orbit about the center of the Milky Way about once every 225 million years. This makes us about 20 galactic years old, in other words, we've made about 20 revolutions around the Galaxy since the Sun was born.



On this scale, life began on Earth about 17 galactic years ago, multicellular life appeared about 7 galactic years ago, the KT extinction event occurred 0.3 galactic years ago, and modern humans appeared 0.001 galactic years ago (roughly 200,000 years ago). The Sun has only moved about 145 light years in the time since humans have walked on Earth, a tiny fraction of its galactic orbit that's roughly the diameter of the radio sphere.


The Sun's orbit is remarkably stable, in contrast to other stars that orbit the Galaxy in irregular, unstable orbits, inside and outside the Galactic disk.


 *Turn off the Sun's Orbit and the Milky Way Halo.*


Contemplating the Milky Way and all its worlds, we now turn to what lies outside the Galaxy and the multitude of objects that lie beyond our home star system.


Local Group

 Turn on the Local Group and the Tully Galaxies.

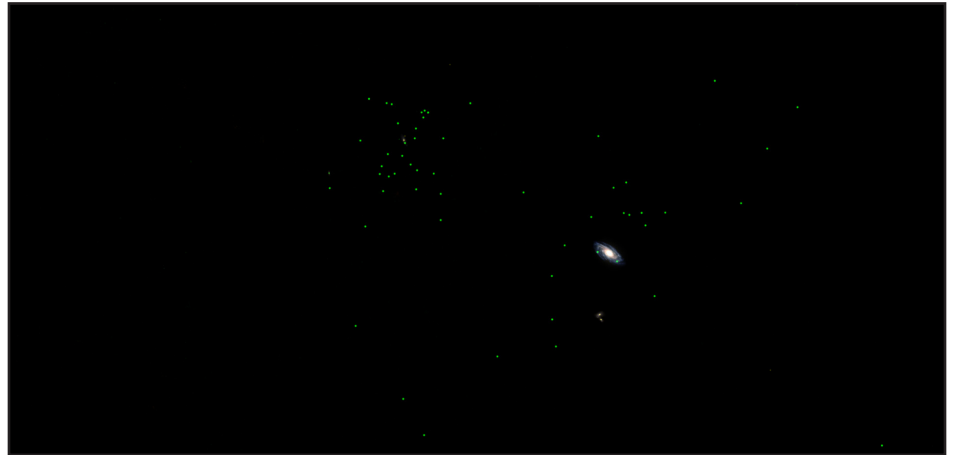
 Dwarf galaxies are small systems with up to several billion stars. They often orbit and interact with larger galaxies, which play a part in their evolution. The Milky Way has many such dwarfs in its sphere of influence.

 Fly away from the Milky Way to see some of the nearby galaxies come into view.

 Turn on the Local Group Boundary.

 The colors of the Local Group galaxies are sorted by gravitational influence. The galaxies in the Milky Way's gravitational influence are green. Blue galaxies are those huddled around the Andromeda Galaxy. Yellow galaxies don't belong to either subgroup, and gray objects are outside the Local Group.

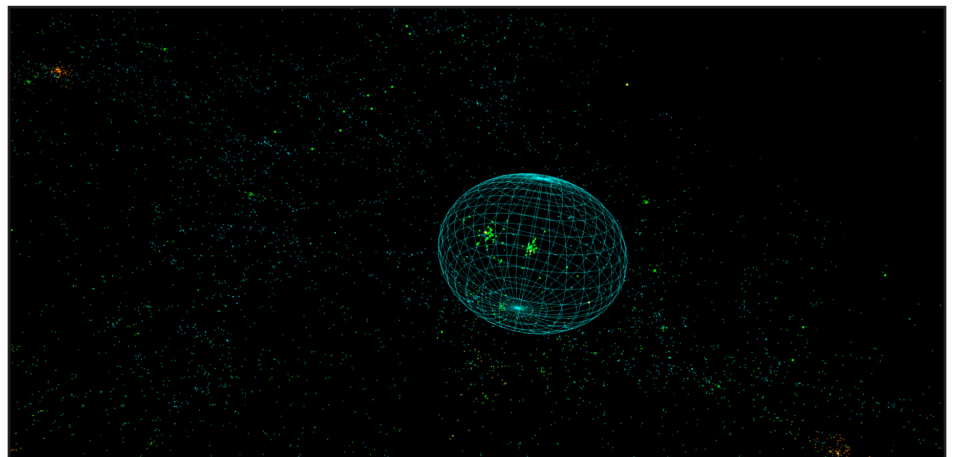
The Milky Way is surrounded by many smaller objects called dwarf galaxies*. These include the Large and Small Magellanic Clouds (two small, nearby galaxies), and other small star systems, some of which are colliding with the Milky Way right now.



The Milky Way dominates this area, but nearby is the Andromeda galaxy, another large spiral galaxy about 2.5 million light years away. It is slightly larger than the Milky Way, and also has a number of dwarf galaxies huddled around it, caught in its gravitational pull.

These two large spiral galaxies, along with another called Triangulum (or, Messier 33), and the many dwarf galaxies, comprise what's called the Local Group.

The wire-frame ellipsoid delineates the Local Group spatially. It is roughly 10 million light years in diameter.




All of these galaxies are influencing one another gravitationally. In fact, the Milky Way and Andromeda are on a collision course toward one another. In about four billion years (22 galactic years from now), the two mammoth galaxies will begin their dance, ramming directly into one another.

Eventually, these two galaxies will coalesce into one large system, in about 30 galactic years from now—long after Earth becomes inhospitable and the Sun is extinguished.

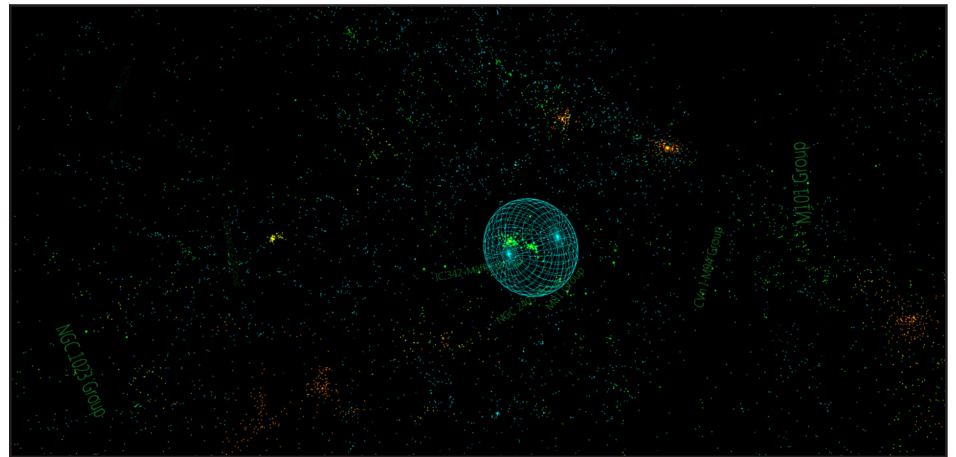
Far off in the future, circa 150 billion years from now, all the galaxies of the Local Group will have coalesced into one large galaxy, but that’s a topic for another tour.


Nearby Universe

 *Fly away from the Local Group to see other nearby galaxies come into view.*


As we pull away from the Local Group, we begin to see the local universe is populated with many galaxies. These galaxies are in the Tully Catalog, compiled by Brent Tully. It is one of the earliest three-dimensional catalogs of the nearby universe, and its roughly 30,000 galaxies remain one of the richest galaxy atlases, with properly scaled and inclined images. Turn on the Galaxy Groups labels to see most of the nearby galaxy groups.


 *Turn on the Galaxy Groups labels.*



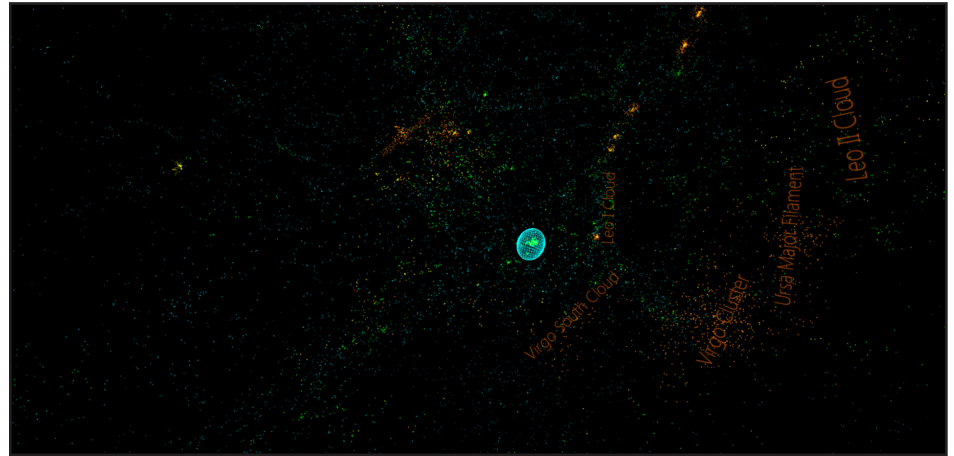
 *The Messier catalog is a compilation of fuzzy objects in the night sky recorded by Charles Messier in the 18th century. He was searching for comets, and noted these stationary look-alikes so as not to confuse them with comets. M51, for example, is the 51st object in the catalog, and is also called the Whirlpool Galaxy.*

None of these other groups are as rich as the Local Group because we cannot see tiny dwarf galaxies from such great distances. From out here, we would likely only see Andromeda, Milky Way, and Triangulum—the large, luminous galaxies. Many of the Messier* galaxies are somewhat local, like M81, M101, M51. One can imagine a cadre of small dwarf galaxies around each of these groups.

 Turn on the *Galaxy Clusters* labels. Increase the brightness of the *Tully Galaxies*.

 Fly farther away so that you see the *Galaxy Clusters* labels in view.

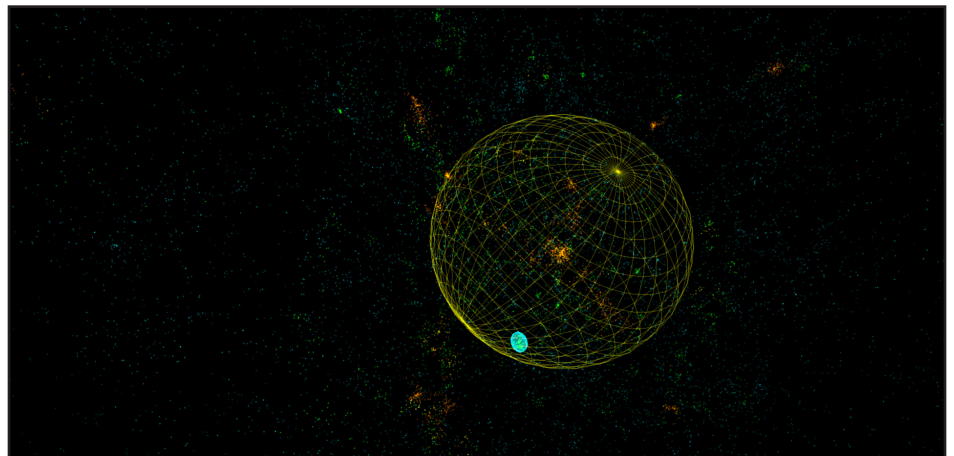
A little farther out and we can see the galaxy clusters in orange. The Virgo Cluster is the nearest, large cluster to us. It's over 50 million light years away, and contains over 1,000 galaxies. This is the bustling center in our corner of the universe.




The Virgo Cluster is the heart of the Virgo Supercluster. A supercluster is a conglomeration of galaxy clusters and groupings. They are among the largest structures known. But, their constituent clusters and galaxies are not necessarily bound gravitationally, their motions are guided more by the overall expansion of the universe.

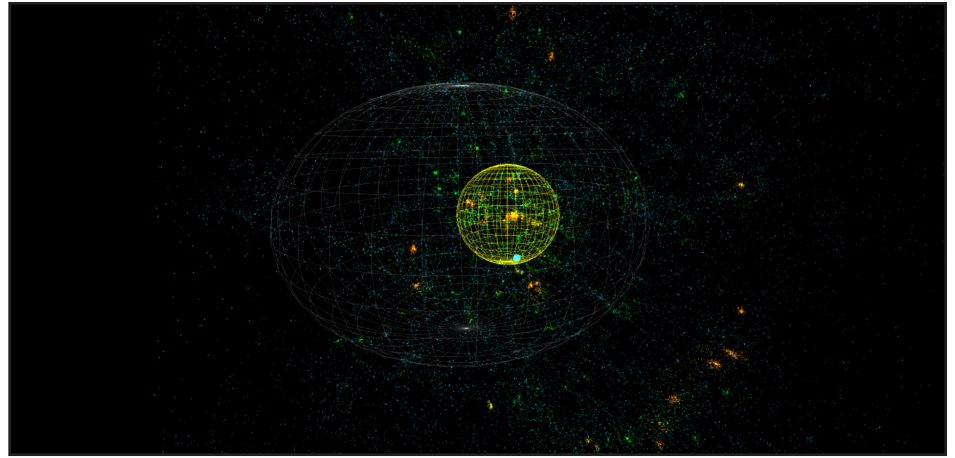
 Turn on the *Virgo Supercluster Boundary*.


With the Virgo Supercluster Boundary on, you can see the Local Group is only a tiny part of the supercluster, and located far from its center.




 Increase the brightness of the *Tully Galaxies*. Then, turn on the *Laniakea Supercluster Boundary*.

In 2014, Brent Tully and a group of astronomers discovered that we are part of an even larger structure which they named the Laniakea Supercluster. This humongous region contains the Milky Way and many thousands of galaxies. The Virgo Supercluster is now just one region among a larger complex of galaxy clusters, connecting strands, and filaments.

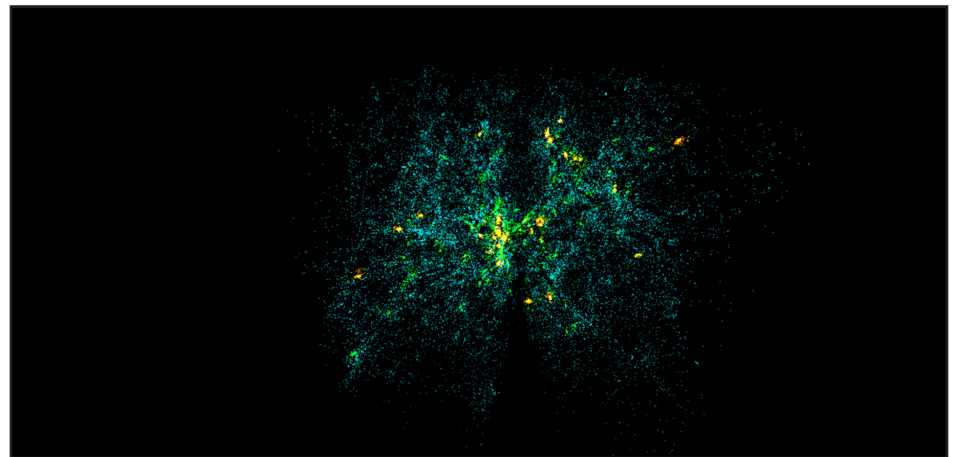



 Turn off the Virgo Supercluster Boundary and the Laniakea Supercluster Boundary.

 Orbit a little faster around the Tully Galaxies.

With the boundaries off, we now see the nearby galaxies more clearly. As you orbit more quickly, the weblike structure of the local universe becomes more apparent. We see clusters of galaxies connected by strands and filaments of galaxies. Between them, we see relatively empty areas, called Voids.

Once you're outside the 30,000 galaxies in Tully, you'll notice that it forms a cube. The universe, of course, is not cube shaped. This squared-off boundary ensures that these data remain consistent. In other words, including galaxies beyond this area would selectively include the brighter galaxies, but not the dim ones represented in the data you see. These data would no longer be representative of the structure of the universe.





 The zone of obscuration is an observational effect whereby the band of light in the sky—the Milky Way—blocks our view of what lies beyond.

Astronomers call this the “zone of avoidance” because when they began plotting these galaxies on the sky, they noticed none were located along the galactic plane.

You may also notice a cleft in the middle of the dataset. This is what we call the *zone of obscuration*^{*}. It delineates an absence of galaxies, but it is an observational phenomenon. We cannot see the galaxies that exist in these areas because that band of light in the night sky—the Milky Way—blocks our view of the galaxies beyond.

Extended Galaxy Surveys

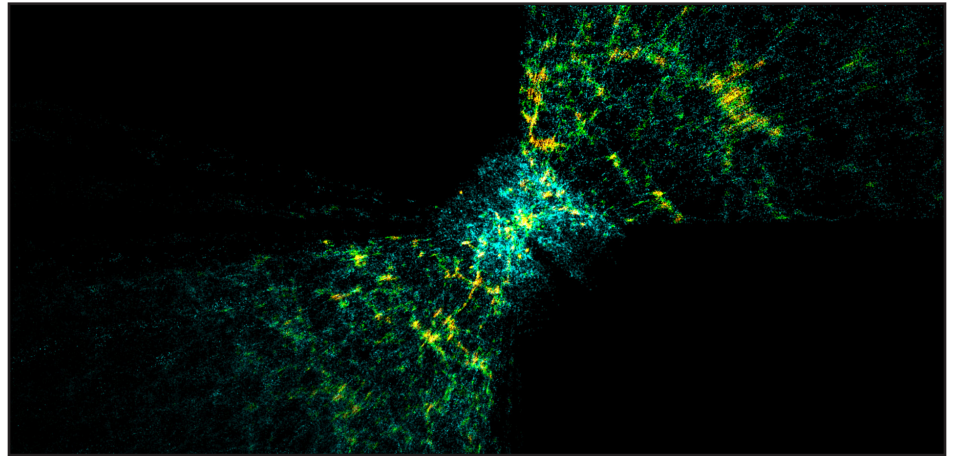
 Fly farther away from the Tully galaxies and continue orbiting.

 Turn on the 2dF Survey.

The Tully Catalog is special because it's an all-sky survey—galaxies were observed in all directions. As we look to more distant objects, it becomes more difficult to achieve this because it takes far more time to peer deeper into the universe.


Galaxy surveys farther out from Tully cover only part of the sky. If one viewed them from Earth, they form distinct patches on the sky, but in three dimensions, they fill out a conical shape, and galaxies lie across a range of distances for each line of sight.

The Two-Degree Field Survey (2dF) is an excellent example. The project was designed to observe along two strips of sky that are opposite one another, but in three dimensions they are narrow fins, shaped like a bow tie, if you will. We benefit, visually, from their narrowness because we can see the rich structure within these fins.

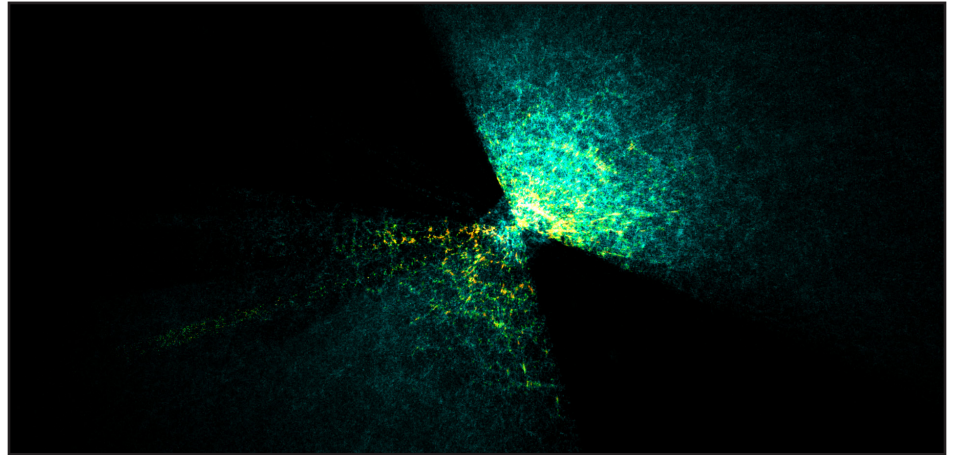


Density scales with color. Orange galaxies are in more dense regions, green galaxies are in more sparse areas of the cosmos, while aqua galaxies are in the middle, density wise.

The 2dF's 229,000 galaxies show the same sponge-like structure, with clusters, filaments, and voids. We also see larger-scale structures like sheets and so-called *walls* of galaxies.

 Turn on the Sloan Survey.


Peering even deeper, the Sloan Digital Sky Survey covers more of the sky. It contains over 2.5 million galaxies, and also echoes the large-scale structure we observe in other surveys.




With these surveys, it's important not to lose sight of the fact that each point you see is a large galaxy akin to the Milky Way. Each point has billions of stars, and who knows how many planets.

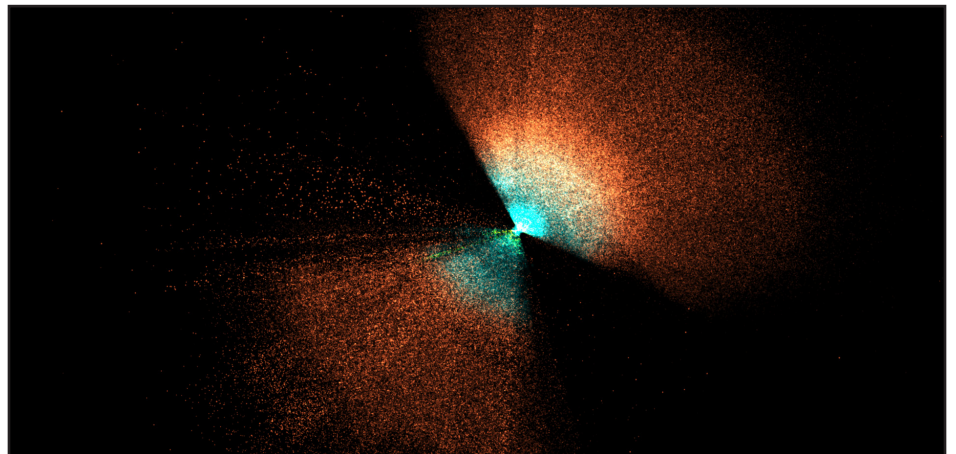
These deep surveys demonstrate that we are only one small planet, orbiting an ordinary star, in an unremarkable galaxy, in a nondescript part of the universe.

Quasars

 Fly farther away from the galaxy surveys and continue orbiting.

Beyond the galaxy surveys are quasars—the farthest objects we see. *Quasar* is just another name for an active galaxy. An active galaxy is one where the central black hole is gobbling up material at a rapid rate. This process causes immense amounts of energy to be released just outside the black hole, as the material falls into it, making these objects extremely luminous. The Milky Way is no longer this active, in this sense, so astronomers call it a *normal* galaxy.


 Turn on the Quasar Survey.



Upon initial observation, these mystery objects were called quasi-stellar objects, and the shortened name, *quasar*, stuck. But, really we're mapping active galactic nuclei, or, in another sense, you can think of this as a catalog of supermassive black holes.

This catalog consists of a half million quasars, and you can see they extend to far greater distances than the galaxies. However, we are now only seeing the brightest objects, so no discernible structure is apparent. There are radial artifacts where more quasars lie, but these are not real, they result from how the data were observed.

You may also notice that there are no quasars near the Milky Way. We only see so-called normal galaxies around us, like our own. Why is this?

 *The Andromeda galaxy is the farthest object you can see with the unaided eye. But, you must be in a very dark sky.*

As we look deeper into the universe, we are looking back in cosmic time. When we see the 2.5-million-light-year-distant Andromeda galaxy with our eyes* or a telescope, we're seeing it as was 2.5 million years ago. When we see one of these quasars, we're seeing light that left billions of years ago. So, we're looking at an earlier epoch in the universe. It's likely that these quasars have evolved into normal galaxies by now, but the light has not had enough time to reach our eyes. So, all the quasars that once dominated our neighborhood have now evolved into normal galaxies, and their light has had enough time to reach our eyes on Earth.

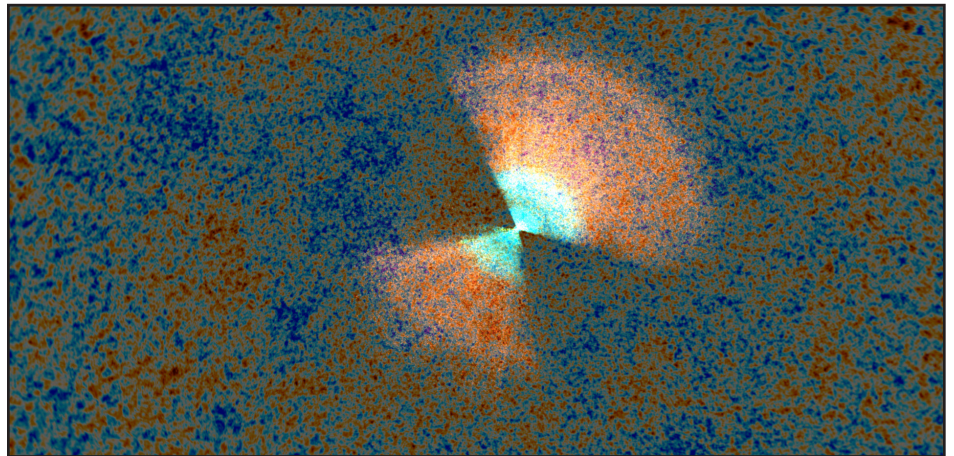
Quasars are the farthest objects we see in the universe, and represent some of the brightest objects we see. The farthest object ever seen is a quasar whose light began its journey when the universe was less than a billion years old. Peak activity for quasars was around 10 billion years ago, when the universe was about 4 billion years old.

Cosmic Microwave Background

 Turn on the Planck Survey.

Quasars may be the most distant *objects* we see, but there is light from an earlier epoch of the universe that remains visible to us. The so-called baby picture of the universe is the cosmic microwave background (CMB). It is light we observe in microwave wavelengths, and marks an important transition in the young universe.

The Planck map. The Planck mission delivered the most recent survey of the CMB in 2013. It is a map of temperature variation in microwave light. The differences between the orange and blue areas is 1/100,000 of a degree, so the telescope that detects these differences is very precise. This light marks the beginning of the radiation epoch in the universe—when light began to travel freely across the universe.

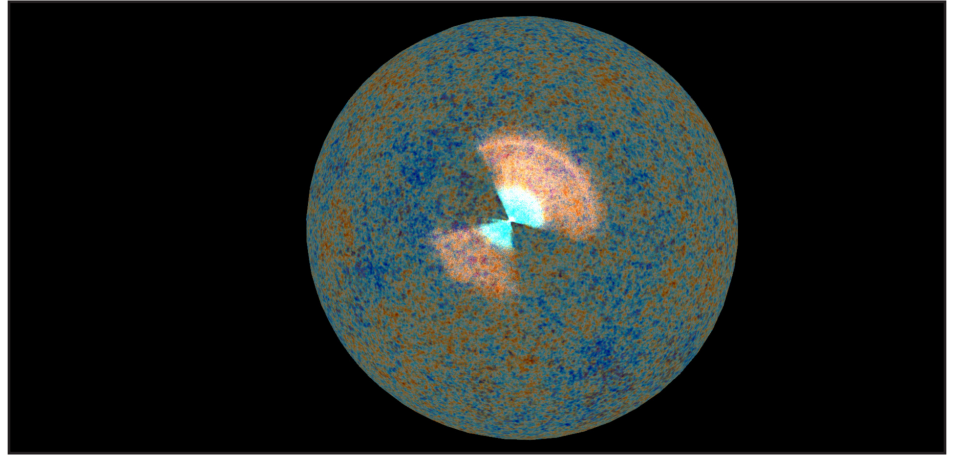


The Big Bang occurred 13.8 billion years ago. The early universe expanded rapidly and was a sea of protons and free electrons. Any light in the early universe was constantly scattered off these particles, just as light is scattered off water vapor on a foggy day, preventing us from seeing objects in the distance.

The fog lifted. Around 400,000 years after the Big Bang, the universe expanded and cooled enough to allow these free electrons to combine with the protons and form hydrogen. When this occurred, it was as if the fog lifted, and light was able to freely travel across the universe.

The CMB is an imprint of the universe at this time. These slight differences in temperature reflect the tiny fluctuations in density in the early universe—the structure of the universe shortly after the Big Bang. These are the seeds that will eventually grow, by gravity, into the large-scale structure of galaxy clusters and filaments we see today. How we went from these small fluctuations in this map to present-day structure remains one of the great challenges in astrophysics today.

When recombination took place, the light from the Big Bang peaked at about 1 micrometer, which is in the infrared. At that time the gas would have been about 3,000 Kelvin (about 2,700 °C or 5,000 °F) and would have glowed orange-red in the visible spectrum. However, the universe has expanded 1,000 times since, and the light within space has been shifted to longer and longer wavelengths because of that expansion. Today, the peak wavelength is close to 1 mm (1 micrometer \times 1,000 = 1 mm) and corresponds to a gas temperature around 3 Kelvin (3,000 K \div 1,000 = 3 K), which is in the microwave spectrum (about -270 °C or -454 °F).



Placement. We place the CMB on a sphere that signifies the boundary of our observable universe. This is a bit misleading. While this is the earliest light we can see, it is ubiquitous throughout the universe, even in the Solar System.


And, what does it mean to fly outside the observable universe? It is not physically relevant, but represents, at best, a thought experiment. We prefer to stay within the bounds of what we see.

A Cosmic Perspective

We've now covered the observable universe. Does that cover the entire universe? No. In a way, this defines the bubble that we can see. We can imagine if we lived on one of these far-off quasars, our bubble would be centered on that quasar.

We are not the center. These surveys might tempt us to think we're at the center of everything. This is merely an artifact of our perspective—everything you see in this atlas is observed data seen from our vantage point. And, every point in the universe has its own unique vantage point.

There is no center. In fact, the universe has no center. The best analogy to describe the fabric of spacetime that comprises the universe is to imagine inflating a balloon. As the balloon grows larger, the distance between any two points on its surface increases. And, more importantly, everything in the universe exists *on the surface* of the balloon. To go from point A to point B, one cannot go through the center of the balloon, one must travel along the surface of the balloon. The universe behaves in a similar manner, albeit with far greater complexity.

 *Fly back to Earth in a gentle, spiral motion.*

As we return to Earth, we traverse the scales of the universe, from a view that encompasses billions of light years, down to objects in the Milky Way that are tens to hundreds of light years in size, to the kilometer-scale continents on earth. Our ability to bridge all these scales allows us to see these data in one, consistent scene, all within the context of the scales that surround it.

Upon returning to Earth, it's easy to see just how small we are and how insignificant Earth is, even in our own galaxy, let alone the rest of the universe. But, it also reveals the staggering probability that life (in some form or fashion) exists somewhere, in another far-off galaxy, or even within the Milky Way. The possibility is just too great to assume that life exists only on Earth.

Conclusion. That's the grand tour. Hopefully, you have an idea of the scale of the observable universe, and what surrounds us in the Solar System, the Milky Way galaxy, and outside the Galaxy. We are a tiny spec among many other specs in the universe, and we've come to understand so much about how the universe formed, our place within it, and its ultimate fate. The universe never fails to invoke a sense of wonder and, in its light, presents pieces to a puzzle that we yearn to solve.