Digital Universe

Data Profiles

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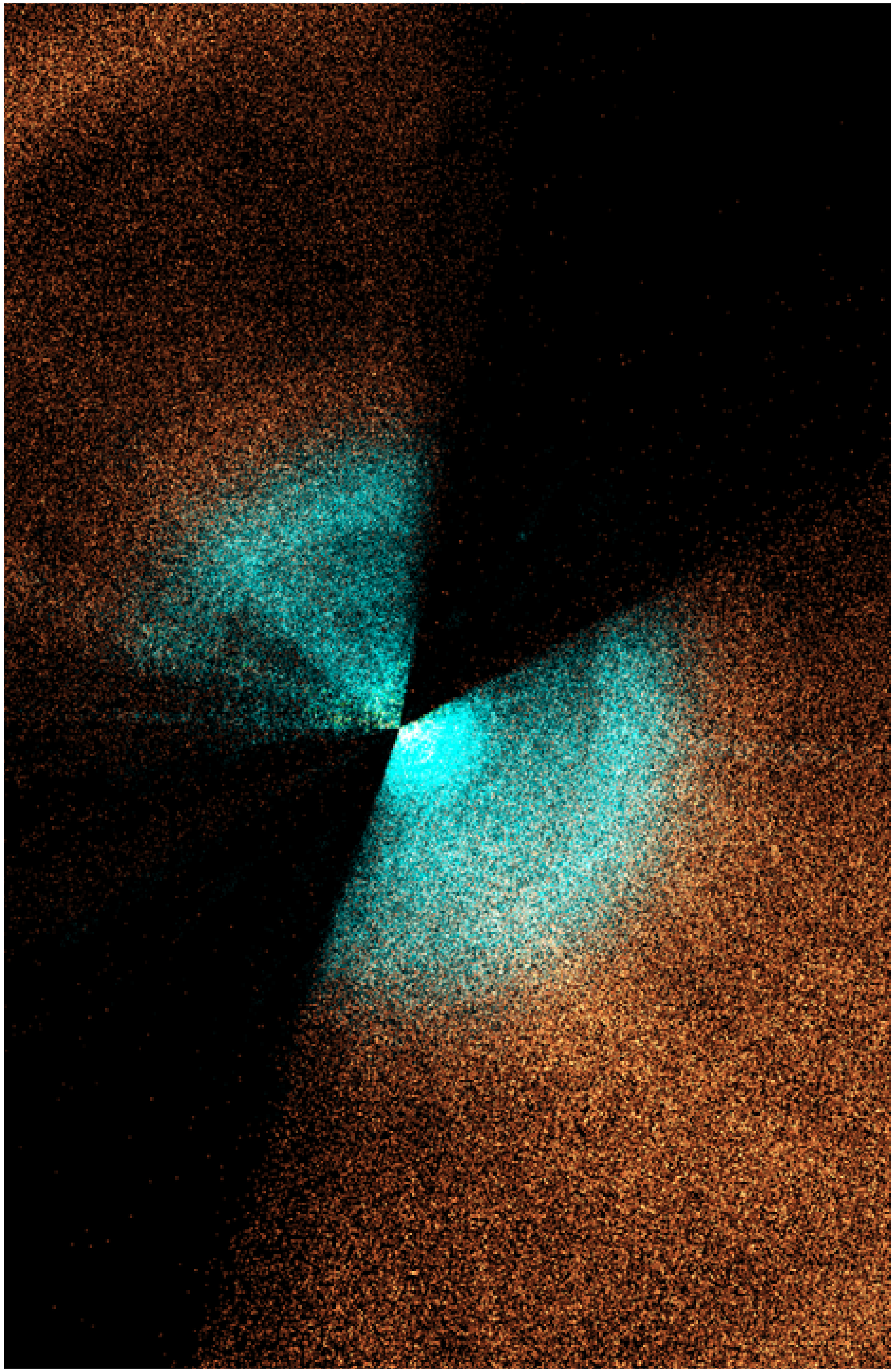
American Museum of Natural History
Revised 2020



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See the Digital Universe website for more information.

Left: The distribution of Sloan galaxies (aqua) and quasars (orange). The bow tie shape occurs because galaxies and quasars that surely exist in the dark areas have not yet been observed.

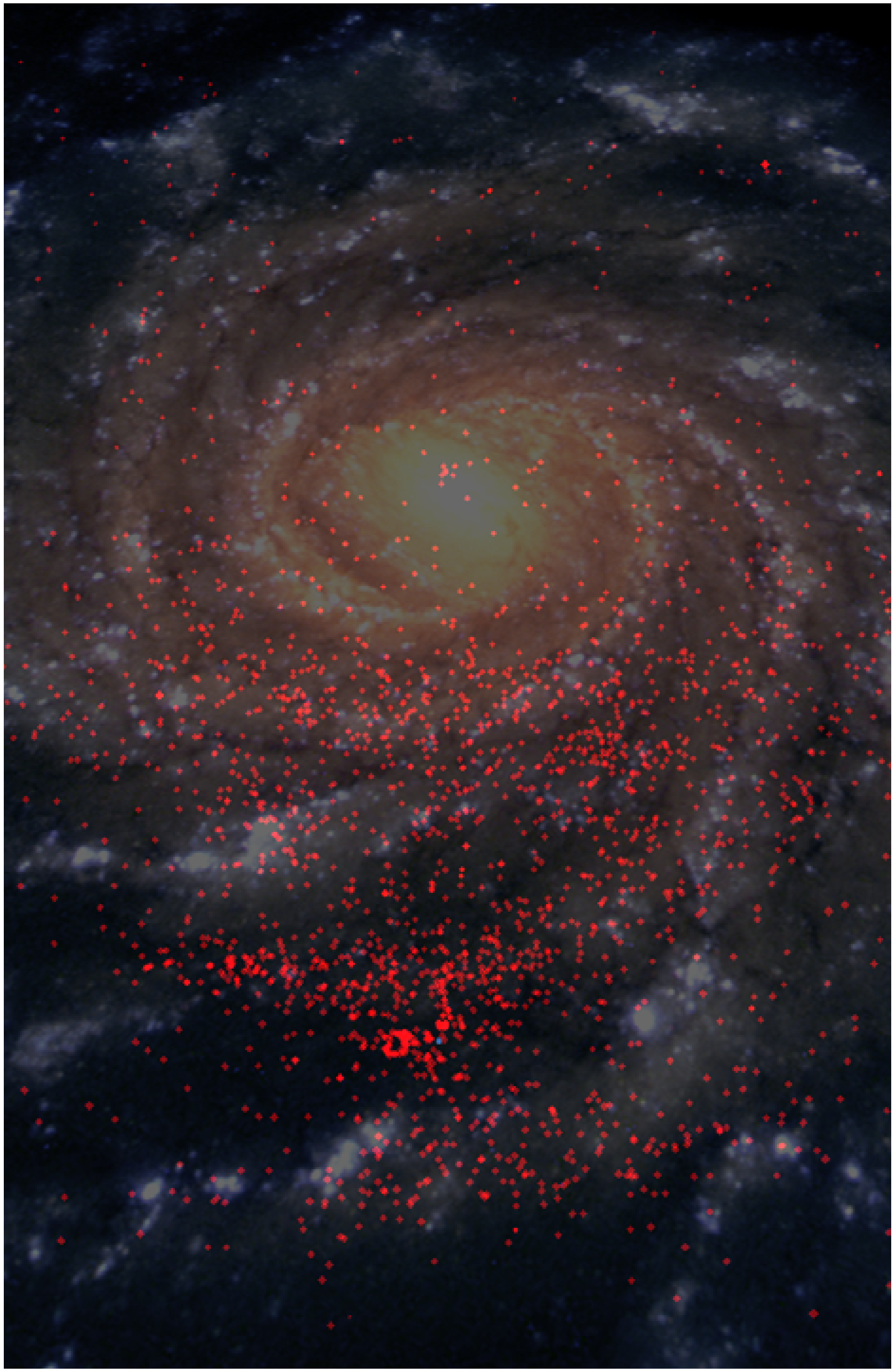
Contents

Preface

This guide is designed to provide cursory information for each data set in the Digital Universe. It cannot comprehensively explain the history, evolution, and intricacies of the universe and each dataset. Instead, we will cover the more elaborate stories and their methods in our tutorials. These are in the process of being adapted from the old Digital Universe Guide. The first one is included in this package and is called *The Grand Tour*.

The order of these sections follows a logical progression that resembles how one could explore these data sets. We begin with the familiar—our night sky—and move out into the Milky Way and then into the large-scale structure of the universe. The order will take you from one dataset to another in the same way stepping stones guide you down a path. With a few exceptions, this order provides a spatial progression to the atlas.

This guide is designed to be software agnostic. The Digital Universe runs on many platforms and software packages, each with their own interface and command structure. This guide merely provides information about the datasets and some of the compelling stories of the universe.



Right: Looking down on the Milky Way with the pulsars (red) on display.

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Stars

Description	Stars in the local galactic neighborhood for which we can determine a relatively accurate distance.
Census	Full catalog: 385,477,132 Abridged version: 104,452 with 324 labels
Version	7.9

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Left: The stars as seen in Earth's night sky, looking toward Orion, with the nearby stars Sirius and Procyon. **Right:** The stars from a vantage point looking back toward Earth. Polaris, the North Star, is in the foreground. Earth is inside the 80-light-year blue sphere.

The abridged version of our catalog has a limited number of stars so that one can run it on software with less sophisticated memory management. Running the full set of stars requires advanced, under-the-hood capabilities to display this quantity of stars.

The stars form the backbone for our atlas, but also for the universe itself. We base much of what we know about the universe on the characteristics of the stars, and they are the first rung on the so-called distance ladder that other distance-determination methods rely upon.

Source Catalogs. Gaia, the ESA mission to derive accurate distances to the stars, has given us a revolutionary picture of the Galaxy. With over 1 billion stars mapped, it is the most accurate data for the nearby stars and includes a number of star clusters. It also includes motion information for a large subset of stars, so we can see how different populations

Prior to Gaia, the Hipparcos Catalog, released in 1997, was the most complete catalog with reliable distances for roughly 118,000 stars. Named after Hipparchus, the second-century-BC astronomer who first cataloged the stars, Hipparcos, the mission, was remarkably successful at mapping the nearby stars around the Sun.

The first time astronomers measured a relatively accurate distance to a star outside the solar system was in 1838, when the star 61 Cygni was observed by the German astronomer-mathematician Friedrich Bessel. Before Hipparcos, we had distances to about 3,500 stars compiled in a catalog by Wilhelm Gliese in 1969 and updated in 1991.

This star catalog is a combination of all available star catalogs, wherein we choose the best distance available to place the stars around the Sun as accurately as is possible.

Star Names. The stars' names are now approved by the International Astronomical Union. Many of them are Arabic in origin and date from the Middle Ages or before. Alternate names, like the Greek-lettered names, are provided in the Alternate Labels, described in the next section.

Alternate Star Names

Description	Common star names from long-standing star catalogs that attempt to name most of the visible stars, beyond those that have specific names.
Census	3,365 star names
Version	1.8

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Left: Stars with the alternate labels on, looking toward Orion. Sirius, or Alpha Canis Majoris (Alp CMa) is relatively near, as are the dimmer Pi^3 Orionis. **Right:** The alternate labels from a distant point in space, with Polaris, or Alpha Ursa Minoris (Alp UMi) and Beta Cepheid in the foreground.

To effectively visualize these star names, it helps to limit the number of labels drawn. This is typically controlled by drawing only labels that are larger than specified size, thereby removing the smaller, more distant labels.

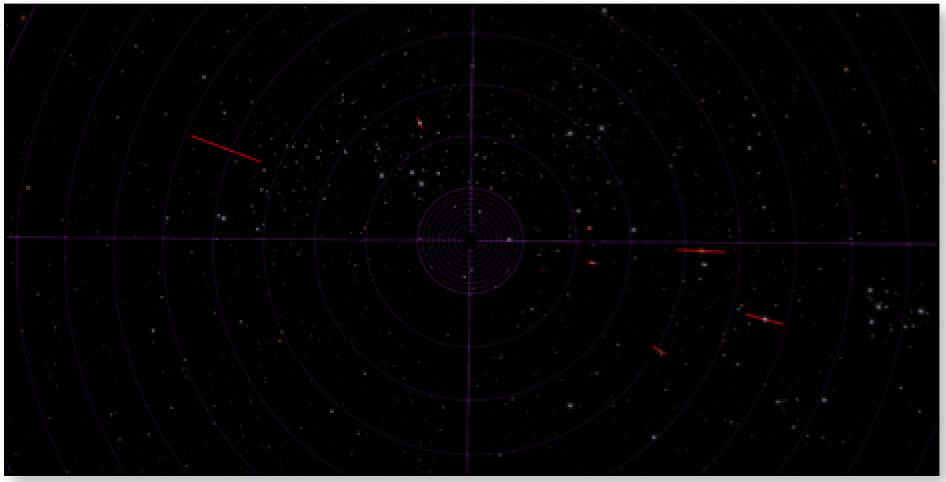
The main star data identify the accepted IAU star names for the brightest stars. However, astronomers have long cataloged thousands of stars beyond the brightest ones we see. Several attempts over thousands of years to name all the visible stars have led to two main catalogs: Johann Bayer's Catalog from 1603 and John Flamsteed's Catalog published in 1725.

The Bayer names (which take precedence in this data set) are designated by a Greek letter along with the genitive form of the constellation name. The stars were ranked by brightness and their names are sequential through the Greek alphabet. For example, the brightest star in each constellation received the alpha (α) designation because that is the first letter in the alphabet. The second-brightest is named beta (β), and so on to omega (ω), provided there are enough stars in the constellation. So, Betelgeuse is α Orionis and Rigel is β Orionis (we use a three-letter abbreviation for the Greek letter and the constellation names, for example, *Alp Ori*).

The Flamsteed Catalog uses numbers as designations along with the constellation name. Originally they were sequenced according to their position in the sky; however, precession has created inconsistencies over the centuries. Flamsteed names take the form *58 Orionis*, which is Betelgeuse. Unlike the Bayer names, which are limited by the twenty-four letters of the Greek alphabet, Flamsteed numbers can exceed 100 for a particular constellation.

Stellar Distance Uncertainty

Description	A visual representation of the uncertainty of a star's distance for select stars.
Census	7 stars with uncertainty data
Version	4.4



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Red lines show the distance uncertainty for several stars near the Sun (at center). The closer the star, the better the measurement, so there is less uncertainty.

Stars with Mapped Uncertainty (in light years)				
Star Name	**Other Name**	**Distance**	**Range**	**Uncertainty**
Bellatrix	γ Orionis	252	242 – 262	20
Spica	α Virginis	249	237 – 262	25
Betelgeuse	α Orionis	497	441 – 553	112
Polaris	α Ursae Minoris	432	426 – 438	12
Antares	α Scorpii	553	473 – 634	161
Rigel	β Orionis	862	791 – 933	142
Deneb	α Cygni	1,411	1,239 – 1,583	344

The position of each object in the Digital Universe has an uncertainty associated with it. To illustrate this, we demonstrate distance uncertainty for several stars of various distances and luminosities.

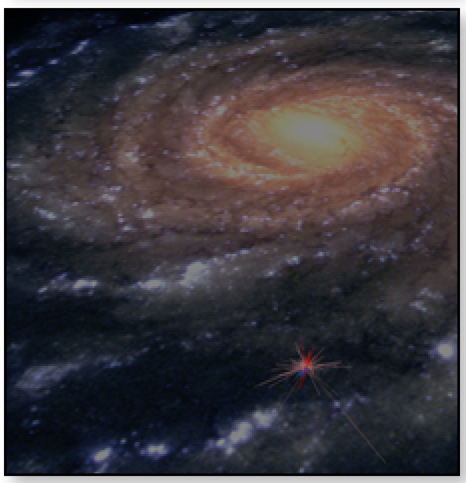
From Earth, we can measure a star's two-dimensional position in the sky to great accuracy. However, the star's distance remains elusive. Our most accurate distances come from the measurement of an angle in the sky that is imperceptible to the naked eye. This angle results from the trigonometric parallax (the apparent motion of the star resulting from the Earth's motion around the Sun), and the uncertainties and errors in the measurement of this angle translate into uncertainties in the star's distance.

Representing uncertainty. In the atlas, uncertainties are represented by a series of points that, when viewed from a distance, appear to form a line. The points are spaced 1 light year apart, and we leave a space for the published parallax distance. Labels, in light years, denote the near distance uncertainty, the published distance, and the far distance uncertainty.

The star Bellatrix in Orion one of the closer star in this sample. At 252 light years, it has a mere 20-light-year uncertainty. Compare that with Betelgeuse, a star that is nearby in the sky but lies about 250 light years beyond the Bellatrix. Rigel, also in Orion, is about twice the distance of Betelgeuse and has a larger uncertainty. As you explore the atlas of stars, nebulae, and galaxies, consider that there is uncertainty associated with each of these objects and often the uncertainty for nonstellar objects is far greater.

Constellations

Description	The "stick figures" that connect the major stars of each constellation.
Census	88 constellations and labels
Version	3.3



Top left: The constellation connectivity lines as seen in the night sky. Here, we're looking toward Orion, the hunter.

Top right: The constellation lines quickly lose their meaning once we move away from the Sun. A distorted Orion is visible behind the Sun.

Bottom: The constellation lines may be used as a signpost that marks the location of the Sun in the Milky Way.

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Throughout history, and across all cultures, artists have used the night sky as a visual aid for stories that recount their mythology and folklore.

As a continent is divided into countries, astronomers divide the sky into eighty-eight regions called constellations. These modern constellations are largely based on those of the Babylonians and Greeks; however, most cultures have their own figures and stories of the sky. More than half the official constellations adopted by scientists in 1930 were known to the ancients over 2,000 years ago.

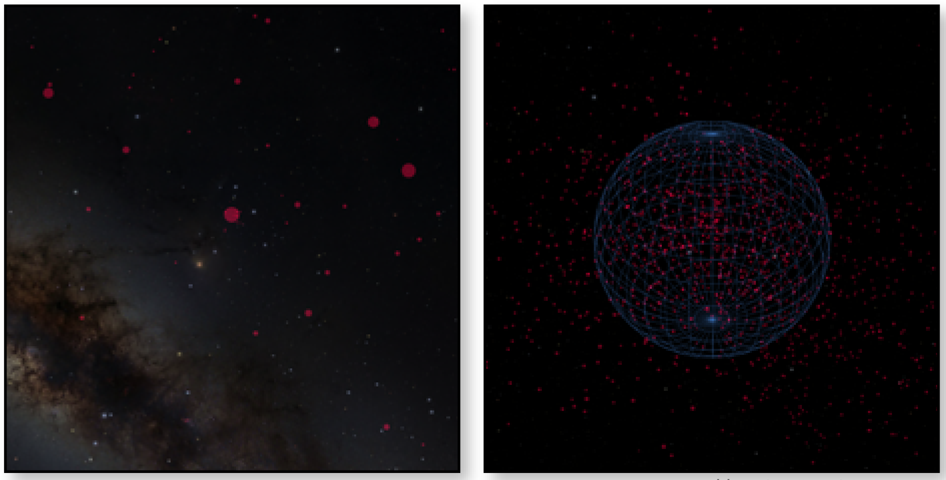
Each star falls into one of these 88 regions. Of course, today we know the stars in any given constellation do not necessarily have any physical relationship with one another. One star may be nearby, while an adjacent star in the sky may be far away.

Constellation connectivity lines. In the Atlas, we represent the constellations by connecting the main stars that make up the constellation "stick figures," as seen from Earth. While there are many philosophies on how to connect the stars—some people swear by the constellation art by author H. A. Rey (famous for the *Curious George* children's books), others by their favorite star atlas—we have chosen configurations that we are comfortable with.

Each constellation has a label that is positioned within the constellation and arbitrarily placed 80 light years from Earth.

Dwarf Catalog

Description	A catalog of substellar objects, not large enough to be fully fledged stars, but larger than planets. Some are brown dwarfs, others are not even massive enough for that moniker.
Census	785 L dwarfs, 101 T dwarfs, 17 Y dwarfs
Version	6.4



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Left: Substellar objects, called brown dwarfs, as seen from the night sky and, **right**, their distribution around the Sun, which lies at the center of the blue, 80-light-year sphere.

None of these objects are visible to the eye, so we represent these objects conceptually with oversized points, tinted according to their type: **L dwarfs**, **T dwarfs**, and **Y dwarfs**. Their brightness (size) is grossly exaggerated relative to the stars.

In astronomy, there are dwarf stars—red, white, and brown—dwarf novae, and even dwarf galaxies. As you might imagine, astronomers use the term *dwarf* when they refer to the smaller objects in any given class.

For decades it was believed that M stars were the coolest stars in the Galaxy. Some M stars, called red dwarfs, make up 70% of the stars in the Galaxy, including our nearest known neighbor, Proxima Centauri. However, a new class of objects, even cooler than M stars, was recently discovered and given a spectral type of *L*. L-type objects straddle the boundary between red dwarfs and brown dwarfs, the latter of which are not massive enough to ignite the nuclear processes necessary for it to shine as a star. L-type objects are typically very dim stars or brown dwarfs.

Even cooler than L-type objects are T-type objects. These are mostly brown dwarfs and resemble large, massive, Jupiter-like objects, too large to be planets and typically too small to be stars. Beyond the T dwarfs are the Y-type objects, which are even more dim.

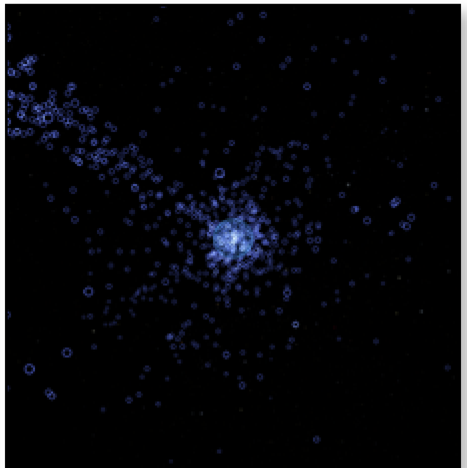
Brown dwarfs are extremely difficult to see, mainly because they are so dim in optical light. However, they appear brighter in infrared light. Using infrared surveys, such as the Wide-field Infrared Survey Explorer (WISE), astronomers compared data from infrared images to optical images. If an object appeared bright in the infrared, but was dim or nonexistent in optical light, it was targeted for further observation to confirm its identity as a dwarf.

Type	Spectral Index	Description
L	10 – 19.9	The dwarfs objects have numerical spectral types that may be used to isolate a particular class from the others.
T	20 – 29.9	
Y	30 – 39.9	

These dwarf objects are a burgeoning field in astronomy as scientists define the line between planet, brown dwarf, and low-mass star.

Exoplanets

Description	Indicators mark each star that hosts a system of planets.
Census	4,352 planets in 3,219 systems
Version	20.12



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Blue rings indicate stars that have planets. Labels are shown on foreground systems and take the name of the host star. A number in parenthesis indicates the number of planets in that system. A label without such a number has only one discovered planet. **Left:** Exoplanets from Earth's perspective. **Right:** Exoplanets as they are distributed around the Sun.

Exoplanet labels with a number in parentheses signifies the num ber of planets in the system. Exoplanet labels with no parenthetical number has only one confirmed planet.

Extrasolar planets, or exoplanets, are a relatively new phenomenon in astronomy. While many astronomers believed in their existence, no observational evidence was available until 1995. Since that time, scientists have discovered thousands of systems consisting of one or more planets around a host star.

Lost in starlight—detecting exoplanets. To the eye, exoplanets are lost in the glare of their host star. Unconventional techniques are required to infer or observe them. The most common method, thanks to the Kepler and TESS missions, uses the transit of the planet in front of its host star. This, of course, requires the alignment of its orbit be edge-on from our vantage point, which is not terribly probable. However, this method can detect planets a few thousand light years away. Projects include the Transiting Exoplanet Survey Satellite (TESS), Kepler, Wide Angle Search for Planets (WASP), the Kilodegree Extremely Little Telescope (KELT), the Hungarian Automated Telescope (HAT), and the Convection Rotation and planetary Transits (CoRoT). TESS, the Transiting Exoplanet Survey Satellite, is the current generation of planet-detecting telescopes. It was launched in April 2018 and has begun discovering exoplanets.

The radial velocity method is the next most common. A variation in the star's radial velocity is observed in the spectrum which results from the planet's motion around the star. While we think the Sun is stationary, it actually moves, or wobbles, because of the planets that orbit it. The larger the planet, the larger the wobble. This is because the center of the orbit is actually located at a point called the *center of mass* of the system. So, for example, the Sun-Jupiter system's center of mass is more than 778,000 kilometers (483,000 miles) from the Sun's center. This point, along the line connecting the two bodies, lies just outside the Sun's photosphere, or "surface," which has a radius of about 696,000 km (432,000 miles). While we do not perceive it, the Sun is orbiting this point and would be observed to wobble from a point of view outside the Solar System. Some projects detecting radial velocities include High Accuracy Radial Velocity Planet Searcher (HARPS) and the High Resolution Echelle Spectrometer (HIRES) on the Keck Telescope.

The next most common method for exoplanet discovery uses gravitational microlensing to detect a planet. Lensing occurs when the light of a distant star is magnified by a foreground star. When the foreground star has a planet, its gravitational influence is seen in the lensed light from the background star. This requires two stars to align with one another, which only happens for a short time, given Earth is in motion, along with the two stars in question. This requires continuous monitoring to catch one of these lensing events. The Optical Gravitational Lensing Experiment (OGLE) developed a technique for observing such events. The benefit of this technique is that lensing can reveal low-mass planets with smaller orbits. The drawback is that the observation cannot be repeated, and science favors reproducibility.

At the bleeding edge of exoplanet science is direct imaging. Planets that orbit far from their host star tend to reflect less starlight and so we can detect their thermal energy. This method is only really beneficial for systems near the sun, and for large planets that orbit far from their host star. But, it is a growing field and about one percent of these planets were found by direct imaging.

Less than one percent of the known systems were discovered using other methods, including pulsar timings that measure the periodic variation in the light arrival time.

Planets visualized. The exoplanet systems are represented by a blue ring centered on each host star. The ring is not intended to signify an orbit; the various ring sizes reveal their distance from you. The labels list the host star name, and if there is more than one planet, will list the number of planets in parentheses.

Metadata. Several columns of metadata are available for manipulation. We include the distance in light years, the number of planets in the system, the year of discovery, and an index for the discovery method.

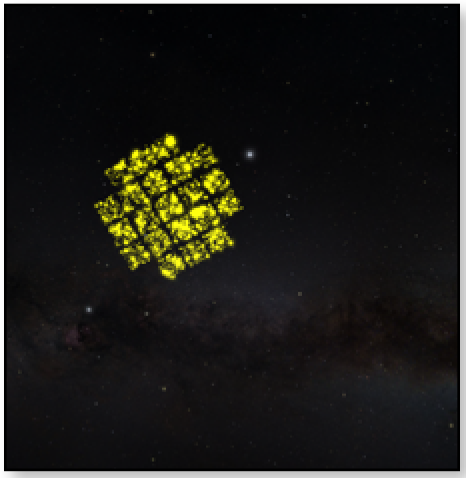
The discovery method is described via the method number, and an index is assigned to each method according to the following table:

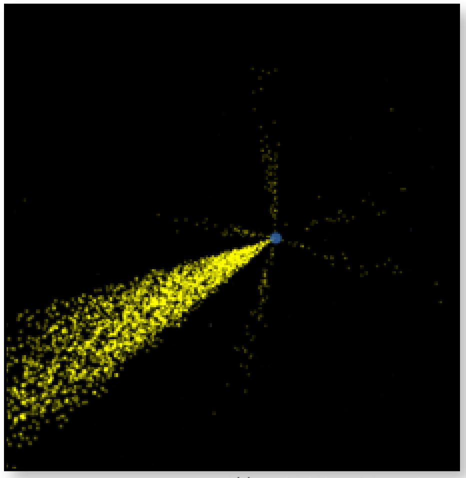
Discovery Method for Exoplanets

Method Index	Number of Systems	Description
1	553	Radial velocity
2	2,335	Transit
3	42	Imaging
4	3	Pulsar timing
5	76	Microlensing
6	1	Astrometry
7	3	Orbital brightness modulation
8	2	Pulsar timing variations
9	8	Eclipse timing variations

Exoplanet Candidates

Description	Exoplanet candidates are stars observed that have a high probability for hosting planets. These stars show promise, but have not yet been confirmed as planetary hosts.
Census	4,110 stars
Version	10.8





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The exoplanet candidate stars are visualized as generic, yellow objects. Each of these stars was deemed by the Kepler or TESS mission as a likely host for planets, and many have been confirmed. **Left:** Kepler's exoplanet candidates as seen in the night sky. Kepler's main mission stared at one small patch of sky, and here we see the detector's footprint on the sky as reflected in these data. **Right:** The exoplanet candidate stars in 3-D. The Kepler field's stars form a cone that appears to emanate from Earth, while the K2 mission stars form smaller cones that encircle the Sun mixed in with TESS stars.

Includes data from the TESS, Kepler, and K2 missions.

The exoplanet candidate stars are likely hosts for exoplanets. These are stars plucked from NASA's Kepler and TESS space telescopes. The Kepler mission was designed to stare at one spot, roughly twelve degrees across, in the constellation Cygnus. By staring at one spot, the spacecraft could monitor over 500,000 stars in that field for subtle variations in brightness.

These slight differences in brightness signify the transit of the star's planet, so we must view the planetary orbit edge-on for Kepler to detect a planet. In order to be considered a candidate for exoplanets, the observations must pass several tests to rule out other factors that could affect the brightness.

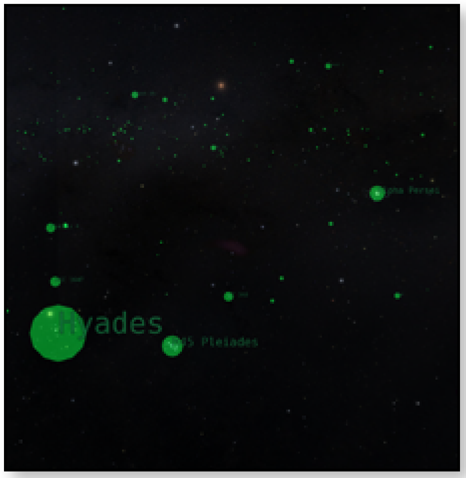
In July 2012, Kepler lost control of four of its reaction wheels that provide attitude control of the spacecraft. And, less than one year later, one of the two remaining reaction wheels failed, threatening the entire mission. In response to this, the K2 mission was proposed as an extension of the original mission. The spacecraft was limited to searching along the ecliptic, the plane containing Earth's orbit around the Sun (or the annual path of the Sun in the sky).

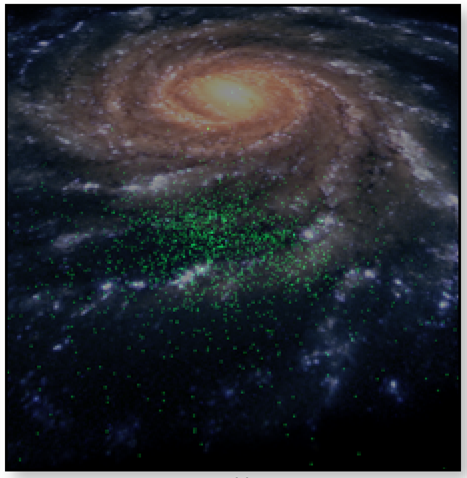
The Kepler telescope was shut down in late 2018 after its fuel was expended; however, TESS was launched that same year and is now detecting planets. Kepler, with its narrow patch of sky coverage, was a case study, if you will. TESS will observe a much larger swath of sky and will detect a far greater number of planets.

Visualization. The data included here are the stars that are considered good candidates to host planets. Rather than represent them photo-realistically, with accurate colors, we choose to visualize them as generic, pure yellow stars. The nature of these stars is not important, it is the sheer numbers of potential exoplanets in these segments of the sky that allows us to wonder just how many we will find in the entire Galaxy, and TESS gives us that fuller picture.

Open Star Clusters

Description	Positions of open star clusters in the Milky Way.
Census	2,609 clusters
Version	6.8





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Open star clusters are marked with green, circular markers. **Left:** The open clusters as seen from Earth, looking toward the nearby Hyades and Pleiades clusters in Taurus. **Right:** The distribution of open clusters in the Milky Way.

An open star cluster is a loose assemblage of stars numbering from hundreds to thousands that are bound by their mutual gravitation. Astronomers know from their stellar spectra that stars in open clusters are typically young. (With a star's spectrum, we can determine the spectral type and the luminosity class, revealing the star's age.)

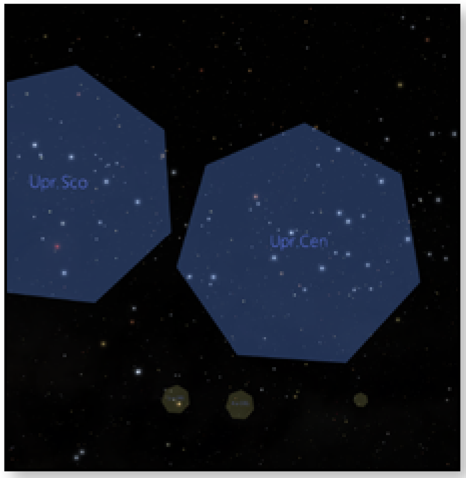
Because these are young stars, we expect to see them in the star-forming regions of our Galaxy, namely in the spiral arms. For this reason, open clusters exist, for the most part, in the plane of the Galaxy, where we view the arms edge-on as that band of light in the night sky. Because of this, open clusters were originally known as Galactic clusters, but this term fell out of favor once astronomers began to understand that the Galaxy includes objects beyond the Milky Way's disk.

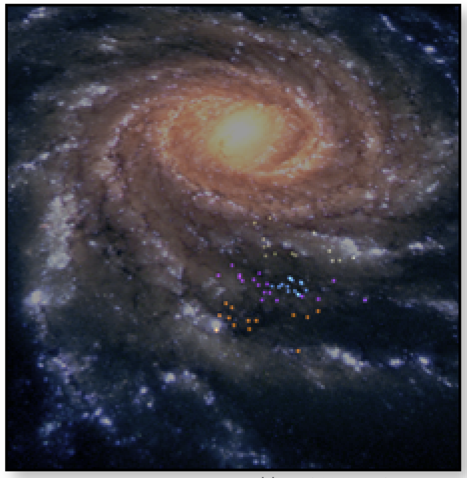
Source catalog. The main open cluster catalog was compiled by Wilton Dias and collaborators in Brazil and Portugal. It is a comprehensive collection of data from other catalogs. We supplement this with a new catalog by Alfred Castro-Ginard in Spain, who incorporated the Gaia star catalog to increase the number of known clusters by 45%.

Exploring the data. Open clusters are good tracers of local spiral structure. Using the `logage` metadata, we can highlight the youngest clusters, which tightly trace the spiral arms. From outside the Galaxy, these clusters vaguely trace out the local spiral structure, which form three distinct arms: the Sagittarius Arm toward Galactic center; the Orion Spur, where we live; and the Perseus Arm, toward the outer edge of the Galactic disk. To emphasize the point further, turn on the OB associations. These are in exact agreement with the open clusters, each providing a measure of the Galactic structure in our part of the Galaxy. The spiral structure is also visible in the pulsars and the star-forming regions. Read about these groups in the coming sections.

OB Associations

Description	Stellar associations are loose agglomerations of stars. OB associations typically have on the order of dozens of O and B stars in them (hotter, massive, younger stars) in addition to cooler stars.
Census	61 OB associations
Version	2.4





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Multicolored OB Associations vary in size according to their physical size. **Left:** the view from the night sky, with the large Upper Scorpius and Upper Centaurus regions. **Right:** the view from above the Milky Way, where the OBs delineate the nearest spiral arms of the galaxy.

These objects are color coded by their spiral arm membership.
Blue associations trace the Sagittarius Arm
Purple associations are in the local Orion Spur
Orange associations are in the Perseus Arm.

One of the few datasets that are sized according to their physical size. Most data are sized according to brightness, or are all sized equally, in which case the size of the point conveys its distance—larger points are closer to you. The OB associations are scaled according to their physical diameter.

OB associations are young groups of stars that were formed within a giant molecular cloud, but have dispersed after the original gas and dust from the cloud was blown away by the star's radiation pressure. Although an association's stars are no longer gravitationally bound to one another, they share a common motion in space because they were formed from the same cloud. This allows astronomers to easily determine OB association membership stars.

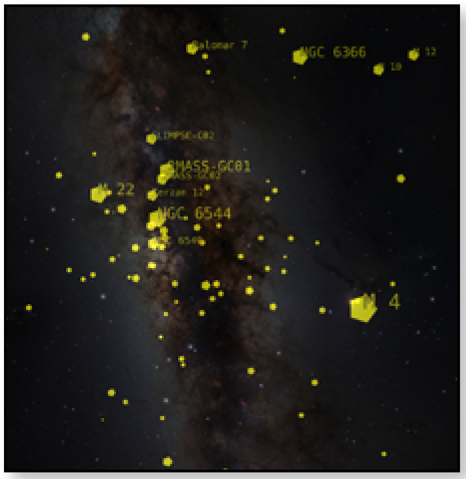
Associations typically have anywhere from 10 to 100 massive stars (O and B stars), and hundreds or thousands of lower-mass stars. The short-lived O stars will explode via supernova in roughly a million years, so they do not move far from their birthplace.

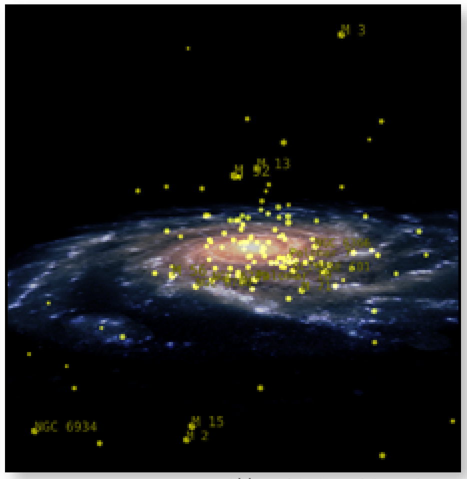
O and B stars are quite luminous, making OB associations visible to great distances. And because O and B stars are young stars, we know they form in the regions of the Galaxy where star formation occurs: the spiral arms. Therefore, OB associations are good tracers for spiral structure. We assign colors to these objects based on their spiral arm membership (see the note to the left).

Because O and B stars are relatively short lived, OB associations are generally young. Their member stars do not have much time to stray from their birthplace, so young associations tend to be fairly consolidated, although not as condensed as a star cluster.

Globular Star Clusters

Description	Globular star clusters are dense balls of 100 thousand to 1 million stars that orbit the Milky Way outside the Galaxy's disk.
Census	157 globular clusters
Version	2.6





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Globular star clusters are marked with yellow pentagons. In reality, the actual star cluster would be much smaller than these markers. **Left:** Globular clusters as seen from Earth looking toward Scorpius. At around 6,200 light years, Messier 4 is one of the closer globular clusters to us. **Right:** The globular clusters as seen from outside the Milky Way, distributed spherically around the Galaxy.

Globular star clusters are gravitationally bound groups of 100,000 to 1 million stars. They are compact, spherical "balls" of stars with very high stellar densities in their centers (stars near their center are within a light year of one another). These clusters are typically 30 to 100 light years in diameter. If Earth were located inside one of these clusters, our sky would be lit by an abundance of stars brighter than the Sun.

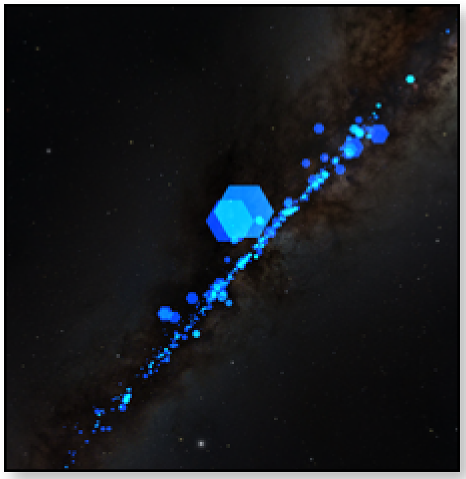
Size of our star system. Globular clusters were instrumental in our understanding of the size and nature of the Galaxy and universe. The story began in 1912, when Henrietta Leavitt (1868–1921), a "computer" for astronomers at the Harvard College Observatory, discovered a relationship between the period of Cepheid variable stars and their intrinsic luminosity, allowing her to determine their distance. In 1918, the astronomer Harlow Shapley (1885–1972) noted that the open clusters were mainly in the plane of the Milky Way, while more than half the globular clusters were in or near the constellation Sagittarius. He deduced the center of our galaxy must be far off in the direction of Sagittarius.

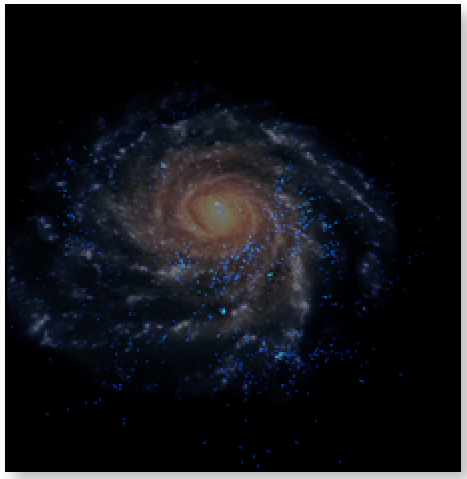
Exploring the catalog. The globular clusters form one of the most complete data sets in the Atlas. Data for the clusters represent almost all the clusters in our Galaxy—several on the opposite side of Galactic center may be invisible to us. The clusters orbit the Milky Way in random orientations, as comets orbit the Sun.

Cosmically old objects. Globular clusters are among the oldest objects in the Galaxy. They were around when the Galaxy formed 12–13 billion years ago, perhaps even before the disk evolved into the shape it is today. Some of the oldest stars in the entire Galaxy are found in these clusters.

Star-forming (HII) Regions

Description	HII (*H-two*) regions are clouds of hydrogen where the light from young stars are exciting and illuminating the gas that enshrouds them.
Census	1,481 nebulae
Version	5.6





Brian Abbott / AMNH / OpenSpace

The star-forming regions are marked with blue hexagons. **Left:** As seen from Earth, the HII regions are tightly correlated with the plane of the Galaxy. Only nearby regions will appear off-plane. **Right:** The HII regions are excellent tracers of the Galaxy's spiral arms.

HII (pronounced *H-two*) regions are stellar nurseries for newborn stars. Stars are born from condensing clouds of hydrogen gas. As these clouds condense, the densities become high enough to form stars.

Typical gas clouds in the interstellar medium have densities too low to form stars. They need an outside stimulus or perturbation, like a nearby supernova, to compress parts of the cloud. If this occurs, small fragments are compressed, and heat up the gas. If the cloud densities continue to increase, the cloud will collapse into a protostar. This protostar will contract under its own gravity, causing it to heat up. Eventually the protostar is hot enough to clear away the gas and dust that enshroud it. When the core temperature is hot enough for hydrogen fusion, the star is born.

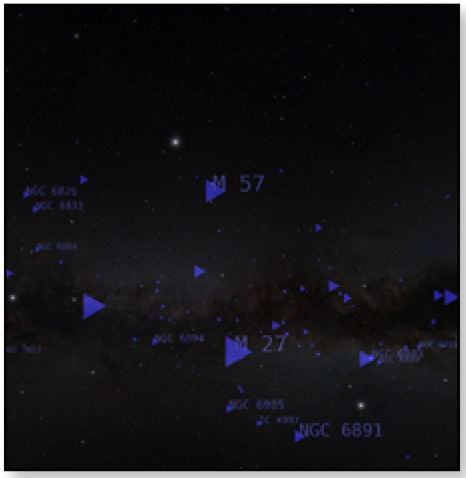
HII regions are the surrounding clouds of hydrogen that glow from the stars born within them. It takes ultraviolet light to ionize hydrogen, light that can come only from hot, luminous stars (like O stars). When the star "turns on," the electrons in the surrounding hydrogen are stripped away. The hotter the star, the farther the ionization radius and the more gas that is illuminated. An O5 star can excite hydrogen up to 65 light years from the star.

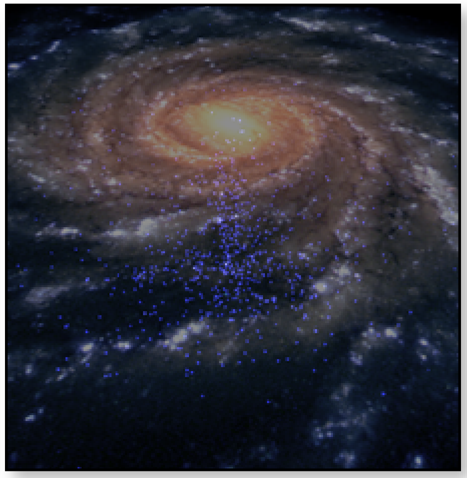
The result is a bright, glowing nebula which is seen to great distances. One local celebrity among HII regions is the Orion Nebula (M42). About 1,500 light years away, the wispy cloud is visible to the naked eye in Orion's sword and resembles a hazy star.

Tracing Galactic structure. From Earth's perspective, you'll notice that the HII regions all lie close to the Galactic plane. This is not an accident of nature. These star-forming regions lie in the plane of the Galaxy because that is where star formation occurs in spiral galaxies such as our Milky Way. Because of this, they are great tracers of the spiral arms of the Galaxy, and were instrumental in our understanding of the Galaxy's overall structure.

Planetary Nebulae

Description	A planetary nebula appears when an average-sized star begins to die. An expanding shell of gas is illuminated by the stellar remnant, creating a glowing gas cloud.
Census	283 nebulae
Version	2.8





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Planetary nebulae are marked with cornflower blue triangles. **Left:** Some nearby planetary nebulae in the night sky include Messier 27, the Dumbbell Nebula, and M57, the Ring Nebula. **Right:** The planetary nebulae distributed in the plane of the Milky Way.

A planetary nebula is an expanding shell of gas ejected from a star late in its life cycle. Appearing like greenish disks to a telescopic observer, planetary nebulae received their name from their resemblance to the gaseous planets of our solar system. In no way are they related to planets, rather, they are products of dying stars.

As an intermediate-mass star exhausts its core hydrogen fuel, its helium core contracts and heats to meet the energy needs of the star. The core contraction releases gravitational energy, which has two effects. First, hydrogen just outside the core begins to burn, producing a more massive helium core over time. Second, the expansion of the star's outer layers occurs. Ultimately, the star becomes a red giant.

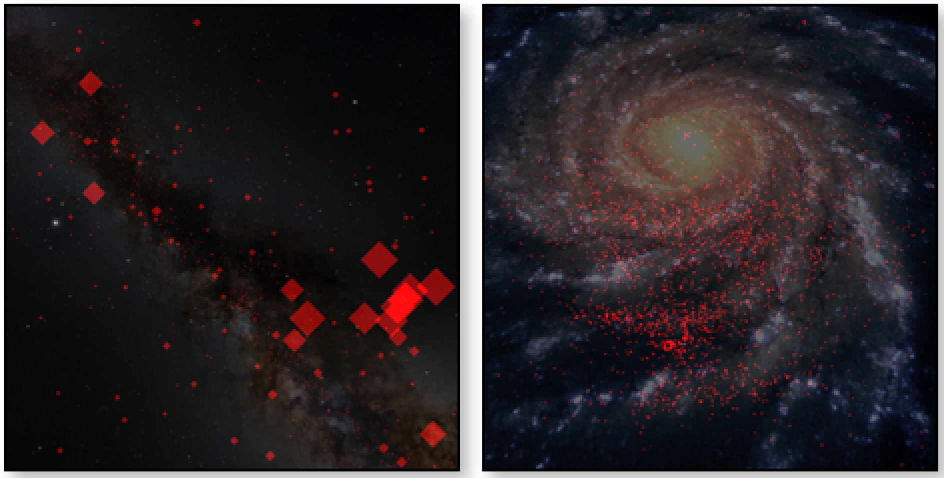
For stars of less than about two solar masses, the core continues to condense until the temperature and density become sufficient to burn helium into carbon. The ignition of helium occurs rapidly, producing a flash of light, and the star's outer shells expand, leaving a bright core that soon becomes a white dwarf star. These expanding shells become the planetary nebula.

Planetary nebulae are often spherical. As the gas from the star expands, it sweeps up the cooler gas like a snowplow. The gas glows because of the ultraviolet light from the stellar remnant at the center.

Planetary nebulae in the Galaxy. The Milky Way consists of two major star populations: the older halo population and the younger disk population. Because the planetary nebula phase of a star's evolution is relatively short, we observe only those that have occurred recently in the younger stellar population. Therefore, we expect to see planetary nebulae in the disk of the Galaxy. The stars that will evolve into planetary nebulae also typically have relatively eccentric orbits around the Galaxy and, therefore, a wider range of distances above and below the Galactic disk.

Pulsars

Description	A pulsar is a spinning neutron star, an ultra-dense remnant resulting from a supernova-driven collapse of the stellar core.
Census	2,755 pulsars
Version	6.6



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Pulsars are marked with red squares. **Left:** Pulsars in the night sky toward Scorpius. **Right:** Pulsars distributed in the Galaxy's disk trace its local spiral structure.

Pulsars in globular clusters. If pulsars are young objects, why do we see them in the relatively ancient globular clusters? The answer seems to be that these pulsars are drawing in material from a nearby companion star. This matter causes the star to spin faster, re-energizing the system. These are called millisecond pulsars for their periods, which can be as short as 0.002 seconds (2 milliseconds). More than 30 of these have been found and are easily seen to line up with the globular clusters in the atlas. Often, the distance of the pulsar and the independently deduced distance to the globular cluster will not match, demonstrating that distances in astronomy are by no means an exact science.

Upon death, stars leave behind one of three possible remnants: a white dwarf, a neutron star, or a black hole. Stars that are more massive than the sun will often become neutron stars in a violent explosion called a supernova. During a supernova, the core of the star collapses under such high pressure that the electrons, which normally remain outside the atomic nucleus, are forced to combine with the protons in the nucleus. Atomic nuclei break apart, producing what is called a *degenerate* state of matter. The collapse is halted when the material cannot be packed any tighter. At this point, the star has a radius of about 10 to 15 kilometers. The density of this material is so high that a teaspoonful would weigh about 100 million tons on Earth.

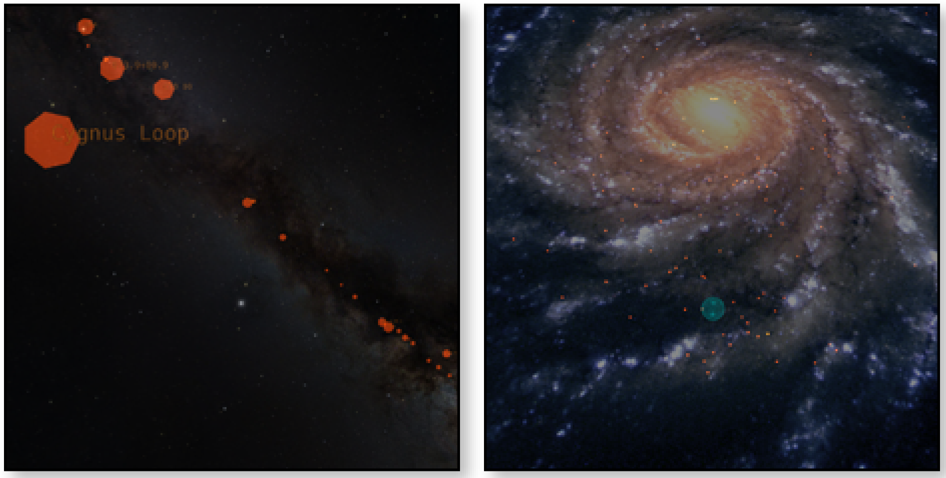
Just as ice skaters spin faster as they pull their arms in, dying stars rotate faster as they collapse. If the Sun were to suddenly collapse to a radius of 10 km, its rotation period would increase from its current 25 days to 1,000 times per second. Similarly, after a supernova, the neutron star is spinning fast from the rapid collapse, but it slows over time as it converts rotational energy into radiation.

Astronomers now know that pulsars are not pulsing but are spinning neutron stars whose beams of radiation point toward Earth just as a lighthouse sweeps the horizon. Pulsars have strong magnetic fields that funnel beams of light from its magnetic poles. When these beams point to Earth, we see a strong radio signal.

Pulsars and supernova remnants. Many pulsars are found in the Supernova Remnants group. Because supernova remnants have short lifetimes, we can assume that the pulsars seen in them are quite young. Once the supernova remnant disappears, the pulsar's rotation period continues to slow. After about 1 million years the pulsar is no longer visible; therefore, all the pulsars we see today must be the remnants of stars that have died over the previous 100,000 to 1 million years.

Supernova Remnants

Description	A supernova remnant is the ejected gas that results from a supernova. It glows for a cosmically short period of time before mixing with the interstellar medium.
Census	112 supernova remnants
Version	4.7



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Supernova remnants are marked with seven-sided orange shapes. **Left:** From Earth's perspective, most of these lie in the galactic plane, except for those relatively near to Earth. **Right:** the remnants are scattered throughout the disk of the Milky Way. The green sphere marks the location of the Sun and is 2,000 light years in diameter.

A supernova remnant is the nebulous gas left over from a supernova explosion. During a supernova, one-fifth the mass of the original star may be expelled. This gas expands at great speeds, up to 20,000 km/sec, and rams into the surrounding interstellar gas. The expanding gas excites the surrounding gas, causing it to glow, producing the nebulous cloud we observe from Earth.

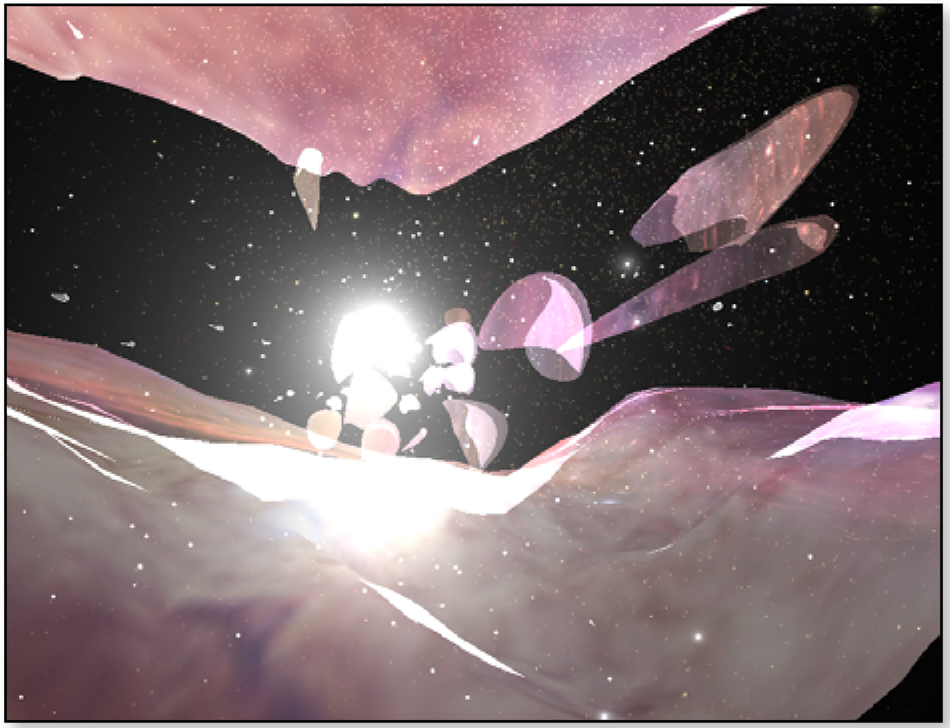
A supernova remnant contains a neutron star or pulsar at its center, the core of the dying star. The cloud that enshrouds the core does not last long, though. After about 50,000 years, the gas mixes into the interstellar medium and no longer glows. Astronomically, this is a very short time, so the supernova remnants we see must be left from explosions that have occurred recently, cosmically speaking.

The most recent supernova occurred in the Large Magellanic Cloud in 1987. The most studied supernova in history, SN 1987A is the latest in a series of explosions observed by astronomers. In 1054, the Chinese recorded the appearance of a "guest star" in Taurus. Bright enough to see in the daytime, the star brightened rapidly, then faded from sight over the next two years. Modern astronomers pointed their telescopes to the star and found a gas cloud about 4.4 light years in radius expanding at a rate of 1,400 km/sec (about a one-half light years per year). Projecting this expansion back in time, they found that the explosion began about 900 years ago, confirming the Chinese records. We call the object Messier 1 (M1), or the Crab Nebula. In the past 2,000 years, only 14 supernovae have been recorded in our own Galaxy.

Location in the Galaxy. Similar to pulsars, supernova remnants are found in the disk of the Galaxy. These remnants are short-lived nebulae and will be visible only in areas of active star formation. Because they have such short lifetimes, you would expect them to be tightly correlated with the Galactic disk and, relative to the pulsars, lie very close to the plane of the Galaxy.

Orion Nebula Model

Description	A 3-D model of the Orion nebula, its associated proplyds, and shock fronts, along with the star cluster NGC 1976.
Census	1 nebula model, with proplyds and shocks, 815-star cluster
Version	1.0 nebula model; 1.7 star cluster



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The Orion Nebula model is a primitive surface model that shows the elements of the nebula, the proplyds, and the shock fronts. Here we are inside the nebula looking back toward the Sun, which is about 1,500 light years away. The stars are part of NGC 1976, the star cluster that formed from the cloud. The brightest star, Theta 1 Orionis, is responsible for exciting and illuminating the hydrogen gas in the nebula.

The Orion Nebula, at about 1,500 light years, is one of the closest star-forming regions (also called HII regions) to us. Ultraviolet light from its young, hot stars causes the surrounding hydrogen gas to glow.

Most HII regions that we see lie close to the edge of dense clouds of hydrogen. The ionizing radiation comes primarily from a single star, θ^1 Orionis C, which allowed the astronomers Zheng Wen and C. Robert O'Dell to reconstruct the three-dimensional form of the ionization front. Assuming a constant thickness for the emitting layer, one can actually determine its distance from the nebula's brightest star. We know the spectrum of the light coming from the star, and we know how the atoms in the nebula respond to the star's radiation—each atom acts like an electromagnetic tuning fork, ringing with a particular frequency of light. Thus, the shape of a nebula can be determined through careful observation and a knowledge of the laws of atomic physics.

The model. In the Digital Universe model of the Orion Nebula, we depict the ionization front effectively as a terrain, with a flat Hubble image of the nebula mapped on the undulating surface. In reality, the ionization front has a slight thickness to it—about a third of a light year—but is quite thin compared to the overall size of the nebula, which stretches about ten light years from side to side.

Close into the center, we see small teardrop-shaped structures with their narrow ends pointing away from the bright star: these are protoplanetary disks, or *proplyds*, of dense gas and dust surrounding young stars. The larger formations that one sees farther away from the center of the nebula take on a cup-like shape, with the narrow end pointing away from the nebula's center. These enormous structures are bow shocks that delineate the region where high-speed winds from the central star slow from supersonic to subsonic speeds. You can think of an HII region as a sort of tremendous explosion, taking place over millennia, and the bow shocks are part of the outward rush of material.

The star cluster. In order to have an accurate depiction of the Orion nebula, we need to include the star cluster that was birthed from it. We turned to a study of the cluster's stellar population by Lynne Hillenbrand, who was working at the University of California, Berkeley at the time.

The catalog from her paper contains more than 1,500 stars, about half the stars in the actual cluster. The cluster is very crowded, with a peak density of 10,000 stars per cubic parsec over a wide range of masses from a tenth the sun's mass up to 50 times its mass. We were presented with one problem: there are no distances.

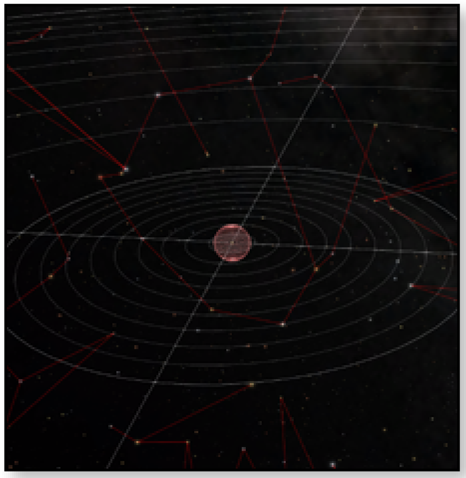
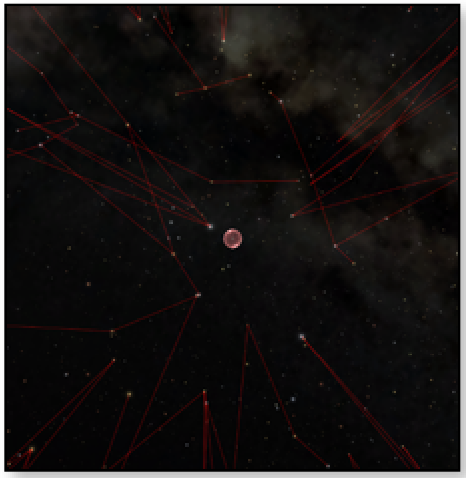
For the stellar distances, we needed to deduce them by statistical methods. Knowing the size of the cluster and approximating the shape to be roughly spherical, we placed each star along a line of sight through this imaginary sphere centered on the cluster. In this sense, these data are observed data and the view from Earth is accurate. But the distance of each star has been derived from this educated-guess approach for the cluster distribution.

NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Project Team

The Orion Nebula as seen by the Hubble Space Telescope. This is a 520-image composite of the nebula and shows the complexity of the cloudscape. The central stars largely responsible for illuminating the gas are indicated with an arrow.

Oort Cloud Sphere

Description	A sphere representing the highest-density region of the Oort cloud, a region surrounding the Sun where comets are believed to originate.
Census	1 wire-frame sphere
Version	1.2

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The Oort cloud sphere, representing where the cloud is at its most dense. The Oort cloud is not discrete, as this model is, but has a thickness that reaches out to twice the distance of this sphere. One can imagine each star will have a similar sphere around it of varying size.

The Oort cloud is a region of space surrounding the Sun where comets are believed to originate. Proposed by Jan Oort in the 1950s, the Oort cloud is believed to extend from 20,000–100,000 Astronomical Units (AU), with its greatest concentration around 50,000 AU (1 AU is the average Earth-Sun distance, which equals 149 million kilometers, or 93 million miles).

Comets are small, icy bodies that orbit the Sun. Perhaps the most famous is Halley's Comet, which travels around the Sun in an eccentric orbit every 76 years and reaches a maximum distance of 35 AU. Comets were likely ejected from the solar system once the planets formed. Jupiter, Saturn, Uranus, and Neptune's strong gravitational field likely ejected many comet-sized bodies out of the solar system in random directions, where they settled into a cloud.

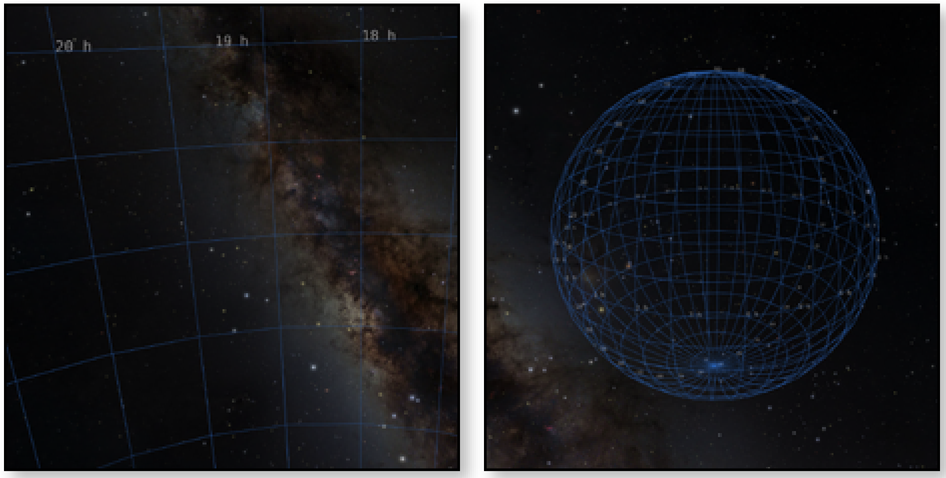
Occasionally, one comet in the cloud interacts with another or is perturbed by a passing star or a passing star's comet cloud. This could send the comet toward the Sun and planets, where it may enter into an eccentric, long-period orbit.

We represent the Oort cloud with a 50,000-AU-radius, wire-frame sphere representing the location of the central concentration. Fifty thousand astronomical units is equal to about 10 light months, which is 0.8 light years, or 4.8 trillion miles. Keep in mind, though, that the Oort cloud is 80,000 AU thick and imagine a similar sphere around each star in the atlas. Would any two overlap? Of course, stars of different luminosities have Oort clouds of different sizes, or perhaps no Oort cloud at all. Visualizing the Oort cloud allows us to see the possibility of stars interacting.

The Oort cloud is the last outpost of our solar system. Beyond it is the gas of the interstellar medium through which the Sun, planets, and comets move as they orbit the Galaxy once every 225 million years.

Equatorial Coordinates & Radio Sphere

Description	A 80-light-year radius sphere aligned to the equatorial coordinates.
Census	1 wire-frame sphere
Version	3.7



Brian Abbott / AMNH / OpenSpace

The equatorial coordinates, an extension of Earth's longitude and latitude, also acts as the Radio Sphere when viewing in 3-D. **Left:** The coordinates on the sky, expressed in hours of right ascension and degrees of declination. **Right:** The 80-light-year sphere which we call our radio sphere.

From Earth's perspective, this object provides a mapping of equatorial coordinates on the sky, and serves as the radio sphere in 3-D.

The equatorial coordinate system is a projection of our Earth-based coordinate system of latitude and longitude onto the "celestial sphere." The celestial sphere is an imaginary shell that surrounds Earth upon which all objects in the sky are projected. Astronomers describe an object's position in the sky by its right ascension (RA) and declination (Dec).

Declination is simply a projection of our latitude on Earth. The point directly above the North Pole is the North Celestial Pole and is expressed as +90° declination. If you're standing on Earth's equator, your zenith—that point directly overhead—would lie on the Celestial Equator, or 0° declination. No matter your latitude on earth, the point directly above your head has a declination equal to your latitude.

Right ascension is based on Earth's longitude but is expressed in hours instead of degrees. Astronomers have split the sky into 24 hours (15° per hour) measured from the vernal equinox. An object's location is then described in hours, arcminutes, and arcseconds.

Arcminutes and arcseconds remind us that the length of these units depends on your declination and are projected on a sphere. Akin to longitude on earth, when you're close to the poles, one degree of longitude is short, while on the equator it is at its maximum length. In the sky, an arc length of one hour of right ascension will be relatively short near the north or south celestial poles, while at the equator, it will be at its maximum. As with lines of longitude on Earth, lines of right ascension are not parallel with one another.

The radio sphere. We have not chosen the radius of this sphere arbitrarily. The RA/Dec coordinate sphere takes on another role when you're away from the Sun that we call the radio sphere.

The radio sphere describes the theoretical extent of Earth's radio signals in space. In the early 20th century, radio began to take hold after the discovery that certain radio waves bounce, or reflect, from Earth's ionosphere, a region in the upper atmosphere where gases are ionized by incoming solar particles. However, early broadcasts were not powerful enough to penetrate the ionospheric layers and their signals remained confined to Earth.

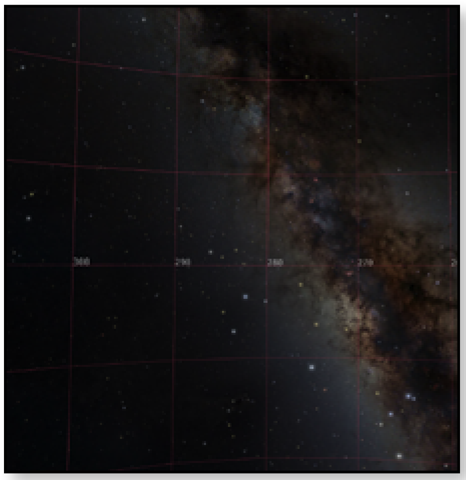
Before television carrier waves, early-warning radar first used in World War II, and the detonation of atomic weapons, Earth was radio-quiet to the universe (AM and FM radio signals bounce off the atmosphere and do not escape it). After the use of these and other radio emitters began, in the late 1930s and early 1940s, signals were able to escape the atmosphere and travel into space at the speed of light (300,000 km/sec or 186,000 miles/sec). Since then, we have been broadcasting to the universe.

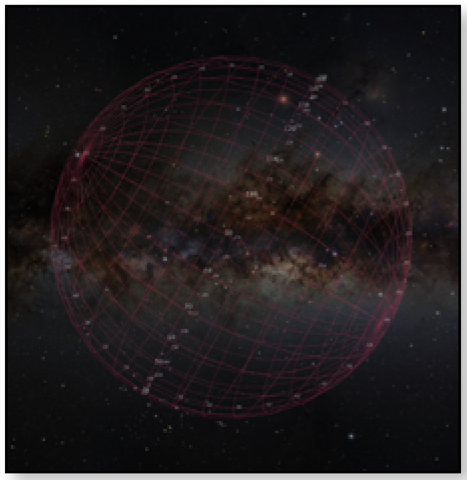
As we look farther into space, we look further back in time. Turn on a 1 light year grid and imagine what happened one year ago. Broadcasts from that time, traveling at the speed of light, are now reaching the 1 light year mark, 5.89 trillion miles from Earth. At the edge of the sphere are those transmissions of the 1940s: atomic testing and the echoes of World War II. Turn this principle around and consider the light from distant sources, and we see now why looking deep into space means we are looking back in time to a younger universe.

A theoretical footprint. We mention earlier that this is the *theoretical* extent of these signals. In reality, these signals will dissipate rapidly into the ambient cosmic noise of the universe. All light falls off as the square of the distance ($1/r^2$), and radio waves are no different. The signals that emanate from Earth are likely lost in the noise before they leave the solar system, but the radio sphere remains a visually compelling astronomical concept.

Ecliptic Coordinates

Description	A 500-light-year-radius sphere aligned to the ecliptic coordinate system.
Census	1 wire-frame sphere
Version	1.7





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The ecliptic coordinates are calibrated to the plane of the solar system. The "equator," called the ecliptic here, is traced by the path of the Sun in the sky. **Left:** The ecliptic coordinates expressed in degrees on the night sky. **Right:** The ecliptic coordinates in 3-D form a 500-light-year sphere. The ecliptic (plane of the solar system) is tipped roughly 60° to the plane of the Milky Way, as you can see in this figure.

Ecliptic coordinates are based on the imaginary line in the sky traced by the Sun throughout the year. This line is called the *ecliptic* and, in 3-D, also defines the plane that contains the Sun and Earth.

Because Earth is tilted on its axis 23.5° to this plane, the Sun appears to move in declination throughout the year. Two days a year, on the equinoxes, around March 21 and September 21, the Sun crosses the celestial equator. Around June 21, it lies over the Tropic of Cancer (the summer solstice in the Northern Hemisphere), and around December 21, it lies over the Tropic of Capricorn (winter solstice for the Northern Hemisphere). It's no coincidence that the Tropics of Cancer and Capricorn are at 23.5° north and 23.5° south latitude, respectively.

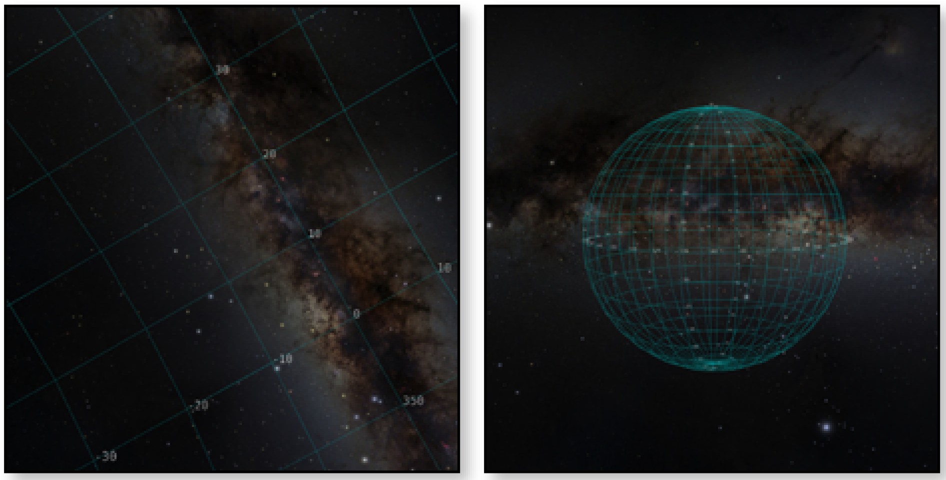
Ecliptic coordinates are described by ecliptic longitude and latitude measured in degrees. Longitude is measured from the vernal equinox, (RA, Dec) = (0h, 0°), and the ecliptic north pole is in the constellation Draco (23.5° from the celestial north pole and the north star, Polaris).

A new horizon. From the night sky perspective, notice the tilt of the ecliptic to the band of the Milky Way. These two planes, the plane of the solar system and the plane of the Galaxy, are tilted about 60° to each other (62.87° to be precise).

Many of us are used to thinking of the solar system plane as our cosmic horizon line. All the planets lie roughly within this plane, so it makes sense that this should be the plane from which we measure up, down, over, and under. However, the Milky Way band tells us otherwise. The Sun and all its planets are orbiting the center of the Galaxy once every 225 million years, and doing so while tipped 60° to the Galactic plane. We now see there's a more significant horizon to obey—that of our home Galaxy.

Galactic Coordinates

Description	A 1,000-light-year-radius sphere aligned to galactic coordinates.
Census	1 wire-frame sphere
Version	1.7



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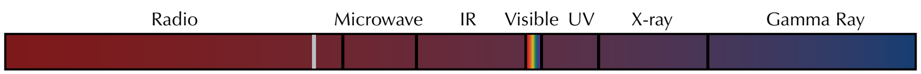
Galactic coordinates are calibrated to the plane of the Milky Way galaxy. The galactic equator traces the Milky Way's plane, which is also the band of light we see in the sky. **Left:** Galactic coordinates in the sky, in degrees. **Right:** The galactic coordinates forms a 1,000-light-year sphere in 3-D.

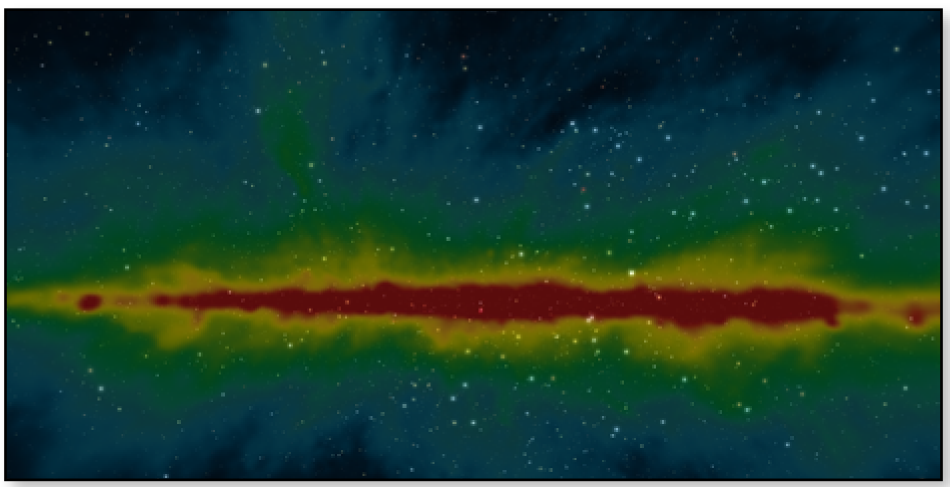
Once astronomers understood the structure of our Galaxy in the early part of the twentieth century, it was necessary to devise a coordinate system based on that structure. Galactic coordinates are defined by galactic longitude, *l*, and galactic latitude, *b*, measured in degrees. The "equator" coincides with the plane of the Galaxy. Galactic longitude is measured from Galactic center, which is generally in the direction of Sagittarius A*, a compact radio source that astronomers now know to be about 5 arcminutes from the Galactic nucleus.

The North Galactic Pole (b = +90°) lies in the constellation Coma Berenices, while the South Galactic Pole (b = –90°) is in the constellation Sculptor. These points are perpendicular to the plane of the Galaxy. If you look toward these points in the sky, you are looking directly out of the Galactic plane. Because there are not as many stars or much gas and dust in this direction, we see objects to greater distances when we look toward the Galactic poles. Other galaxies and clusters of galaxies are easier to find in these regions of the sky.

Radio Continuum All-sky Survey

Description	The radio continuum at 408 MHz, which shows hot interstellar gas—the gas between the stars in the Galaxy.
Census	1 all-sky image
Version	1.2
Wavelength	73.5 cm (408 MHz)





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The 408 MHz radio light, in technicolor. The "rainbow" colors represent intensity, with red and yellow showing areas of higher intensity at these wavelengths.

The 408 megahertz all-sky map is one of the most complete radio maps of the sky and remains critical to our understanding of the universe.

At this frequency, the radio continuum is mainly showing hot, ionized interstellar gas. More specifically, observations at this wavelength show light from the scattering of free electrons in interstellar plasmas. This hot gas is typically the result of supernova explosions that compress and heat interstellar gas.

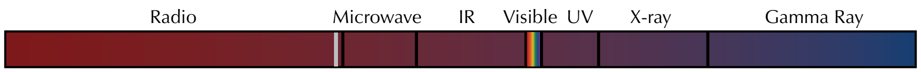
The most striking feature of the map is the sweeping arc of light in the northern sky. This is called (and is labeled) the North Polar Spur, and was originally thought to be associated with outflows of hot gas from the inner galaxy. However, astronomers now believe it may be a hot, interstellar bubble of gas associated with a nearby supernova that occurred thousands of years ago, or perhaps is associated with the Scorpius-Centaurus star-forming region around 500 light years away. This phenomenon remains an active topic of study, decades after its discovery.

Other objects visible in the map include the Orion Nebula, the Crab Nebula, the Large and Small Magellanic Clouds, the Andromeda Galaxy, and the Vela and Cassiopeia A supernova remnants.

The false colors represent intensity, with reds and yellows representing higher intensity in these radio wavelengths.

Atomic Hydrogen All-sky Survey

Description	An all-sky image showing concentrations of warm neutral hydrogen gas.
Census	1 all-sky image
Version	2.2
Wavelength	21 cm (1.4 GHz)



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The 21-centimeter radio light, showing the intensity of warm interstellar hydrogen gas. This gas is not excited, as it is in bright nebulae, but is in a neutral state and, therefore, invisible to our eyes.

Warm neutral hydrogen radiates in the radio spectrum at a wavelength of 21 centimeters. In a hydrogen atom, the electron and proton are magnetized, giving each a north and south pole just like a bar magnet. Any particular neutral hydrogen atom can exist in two configurations: a lower energy state, in which the north poles of the electron and proton are pointing in the same direction, and a higher energy state, in which they point in opposite directions.

The warm interstellar gas provides the energy to boost the atom into this higher energy state. Once the atom inevitably returns to its more stable, lower energy state, it gives off light at a wavelength of 21 cm. The survey shows light from this atomic transition, and allows us to trace where hydrogen atoms are present.

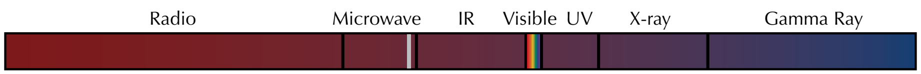
This light also penetrates the dust in the interstellar medium, allowing us to see it across the galaxy. The 21-cm light is perhaps the most important tracer we have for determining the structure of our Galaxy.

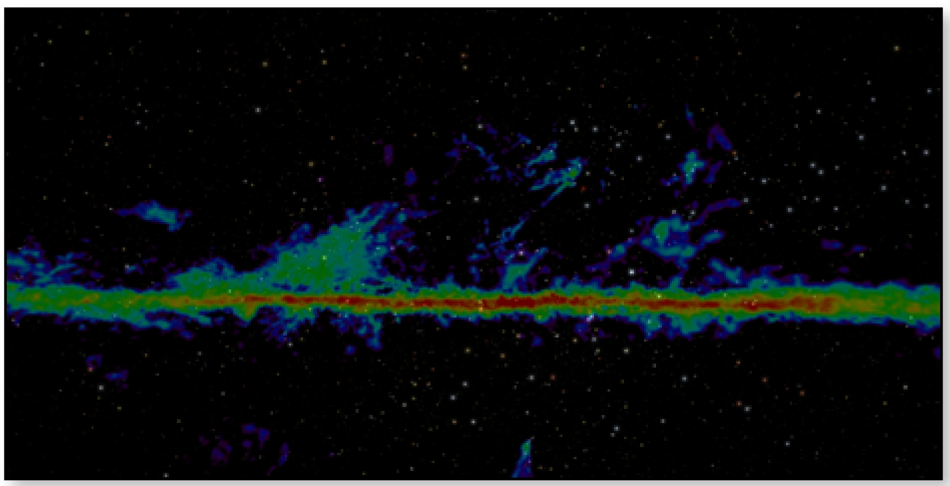
Image colors. This map conveys more information than light intensity. The brightness (the number of atoms in any particular direction) is proportional to the intensity on a log scale, allowing us to see more detail in the dimmer parts of the image. The color delineates the speed of the gas along the line of sight, called the radial velocity. Orange, yellow, and green hues indicate gas that is moving away from us, while blue and violet colors show gas that is moving toward us. Most notably among these is the Andromeda Galaxy and Messier 33, neighboring galaxies that are approaching the Milky Way.

Labels reveal some of the prominent features of the map, including the Large and Small Magellanic Clouds, the Andromeda Galaxy, and M33, and the wispy strands of gas that surround us.

Carbon Monoxide All-sky Survey

Description	Carbon monoxide all-sky survey traces large clouds of molecular hydrogen. Often, stars form on the edges of these clouds and illuminate part of the cloud as a bright nebulous region.
Census	1 all-sky image
Version	2.2
Wavelength	2.6 mm (115 GHz)





Brian Abbott / AMNH / Uniview

The intensity of carbon monoxide (CO) in the sky. Visible in the radio spectrum, CO light acts as an indicator of large clouds of molecular hydrogen. Red shows high intensity, and, as we'd expect, this is in the plane of the Milky Way, where much of the gas resides.

In order to map the large clouds of molecular hydrogen (H_2), we look for carbon monoxide (CO). Carbon monoxide is about 10,000 times less abundant than molecular hydrogen, yet we see traces of CO via its radio signature line at 2.6 millimeters (115 GHz). Using radio telescopes, astronomers observe this portion of the radio spectrum where Earth's atmosphere is semitransparent.

Normally, CO molecules would be broken apart by the ultraviolet radiation from stars. However, the CO molecules remain shielded from these harmful UV rays because they are deep within dense, dusty molecular clouds of hydrogen. This allows scientists to infer the existence of large molecular clouds by observing the CO that exists within them.

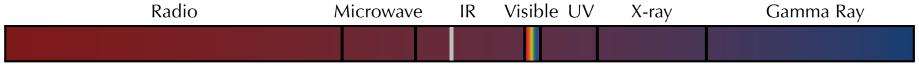
The Orion Nebula is the best example of a nearby giant molecular cloud. The nebula sits on the edge of a much larger cloud that is invisible to us in optical light. However, the cooler atomic hydrogen and CO radiate in this region of the spectrum. We observe CO mainly in the Galactic plane, where most of the gas and dust are concentrated in our Galaxy and where star formation occurs. If we see CO, we can expect to see new stars.

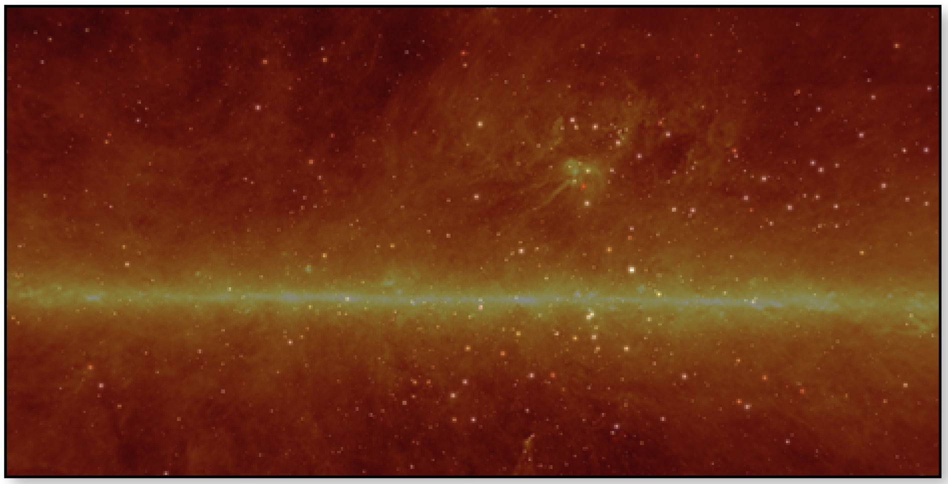
CO intensity is represented by colors mapped to the intensity of the CO spectral line. The violet and blue regions are less intense and the red and yellow regions represent higher intensity. The survey covers the entire range in galactic longitude but only a narrow band centered on the galactic equator. Because CO is confined to the plane of the Galaxy, this is a reasonable range in galactic latitude.

Labels highlight some of the objects and structures: the Orion Nebula, the California Nebula in Perseus, and the Ophiuchus Cloud, a structure we'll see in many other all-sky images. Also, the large star-forming regions in Cygnus and Vela are noted.

Far Infrared All-sky Survey

Description	The far infrared shows warm concentrations of large gas clouds and astrophysical dust (microscopic rocks).
Census	1 all-sky image
Version	3.3
Wavelength	100 microns (3 THz)





Brian Abbott / AMNH / Uniview

The Milky Way in far infrared light shows very cool objects, including cold clouds of gas and astrophysical dust particles. The wispy clouds above and below the Milky Way's disk produce the so-called infrared cirrus.

The InfraRed Astronomy Satellite (IRAS) was launched in January 1983 and orbited 900 km above Earth, observing the sky in infrared for much of that year. With its 56-centimeter (22-inch) mirror, IRAS observed in the near and far infrared at 12, 25, 60, and 100 micron wavelengths. (1 micron = 0.001 mm)

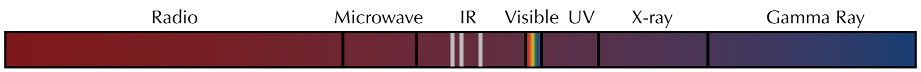
Infrared light comes from cooler objects in the universe: planets, comets, asteroids, cool stars, and dust in space. When astronomers talk about dust, they do not mean those pesky particles that settle on your tabletops. Astrophysical dust refers to microscopic rocks. Dust was once thought to be particles composed of 10,000 atoms or more, but thanks to IRAS and other space telescopes, we now understand that it can include smaller particles of just 100 atoms. These microscopic particles are normally quite cold, close to absolute zero even, but when ultraviolet light shines on them, they can increase in temperature by 1,000 Kelvin (1,300 °F).

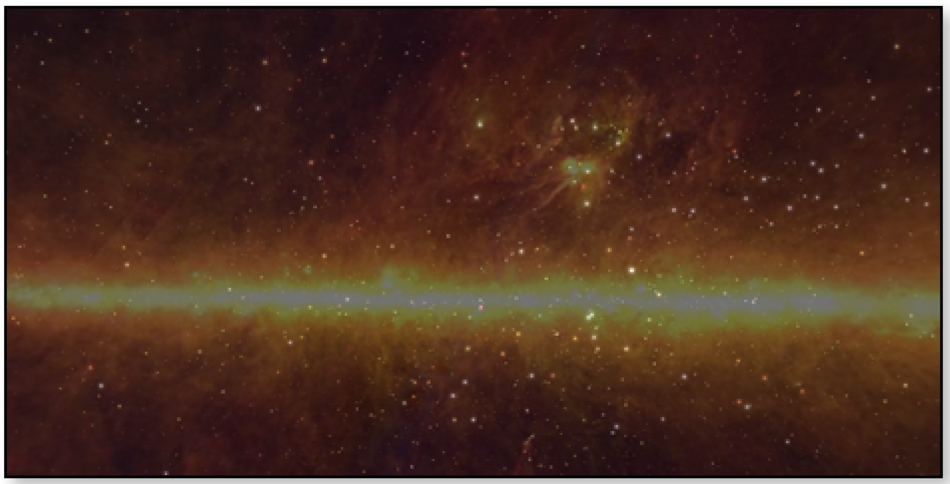
IRAS's most important discovery was the extent to which dust pervades the Galaxy. IRAS provided us with the most detailed map of interstellar dust to date. Dust is created when stars explode and, therefore, is present where stars are forming. For this reason, dust is abundant within interacting galaxies where mergers trigger new stars to form.

This survey is the 100-micron far infrared (FIR) survey. This corresponds to objects with temperatures of about 15–120 Kelvin (-430 to -245 °F) and includes cold dust particles and cold molecular clouds. In some of these clouds, new stars are forming and glow in FIR light. The center of our Galaxy glows brightly in FIR light, where dense clouds of dust are heated by the stars within them. This results in the bright band of light toward Galactic center. This survey is rich in detail, with bright glows in areas of star formation, like the Orion complex. Bright extragalactic sources are visible too, like the Andromeda Galaxy and the Small and Large Magellanic Clouds. Above and below the Galactic plane is the infrared cirrus, the wispy clouds that glow in the IR.

IRAS Composite All-sky Survey

Description	A composite image of three infrared wavelengths from IRAS.
Census	1 all-sky image
Version	2.2
Wavelength	25, 60 and 100 microns (12, 5, and 3 THz)





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The IRAS composite image takes the far infrared image and combines it with two other wavelengths to produce a composite image, highlighting each map's strengths. Various clouds and nebulae are highlighted a bit better in the map as compared to the far infrared map.

IRAS was one of the most successful astronomical missions, increasing the number of known cataloged objects by 70%. Launched in 1983, the orbiting telescope observed in the mid and far infrared, and this map is a composite of the 25, 60, and 100 micron observations. This map is a re-reduction of the original image.

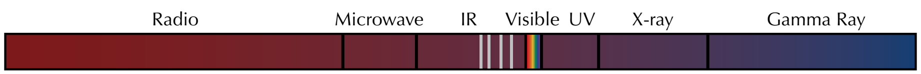
The map is bright across the Galactic plane, as we might expect. Toward the center of the Galaxy, in the direction of Sagittarius, the infrared light is tightly constrained to the plane. In the opposite direction, toward Orion, the band of light seems to break up, becoming more clumpy. This is because we are looking away from the center of the Galaxy, through less material, but we also have some star-forming regions relatively close to us in this direction, which appear higher above and below the plane.

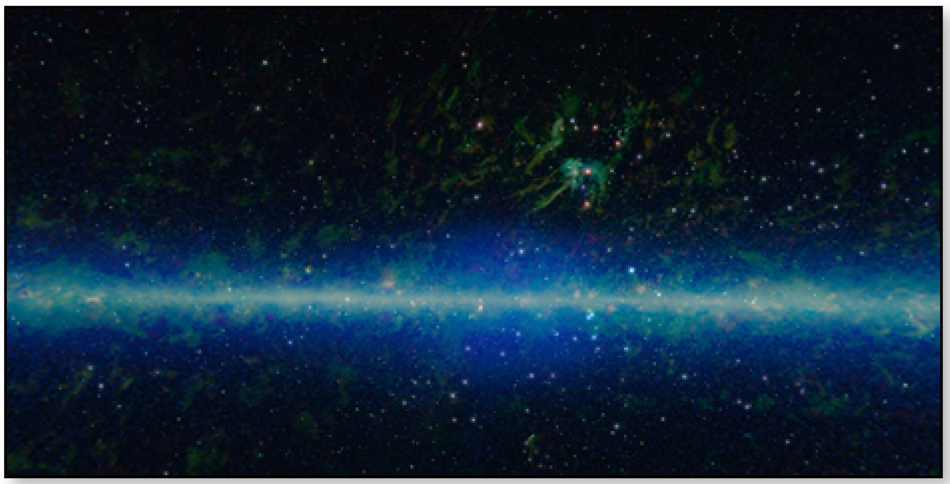
Many objects glow in this part of the sky. The Orion Nebula and the Rosette Nebula are two nearby, bright star-forming regions. The Andromeda Galaxy is visible but faint, and the Ophiuchus cloud is visible above Scorpius (pictured left). There is a faint glow over the Pleiades star cluster, and other bright glows due to star-forming regions. The star Lambda Orionis is also labeled. At these wavelengths, we can see a faint ring around the star. We will revisit this structure in subsequent data sets, a little farther down the infrared spectrum.

You may also notice a subtle, bluish band, particularly outside the band of the Milky Way. This is an image artifact from the data reduction where scientists had to remove zodiacal light from the image. Zodiacal light is the faint, diffuse light from the dust in our solar system. It glows in infrared, and must be removed from the image to get an accurate picture of the IR Milky Way. If you turn the Ecliptic Coordinate Sphere on, you'll see the ecliptic bisects this blue band. Because the ecliptic traces the path of the sun in the sky, it also represents (roughly) the plane of the solar system. We can see here that the plane of the solar system is tipped significantly (by over 60°) with respect to the plane of the Galaxy.

WISE Composite All-sky Survey

Description	An infrared composite all-sky image from the WISE telescope.
Census	1 all-sky image
Version	2.3
Wavelength	3.4, 4.6, 12, and 22 microns (88, 65, 25, and 14 THz)





Brian Abbott / AMNH / Uniview

The WISE all-sky image is a composite of four wavelengths in the mid infrared spectrum. The colors represent the various wavelengths. Blue represents the lower wavelengths and picks up stars and galaxies, green represents glowing clouds of gas, and red hues represent the higher wavelengths and show glowing dust in star-forming regions.

The Wide-field Infrared Survey Explorer (WISE) was designed to observe the entire sky at four infrared wavelengths over a ten-month period. Probing the sky in the mid infrared spectrum yielded new findings as the telescope peered through dust clouds to see star-forming regions, star clusters, and galaxies.

The blue regions are the 3.4-micron band, which is sensitive to stars and galaxies, and the 4.6-micron band, which is more sensitive to substellar sources like brown dwarfs. At 12 microns, the telescope is more sensitive to thermal energy from asteroids and gas and is represented in green. The 22-micron band will pick up the glow from dust in star-forming regions and has a red hue in this map.

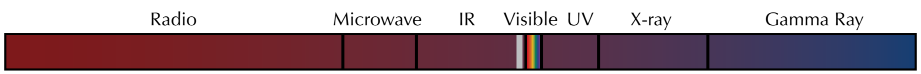
The composite map shows the infrared sky in higher resolution than IRAS. The Orion Nebula, the Pleiades, the Andromeda Galaxy, the Ophiuchus complex, and the Small and Large Magellanic Clouds are easily visible. We also point out the star Zeta Ophiuchi, which is beginning to glow at these wavelengths.

Also, you may notice a ring around a star near Orion's head. The star at the center of this ring is Lambda Orionis, an O star that gives off a lot of light. In later wavelengths, we'll see the glow around this star, but at these wavelengths, we only see the outer edge of what is really a glowing cloud of hydrogen gas. Here, we only see the outer edge of the glow because it is cooler than the inner part of the cloud.

WISE enhanced our knowledge in this part of the infrared spectrum, and is a precursor to the next major space telescope and successor to Hubble, the James Webb Space Telescope.

2MASS Composite All-sky Survey

Description	The two-micron all-sky infrared survey shows mostly starlight.
Census	1 all-sky image
Version	3.3
Wavelength	1.24, 1.66, and 2.16 microns (242, 181, and 139 THz)



Brian Abbott / AMNH / Uniview

The 2MASS infrared all-sky is very close to the visible spectrum, and so the image resembles the visible sky. Stars and gas dominate. We see deeper into the disk of the Milky Way and the dust clouds are more defined at these wavelengths.

The Two Micron All-Sky Survey (2MASS) is an infrared survey of the sky published in 2003. Because it is looking in the infrared, and this is a composite of the 2MASS point-source catalog, most of the light from this survey is starlight. In visible light, clouds of gas and dust obscure our view. However, in infrared, the longer wavelengths of light can penetrate these clouds without being scattered, thereby revealing stars that would normally be hidden to our eye.

The 2MASS data were taken over 1,400 nights from 1997 to 2001 with two, 1.3-meter telescopes located on Mt. Hopkins, Arizona, and Cerro Tololo, Chile. Each telescope had identical detectors that observed light at 1.24, 1.66, and 2.16 micron wavelengths. The 2MASS Image Atlas contains more than 4 million images in these wavelengths that cover 99.998% of the sky.

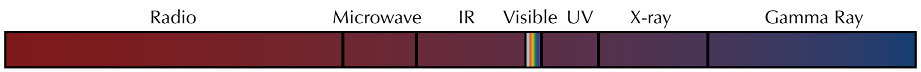
The 2MASS all-sky image contains many point sources. If you turn up the image's brightness and turn off the stars, you will see many of the stars in the image align with the constellation outlines. Many of the stars, particularly cooler stars, shine in the infrared. If you look toward Orion, you'll see many of the hotter stars in that constellation are not visible or as bright. Conversely, Betelgeuse, the red giant, is bright, radiating much of its light in the infrared.

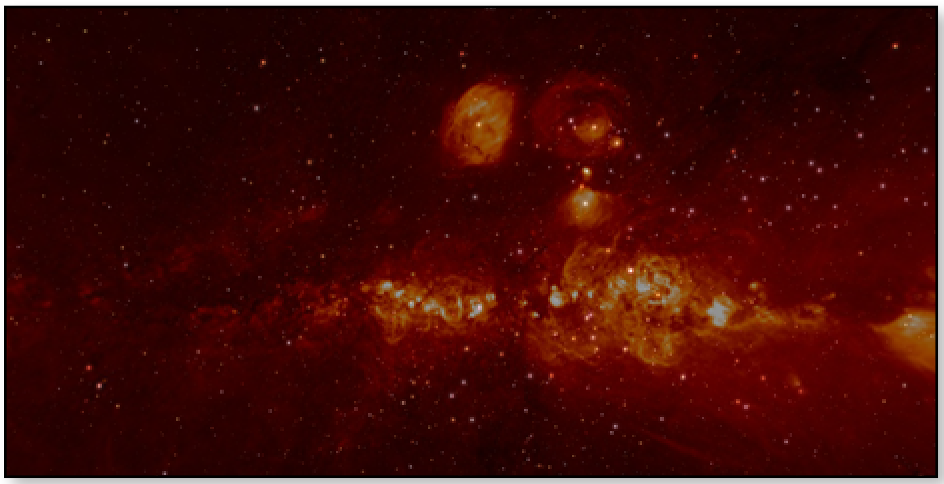
The Galaxy itself is quite prominent, with the bright disk and the Galactic bulge toward the center of the Milky Way and virtually no disk showing toward Orion, away from Galactic center. Clouds of gas and dust are also apparent and are a brownish color, correlating exactly with the carbon monoxide all-sky survey.

Few features pop out as they do on other surveys. The Large and Small Magellanic Clouds are visible, as is the glow of the Pleiades star cluster, but beyond these, the survey is mainly starlight with a narrower Milky Way band.

Hydrogen-alpha All-sky Survey

Description	An image of the sky in hydrogen-alpha light, a narrow part of the visible, red spectrum.
Census	1 all-sky image
Version	2.2
Wavelength	656 nm (457 THz)





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Hydrogen-alpha represents a narrow wavelength at the red end of the visible spectrum. Isolating this one wavelength clearly shows where the excited clouds of hydrogen are located.

Hydrogen-alpha, or H-α, is a term that describes light from the ground state of the hydrogen atom. When an electron in an atom moves from one energy level to a higher one, we say the atom is excited. But the electron does not move to this higher energy level without the atom absorbing energy from either another atom or a passing photon (packet of light).

Once the atom is excited, it cannot remain in that state for long before it wants to return to its ground state. When the electron moves back down to the lower energy level, light is released at a wavelength commensurate with the energy between the two levels. For the H-α line, this energy difference translates to a wavelength of 656 nanometers in the extreme red end of the visible spectrum.

This survey of the sky is a snapshot of light from this wavelength. We can see this light with our eyes, but it is lost within the integrated light from the entire visible spectrum.

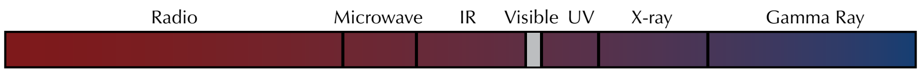
Image features. One distinctive element of the sky at this wavelength is the presence of large, spherical bubbles surrounding hot stars. Two prominent examples are Lambda Orionis and Zeta Ophiuchi; each are extremely hot stars that excite the surrounding hydrogen gas, causing it to glow.

Many nebulae and star-forming regions are visible, including the California Nebula, and what could be called the Orion nebluplex. Among the sights in the lower part of Orion, the Great Nebula of Orion is among the most beautiful star-forming regions in our neighborhood. Just above it is the Horsehead Nebula, an emission nebula with a small, obscuring dust cloud in the shape of a horse's head. Surrounding this is the extended supernova remnant called Barnard's Loop.

We also see that galaxies emit H-α light, including the Andromeda Galaxy and the faint M33, the large face-on spiral in Triangulum. In the southern sky are the Large and Small Magellanic Clouds (LMC and SMC), two nearby satellite galaxies that are interacting with the Milky Way.

Visible All-sky Survey

Description	An image of the night sky as our eye sees it (in the visible spectrum), with the stars removed.
Census	1 all-sky image
Version	1.4
Wavelength	400–700 nm (750–430 THz)



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The visible all-sky image represents what we see with our eyes. This image was constructed from many smaller images that were combined to convey more detail and a higher fidelity in the image.

In ancient times, our ancestors knew of the stars, the wandering stars (planets), and the Milky Way. Aside from the occasional comet, guest star (supernova), or aurora, these were the only cosmic features visible to them.

The Milky Way has been the subject of many myths and legends. The Greeks believed it to be a river of milk pouring from the breast of Hera, the wife of Zeus, and called it a “galaxy,” from the Greek word for milk. The Romans called it the Via Lactea, or the Milky Way. But it was not until 1610 that Galileo first observed this faint band of light with his telescope, discovering that it was composed of innumerable faint stars.

In the past 400 years, astronomers and philosophers have speculated about the nature of this band of light, but it was not until the 20th century that astronomers began to understand the nature and structure of our Galaxy.

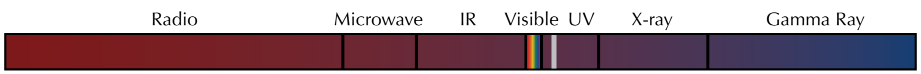
You will see the brightest part of the Galaxy if you look toward Galactic center in the constellations Scorpius and Sagittarius [or, turn on the Galactic coordinates and bring (l, b) = (0, 0)° to center screen]. This bright haze is the light from millions of stars; the dark lanes are foreground dust clouds, obscuring our view of the stars behind them.

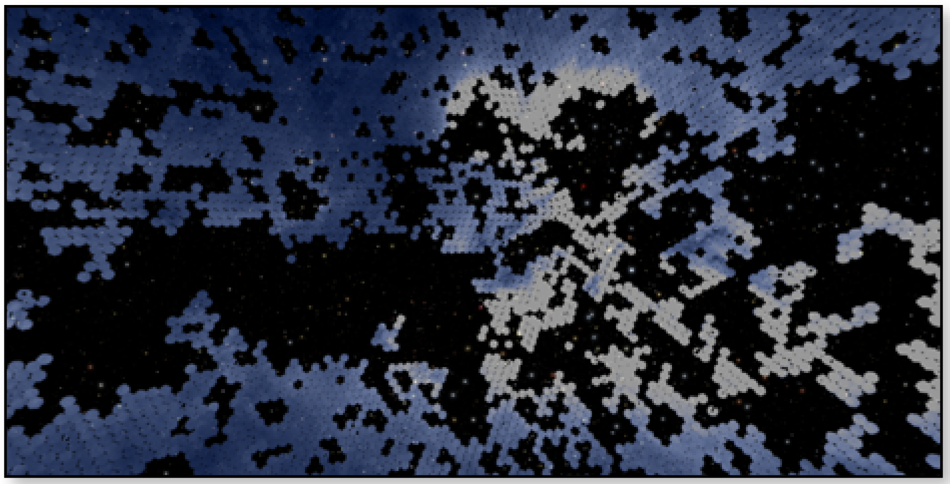
If you turn to look in the opposite direction, toward Orion, you will see that the Milky Way is not too bright on this side of the sky. Here we look out of the Galaxy through what remains of the Galactic disk between the Sun and its outer edge.

This image, by Axel Mellinger, is composed of many photographs of the sky, carefully knitted together in this giant mosaic. The stars have been removed for the most part, but the bright stars show some residual light.

Near Ultraviolet All-sky Survey

Description	An incomplete image of the sky in the near ultraviolet.
Census	1 partial-sky image
Version	1.2
Wavelength	231.6 nm (1,295 THz)





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The best image of the ultraviolet sky is rather incomplete, but shows where UV light is brighter in the sky. In a way, this shows an all-sky image in progress, where the mosaic of telescope images has not completely melded into one image, and the telescope's sky coverage is incomplete.

One of the last major regions of the electromagnetic spectrum without an all-sky map is in ultraviolet light. The map we include here is incomplete, but it remains the best data we have for the ultraviolet sky.

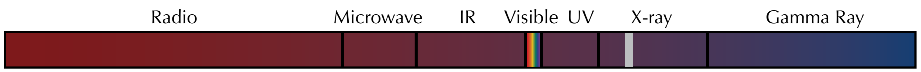
These data are from the Galaxy Evolution Explorer (GALEX), an orbiting UV telescope launched in 2003 and was decommissioned in 2012. The mission's goals were to collect high-resolution, targeted imagery, and by all measures it was a success. It was not designed to collect an all-sky image, but in 2014 Jayant Murthy, a scientist at the Indian Institute of Astrophysics, endeavored to make this mosaic, the first of its kind.

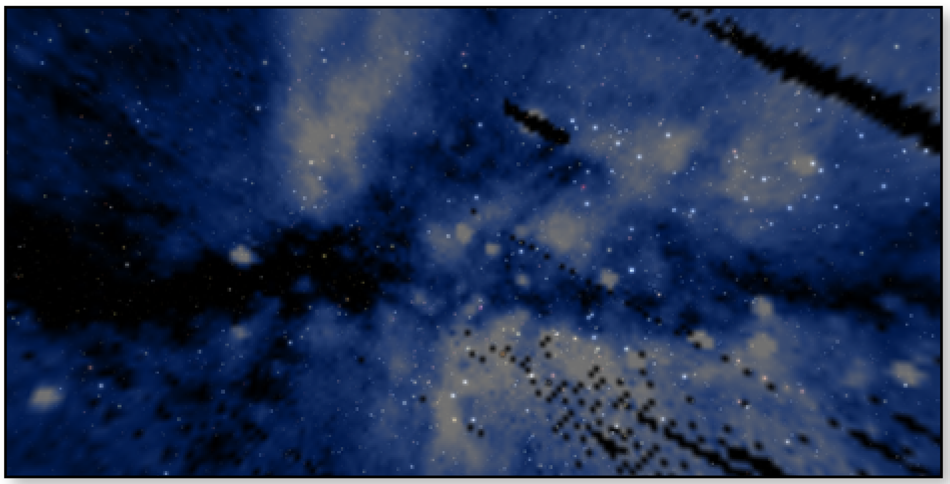
This is a map of the diffuse near ultraviolet light in the sky ("near" because it is closer to the blue end of the visible spectrum). Ultraviolet light stems mainly from hot plasma between about 1,000–10,000 Kelvin, which is found in nearly all corners of the universe: around stars, nebulae, planetary atmospheres, in the interstellar gas, in nuclei of galaxies, near black holes, and in the intergalactic medium.

While this sky map does not show detailed structure, we feel there's value in seeing the best image we have for UV light. The telescope's individual fields are visible in this imperfect mosaic, and many unobserved areas remain. This image crudely shows the brighter areas of ultraviolet light in the sky, but it also demonstrates the effort and challenges involved in constructing an all-sky map from numerous individual images.

X-ray All-sky Survey

Description	An image of the night sky in x-ray from the ROAST satellite.
Census	1 all-sky image
Version	2.3
Wavelength	1.65 nm (0.75 keV)





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The X-ray all-sky image dates from the mid 1990s and is very low resolution, but it remains the best map for X-ray light in the galaxy. Bright areas show concentrations of tenuous gas clouds, often in supernova remnants. Cold, interstellar gas absorbs lower-energy X-rays, so the plane of the Milky Way is conspicuously dark in this image.

The only all-sky survey of the x-ray continuum was taken with the Röntgen Satellite, or ROSAT, and was published in 1995. While the resolution is fairly low, it remains the best all-sky picture of the x-ray sky.

This particular map is in the soft x-ray region, which shows lower energy x-ray emission (hard x-rays are higher-energy light that can penetrate objects and are used to image our broken bones). The intensity in this map shows local, Galactic, and extragalactic x-ray emission. These emissions are mainly from hot, tenuous gas. But, x-rays at lower energies are absorbed by cold, interstellar gas, indicated by the darker areas of the map.

Many objects are visible in this map. Perhaps the most prominent is the large glow of the Vela pulsar. Many other supernova remnants appear in this map, including the SN 1006, the Cygnus Loop (which includes the Veil Nebula), Cassiopeia A, Tycho, the Crab Nebula, and Puppis A.

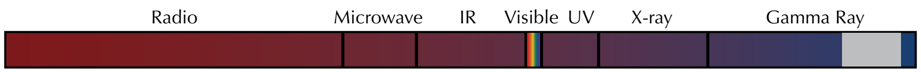
Several black holes glow in x-rays, like Scorpius X-1 and Cygnus X-1, one of the brightest x-ray sources and the first confirmed black hole observation, visible because it has a very bright star orbiting it.

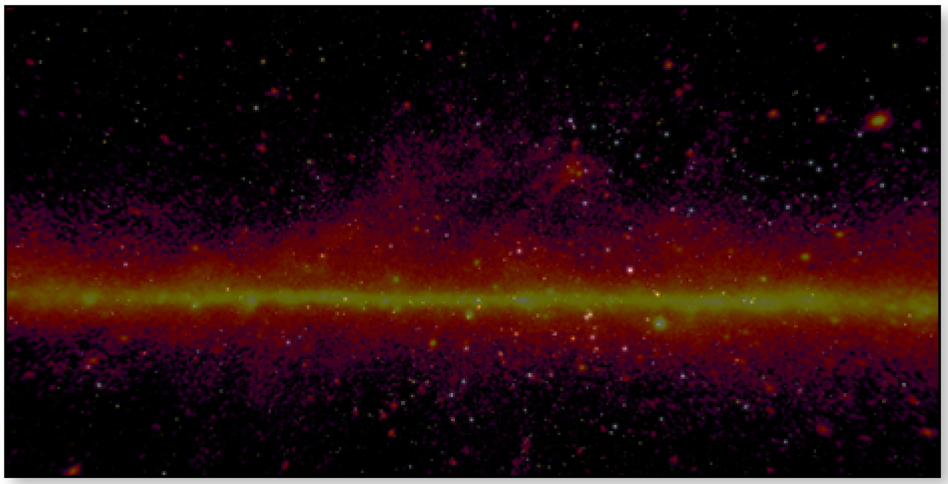
There are also fainter wisps of x-ray gas around some young, hot clouds where recent star formation occurred, like the Orion Nebula and the Pleiades.

Some extragalactic sources also appear in this map, including the Large and Small Magellanic Clouds, the Virgo Cluster, the Perseus Cluster, and wisps around some of the other nearby galaxy clusters. The galaxy M87, in the Virgo Cluster, was the first x-ray source detected outside the Milky Way in 1966. These sources are attributed to the hot gas that exists throughout and around each cluster.

Gamma-ray All-sky Survey

Description	The sky in gamma-ray light, the most energetic light in the universe.
Census	1 all-sky image
Version	2.3
Wavelength	Shorter than 0.0000000012 nm (energies greater than 1 GeV)





Brian Abbott / AMNH / Uniview

Gamma ray light represents the most energetic processes in the universe. This is mostly represented by energetic particles being accelerated in the shock waves of supernovae. When these accelerated particles collide with the gas of the interstellar medium, gamma-ray light is produced.

Gamma rays are the most energetic light in the universe. This radiation arises from radioactive decay of an atomic nucleus. In the cosmos, gamma rays are produced when cosmic rays interact with the atmosphere, or when high-energy electrons are produced and interact with other particles. Mostly, in this map, we're seeing energetic particles, accelerated in the shock waves of supernova remnants, collide with atoms and light in interstellar gas.

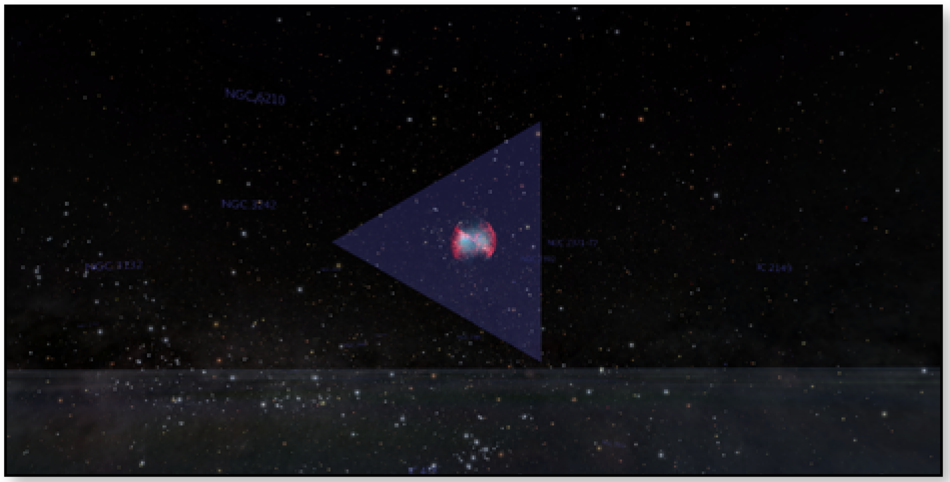
Gamma radiation can ionize other atoms and is, therefore, not the sort of light we want to be around. On earth, it is produced during nuclear fission in a nuclear explosion. As the light passes through our body, it will do real damage to our cells. The only real protection is shielding from a large, thick layer of concrete or other solid material. Luckily, Earth's atmosphere protects us from natural gamma ray radiation.

This all-sky view was collected by the Fermi Space Telescope and is an improvement over the first gamma ray telescope called Compton. The map shows sources of gamma rays, and these include gamma-ray bursts, supernova remnants, pulsars, active galaxies, and even a globular cluster or two. And, we see radiation from all scales: local, Galactic, and extragalactic.

Among the pulsars that appear in Fermi, Vela glows bright in the disk of the Milky Way. Geminga (PSR 0633+1746), in Gemini, and the Crab Nebula are also very bright. A handful of supernova remnants, including the Cygnus Loop, Cassiopeia A, Tycho SN 1572, and IC 443, shine brightly in the map. The Orion Nebula and associated diffuse gas is also present, along with a few dozen active galaxies, like M87, NGC 1275, and Centaurus A. And, a few normal galaxies, the Small and Large Magellanic Clouds, the Andromeda Galaxy, and the starburst galaxies M82 and NGC 253, also appear, albeit dimmer.

Deep Sky Images

Description	Accurately sized images for the Messier objects within the Milky Way.
Census	63 images and labels
Version	1.3



Brian Abbott / AMNH / Uniview

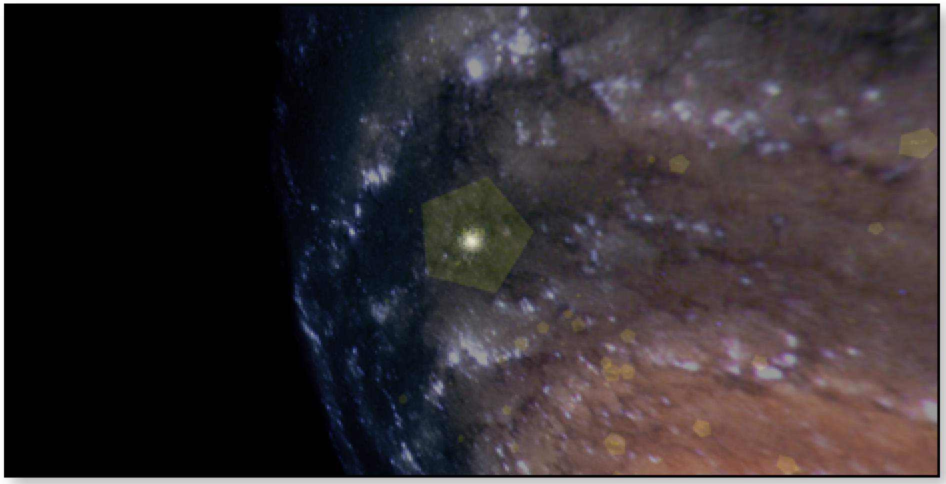
Messier 27, the Dumbbell Nebula, a planetary nebula in the constellation Vulpecula. Here, we have a vantage point beside the nebula looking back toward the Sun, about 1,400 light years away.

Deep-sky object is a term familiar to avid sky watchers as an object in the sky that is not a star or an object that orbits the Sun. These include open and globular star clusters, nebulae, supernova remnants, and galaxies. Often invisible to the unaided eye, they require binoculars or a telescope to view them.

The first list of such objects was compiled by Charles Messier (1730–1817), a French astronomer who was searching for comets. Comets resemble diffuse, fuzzy objects, and with the low-power optics of the day, star clusters, nebulae, and galaxies resembled comets. In order to distinguish these static nebulae, clusters, and galaxies from the comets that move in the sky, Messier created a list of the stationary diffuse objects so he would not confuse them with the comets he was searching for. The resulting list contains 110 objects beginning with Messier object 1, or M1, also known as the Crab Nebula, and ending with M110, a small satellite galaxy of the Andromeda Galaxy, which itself is called M31.

These data are 2-D images of Messier objects placed in 3-D space. Not only do we place these images at the proper location and give them the correct orientation, we also size them accurately so that you can fly to the globular cluster M13, for example, and see just how small the cluster of hundreds of thousands of stars is relative to the rest of the Galaxy.

The group consists mainly of open star clusters, globular clusters, diffuse nebulae, and planetary nebulae. All together, sixty-three of the Messier objects are represented. We do not include galaxies (they are represented elsewhere) or objects for which we have 3-D data. For example, you will not see the Orion Nebula (M42 and M43) because we have a 3-D Orion Nebula model in the atlas. Similarly, we have 3-D stars in place for M45 (Pleiades), M44, and a few other open star clusters. Below we list the Messier objects included in the this group.



Brian Abbott / AMNH / Uniview

Messier 13, a globular star cluster in the constellation Hercules. From this view beside the cluster, we're above the disk of the Milky Way, roughly 22,000 light years from the Sun.

Messier Objects in the DSO Group	
Object Type	**Messier Object Number**
Open star clusters	6, 7, 11, 16, 18, 21, 23–26, 29, 34–39, 41, 46–48, 50, 52, 67, 93, 103
Globular star clusters	2–5, 9, 10, 12–15, 19, 22, 28, 30, 53–56, 68–72, 75, 79, 80, 92, 107
Planetary nebulae	27, 57, 76, 97
Diffuse nebulae	8, 17, 20, 78
Supernova remnants	1

You may know some of these objects by their common names:

M1	Crab Nebula	M27	Dumbbell Nebula
M8	Lagoon Nebula	M44	Beehive star cluster
M16	Eagle Nebula	M45	Pleiades star cluster
M17	Omega Nebula	M57	Ring Nebula
M20	Trifid Nebula	M97	Owl Nebula

I don't see any images. By default, this data group is on, but you are not likely to notice them just as you don't typically see these objects in the night sky. This is due to their size, which in most cases is quite small. One way to pick them out is to turn on the labels for the group. To see the image, you can either zoom in from your current location on Earth, or fly out to the object.

To view the images from Earth's position, change your field of view to simulate looking at the sky through binoculars or a telescope. Center one of the objects in your view and narrow the field of view. The default value for the Digital Universe is 60°. A value of 5–10° might simulate a pair of binoculars while a value less than 0.5° replicates a telescopic view.

Image credits. For information such as credits, you can choose the object and the resulting report will have the image credit. Or, look at the data file which lists the credits for each image.

Milky Way Galaxy Model

Description	A conceptual representation of the Milky Way galaxy as a flat image properly sized and oriented.
Census	1 image
Version	2.2

Brian Abbott / AMNH / OpenSpace

This stand-in, if you will, for the Milky Way is an image of the galaxy NGC 1232. We do not have a view of the Milky Way from this perspective, so we must use a galaxy that resembles the Milky Way to represent the Galaxy in 3-D. The green sphere marks the location of the Sun, and many of the stars we see in the sky are within that sphere.

A problem that continues to baffle astronomers today is defining the structure of our star system, the Milky Way. Because we reside within our Galaxy, we cannot see the larger picture of what the Galaxy actually looks like. Astronomers continue to debate the structure of the Milky Way with more uncertainty than that of other galaxies that are millions of light years away.

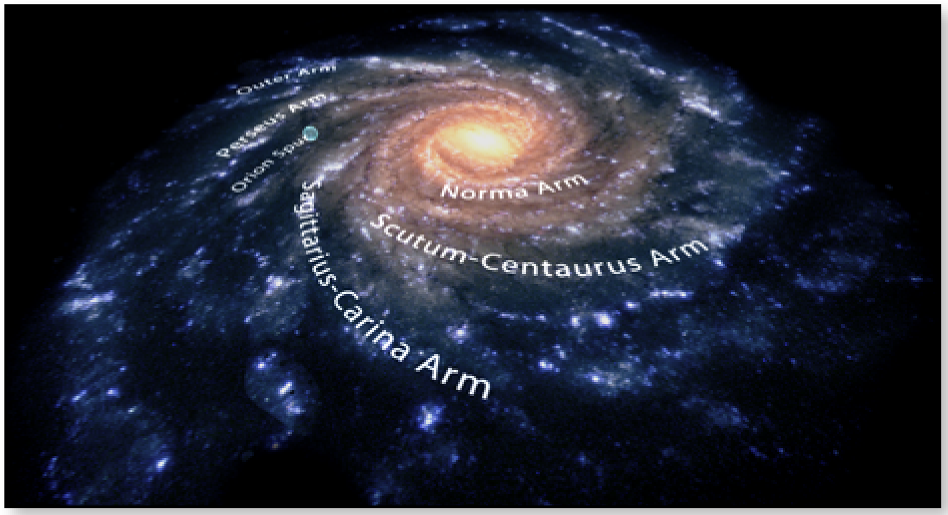
In 1918 and 1919, a series of papers by Harlow Shapley was published that described the dimensions of our Galaxy. Using the distribution of globular clusters in the sky, Shapley deduced that the center of our star system was in the direction of Sagittarius and that the distance to those clusters was greater than anyone had ever proposed.

A great debate had taken the astronomical world by storm. Was the Andromeda Nebula inside our own Galaxy, or was it a distant extragalactic object similar in stature to our Galaxy? Within five years, Edwin Hubble solved the debate by observing Cepheid variable stars in the Andromeda Nebula, which allowed him to measure the distance to the star system, now considered a galaxy in its own right. With other galaxies as examples, it soon became clear that we were inside a spiral galaxy similar to Andromeda.

The Galaxy image. The exterior view of the Milky Way is simply a two-dimensional image. The image is that of NGC 1232, a galaxy thought to resemble our Milky Way. The image has been properly sized and approximately oriented to function as a placeholder, allowing one to see the context of the Galaxy relative to other data in the atlas. The features you see in the image, of course, do not represent our Galaxy, per se, but resemble similar features found in our Galaxy.

Milky Way Spiral Arm Labels

Description	A mostly transparent image, with spiral arm labels mapped on top of the Milky Way Galaxy Model image.
Census	1 image
Version	1.2



Brian Abbott / AMNH / Partiview

The spiral arm labels is a transparent image with labels traced on the major spiral arms of the Galaxy. This is not exact because the image we trace this upon is not an image of the Milky Way (see the previous section), but it illustrates the general scale and configuration of the arms.

"Baked" labels. Because these labels are "baked into" this image and sit stationary on the Galaxy, they will read backward from one side of the Galaxy.

This image contains labels for the Milky Way's spiral arms. We label them in this manner ("hard coding" the labels into an image rather than having native labels) so that they can retain their size, shape, and location as they overlay the galaxy.

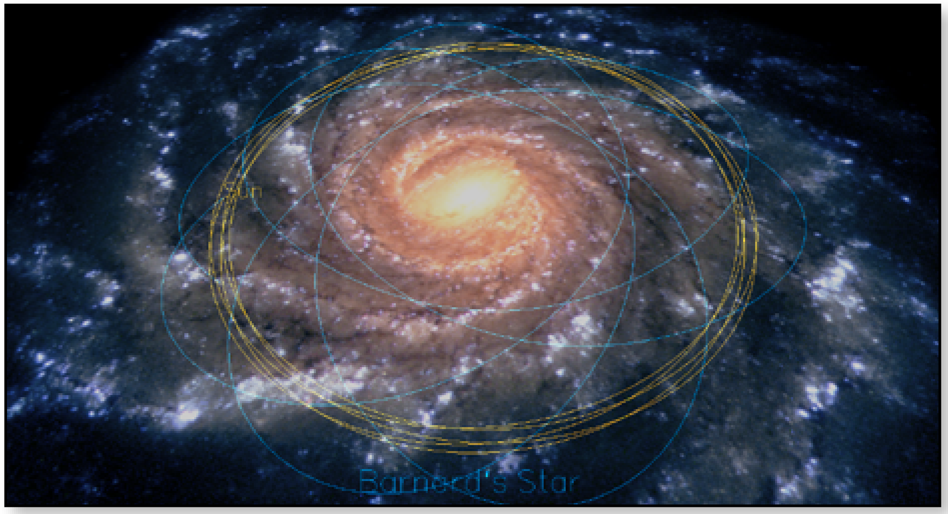
We reiterate that these are guides and not based in reality, because we never have this view of the Milky Way and can only infer its structure. The labels in this data group build upon the scientifically informed positioning of the galaxy image, and these arm labels are anchored in those presumptions, but also reflect the reality of the star-forming regions, which we know accurately.

The sun is located in the Orion Spur, a sub-arm that's likely an offshoot from a major spiral arm. As we look away from the center of the Galaxy in the plane, we look toward the Perseus Arm, and beyond that is the Outer Arm. If we look toward the center of the Galaxy, we are beside the Sagittarius-Carina Arm, and inside that is the Scutum-Centaurus Arm, and inside that is the Norma Arm and the 3 kiloparsec arms that surround the Galactic center.

These labels are designed to be a guide, and they map more accurately to the various datasets in the Atlas. For example, the pulsars, the star-forming (HII) regions, and open clusters all show the local spiral structure. We can use trends in these data sets to map the arms of the Milky Way.

Star Orbits

Description	A selection of stellar trajectories around the center of the Galaxy, describing the positions of these stars over the next billion years.
Census	7 star orbits
Version	1.5



Brian Abbott / AMNH / Partiview

Stellar orbits superimposed on the Milky Way galaxy. Shown here is the Sun's orbit (orange) and Barnard's Star (blue), a dim, nearby star. Each orbit shows the star will go over the next billion years.

If you're using Partiview, note that only the Sun's orbit is visible by default. To see the other orbits, you must change their color from black to a color of your chice. Alternativiely, alter the starorbits.cf file and remove or comment out the orbit's black color setting.

Everything in the Universe moves. The Sun and its family of planets, asteroids, and comets move through the Milky Way galaxy at about 860,000 kilometers per hour (530,000 miles per hour) in a relatively stable orbit. One circuit around—our "galactic year"—takes about 225 million years. The last time the Sun was in the same spot in the Galaxy, dinosaurs ruled Earth. In this data group, we illustrate one-billion-year orbital trajectories for seven stars with varying speeds and directions.

Currently, the Sun is heading in the direction of the constellation Cygnus and lies about 50 light years above the plane of the Galaxy. The Sun's position oscillates above and below the plane every 38 billion years, reaching a maximum of about 260 light years above or below the plane. Imagine how our night sky changes due to this periodic motion. When we are centered on the plane of the Galaxy, the band of light across the sky will be at its thinnest. Conversely, when we are 260 light years above or below the plane, the band of light will appear a little thicker.

Barnard's Star, the fourth-closest star to the Sun, has the highest proper motion of any star in the night sky. While its path generally remains in the Galactic disk, its radius from the Galactic center varies greatly.

Not all stars are so well behaved. The halo star PM J13420-3415 moves perpendicular to the Galactic disk. Imagine how your night sky will appear under these circumstances. If we were living on a planet whose host star was high above or below the disk, we would have a magnificent, face-on view of the Galaxy.

Galactic Bar

Description	A model of the size, shape, and orientation of the Milky Way's bar.
Census	1 wire-frame oblate spheroid model, 1 image
Version	2.2

Brian Abbott / AMNH / Uniview

A model of the Galactic bar, a concentration of gas and stars in the center of the galaxy. The model is a wire-frame structure with the dimensions and position of the Galaxy's bar.

The Milky Way has two main structural elements: the disk and the spherical component. The disk is a thin layer of stars, gas, and dust that contains the Galaxy's spiral arms. The spherical component includes the Galactic bulge and the Galactic halo. The bulge, at the center of the Galaxy, contains both old and young stars with some gas and dust.

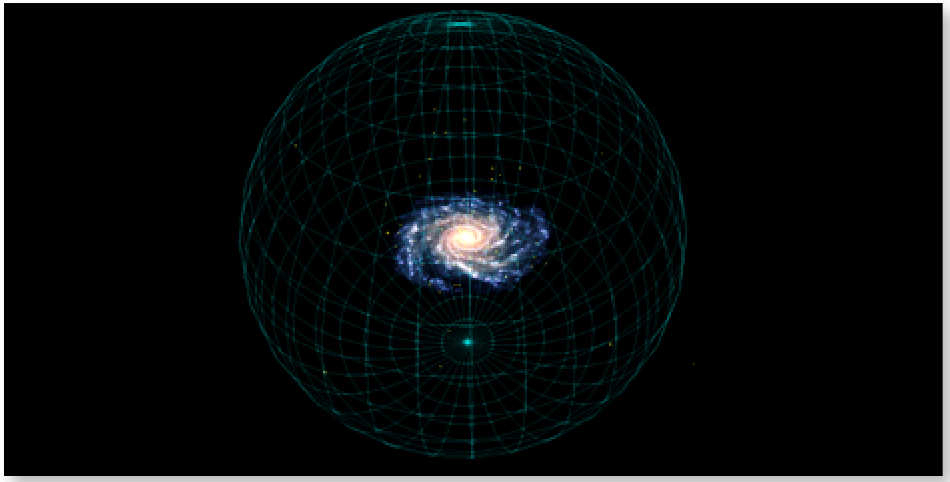
Most of the mass and luminosity of the Galaxy is contained in the Galactic bar, an oblate spheroid located at the center of the Galaxy. The bar is shaped like an American football, with axes of (a_x, a_y, a_z) = (5500, 2050, 1370) light years. Given that we're located far from the Galactic center, and that the intervening gas and dust obscure our view of distant parts of the Galaxy, how do we know there is a bar if we cannot see it?

The main evidence for the existence of a bar is the infrared luminosity differences around the Galactic center. Because infrared light is less obscured by dust (we can see farther in infrared), astronomers can examine the Galaxy in IR and see that the intensity on one side of the Galactic center is higher than it is on the opposite side. Astronomers deduced that there must be a triaxial bar present, with the bright side of Galaxy center corresponding to the end of the bar that is closest to us. Currently, the long axis of the bar (which is parallel to the Galactic plane) is believed to be inclined 30° to the line connecting the Sun and the center of the Galaxy.

We represent the bar as a yellow, wire-frame ellipsoid with a glow texture at its center. The glow is composed of three polygons that lie in the x, y, and z planes, respectively. The glow can be turned off.

Galactic Halo

Description	The halo outlines the spherical component of the Milky Way and contains the globular clusters and countless uncatalogued, dim stars.
Census	1 wire-frame model
Version	1.2



Brian Abbott / AMNH / Uniview

A model of the Galaxy's halo, a spherical component of the Milky Way. The disk of the Galaxy is rather small compared to the halo. Inside this sphere are numerous dim, cool, old stars. Concentrations of these stars are called globular clusters.

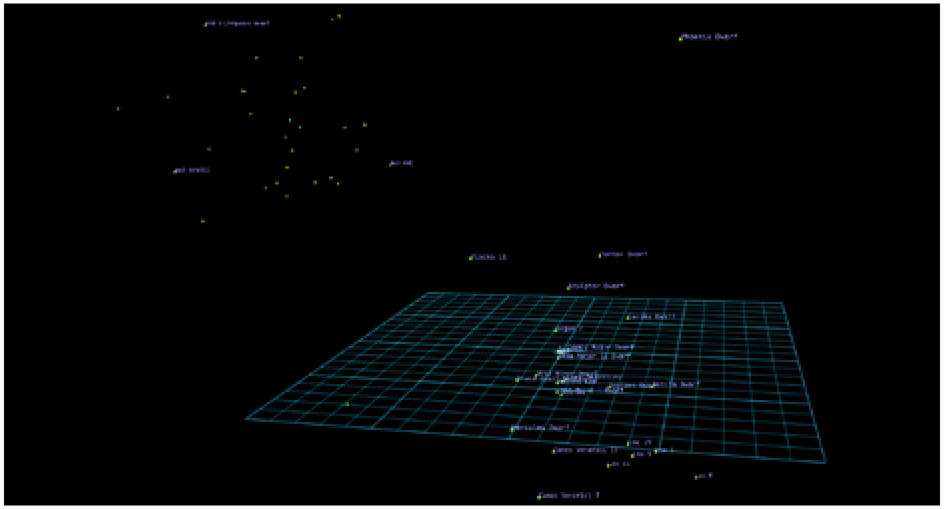
Surrounding the disk of the Milky Way is the spherical Galactic halo. Unlike the population of the disk, where stars continue to form, the halo population is devoid of gas and dust and, therefore, star formation. It contains cooler, dimmer stars left over from an era of star formation in the Galaxy's early history. There are no young, luminous stars in this population.

The main structural element in the Galactic halo is the system of globular clusters. Numbering about 160, the Milky Way's globulars are spherically distributed about the Galactic center, and most are within the halo. The stars in the halo are so intrinsically dim that it is difficult to see them unless they are close to the Sun. These stars travel in elliptical orbits about the center of the Galaxy that are not confined to the disk but are distributed throughout the spherical halo.

Many properties of the halo are still under consideration by astronomers. With the introduction of dark matter and the discovery of more small satellite galaxies around the Milky Way, the halo seems to come under continual scrutiny. We place the radius of the halo at about 134,000 light years (41,000 parsecs); however, some astronomers believe it to be far larger, perhaps as much as 300,000–800,000 light years in radius. The model here serves as a rough guide for the scale of the Galaxy's halo.

The Local Group

Description	The Milky Way's local galactic neighbors. Most are small, dwarf galaxies, with a handful of larger galaxies.
Census	102 galaxies
Version	6.4



Brian Abbott / AMNH / OpenSpace

The Local Group of galaxies with the Milky Way and its companion galaxies around the coordinate plane, and Andromeda and its dwarf companions to the upper left.

These objects are color coded by their galactic subgroup.
Green galaxies are bound to the Milky Way
Blue galaxies are bound to the Andromeda Galaxy
Yellow galaxies are other members of the Local Group
Gray galaxies are nearby, but not members of the Local Group

A *group* of galaxies is a small number of large galaxies that are typically surrounded by a large number of small galaxies. The Milky Way belongs to the Local Group, and is one of roughly 100 galaxies in that group.

The Milky Way, the Andromeda Galaxy (also known as Messier 31, or M31), and the Triangulum Galaxy (M33) are three of the largest galaxies in the Local Group. Each is a spiral galaxy containing hundreds of billions of stars.

Surrounding the Milky Way and Andromeda are a bevy of dwarf galaxies—smaller, often irregular galaxies, that contain hundreds of millions to a few billion stars.

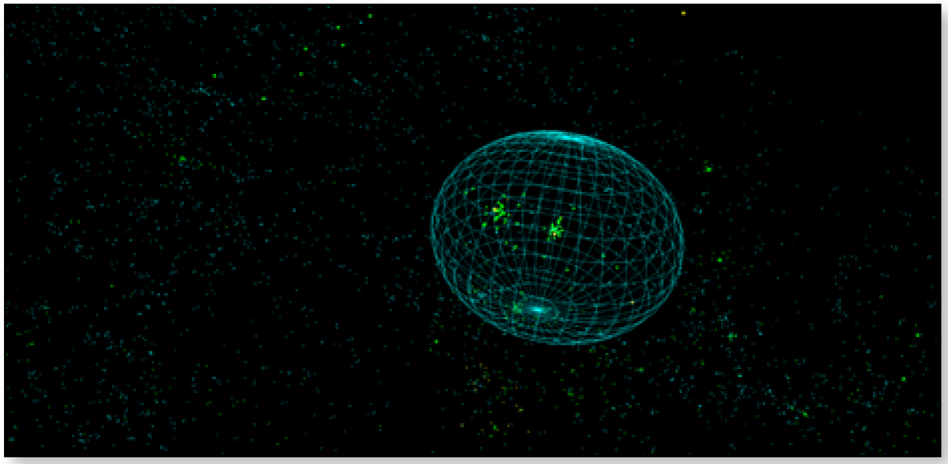
These dwarf galaxies are typically under the gravitational influence of a larger galaxy, and are often shredded by them at some point over their lifetime. Collisions between galaxies are common, and these smaller galaxies may even be key to maintaining life in a larger galaxy by instigating star formation and replenishing its gas, the material that forms stars.

The group members are colored by their "host" galaxy, or subgroup. Those in the Milky Way's influence have a green color. Andromeda's associated dwarfs are blue. Yellow galaxies are in the Local Group but not affiliated with the Milky Way or Andromeda. And, gray galaxies are Local Group neighbors.

The Galaxy Groups data (see page 46) identify many other nearby galaxy groups. Because the Local Group is nearby, we see a fairly accurate picture of the dwarf galaxies that inhabit it. Neighboring groups are so far away, it's difficult to see their smaller members. With these other groups, we really only see the largest, brightest galaxies. If we considered the Local Group from afar, we would probably only see the Milky Way, Andromeda, and M33.

Local Group Boundary

Description	A wire-frame spheroid marking the approximate boundary of the Local Group.
Census	1 wire-frame model
Version	1.2



Brian Abbott / AMNH / Uniview

A rough boundary of the Local Group, the green galaxies inside the oblate sphere. The model is about 10 million light years across. Outside the Local Group in the frame are the Tully galaxies.

The Local Group Boundary is an oblate sphere that roughly outlines the size of the Local Group of galaxies. The model's long axis is roughly 10 million light years across and contains the galaxies that make up the Local Group, including the Milky Way, Andromeda, and all of their dwarf galaxies.

This is a rough perimeter and is not derived from dynamic parameters. It's meant as a guide to see how large the Local Group is among the nearby galaxy groups and clusters, and where it is in comparison to the large-scale structure of the universe.

The model can act as a marker for the Milky Way when you're exploring the universe from most distant locales.

Galaxy Survey Colors

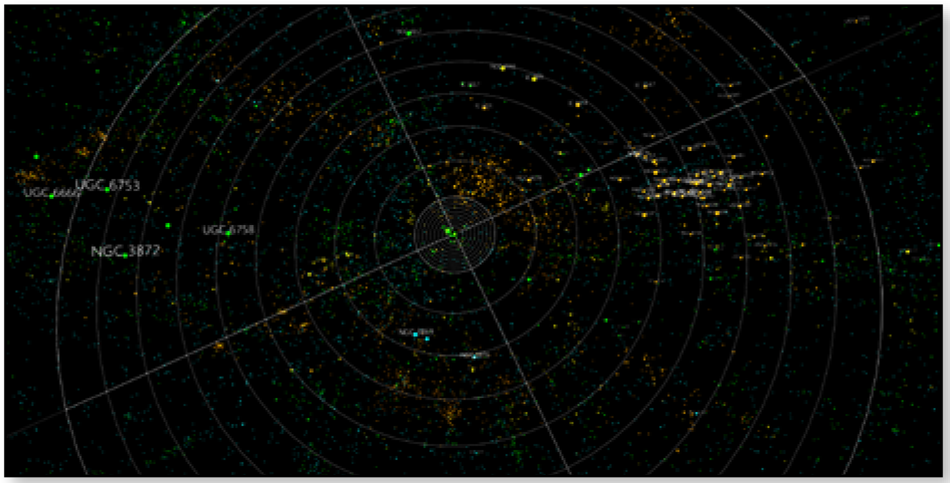
For each of the forthcoming galaxy surveys (see below), the colors of the points reflect the local density. In other words, how many galaxies surround any given galaxy in the catalog.

We split the density spectrum into three regions. Galaxies in the most dense regions, like galaxy clusters and filaments, are colored orange. Aqua galaxies show intermediate-density regions. Green galaxies show so-called field galaxies, those that are in relatively empty areas.

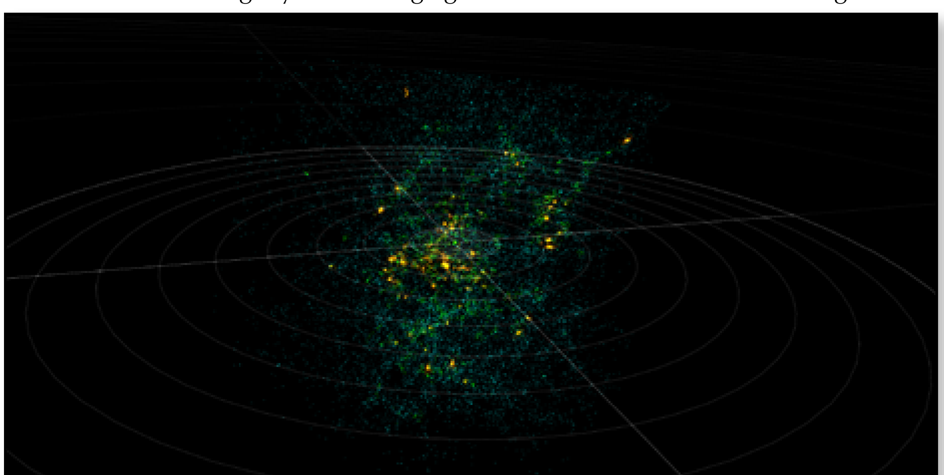
Orange galaxies show dense regions of galaxies.
Aqua galaxies are areas of intermediate density.
Green galaxies are areas of lower density.

Tully Galaxy Catalog

Description	The Tully catalog is a rich, curated atlas of the roughly 30,000 galaxies around the Milky Way and shows nearby galaxy groups and clusters.
Census	30,059 galaxies
Version	1.5



The Tully galaxies from within, looking back toward the Milky Way (center) from about 150 million light years. Orange galaxies are in clusters of denser regions.



Brian Abbott / AMNH / Uniview

The Tully galaxies from outside the dataset, with large-scale structure in orange.

The Tully Catalog is the most polished, accurate catalog of nearby galaxies. It includes over 30,000 galaxies in the local universe that surround the Milky Way. This catalog demonstrates the large-scale structure of the universe exceptionally well. And, each galaxy has a representative image reflecting its morphological type, and is properly sized and inclined.

Size and shape. The data form a cube, which is an arbitrary cutoff based on the completeness of these data. Beyond this, data from these sources are not as reliable, so effort is made to show a complete picture, albeit limited by observations (for example, we cannot see dwarf galaxies much beyond the Local Group).

The size of the cube is roughly 1 billion light years on a diagonal (so the farthest galaxies in the dataset are about 1 billion light years from the Milky Way), or about 700 million light years per side.

Colors. The colors of these galaxies adhere to the description box on page 43. Orange denotes more dense regions of the local universe, aqua is given to galaxies in an intermediate-density area, and green is given to lower density regions.

Galaxy images. Each galaxy is represented by an image that represents its morphological type (spiral, elliptical, etc.). Most of these come from The Galaxy Catalog. A handful of nearby galaxies are represented by their actual images, which come mostly from the National Optical Astronomy Observatory (NOAO).

Each of these images has been altered from its original state. These images were taken from Earth on some of the world's largest telescopes, so foreground stars from our own Galaxy appear in each image. We are representing galaxies in extragalactic space, so we have removed the stars from each image.

Our Cosmic Perspective

One of the consequences of showing real scientific data observed from telescopes on Earth, or in orbit around Earth, is that it appears that the Milky Way and the Sun and the Earth are at the center of the universe.

Nothing could be further from the truth.

We are the center of these data sets merely because Earth is our observation point. In reality, the universe has no center. The Big Bang describes the beginning of the universe, when the universe began to expand everywhere. The Big Bang was not an explosion that radiated from one point—The Big Bang describes the expansion of the universe at *every* point.

The common analogy is to imagine an infinitely large raisin bread. As the bread rises (expands), the space between two points increases. The raisins represent galaxies, which do not expand themselves, but do recede from one another as the expansion continues.

Another two-dimensional analogy is to imagine an infinitely large rubber sheet that's being stretched from all directions. No matter where you are, every other point will be moving farther away from you.

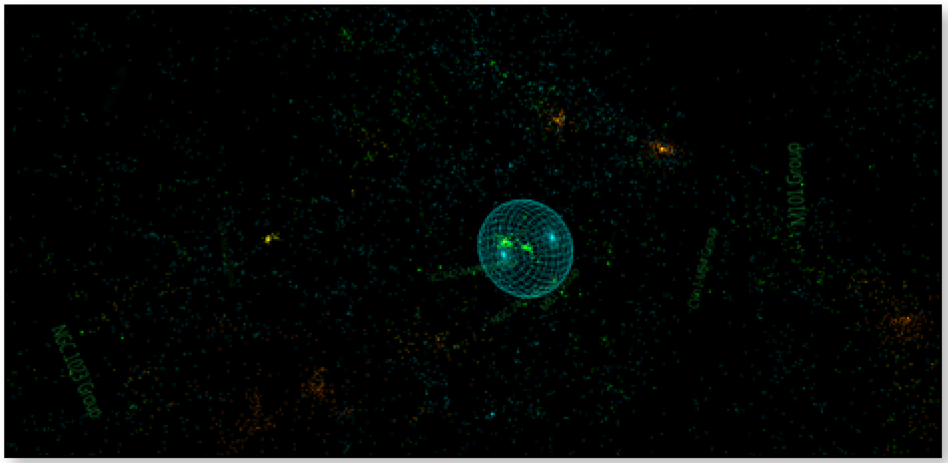
That is the nature of the universe. There is no center and, except for very nearby galaxies where gravity remains influential, everything is receding from an observer at any location.

Galaxy morphological type. The galaxy morphological type metadata is an integer that reflects the type of galaxy classified first by Edwin Hubble (1889–1953) in the 1930s. The classification scheme has four main groups: elliptical galaxies (E), barred spiral galaxies (SB), unbarred spiral galaxies (S), and irregular galaxies (Irr). The integers assigned to these types are decoded in the table below. In this numbering system, barred and unbarred spiral galaxies (S & SB) are merged, since data on bars are often inconclusive.

Code	Galaxy Type		Census
-5	E	Elliptical	990
-3	E/SO	Elliptical/Lenticular (class uncertain)	652
-2	SO	Lenticular	1439
0	SO/a	Lenticular/Spiral	9132
1	Sa	Spiral	1314
2	Sab	Spiral	1629
3	Sb	Spiral	2046
4	Sbc	Spiral	2332
5	Sc	Spiral	3323
6	Scd	Spiral	2284
7	Sd	Spiral	581
8	Sdm	Spiral	498
9	Sm	Spiral/Irregular	311
10	Irr	Irregular	481
12	S	Spiral/Irregular (class uncertain)	0
13	P	Peculiar	0

Galaxy Groups

Description	A label set that marks all the nearby galaxy groups akin to our Local Group.
Census	62 galaxy group labels
Version	1.2



Brian Abbott / AMNH / Uniview

Labels mark the galaxy groups that surround the Local Group, marked by its green boundary.

The Galaxy Groups data are a set of labels that mark the nearby galaxy groups. The Milky Way is in the Local Group, and we are surrounded by many other groups.

Some of the closest groups include the M81 Group, the Sculptor Group, the Cen A Group, and the NGC 2403 Group. Each of these contain one or more large galaxies. Historically, the term *cloud* was used to describe groups of groups, but this term has fallen from favor given it’s physically ambiguous.

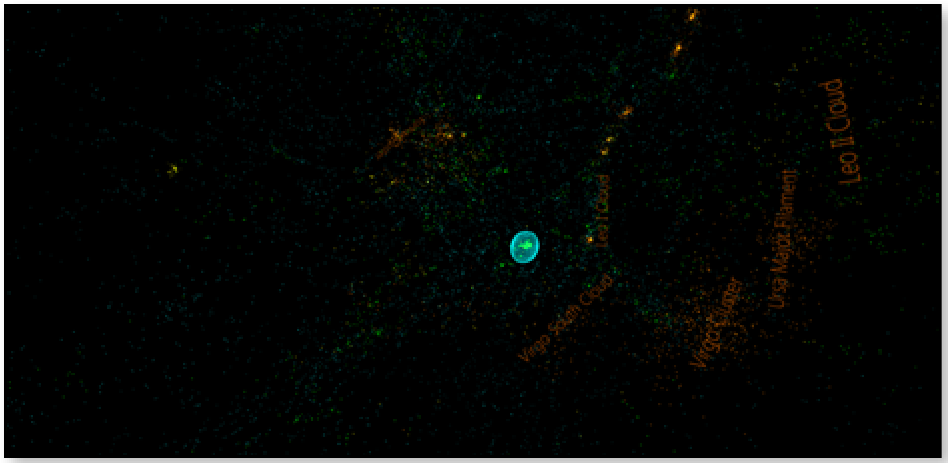
The Local Group is populated with several large galaxies, and many dozens of dwarf galaxies. Only the big, bright galaxies will be visible in more distant groups, so these consist of a few galaxies each. Presumably, they each contain many small dwarf galaxies like we see in the Local Group, but they remain too faint for us to see.

Use in conjunction with the Tully Galaxy group.

This data group consists only of labels that mark nearby galaxy groups, including the Local Group.

Galaxy Clusters

Description	A label set of the nearby galaxy clusters.
Census	15 galaxy cluster labels
Version	1.2



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Labels denote the prominent galaxy clusters near the Milky Way. The Virgo Cluster, around 55 million light years away, is the nearest, large galaxy cluster to the Sun.

Use in conjunction with the Tully Galaxy group.

This data group consists only of labels that mark nearby galaxy clusters.

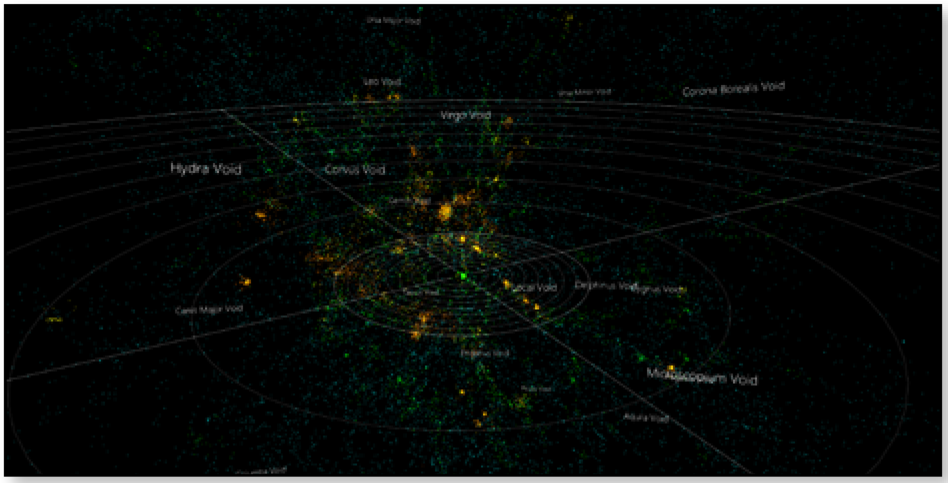
The Galaxy Clusters dataset is a series of labels that mark where the large clusters of galaxies are in the nearby universe. These labels must be used in conjunction with the Tully galaxy group.

The nearest large cluster to the Milky Way is the Virgo Cluster, which is about 55 million light years from Earth. It contains over 1,000 galaxies in reality. On the opposite side of the sky is the Fornax Cluster, another nearby large cluster.

Additional nearby clusters within Tully are labeled in this dataset. They often take the name of constellations because it is in these constellations that we see these clusters from our night sky perspective. For example, the Virgo Cluster appears in the constellation Virgo in the night sky.

Voids

Description	A label set of cosmic voids in the nearby universe.
Census	24 cosmic voids
Version	1.2



Brian Abbott / AMNH / Uniview

Labels roughly denote the location of cosmic voids in the Tully galaxies. Voids are only visible with motion cuing as you spin around these data. The labels help to guide the eye and provide sign posts for the largest voids in our cosmic neighborhood.

Use in conjunction with the Tully Galaxy group.

Cosmic voids are vast, empty spaces where there are either no galaxies, or very few galaxies. They are associated with cold spots in the cosmic microwave background (CMB) light, the earliest picture we have of the universe (see page 58). Those cold spots in the CMB evolved into large voids, some as much as 300 million light years in diameter.

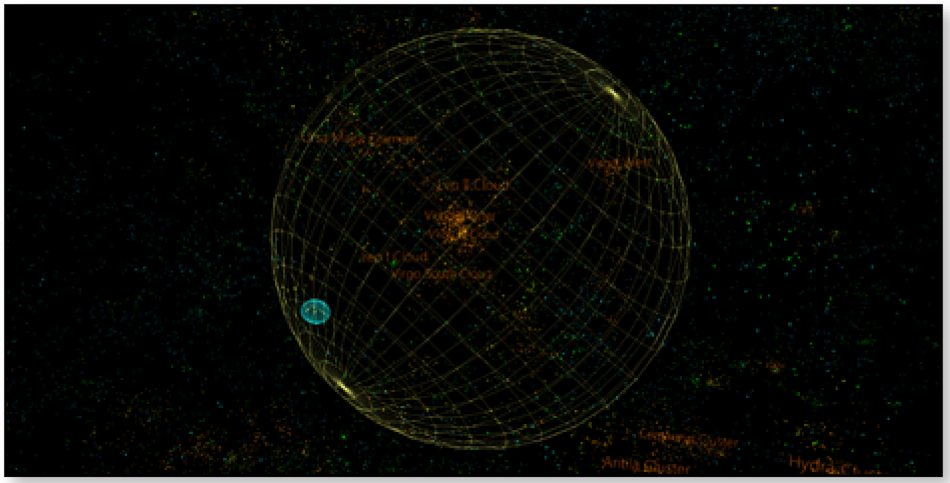
Voids likely have some matter in them, but are overshadowed by the more massive galaxies that gravitate toward the large-scale structure that we see—clusters and filaments of galaxies. Voids typically have about a tenth (or less) of the mass of the surrounding universe.

Voids are often mostly spherical, partly shaped by the expansion of the universe. They, therefore, are important for studying dark energy and other properties of the expanding universe.

These labels point out the voids within the Tully data. It's a bit difficult to see them unless you twirl these data around a bit and see the three-dimensional structure. The voids become more apparent as you orbit outside the Tully data.

Virgo Supercluster Boundary

Description	An approximate boundary for the Virgo Supercluster, also known as the Local Supercluster.
Census	1 wire-frame model
Version	1.2



Brian Abbott / AMNH / Uniview

The yellow wire-frame model roughly delineates the boundary of the Virgo Supercluster, also called the Local Supercluster. At its center are the orange-colored galaxies that comprise the Virgo Cluster. The Local Group (green model) is located near the edge of the supercluster, in a relatively nondescript part of the universe.

The Virgo Supercluster, also known as the Local Supercluster, is a huge concentration of galaxies that include the Virgo Cluster, and the Milky Way and its neighbors in the Local Group. This data group represents the approximate boundary of the Virgo Supercluster.

Dominating the Virgo Supercluster is the centrally located Virgo Cluster, a dense group of over 1,000 galaxies. The Virgo Cluster is the densest region of the supercluster, and the density of galaxies falls off as the distance form this cluster. Overall, the supercluster is about 110 million light years across and contains about 50,000 galaxies.

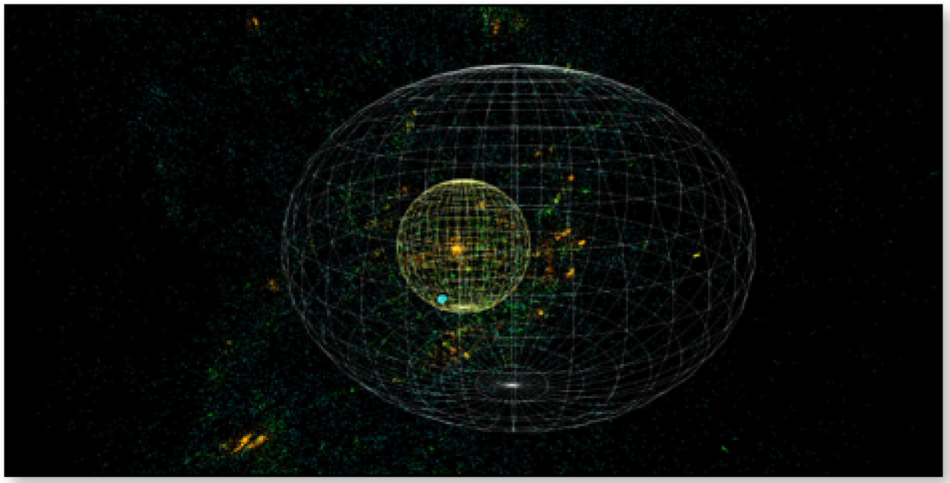
The Local Group is located at the outer edge of the supercluster, in a less dense filament connecting the Virgo and Fornax Clusters, the two nearest galaxy clusters to the Milky Way.

Among the roughly 10 million superclusters in the observable universe, Virgo is not among the largest or most galaxy-rich. Most other superclusters have several Virgo Cluster-sized nodes that form the nexus of the supercluster.

In 2014, astronomers discovered that the Virgo Supercluster is merely a small part of a larger structure called the Laniakea Supercluster, which we describe in the next section.

Laniakea Supercluster Boundary

Description	A rough model outlining the newly discovered Laniakea Supercluster.
Census	1 wire-frame model
Version	1.2



Brian Abbott / AMNH / Uniview

The Laniakea Supercluster (gray model), a larger structure composed of galaxies that are co-moving with one another, was recently discovered in 2014. The Virgo Supercluster (yellow model), is now just one lobe of Laniakea. The Local Group (green model) is almost too small to be seen at this scale.

The Laniakea Supercluster was discovered in 2014, and supplanted Virgo as our home supercluster. The Virgo Supercluster is now merely a small part of this larger structure.

The oblate spheroid that forms this boundary roughly encompasses the galaxies and galaxy clusters that make up the newly discovered structure. As you can see, the Virgo Cluster is just a subsection of the larger Laniakea.

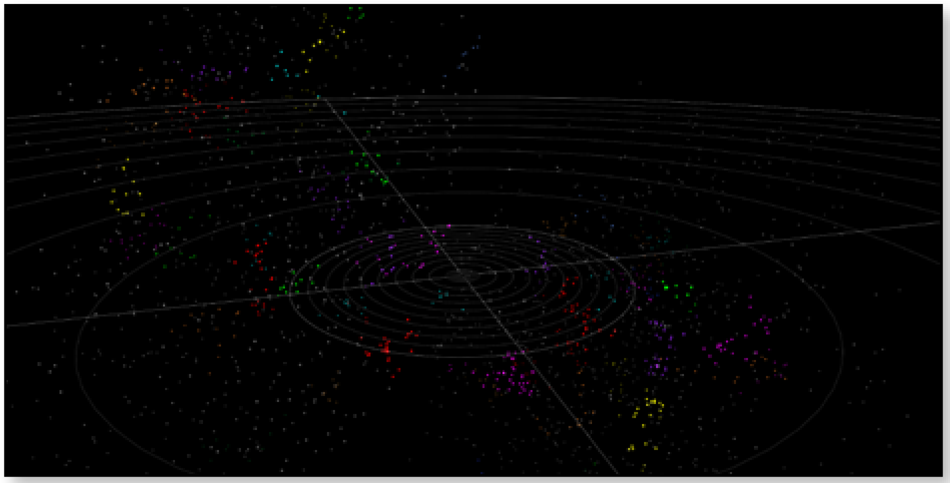
Laniakea contains approximately 100,000 galaxies and is over 500 million light years across. Its main concentrations include Virgo, the Hydra-Centaurus Supercluster, and the Great Attractor. In addition to Virgo and Hydra-Centaurus, two other superclusters were absorbed into this giant structure, including Pavo-Indus, and the Southern Supercluster, which includes the Fornax galaxy cluster.

This structure was discovered using a new method: analysis of the motions of the galaxies. By subtracting out the motion from the expanding universe, localized flow can be deduced, and, therefore, galaxies within the same related structure become apparent. But, this method has limitations.

Superclusters like this are not gravitationally bound and will disperse as the universe expands. While the edges of these superclusters remain a bit ambiguous, we include this approximation to guide the eye on the size and scale of the supercluster.

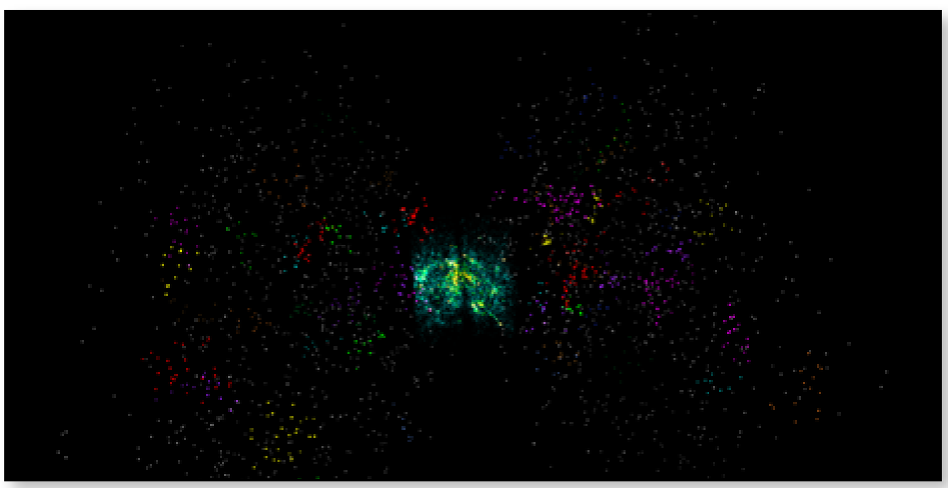
Abell Galaxy Clusters

Description	A plotting of galaxy clusters, where each point represents hundreds or thousands of individual galaxies.
Census	2,246 galaxy clusters
Version	1.3



Brian Abbott / AMNH / Uniview

The Abell galaxy clusters—each point represents hundreds to thousands of galaxies akin to the Virgo Cluster. **Top:** Clusters surrounding the Sun (center) with colored points representing superclusters. **Bottom:** Abell clusters shown with the Tully galaxies.



The Abell catalog includes all the nearby, and not so nearby, galaxy clusters. The northern hemisphere survey, published in 1958, was compiled by George Abell (1927–1983) from the Palomar Sky Survey plates. A subsequent southern hemisphere catalog was published posthumously in 1989. Further analysis by Brent Tully determined their distance and three-dimensional distribution.

Each point in this data set represents a cluster of tens to hundreds (possibly even thousands) of galaxies, similar to the Virgo or Fornax Clusters. You will notice some points are assigned colors while most are gray. The data set also has an arbitrary cut-off for completeness, resulting in the rectangular shape of the data set.

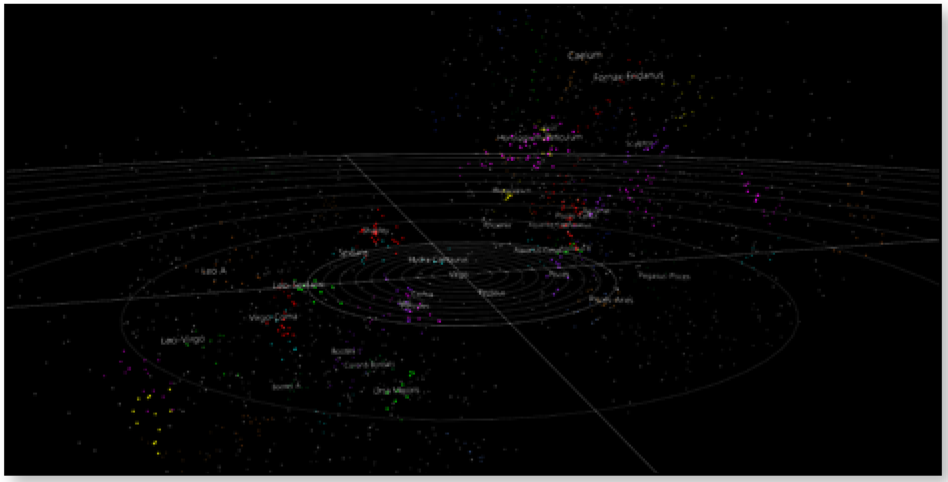
Clusters of clusters. Galaxies group together to form the large-scale structure of the Universe. Dense clusters of galaxies are connected by filaments, or strands, of galaxies. Between them, vast voids resemble the inside of a bubble and are occupied by less dense material. Beyond these structures, astronomers have found larger-scale constructs called superclusters, as we described in the previous sections.

Larger than a cluster of galaxies, superclusters are made from many galaxy clusters. In the Abell data, each point that is not gray belongs to a supercluster. These mammoth objects are on the order of 300 million light years in diameter. Compare that to the size of one cluster, Virgo, which is only 15 million light years across, or our Galaxy, which is a scant 100,000 light years across.

Labels. The labels for this group will appear when you're close to an Abell cluster, and will reflect the name of that cluster. However, to see the names of the superclusters (the colored groupings), which is more useful, turn on the Superclusters data group, which we describe next.

Superclusters

Description	A label set indicating the major superclusters.
Census	33 labels
Version	1.3



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Labels for the superclusters within the Tully and Abell catalogs. These labels overlay the Abell data group.

Use in conjunction with the Tully Galaxy group and the Abell Clusters group.

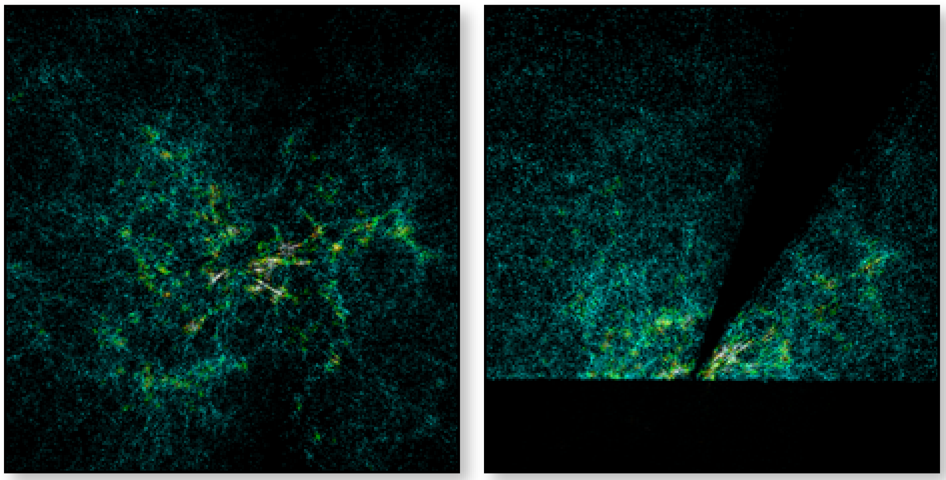
The superclusters dataset is a set of labels that mark the major galaxy superclusters in the local universe. They correspond to, and should be viewed with, the Abell clusters. Astronomers estimate there are 10 million superclusters in the observable universe.

What is a supercluster? A supercluster is a group of smaller galaxy clusters. They are among the largest structures in the universe. However, they are not bound by gravity, so individual galaxy clusters will drift away from one another due to the expansion of the universe and lead to the dispersion of the supercluster over time.

This data group includes thirty-three labels that delineate the nearby superclusters.

6dF Galaxy Survey

Description	The Six-degree Field Survey galaxy catalog
Census	109,569 galaxies
Version	1.3



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The 6dF galaxy survey. In the **left** panel we're looking at the galaxies from above the data. In the **right** panel, we're seeing the partiality of the survey. This survey did not observe in the northern hemisphere, and the wedge-shaped area reflects the lack of observations in the plane of the Milky Way.

The Six-degree Field (6dF) Galaxy Survey mapped nearly half the sky from the Anglo-Australian Observatory. Unlike previous datasets, this one is not all-sky, meaning there are patches of sky that are not covered. In this case, the entire northern hemisphere has no coverage at all.

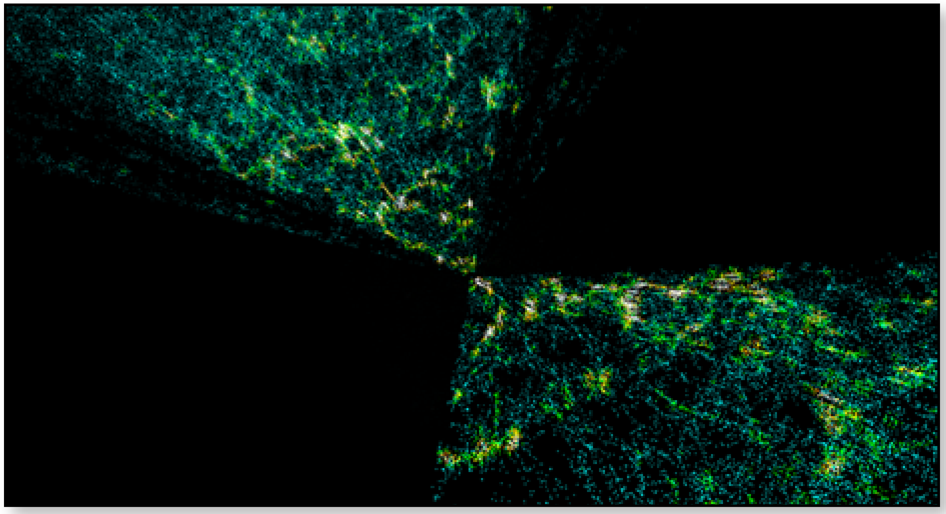
This catalog overlaps with the Tully dataset, and there is a noticeable difference in the quality of these datasets. Tully is much tighter and the structure is more apparent, while the 6dF data are more spread out. This is because of local motions within galaxy clusters have not been corrected in these data.

Fingers of God. Early in the process of mapping the local universe, astronomers noticed that galaxies, when plotted, appeared on lines that pointed radially back to Earth. It turns out, these lines, dubbed "fingers of god," are a cluster of galaxies spread out radially (along the line of sight) because of the local motions within the cluster result in a "smearing" of the redshift, which we use to compute the distance. For example, the galaxies of the Local Group are all moving in seemingly random directions as they gravitationally interact with one another—many are blueshifted (coming toward us) even as the universe expands. These local motions within clusters contaminate the overall redshift in the spectrum, causing the distances to be less accurate, which appears to stretch these clusters along our line of sight.

Completeness. Unlike the Tully galaxies, these data show an incompleteness in the sample. Most of the rich structure is visible closer to the Milky Way, where we see more of the dimmer galaxies. Toward the edge of the data set we see galaxies by their lonesome. This is because these data are not as complete. We're only seeing the brighter galaxies to this distance, and therefore less complex structures are visible.

2dF Galaxy Survey

Description	The Two-degree Field Survey galaxy catalog
Census	229,293 galaxies
Version	1.7



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The 2dF galaxy survey looking back toward the Milky Way, which lies at the center but is invisible from this distance. 2dF observed two swaths of sky in opposite directions, hence the bow tie-shaped distribution. The galaxy clusters, filaments, walls, and voids are readily apparent mainly because each of these "wings" is fairly thin.

The Two-degree Field (2dF) Survey was a project designed to map portions of the extragalactic universe. The 2dF instrument was mounted on the 3.9-meter (12.8-foot) Anglo-Australian Telescope (AAT), located 450 km (280 miles) northwest of Sydney. The telescope has a two-degree field of view on the sky, enabling large parts of the sky to be observed at one time. For each pointing of the telescope, the instrument can acquire up to 400 spectra simultaneously via optical fibers that feed into two spectrographs. Each spectrograph sees light that is between 350 nm and 800 nm, spanning the visible spectrum.

The 2dF survey has three main components: the North Galactic Pole strip, the South Galactic Pole strip, and the random fields that surround the South Galactic Pole strip. The galaxy survey is composed of about 230,000 galaxies with brightness and redshift measurements.

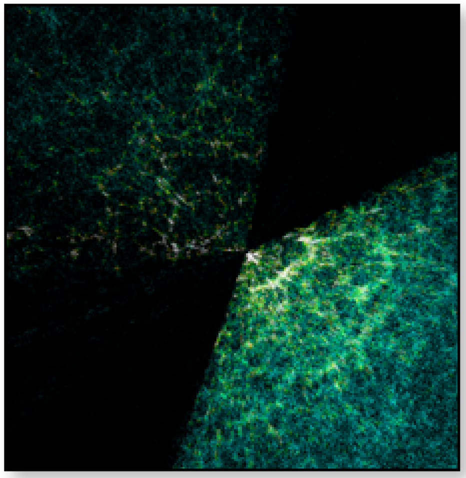
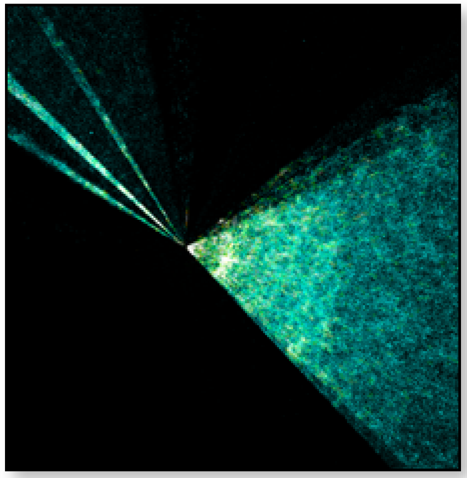
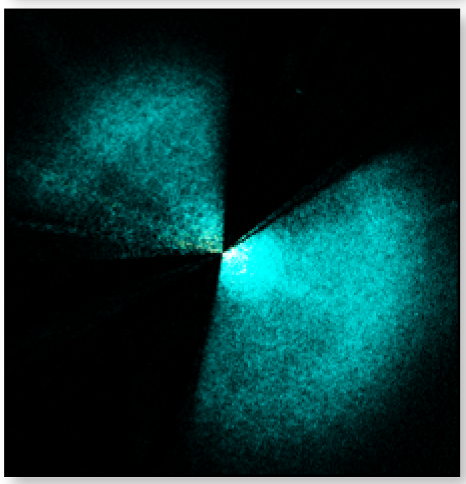
Distribution. The 2dF survey covers the same general volume as the 6dF, but 90% of these galaxies are within 2.5 billion light years, so it surveys a little deeper into the universe than 6dF. This corresponds to a lookback time of 2.3 billion years. Because the observations were along narrow swaths of sky, they result in relatively thin sheets of galaxies, which makes it easier to see the large-scale structure within them. So, clusters, connecting filaments of galaxies, and voids are readily apparent in the 2dF survey.

Lookback Distance

Lookback distance is equivalent to the light travel distance. It implies the distance of the object when the light that we see today left that object. Because the universe has expanded, and spacetime can expand faster than the speed of light (matter cannot, but the intervening fabric of spacetime can), it produces a discrepancy between how far an object was when its light left versus how far it actually is at this moment.

Sloan Galaxies

Description	The galaxy data from the Sloan Digital Sky Survey.
Census	2,799,051 galaxies
Version	11.7

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The Sloan Digital Sky Survey galaxy catalog. This is not an all-sky survey, so there are large parts of the sky that remain unobserved, which produces the bow tie distribution and the black areas where there surely are galaxies, but we have yet to observe them.

Top-left: Looking face-on to the survey reveals the large-scale structure.

Top-right: The edge-on view shows the main areas of observation.

Bottom: A view from outside the data set, where the fidelity of the structure falls off as the dimmer galaxies fade from view.

The Sloan Digital Sky Survey (SDSS) is an ambitious project to image about 35% of the sky, deep into the universe. The survey measured the position and brightness of almost 1 billion objects, and obtained spectra to more than 4 million objects.

The telescope is located at Apache Point Observatory in south-central New Mexico (US) and began operating in June 1998. It is 2.5 meters (8.2 feet) in diameter and was designed specifically for this mapping project. The telescope takes images of the sky as well as spectra for individual objects. The spectral range for the SDSS is 380 nm–920 nm, stretching from the blue end of the visible spectrum to the red, and barely into the infrared.

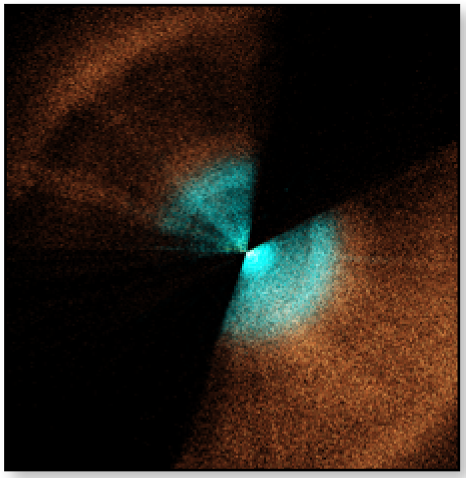
The SDSS galaxies are similar to the 2dF data in that they form triangular wedges, revealing those parts of the sky observed by the telescope. If the entire sky were covered, you would see a spherical distribution of galaxies surrounding the Milky Way. With only 35% of the entire sky observed, we see only a few select slices or larger wedgelike portions from that sphere.

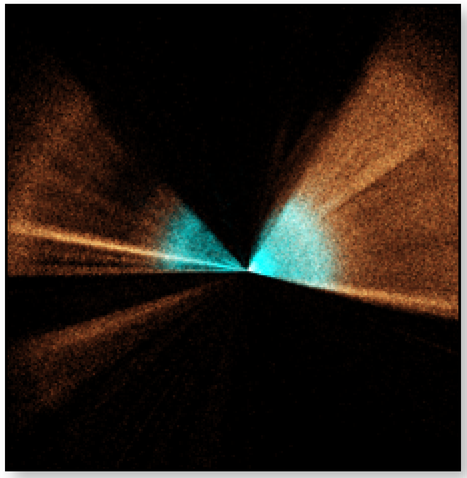
Distribution. These galaxies appear to extend beyond the 2dF survey to distances that exceed 5 billion light years. However, the weblike structure of clusters, filaments, and voids seems to fade by about 2 billion light years. Beyond this distance, the completeness of the survey drops so that only the intrinsically bright galaxies are visible.

The weblike cosmic structure is echoed in these data, with orange clusters standing out among the less dense aqua-colored galaxies and the less dense regions of green-colored galaxies.

Quasars

Description	A consolidated catalog of quasars, including the Sloan and 2dF data.
Census	595,972 quasars
Version	3.2





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The quasars, in orange, are the farthest objects we see and hearken back to an earlier time in the universe. The blue points are the Sloan galaxies for context. **Left:** Looking down, face-on, to the quasar distribution. **Right:** The edge-on view of the distribution echoes the Sloan and 2dF distributions.

Quasars are the most distant objects we can see. They are extremely active galaxies that contain supermassive black holes which are gobbling up material at a furious rate.

Discovering quasars. Radio astronomy was born in 1931, when Karl Jansky of Bell Telephone Laboratories discovered that the Milky Way was radiating its own radio waves. In the years following World War II, hundreds of radio observations were recorded and cataloged in the Third Cambridge (3C) Catalog of radio sources. Many of these sources were identified to have a nebulous optical counterpart, like the Crab Nebula.

However, in 1960, astronomers detected the first object that radiated radio light, but appeared like a faint blue star rather than a nebulous cloud. This object, 3C 48, was mysterious because its spectrum revealed lines that were unfamiliar. Astronomers thought they had discovered a new class of radio-emitting stars.

About two years later, this object was joined by another, 3C 273. Astronomers observed the same spectral features in this object, and, in 1963, Maarten Schmidt of Palomar Observatory discovered that these were not new lines but were the familiar hydrogen lines shifted by 16% into the radio spectrum. This redshift (0.16) was the largest that had been observed to date and meant that the object was receding from us at about 16% the speed of light.

With such large redshifts, these objects were clearly not stars in our Galaxy. Furthermore, their enormous distances implied that they must be incredibly bright. In fact, they are the brightest objects in the universe, comparable in luminosity to 20 trillion suns or 1,000 Milky Way galaxies. But what are these mysterious objects?

What are quasars? Quasars have been observed in all regions of the electromagnetic spectrum, but they emit most of their light in the infrared. They resemble active galaxies but have much higher luminosities. An active galaxy has a supermassive black hole at its center that gobbles up gas from a surrounding accretion disk. This process emits high-energy light that can be seen to great distances.

Quasars are simply more intense versions of these active galaxies. The central black hole consumes more material over the same period.

Quasars are our baby pictures of the "normal" galaxies we see nearby. The lookback distances for these quasars range from 1.4 billion to more than 13 billion light years. Consider a quasar with an 11 billion-light year lookback distance. The light we see from that quasar left 11 billion years ago, when the universe was very young. By now, the quasar has no doubt evolved into something else, perhaps a calmer, "normal" galaxy, like the Milky Way.

The Size of the Universe

In the Digital Universe, we depict objects in their present locations. This may seem like a sensible approach when one is creating an atlas of the universe; however, the universe is not always so straightforward. When we're dealing with cosmically close objects, such as stars or star-forming regions in the Milky Way, it's simple to take the distance data and interpret that. However, at great distances outside the Milky Way, the expansion of the universe begins to affect the distance of objects.

The light we see from a distant galaxy on any given night left from a point in space, which is reflected in its measured distance and called the lookback distance. But, the object itself will, at this instant, be farther than that point because of the expanding universe. This is the real distance at this instant in time.

In the Digital Universe, we plot objects according to where they are at this instant. And, because the universe has expanded faster than the speed of light over its 13.8-billion-year history, the size (radius) of the observable universe at this instant is not 13.8 billion light years, but is about 45 billion light years, or about 90 billion light years across. Quasars, and even distant galaxies, will lie beyond the 13-billion-light-year limit.

In essence, everything is "stretched," and the amount of stretching increases as the distance from Earth increases. Nearby objects in the Milky Way have an imperceptible stretch, but as one examines farther galaxies and quasars, this stretch begins to become significant when computing an object's true distance.

Astronomers believe that quasars are snapshots from the formation stage of galaxies. As a galaxy comes together, it is very active and unsettled. This is the quasar stage. As the object evolves, its central black hole consumes material left over from the galaxy's formation and that rate of consumption slows over time. This is the active, or radio, galaxy phase when the material around the black hole is emitting a lot of light and energy that is so bright, we can see it to great distances. Once there is a lack of material for the black hole to feed on, the galaxy becomes less active and enters its normal stage, like the Milky Way. The Milky Way still has a massive black hole at its center, but its rate of consumption has slowed to the point where the energy emitted is much less than that of an active galaxy.

Furthermore, if we could travel instantaneously to a quasar that is 10 billion light years from Earth (and violate all physical laws doing so), we would see that the quasar has evolved into a "normal" galaxy like those in our neighborhood. And looking back to the Milky Way, we would likely see a galaxy in its quasar stage of evolution.

Distribution. Quasars appear to have no obvious signs of large-scale structure. This makes sense because we're only seeing a sparse sampling of the large-scale structure that exists. One can think of these as a young galaxy map, but can also consider it a black hole map showing an earlier epoch of the universe.

The Million Quasars Catalogue is an aggregate catalog of several surveys, including 2dF and Sloan. So, it should not be surprising that the shape of these data mimic the shape of the Sloan and 2dF galaxy surveys, with large parts of the sky unobserved.

Cosmic Microwave Background

The cosmic microwave background (CMB) radiation is our baby picture of the universe. It is the earliest light that we can see and reveals the primordial conditions in the early universe. For the past century, we have searched for and refined our knowledge of the CMB using space telescopes, but the history of its discovery predates our ventures into space.

Origin of the CMB. In the beginning, the universe was very hot and free electrons (those not attached to any atom) prohibited light from traveling freely, just as fog prevents light from traveling long distances.

As the universe began to expand, the temperature dropped several thousand Kelvin, allowing protons and electrons to combine to form hydrogen atoms. This occurred about 380,000 years after the Big Bang. Once most of the free electrons were bound to hydrogen atoms, the universe became transparent to light, allowing the cooled radiation left over from the Big Bang to travel freely throughout the universe. In short, the fog lifted.

When this happened, the light from the Big Bang peaked at about 1 micron in the infrared. At that time the gas would have been about 3,000 Kelvin 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 redshifted to longer and longer wavelengths because of that expansion. Today, the peak wavelength is close to 1 mm (1 micron × 1,000 = 1 mm) and corresponds to a gas temperature around 3 Kelvin (3,000 K ÷ 1,000 = 3 K).

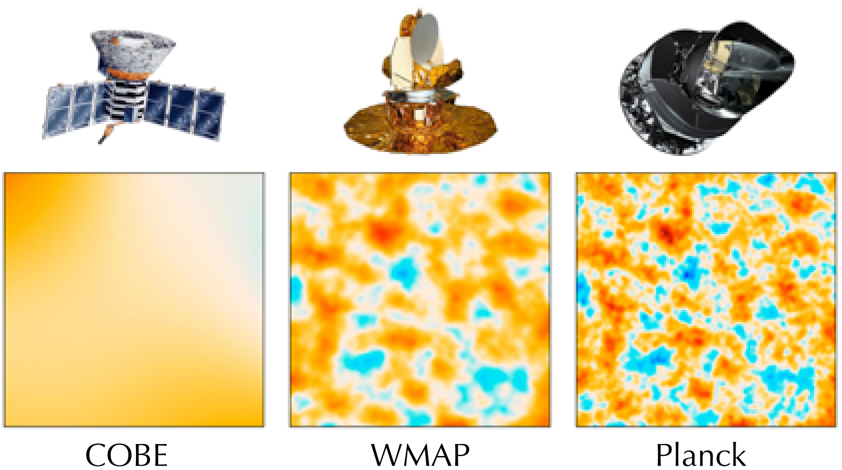
History of the CMB. In 1948, astronomers Ralph Alpher (1921–2007), Hans Bethe (1906–2005), and George Gamow (1904–1968) published their assertion that the gas in the early universe must have been very hot and dense and that this gas should be present throughout today's universe, albeit much cooler and less dense. Alpher searched for this cool gas, but it would be another 16 years before it was discovered, not by astronomers but by two physicists working at Bell Telephone Laboratories in New Jersey. In 1964, Arno Penzias (b. 1933) and Robert Wilson (b. 1936) were trying to communicate with a recently launched communications satellite and could not remove "noise" from their transmissions. This weak hiss was a constant nuisance that was present during the day, the night, and throughout the year. This fact ruled out possibilities such as equipment interference, atmospheric effects, or even bird droppings on the radio telescope built to communicate with their satellite.

Penzias and Wilson tried their best to remove this noise but were unsuccessful. In the end, they acknowledged that the faint microwave signal must be real and is not from some defect or artificial interference.

In the meantime, researchers down the road at Princeton University were on Alpher's trail, investigating this gas from the early universe. They maintained that the hot radiation would have been redshifted from gamma rays into x-rays, ultraviolet, visible light, and into the radio range of the EM spectrum. Furthermore, astronomers expected this radiation to be thermal, or what astronomers call blackbody radiation. An object is said to be a blackbody when it emits all the radiation it absorbs. In the early universe, with only free electrons and nuclei (protons and neutrons), light scattered off electrons just as light travels through a dense fog and would have produced a blackbody spectrum.

If the signal detected at Bell Labs corresponded to a blackbody, it would have a temperature of about 3 Kelvin, which is equivalent to −270°C or −454°F. But the Bell Labs observations could not confirm that the radiation was in fact from a blackbody, and they could not conclude with certainty that this was the radiation left from the Big Bang.

Mapping Efforts. The CMB has been mapped by three main missions: COBE, WMAP, and Planck. The Cosmic Background Explorer (COBE) operated between 1989 and 1993 and returned the first detailed all-sky image of the CMB. The Wilkinson Microwave Anisotropy Probe (WMAP) gathered data from 2001 through 2010 and offered a much clearer picture of the CMB. Planck's mission ran from 2009 to 2013 and is the best image to date of the CMB.



NASA/JPL-Caltech/ESA

A comparison of the COBE, WMAP, and Planck imagine capabilities alongside a likeness of each satellite.

What the maps reveal. The CMB images map the temperature in the microwave spectrum for the entire sky. The differences in color correspond to small differences in temperature. Those slight differences are on the order of 0.00001 Kelvin, or one one-hundred-thousandth Kelvin.

These 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 we see today. Today's galaxy clusters and filaments began as minute fluctuations in the early universe, imprinted in this light 380,000 years after the Big Bang.

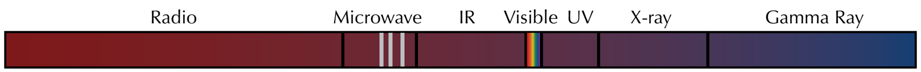
Cosmological constraints. Mapping these cosmic fluctuations yields information about the nature of the universe. Measuring these fluctuations tells us about the density and composition of the universe, the nature of the expansion of the universe, and knowing the matter and energy of the universe, we can use Einstein's theory of general relativity to understand the rate of expansion then turn the clock back and deduce the age of the universe, which stands at around 13.8 billion years.

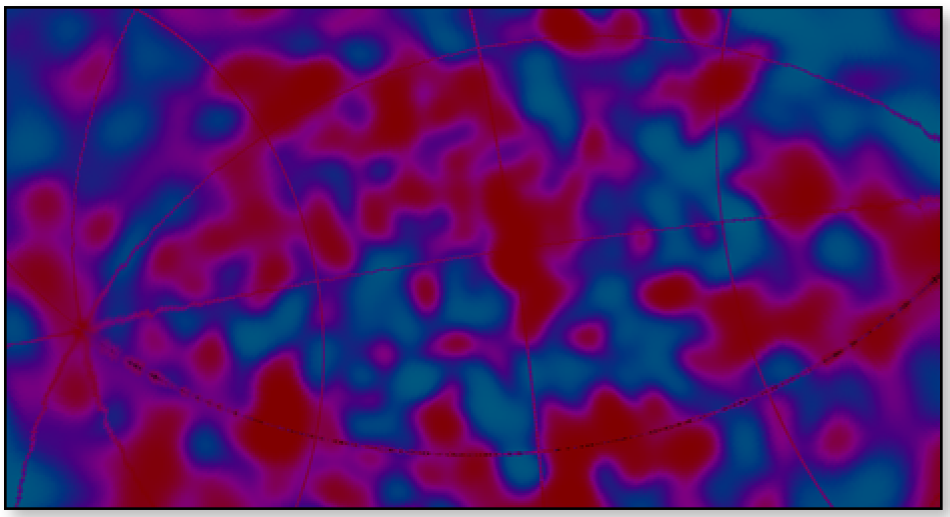
Placement. We place the CMB on a sphere that signifies the boundary of our observable universe. This is a bit misleading. While this is the earliest light we can see, it is ubiquitous throughout the universe, even in the solar system.

The significance of the sphere for these maps is that it represents the farthest extent of our observable universe. It is intended to be conceptual and not represent anything physical.

COBE All-sky Survey

Description	The COBE mission's image of the cosmic microwave background light, the first detailed map of this light.
Census	1 all-sky image
Version	2.2
Wavelength	3.33, 5.66, and 9.52 mm (90, 53, 31.5 GHz)





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The COBE map showing small variations in temperature in the CMB. Red areas are slightly warmer than average and blue areas are slightly cooler than average.

The red areas of this map correspond to hotter areas, while the blue areas are cooler.

In 1989, the Cosmic Background Explorer (COBE) was launched into orbit to see, once and for all, whether the CMB was a blackbody. COBE's Differential Microwave Radiometer observed light in the range from a few millimeters to about 1 cm. The results were indisputable. COBE had confirmed decades of theories and conflicting experiments with observational proof that the CMB was indeed the light left over from a Big Bang.

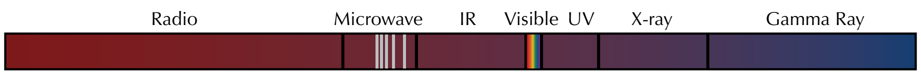
COBE also confirmed that the light was remarkably uniform. No matter where the telescope looked, it observed radiation equivalent to a 2.73-Kelvin blackbody with deviations on the order of one part in 100,000. These slight differences in temperature map to the density structure of the universe at this time, 380,000 years after the Big Bang. These fluctuations in density are the seeds of the large-scale structure we see today.

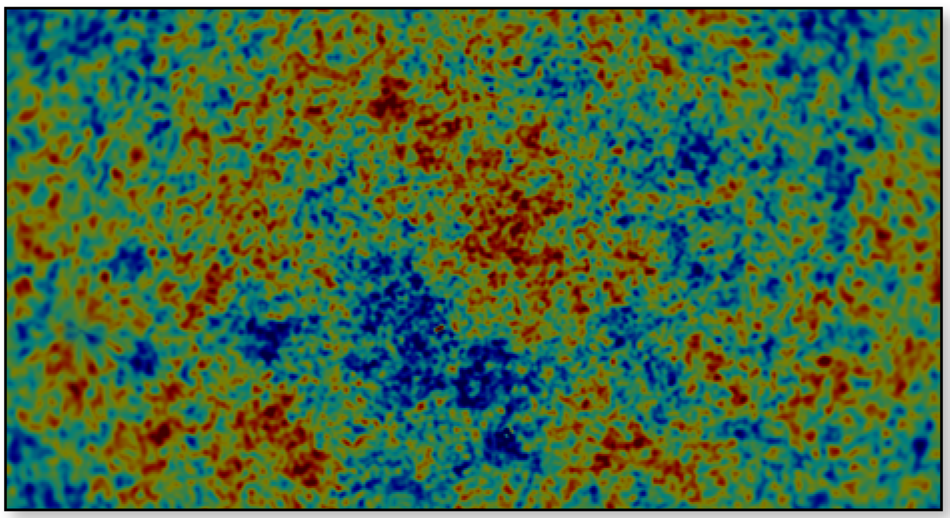
The red areas are relatively hotter areas of the CMB, while the blue areas are cooler than the average. The lines of latitude and longitude are baked into this image, and reflect galactic coordinates.

While the COBE map yielded the first all-sky image of the CMB, and netted two of its principle scientists Nobel Prizes, it was superseded by more accurate maps in the coming years, namely the WMAP and Planck missions.

WMAP All-sky Survey

Description	The WMAP mission's all-sky image of the cosmic microwave background light.
Census	1 all-sky image
Version	4.2
Wavelength	3.19, 4.91, 7.31, 9.08, 13.0 mm (94, 61, 41, 33, 23 GHz)





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The WMAP microwave background light. Looking at the same patch of sky as the previous COBE figure, here the blue colors are slightly cooler than average and red is slightly warmer, with fluctuations of about a 100,000th of a degree.

The colors represent the range of temperatures. Red are slightly warmer areas, while blue represents slightly cooler areas.

In 1995, a new mission to explore the CMB to greater resolution was proposed to NASA. Called the Microwave Anisotropy Probe (MAP), it was approved by NASA and launched on June 30, 2001, aboard a Delta II rocket. With the death of David Wilkinson in 2002, one of the founding members of MAP and COBE, the mission was named in his honor to the Wilkinson Microwave Anisotropy Probe (WMAP).

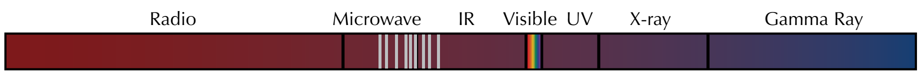
WMAP gathered data for a few years, and aimed to observe the cosmic temperature fluctuations in five wavelengths to much greater sensitivity than COBE. In fact, it was forty-five times more sensitive than COBE with far greater resolution. This improved sensitivity is apparent in the two maps.

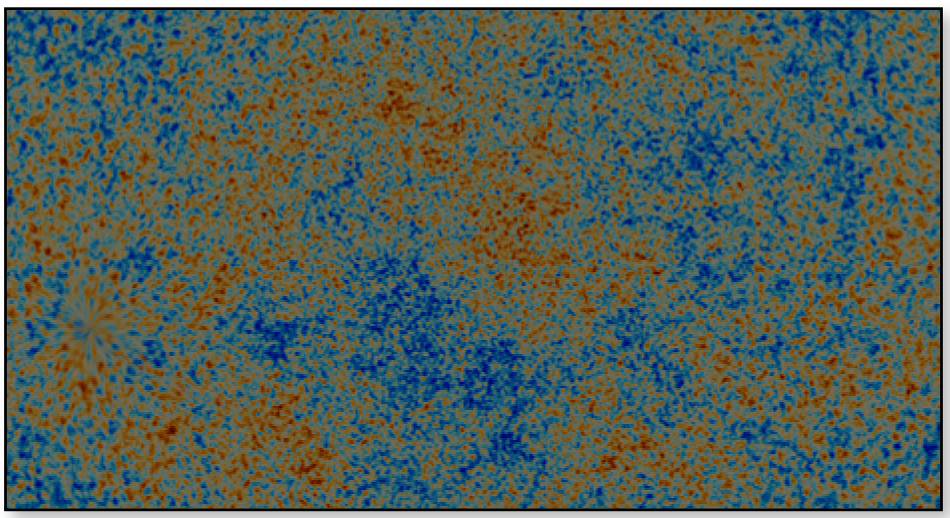
In this map, the red areas are hotter and the blue areas are cooler, but as we mentioned in the last section, these differences are to one part in 100,000 Kelvin—extremely sensitive instruments are necessary to see these differences.

Removing Foreground Light. Unlike the all-sky maps in the radio, infrared, and other wavelengths, all the CMB maps have been processed such that the foreground light from the inside the Milky Way and local universe has been removed. This reveals the CMB at all points in the sky without the overshadowing band of the Milky Way.

Planck All-sky Survey

Description	The Planck mission's image of the cosmic microwave background light, the most detailed view of the CMB.
Census	1 all-sky image
Version	2.3
Wavelength	0.35, 0.55, 0.87, 1.38, 2.10, 3.00, 4.28, 6.81, 10.0 mm (857, 545, 343, 217, 143, 100, 70, 44, 30 GHz)





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The Planck survey showing the same region of sky as in the WMAP and COBE figures above. Orange shows warmer, and hence slight over-densities, and blue areas are cooler and represent slight under-densities in the early universe.

The colors represent the slight range in temperature. Orange areas are slightly warmer, while blue represents slightly cooler areas.

In 2009, the European Space Agency launched the Planck satellite into space. Its first all-sky map of the CMB was released in 2013 and greatly improved upon WMAP's results. The mission was named after Max Planck, who derived the equation for a blackbody (an object that absorbs light completely).

Planck observed the sky in nine wavelengths to better constrain the foreground light (WMAP observed in five wavelengths). The resulting map is more precise than WMAP and will be more accurate in subtracting the foreground light.

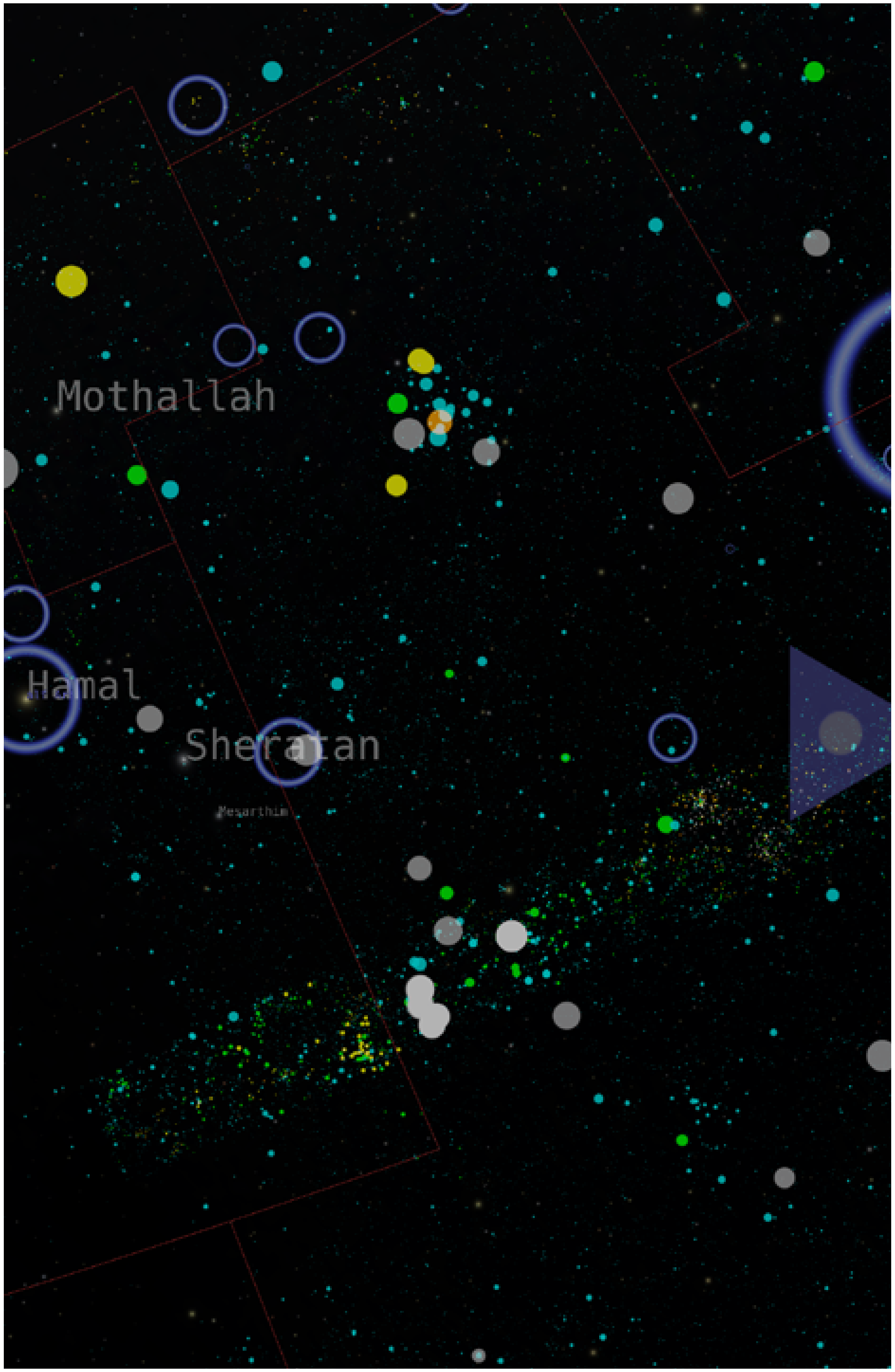
The orange areas represent the slightly hotter areas, and the blue areas show the areas that are slightly cooler.

Conclusions

This booklet is designed to act as a quick reference for each of the datasets included in the Digital Universe—mainly all the data outside the solar system.

It is a first step toward understanding the universe and the progress scientists have made toward mapping the cosmos. The next step is to read some of the tours, which are more narrative in style and cover a variety of cosmic curiosities while providing a cohesive story.

Our first tour, called the Grand Tour, covers the entire universe from the Sun out to the edge of the observable universe. We typically give this as a show in about 50 minutes in our theater. Subsequent tours will be written to cover areas of the cosmos in more detail.



Right: A smattering of datasets as seen from Earth's night sky. Shown are exoplanets (blue rings), constellation boundary lines, planetary nebulae (blue triangles), and galaxies (multicolored points) from several surveys.

Carter Emmart / AMNH / OpenSpace

References & Credits

All-sky Surveys

Data Group	Reference	Prepared by	Labels	Notes
408 MHz Radio Continuum	Reprocessed Haslam 408 MHz All-Sky Map (Remazeilles+, 2014)	Brian Abbott (AMNH)	✔	73.48 cm 408 MHz
Atomic Hydrogen Survey	HI4PI: An HI survey based on EBHIS and GASS (AIfA, MPIfR, and CSIRO; Image: Benjamin Winkel, 2016)	Brian Abbott (AMNH)	✔	21 cm 1.4 GHz
Carbon Monoxide Survey	The Milky Way in Molecular Clouds (Dame+, 2001)	Brian Abbott (AMNH)	✔	2.6 mm 115 GHz Data only along the plane of the Milky Way.
Far Infrared Survey	IRAS Sky Survey Atlas Explanatory Supplement (Wheelock+, 1994)	Ryan Wyatt (AMNH)	✔	100 µm 3,000 GHz
Infrared Composite Survey	IRAS Sky Survey Atlas Explanatory Supplement (Wheelock+, 1994) IRIS: A New Generation of IRAS Maps (Miville-Deschênes+, 2005)	Carter Emmart, Brian Abbott (AMNH)	✔	100, 60, 25 µm 3, 5, 12 THz
Mid Infrared Composite Survey	Wide-field Infrared Survey Explorer (NASA/JPL-Caltech/UCLA, 2012)	Brian Abbott (AMNH)	✔	22, 12, 4.6, 3.4 µm 14, 25, 65, 88 THz
Near Infrared Composite Survey	Two Micron All-Sky Survey (UMass, IPAC/CalTech, NASA, NSF, 2003)	Brian Abbott (AMNH)	✔	2.16, 1.66, 1.24 µm 139, 181, 242 THz
Visible Survey	Axel Mellinger (Universitaet Potsdam)	Ryan Wyatt, Carter Emmart (AMNH)	✔	700 nm – 400 nm 430 THz – 750 THz
Hydrogen-alpha Survey	Doug Finkbeiner (Princeton)	Brian Abbott (AMNH)	✔	656 nm 457 THz

Data Group	Reference	Prepared by	Labels	Notes
Ultraviolet Survey	GALEX Diffuse Observations of the Sky (Murthy, 2014)	Brian Abbott (AMNH)	✔	231.6 nm 1,295 THz Not an all-sky survey, but the best UV map available.
Soft X-ray Survey	ROSAT Soft X-ray All-sky Survey (Digel & Snowden (GSFC), ROSAT, MPE, NASA, 1995)	Brian Abbott (AMNH)	✔	1.65 nm 0.75 keV
Gamma-ray Survey	Fermi Gamma-ray Space Telescope (NASA/DOE/Fermi LAT Collaboration, 2013)	Brian Abbott (AMNH)	✔	< 0.0000000012 nm > 1 GeV

Milky Way Catalogs

Data Group	Reference	Prepared by	Labels	Notes
AMNH Star Catalog	Gaia DR2 (Gaia Collaboraiton 2016) XHIP: Extended Hipparcos Compilation (Anderson+ 2012) Hipparcos, New Reduction (van Leeuwen 2007) Tycho-2 Catalogue (Hog+ 2000) Hipparcos Catalog (European Space Agency 1997) Third Catalog of Nearby Stars (Gliese+ 1991)	Brian Abbott (AMNH) Andrew Ayala (AMNH) Jackie Faherty (AMNH) David R. Rodriguez (AMNH) Ron Drimmel (U Torino, Italy) Carter Emmart (AMNH) Stuart Levy (NCSA/UIUC) James Adams (AMNH)	✔	Full catalog: 385,477,132 Abridged version: 104,452 stars 324 labels
Alternate Star Labels	See AMNH Star Catalog	Brian Abbott (AMNH)	✔	3,365 labels Use with AMNH Star Catalog
Stellar Distance Uncertainty	See AMNH Star Catalog	Brian Abbott (AMNH)	✔ Marking the distance extremes	7 stars with uncertainty data
Constellation Connectivity Lines	N/A	Brian Abbott, Carter Emmart (AMNH)	✔	88 constellations and labels

Data Group	Reference	Prepared by	Labels	Notes
Dwarf Catalog	Private communication (Faherty, 2019)	Brian Abbott (AMNH)	✔	785 L dwarfs 101 T dwarfs 17 Y dwarfs
Exoplanets	NASA Exoplanet Archive (CalTech/NASA)	Brian Abbott (AMNH)	✔	3,219 systems with 4,352 planets 10 systems have no distance
Exoplanet Candidates	NASA Exoplanet Archive (CalTech/NASA)	Brian Abbott, Emily Rice, Jason No (AMNH)	✘	2,204 Kepler stars 454 K2 stars 1,472 TESS stars
Earth's Radio Boundary	N/A	Carter Emmart, Brian Abbott (AMNH)	✔	Configured to RA/Dec grid on sphere.
OB Associations	New List of OB Associations (Melnick+ 1995)	Brian Abbott (AMNH)	✔	61 OB associations Blue = Sagittarius Arm Purple = Orion Spur Orange = Perseus Arm
Open Clusters	Optically Visible Open Clusters & Candidates (Dias+ 2015) XHIP: Extended Hipparcos Compilation (Anderson+ 2012) Hunting for open clusters in Gaia DR2: 582 new open clusters in the Galactic disc. (Castro-Ginard+ 2020)	Brian Abbott (AMNH)	✔	2,609 clusters with labels
Globular Star Clusters	Properties of Galactic Globular Clusters (Francis+ 2014)	Brian Abbott (AMNH)	✔	157 clusters with labels
Pulsars	ATNF Pulsar Catalogue (Manchester+ 2017)	Brian Abbott (AMNH)	✔	2,755 pulsars and labels
Planetary Nebulae	Planetary Nebulae distances in Gaia DR2 (Kimeswenger+, 2018) Strasbourg-ESO Catalogue of Galactic Planetary Nebulae (Acker+ 1992)	Brian Abbott (AMNH)	✔	283 nebulae and labels

Data Group	Reference	Prepared by	Labels	Notes
Supernova Remnants	The First Fermi LAT SNR Catalog (Acero+, 2016)	Brian Abbott (AMNH)	✔	112 supernova remnants
Star Forming Regions	The WISE catalog of Galactic HII regions (Anderson+, 2014)	Brian Abbott (AMNH)	✔	1,481 star-forming regions 459 labels
Orion Nebula	Model: Wen & O'Dell, The Astrophysical Journal, v438, p784 Image: NASA, ESA, M. Robberto (STScI/ESA), Hubble Space Telescope Orion Treasury Project Team Stars: Orion Nebula Cluster Population (Hillenbrand 1997)	Carter Emmart, Erik Wesselak, Brian Abbott, Ryan Wyatt (AMNH)	✘	813 stars; 1 3-D nebula model with shocks and proplyds Star distances are statistically generated
Deep Sky Images	NOAO, see data file for image credits	Nate Greenstein, Matt Everhart, Ryan Wyatt, Brian Abbott (AMNH)	✔	65 images
Milky Way Galaxy Image	European Southern Observatory	Carter Emmart, Brian Abbott (AMNH)	✘	1 image, varies by software
Galaxy Arm Labels	N/A	Brian Abbott (AMNH)	✘	Labels are baked into an image that overlays the galaxy.
Star Orbits	Sébastien Lépine (AMNH)	Sébastien Lépine (AMNH), Brian Abbott (AMNH)	✔	7 stellar orbits
Galactic Bar Boundary	Merrifield, M. & Binney, J. 1998, Galactic Astronomy (Princeton: Princeton University Press)	Carter Emmart, Brian Abbott (AMNH)	✘	A wire-frame model that outlines the bar.
Galactic Halo Boundary	Merrifield & Binney 1998, Galactic Astronomy (Princeton: Princeton University Press)	Brian Abbott (AMNH)	✘	A wire-frame model that encompasses the halo.

Extragalactic Catalogs

Data Group	Reference	Prepared by	Labels	Notes
Local Group Galaxies	N/A	Brian Abbott (AMNH)	✔	102 galaxies
Local Group Boundary	N/A	Brian Abbott (AMNH)	✘	A sphere showing the extent of the Local Group
Tully Galaxy Catalog	Tully 8,000 km/s Galaxy Catalog (Brent Tully, U Hawaii) The Galaxy Catalog (Zsolt Frei and James E. Gunn) National Optical Astronomical Observatory Optical Astronomy Observatory (NOAO). These include the Large and Small Magellanic Clouds (NOAO/AURA/NSF), the Andromeda Galaxy or M31 (Bill Schoening, Vanessa Harvey/REU program/NOAO/AURA/NSF), M33 [T. A. Rector (NRAO/AUI/NSF and NOAO/AURA/NSF) and M. Hanna (NOAO/AURA/NSF)], M81 (N. A. Sharp/NOAO/AURA/NSF), M101 (George Jacoby, Bruce Bohannan, Mark Hanna/NOAO/AURA/NSF), M51 (Todd Boroson/NOAO/AURA/NSF), and Centaurus A (Eric Peng, Herzberg Institute of Astrophysics and NOAO/AURA/NSF).	R. Brent Tully (U Hawaii) Stuart Levy (NCSA/U Illinois)	✔	30,059 galaxies
Galaxy Group Labels	Tully 8,000 km/s Galaxy Catalog (Brent Tully, U Hawaii)	Brian Abbott (AMNH)	✔	62 galaxy group labels-Must view with Tully.
Galaxy Clusters Labels	Tully 8,000 km/s Galaxy Catalog (Brent Tully, U Hawaii)	Brian Abbott (AMNH)	✔	15 galaxy cluster labels Must view with Tully.
Voids	N/A	Brian Abbott (AMNH)	✔	24 cosmic void labels
Virgo Supercluster Boundary	N/A	Brian Abbott (AMNH)	✘	1 sphere showing the extent of the Virgo Supercluster
Laniakea Supercluster Boundary	Brent Tully+ (U Hawaii)	Brian Abbott (AMNH)	✘	1 sphere showing the extent of the Laniakea Supercluster

Data Group	Reference	Prepared by	Labels	Notes
Abell Galaxy Clusters	A Catalog of Rich Clusters of Galaxies (Abell+ 1958, 1989) With alterations by R. Brent Tully (U Hawaii)	R. Brent Tully (U Hawaii) Stuart Levy (NCSA/U Illinois)	✔	2,246 galaxy clusters
Superclusters	Superclusters of Abell and X-ray Clusters (Einasto+, 2001)	Brian Abbott (AMNH)	✔	33 supercluster labels
6dF Galaxy Survey	6dF Galaxy Survey (Jones+, 2009)	Brian Abbott (AMNH)	✘	109,569 galaxies
2dF Galaxy Survey	2dF galaxy redshift survey (Colless+ 2003)	Brian Abbott (AMNH) Eric Gawiser (Rutgers U)	✘	229,293 galaxies
Sloan Galaxy Survey	Sloan Digital Sky Survey	Brian Abbott (AMNH) Eric Gawiser (Rutgers U)	✘	2,799,051 galaxies
Quasars	Million Quasars Catalogue (Flesch, 2017)	Brian Abbott (AMNH)	✘	595,972 quasars
Cosmic Microwave Background: COBE Survey	Cosmic Background Explorer (NASA, 1992)	Brian Abbott (AMNH)	✘	9.5, 5.7, 3.3 mm 31.5, 53, 90 GHz
Cosmic Microwave Background: WMAP Survey	Wilkinson Microwave Anisotropy Probe (NASA / WMAP Science Team, 2003-2012)	Brian Abbott (AMNH)	✘	13, 9.1, 7.3, 4.9, 3.2 mm 23,33,41,61,94 GHz
Cosmic Microwave Background: Planck Survey	Planck (ESA, 2013)	Brian Abbott (AMNH)	✘	10,000 – 850 µm 30 – 857 GHz