

Observable universe

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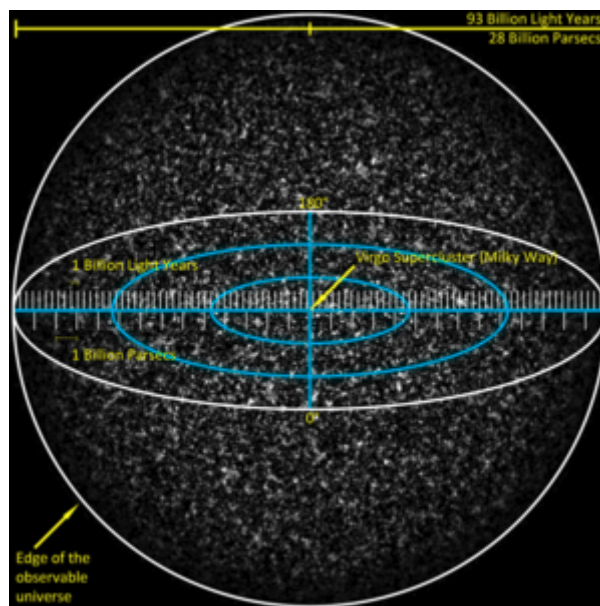
The **observable universe** is a spherical region of the Universe comprising all matter that can be observed from Earth at the present time, because light and other signals from these objects have had time to reach Earth since the beginning of the cosmological expansion. There are at least two trillion galaxies in the observable universe,^{[7][8]} containing more stars than all the grains of sand on planet Earth.^[9]

Assuming the universe is isotropic, the distance to the edge of the observable universe is roughly the same in every direction. That is, the observable universe is a spherical volume (a ball) centered on the observer. Every location in the Universe has its own observable universe, which may or may not overlap with the one centered on Earth.

The word *observable* used in this sense does not depend on whether modern technology actually permits detection of radiation from an object in this region (or indeed on whether there is any radiation to detect). It simply indicates that it is possible *in principle* for light or other signals from the object to reach an observer on Earth. In practice, we can see light only from as far back as the time of photon decoupling in the recombination epoch. That is when particles were first able to emit photons that were not quickly re-absorbed by other particles. Before then, the Universe was filled with a plasma that was opaque to photons. The detection of gravitational waves indicates there is now a possibility of detecting non-light signals from before the recombination epoch.

The surface of last scattering is the collection of points in space at the exact distance that photons from the time of photon decoupling just reach us today. These are the photons we detect today as cosmic microwave background radiation (CMBR). However, with future technology, it may be possible to observe the still older relic neutrino background, or even more distant events via gravitational waves (which also should move at the speed of light). Sometimes astrophysicists distinguish between the *visible* universe, which includes only signals emitted since recombination – and the *observable* universe, which includes signals since the beginning of the cosmological expansion (the Big Bang in traditional physical cosmology, the end of the inflationary epoch in modern cosmology). According to calculations, the *comoving distance* (current proper distance) to particles from which the CMBR was emitted, which represent the radius of the visible universe, is about 14.0 billion parsecs (about 45.7 billion light years), while the comoving distance to the edge of the observable universe is about 14.3 billion parsecs (about 46.6 billion light years),^[10] about 2% larger.

Observable universe



Visualization of the whole observable universe. The scale is such that the fine grains represent collections of large numbers of superclusters. The Virgo Supercluster – home of Milky Way – is marked at the center, but is too small to be seen.

Diameter	8.8×10^{23} km (28.5 Gpc or 93 Gly) ^[1]
Volume	4×10^{80} m ³ ^[2]
Mass (ordinary matter)	10^{53} kg ^[3]
Density	9.9×10^{-30} g/cm ³ (equivalent to 6 protons per cubic meter of space) ^[4]
Age	13.799 ± 0.021 billion years ^[5]
Average temperature	2.72548 K ^[6]
Contents	Ordinary (baryonic) matter (4.9%) Dark matter (26.8%) Dark energy (68.3%)

The best estimate (as of 2015) of the age of the universe is 13.799 ± 0.021 billion years^[5] but due to the expansion of space humans are observing objects that were originally much closer but are now considerably farther away (as defined in terms of cosmological proper distance, which is equal to the comoving distance at the present time) than a static 13.8 billion light-years distance.^[11] It is estimated that the diameter of the observable universe is about 28.5 gigaparsecs (93 billion light-years, 8.8×10^{23} kilometres or 5.5×10^{23} miles),^[12] putting the edge of the observable universe at about 46.5 billion light-years away.^{[13][14]} The total mass of ordinary matter in the universe can be calculated using the critical density and the diameter of the observable universe to be about 1.5×10^{53} kg.^[15]

Contents

- 1 The Universe versus the observable universe
- 2 Size
 - 2.1 Misconceptions on its size
- 3 Large-scale structure
 - 3.1 Walls, filaments, nodes, and voids
 - 3.2 End of Greatness
 - 3.3 Observations
 - 3.4 Cosmography of our cosmic neighborhood
- 4 Mass of ordinary matter
 - 4.1 Estimates based on critical density
- 5 Matter content – number of atoms
- 6 Most distant objects
- 7 Horizons
- 8 See also
- 9 References
- 10 Further reading
- 11 External links

The Universe versus the observable universe

Some parts of the Universe are too far away for the light emitted since the Big Bang to have had enough time to reach Earth, so these portions of the Universe lie outside the observable universe. In the future, light from distant galaxies will have had more time to travel, so additional regions will become observable. However, due to Hubble's law, regions sufficiently distant from the Earth are expanding away from it faster than the speed of light (special relativity prevents nearby objects in the same local region from moving faster than the speed of light with respect to each other, but there is no such constraint for distant objects when the space between them is expanding; see uses of the proper distance for a discussion) and furthermore the expansion rate appears to be accelerating due to dark energy. Assuming dark energy remains constant (an unchanging cosmological constant), so that the expansion rate of the Universe continues to accelerate, there is a "future visibility limit" beyond which objects will *never* enter our observable universe at any time in the infinite future, because light emitted by objects outside that limit would never reach the Earth. (A subtlety is that, because the Hubble parameter is decreasing with time, there can be cases where a galaxy that is receding from the Earth just a bit faster than light does emit a signal that reaches the Earth eventually^{[14][16]}). This future visibility limit is calculated at a comoving distance of 19 billion parsecs (62 billion light years), assuming the Universe will keep expanding forever, which implies the number of galaxies that we can ever theoretically observe in the infinite future (leaving aside the issue that some may be impossible to observe in practice due to redshift, as discussed in the following paragraph) is only larger than the number currently observable by a factor of 2.36.^[17]



Artist's logarithmic scale conception of the *observable universe* with the Solar System at the center, inner and outer planets, Kuiper belt, Oort cloud, Alpha Centauri, Perseus Arm, Milky Way galaxy, Andromeda galaxy, nearby galaxies, Cosmic Web, Cosmic microwave radiation and the Big Bang's invisible plasma on the edge.

Though in principle more galaxies will become observable in the future, in practice an increasing number of galaxies will become extremely redshifted due to ongoing expansion, so much so that they will seem to disappear from view and become invisible.^{[18][19][20]} An additional subtlety is that a galaxy at a given comoving distance is defined to lie within the "observable universe" if we can receive signals emitted by the galaxy at any age in its past history (say, a signal sent from the galaxy only 500 million years after the Big Bang), but because of the Universe's expansion, there may be some later age at which a signal sent from the same galaxy can *never* reach the Earth at any point in the infinite future (so for example we might never see what the galaxy looked like 10 billion years after the Big Bang),^[21] even though it remains at the same comoving distance (comoving distance is defined to be constant with time – unlike proper distance, which is used to define recession velocity due to the expansion of space), which is less than the comoving radius of the observable universe. This fact can be used to define a type of cosmic event horizon whose distance from the Earth changes over time. For example, the current distance to this horizon is about 16 billion light years, meaning that a signal from an event happening *at present* can eventually reach the Earth in the future if the event is less than 16 billion light years away, but the signal will never reach the Earth if the event is more than 16 billion light years away.^[14]

Both popular and professional research articles in cosmology often use the term "universe" to mean "observable universe". This can be justified on the grounds that we can never know anything by direct experimentation about any part of the Universe that is causally disconnected from the Earth, although many credible theories require a total universe much larger than the observable universe. No evidence exists to suggest that the boundary of the observable universe constitutes a boundary on the Universe as a whole, nor do any of the mainstream cosmological models propose that the Universe has any physical boundary in the first place, though some models propose it could be finite but unbounded, like a higher-dimensional analogue of the 2D surface of a sphere that is finite in area but has no edge. It is plausible that the galaxies within our observable universe represent only a minuscule fraction of the galaxies in the Universe. According to the theory of cosmic inflation initially introduced by its founder, Alan Guth (and by D. Kazanas^[22]), if it is assumed that inflation began about 10^{-37} seconds after the Big Bang, then with the plausible assumption that the size of the Universe before the inflation occurred was approximately equal to the speed of light times its age, that would suggest that at present the entire universe's size is at least 3×10^{23} times the radius of the observable universe.^[23] There are also lower estimates claiming that the entire universe is in excess of 250 times larger than the observable universe^[24] and also higher estimates implying that the universe is at least 10^{10} ^{10²²} times larger than the observable universe.^[25]

If the Universe is finite but unbounded, it is also possible that the Universe is *smaller* than the observable universe. In this case, what we take to be very distant galaxies may actually be duplicate images of nearby galaxies, formed by light that has circumnavigated the Universe. It is difficult to test this hypothesis experimentally because different images of a galaxy would show different eras in its history, and consequently might appear quite different. Bielewicz et al.^[26] claims to establish a lower bound of 27.9 gigaparsecs (91 billion light-years) on the diameter of the last scattering surface (since this is only a lower bound, the paper leaves open the possibility that the whole universe is much larger, even infinite). This value is based on matching-circle analysis of the WMAP 7 year data. This approach has been disputed.^[27]

Size

The comoving distance from Earth to the edge of the observable universe is about 14.26 gigaparsecs (46.5 billion light years or 4.40×10^{26} meters) in any direction. The observable universe is thus a sphere with a diameter of about 28.5 gigaparsecs^[28] (93 Gly or 8.8×10^{26} m).^[29] Assuming that space is roughly flat, this size corresponds to a comoving volume of about 1.22×10^4 Gpc³ (4.22×10^5 Gly³ or 3.57×10^{80} m³).^[30]

The figures quoted above are distances *now* (in cosmological time), not distances *at the time the light was emitted*. For example, the cosmic microwave background radiation that we see right now was emitted at the time of photon decoupling, estimated to have occurred about 380 000 years after the Big Bang,^{[31][32]} which occurred around 13.8 billion years ago. This radiation was emitted by matter that has, in the intervening time, mostly condensed into galaxies, and those galaxies are now calculated to be about 46 billion light-years from us.^{[10][14]} To estimate the distance to that matter at the time the light was emitted, we may first note that according to the Friedmann–Lemaître–Robertson–Walker metric, which is used to model the expanding universe, if at the present time we receive light with a redshift of z , then the scale factor at the time the light was originally emitted is given by^{[33][34]}

$$r(t) = \frac{1}{1+z}.$$

WMAP nine-year results combined with other measurements give the redshift of photon decoupling as $z = 1\,091.64 \pm 0.47$,^[35] which implies that the scale factor at the time of photon decoupling would be $\frac{1}{1092.64}$. So if the matter that originally emitted the oldest CMBR photons has a *present* distance of 46 billion light years, then at the time of decoupling when the photons were originally emitted, the distance would have been only about 42 *million* light-years.

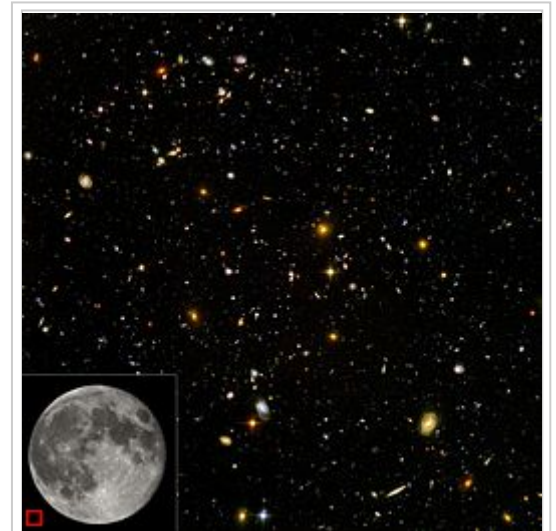
Misconceptions on its size

Many secondary sources have reported a wide variety of incorrect figures for the size of the visible universe. Some of these figures are listed below, with brief descriptions of possible reasons for misconceptions about them.

13.8 billion light-years

The age of the universe is estimated to be 13.8 billion years. While it is commonly understood that nothing can accelerate to velocities equal to or greater than that of light, it is a common misconception that the radius of the observable universe must therefore amount to only 13.8 billion light-years. This reasoning would only make sense if the flat, static Minkowski spacetime conception under special relativity were correct. In the real universe, spacetime is curved in a way that corresponds to the expansion of space, as evidenced by Hubble's law. Distances obtained as the speed of light multiplied by a cosmological time interval have no direct physical significance.^[36]

15.8 billion light-years



Hubble Ultra-Deep Field image of a region of the observable universe (equivalent sky area size shown in bottom left corner), near the constellation Fornax. Each spot is a galaxy, consisting of billions of stars. The light from the smallest, most red-shifted galaxies originated nearly 14 billion years ago.



An example of one of the most common misconceptions about the size of the observable universe. This plaque appears at the Rose Center for Earth and Space in New York City.

This is obtained in the same way as the 13.8 billion light year figure, but starting from an incorrect age of the universe that the popular press reported in mid-2006.^{[37][38]} For an analysis of this claim and the paper that prompted it, see the following reference at the end of this article.^[39]

27.6 billion light-years

This is a diameter obtained from the (incorrect) radius of 13.8 billion light-years.

78 billion light-years

In 2003, Cornish et al.^[40] found this lower bound for the diameter of the *whole* universe (not just the observable part), if we postulate that the universe is finite in size due to its having a nontrivial topology,^{[41][42]} with this lower bound based on the estimated current distance between

points that we can see on opposite sides of the cosmic microwave background radiation (CMBR). If the whole universe is smaller than this sphere, then light has had time to circumnavigate it since the Big Bang, producing multiple images of distant points in the CMBR, which would show up as patterns of repeating circles.^[43] Cornish et al. looked for such an effect at scales of up to 24 gigaparsecs (78 Gly or 7.4×10^{26} m) and failed to find it, and suggested that if they could extend their search to all possible orientations, they would then "be able to exclude the possibility that we live in a universe smaller than 24 Gpc in diameter". The authors also estimated that with "lower noise and higher resolution CMB maps (from WMAP's extended mission and from Planck), we will be able to search for smaller circles and extend the limit to ~ 28 Gpc."^[40] This estimate of the maximum lower bound that can be established by future observations corresponds to a radius of 14 gigaparsecs, or around 46 billion light years, about the same as the figure for the radius of the visible universe (whose radius is defined by the CMBR sphere) given in the opening section. A 2012 preprint by most of the same authors as the Cornish et al. paper has extended the current lower bound to a diameter of 98.5% the diameter of the CMBR sphere, or about 26 Gpc.^[44]

156 billion light-years

This figure was obtained by doubling 78 billion light-years on the assumption that it is a radius.^[45] Because 78 billion light-years is already a diameter (the original paper by Cornish et al. says, "By extending the search to all possible orientations, we will be able to exclude the possibility that we live in a universe smaller than 24 Gpc in diameter," and 24 Gpc is 78 billion light years),^[40] the doubled figure is incorrect. This figure was very widely reported.^{[45][46][47]} A press release from Montana State University–Bozeman, where Cornish works as an astrophysicist, noted the error when discussing a story that had appeared in *Discover* magazine, saying "*Discover* mistakenly reported that the universe was 156 billion light-years wide, thinking that 78 billion was the radius of the universe instead of its diameter."^[48]

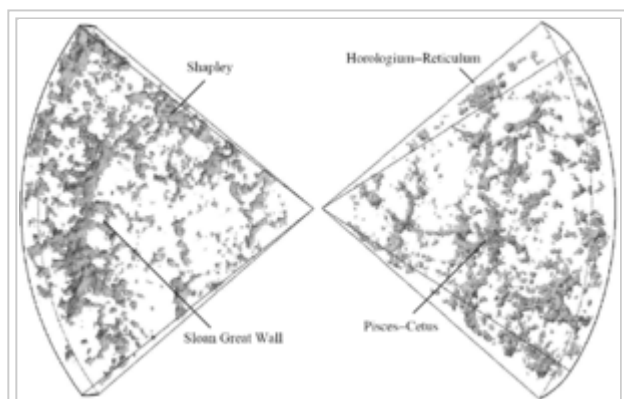
180 billion light-years

This estimate combines the erroneous 156-billion-light-year figure with evidence that the M33 Galaxy is actually fifteen percent farther away than previous estimates and that, therefore, the Hubble constant is fifteen percent smaller.^[49] The 180-billion figure is obtained by adding 15% to 156 billion light years.

Large-scale structure

Sky surveys and mappings of the various wavelength bands of electromagnetic radiation (in particular 21-cm emission) have yielded much information on the content and character of the universe's structure. The organization of structure appears to follow as a hierarchical model with organization up to the scale of superclusters and filaments. Larger than this (at scales between 30-200 megaparsecs^[50]), there seems to be no continued structure, a phenomenon that has been referred to as the *End of Greatness*.^[51]

Walls, filaments, nodes, and voids



DTFE reconstruction of the inner parts of the 2dF Galaxy Redshift Survey

The organization of structure arguably begins at the stellar level, though most cosmologists rarely address astrophysics on that scale. Stars are organized into galaxies, which in turn form galaxy groups, galaxy clusters, superclusters, sheets, walls and filaments, which are separated by immense voids, creating a vast foam-like structure^[52] sometimes called the "cosmic web". Prior to 1989, it was commonly assumed that virialized galaxy clusters were the largest structures in existence, and that they were distributed more or less uniformly throughout the Universe in every direction. However, since the early 1980s, more and more structures have been discovered. In 1983, Adrian Webster identified the Webster LQG, a large quasar group consisting of 5 quasars. The discovery was the first

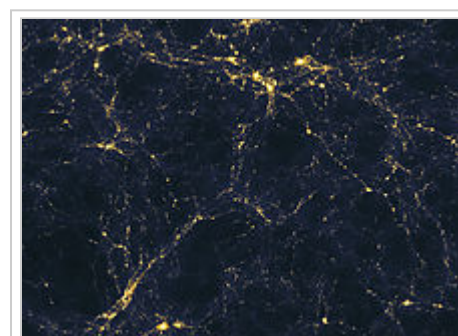
identification of a large-scale structure, and has expanded the information about the known grouping of matter in the Universe. In 1987, Robert Brent Tully identified the Pisces–Cetus Supercluster Complex, the galaxy filament in which the Milky Way resides. It is about 1 billion light years across. That same year, an unusually large region with no galaxies was discovered, the Giant Void, which measures 1.3 billion light years across. Based on redshift survey data, in 1989 Margaret Geller and John Huchra discovered the "Great Wall",^[53] a sheet of galaxies more than 500 million light-years long and 200 million light-years wide, but only 15 million light-years thick. The existence of this structure escaped notice for so long because it requires locating the position of galaxies in three dimensions, which involves combining location information about the galaxies with distance information from redshifts. Two years later, astronomers Roger G. Clowes and Luis E. Campusano discovered the Clowes–Campusano LQG, a large quasar group measuring two billion light years at its widest point, and was the largest known structure in the Universe at the time of its announcement. In April 2003, another large-scale structure was discovered, the Sloan Great Wall. In August 2007, a possible supervoid was detected in the constellation Eridanus.^[54] It coincides with the 'CMB cold spot', a cold region in the microwave sky that is highly improbable under the currently favored cosmological model. This supervoid could cause the cold spot, but to do so it would have to be improbably big, possibly a billion light-years across, almost as big as the Giant Void mentioned above.

Another large-scale structure is the Newfound Blob, a collection of galaxies and enormous gas bubbles that measures about 200 million light years across.

In 2011, a large quasar group was discovered, U1.11, measuring about 2.5 billion light years across. On January 11, 2013, another large quasar group, the Huge-LQG, was discovered, which was measured to be four billion light-years across, the largest known structure in the Universe that time.^[55] In November 2013, astronomers discovered the Hercules–Corona Borealis Great Wall,^{[56][57]} an even bigger structure twice as large as the former. It was defined by the mapping of gamma-ray bursts.^{[56][58]}

End of Greatness

The *End of Greatness* is an observational scale discovered at roughly 100 Mpc (roughly 300 million lightyears) where the lumpiness seen in the large-scale structure of the universe is homogenized and isotropized in accordance with the Cosmological



Computer simulated image of an area of space more than 50 million light years across, presenting a possible large-scale distribution of light sources in the universe - precise relative contributions of galaxies and quasars are unclear.

Principle.^[51] At this scale, no pseudo-random fractalness is apparent.^[59] The superclusters and filaments seen in smaller surveys are randomized to the extent that the smooth distribution of the Universe is visually apparent. It was not until the redshift surveys of the 1990s were completed that this scale could accurately be observed.^[51]

Observations

Another indicator of large-scale structure is the 'Lyman-alpha forest'. This is a collection of absorption lines that appear in the spectra of light from quasars, which are interpreted as indicating the existence of huge thin sheets of intergalactic (mostly hydrogen) gas. These sheets appear to be associated with the formation of new galaxies.

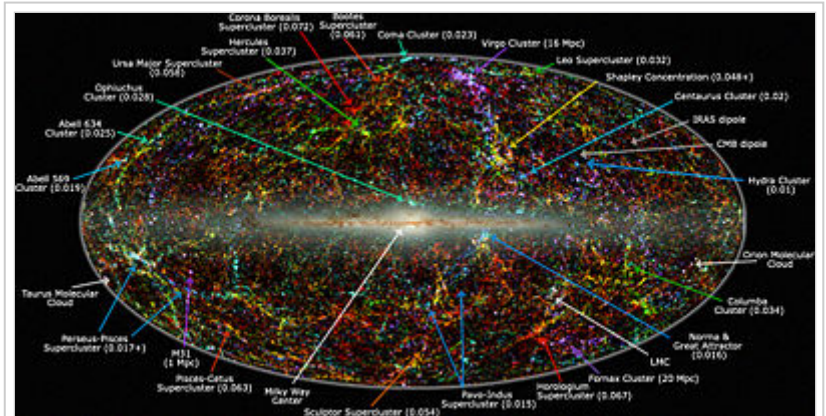
Caution is required in describing structures on a cosmic scale because things are often different from how they appear.

Gravitational lensing (bending of light by gravitation) can make an image appear to originate in a different direction from its real source. This is caused when foreground objects (such as galaxies) curve surrounding spacetime (as predicted by general relativity), and deflect passing light rays. Rather usefully, strong gravitational lensing can sometimes magnify distant galaxies, making them easier to detect. Weak lensing (gravitational shear) by the intervening universe in general also subtly changes the observed large-scale structure. As of 2004, measurements of this subtle shear showed considerable promise as a test of cosmological models.

The large-scale structure of the Universe also looks different if one only uses redshift to measure distances to galaxies. For example, galaxies behind a galaxy cluster are attracted to it, and so fall towards it, and so are slightly blueshifted (compared to how they would be if there were no cluster) On the near side, things are slightly redshifted. Thus, the environment of the cluster looks a bit squashed if using redshifts to measure distance. An opposite effect works on the galaxies already within a cluster: the galaxies have some random motion around the cluster center, and when these random motions are converted to redshifts, the cluster appears elongated. This creates a "*finger of God*" – the illusion of a long chain of galaxies pointed at the Earth.

Cosmography of our cosmic neighborhood

At the centre of the Hydra-Centaurus Supercluster, a gravitational anomaly called the Great Attractor affects the motion of galaxies over a region hundreds of millions of light-years across. These galaxies are all redshifted, in accordance with Hubble's law. This indicates that they are receding from us and from each other, but the variations in their redshift are sufficient to reveal the existence of a concentration of mass equivalent to tens of thousands of galaxies.



"Panoramic view of the entire near-infrared sky reveals the distribution of galaxies beyond the Milky Way. The image is derived from the 2MASS Extended Source Catalog (XSC)— more than 1.5 million galaxies, and the Point Source Catalog (PSC) —nearly 0.5 billion Milky Way stars. The galaxies are color-coded by 'redshift' obtained from the UGC, CfA, Tully NBGC, LCRS, 2dF, 6dFGS, and SDSS surveys (and from various observations compiled by the NASA Extragalactic Database), or photo-metrically deduced from the K band (2.2 μ m). Blue are the nearest sources ($z < 0.01$); green are at moderate distances ($0.01 < z < 0.04$) and red are the most distant sources that 2MASS resolves ($0.04 < z < 0.1$). The map is projected with an equal area Aitoff in the Galactic system (Milky Way at center)."^[60]

The Great Attractor, discovered in 1986, lies at a distance of between 150 million and 250 million light-years (250 million is the most recent estimate), in the direction of the Hydra and Centaurus constellations. In its vicinity there is a preponderance of large old galaxies, many of which are colliding with their neighbours, or radiating large amounts of radio waves.

In 1987, astronomer R. Brent Tully of the University of Hawaii's Institute of Astronomy identified what he called the Pisces–Cetus Supercluster Complex, a structure one billion light years long and 150 million light years across in which, he claimed, the Local Supercluster was embedded.^{[61][62]}

Mass of ordinary matter

The mass of the observable Universe is often quoted as 10^{50} tonnes or 10^{53} kg.^[3] In this context, mass refers to ordinary matter and includes the interstellar medium (ISM) and the intergalactic medium (IGM). However, it excludes dark matter and dark energy. This quoted value for the mass of ordinary matter in the Universe can be estimated based on critical density. The calculations are for the observable universe only as the volume of the whole is unknown and may be infinite.

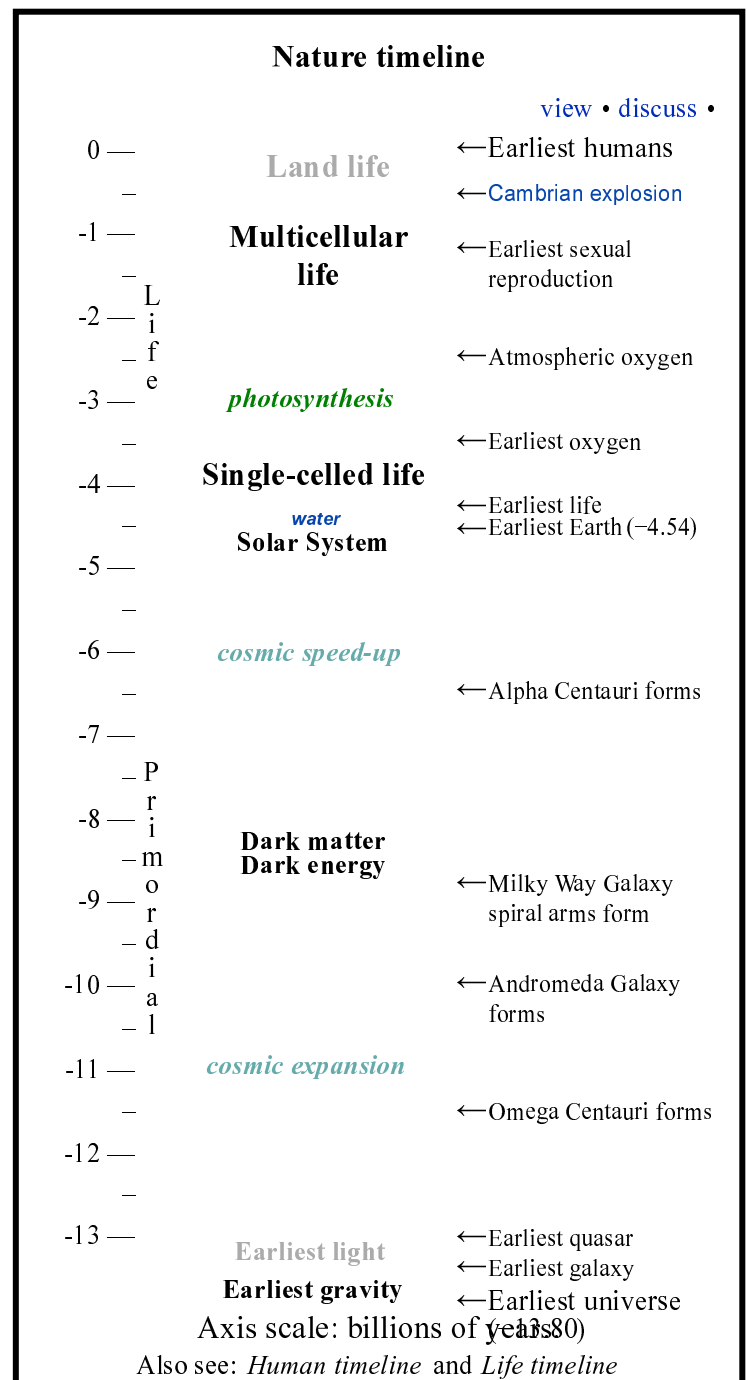
Estimates based on critical density

Critical Density is the energy density where the expansion of the Universe is poised between continued expansion and collapse.^[63] Observations of the cosmic microwave background from the Wilkinson Microwave Anisotropy Probe suggest that the spatial curvature of the Universe is very close to zero, which in current cosmological models implies that the value of the density parameter must be very close to a certain critical density value. At this condition, the calculation for ρ_c critical density, is:^[64]

$$\rho_c = \frac{3H_0^2}{8\pi G}$$

where G is the gravitational constant. From The European Space Agency's Planck Telescope results: H_0 is 67.15 kilometers per second per mega parsec. This gives a critical density of 0.85×10^{-26} kg/m³ (commonly quoted as about 5 hydrogen atoms per cubic meter). This density includes four significant types of energy/mass:

ordinary matter (4.8%), neutrinos (0.1%), cold dark matter (26.8%), and dark energy (68.3%).^[65] Note that although neutrinos are defined as particles like electrons, they are listed separately because they are difficult to detect and so different from ordinary matter. Thus, the density of ordinary matter is 4.8% of the total critical



density calculated or $4.08 \times 10^{-28} \text{ kg/m}^3$. To convert this density to mass we must multiply by volume, a value based on the radius of the "observable universe". Since the Universe has been expanding for 13.8 billion years, the comoving distance (radius) is now about 46.6 billion light years. Thus, volume ($\frac{4}{3}\pi r^3$) equals $3.58 \times 10^{80} \text{ m}^3$ and mass of ordinary matter equals density ($4.08 \times 10^{-28} \text{ kg/m}^3$) times volume ($3.58 \times 10^{80} \text{ m}^3$) or $1.46 \times 10^{53} \text{ kg}$.

Matter content – number of atoms

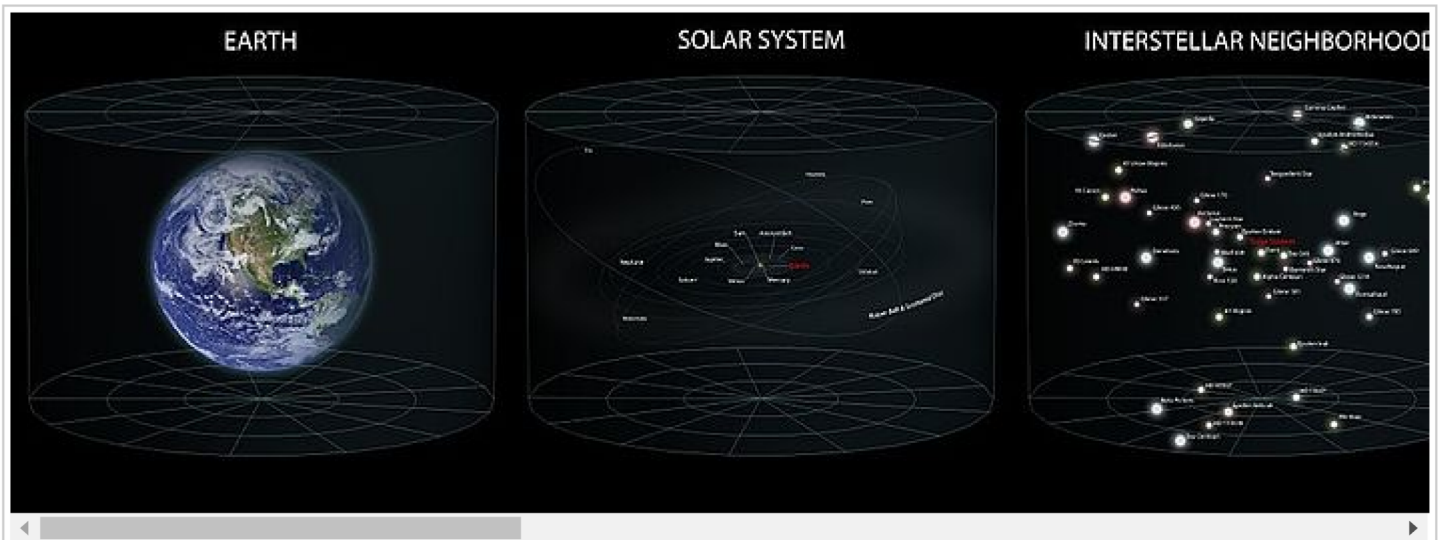
Assuming the mass of ordinary matter is about $1.45 \times 10^{53} \text{ kg}$ (refer to previous section) and assuming all atoms are hydrogen atoms (which in reality make up about 74% of all atoms in our galaxy by mass, see Abundance of the chemical elements), calculating the estimated total number of atoms in the observable Universe is straightforward. Divide the mass of ordinary matter by the mass of a hydrogen atom ($1.45 \times 10^{53} \text{ kg}$ divided by $1.67 \times 10^{-27} \text{ kg}$). The result is approximately 10^{80} hydrogen atoms. The chemistry of life may have begun shortly after the Big Bang, 13.8 billion years ago, during a habitable epoch when the Universe was only 10–17 million years old.^{[66][67]} According to the panspermia hypothesis, microscopic life – distributed by meteoroids, asteroids and other small Solar System bodies – may exist throughout the Universe.^[68] Though life is confirmed only on the Earth, many think that extraterrestrial life is not only plausible, but probable or inevitable.^{[69][70]}

Most distant objects

The most distant astronomical object yet announced as of January 2011 is a galaxy candidate classified UDFj-39546284. In 2009, a gamma ray burst, GRB 090423, was found to have a redshift of 8.2, which indicates that the collapsing star that caused it exploded when the Universe was only 630 million years old.^[71] The burst happened approximately 13 billion years ago,^[72] so a distance of about 13 billion light years was widely quoted in the media (or sometimes a more precise figure of 13.035 billion light years),^[71] though this would be the "light travel distance" (*see* Distance measures (cosmology)) rather than the "proper distance" used in both Hubble's law and in defining the size of the observable universe (cosmologist Ned Wright argues against the common use of light travel distance in astronomical press releases on this page (http://www.astro.ucla.edu/~wright/Dltt_is_Dumb.html), and at the bottom of the page offers online calculators that can be used to calculate the current proper distance to a distant object in a flat universe based on either the redshift *z* or the light travel time). The proper distance for a redshift of 8.2 would be about 9.2 Gpc,^[73] or about 30 billion light years. Another record-holder for most distant object is a galaxy observed through and located beyond Abell 2218, also with a light travel distance of approximately 13 billion light years from Earth, with observations from the Hubble telescope indicating a redshift between 6.6 and 7.1, and observations from Keck telescopes indicating a redshift towards the upper end of this range, around 7.^[74] The galaxy's light now observable on Earth would have begun to emanate from its source about 750 million years after the Big Bang.^[75]

Horizons

The limit of observability in our universe is set by a set of cosmological horizons which limit—based on various physical constraints—the extent to which we can obtain information about various events in the Universe. The most famous horizon is the particle horizon which sets a limit on the precise distance that can be seen due to the finite age of the Universe. Additional horizons are associated with the possible future extent of observations (larger than the particle horizon owing to the expansion of space), an "optical horizon" at the surface of last scattering, and associated horizons with the surface of last scattering for neutrinos and gravitational waves.



A diagram of our location in the observable universe. (*Alternative image.*)

See also

- Big Bang
- Bolshoi Cosmological Simulation
- Causality (physics)
- Chronology of the universe
- Dark flow
- Event horizon of the universe
- Hubble volume
- Illustris project
- Multiverse
- Orders of magnitude (length)
- Timeline of the Big Bang

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External links

- Calculating the total mass of ordinary matter in the universe, what you always wanted to know (<https://www.youtube.com/watch?v=K8V8Iy9Tozk>)
- "Millennium Simulation" of structure forming (<http://www.mpa-garching.mpg.de/galform/millennium/>) – Max Planck Institute of Astrophysics, Garching, Germany
- Visualisations of large-scale structure: animated spins of groups, clusters, filaments and voids (<http://www.physics.usyd.edu.au/sifa/MSPM/An>) – identified in SDSS data by MSPM (Sydney Institute for Astronomy)
- NASA Astronomy Picture of the Day: The Sloan Great Wall: Largest Known Structure? (7 November 2007) (<https://apod.nasa.gov/apod/ap071107.html>)
- Cosmology FAQ (http://www.astro.ucla.edu/~wright/cosmology_faq.html)
- Forming Galaxies Captured In The Young Universe By Hubble, VLT & Spitzer (<http://www.sciencedaily.com/releases/2007/04/070419125240.htm>)
- NASA featured Images and Galleries (<http://www.nasa.gov/multimedia/imagegallery>)
- Star Survey reaches 70 sextillion (<http://www.cnn.com/2003/TECH/space/07/22/stars.survey/>)
- Animation of the cosmic light horizon (<http://www.phys.ksu.edu/personal/gahs/phys191/horizon.html>)
- Inflation and the Cosmic Microwave Background by Charles Lineweaver (<http://arxiv.org/abs/astro-ph/0305179>)
- Logarithmic Maps of the Universe (<http://www.astro.princeton.edu/universe/>)
- List of publications of the 2dF Galaxy Redshift Survey (<http://www.mso.anu.edu.au/2dFGRS/>)
- The Universe Within 14 Billion Light Years – NASA Atlas of the Universe (<http://www.atlasoftheuniverse.com/universe.html>) – Note, this map only gives a rough cosmographical estimate of the expected distribution of superclusters within the observable universe; very little actual mapping has been done beyond a distance of one billion light years.
- Video: "The Known Universe", from the American Museum of Natural History (<https://www.youtube.com/watch?v=17jymDn0W6U>)
- NASA/IPAC Extragalactic Database (<http://ned.ipac.caltech.edu/>)
- Cosmography of the Local Universe (<http://irfu.cea.fr/cosmography>) at irfu.cea.fr (17:35) (arXiv (<http://arxiv.org/abs/1306.0091>))

- Size and age of the Universe (<http://www.astronoo.com/en/articles/size-of-the-universe.html>) – at Astronoo

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