

Frequently Asked Questions in Cosmology

Tutorial : [Part 1](#) | [Part 2](#) | [Part 3](#) | [Part 4](#) | [Age](#) | [Distances](#) | [Bibliography](#) | [Relativity](#)

- [What is this "anti-gravity"? \[The cosmological constant\]](#)
- [Why do we think that the expansion of the Universe is accelerating?](#)
- [How old is the Universe?](#)
- [If the Universe is only 10 billion years old, why isn't the most distant object we can see 5 billion light years away?](#)
- [If the Universe is only 10 billion years old, how can we see objects that are now 30 billion light years away?](#)
- [How can the Universe be infinite if it was all concentrated into a point at the Big Bang?](#)
- [How can the oldest stars in the Universe be older than the Universe?](#)
- [Can objects move away from us faster than the speed of light?](#)
- [What is the redshift?](#)
- [Are quasars really at the large distances indicated by their redshifts?](#)
- [What about objects with discordant redshifts, like Stephan's Quintet?](#)
- [Has the time dilation of distant source light curves predicted by the Big Bang been observed?](#)
- [Are galaxies really moving away from us or is space-time just expanding?](#)
- [Why doesn't the Solar System expand if the whole Universe is expanding?](#)
- [Is the Universe expanding or is it just that our definitions of length and time are changing?](#)
- [Why haven't the CMBR photons outrun the galaxies in the Big Bang?](#)
- [Where was the center of the Big Bang?](#)
- [What is meant by a flat Universe?](#)
- [Is the Big Bang a Black Hole?](#)
- [What is the Universe expanding into?](#)
- [What came before the Big Bang?](#)
- [Doug Scott's Cosmic Microwave Background Radiation \(CMBR\) FAQ](#)
- [Can the CMBR be redshifted starlight?](#)
- [Why is the sky dark at night?](#)
- [Will the Universe expand forever or recollapse?](#)
- [What is the dark matter?](#)
- [What is the value of the Hubble constant?](#)
- [What can a layperson do in cosmology?](#)
- [Ask your own question!](#)

Why do we think that the expansion of the Universe is accelerating?

The evidence for an accelerating expansion comes from observations of the [brightness of distant supernovae](#). We observe the [redshift](#) of a supernova which tells us by what the factor the Universe has expanded since the supernova exploded. This factor is $(1+z)$, where z is the redshift. But in order to determine the expected brightness of the supernova, we need to know its [distance now](#). If the expansion of the Universe is accelerating due to a [cosmological constant](#), then the expansion was slower in the past, and thus the time required to expand by a given factor is longer, and the distance NOW is larger. But if the expansion is decelerating, it was faster in the past and the distance NOW is smaller. Thus for an accelerating expansion the supernovae at high redshifts will appear to be fainter than they would for a decelerating expansion because their current distances are larger. Note that these distances are all proportional to the age of the Universe [or $1/H_0$], but this dependence cancels out when the brightness of a nearby supernova at z close to 0.1 is compared to a distant supernova with z close to 1.

[Back to top.](#)

If the Universe is only 10 billion years old, why isn't the most distant object we can see 5 billion light years away?

This question makes some hidden assumptions about space and time which are not consistent with all definitions of distance and time. One assumes that all the galaxies left from a single point at the Big Bang, and the most distant one traveled away from us for half the age of the Universe at almost the speed of light, and then emitted light which came back to us at the speed of light. By assuming constant velocities, we must ignore gravity, so this would only happen in a nearly empty Universe. In the empty Universe, one of the many possible definitions of distance does agree with the assumptions in this question: the *angular size distance*, and it does reach a maximum value of the speed of light times one half the age of the Universe. See [Part 2](#) of the cosmology tutorial for a discussion of the other kinds of distances which go to infinity in the empty Universe model since this gives an unbounded Universe.

[Back to top.](#)

If the Universe is only 10 billion years old, how can we see objects that are now 30 billion light years away?

When talking about the distance of a moving object, we mean the spatial separation NOW, with the positions of both objects specified at the current time. In an expanding Universe this distance NOW is larger than the speed of light times the light travel time due to the increase of separations between objects as the Universe expands. This is not do to any change in the units of space and time, but just caused by things being farther apart now than they used to be.

What is the distance NOW to the most distant thing we can see? Let's take the age of the Universe to be 10 billion years. In that time light travels 10 billion light years, and some people stop here. But the distance has grown since the light traveled. The average time when the light was traveling was 5 billion years ago. For the **critical density** case, the scale factor for the Universe goes like the 2/3 power of the time since the Big Bang, so the Universe has grown by a factor of $2^{2/3} = 1.59$ since the midpoint of the light's trip. But the size of the Universe changes continuously, so we should divide the light's trip into short intervals. First take two intervals: 5 billion years at an average time 7.5 billion years after the Big Bang, which gives 5 billion light years that have grown by a factor of $1/(0.75)^{2/3} = 1.21$, plus another 5 billion light years at an average time 2.5 billion years after the Big Bang, which has grown by a factor of $4^{2/3} = 2.52$. Thus with 1 interval we got $1.59 * 10 = 15.9$ billion light years, while with two intervals we get $5 * (1.21 + 2.52) = 18.7$ billion light years. With 8192 intervals we get 29.3 billion light years. In the limit of very many time intervals we get 30 billion light years.

Another way of seeing this is to consider a photon and a galaxy 30 billion light years away from us now, 10 billion years after the Big Bang. The distance of this photon satisfies $D = 3ct$. If we wait for 0.1 billion years, the Universe will grow by a factor of $(10.1/10)^{2/3} = 1.0066$, so the galaxy will be $1.0066 * 30 = 30.2$ billion light years away. But the light will have traveled 0.1 billion light years further than the galaxy *because it moves at the speed of light relative to the matter in its vicinity* and will thus be at $D = 30.3$ billion light years, so $D = 3ct$ is still satisfied.

If the Universe does not have the critical density then the distance is different, and for the low densities that are more likely the distance NOW to the most distant object we can see is bigger than 3 times the speed of light times the age of the Universe.

[Back to top.](#)

How can the oldest stars in the Universe be older than the Universe?

Of course the Universe has to be older than the oldest stars in it. So this question basically asks: which estimate is wrong -

- The age of the Universe
- The age of the oldest stars
- Both

The age of the Universe is determined from its expansion rate: the **Hubble constant**, which is the ratio of the radial velocity of a distant galaxy to its distance. The **radial velocity** is easy to measure, but the **distances** are not. Thus there is currently a 15% uncertainty in the Hubble constant.

Determining the **age** of the oldest stars requires a knowledge of their luminosity, which depends on their distance. This leads to a 25% uncertainty in the ages of the oldest stars due to the difficulty in determining distances.

Thus the discrepancy between the age of the oldest things in the Universe and the age inferred from the expansion rate is within the current margin of error. In fact, in 1997 improved distances from the HIPPARCOS satellite suggested that this discrepancy has vanished.

[Back to top.](#)

Can objects move away from us faster than the speed of light?

Again, this is a question that depends on which of the **many distance definitions** one uses. However, if we assume that the distance of an object at time t is the distance to the object measured by a set of observers moving with the expansion of the Universe, and all making their observations when they see the Universe as having age t , then the velocity (change in D per change in t) can definitely be larger than the speed of light. This is not a contradiction of special **relativity** because this distance is not the same as the spatial distance used in SR, and the age of the Universe is not the same as the time used in SR.

[Back to top.](#)

What is the redshift?

The **redshift** of an object is the amount by which the spectral lines in the source are shifted to the red. That is, the wavelengths get longer. To be precise, the redshift is given by

$$z = [\text{WL}(\text{obs}) - \text{WL}(\text{em})] / \text{WL}(\text{em})$$

where $\text{WL}(\text{em})$ is the emitted wavelength of a line, which is known from laboratory measurements, and $\text{WL}(\text{obs})$ is the observed wavelength of the line. In an expanding Universe, distant objects are redshifted, with $z = H_0 D/c$ for small distances. This law was discovered by Hubble and H_0 is known as the Hubble constant.

[Back to top.](#)

Are quasars really at the large distances indicated by their redshifts?

The short answer is

Yes!

[Stockton \(1978, ApJ, 223, 747\)](#) observed faint galaxies near in the sky to bright quasars at moderate redshifts. He chose quasars with moderate redshifts so he would still be able to see galaxies at the redshift of the quasar. He found that a good fraction of the redshifts of the faint galaxies agreed with the redshifts of the quasars. In other words, quasars are associated with galaxies that have the same redshift as the quasar and have just the brightness expected if the quasars are at their cosmological distances. Thus at least some quasars are at the distance indicated by their redshifts, and this includes some of the most luminous quasars: for example [3C273](#). Thus the simple answer selected by Occam's razor is that all quasars are at the distances indicated by their redshifts.

The statistical arguments advanced by Arp and others in favor of anomalous quasar redshifts are often [incorrect](#).

[Back to top.](#)

What about objects with discordant redshifts, like Stephan's Quintet?

One famous example of objects with different redshifts appearing in the same part of the sky is [Stephan's Quintet](#). But the low redshift galaxy (in the lower left) is obviously more resolved into stars and looks "bumpier". By the surface brightness fluctuation method of [distance](#) determination, this bumpiness means that the low redshift galaxy is indeed much closer to us than the other four members of the quintet.

[Back to top.](#)

Has the time dilation of distant source light curves predicted by the Big Bang been observed?

This time dilation is a consequence of the standard interpretation of the redshift: a supernova that takes 20 days to decay will appear to take 40 days to decay when observed at redshift $z=1$. The time dilation has been observed, with 4 different published measurements of this effect in supernova light curves. These papers are:

- [Leibundgut et al](#), 1996, ApJL, 466, L21-L24
- [Goldhaber et al](#), in Thermonuclear Supernovae (NATO ASI), eds. R. Canal, P. Ruiz-LaPuente, and J. Isern.
- [Riess et al](#), 1997, AJ, 114, 722.
- [Perlmutter et al](#), 1998, Nature, 391, 51.

These observations contradict [tired light](#) models of the redshift.

[Back to top.](#)

Are galaxies really moving away from us or is space-time just expanding?

This depends on how you measure things, or your choice of coordinates. In one view, the spatial positions of galaxies are changing, and this causes the redshift. In another view, the galaxies are at fixed coordinates, but the distance between fixed points increases with time, and this causes the redshift. General relativity explains how to transform from one view to the other, and the observable effects like the redshift are the same in both views. [Part 3](#) of the tutorial shows space-time diagrams for the Universe drawn in both ways.

Also see the [Relativity FAQ](#) answer to this question.

[Back to top.](#)

Why doesn't the Solar System expand if the whole Universe is expanding?

This question is best answered in the coordinate system where the galaxies change their positions. The galaxies are receding from us because they started out receding from us, and the force of gravity just causes an acceleration that causes them to slow down. Planets are going around the Sun in fixed size orbits because they are bound to the Sun. Everything is just moving under the influence of Newton's laws (with very slight modifications due to relativity). [\[Illustration\]](#) For the technically minded, [Cooperstock et al.](#) computes that the influence of the cosmological expansion on the Earth's orbit around the Sun amounts to a growth by only one part in a septillion over the age of the Solar System. Even on the much larger (million light year) scale of clusters of galaxies, the effect of the expansion of the Universe is 10 million times smaller than the gravitational binding of the cluster.

Also see the [Relativity FAQ](#) answer to this question.

[Back to top.](#)

Is the Universe expanding or is it just that our definitions of length and time are changing?

The definitions of length and time are not changing in the standard model. The second is still 9192631770 cycles of a Cesium atomic clock and the meter is still the distance light travels in 9192631770/299792458 cycles of a Cesium atomic clock.

[Back to top.](#)

What is meant by a flat Universe?

The Universe appears to be homogeneous and isotropic, and there are only three possible geometries that are homogeneous and isotropic as shown in [Part 3](#). A flat space has [Euclidean](#) geometry, where the sum of the angles in a triangle is 180° . A curved space has [non-Euclidean geometry](#). In a positively curved, or hyperspherical space, the sum of the angles in a triangle is bigger than 180° , and this angle excess gives the area of the triangle divided by the square of the radius of the surface. In a negatively curved or hyperbolic space, the sum of the angles in a triangle is less than 180° . When [Gauss invented](#) this non-Euclidean geometry he actually tried measuring a large triangle, but he got an angle sum of 180° because the radius of the Universe is very large (if not infinite) so the angle excess or deficit has to be tiny for any triangle we can measure. If the radius is infinite, then the Universe is flat.

[Back to top.](#)

[Bolyai](#) developed this geometry and published it, whereupon Gauss wrote to Bolyai's father: "To praise it would amount to praising myself. For the entire content of the work ... coincides almost exactly with my own meditations which have occupied my mind for the past thirty or thirty-five years." And [Lobachevsky](#) had published very similar work in the obscure *Kazan Messenger* .

What is the Universe expanding into?

This question is based on the ever popular misconception that the Universe is some curved object embedded in a higher dimensional space, and that the Universe is expanding into this space. This misconception is probably fostered by the [balloon](#) analogy which shows a 2-D spherical model of the Universe expanding in a 3-D space. While it is possible to think of the Universe this way, it is not necessary, *and there is nothing whatsoever that we have measured or can measure that will show us anything about the larger space*. Everything that we measure is within the Universe, and we see no edge or boundary or center of expansion. Thus the Universe is not expanding into *anything* that we can see, and this is not a profitable thing to think about. Just as Dali's [Corpus Hypercubicus](#) is just a 2-D picture of a 3-D object that represents the surface of a 4-D cube, remember that the balloon analogy is just a 2-D picture of a 3-D situation that is supposed to help you think about a curved 3-D space, but it does not mean that there is really a 4-D space that the Universe is expanding into.

Or you can ask [Dr. Science](#) :)

[Back to top.](#)

What came before the Big Bang?

The standard Big Bang model is *singular* at the time of the Big Bang, $t = 0$. This means that one cannot even define time, since spacetime is singular. In some models like the chaotic or perpetual inflation favored by Linde, the Big Bang is just one of many inflating bubbles in a spacetime foam. But there is no possibility of getting information from outside our own one bubble. Thus I conclude that: "[Whereof one cannot speak, thereof one must be silent.](#)"

From Bruce Margon and Craig Hogan at the Univ. of Washington

[Back to top.](#)

Why is the sky dark at night?

If the Universe were infinitely old, and infinite in extent, and stars could shine forever, then every direction you looked would eventually end on the surface of a star, and the whole sky would be as bright as the surface of the Sun. This is known as [Olbers' Paradox](#) after Heinrich Wilhelm Olbers [1757-1840] who wrote about it in 1823-1826 but it was also discussed earlier. Absorption by interstellar dust does not circumvent this paradox, since dust reradiates whatever radiation it absorbs within a few minutes, which is much less than the age of the Universe. However, the Universe is not infinitely old, and the expansion of the Universe reduces the accumulated energy radiated by distant stars. Either one of these effects acting alone would solve Olbers' Paradox, but they both act at once.

[Back to top.](#)

Will the Universe expand forever or recollapse?

This depends on the ratio of the density of the Universe to the critical density. If the density is higher than the critical density the Universe will recollapse in a *Big Crunch* . But current data suggests that the density is less than or equal to the critical density so the Universe will expand forever. See [Part 3](#) of the tutorial for more information.

[Back to top.](#)

What is the dark matter?

When astronomers add up the masses and luminosities of the stars near the Sun, they find that there are about 3 solar masses for every 1 solar luminosity. When they measure the total mass of clusters of galaxies and compare that to the total luminosity of the clusters, they find about 300 solar masses for every solar luminosity. Evidently most of the mass in the Universe is dark. If the Universe has the critical density then there are about 1000 solar masses for every solar luminosity, so an even greater fraction of the Universe is dark matter. But the theory of Big Bang nucleosynthesis says that the density of ordinary matter (*anything made from atoms*) can be at most 10% of the critical

density, so the majority of the Universe does not emit light, does not scatter light, does not absorb light, and is not even made out of atoms. It can only be "seen" by its gravitational effects. This "non-baryonic" dark matter can be [neutrinos](#), if they have small masses instead of being massless, or it can be WIMPs (Weakly Interacting Massive Particles), or it could be primordial black holes. My nominee for the "least likely to be caught" award goes to hypothetical stable Planck mass remnants of primordial black holes that have evaporated due to Hawking radiation. The Hawking radiation from the not-yet evaporated primordial black holes may be detectable by future [gamma ray](#) telescopes, but the 20 microgram remnants would be very hard to detect.

Also see the [Relativity FAQ](#) answer to this question, Jonathan Dursi's [tutorial](#) on dark matter, and the [Center for Particle Astrophysics](#) on dark matter.

[Dr. Science](#) on dark matter.

[See CDM](#)

[Back to top.](#)

What is the value of the Hubble constant?

This is the question that professional astronomers ask the most frequently, and the answer is:

$$H_0 = 65 \pm 8 \text{ km/sec/Mpc}$$

but I would rather see

42

[Back to top.](#)

What can a layperson do in cosmology?

- Stay in school! There is a lot to learn about the Universe.
- Keep taking math and science courses!
The book of nature lies continuously open before our eyes (I speak of the Universe) but it can't be understood without first learning to understand the language and characters in which it is written. It is written in mathematical language, and its characters are geometrical figures. - Galileo Galilei
That was true 400 years ago and it is much more true today!
- If you are out of school, check out the [bibliography](#).
- Tell your Congressman and Senators to support astrophysics research at NASA, NSF, and DOE.

[Back to top.](#)

[Ned Wright's Home Page](#)

[Tutorial](#) : [Part 1](#) | [Part 2](#) | [Part 3](#) | [Part 4](#) | [Age](#) | [Distances](#) | [Bibliography](#) | [Relativity](#)

© 1996-1999 [Edward L. Wright](#). Last modified 31-Aug-1999