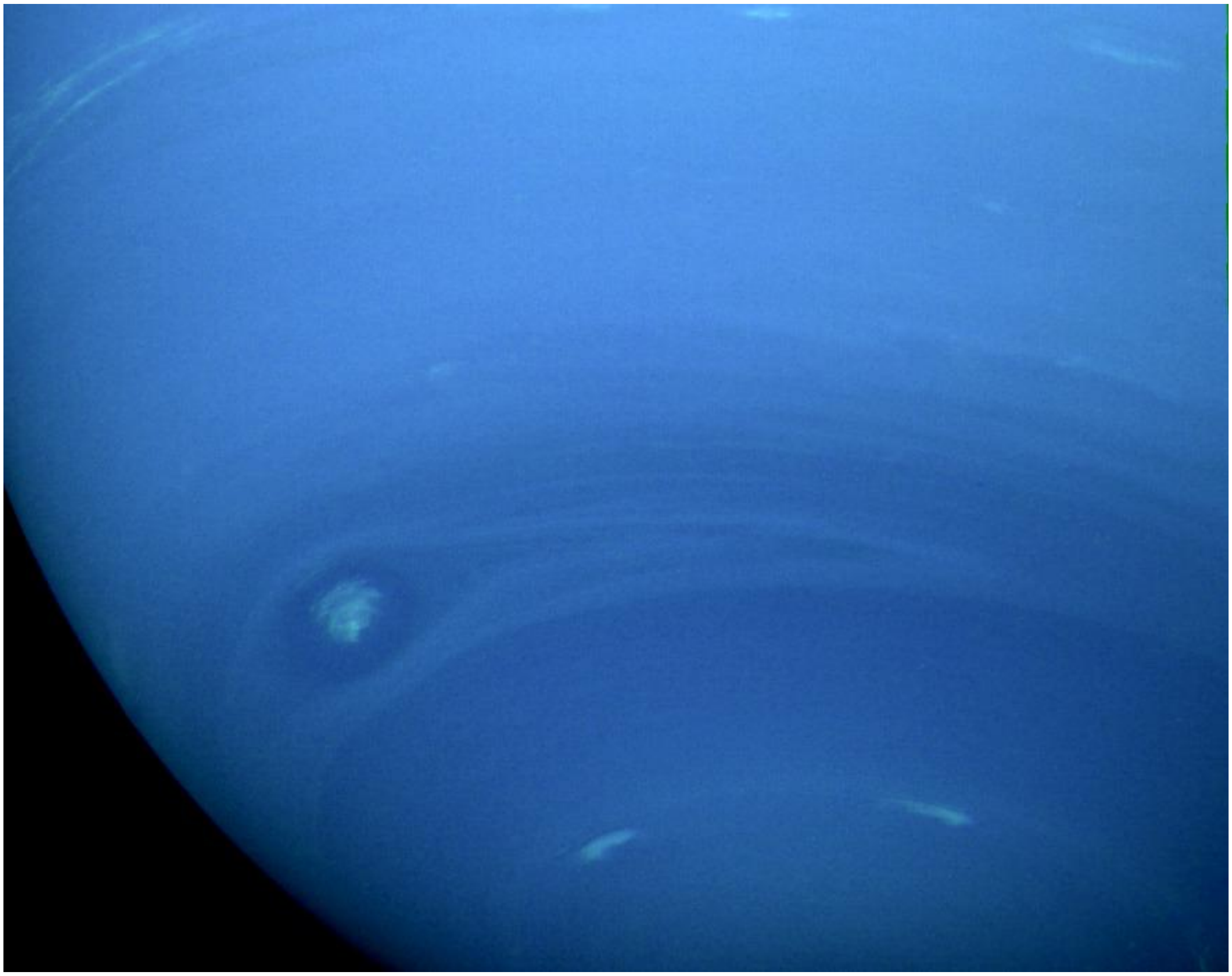
# The Living Universe is Unimaginably BIG, and You're a Part of it

***Max Planck “An experiment is a question which science poses to Nature, and a measurement is the recording of Nature's answer.”***

It would be a sheer understatement to say that the universe is big. Its expanse rivals literally nothing that exists. It’s unfathomable, but let’s begin with something that’s much, much smaller. We’re quite familiar with the fact that the moon is the closest object to the Earth.

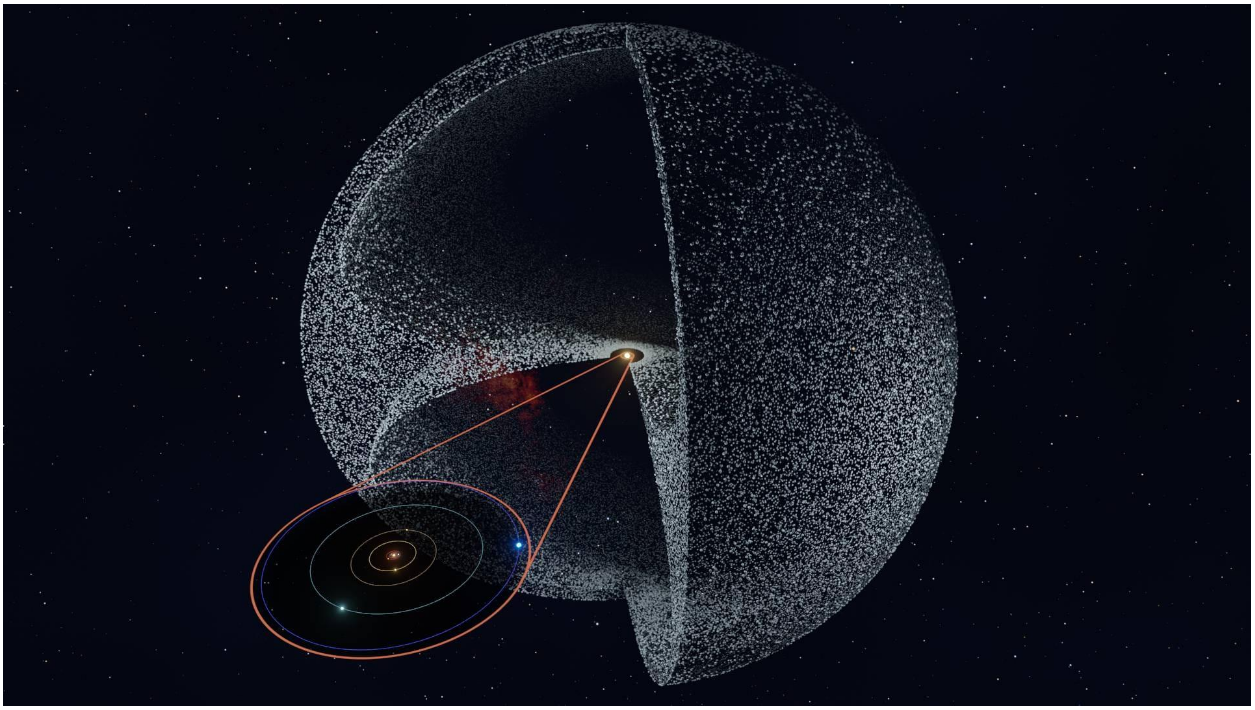
If you were to jump onto a spacecraft that’s using current rocket propulsion, you’d reach the moon in about 3 days. That’s pretty much like taking a train on the California Zephyr route, which is starts at Chicago and travels to San Francisco. Although that route will have a bunch of sights to see, the trip to the moon will probably not have that much to see. You will though, get to look at an incredible beautiful large-scale view of our planet Earth.

Now, let’s try to go a little further, to Neptune, the last legitimate planet in our solar system. With current rocket propulsion speeds, you’d reach Neptune, which is around 2.7 billion miles away, in about a decades time. Some estimates suggest that you could reach Neptune faster in about 8 odd years, but that’s only when Neptune’s approach is closest to the Earth every 13 odd months, so in reality, you’d need to plan way ahead if you want to get there quicker. Just planning a trip to Neptune would require decades of research, let alone looking for a fast route, but anyway...



Neptune

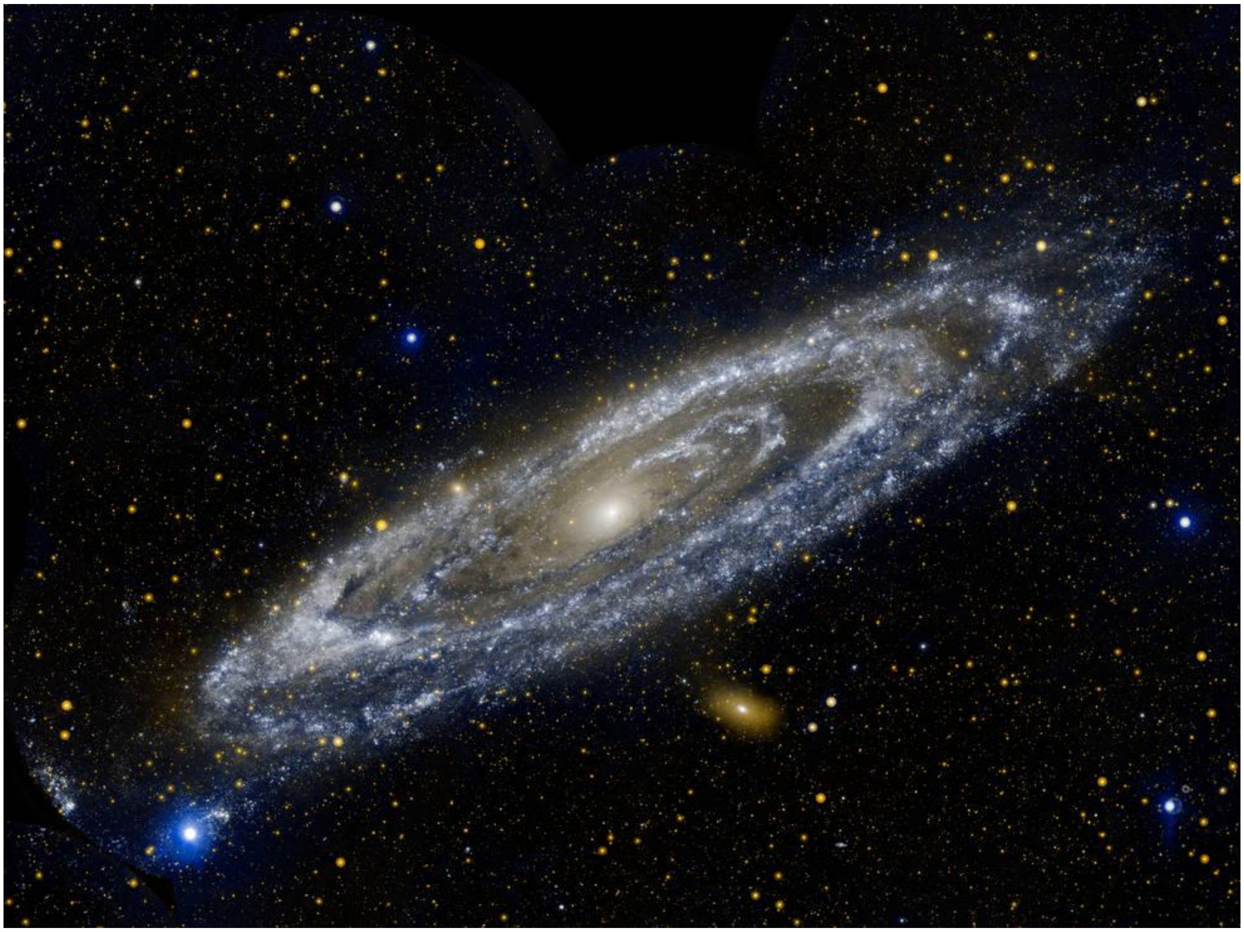
Alright, so we're reaching the end of our solar system, however in reality you're far from it. How long would it take you to get out of it? The solar system is situated inside the Oort cloud, a vast cloud of icy planetesimals surrounding the solar system at distances ranging from 2,000 to 200,000 astronomical units away. That's far too many billions of miles, so from now on, everything is mostly calculated in astronomical units or in light years. The Oort cloud is about 2 light-years away. Once again, using our current rocket propulsion, you'd manage to reach the end of the solar system in about 40,000 years. Make sure you pack a toothbrush.



Oort cloud

So you're out of the solar system now, and you want to head to the closest star system from our own, Alpha Centauri. Shouldn't be too difficult, right? You've managed to survive 40,000 years of travel unscathed, and you have a toothbrush, so you're good to go. The only issue is that you've got to travel another 33,000 years to reach there. On second thought, pack another toothbrush, just in case.

Let's say you want to go all out. You want to just get out there and leave this galaxy altogether. You look at your star map, and you figure out the nearest galaxy from here is Andromeda. A whopping 2.5 million light years away. We're currently seeing light from Andromeda that's 2.5 million years old. However, you decide you want to go there anyway. Once again through our current rocket propulsion speeds, you'd reach Andromeda in about 93 billion years. That's more than 6 times the age of the entire universe.


Andromeda

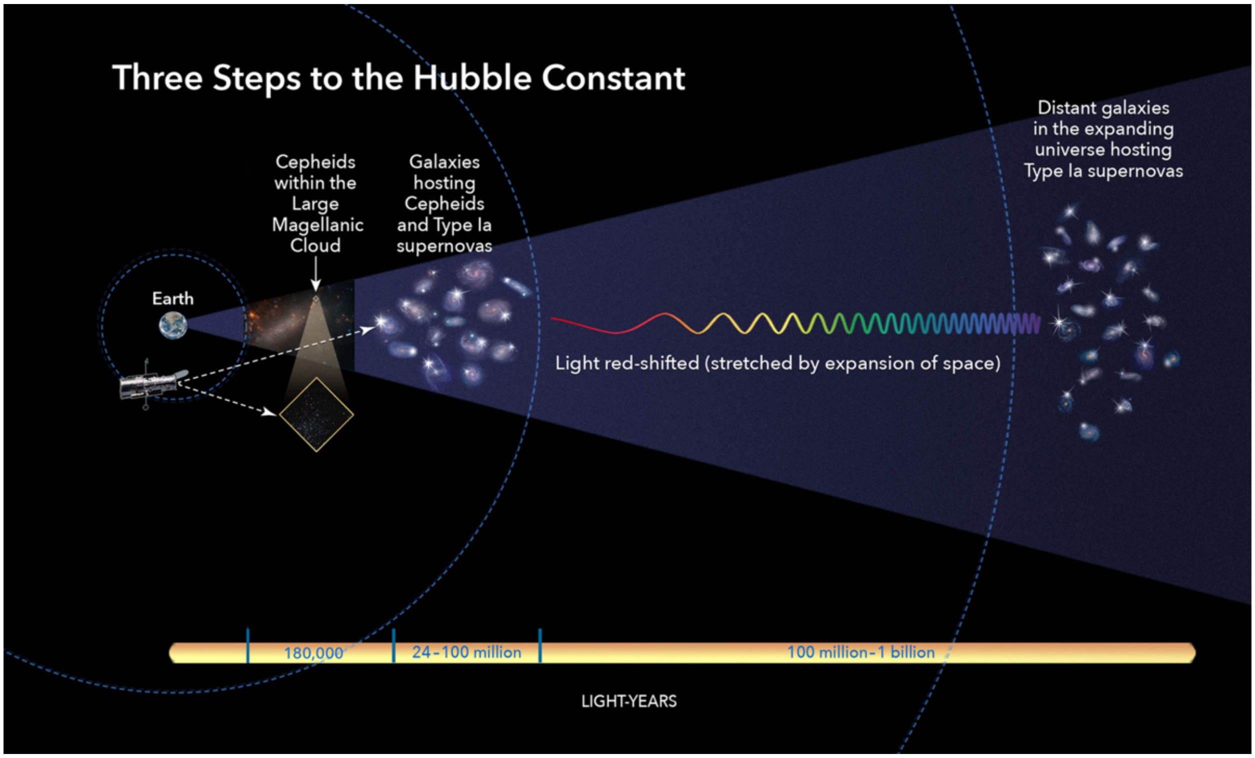
With an expanse of that magnitude just for distances in our galactic neighborhood, it makes you wonder, how big is the entire universe? When we gaze into the cosmos in any direction, it is estimated that the most distant visible regions of the Universe extend about 46 billion light-years away. To put this colossal expanse into perspective, it covers a diameter equivalent to 540 sextillion miles, which 54 followed by 22 zeros. But it's important to remember that this estimate is just a guess. We still don't know how big the Universe really is.

Our ability to observe this is entangled with the distance light, specifically, the microwave radiation originating from the Big Bang, has traveled since the universe's beginning. Since the Universe is believed to have lit up into existence some 13.8 billion years ago, it has continuously expanded outward ever since. But because we can't know exactly how old the Universe is, it's hard to figure out its boundaries beyond our observable range.

Astronomers have sought a valuable parameter, known as the Hubble Constant, to help with the understanding of how big the universe really is. Wendy Freedman, an astrophysicist at the University of Chicago devoted to its study, explains that the Hubble Constant serves as a gauge of the Universe's current expansion rate. It effectively sets up the universe's scope, covering both its dimensions and duration.

A good analogy is to think of the Universe is as a balloon that keeps getting bigger. As stars and galaxies, resembling points on the surface of the balloon, rapidly disengage from one another, the interstellar distances between them expand. From our vantage point, this implies that galaxies located farther from us are receding at faster speeds.

Regrettably, the more astronomers dig into the Hubble Constant, the more it seems to defy expectations rooted in our understanding of space. One method of direct measurement provides a specific value, whereas another approach, which relies on our understanding of other universal parameters, provides another distinct perspective. This difference is a problem. Either our measurements are wrong or our understanding of how the Universe works is flawed.



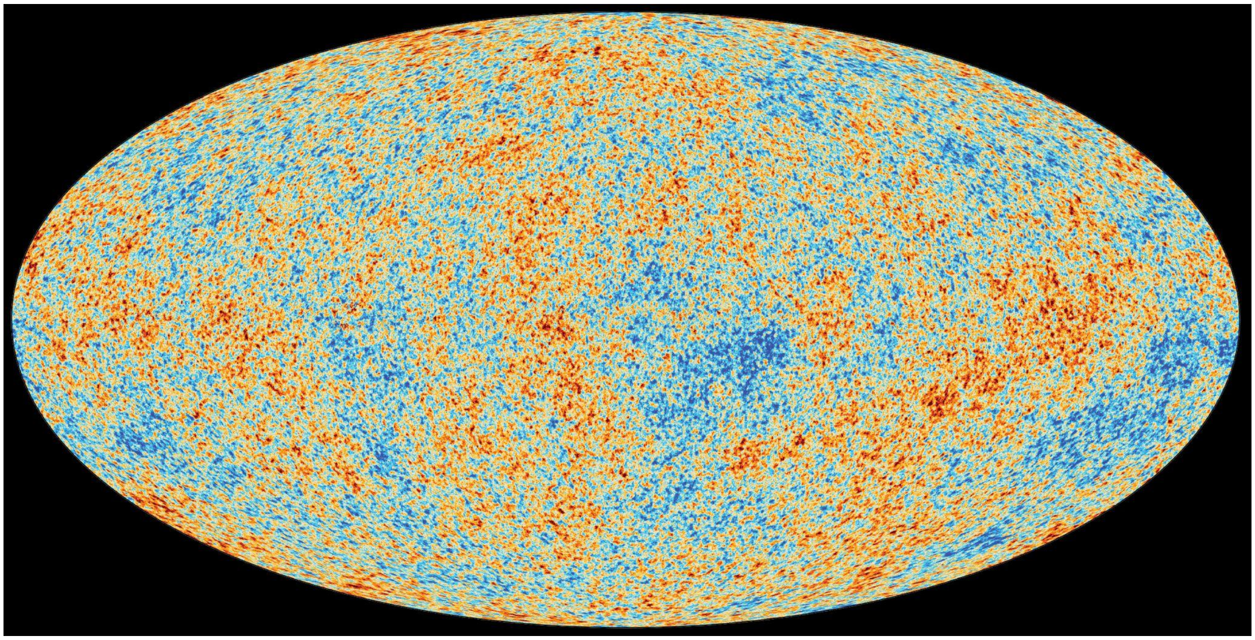

Scientists are now approaching a possible solution to this concern, mainly because of recent experiments and observations that try to figure out what the Hubble Constant is really like.

Rachael Beaton, an astronomer at Princeton University, says that the challenge for cosmologists is an engineering one: how to figure out this number with the most precision and accuracy. She stresses that this endeavor requires not only the collection of information but also the thorough verification of all measurements. From a scientific perspective, it resembles putting together a puzzle rather than being a part of an Agatha Christie mystery.

Edwin Hubble

In 1929, renowned astronomer Edwin Hubble, measured the Hubble Constant, which is named after him, and said that it was 310 miles per second per megaparsec. This value suggests that for every megaparsec, equivalent to approximately 3.26 million light-years, farther away from Earth one looks, galaxies appear to recede at 310 miles per second faster than those situated a distance. Since Hubble's pioneering estimate of cosmic expansion, this number has been repeatedly revised downward. Present-day estimates place it somewhere in the range of 42–46 miles per second per megaparsec.

An important challenge arises from the fact that the determination of the Hubble Constant can vary based on the measurement technique used. Two different ways of measuring the Hubble Constant are used. One way looks at how fast nearby galaxies move away from us, and the other way looks at the cosmic microwave background or CMB, which is the earliest light that came out after the Big Bang.

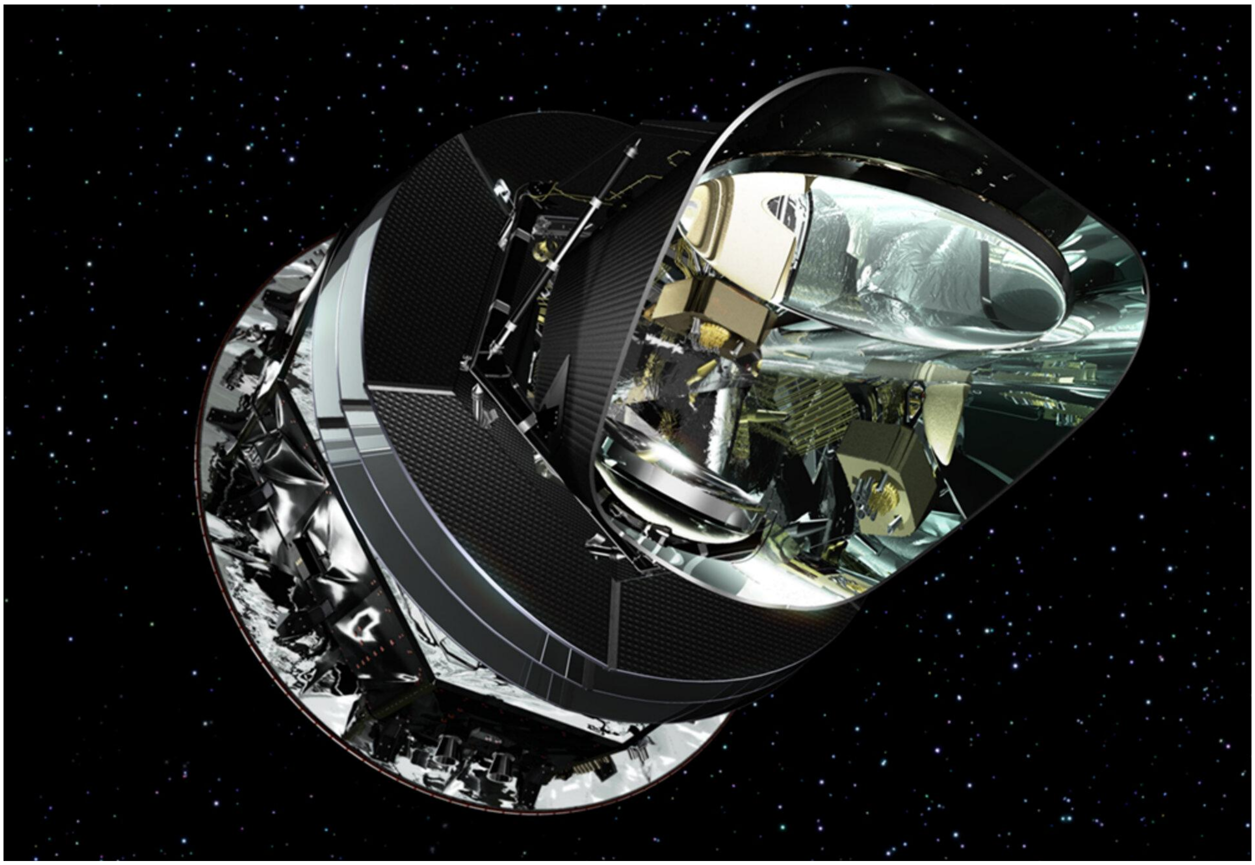


Cosmic Microwave Background

Although this ancient light is visible today, it has been stretched into radio waves due to the Universe's expansion, a process discovered literally by chance in the 1960s. The subtle temperature variations resulting from the cosmic tug of war between gravity's pull and the outward push of radiation during the Universe's infancy are revealed in these radio signals, which offer glimpses into the early cosmos.

Scientists are able to determine how quickly the Universe expanded after the Big Bang by studying these temperature fluctuations. The Standard Model of Cosmology can provide valuable insights into the present expansion rate by incorporating this data. The Standard Model serves as one of our most comprehensive frameworks for understanding the Universe's origin, composition, and the phenomena we observe today.

However, this pursuit has a big problem. Astronomers have a hard time figuring out the Hubble Constant by watching how nearby galaxies move away from us. These measurements show results that are different from those that were derived from earlier observations. Wendy Freedman says that if the standard model is correct, we should expect the values from current local measurements to match the values from earlier observations. Unfortunately, there is no such agreement.



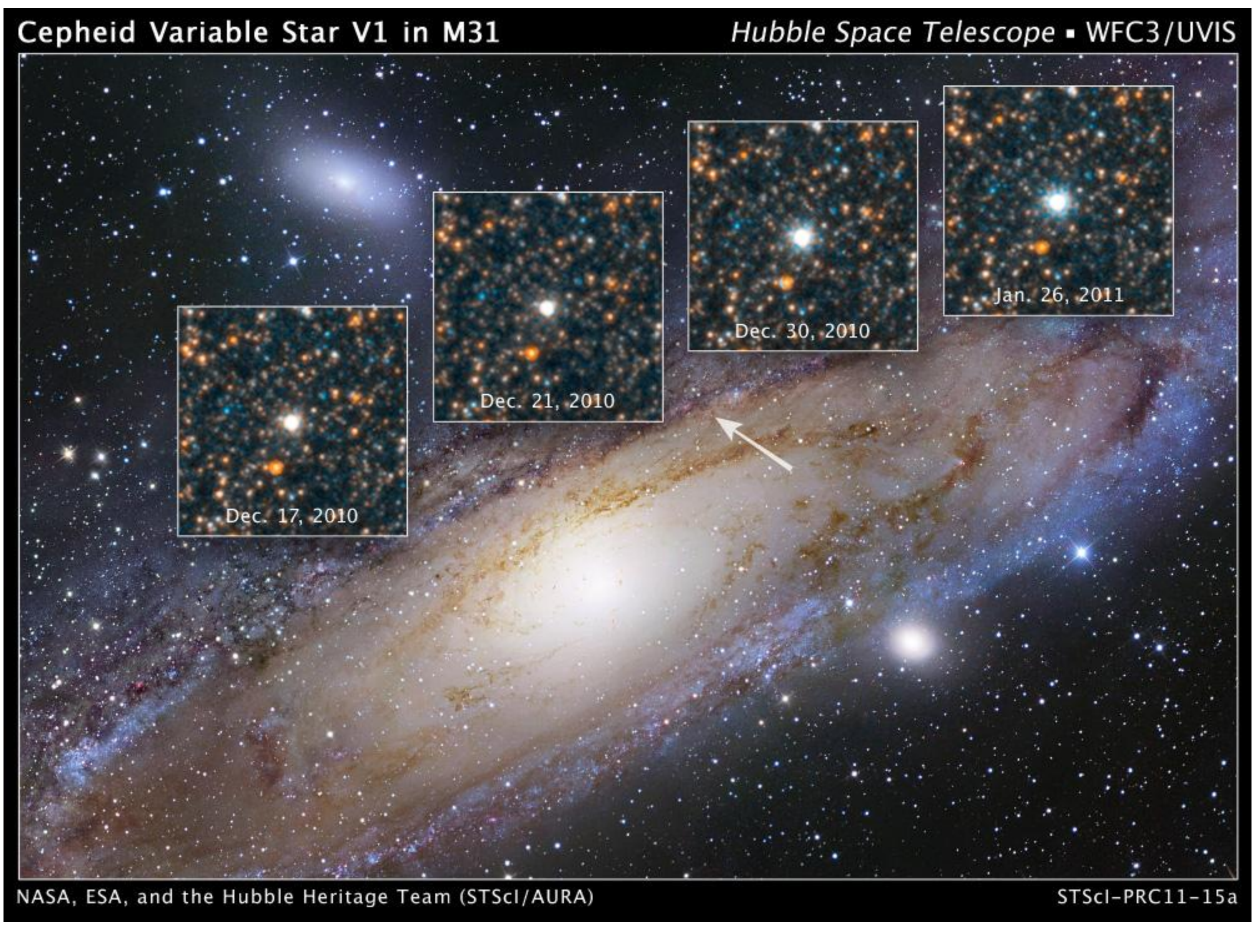
In 2014 and again in 2018, the Planck satellite of the European Space Agency studied the Cosmic Microwave Background and determined a Hubble Constant value of 41.9 miles per second per megaparsec, which is approximately 9% lower than the figures received by astronomers such as Freedman when studying nearby galaxies.

Subsequent CMB measurements in 2020 using the Atacama Cosmology Telescope matched with Planck's data, reducing the probability of systematic issues with Planck. As Rachael Beaton puts it, *“This helps to rule out that there was a systematic problem with Planck from a couple of sources.”* if the CMB measurements are true, it leaves two possible explanations: either the techniques used to measure the light from nearby galaxies were wrong, or the Standard Model of Cosmology needs to be revised.

Wendy Freedman and her coworkers use a method that uses Cepheid variable stars. These stars, which were discovered by Henrietta Leavitt approximately a century ago, display fluctuations in brightness, changing between fainter and brighter phases over days or weeks. Leavitt observed a correlation between the brightness of a star and the duration required to complete its brightness cycle.

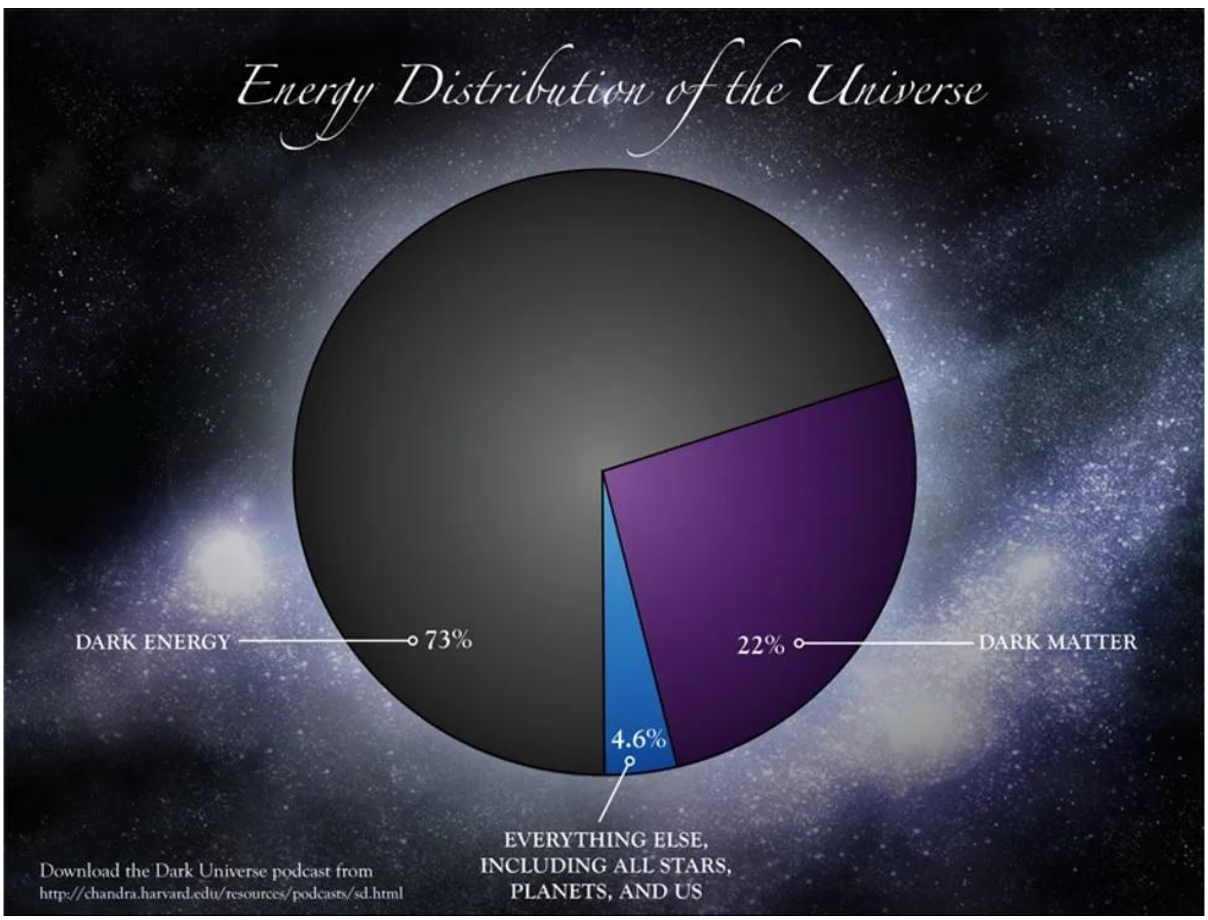
Today, astronomers are able to precisely determine a star's true brightness by analyzing brightness fluctuations. This allows them to calculate a star's distance accurately by measuring its apparent brightness from Earth and considering how light dims over distance.

The team led by Freedman pioneered the use of Cepheid variables in nearby galaxies to measure the Hubble Constant, using data from the Hubble Space Telescope. In 2001, their measurements placed it at 44.7 miles per second per megaparsec.



Since then, the value derived from the study of local galaxies has been relatively stable. In 2019, another group used the Hubble Space Telescope to study the same types of stars. They found out that the speed of the stars was 46 miles per second per megaparsec. A few months later, a distinct team of astrophysicists employed a technique that used the light emitted by quasars, resulting in a velocity of 45.3 miles per second per megaparsec.

If these measurements are right, it could mean that the Universe is expanding faster than what the Standard Model of Cosmology says. This model, which is our most complete way of describing the Universe, might need to be modified if something unexpected happens. While certainty is not available at this point, the implications could be profound if confirmed.' Wendy Freedman reveals, *"It could be telling us something is missing from what, we think, is our standard model. We don't yet know the reason why this is happening, but it's an opportunity for a discovery."*



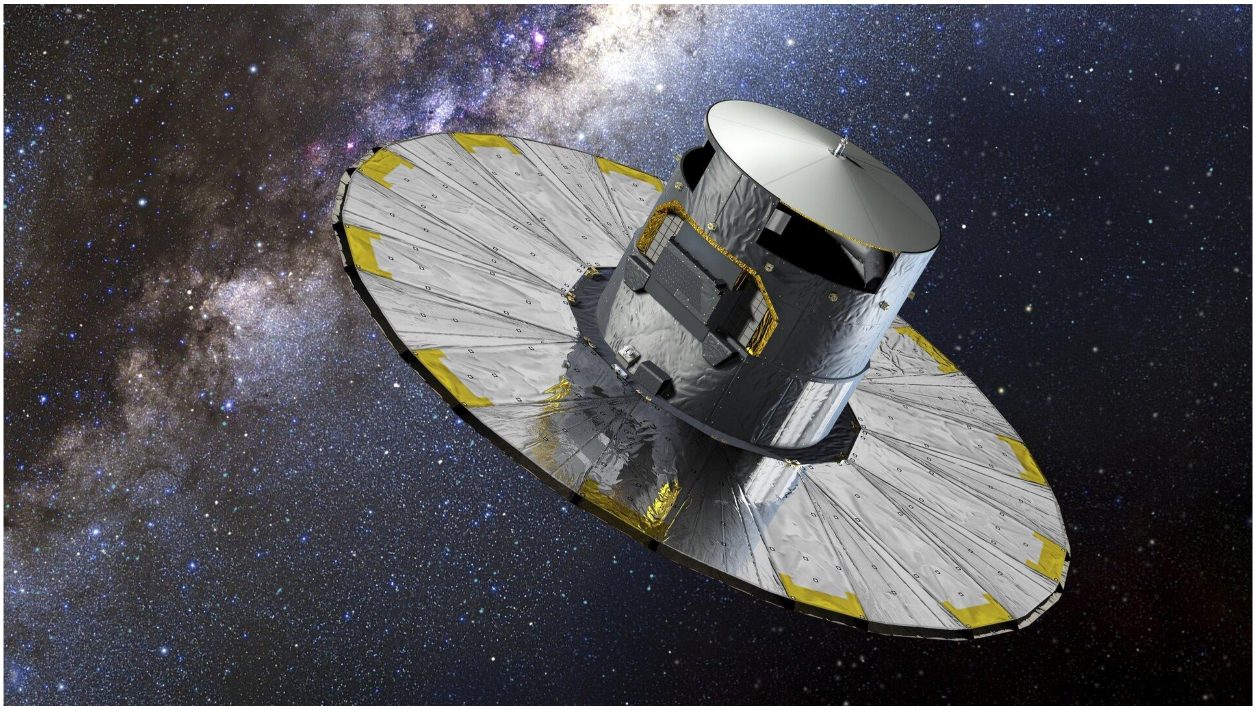
Should the Standard Model be found to be incorrect, it raises the possibility that our current models of the Universes composition, covering the proportions of baryonic which is normal matter, dark matter, dark energy, and radiation, may require modifications. Also, if the Universe is expanding at a faster rate than previously thought, it could mean a new age estimate, possibly different from the current estimate of 13.8 billion years.

Another explanation for the observed inconsistency is that the part of the Universe we live in might have special characteristics or characteristics that are different from the rest of the cosmos. This uniqueness could cause measurements to be distorted.

Rachael Beaton gives an example, but it's not perfect. Think about how your car's speed or acceleration can change when you go uphill, even if you keep pressing the gas pedal. It's unlikely that the Hubble Constant's values are the ultimate cause, but it's important to acknowledge and respect the hard work that went into getting these results.

Astronomers think they are getting closer to figuring out the true value of the Hubble Constant and which measurement is accurate. Freedman reveals, *“What's exciting is I think we really will resolve this in fairly short order, whether it's a year or two or three. There are so many things that are coming on the horizon that will improve the accuracy with which we can make these measurements that I think we will get to the bottom of this.”*

The European Space Agencies Gaia space observatory, which was launched in 2013, is a good tool for this. Gaia carefully tracks the positions of around one billion stars. This helps scientists figure out how far away they are from each other using a technique called parallax. It uses Gaia's changing position as it goes around the Sun.

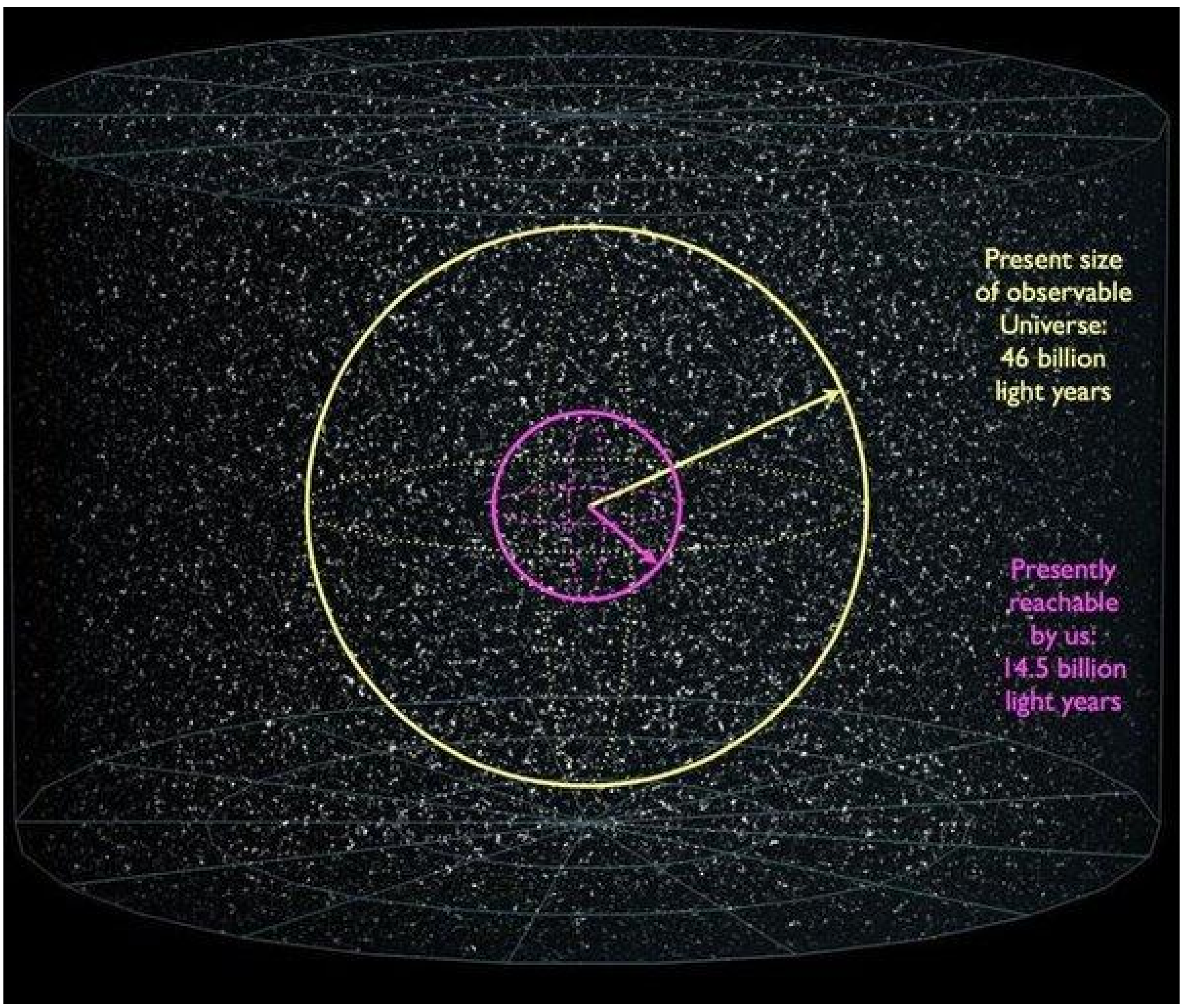


Like looking at an object with one eye and then the other, Gaia's shifting perspective lets researchers figure out how fast stars are moving away from our Solar System by studying them at different points in its orbit. One other asset set that could contribute to resolving the Hubble Constants value is the James Webb Space Telescope. It operates in the infrared spectrum, which promises more precise measurements without the interstellar dust between us and the stars.

If the Hubble Constant continues to differ, it will require a re-evaluation of our current understanding of physics. Several theories have been proposed to explain this distinction, but none of them match up with what we've been able to see. Each possible explanation has its own limitations, of course. For example, it seems unlikely that another type of radiation existed in the early universe because of how precise our Cosmic Microwave Background measurements are. Another theory suggests that dark energy might change over time.

Wendy Freedman reveals, *"That looked like a promising avenue to pursue, but now there are other constraints on how much the dark energy could change as a function of time. You'd have to do it in a really contrived way and that doesn't look* *very promising."* An alternative conjecture proposes the existence of dark energy in the early universe that subsequently vanished, yet there is no apparent rationale for such an occurrence.

So, scientists have had to come up with new ideas to explain what they've seen. Freedman further reveals, "*People are working really hard at it, and it's exciting. Just because no one's realized what, the explanation, is yet doesn't mean that there won't be a good idea that will emerge."* Depending on the discoveries made by these advanced telescopes, Rachael Beaton and Wendy Freedman may find themselves caught in a mystery similar to that of an Agatha Christie novel.

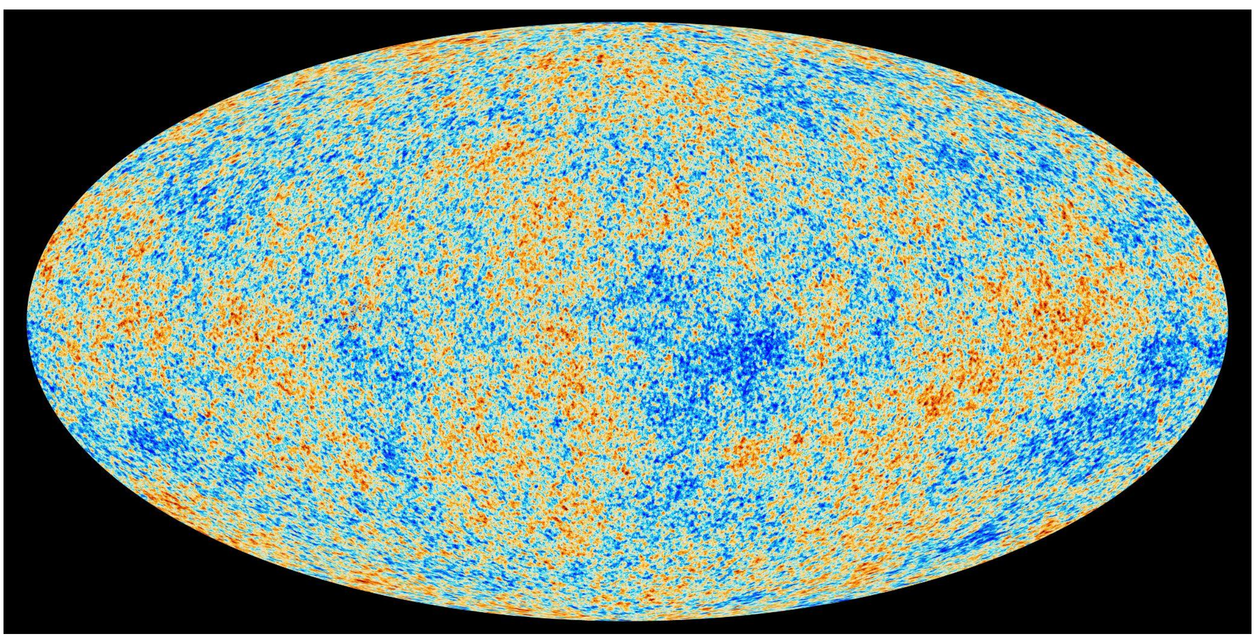



One question that still remains is: what lies beyond this limit, in the unobservable Universe?

The Universe may be much larger than what we can currently observe. If we think about the possibility of a spatial curvature and the uncertainty of the curvature parameter, the Universe could be at least 23 trillion light years in diameter and contain a volume over 15 million times bigger than our observable part.

One thing that is interesting is that the Universe is not limited by its size today. It covers its entire history, from the early stages to the cool and clumpy state we see today. As we gaze into the cosmos, we are privy to distant objects and able to retrace our steps through time, owing to the limited speed of light. Distant regions appear to be far away and ancient, showing how the Universe has changed over billions of years.

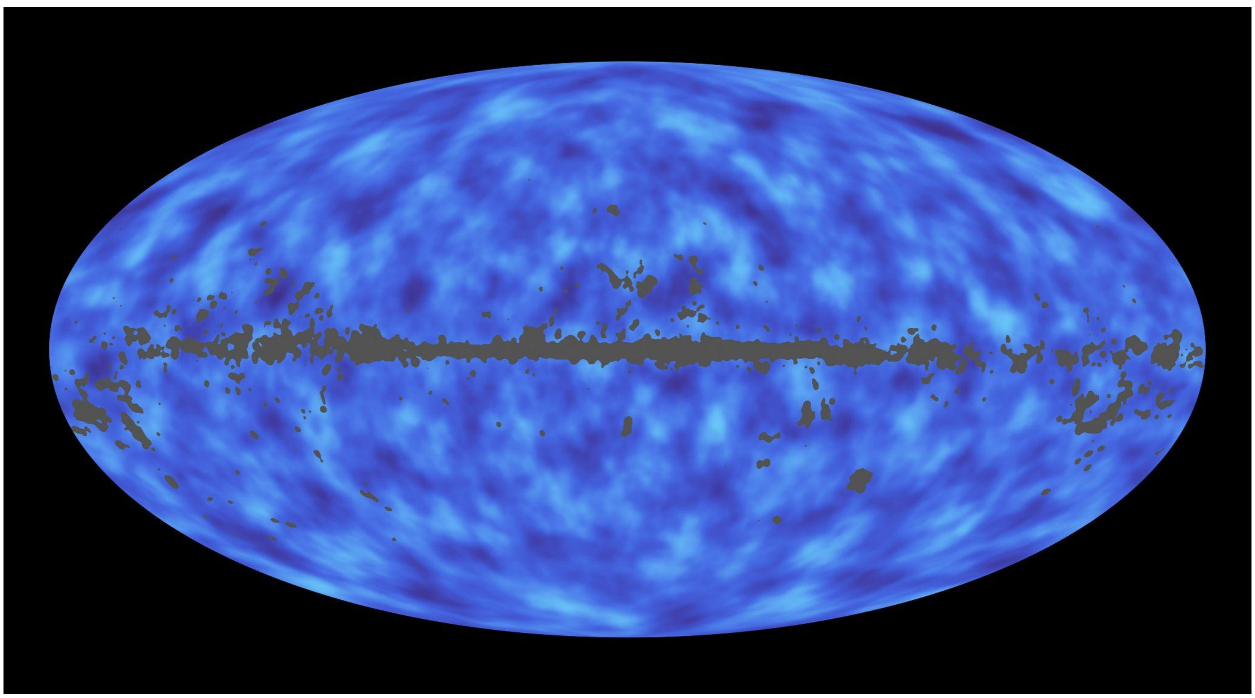
The early universe was considerably hotter, and as it expanded, the wavelength of light began to stretch, causing it to lose energy and cool down. It is evident in the cosmic microwave background, a remainder of the early universes hot, dense state. Today, this radiation is a blackbody spectrum with a temperature of 2.725 Kelvin, which confirms the predictions of the Big Bang model.



Observable Universe Heat map

To understand the true size of the universe, we must examine its past. The expansion of the Universe led to the stretching of light waves, which reduced their energy. We trace back in time and discover that the Universe was far hotter and denser. At just 0.092% of its current size, the Universe reached temperatures of around 3000 Kelvin, turning all matter into an ionized plasma.

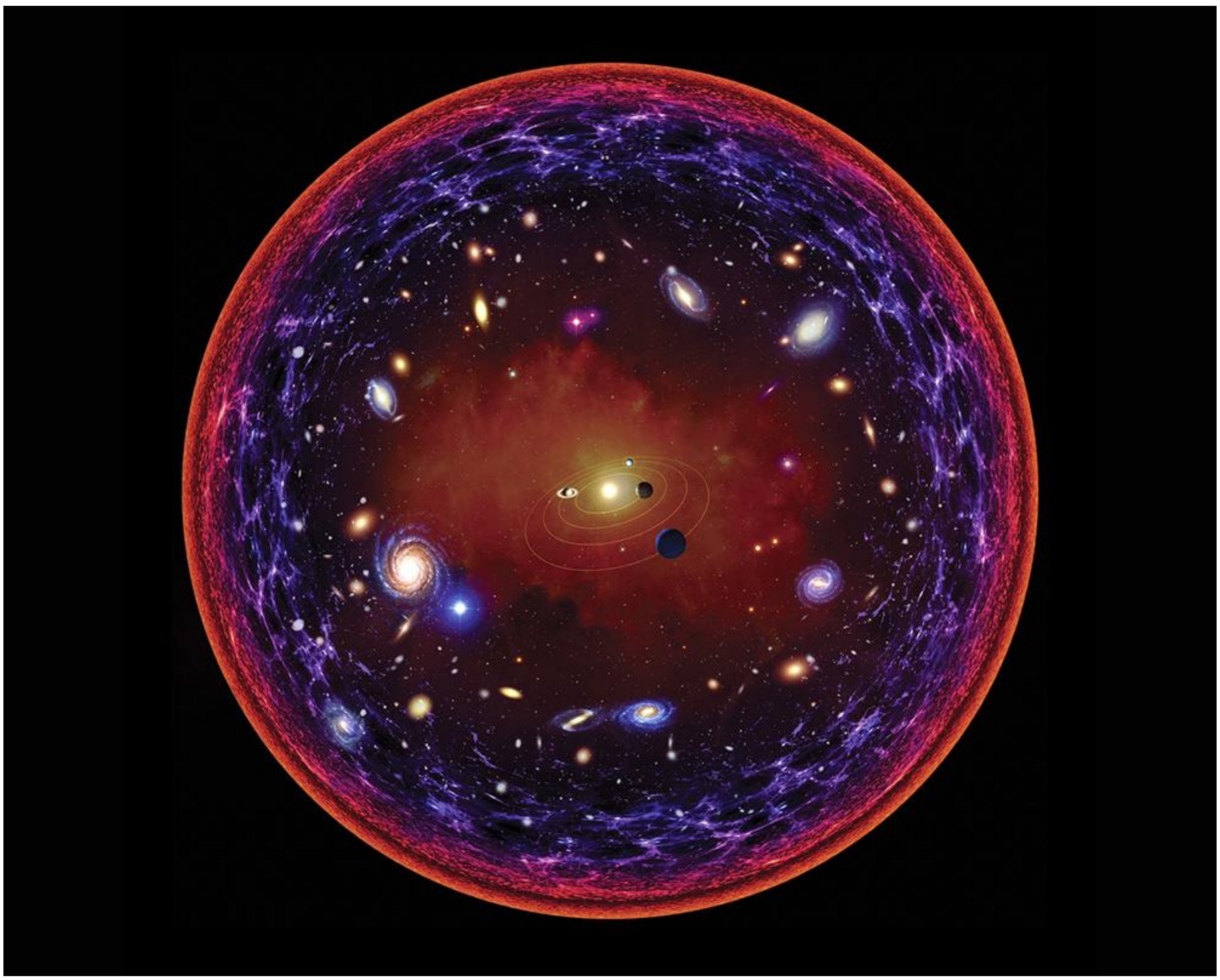
The size of the Universe is connected to its history and how it was made. Observations from different places like the Cosmic Microwave Background, supernovae, big structures, and baryon acoustic oscillations give us a complete picture of our Universe. The sum of these numbers suggests that the universe we observe, 13.8 billion years old since the Big Bang, covers a radius of 46.1 billion light years as we mentioned earlier.



But we still don't know what's beyond our current view. The principles of physics, as comprehended by us, govern the behavior and structure of our Universe. Our observations indicate that the Universe is flat on its biggest scales and that it doesn't change direction more than 0.25% If we assume that our current laws of physics are true, we can estimate a lower limit for the size of the Universe that cannot be seen. This means that it must be at least 250 times bigger than the Universe we can see, which is about 23 trillion light years. In addition, we can think that the Universe we can't see might be even bigger than this lower limit.

Our understanding is further complicated by the concept of cosmic inflation. Before the Big Bang, the Universe underwent a period of rapid expansion, commonly referred to as inflation. During this phase, space grew exponentially, creating new space at an amazing rate. The duration and effects of inflation are still unclear, which leads to important questions.

What size was the region that started the hot Big Bang after inflation? Does the idea of “eternal inflation” hold true, meaning that some regions keep growing? How long did inflation last before it changed to the hot Big Bang phase?



The answers to these questions have a critical impact on our perception of the size of the Universe. The region where inflation happened may have been only slightly bigger than our observable Universe, or evidence for an “edge” to inflation could come out soon. Conversely, the Universe might be vastly larger than our observations can currently recognize.

Even though we are keen to learn more, we can't understand everything in the Universe completely right now. Our universe, which spans 46 billion light years in all directions, serves as our cosmic vantage point. The existence of the Universe in its entirety, regardless of its finite or infinite nature, remains a matter of debate, yet our access remains restricted to a finite portion.

In our quest to figure out this cosmic mystery, we have to go beyond our observational abilities. Until we find ways to expand our understanding or figure out the Universes secrets, the true nature of its size will remain a mystery.

We might never know what the true size of our universe really is, but we’re certain to keep trying. If meticulous research and development of newer technologies continue to prosper, we're most definitely rooted to find out. While our very solar system, and galaxy has more questions than answers, let alone the rest of the universe, we're certain to unravel most of those mysteries.

It might also boil down to perception, and new ways to crack the code that's missing. Maybe it isn't so much about looking at the bigger picture, rather that the answers to the universe might just be evident on our home planet. The concepts and discoveries yet to come can only enamor us for the future. Fasten your seatbelts because a whole new universe of answers is on its way.

***So what do you think? Is the universe infinite? Or has it always been static? And will we ever know the true expanse of the universe? Let us know in the comments below. Consider subscribing to the channel and hitting like on this video if you enjoyed it. As always, thanks for watching, and we'll see you in the next one!***

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