

how big is our universe?

[an exploration through space and time]

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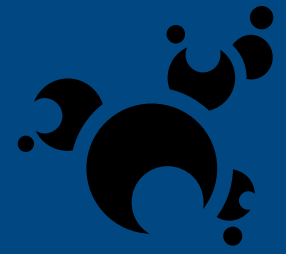
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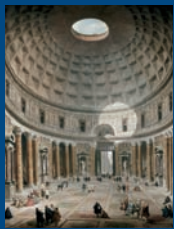
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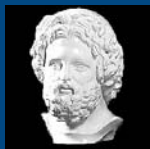
how far away?

On a beautiful, clear night, the stars seem so close you could almost reach out and touch them. How far away are the stars? What lies beyond them? How large is the universe as a whole?



Without knowing distances, the sky is just a starry bowl over our heads – like the dome of a planetarium. If we can figure out the distance to the stars, we will begin to see what the universe looks like in three dimensions, and we will begin to answer some of the greatest of questions: How old is the universe? Is it infinitely large? What is our place in the cosmos?

This booklet shows how generations of explorers have taken us, step by step, ever further into the vast expanse of the universe. It is a journey of discovery that has only just begun.



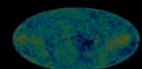
Third century BC. Aristarchus of Samos measures the distance to the Moon by looking at the shadow of the Earth during a lunar eclipse.

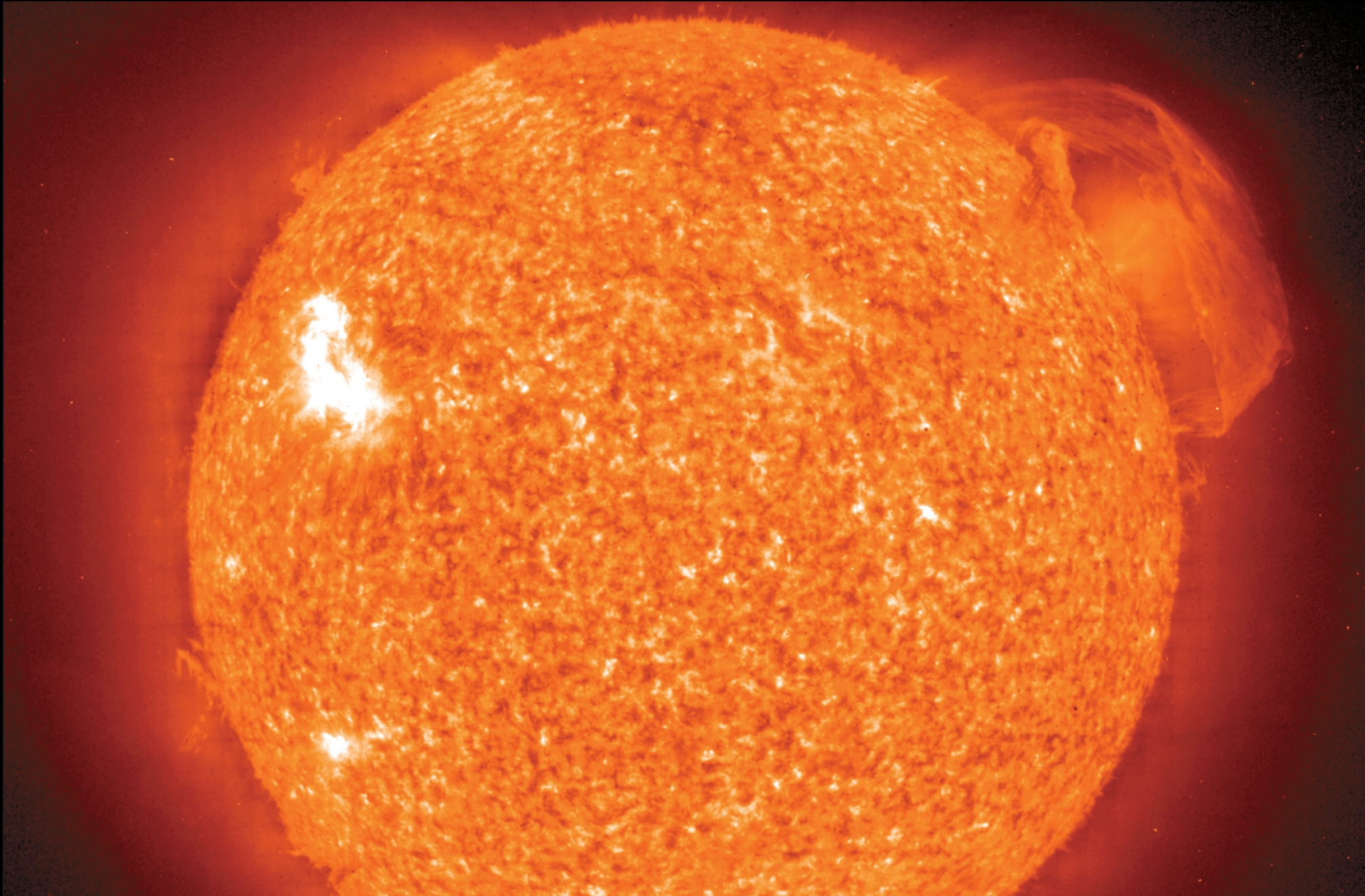
imagine this:

This composite image shows all the places in the universe that humans have been to.

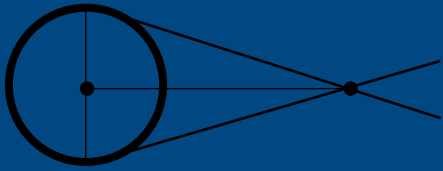


Our view starts here.





Our Sun is the nearest star. At 93 million miles, the Sun provides the warmth that has allowed life to evolve on Earth. Has life evolved elsewhere?



how far are the sun and planets?

The Sun is so far away that it would take the Space Shuttle seven months to fly there. That's why the Sun, which is one hundred times the diameter of the Earth, looks so small!



Three hundred years ago, astronomer **Edmund Halley** found a way to measure the distance to the Sun and to the planet Venus. Knowing these distances helped find the true scale of the entire solar system for the first time.

Halley knew that every 121 years the planet Venus passes in front of the Sun. Venus' position, relative to the Sun behind it, appears very different when viewed from two different places on Earth. How different depends on how far away Venus and the Sun are from the Earth.



1761. Using observations of the "transit of Venus" made by astronomers around the world, the distance to the Sun is determined to be 93 million miles. This photograph is from the 1882 transit of Venus.



try this:

your "point of view" makes a difference!

Hold up your thumb at arm's length. With one eye closed, line up your thumb with an object in the distance. Now switch eyes so that only the other eye is open. Does your thumb suddenly change position? Move your thumb closer to your nose and try again. Can you see your thumb jump even more?

Astronomers call this effect "parallax." The closer an object, the more it appears to shift against the distant background, when viewed from two different spots.

The furthest human object is the space probe Voyager 1. Launched in 1977, it is now more than twice as far from the Earth as Pluto.





The Pleiades star cluster is 400 light years away. One light year is 6 trillion miles. The blue veil is starlight reflecting off dust that envelops the cluster.



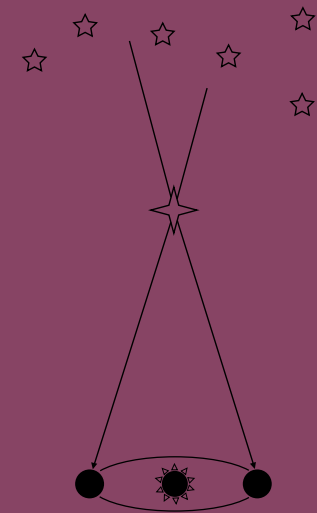
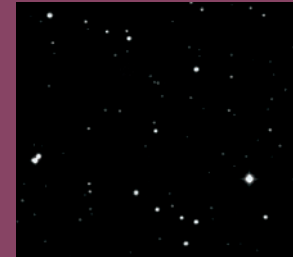
how far are the stars?

Traveling to the stars? Don't pack for a week or a month. Pack for 70,000 years – the travel time to the nearest star beyond our Sun using our fastest spaceship!

As the Earth moves around the Sun, our view of nearby stars changes slightly against the background of other stars that are further away. Astronomers use this effect, called parallax, to determine the distance to the nearest stars.



1836. German scientist **Friedrich Bessel**, using a specially designed telescope, is the first to see a star's position appear to change as the Earth moves around the Sun. He finds the star to be 700,000 times further away than our Sun!

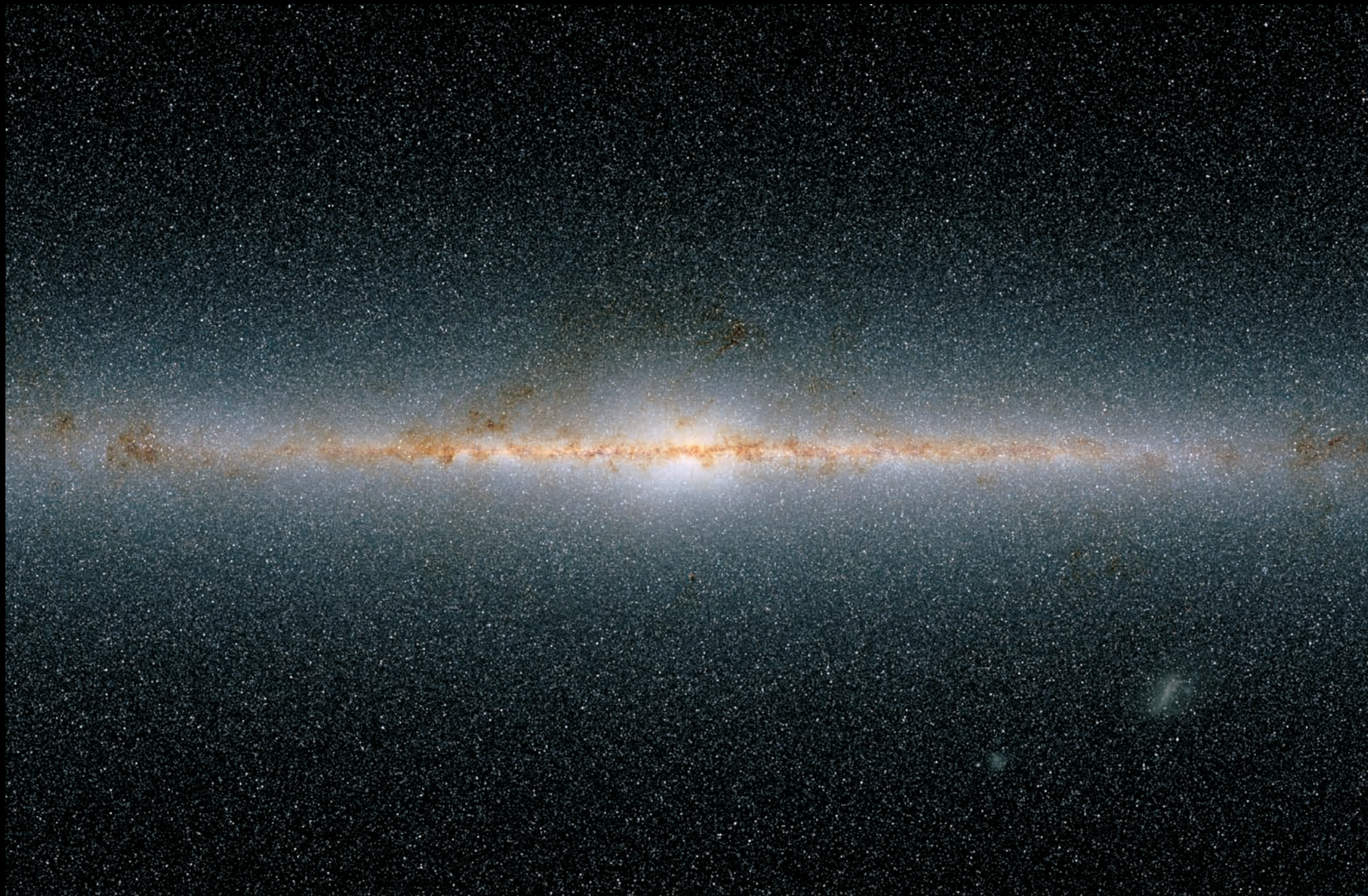


try this: jumping stars

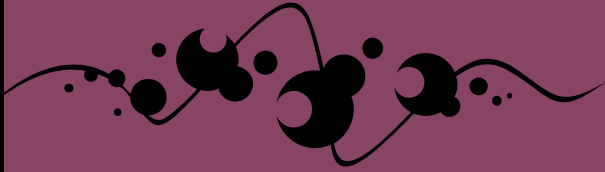
These pictures were taken six months apart, when Earth was on opposite sides of its orbit. Can you tell which star is closer than the rest? Look for the star that appears to change position, like your thumb when seen from two points of view.

Deneb, in the constellation Cygnus, is one of the most distant stars you can see by eye. It takes light from Deneb 1600 years to reach us.





This view toward the center of our galaxy shows the Milky Way as an immense city of stars. Our Sun and all the stars in the night sky are its residents.



how far is it across the milky way?

Our Milky Way galaxy of stars is so huge that even at the speed of light it would take 100,000 years to travel across it!

The further a star, the fainter it looks. Astronomers use this clue to figure out the distance to very distant stars. But there's a big challenge to this method: You need to know the star's "wattage" – how bright it really is – to begin with.



1908. Henrietta Leavitt discovers a way to tell the "wattage" of certain pulsating stars by observing how long it takes them to brighten and dim. The method opens the way to measuring distances all the way across the Milky Way galaxy.



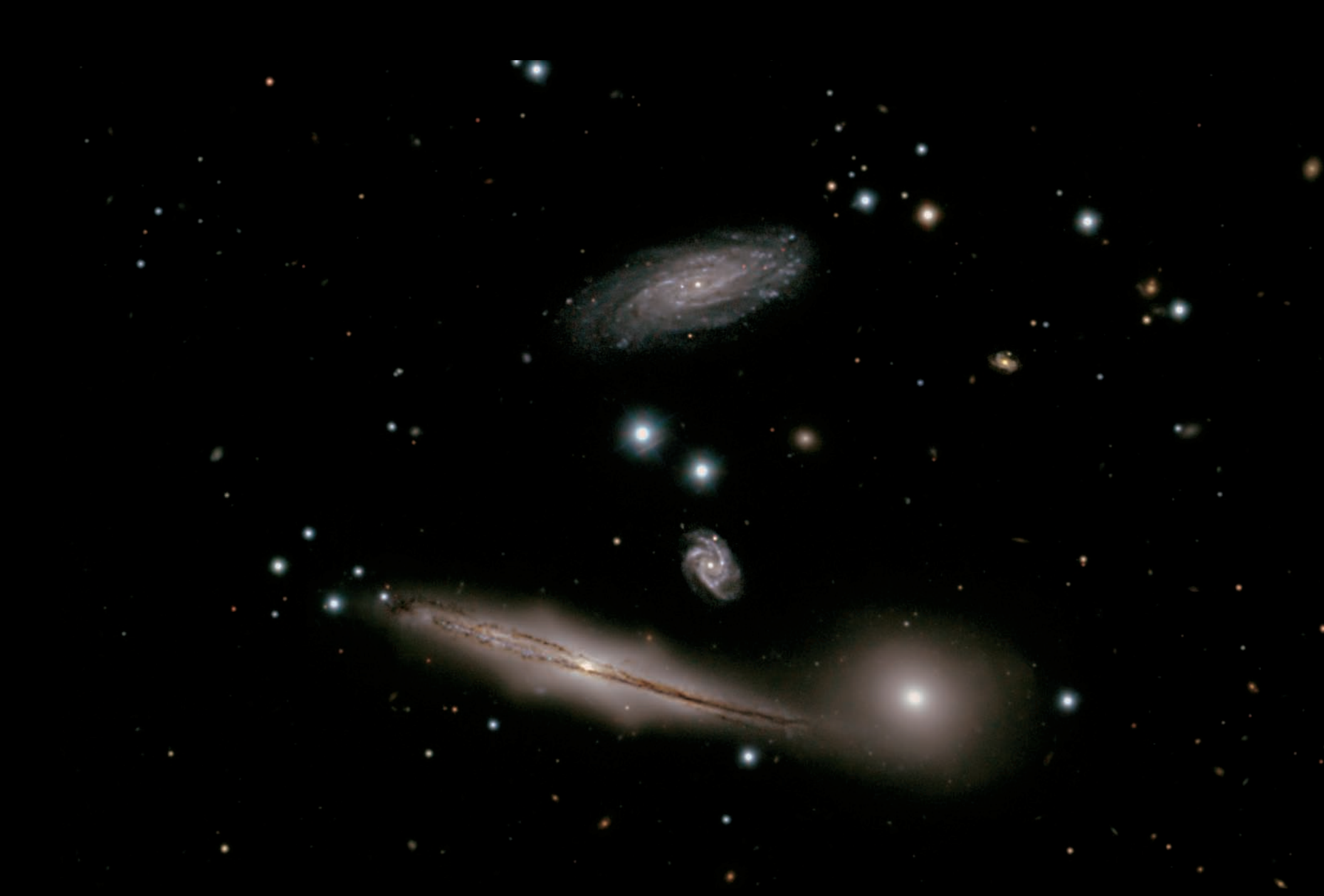
making a mental model: how big is the milky way?

Imagine that our entire solar system were the size of a quarter. The Sun is now a microscopic speck of dust, as are its planets, whose orbits are represented by the flat disc of the coin.

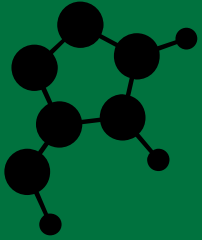
On this scale, the diameter of our Milky Way galaxy will be about the size of the United States! How far away is the nearest star to our Sun? In our model, Proxima Centauri (and any planets that might be around it) would be another quarter, two soccer fields away. This is the typical separation of stars in our part of the galaxy.

Our solar system is about 2/3 of the way from the center of our Milky Way galaxy.





These galaxies — a group called HCG 87 — are a few of the billions of galaxies discovered beyond our Milky Way.



how far are other galaxies?

Even “nearby” galaxies beyond our own Milky Way galaxy are so far that it takes their light millions of years to reach us. The images we take today show how these galaxies looked millions of years ago.

The further a galaxy, the smaller it appears. You can use this method to get a rough idea which galaxies are closer and which are further. Although galaxies come in different shapes and sizes, the spiral galaxies similar to our own Milky Way are thought to be roughly the same size. So if a spiral galaxy looks half as big as another, it is probably twice as far away.



1924. Edwin Hubble presents the first evidence that galaxies lie far beyond the Milky Way. To date, billions of galaxies have been discovered.



try this: far and small

You’ve been asked to award a prize to the balloon that has traveled the furthest from the starting line. But you have only this photo taken from the starting line to go on.

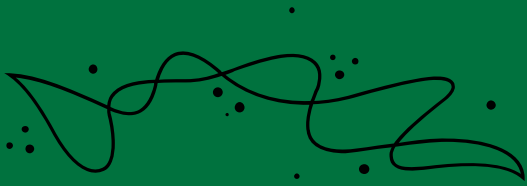
What clues will you use? How do you know that the balloons that look smaller are further away and not just smaller balloons? Which balloon would you choose, and why? Astronomers face the same challenges trying to determine the distance between galaxies.

The furthest thing you can see by unaided eye is the Andromeda Galaxy, the nearest large galaxy to our Milky Way. Light from Andromeda takes 2 million years to reach us!





The deeper we see into space, the more galaxies we discover. Only a few points of light in this image come from stars in our own Milky Way; everything else is a distant galaxy.



how far are the distant galaxies?

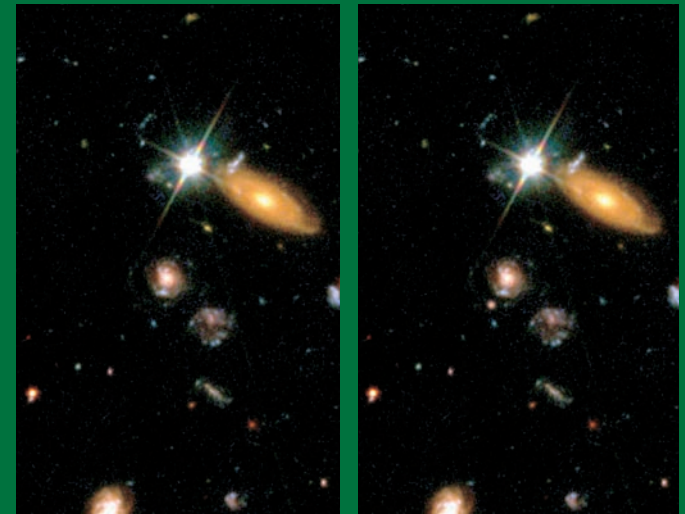
They're so far that the light arriving on Earth today set out from the galaxies billions of years ago. We see the galaxies not as they are today, but as they looked long before there was life on Earth.

Some galaxies are so far away that they appear as tiny smudges, even through the largest telescopes. It's tough to determine how large or bright these fuzzy distant galaxies are. But astronomers can figure out the distance to these galaxies, by watching for incredibly bright exploding stars called supernovae.

Some types of supernovae have a known brightness – or “wattage” – so we can figure out how far they are, and therefore the distance to their home galaxy.



1986. Astronomers begin to use supernovae to find the distance to the furthest galaxies we can see.



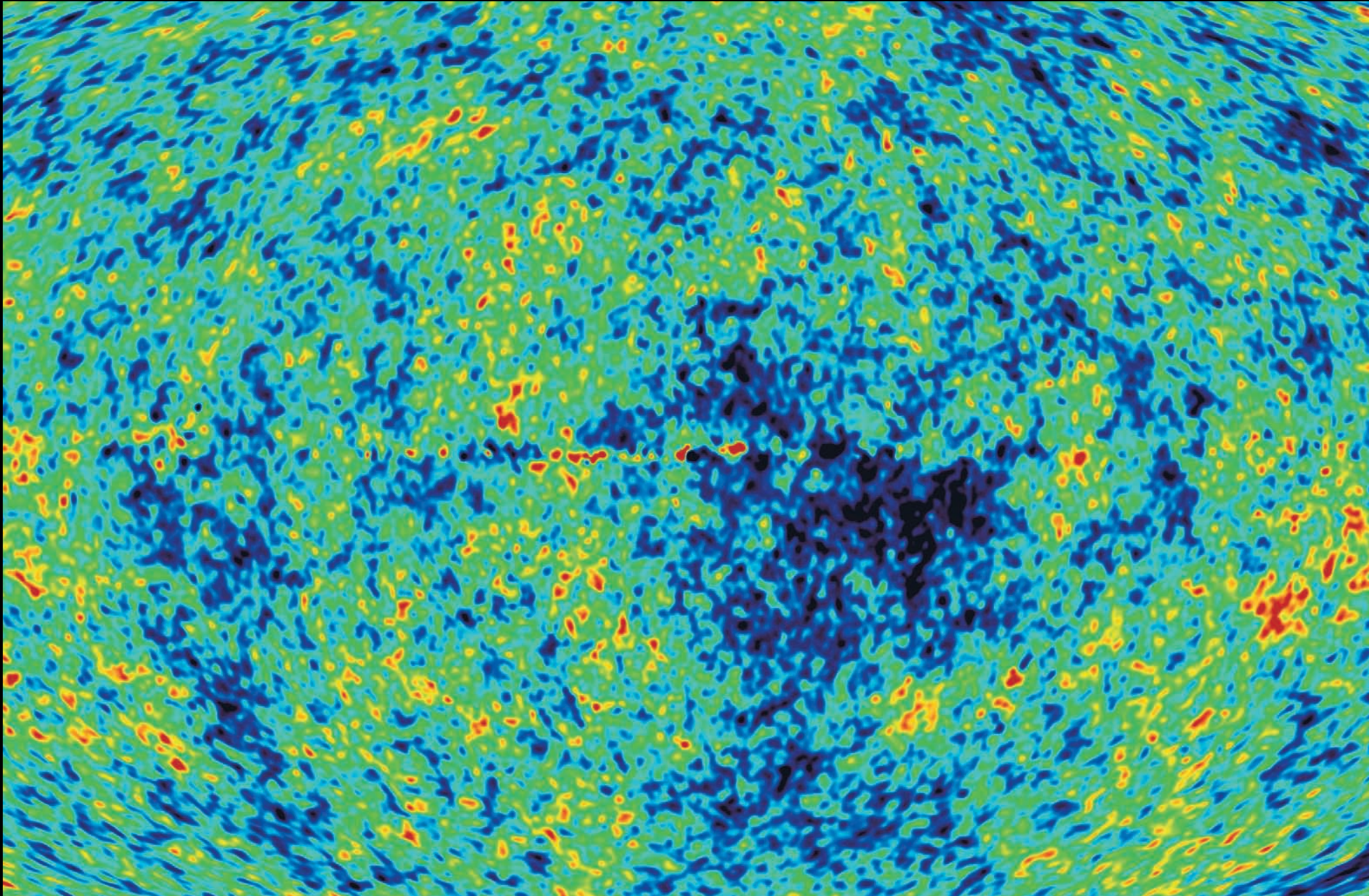
try this:

can you spot the exploding star?

The picture on the right was taken three weeks after the one on the left. In that time, a star at the edge of one of these distant galaxies has exploded — “gone supernova.” Can you spot the supernova in the picture at right? Even though the explosion is as bright as a billion suns, it is so far away that it is just a speck of light!

Light from the furthest galaxies we can see has taken more than ten billion years to reach us!





The furthest we can see (image colorized and enhanced). The patterns show clumps of matter that will eventually form galaxies of stars.

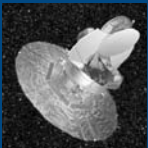


how far can we see?

Time, not space, limits our view of the universe. Beyond a certain distance, light hasn't had time to reach us yet since the beginning of the universe.

The image at left is the oldest and youngest picture of the universe ever taken. Oldest, because it has taken the light nearly 14 billion years to reach us. Youngest, because it is a snapshot of our newborn universe, long before the first stars and galaxies formed. The bright patterns show clumps of simple matter that will eventually form stars and galaxies.

Although this light fills the entire night sky, it is so faint and has so little energy that it is detectable only with special instruments. This colorized image was taken by NASA's Wilkinson Microwave Anisotropy Probe.



2003. NASA's WMAP satellite takes images of the most distant part of the universe observable from Earth. The image shows the furthest we can see using any form of light.



making a mental model: how big is the universe that we can see?

Imagine that our entire Milky Way galaxy were the size of a CD. On this scale, the nearest spiral galaxy, Andromeda, would be another CD about eight feet away.

The furthest galaxies we have ever seen, pictured in the Hubble Ultra Deep Field above, would be CDs about nine miles away. The edge of the observable universe, the furthest we can possibly see, is only another mile beyond that.

The universe of 14 billion years ago was so hot and dense that living then would have been like living *inside* the Sun!





New telescopes on Earth and in space will continue to expand our view of this magnificent universe.



how big is the universe?

No one knows if the universe is infinitely large, or even if ours is the only universe there is.

Although our view of the universe is limited, our imaginations are not. Astronomers have indirect evidence that the universe of galaxies extends far beyond the region we can see. But no one knows if the whole universe is infinitely large — large beyond limit.

According to the leading theories, other parts of the universe may look very different from our own — and may even have different laws of nature. We may never be able to find out for sure. But it is possible that clues to the answer lie in plain view, just waiting to be discovered!



The Future. NASA's LISA mission will look for ripples in the fabric of space, predicted by Albert Einstein. Such clues may help refine theories about what the rest of the universe is like.



try this: picturing your local universe

Is the view from your window typical of planet Earth?

Is there any thing that would suggest the Earth is flat or round?

Is there anything that gives you a clue that the larger world may be very different?

There is a limit to what we can see, but is there a limit to what we can understand?

$$d\tau^2 = dt^2 - R^2(t) \left\{ \frac{dr^2}{1 - kr^2} + r^2 d\theta^2 + r^2 \sin^2 \theta d\phi^2 \right\}$$

credits

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A web version of this booklet can be found at: <http://www.universeforum.org/howfar>

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Distant supernova, NASA and Adam Riess (STScI)

Cosmic Microwave Background, NASA/WMAP Science Team

3



The Sun

An image of the Sun taken in ultra-violet light by the Solar and Heliospheric Observatory (SOHO) satellite. The picture shows a large eruption of gas, called a prominence, in the upper right. Such eruptions create the beautiful aurorae, but can also disrupt communications and power grids.

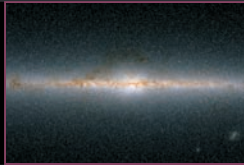
The Stars

The Pleiades or "Seven Sisters" star cluster photographed from UK Schmidt plates by David Malin. The cluster is made up of several thousand stars, of which only the brightest seven can be seen by eye. Light from the Pleiades takes about 400 years to reach us.



5

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The Milky Way

A picture of our Milky Way galaxy taken in infrared light as part of the 2 Micron All-Sky Survey (2MASS). Infrared light can make it through all the clouds of dust that fill our galaxy, giving us a clear view of over half a billion stars.

The Nearby Galaxies

Hickson Compact Group #87 photographed by the Gemini South Telescope. HCG 87 is a small group of galaxies bound together by gravity. It has taken light from these galaxies 400 million years to reach us. Some of the smaller galaxies in the picture are much further away and not part of the group.



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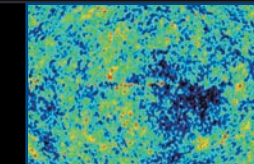


The Distant Galaxies

This image, taken by the Hubble Space Telescope, is among the deepest images of the universe ever taken. The faintest and reddest objects in the image are galaxies that formed early in the universe's history, 600 million years after the Big Bang.

The Cosmic Microwave Background

A snapshot of the universe when it was 300,000 years old taken by the Wilkinson Microwave Anisotropy Probe (WMAP) satellite. The photograph was taken in microwave light (radio waves), which are invisible to our eyes. The color has been added so we can see which regions are slightly hotter (red) and slightly cooler (blue).



13

15



Gemini Telescope

The Gemini North Telescope is located on Mauna Kea in Hawaii. It is one of the largest telescopes in the world, with a mirror over 26 feet across. Behind it rises the dusty band of light we call the Milky Way.



Produced by the NASA-SAO Education Forum on the Structure and Evolution of the Universe.
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