

The Evolution of the Universe

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Last Updated 2013-7-14

Note: In PDF format most of the images in this web paper
can be enlarged for greater detail.

“If being educated means having an informed sense of time and place, then it is essential for a person to be familiar with the scientific aspects of the universe and know something of its origin and structure.”

Project 2061, American Association for the Advancement of Science

"The effort to understand the universe is one of the very few things that lifts human life a little above the level of farce, and gives it some of the grace of tragedy." —Steven Weinberg

Steven Weinberg is winner of the Nobel Prize in Physics in 1979, and author of the book "The First Three Minutes".

Introduction

Science at the beginning of the twenty-first century can make some bold, yet simple observations:

- 1) the universe has evolved;
- 2) we are a result of that evolution.

“We are the first generation of human beings to glimpse the sweep of cosmic history, from the universe's fiery origin in the Big Bang to the silent, stately flight of galaxies through the intergalactic night.” (National Research Council)

Order in the Universe

Cosmology is the study of the evolution of the universe from its first moments to the present. In cosmology the most fundamental question we can ask is: Does our universe have intelligible regularities that we can understand—is it ordered? This question lies at the heart of the scientific revolution beginning in the sixteenth century. That revolution began with the discoveries by Copernicus, Galileo, and Newton of order in our world. Today our scientific understanding of nature's order has reached a critical threshold. Only now can we begin to piece together a coherent picture of the whole. Only now can we begin to see the deep order of our universe.

“The evolution of the world can be compared to a display of fireworks that has just ended; some few red wisps, ashes and smoke. Standing on a cooled cinder, we see the slow fading of the suns, and we try to recall the vanishing brilliance of the origin of the worlds.” —Abbé Georges Lemaître

We now understand the order in our world by using the standard Hot Big Bang model of the evolution of the universe. The four key observational successes of the model are:

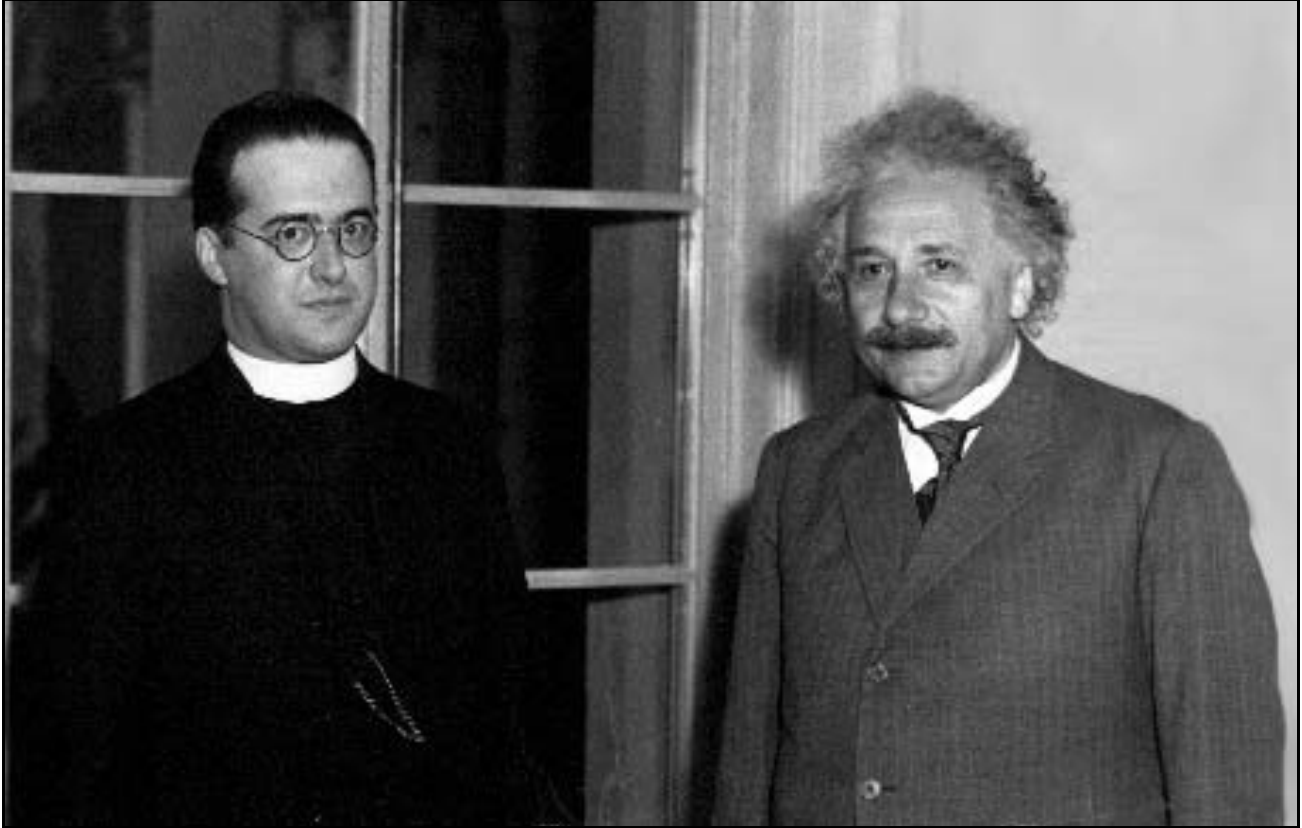
The Expansion of the Universe

Nucleosynthesis of the light elements

Origin of the cosmic background radiation

Formation of galaxies and large-scale structure

The Big Bang model makes accurate and scientifically testable hypotheses in each of these areas, and the remarkable agreement with the observational data gives us considerable confidence in the model.



Lemaître with Einstein

Abbé Georges Edouard Lemaître (1894 -1966) was a Belgian astrophysicist and Priest who developed an evolving cosmological model which indicated that the universe had begun in a "Big Bang."

Einstein's theory of general relativity, announced in 1916, had led to various cosmological models, including Einstein's own model of a static universe. Lemaître in 1927 (and, independently, Alexander Friedmann in 1922) discovered a family of solutions to Einstein's field equations of relativity that described not a static but an expanding universe. This idea of an expanding universe was demonstrated experimentally in 1929 by Edwin Hubble who was unaware of the work of Lemaître and Friedmann. Lemaître's model of the universe received little notice until Eddington arranged for it to be translated and reprinted in 1931. It was not only the idea of an expanding universe which was so important in Lemaître's work, on which others were soon working, but also his attempt to think of the cause and beginning of the expansion.

If matter is everywhere receding, it would seem natural to suppose that in the distant past it was closer together. If we go far enough back, argued Lemaître, we reach the "primal atom", a time at which the entire universe was in an extremely compact and compressed state. He spoke of some instability being produced by radioactive decay of the primal atom that was sufficient to cause an immense explosion that initiated the expansion.



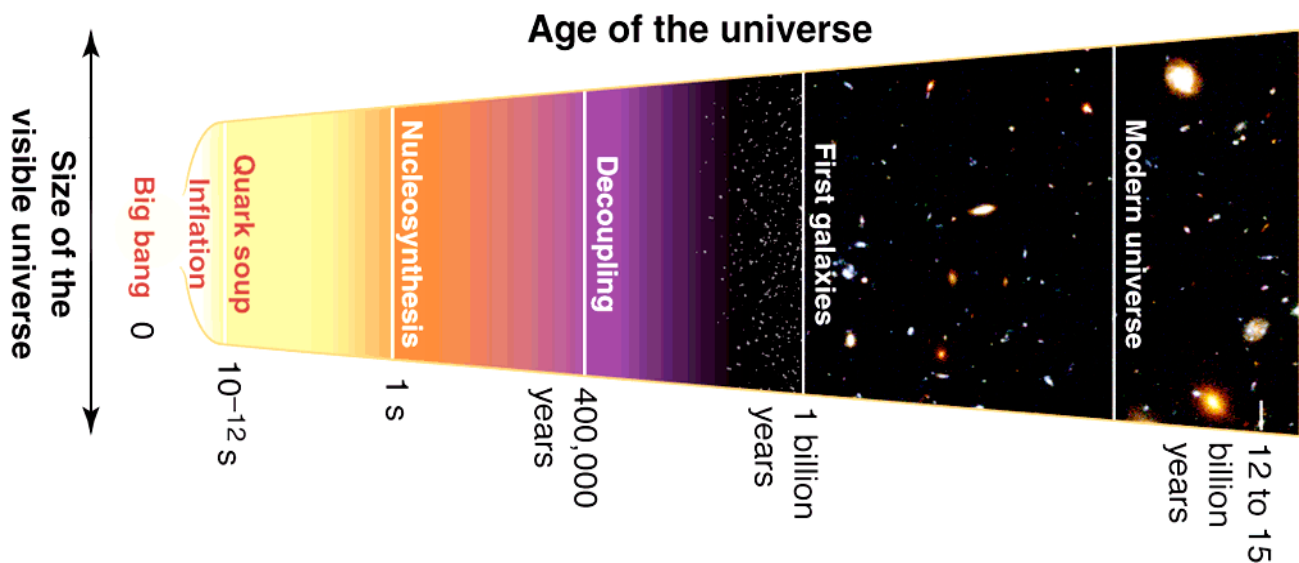
George Gamow (1904-1968)

Lemaître's Big-Bang model did not fit well with the available time scales of the 1930s. Nor did he provide enough mathematical detail to attract serious cosmologists. Its importance today is due more to the revival and revision it received at the hands of George Gamow and Ralph Alpher in 1948.

Web Reference for George Gamow:
http://en.wikipedia.org/wiki/George_Gamow

For an excellent history of the development of the Big Bang theory see:

Big Bang: The Origin of the Universe by Simon Singh (2004).
<http://www.npr.org/templates/story/story.php?storyId=4505414>



The Expansion of the Universe (1993)

As bizarre as it may seem, space itself is expanding—specifically, the vast regions of space between galaxies. According to Einstein, space is not simply emptiness; it's a real, stretchable, flexible thing. The notion that space is expanding is a prediction of Einstein's theory of gravity, which describes a simple but universal relationship between space, time, and matter.

In the late 1920's, the astronomer Edwin Hubble first observed that distant galaxies are moving away from us, just as would be expected if the space between galaxies were growing in volume and just as predicted by Einstein's theory of gravity. Since then, astronomers have measured this recession for millions of galaxies.



Galaxy NGC 3370, a spiral galaxy like our own Milky Way

The galaxies sit more or less passively in the space around them. As the space between galaxies expands, it carries the galaxies further apart—like raisins in an expanding dough. However, the universe is a chaotic place and the gravity from one galaxy, or from a group of galaxies, may disturb the motion of its near neighbors, causing them to collide. But on average, when you compare two large enough chunks of space, the galaxies in one are moving away from the galaxies in the other. Amazingly, space is not actually expanding "into" anything. Put another way, a given region of space doesn't actually "push" the rest of the universe out of the way as it expands.

Web Reference

<http://apod.nasa.gov/apod/ap030911.html>

(The following essay is from the *Universe Forum* produced for NASA by the Harvard Smithsonian Center for Astrophysics in 2004.)

The Big Bang “Theory”

The Big Bang is actually not a "theory" at all, but rather a scenario or model about the early moments of our universe, for which the evidence is overwhelming.

It is a common misconception that the Big Bang was the origin of the universe. In reality, the Big Bang scenario is completely silent about how the universe came into existence in the first place. In fact, the closer we look to time "zero," the less certain we are about what actually happened, because our current description of physical laws do not yet apply to such extremes of nature. The Big Bang scenario simply assumes that space, time, and energy already existed. But it tells us nothing about where they came from or why the universe was born hot and dense to begin with.

But if space and everything with it is expanding now, then the universe must have been much denser in the past. That is, all the matter and energy (such as light) that we observe in the universe would have been compressed into a much smaller space in the past. Einstein's theory of gravity enables us to run the "movie" of the universe backwards—i.e., to calculate the density that the universe must have had in the past. The result: any chunk of the universe we can observe—no matter how large—must have expanded from an infinitesimally small volume of space.

By determining how fast the universe is expanding now, and then "running the movie of the universe" backwards in time, we can determine the age of the universe. The result is that space started expanding 13.77 billion years ago. This number has now been experimentally determined to within 1% accuracy.

It's a common misconception that the entire universe began from a point. If the whole universe is infinitely large today (and we don't know yet), then it would have been infinitely large in the past, including during the Big Bang. But any finite chunk of the universe—such as the part of the universe we can observe today—is predicted to have started from an extremely small volume.

Part of the confusion is that scientists sometimes use the term "universe" when they're referring to just the part we can see "**the observable universe**". And sometimes they use the term universe to refer to everything, including the part of the universe beyond what we can see.

It's also a common misconception that the Big Bang was an "explosion" that took place somewhere in space. But the Big Bang was an expansion of space itself. Every part of space participated in it. For example, the part of space occupied by the Earth, the Sun, and our Milky Way galaxy was once, during the Big Bang, incredibly hot and dense.

The same holds true of every other part of the universe we can see. We observe that galaxies are rushing apart in just the way predicted by the Big Bang model. But there are other important observations that support the Big Bang.

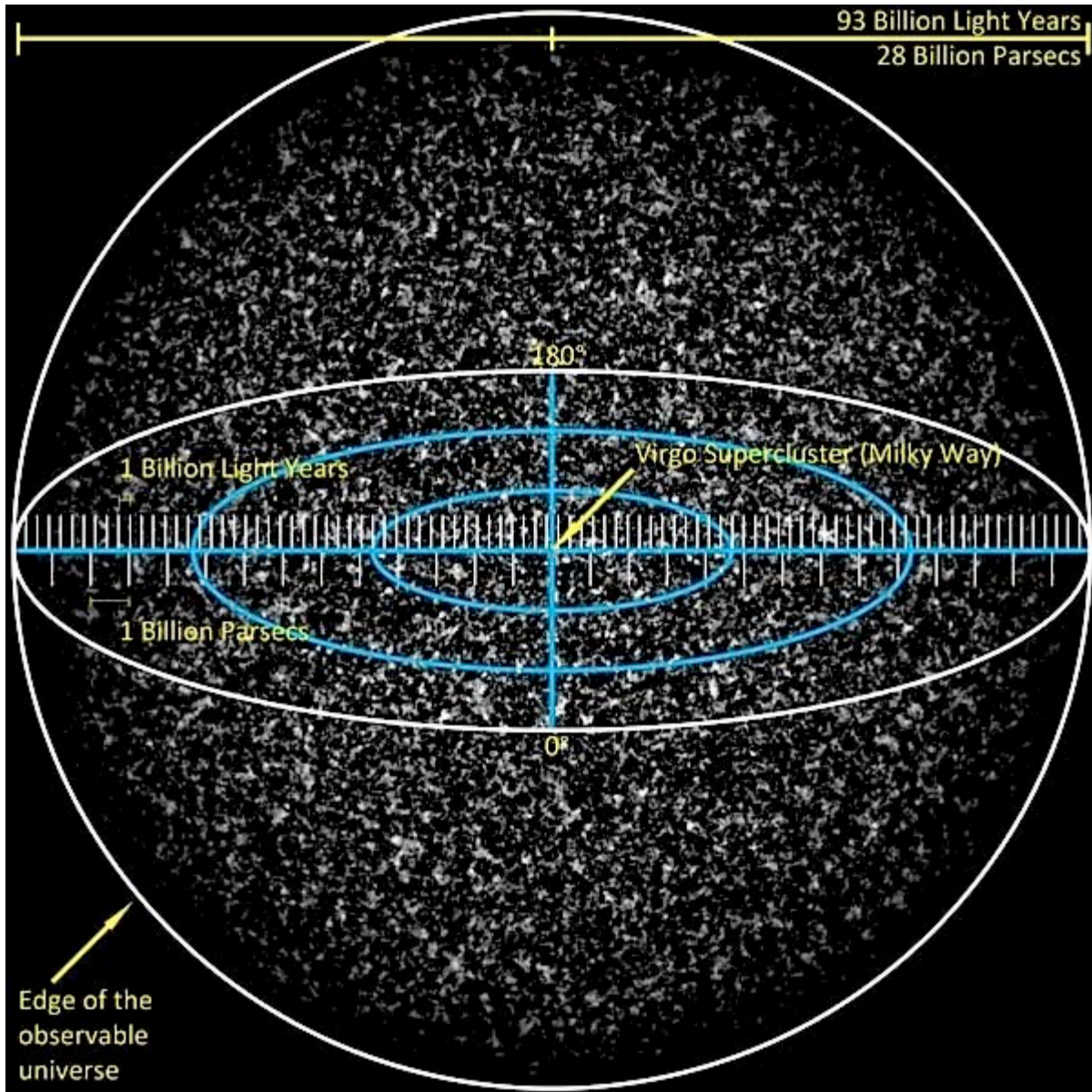
Astronomers have detected, throughout the universe, two chemical elements that could only have been created during the Big Bang: hydrogen and helium. Furthermore, these elements are observed in just the proportions (roughly 75% hydrogen, 25% helium) predicted to have been produced during the Big Bang. This is the nucleosynthesis of the light elements. This prediction is based on our well-established understanding of nuclear reactions— independent of Einstein's theory of gravity.

Second, we can actually detect the light left over from the era of the Big Bang. This is the origin of the **cosmic microwave background radiation**. The blinding light that was present in our region of space has long since traveled off to the far reaches of the universe. But light from distant parts of the universe is just now arriving here at Earth, billions of years after the Big Bang. This light is observed to have all the characteristics expected from the Big Bang scenario and from our understanding of heat and light.

The standard Hot Big Bang model also provides a framework in which to understand the collapse of matter to form galaxies and other large-scale structures observed in the Universe today. At about 10,000 years after the Big Bang, the temperature had fallen to such an extent that the energy density of the Universe began to be dominated by massive particles, rather than the light and other radiation which had predominated earlier. This change in the form of matter density meant that the gravitational forces between the massive particles could begin to take effect, so that any small perturbations in their density would grow. Thirteen point eight billion years later we see the results of this collapse in the structure and distribution of the galaxies.

Web Reference

<http://cfa-www.harvard.edu/seuforum/>

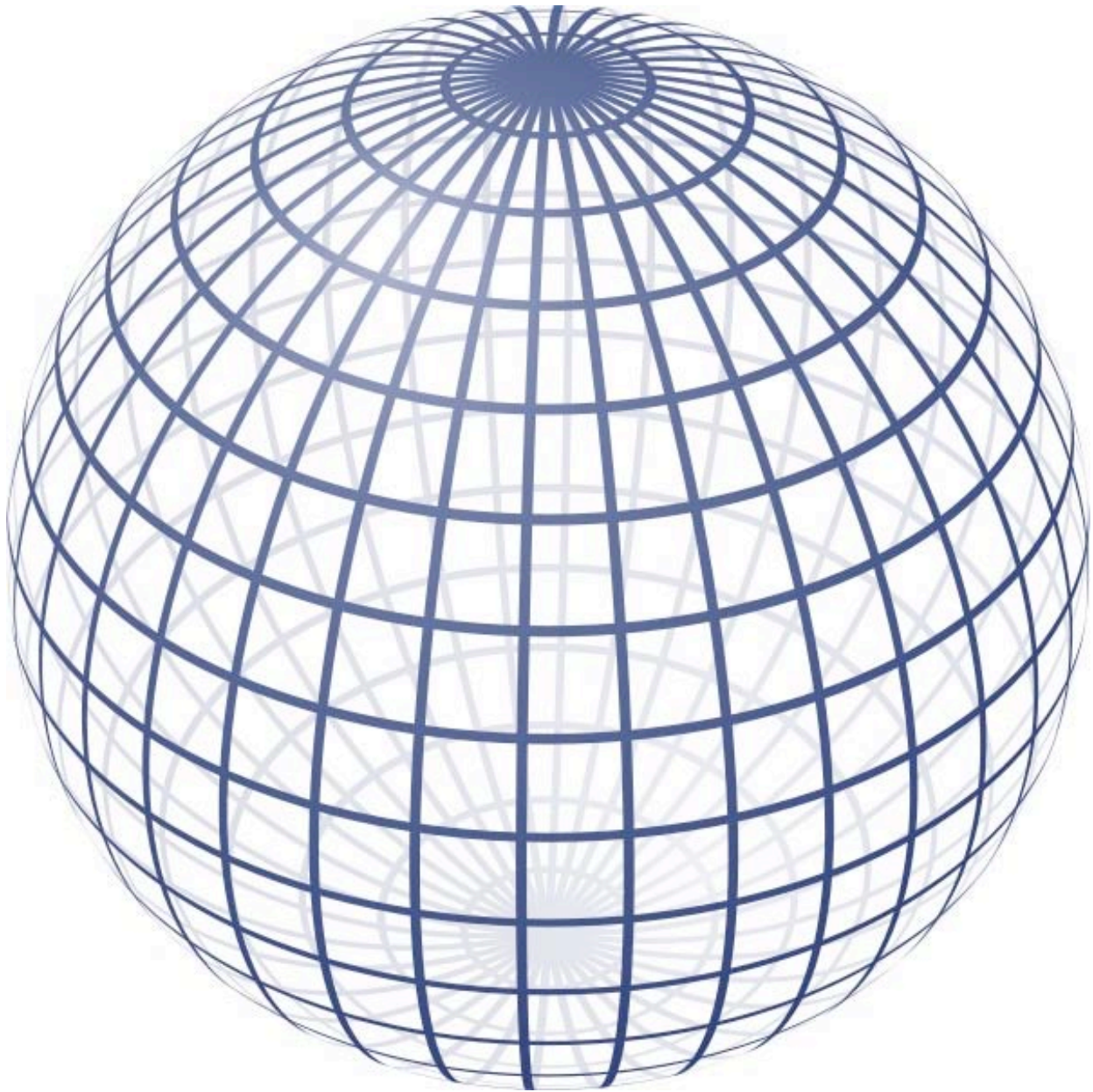


The Observable Universe

The best estimate of the age of the universe as of 2013 is **13.798 ± 0.037 billion years** 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 co-moving distance at the present time) than a static 13.8 billion light-years distance. The diameter of the observable universe is estimated at about **93 billion light-years (28 billion parsecs)**, putting the edge of the observable universe at about 46–47 billion light-years away.

Web Reference

http://en.wikipedia.org/wiki/Observable_universe



The observable universe is a spherical volume of space.

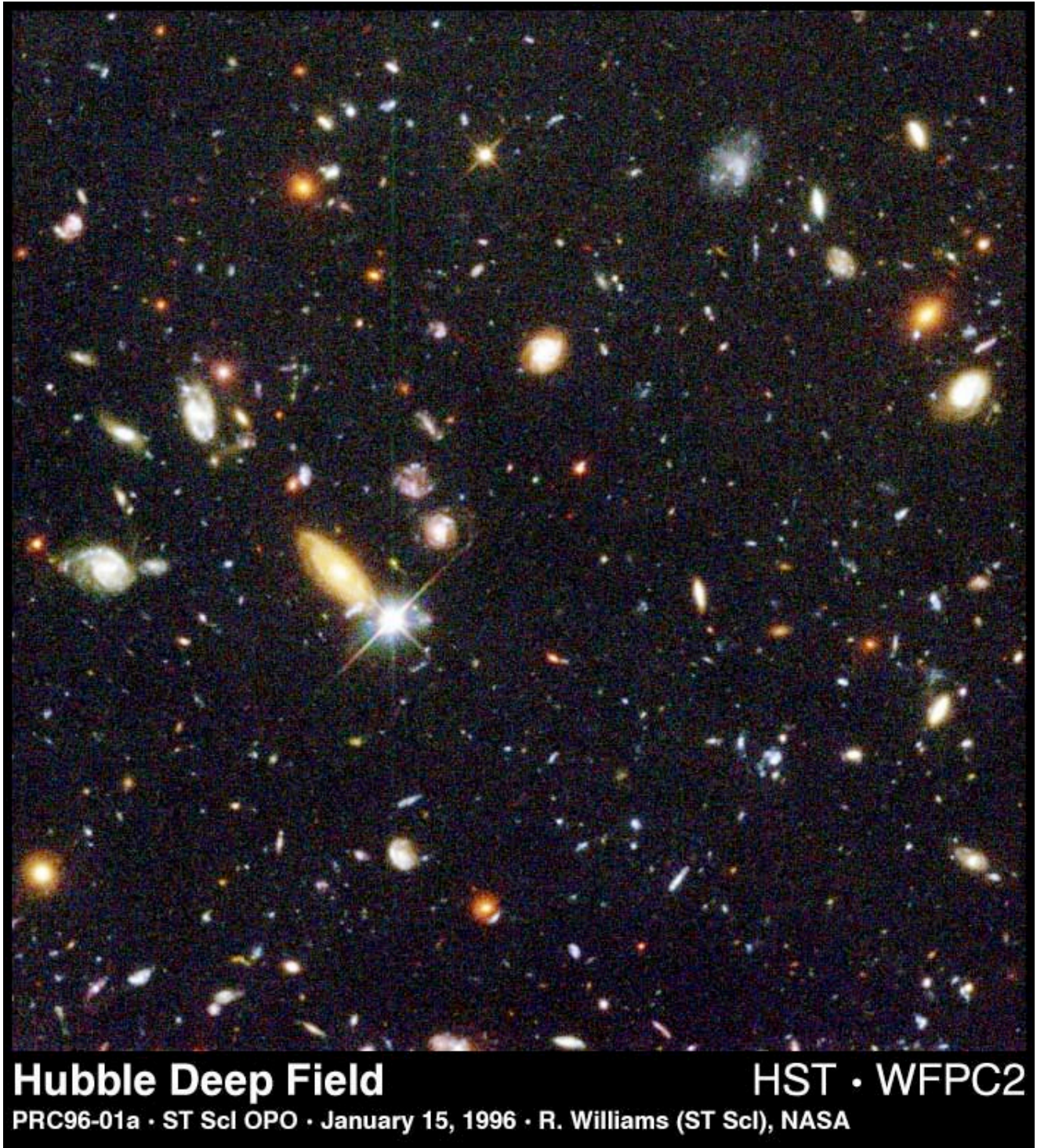
The co-moving distance from Earth to the edge of the "visible" universe (also called the particle horizon) is about 46.5 billion light-years in any direction. This defines a lower limit on the co-moving radius of the "observable" universe, although it is expected that the visible universe is somewhat smaller than the observable universe since we see only light from the cosmic microwave background radiation that was emitted after the time of recombination, giving us the spherical surface of last scattering. The visible universe is thus a sphere with a diameter of **about 93 billion light-years**.



The Hubble Space Telescope 1996

Web Reference

<http://hubblesite.org/newscenter/archive/releases/1996/01/background/>

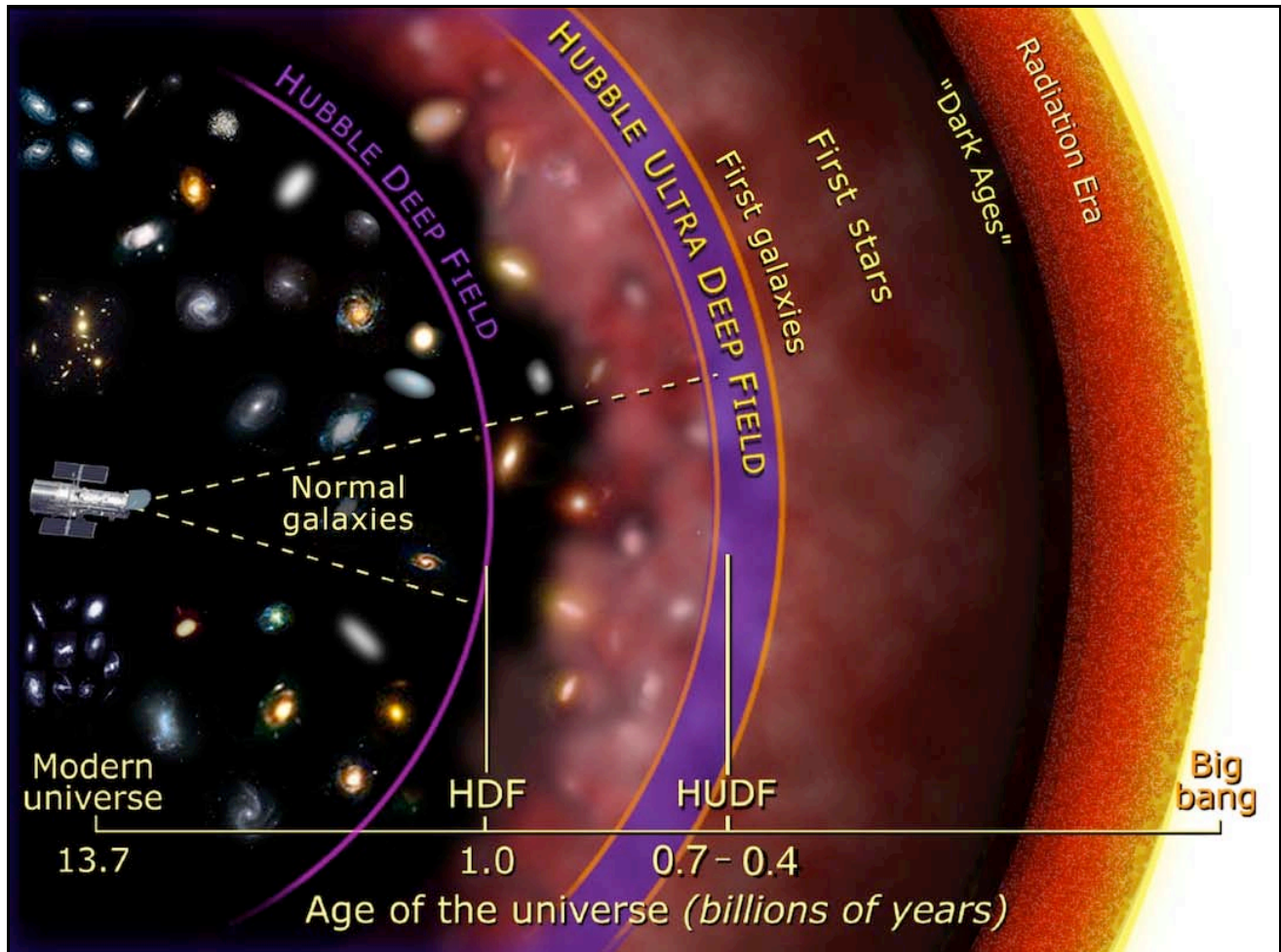


The Hubble Deep Field (HDF) 1996

Web References

<http://hubblesite.org/newscenter/archive/releases/1996/01>

http://en.wikipedia.org/wiki/Hubble_Deep_Field



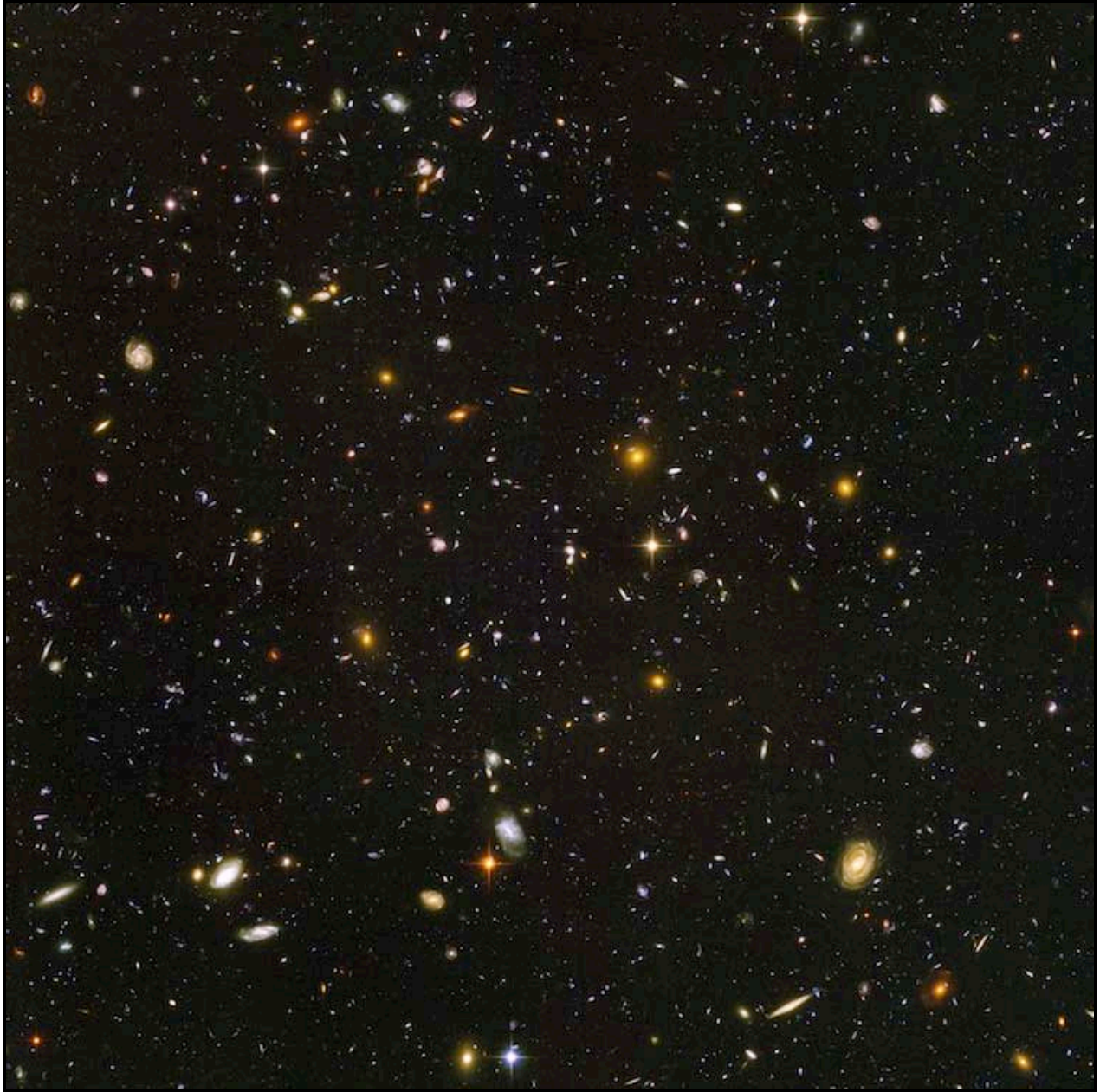
Hubble Ultra Deep Field Diagram

The Hubble Deep Field visible-light (HDF), released in **1996**, looked back to within 1.0 billion years after the Big Bang. The Hubble Ultra Deep Field visible-light (HUDF), released **March 2004**, looks back even further to a time only 0.7 billion years after the Big Bang, close to the period when the first galaxies formed.

HUDF Image Credits: NASA, ESA, S. Beckwith (STScI) and the HUDF Team

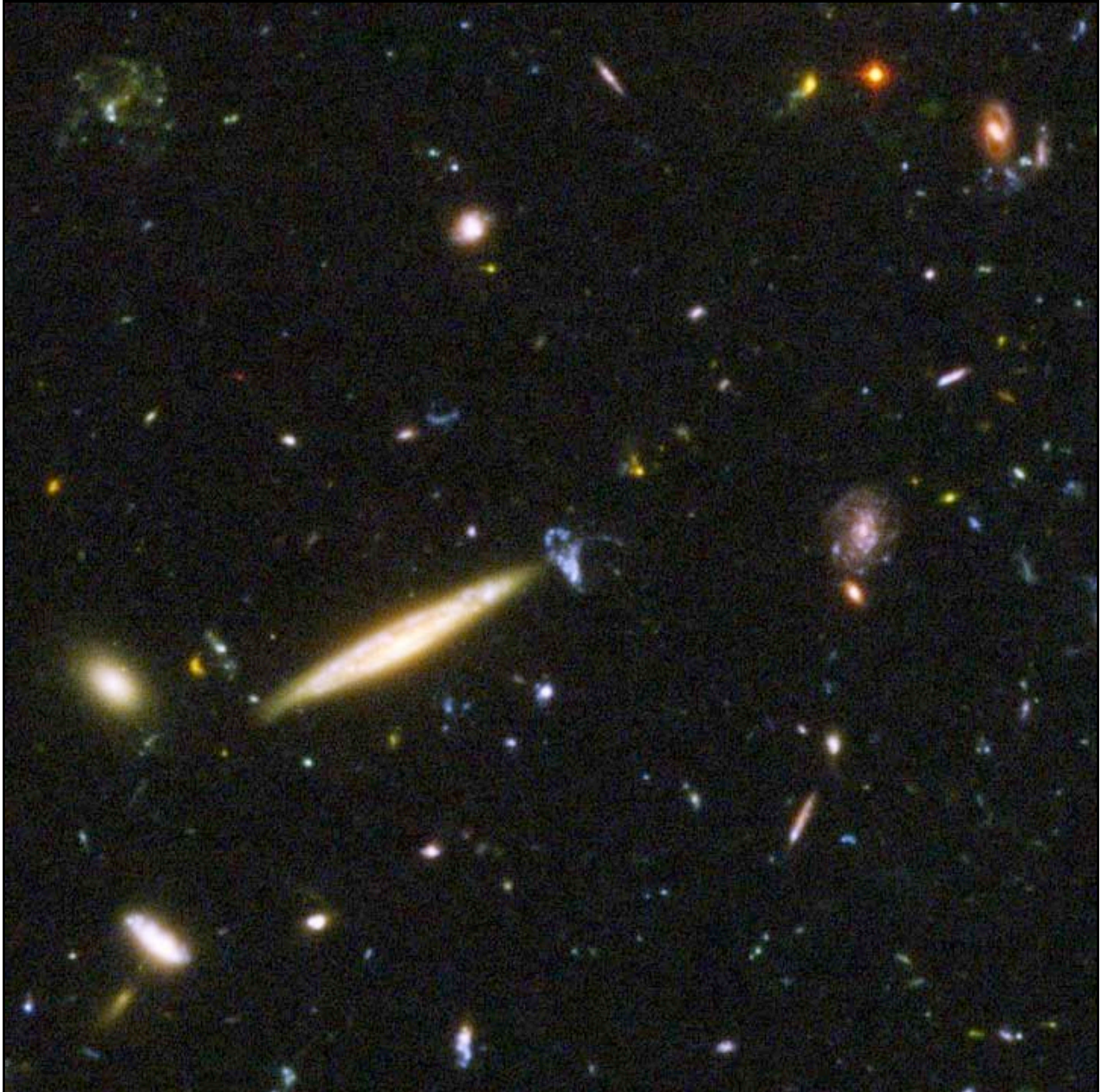
Web References for HUDF diagram

<http://hubblesite.org/newscenter/archive/releases/2004/07/image/j/>



Hubble Ultra Deep Field (HUDF) 2004

This Hubble Ultra Deep Field (HUDF) view of nearly 10,000 galaxies was the deepest visible-light image of the cosmos in 2004. This galaxy-studded view of the Hubble Ultra Deep Field represents a "deep" core sample of the universe, cutting across billions of light-years. HUDF is an image of a small region of space in the constellation Fornax, composited from Hubble Space Telescope data accumulated over a period from September 3, 2003 through January 16, 2004. The patch of sky in which the galaxies reside was chosen because it had a low density of bright stars in the near-field.

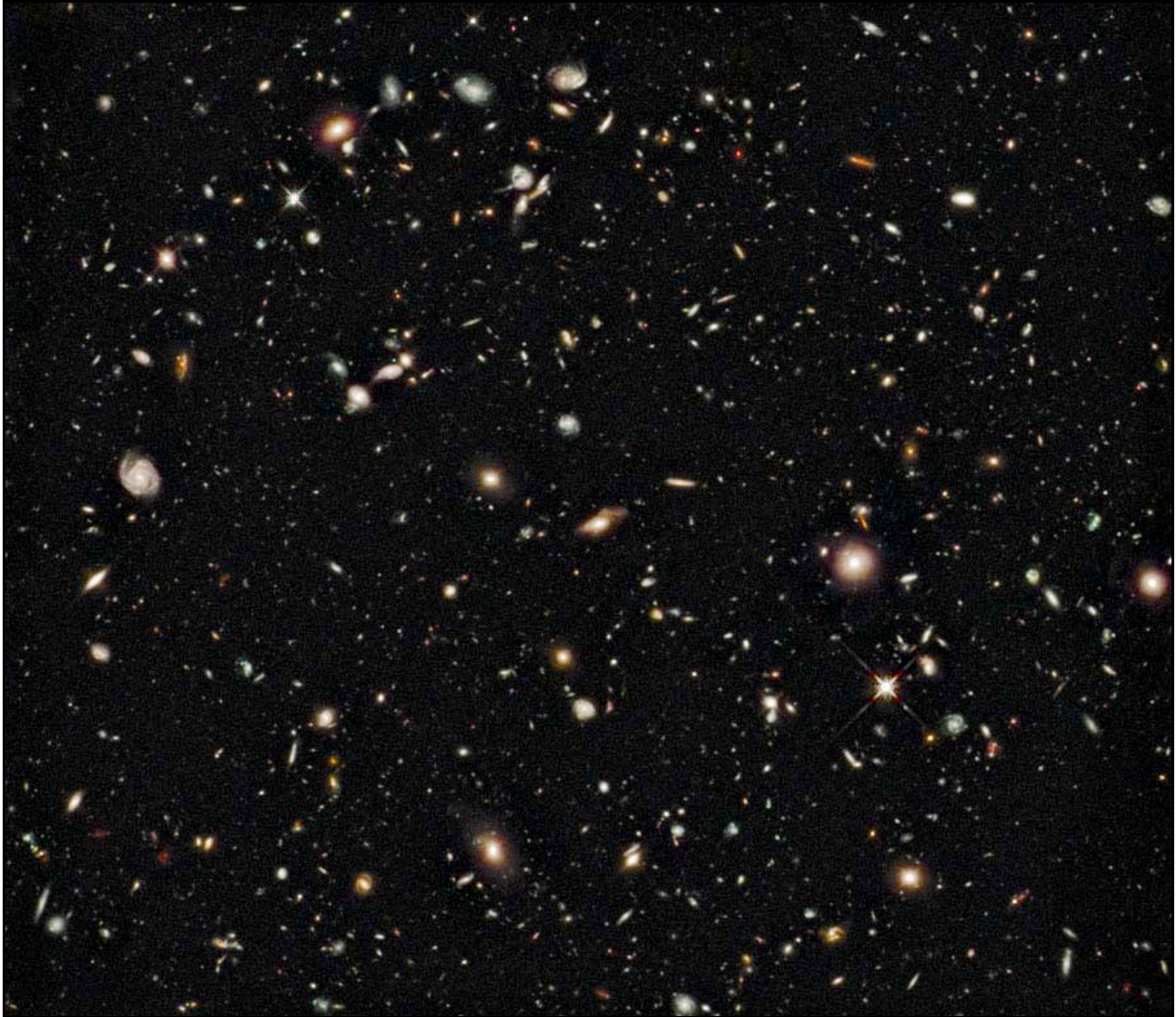


In vibrant contrast to the rich harvest of classic spiral and elliptical galaxies, there is also a zoo of oddball galaxies littering the field, as shown in this close-up view of the HUDF. Some look like toothpicks; others like links on a bracelet. A few appear to be interacting. These oddball galaxies chronicle a period when the universe was younger and more chaotic. Order and structure were just beginning to emerge.

HUDF 2004 References:

http://en.wikipedia.org/wiki/Hubble_Ultra-Deep_Field

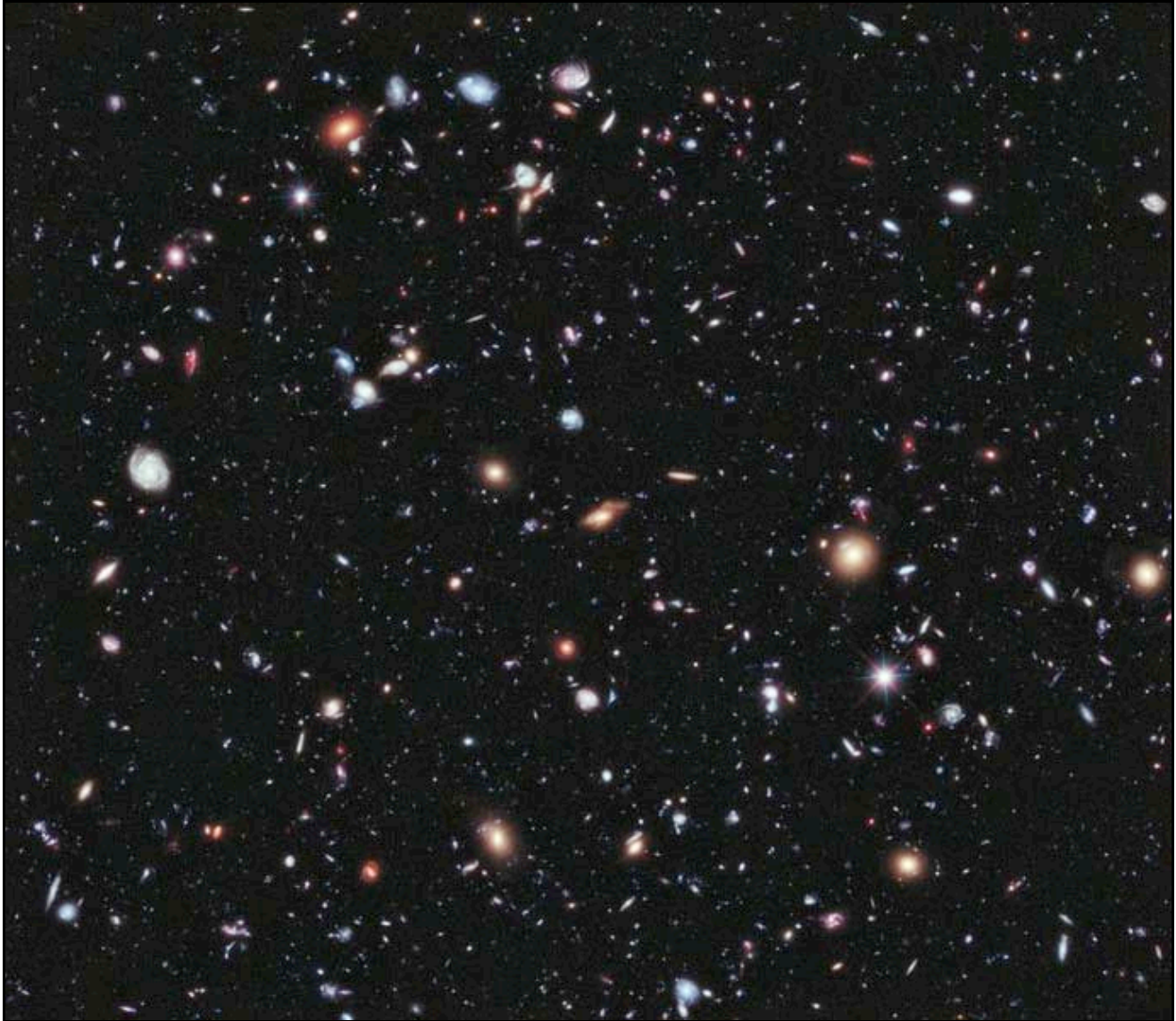
<http://hubblesite.org/newscenter/archive/releases/2004/07/image/e/>



Dawn of the Galaxies: HUDF Infrared 2009

When did galaxies form? To find out, the deepest near-infrared image of the sky ever, has been taken of the same field as the optical-light Hubble Ultra Deep Field (HUDF) in 2004. This image was taken the **summer of 2009**, by the newly installed **Wide Field Camera 3 on the refurbished Hubble Space Telescope**. Faint red smudges identified on this image likely surpass redshift 8 in distance. These galaxies, therefore, likely existed when the universe was only a few percent of its present age, and may well be members of the first class of galaxies. This early class of low luminosity galaxies likely contained energetic stars emitting light that transformed much of the remaining normal matter in the universe from a cold gas to a hot ionized plasma. Some large modern galaxies make a colorful foreground to these distant galaxies.

Web Reference: <http://antwrp.gsfc.nasa.gov/apod/ap091209.html>

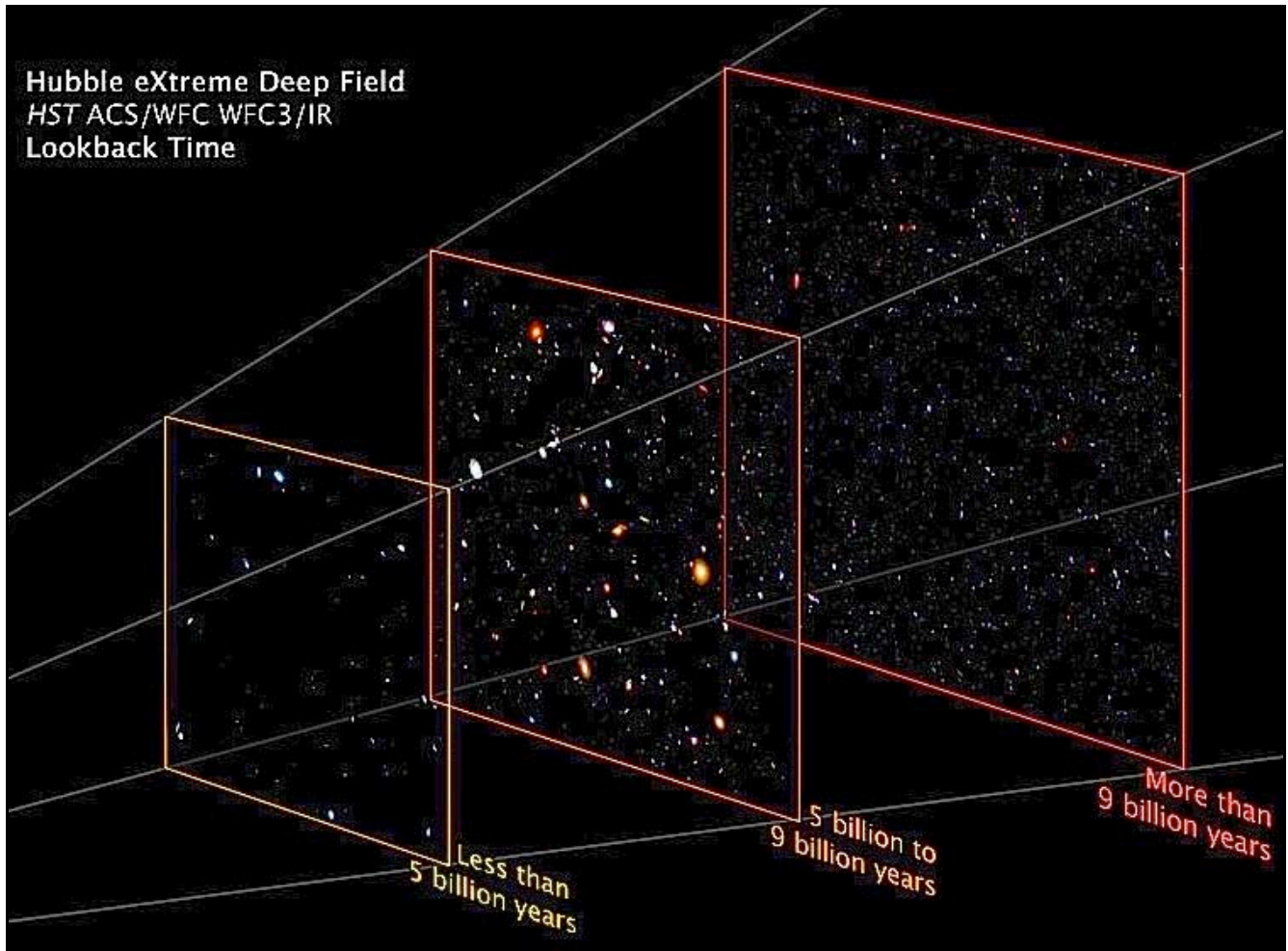


The Hubble eXtreme Deep Field 2012

The Hubble eXtreme Deep Field (XDF) is an image of a small part of space in the center of the Hubble Ultra Deep Field within the constellation Fornax, showing the deepest optical view in space. Released on **September 25, 2012**, the XDF image compiled 10 years of previous images and shows galaxies from 13.2 billion years ago. The exposure time was two million seconds, or approximately 23 days. The faintest galaxies are one ten-billionth the brightness of what the human eye can see. Many of the smaller galaxies are very young galaxies that eventually became the major galaxies, like the Milky Way and other galaxies in our galactic neighborhood.

Web Reference

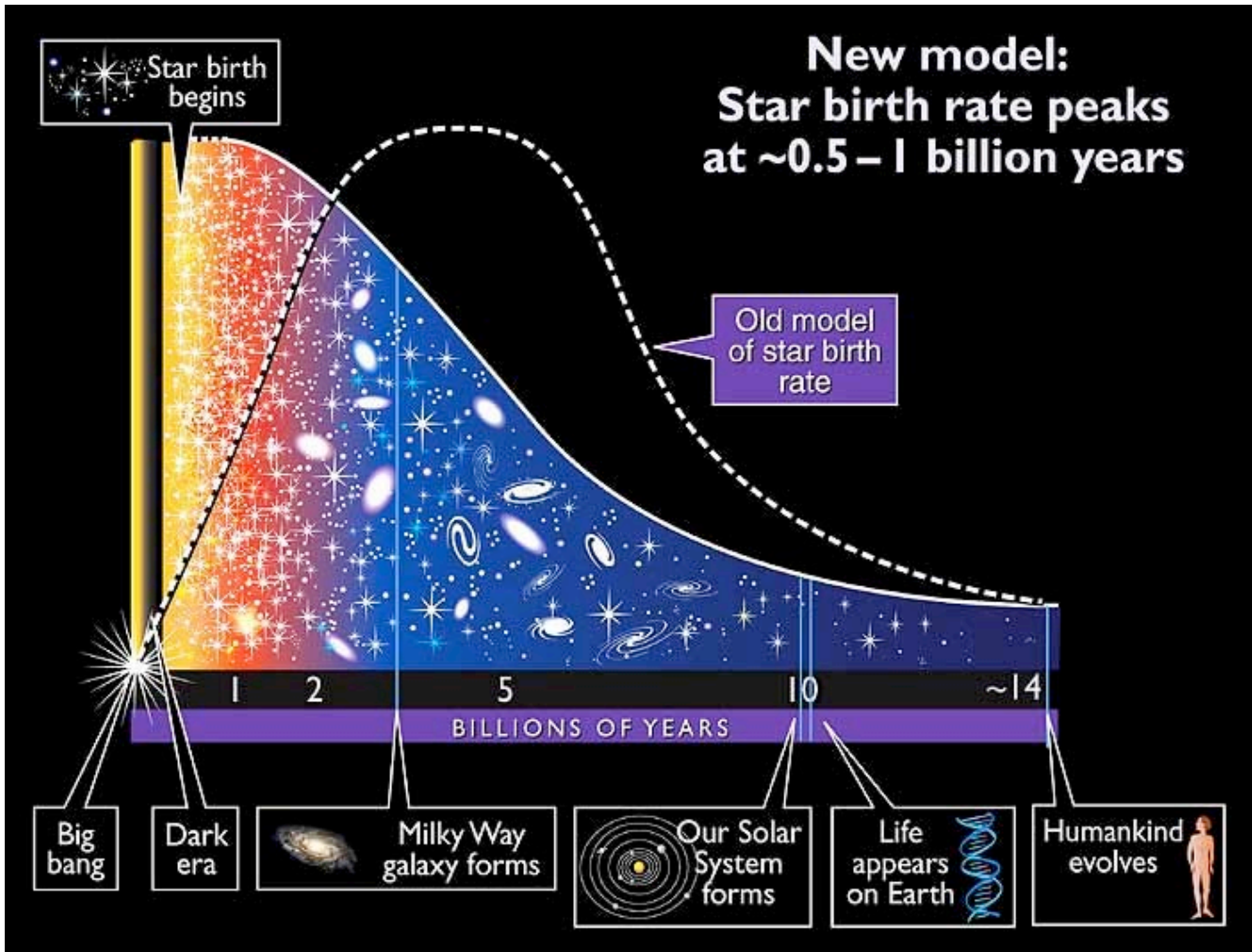
http://en.wikipedia.org/wiki/Hubble_Extreme_Deep_Field



This illustration separates the XDF into three planes showing foreground, background, and very far background galaxies. These divisions reflect different epochs in the evolving universe. Fully mature galaxies are in the foreground plane that shows galaxies as they looked less than 5 billion years ago. The universe is rich in evolving, nearly mature galaxies from 5 to 9 billion years ago. Beyond 9 billion years the universe is awash in compact galaxies and proto-galaxies, blazing with young stars.

Web Reference

<http://hubblesite.org/newscenter/archive/releases/2012/37/image/d/>



From the Dark Age to Starburst

Stellar 'Fireworks Finale' Came First in the Young Universe—subsequent analysis of Hubble Space Telescope deep sky images supported the theory that the first stars in the universe appeared in an abrupt eruption of star formation, rather than at a gradual pace. The universe could go on making stars for trillions of years to come, before all the hydrogen is used up, or is too diffuse to coalesce. But the universe will never again resemble the star-studded tapestry that brought light to the darkness.

Web Reference

<http://hubblesite.org/newscenter/archive/releases/2002/02/image/b/>



The End of the Dark Age

This is an artist's impression of how the very early universe might have looked when it went through a voracious onset of star formation, converting primordial hydrogen into myriad stars at an unprecedented rate. Back then the sky would have looked markedly different from the sea of quiescent galaxies around us today. This sky is ablaze with primeval starburst galaxies; giant elliptical and spiral galaxies have yet to form. Within the starburst galaxies, bright knots of hot blue stars come and go like bursting fireworks shells. The most massive stars self-detonate as supernovas, which explode across the sky like a string of firecrackers. The foreground starburst galaxies at the lower right are sculpted with hot bubbles from supernova explosions and torrential stellar winds.

Web Reference

<http://hubblesite.org/newscenter/archive/releases/2002/02/image/a/>

The Early Cosmos: Out of the Darkness

Although no stars and galaxies existed just after the Big Bang, the young cosmos was anything but dull. It was humming with activity. In the beginning, physical conditions were so extreme that matter as we know it today did not exist.

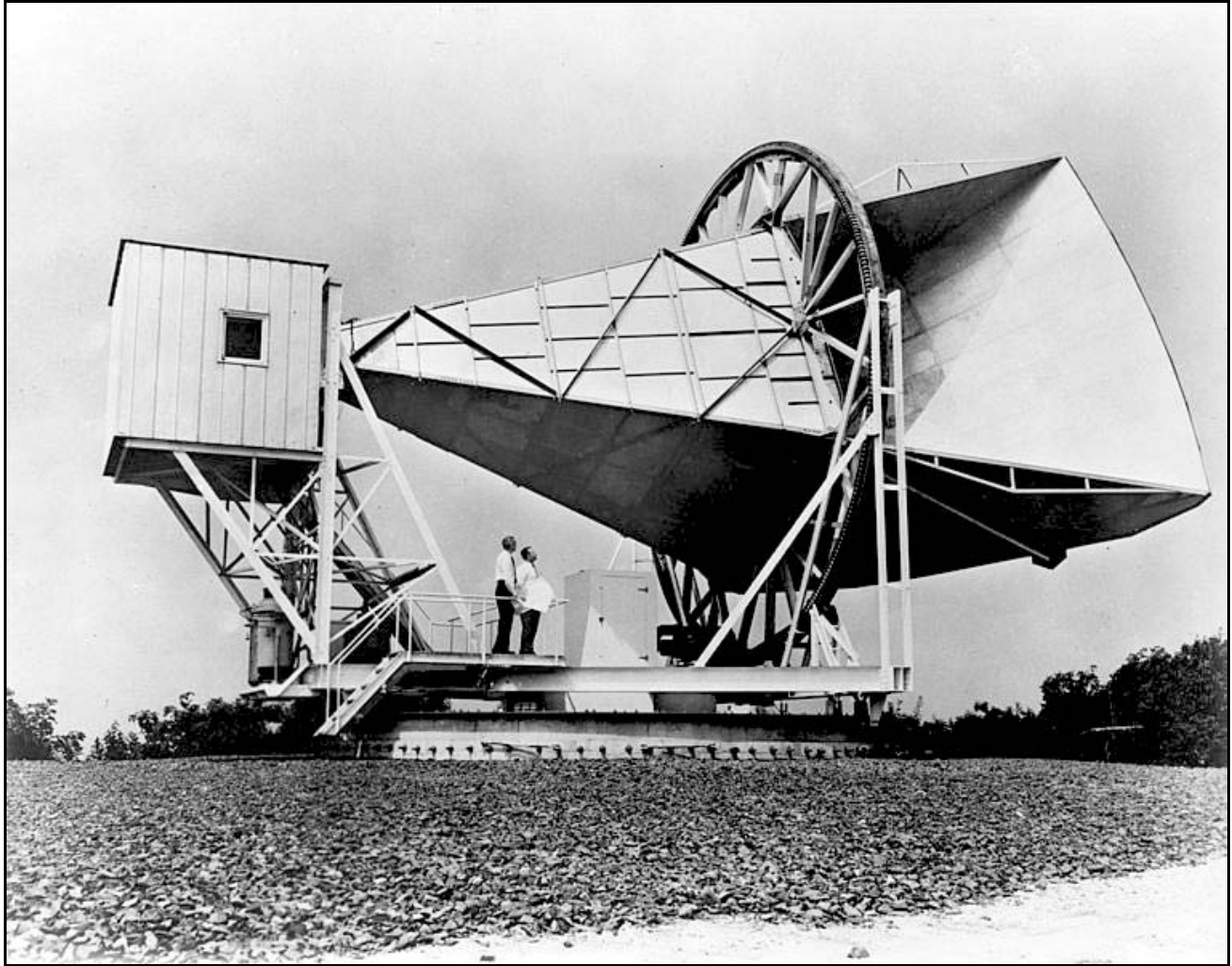
During the early part of its existence, after one times ten to the minus 12th of a second, our universe was so small and dense that light and matter intertwined; space was hot, dark, and ionized—filled with a plasma of charged particles. By the time the universe was one second old, the temperatures and densities had dropped enough for protons and neutrons to form from quarks. Within the next few minutes, the nuclei of the light elements, hydrogen, helium, and lithium, were created in a process called primal or Big Bang nucleosynthesis. The universe at this point was cooling rapidly enough to shut off the process of nucleosynthesis before elements heavier than boron could form.

About four hundred thousand years after the Big Bang the cosmos had grown large enough for matter and energy to move through space without immediately colliding—ending the plasma state of the early universe. The universe had cooled to about 3,000 degrees Celsius (5,400 degrees Fahrenheit) allowing electrons, protons, and neutrons to come together to form neutral atoms—the basic building blocks of all visible matter in the universe. This marked the “Decoupling” of matter and energy that we detect today as the **cosmic microwave background radiation**. This radiation has been stretched and cooled by the expansion of the universe from three thousand degrees to minus 270.42 degrees Celsius, or just three degrees above absolute zero.

At this point the universe was made up mostly of clouds of hydrogen and helium atoms. As the universe expanded and cooled, some regions of space amassed slightly higher densities of hydrogen. As millions of years passed, the slight differences grew large, as dense areas drew in material because they had more gravity. Researchers have dubbed this period of coalescing the "Dark Ages."

Web Reference

http://en.wikipedia.org/wiki/Cosmic_microwave_background_radiation

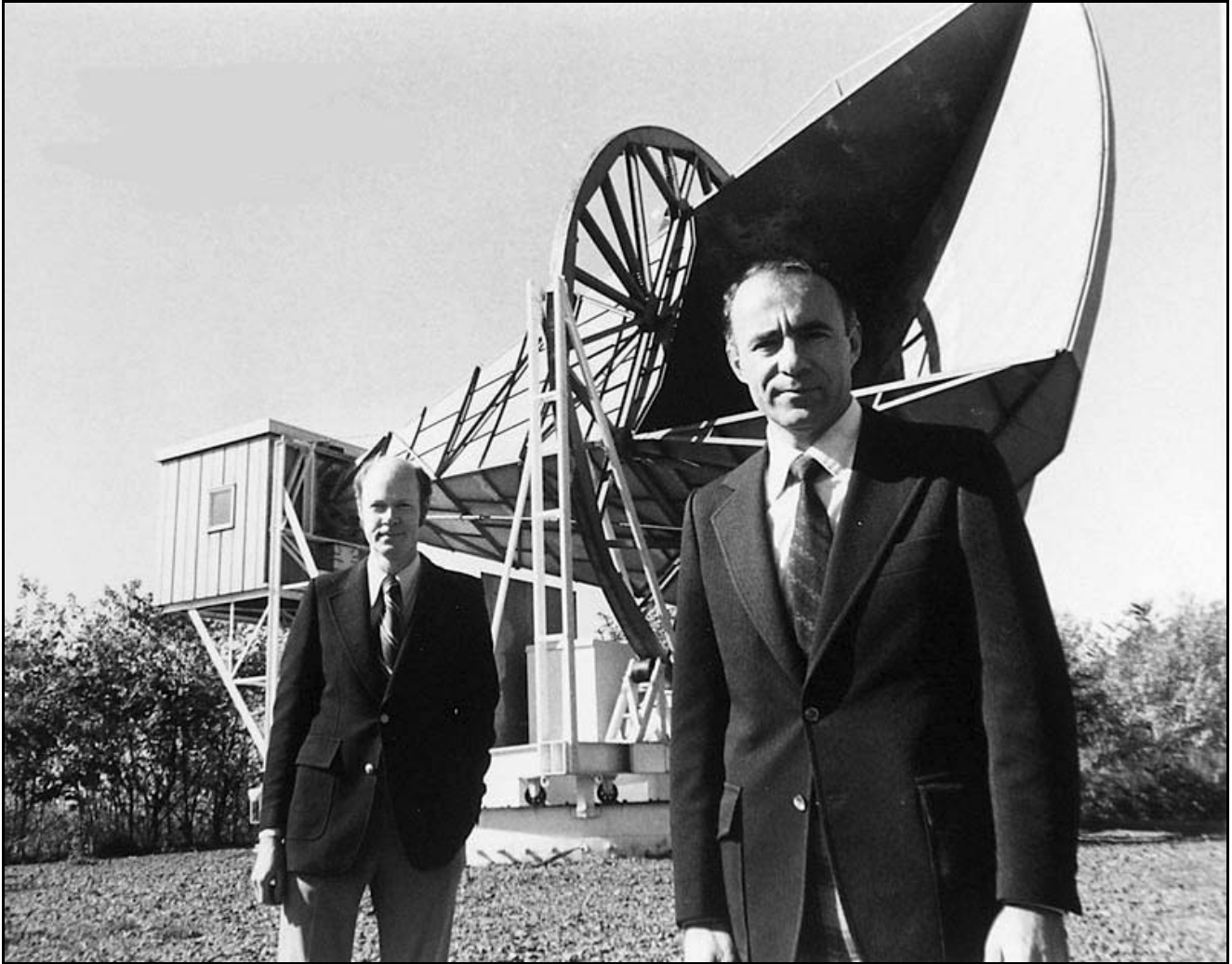


Penzias and Wilson at the Holmdel Horn Antenna, New Jersey in 1964

In 1964, while using the horn antenna, Penzias and Wilson stumbled on the microwave background radiation that permeates the universe. Cosmologists quickly realized that Penzias and Wilson had made the most important discovery in modern astronomy since Edwin Hubble demonstrated in the 1920s that the universe was expanding. This discovery provided the evidence that confirmed George Gamow's and Abbe Georges Lemaitre's "Big Bang" theory of the creation of the universe and forever changed the science of cosmology from a field for unlimited theoretical speculation into a subject disciplined by direct observation..

Web Reference

<http://www.npr.org/templates/story/story.php?storyId=4655517>



Dr. Robert Wilson (left) and Dr. Arno Penzias (right) 1975
in front of the Holmdel Horn Antenna, Crawford Hill, N.J. (Photo Credit: Bell Labs)

In 1978, Penzias and Wilson received the Nobel Prize for Physics for their momentous discovery.

Web Reference

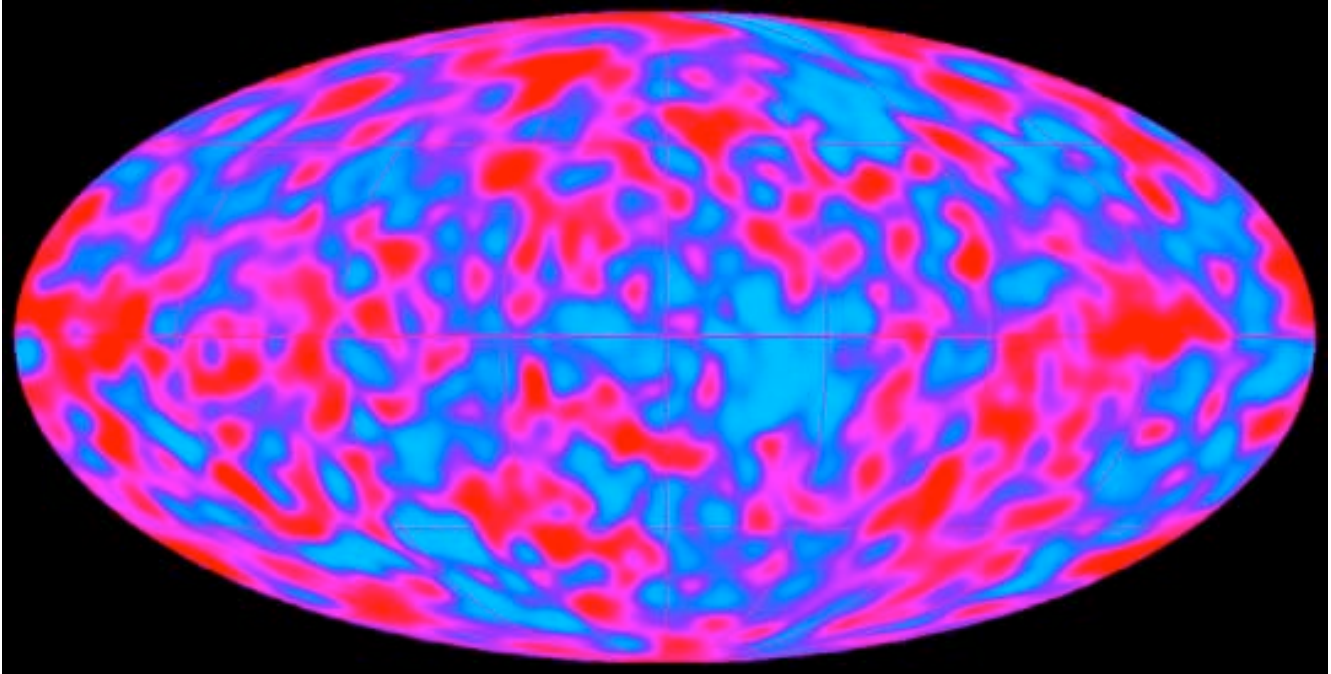
http://map.gsfc.nasa.gov/universe/bb_tests_cmb.html



An artist's concept of the COBE satellite in Earth orbit in 1989.

Web Reference

<http://wmap.gsfc.nasa.gov/resources/cobeimages.html>



COBE All-Sky Map 1992

The **Cosmic Background Explorer (COBE)** satellite was launched in 1989, twenty five years after the discovery of the microwave background radiation in 1964. In **1992**, the COBE team announced that they had discovered “ripples at the edge of the universe”, that is, the first sign of primordial fluctuations at **380,000 years after the Big Bang**. These are the imprint of the seeds of galaxy formation. These appear as temperature variations on the full sky map that COBE obtained (shown above). Red areas represent areas with slightly higher temperatures and blue areas a slightly lower temperature than the mean.

Web Reference

http://www.nasa.gov/topics/universe/features/cobe_20th.html

In 2006, two American astronomers, John C. Mather of the NASA Goddard Space Flight Center in Greenbelt, Md., and George F. Smoot of the Lawrence Berkeley National Laboratory at the University of California, Berkeley, won the Nobel Prize in Physics for their work on the COBE project.

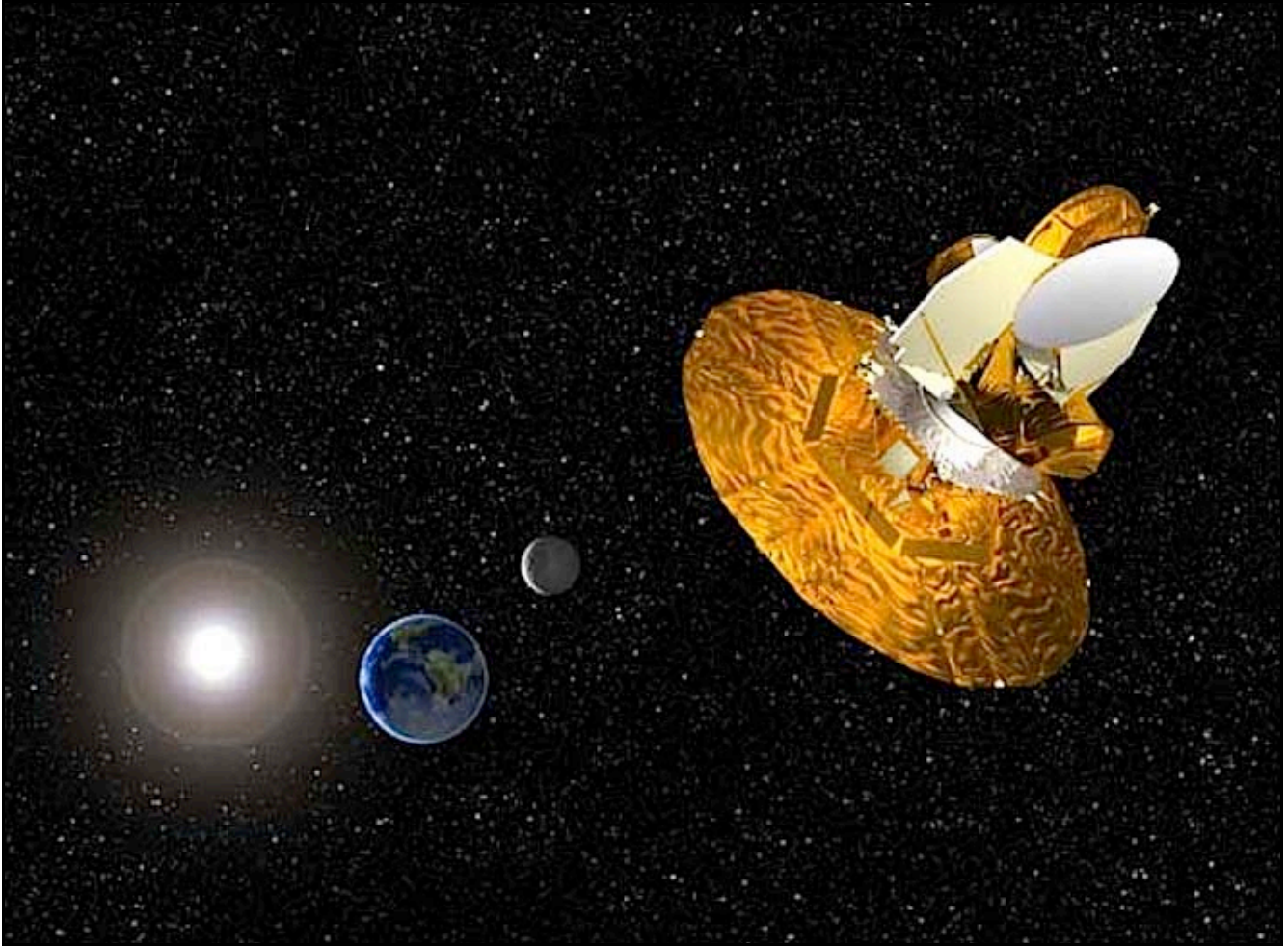


Wilkinson Microwave Anisotropy Probe (WMAP) Satellite

The WMAP mission was proposed to NASA in 1995 and **launched in 2001**.

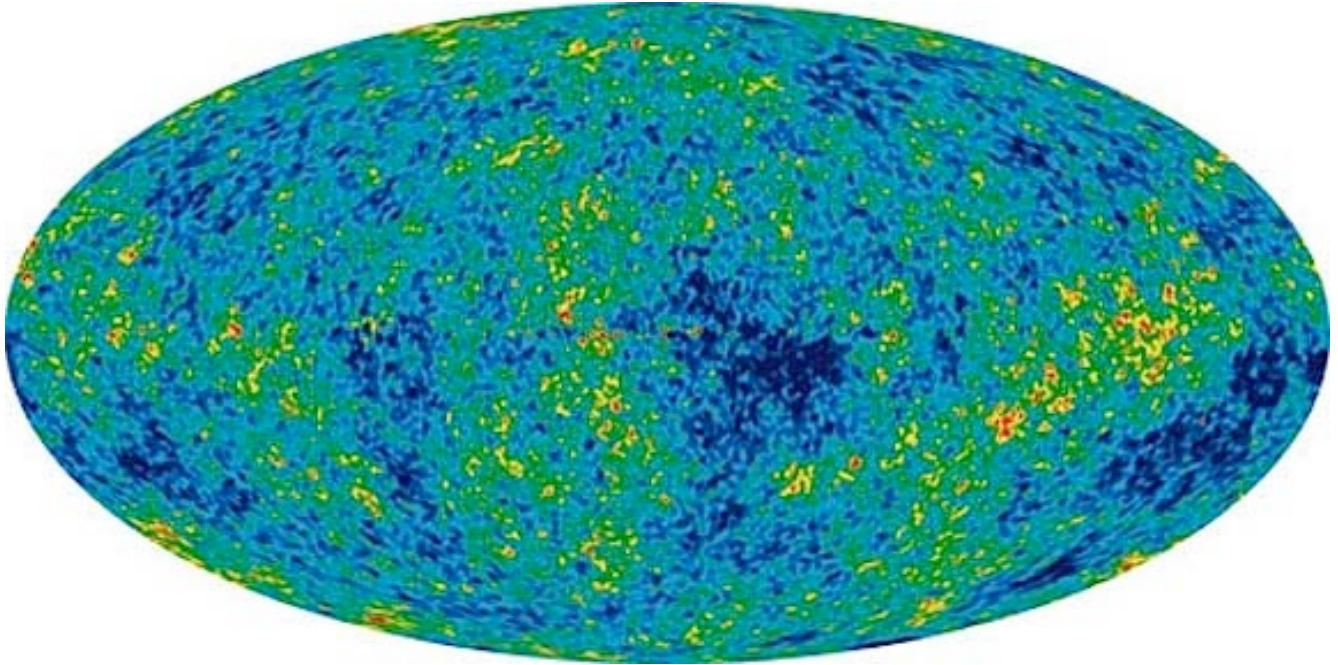
Web Reference

<http://map.gsfc.nasa.gov/mission/observatory.html>



WMAP Spacecraft with the Earth, Moon, and Sun in the background.

The final command to stop collecting data was transmitted to the WMAP satellite on **August 19th 2010.**

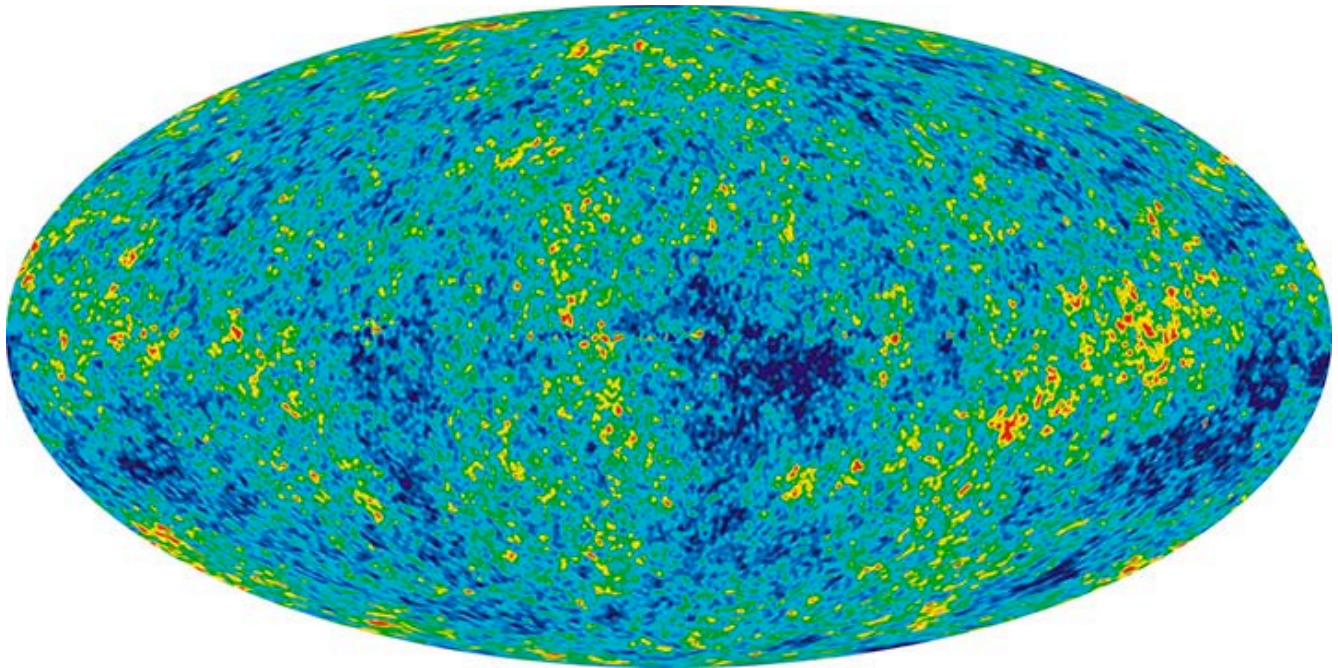


WMAP All-Sky Map 2003

Analyses of a high-resolution map released in 2003, of microwave light emitted only 380,000 years after the Big Bang (pictured above) appear to define our universe more precisely than ever before. The results from the orbiting **Wilkinson Microwave Anisotropy Probe** resolve several long-standing disagreements in cosmology rooted in less precise data. Specifically, present analyses of the WMAP all-sky map indicate that the universe is 13.7 billion years old (accurate to 1 percent), composed of 74 percent "**dark energy**", **22 percent cold "dark matter"**, and only 4 percent atoms, is currently expanding at the rate of 71 km/sec/Mpc (accurate to 5 percent), and underwent an episode of rapid expansion called "inflation".

Web Reference

<http://map.gsfc.nasa.gov/resources/cmbimages.html>



WMAP All-Sky Map 2012-9 year

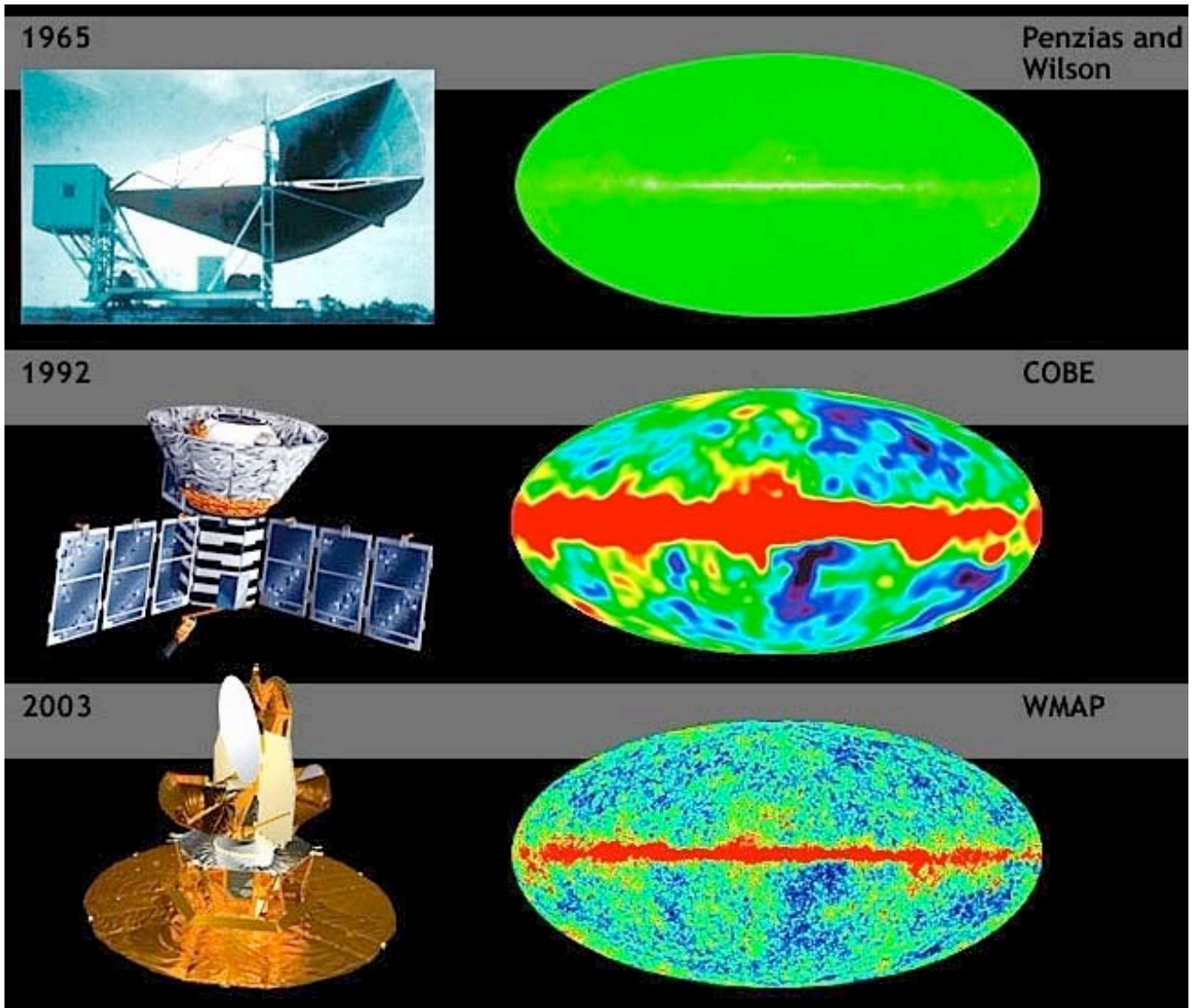
The universe is 13.73 billion years old, give or take 120 million years, astronomers announced in early March 2008. That age, based on precision measurements of the oldest light in the universe, agrees with results announced in 2006. Two additional years of data from a NASA's Wilkinson Microwave Anisotropy Probe have narrowed the uncertainty by tens of millions of years (Chang, 2008).

About 380,000 years after the Big Bang, the universe cooled enough for protons and electrons to combine into hydrogen atoms. That released a burst of light, which over the billions of years since has cooled to a bath of microwaves pervading the cosmos. Yet there are slight variations in the background, which the NASA satellite had been measuring since 2001. Those variations have given evidence supporting an idea known as cosmic inflation, a rapid expansion of the universe in the first trillionth of a trillionth of a second of its existence. The new set of data was precise enough to differentiate between various proposed models of inflation. Astronomers can also now see strong evidence for the universe being awash in almost mass-less subatomic particles known as neutrinos. This sea of primordial neutrinos created in the Big Bang was expected.

The new data also refined findings that the earliest stars switched on 400 million years after the Big Bang. The starlight started breaking up interstellar hydrogen atoms back into charged protons and electrons—creating a fog that deflected the cosmic microwaves—but took half a billion years to break apart all of the atoms.

Web Reference

<http://map.gsfc.nasa.gov/resources/cmbimages.html>

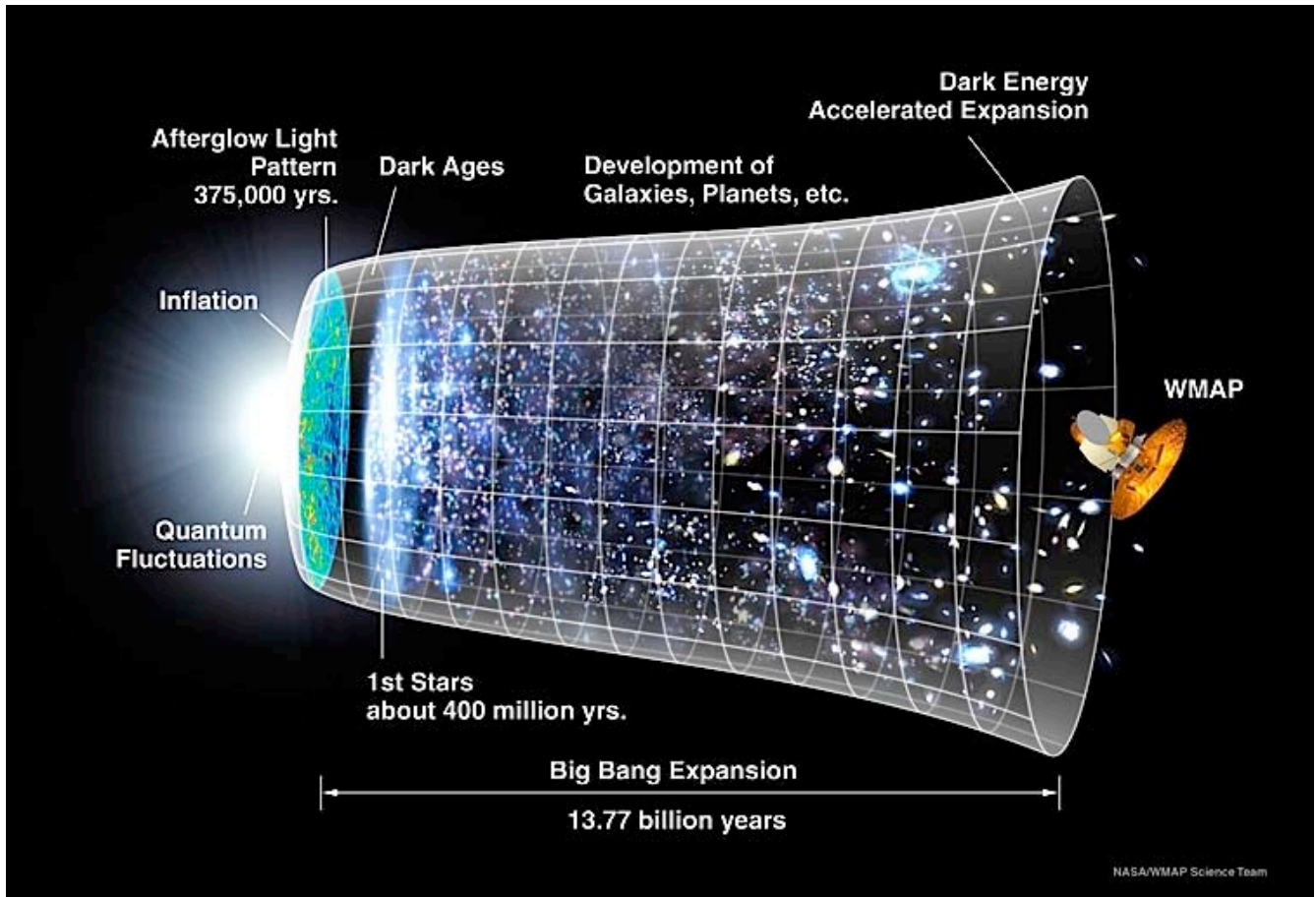


38 Years of Studying the CMB

This image allows a comparison of the resolution of the Holmdel Horn Antenna in 1965, to COBE in 1992, to WMAP in 2003, a time span of 38 years. The vague light across the horn antenna view of the CMB and the red streaks across COBE and WMAP are light from the Milky Way.

Web Reference

<http://map.gsfc.nasa.gov/resources/cmbimages.html>



WMAP 2012-9 year Time Line of the Universe

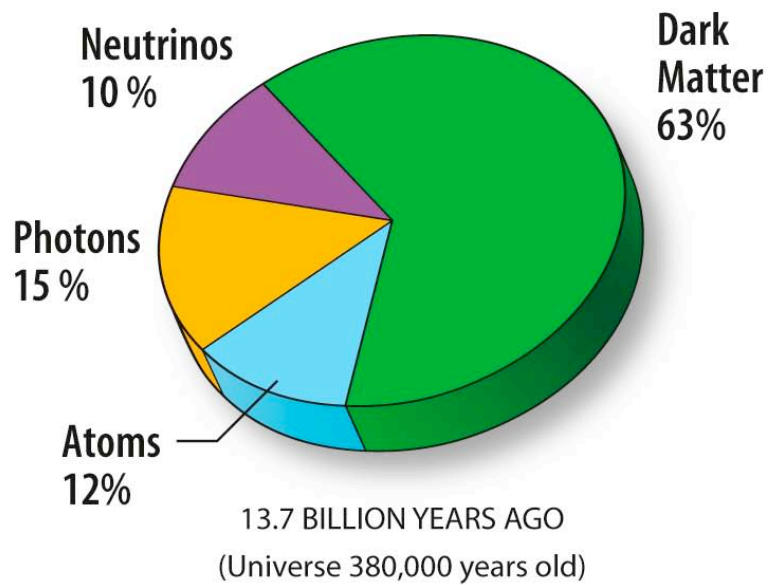
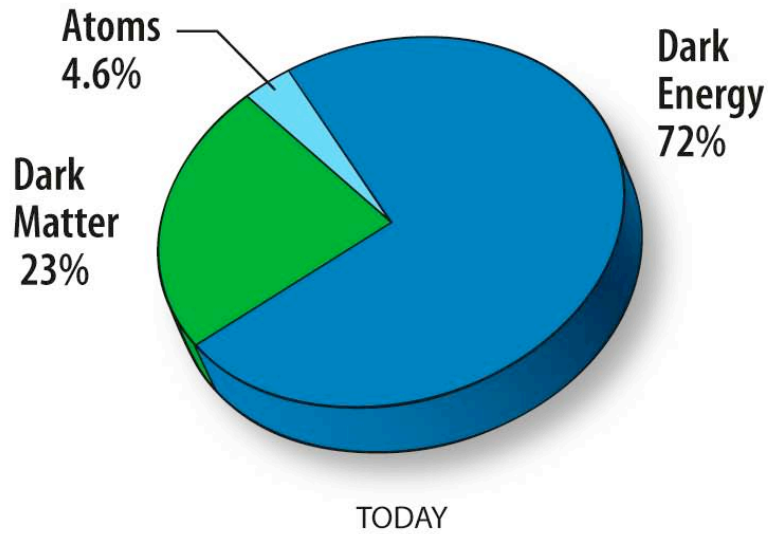
The expansion of the universe over most of its history has been relatively gradual. The notion that a rapid period "inflation" preceded the Big Bang expansion was first put forth 25 years ago by Alan Guth. The new WMAP observations favor specific inflation scenarios over other long held ideas.

Web Reference

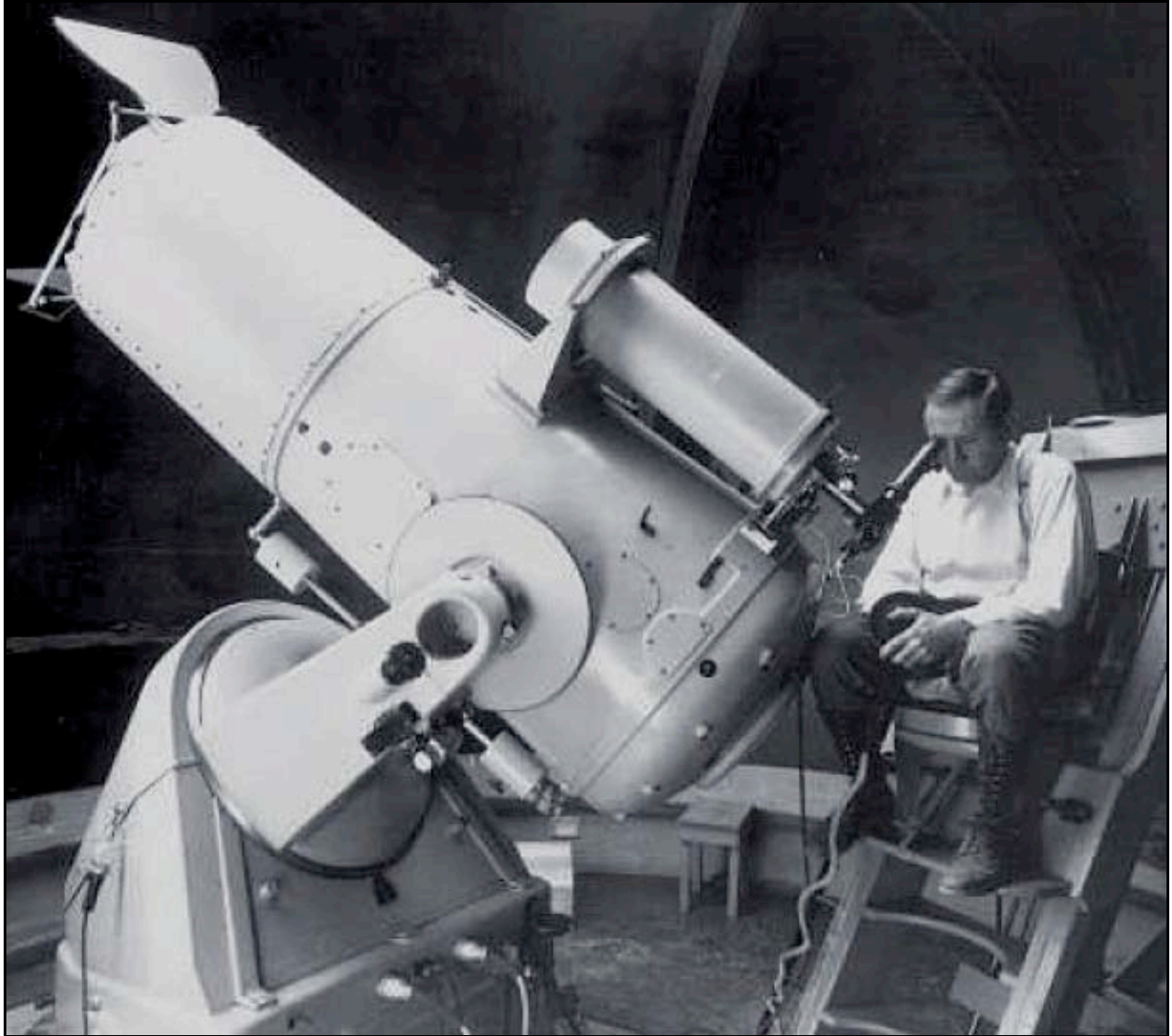
<http://wmap.gsfc.nasa.gov/media/060915/index.html>

For more on the development of "inflation" theory see:

http://en.wikipedia.org/wiki/Alan_Guth



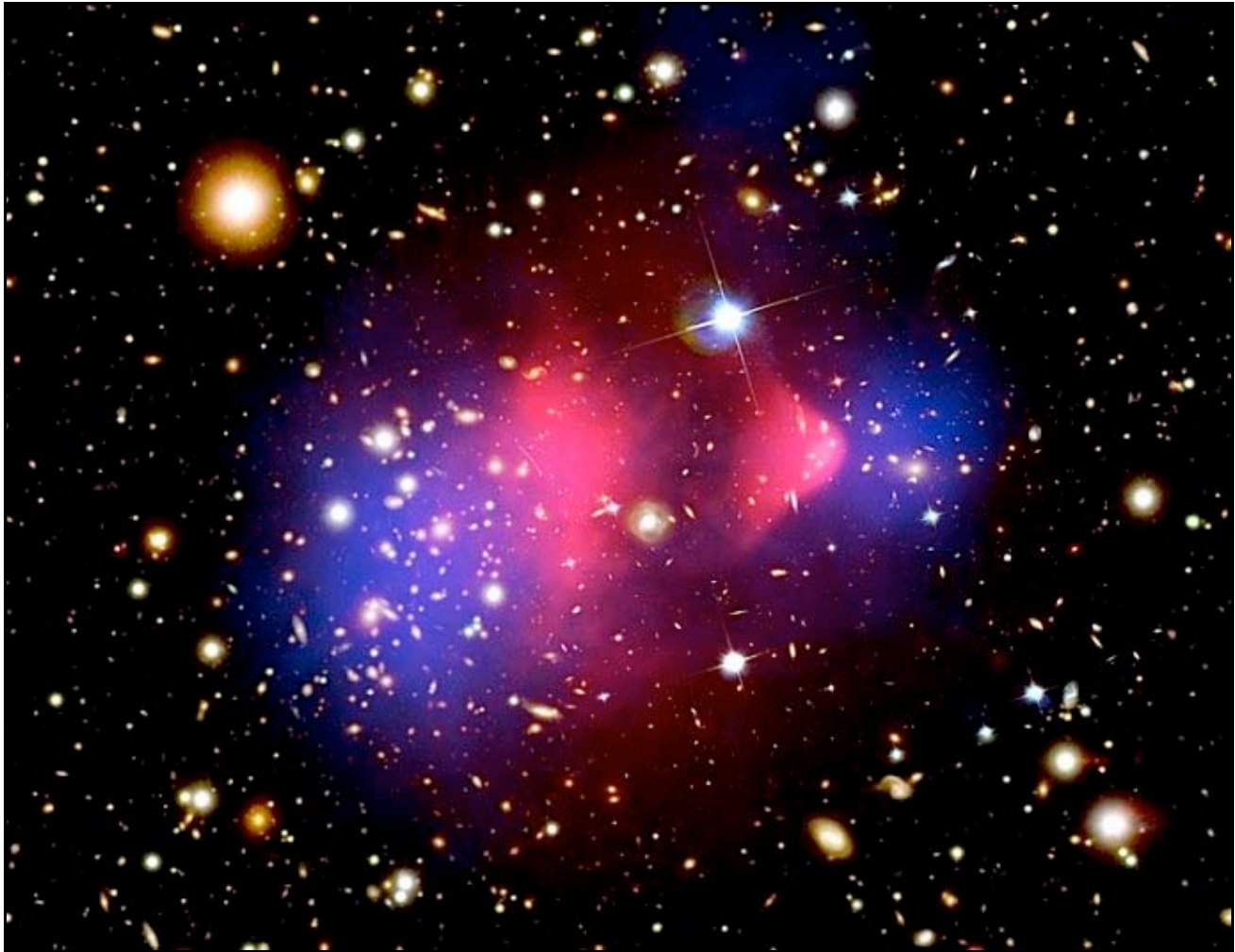
WMAP data from **2008** revealed that the universe's contents include $\sim 4.6\%$ atoms, the building blocks of stars and planets. **Dark matter comprised $\sim 23\%$ of the universe.** This matter, different from atoms, does not emit or absorb light. It has only been detected indirectly by its gravity. And that **$\sim 72\%$ of the universe is composed of "dark energy"** that acts as a sort of anti-gravity. This energy, distinct from dark matter, is responsible for the present-day acceleration of the universal expansion. WMAP data is accurate to two digits, so the total of these numbers is not 100%. This reflects the limit of WMAP's ability to define Dark Matter and Dark Energy.



Fritz Zwicky and Dark Matter

"Most of us think of the universe as all the matter there is, and by matter we mean the stuff we can see from afar or could touch if it were up close. But the motion of the observable objects in the universe, like stars and galaxies and clouds of gas, make no sense if the universe contains only ordinary, perceptible matter. **This became apparent in 1933, thanks to an astronomer named Fritz Zwicky.**

He discovered that parts of a distant cluster of galaxies were moving too fast to remain within the cluster if it contained only ordinary matter. He concluded that "dark matter", a phrase he coined, held the cluster together. But for 70-plus years since, no one had observed dark matter. It would be like seeing gravity. That has now changed."



Dark Evidence:

A composite image depicting normal matter (pink) and gravity (blue) shows dark matter's presence in the "bullet cluster" of galaxies (2006).

Astronomers using ground-based telescopes and satellite observatories have witnessed a separation between visible matter and the dark matter that shapes its motions (see above). It occurred 100 million years ago when two galaxy clusters three billion light-years away passed through each other at about 10 million miles an hour.

Imagine two crowds of pedestrians on a collision course. Some people in both groups—no doubt dressed in black—basically refuse to engage with anyone and just keep moving. But the ordinary people want to stop and chat. As the two crowds merge and then head in opposite directions, the people in black will have pushed ahead, separating themselves from the rest. That, in a nutshell, is what the astronomers saw, minus the people, of course.

Observing what was predicted a lifetime ago is an extraordinary accomplishment. It confirms that this part of our picture of the universe is essentially correct. But observing dark matter and knowing what it is are very different, and we are nowhere near the latter.

The matter in galaxy cluster 1E 0657-56, known as the "bullet cluster", is shown in the composite image on the previous page. The bullet cluster's individual galaxies are seen in the optical image data, but their total mass adds up to far less than the mass of the cluster's two clouds of hot x-ray emitting gas shown in red. Representing even more mass than the optical galaxies and x-ray gas combined, the blue hues show the distribution of dark matter in the cluster.

Otherwise invisible to telescopic views, the dark matter was mapped by observations of gravitational lensing of background galaxies. In a text book example of a shock front, the bullet-shaped cloud of gas at the right was distorted during the titanic collision between two galaxy clusters that created the larger bullet cluster itself. But the dark matter present has not interacted with the cluster gas except by gravity. The clear separation of dark matter and gas clouds is considered direct evidence that dark matter exists.

Web Reference

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Reference:

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Credits:

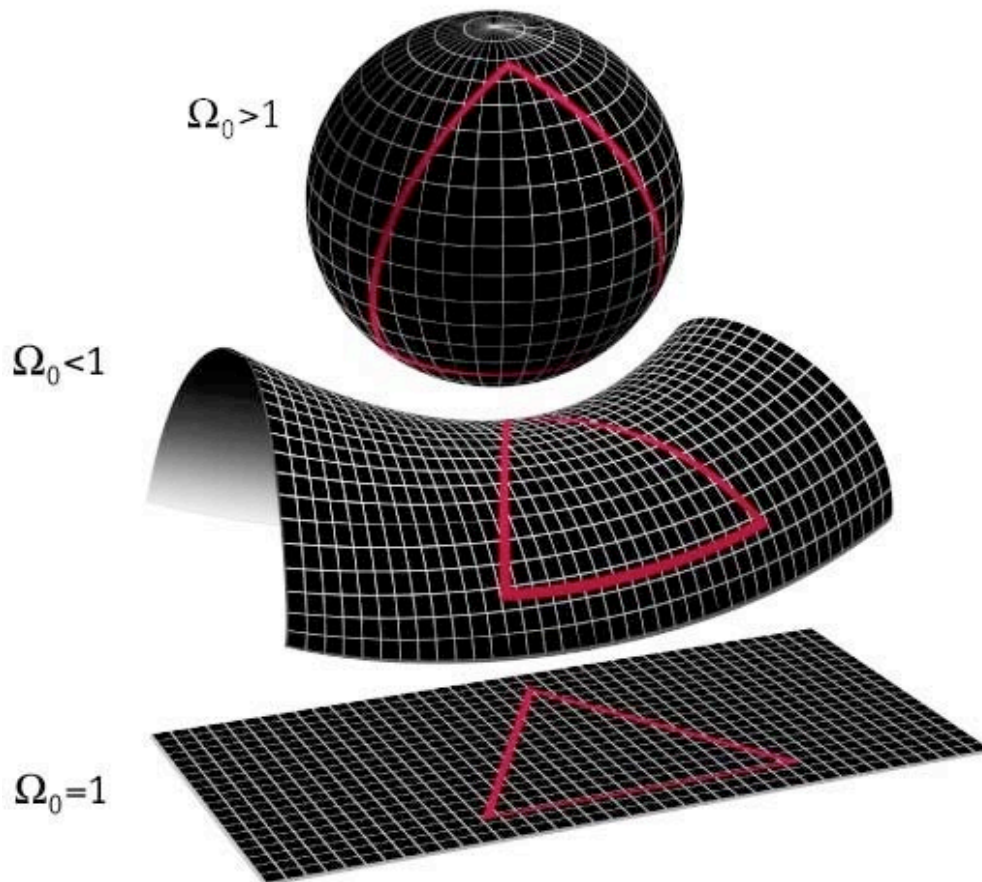
Composite Image Credits: X-ray: NASA/CXC/CfA/ M. Markevitch et al.
Lensing Map: NASA/STScI; ESO WFI; Magellan/U. Arizona/ D. Clowe et al.
Optical: NASA/STScI; Magellan/U. Arizona/D. Clowe et al.

The Fate of the Universe before Dark Energy

Dr. Allan Sandage, the Carnegie Observatories astronomer, once called cosmology "the search for two numbers" The first number is the Hubble constant, which tells how fast the universe is expanding. Together with the other number telling how fast the expansion is slowing, they determine whether the universe will expand forever or not.

The second number, known as the deceleration parameter, indicates how much the cosmos had been warped by the density of its contents. In a high-density universe, space would be curved around on itself like a ball. Such a universe would eventually stop expanding and fall back together in a big crunch that would extinguish space and time, as well as the galaxies and stars that inhabit them. A low-density universe, on the other hand, would have an opposite or "open" curvature like a saddle, harder to envision, and would expand forever.

In between with no overall warpage at all was a "Goldilocks" universe with just the right density to expand forever but more and more slowly, so that after an infinite time it would coast to a stop. This was a "flat" universe in the cosmological parlance, and to many theorists the simplest and most mathematically beautiful solution of all.



Web Reference

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(Excerpts from: *A Cosmic Conundrum* by Lawrence M. Krauss and Michael S. Turner.)

An Accelerating Universe

"Beginning in 1998, the cozy picture of a flat, ever expanding universe began to unravel. In 1998, two research groups, working independently, one led by Saul Perlmutter, the other by Brian Schmidt, both made the same startling discovery. Over the past five billion years the expansion of the universe has been speeding up, not slowing down as it would under the influence of gravity alone. Since then the evidence for a cosmic speedup has gotten much stronger and has revealed not only a current accelerating phase but an earlier epoch of deceleration dominated by gravity. Added to the question of what is causing the acceleration, a flat universe requires a critical energy density, but ordinary matter even combined with cold dark matter together comprise only 26 percent of the needed mass, leaving the balance of 74 percent to be in the form of a mysterious "dark energy".

Vacuum or Dark Energy—a new form of energy driving the cosmic expansion

"One proposal for what is driving the current accelerating phase of the universe is the energy of space itself. In quantum mechanics even empty space has an energy density in the form of virtual particles that appear and then disappear almost instantaneously. On the very small scales where quantum effects become important, even empty space is not really empty. Instead virtual particle-antiparticle pairs pop out of the vacuum travel for a short distance and then disappear again on timescales so fleeting that one cannot observe them directly. Yet their indirect effects are very important and can be measured. This vacuum energy is now thought of as Einstein's cosmological term. This new concept of the cosmological term, however, is quite different from the one Einstein introduced into his equations. The problem with this picture, however, is that all calculations and estimates of the magnitude of the empty-space energy so far, lead to absurdly large values.

It is also possible that the explanation of cosmic acceleration will have nothing to do with resolving the mystery of why the cosmological term is so small or how Einstein's theory can be extended to include quantum mechanics. General relativity stipulates that an object's gravity is proportional to its energy density plus three times its internal pressure. Any energy form with a large, negative pressure—which pulls inward like a rubber sheet instead of pushing outward like a ball of gas—will therefore have repulsive gravity. So cosmic acceleration may simply have revealed the existence of an unusual energy form, dubbed "**dark energy**", that is not predicted by either quantum mechanics or string theory."

(The following essay is from the *Universe Forum* produced for NASA by the Harvard Smithsonian Center for Astrophysics.)

Where did the universe come from?

The ultimate mystery is inspiring new ideas and new experiments.

"No one knows how the first space, time, and matter arose. And scientists are grappling with even deeper questions. If there was nothing to begin with, then where did the laws of nature come from? How did the universe "know" how to proceed? And why do the laws of nature produce a universe that is so hospitable to life? As difficult as these questions are, scientists are attempting to address them with bold new ideas—and new experiments to test those ideas.

Understanding how the universe began requires developing a better theory of how space, time, and matter are related. In physics, a theory is not a guess or a hypothesis. It is a mathematical model that lets us make predictions about how the world behaves. Einstein's theory of gravity, for example, accurately describes how matter responds to gravity in the large-scale world around us. And our best theory of the tiny sub-atomic realm, called quantum theory, makes very accurate predictions about the behavior of matter at tiny scales of distance. But these two theories are not complete and are not able to make accurate predictions about the very earliest moments when the universe was both extremely dense and extremely small.

Some of the best minds in physics are working on a new theory of space, time, and matter, called "string theory," that may help us better understand where the universe came from. String theory is based on new ideas that have not yet been tested. The theory assumes, for example, that the basic particles in nature are not point particles, but are shaped like strings. And the theory requires, and predicts, that space has more than the three dimensions in which we move. According to one version of the theory, the particles and forces that make up our world are confined to three dimensions we see—except for gravity, which can "leak" out into the extra dimensions.

String theory has led to some bizarre new scenarios for the origin of the universe. In one scenario, the Big Bang could have been triggered when our own universe collided with a "parallel universe" made of these extra dimensions. Scenarios like these are very speculative, because the string theory is still in development and remains untested, but they stimulate astronomers to look for new forms of evidence.

Is our universe unique?

"Perhaps the most unsettling and far-reaching prediction of string theory, and also of the inflationary universe model, is that the universe we live in is probably not unique. The inflationary model predicts that Big Bangs are continually taking place in other regions of space, and string theory suggests that these other mini-verses may be so different from our own that even the laws of nature and the number of dimensions of space may be different.

This notion—that the universe as a whole may not look like the part we live in—may help explain a puzzling mystery about our own universe: Why are the constants and laws of nature just so, and not different? For example, why is the speed of light not faster than it is? Why are electrons so much lighter than the protons they orbit in atoms? What we do know is that if these fundamental laws and constants were even slightly different from what is observed, then life *as we know it* would not exist. (For example, atoms would be less stable, or stars and planets would not form.) Traditionally, physicists have sought some logical explanation for why the universe is as it is. But the likelihood of multiple universes raises the possibility that nature is merely playing dice: some universes have the right conditions for life, while others—the vast majority—do not.

Nature is full of surprises, and this dialogue with nature has far to go. With every generation, the universe we observe seems to be getting larger and more mysterious. Just a few hundred years ago, the stars we see in the night sky seemed to be the limits of our universe. Then Galileo's telescope opened up the panorama of stars that make up our Milky Way galaxy of stars. A mere century ago, humanity still had not discovered that there are billions of galaxies far beyond our own. Today, we can see as far as nature currently allows—back to the moment of the Big Bang itself. Our ideas and ingenuity are conjuring a universe even larger and more varied than we had ever imagined."

Web Reference for Essay

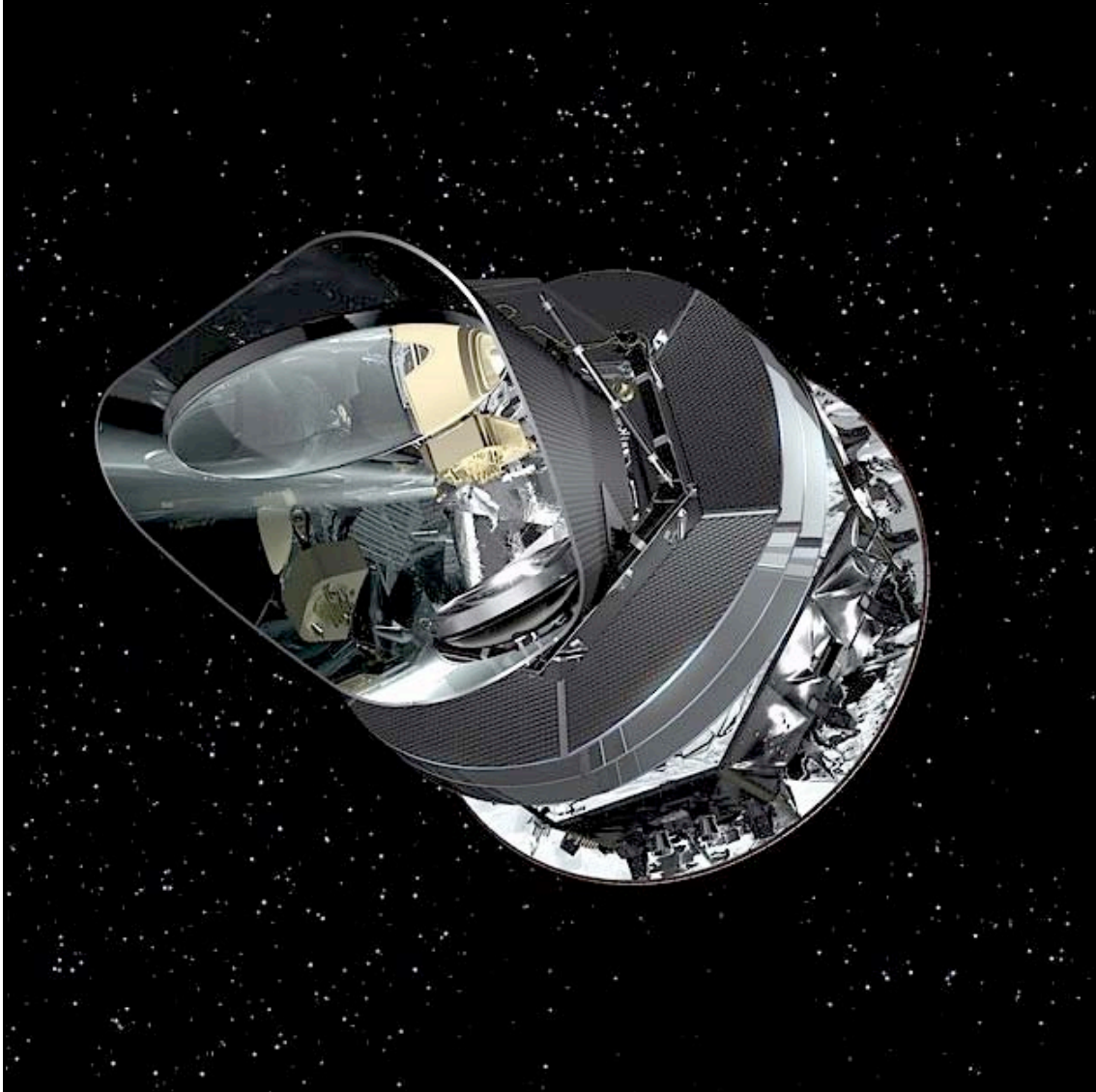
http://www.cfa.harvard.edu/seuforum/bb_whycafe.htm

The Fate of the Universe with Dark Energy

"The discovery of cosmic acceleration has forever altered our thinking about the future of the universe. Einstein's cosmological model was a universe finite in space but infinite in time, remaining the same fixed size for eternity—a static universe. This universe has no spatial boundaries; it curves back on itself like a sphere.

After the discovery of cosmic expansion by Edwin Hubble in 1929, cosmologists constructed a model of an infinite universe in which the rate of expansion continuously slowed because of gravity, possibly leading to collapse and another cycle of expansion. In the 1980s theorists added an early phase of rapid growth called inflation.

In the past six years observations have shown that the cosmic expansion began to accelerate about five billion years ago. The ultimate fate of the universe—continued expansion, collapse or a hyper-speedup called the "Big Rip", or something else—depends on the nature of the mysterious dark energy driving the accelerated expansion. Given this, we won't be able to predict what the fate of the universe will be until we understand the nature of "**dark energy**".

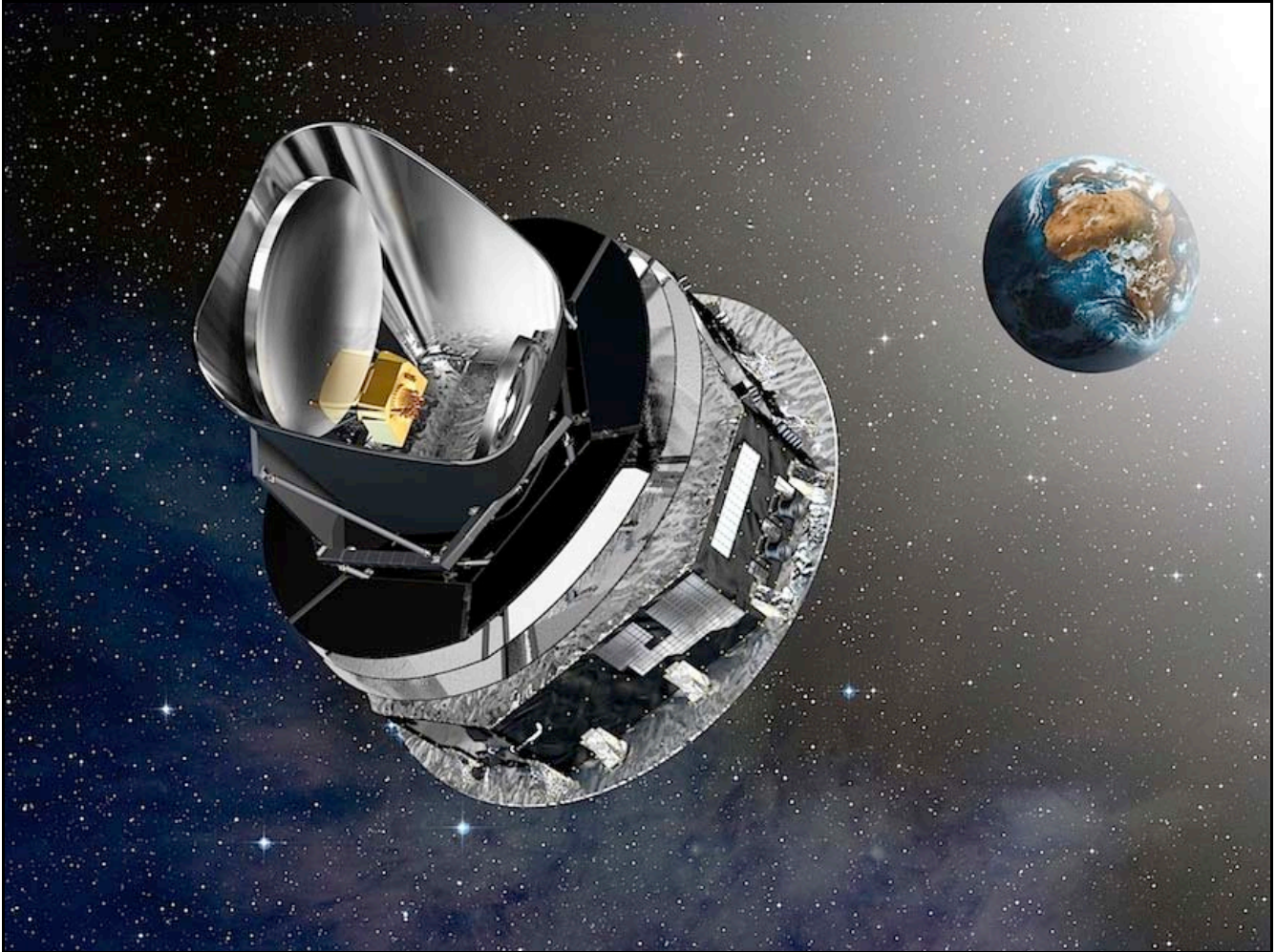


Enter Planck

Planck, shown above, is a space observatory satellite of the European Space Agency (ESA) designed to observe the anisotropies of the cosmic microwave background (CMB) over the entire sky, at microwave and infra-red frequencies with high sensitivity and small angular resolution. The project is named in honor of the German physicist Max Planck (1858–1947), who won the Nobel Prize in Physics in 1918.

Planck was launched in May 2009, reaching the Earth/Sun L_2 point in July, and by February 2010 had successfully started a second all-sky survey. On 21 March 2013, the mission's all-sky map of the cosmic microwave background was released.

For an essay on the Planck mission go to:
<http://fire.biol.wvu.edu/trent/alles/Efstathiou.pdf>



ESA's Planck Cruising to the L2 Point

Planck's mission complements and improves upon observations made by NASA's Wilkinson Microwave Anisotropy Probe (WMAP), which has measured the anisotropies at larger angular scales and lower sensitivity than Planck.

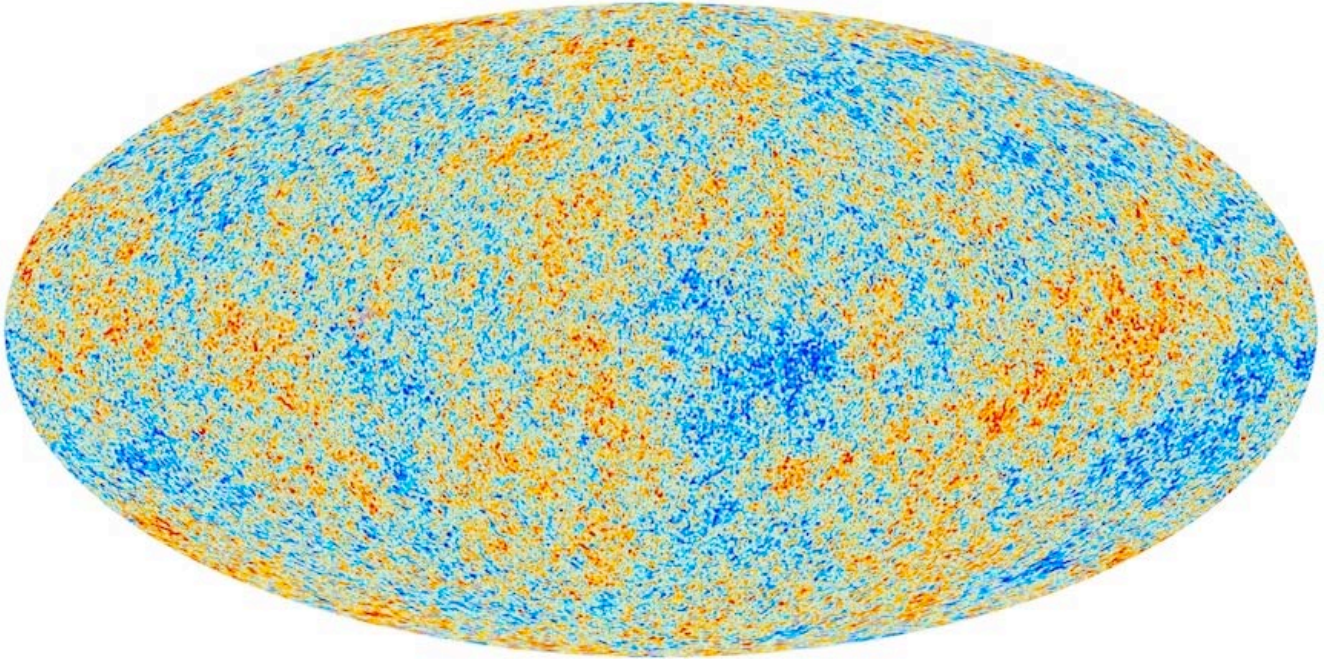
Planck represents an advance over WMAP in several respects:

- It has higher resolution, allowing it to probe the power spectrum of the CMB to much smaller scales ($\times 3$).
- It has higher sensitivity ($\times 10$). It observes in 9 frequency bands rather than 5, with the goal of improving the astrophysical foreground models.

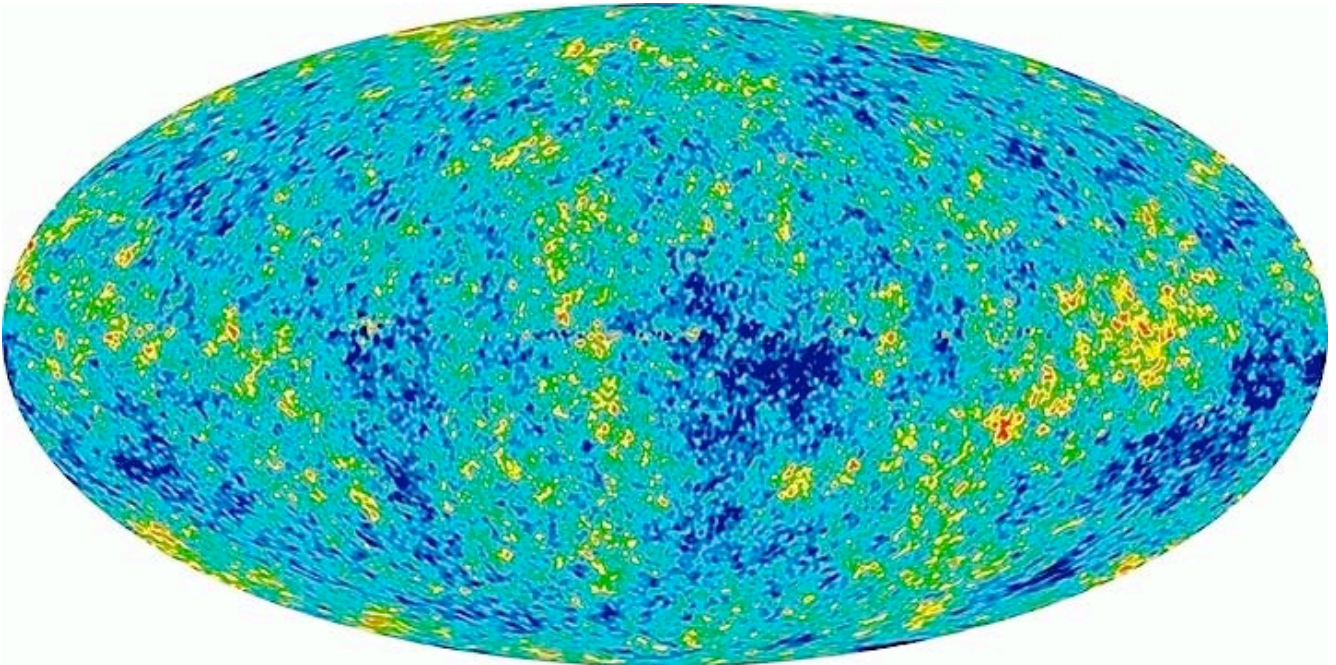
On the following page are two images that compare Planck's first CMB image to the last of WMAP's images of the CMB.

L2 Point

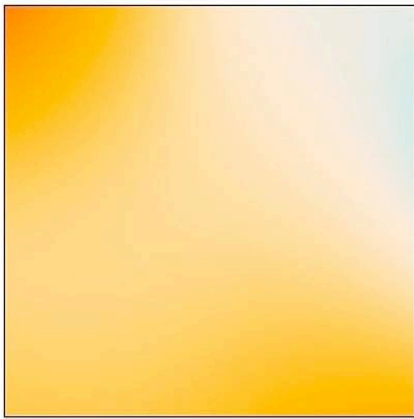
http://www.esa.int/Our_Activities/Operations/What_are_Lagrange_points



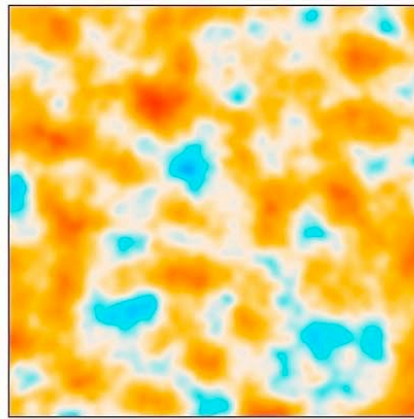
Planck CMB 2013-3-21



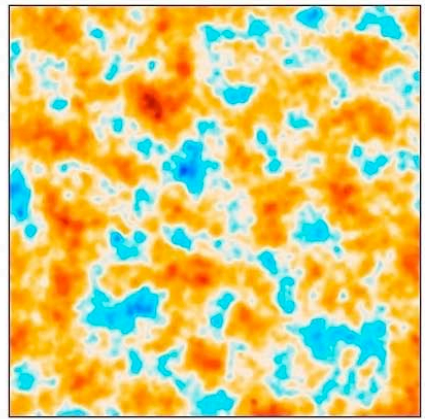
WMAP CMB 2012-9 yrs



COBE



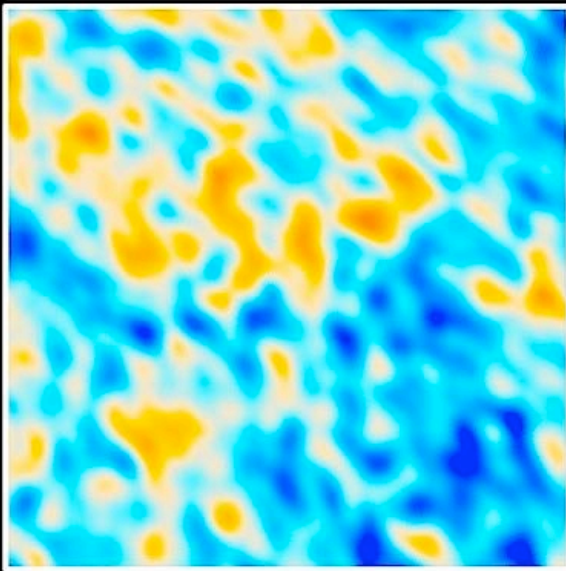
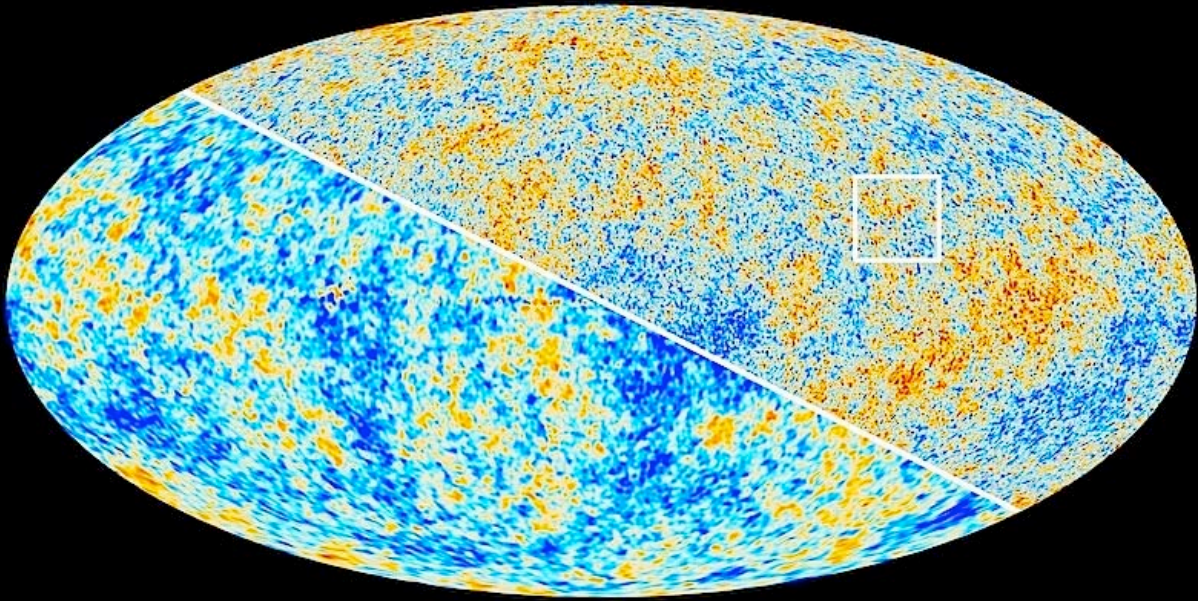
WMAP



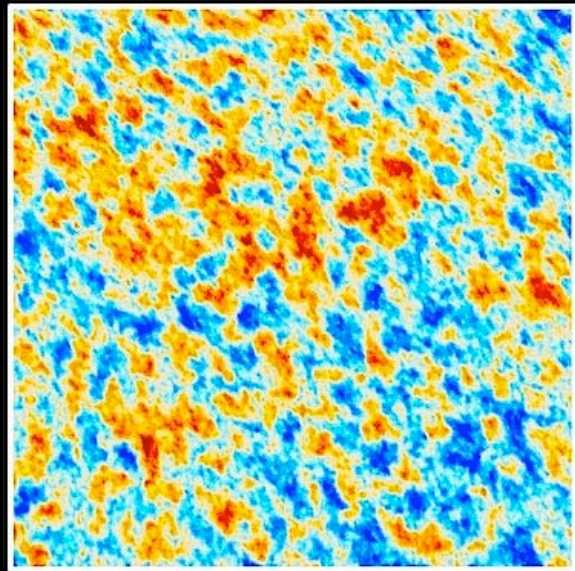
Planck

This comparison shows the dramatic difference in resolution between COBE and WMAP, and WMAP and Planck.

The Cosmic Microwave Background as seen by Planck and WMAP

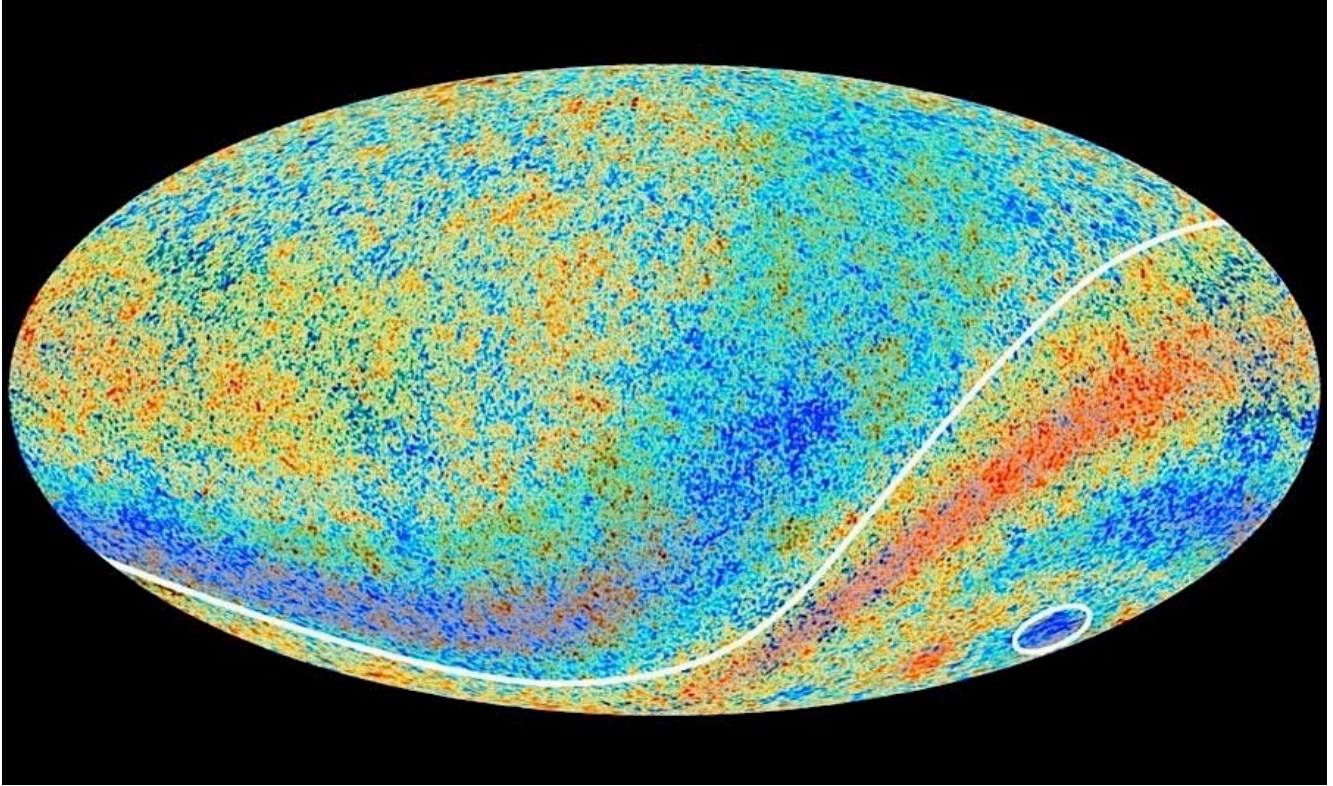


WMAP



Planck

ESA full sky CMB comparison of WMAP's resolution to Planck's



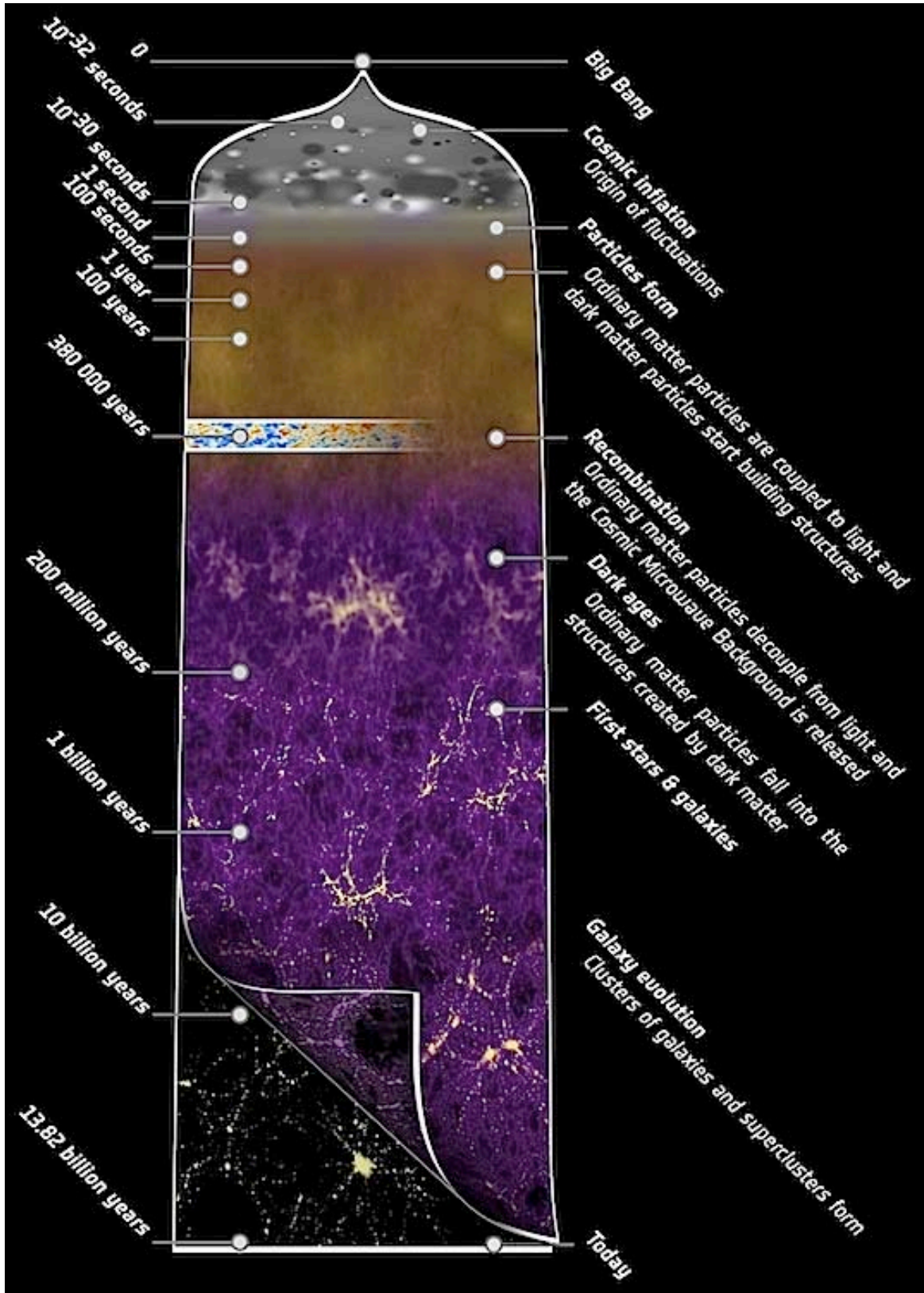
Planck Enhanced Anomalies

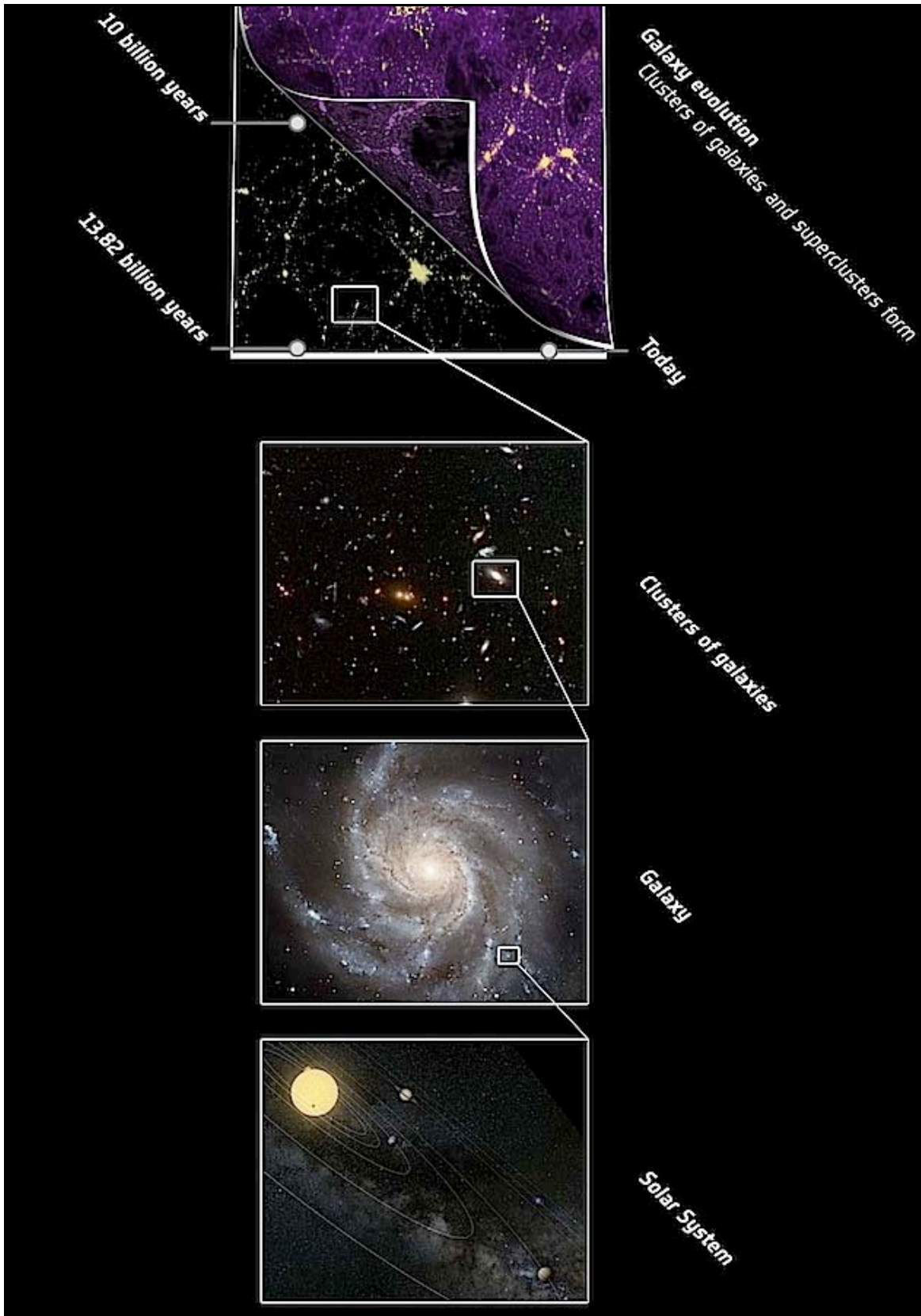
Two CMB anomalous features hinted at by Planck's predecessor, NASA's WMAP, are confirmed in the new high-precision data. One is an asymmetry in the average temperatures on opposite hemispheres of the sky (indicated by the curved line), with slightly higher average temperatures in the southern ecliptic hemisphere and slightly lower average temperatures in the northern ecliptic hemisphere. This runs counter to the prediction made by the standard model that the Universe should be broadly similar in any direction we look. There is also a cold spot that extends over a patch of sky that is much larger than expected (circled). In this image the anomalous regions have been enhanced with red and blue shading to make them more clearly visible.

Web Reference

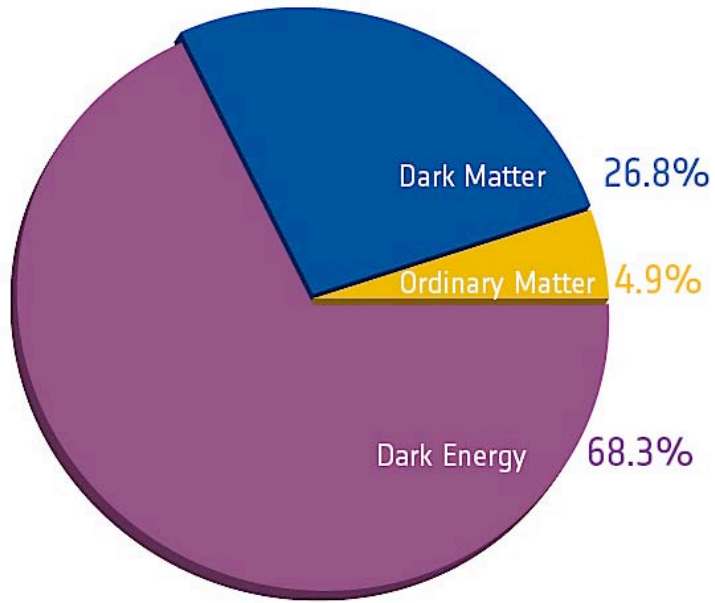
http://spaceimages.esa.int/Images/2013/03/Planck_enhanced_anomalies

ESA's Planck Time Line of our universe

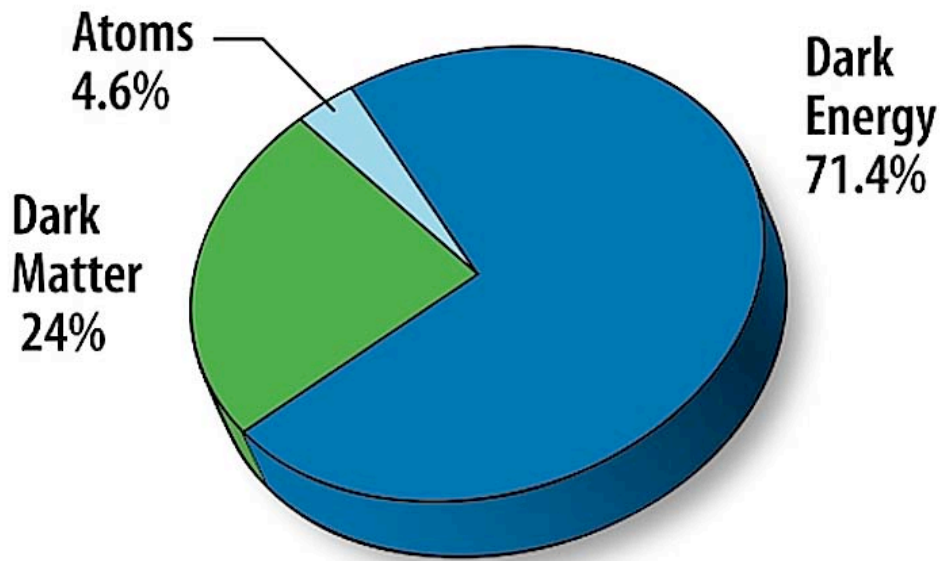




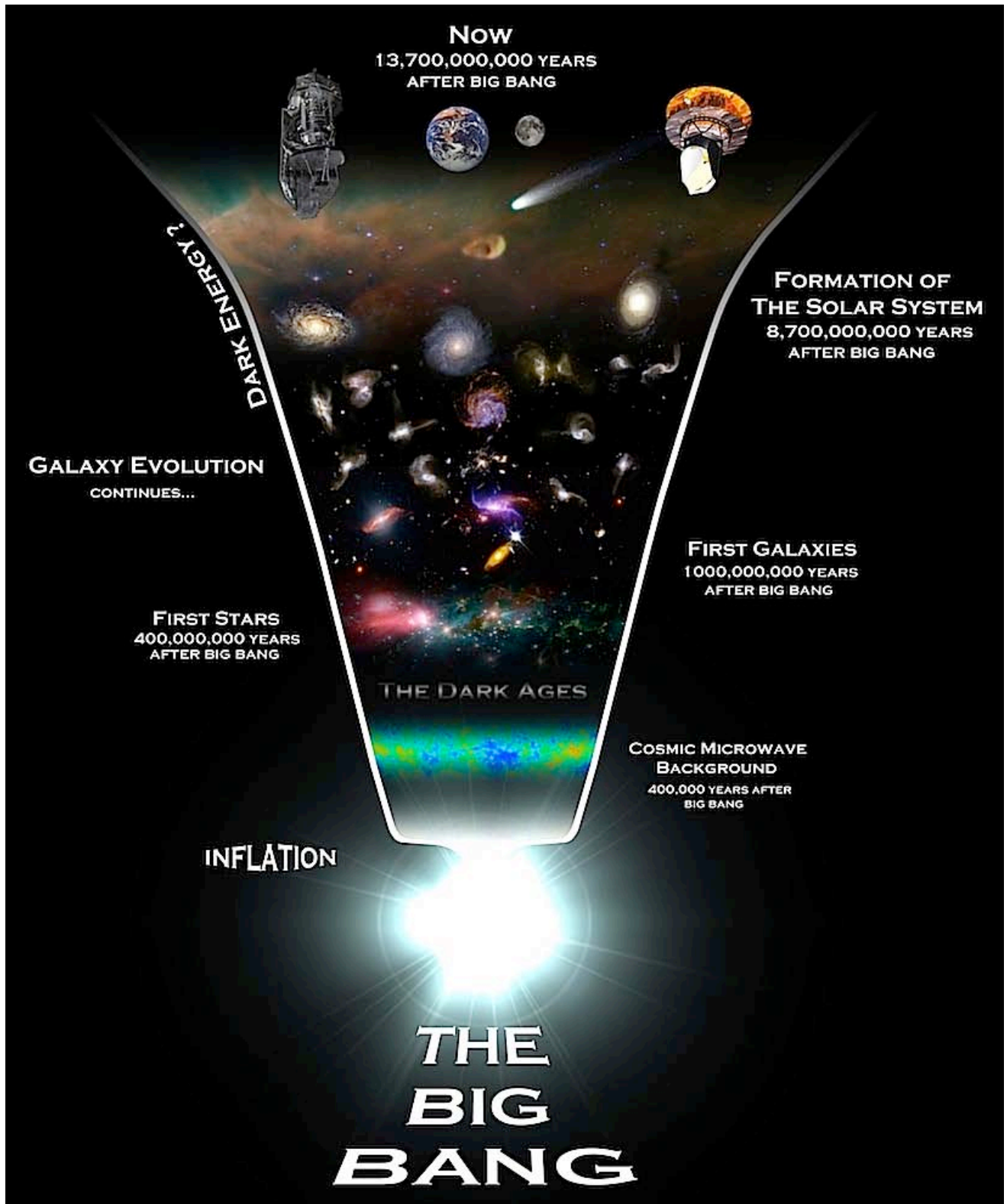
ESA's Planck Resolution of our universe



Planck Cosmic Pie Chart 2013-3-21



WMAP Cosmic Pie Chart 2012-9 yrs



ESA's Evolution of our universe

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Krauss, L. M. & Turner, M. S. (2004). A Cosmic Conundrum. *Scientific American*, (Sept), 71-77.

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On the State of Modern Cosmology

by David L. Alles, 2013-7-14

"The Catholic Church, which put Galileo under house arrest for daring to say that Earth orbits the sun, isn't known for easily accepting new scientific ideas. So it came as a surprise when Pope Pius XII declared his approval in 1951, of a brand new cosmological theory—the Big Bang. What entranced the pope was the very thing that initially made scientists wary: The theory says the universe had a beginning, and that both time and space leaped out of nothingness. It seemed to confirm the first few sentences of Genesis."(3)

As to the Universe from a philosophical view, in this case philosophical naturalism (4), there is only one tenable position. The Universe is eternal in time and infinite in space. There is no "outside of" the Universe. There is also a central tenet in philosophical naturalism that must be followed: We **can not** resort to "special creation"(5)—**ever**. It follows, then, that, if there is "something" now, rather than nothing, then there has always (in an absolute sense) been "something".

In addition to the central tenet of naturalism is the definition of "Universe" itself. The Universe *is* "all that exists"(6). This definition leaves no room for anything else. To view the Universe as finite in time, one would have to conceive of a *universal nothingness* before the existence of the Universe. Zero, zip, nada—reality would not exist. A universal nothingness is not the astrophysicists' concept of "space" where matter pops in and out of a quantum foam. There would be no space or time. A universal nothingness would have no events to mark time, no matter, no "dark matter", no "dark energy", nothing—including "nothing". So you see to go

from a "universal nothingness" to a "universal somethingness" you would have to violate the central tenet of naturalism. Science is restricted to the epistemological tenets of philosophical naturalism, which are commonly referred to as "methodological naturalism"(4).

If, however, the theoretical concept of "Multiverse"(7) is correct, then our particular "universe" is not "all there is." It is only one of possibly an infinite number of "universes" throughout eternity, as in a cyclic Universe (8), or in infinite space, as in multiple universes existing at the same time (9), or both (see Note 1). This implies that the fate of our particular "universe" isn't very important in the grand scheme of things. The "Multiverse" may well be unconcerned about the fate of our "universe".

There are two very important points to be made here:

Point 1) We are back to a very old position (10). Our "universe" because it has a linear history, must cycle into and out of different phases. It's cyclical (8). You see it is, after all, "turtles all the way down"(11) i.e. an infinite regression. But the Multiverse, itself, is infinite in time and space. It had no beginning and will have no end (see Notes 2 and 3).

Point 2) Copernicus strikes again (12)—it would be the greatest of hubris to think our "universe" with, and because of, its linear history, is all there is. Our Earth is not at the center of our "universe" and our "universe" probably isn't at the center of the Multiverse. After all, besides having infinite knowledge, what would it take to *prove* that our "universe" is all that there is? (see Note 4)

And finally, because of Gödel's Incompleteness Theorems (13) it may be fundamentally impossible to prove that our "universe" is all that there is. We are inside of it, and may never be able to see out.

At this point I will invoke "Ignorance" as a central epistemological principle. We simply don't know the fundamental nature of the Universe, and we probably never will. And perhaps we should learn to live with that. The problem is, of course, we don't know what we're capable of knowing. In other words—we don't know, what we can know. (see Note 5)

Notes:

Note 1) Universe or Multiverse; universe or multiverse

At one point or another a consensus must be reached on these terms. Currently, different authors apply different meanings to them as summarized below.

A. Universe—all that there is. It had a beginning, but will have no end (14)

B. Universe—all that there is, including possibly many smaller "baby universes"(9). These baby universes can themselves give rise to other "baby universes". These "baby universes" can also be referred to as "multiverses".

C. Multiverse — a non-cyclic "all that there is", that gives rise to many smaller "baby universes." These baby universes are also non-cyclic, but can give rise to other "baby universes". Tegmark's Level III many-worlds interpretation of quantum mechanics (7)

D. Multiverse — a cyclic M-theory "all that there is". This Multiverse cycles from one "universe" to another throughout eternity (8).



The Steinhardt-Turok Cyclical Multiverse (8)

Note: that I've tried to use capital letters, as in "Universe" and "Multiverse" when these terms are used to mean the entirety of existence — "all that there is." Whereas, I've used the lower case "universe" or "multiverse" to mean that these entities are a part of an all encompassing "Universe" or "Multiverse".

Note 2) Jainism's beliefs about the Cosmos (10)

"Jainism has been a major cultural, philosophical, social and political force since the dawn of civilization in Asia, and its ancient influence has been noted in other religions, including Buddhism and Hinduism." "Jains hold that the Universe is eternal, without beginning or end. However, the universe undergoes processes of cyclical change." "Jains do not believe in an omnipotent supreme being, creator or manager, but rather in an eternal Universe governed by natural laws."

Note 3) In trying to understand an infinite Universe, imagine instead a sphere where all of reality exists, but only on its surface. Then imagine you are on the surface of the sphere at some point—any point. Now you start walking, looking all the while for an edge—the end of reality. Your journey will be eternal, just as a cyclical universe is eternal. This is not a complicated idea. And, yet, as mortals our lives are linear with a beginning and an end. So we expect all of reality to be the same, but it isn't. (By the way, the edge of a sphere is up, not sideways. But in the case of the Universe there is no "up".)



Note 4) The history of Twentieth Century physics may be a history of the evils of hubris in science. We collectively thought we had the fundamental answers to the nature of the universe, but we didn't. "Lawrence Krauss, a cosmologist from Arizona State, said that most theories were wrong. 'We get the notions they are right because we keep talking about them,' he said. Not only are most theories wrong, he said, but most data are also wrong — at first— subject to glaring uncertainties. The recent history of physics, he said, is full of promising discoveries that disappeared because they could not be repeated."(2) Therefore, that ~68% of the universe is now thought to be "dark energy" is dark indeed (15) (16).

Note 5) "Ignorance" as a philosophical principle is underrated. We desperately need to know where our knowledge ends and our ignorance begins. Epistemology should be a fundamental component of what every would-be scientist should study. After all, we must know where the limits of our knowledge are in order to know where we should be working.

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(3) Lemonick, M. D. (2004). Before the Big Bang. *Discover* magazine, February, 36-41.
<http://discovermagazine.com/2004/feb/cover> (see print version)

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See also: http://www.infidels.org/library/modern/barbara_forrest/naturalism.html

(5) Definition of "special creation": http://en.wikipedia.org/wiki/Special_creation

(6) Definition of Universe: <http://en.wikipedia.org/wiki/Universe>

(7) Definition of Multiverse: <http://en.wikipedia.org/wiki/Multiverse>

(8) Definition of Cyclic M-theory Universe: http://en.wikipedia.org/wiki/Cyclic_model

See also Paul J. Steinhardt: <http://www.physics.princeton.edu/~steinh/>

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- (10) Jainism Cosmology: <http://en.wikipedia.org/wiki/Jainism>
- (11) "turtles all the way down": http://en.wikipedia.org/wiki/Turtles_all_the_way_down
- (12) The Copernican Principle: http://en.wikipedia.org/wiki/Copernican_principle
- (13) Gödel's Incompleteness Theorems:
http://en.wikipedia.org/wiki/Gödel's_incompleteness_theorems
- See also: Binder, P.-M. (2008). Philosophy of science: Theories of almost everything. *Nature* 455(16 Oct), 884-885, News and Views | doi:10.1038/455884a
http://fire.biol.wvu.edu/trent/alles/Binder_Nature_article.pdf
- (14) Standard Cosmological Model: http://en.wikipedia.org/wiki/Physical_cosmology.
- (15) Planck's 68.3% dark energy chart:
http://spaceimages.esa.int/Images/2013/03/Planck_cosmic_recipe
- (16) Wikipedia's "Dark Energy" entry: http://en.wikipedia.org/wiki/Dark_energy

Suggested Books:

- Paul J. Steinhardt & Neil Turok (2007). *Endless Universe: Beyond the Big Bang*. New York: Doubleday.
- Carroll, Sean (2010). *From Eternity to Here*. New York: Dutton.
- Krauss, Lawrence M. (2012). *A Universe from Nothing: Why There is Something Rather than Nothing*. New York: Free Press.

For further information on related topics go to:

Alles Lecture: *Cosmological Evolution*
http://fire.biol.wvu.edu/trent/alles/101Lectures_Index.html

Alles Biology Home Page
<http://fire.biol.wvu.edu/trent/alles/index.html>