Cosmic Microwaves and Dark Energy
NASA's First Two Nobel Prizes

Dr. Michelle Thaller
Assistant Director of Science for Communications
Code 600

the third NASA Nobel prize

Mather, John C. (GSFC-6600) <john.c.mather@nasa.gov>

To: THALLER, MICHELLE LYNN. (GSFC-6000) <michelle.thaller@nasa.gov>

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Hi Michelle,
I got to chat with Riccardo Giacconi today at the event with Sen. Mikulski at the Maryland Science Center. He has a NASA connection too, as the first Director of the STScI. He wasn't working at NASA for his Nobel work, but we can still claim him.
Cheers!
John

John Mather, Cell phone: 240-393-3879
Assistant Eileen Barnes, 301-286-5770, Eileen.P.Barnes@nasa.gov

Riccardo Giacconi

Nobel Prize 2002

First Director of STScI
Johns Hopkins University
P.I. Chandra Observatory Deep Field South

Jimmy Kimmel Live “Halloween Costumes that no one else will be wearing”

Two Out of Four of NASA's Nobel Prizes

(And Goddard Still Has Them All)

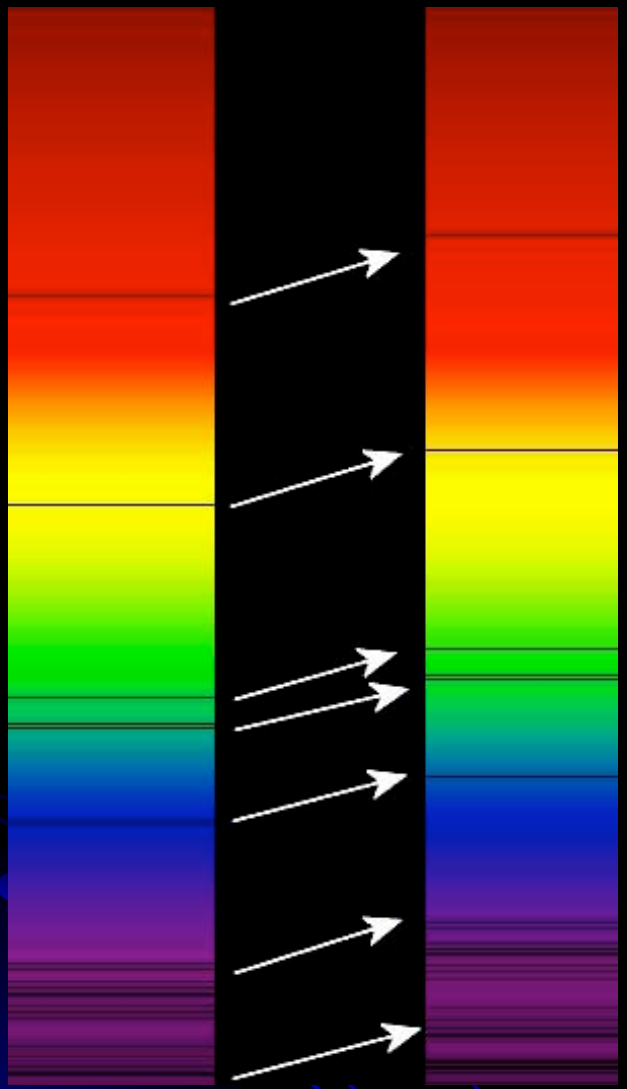
Astronomical scales

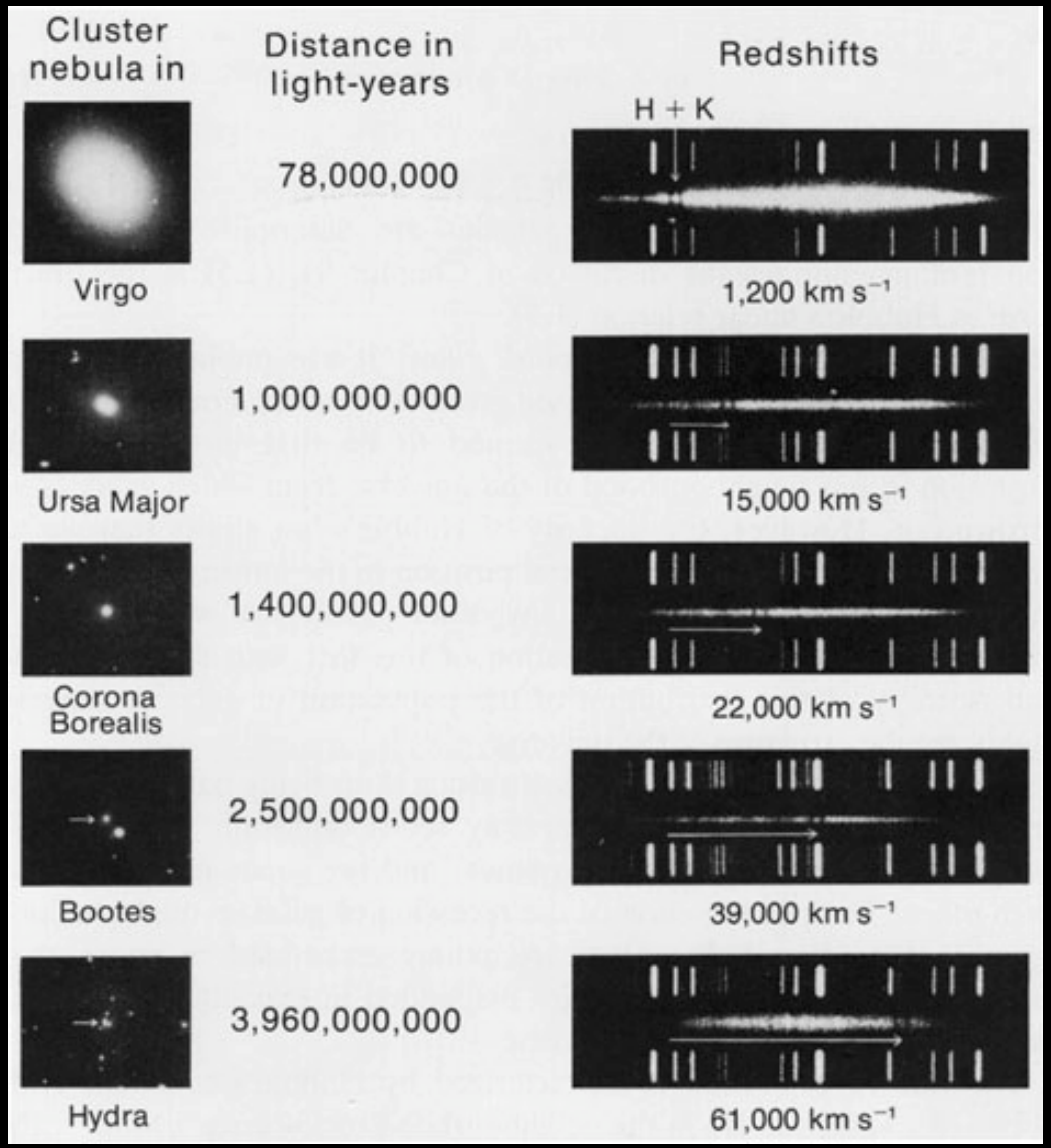
- The speed of light is 30,000,000,000 cm per second, or about 675 Million miles an hour.
- 1 lightyear is the distance light travels in one year, or about 6 trillion miles (6,000,000,000,000 miles)
- This means that everything we see far away in the universe is seen in the past. There is just no way to get the light here any faster.

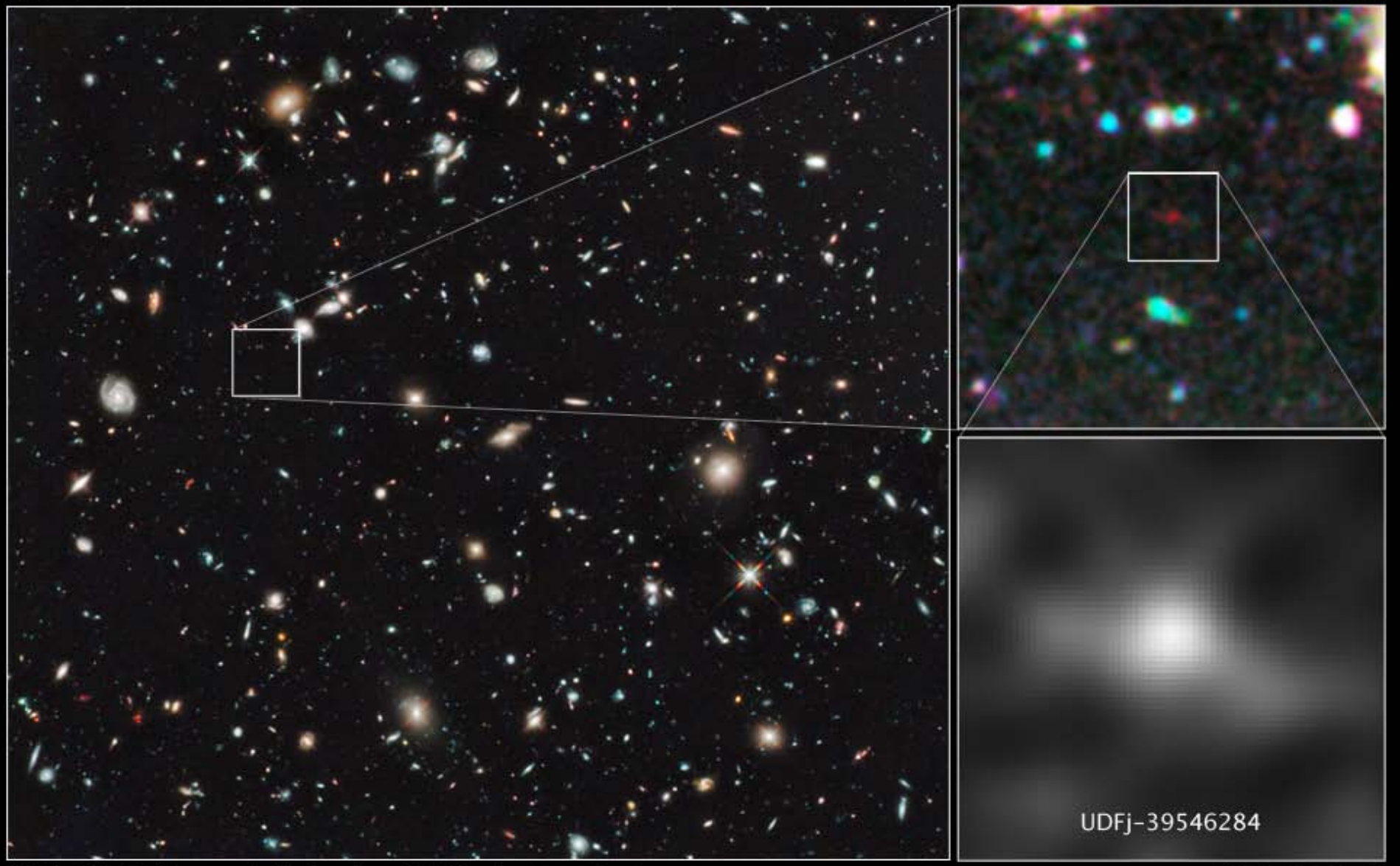
the BIG BANG THEORY

1923: The Discovery of Galaxies

1929: The Universe is Expanding!





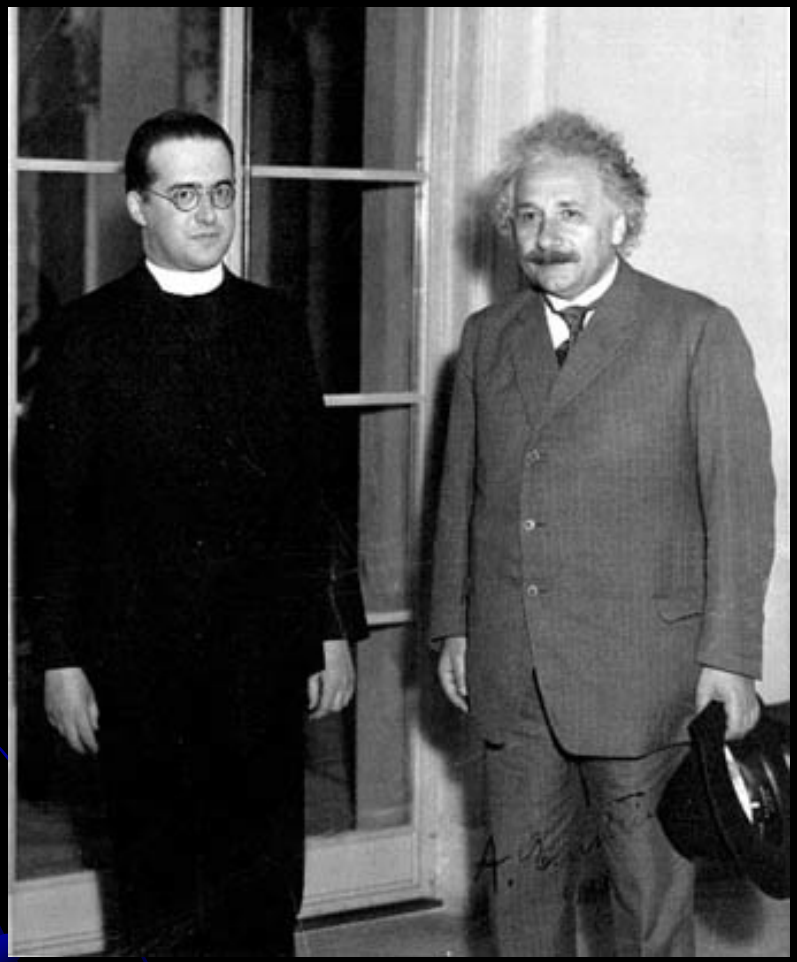


NASA, ESA, G. Illingworth (University of California, Santa Cruz),
R. Bouwens (University of California, Santa Cruz, and Leiden University), and the HUDF09 Team

STScI-PRC11-05

1927: Georges Lemaitre proposes “primeval atom.”

Fred Hoyle asks “Do you mean to say it all started with a big BANG?”



Big Bang Basics

- There is no privileged view-point, so there is no edge and no center of the universe.
- The universe includes all space and time. There is no “outside” of the expansion or “before” the Big Bang that is easily understood by humans (we’re trying, though).
- The universe was once very hot and dense, and has since cooled and expanded.
- All of space is expanding, so the farther away a galaxy is, the faster it recedes from us. The Hubble Constant is about 72 km/s/Mpc

The Theory:

At about 0.00000000000000000000000000000000001 seconds after the Big Bang, the Universe expanded hugely fast, smoothing everything out.

Any irregularities would be due to quantum fluctuations before this “inflation”

Universe was a hot, ionized plasma that was effectively opaque to light

When the whole universe cooled to around 3,000 K, electrons and protons formed Hydrogen atoms. Light now free to travel through the universe for the first time.

This should have happened around 379,000 years after the Big Bang

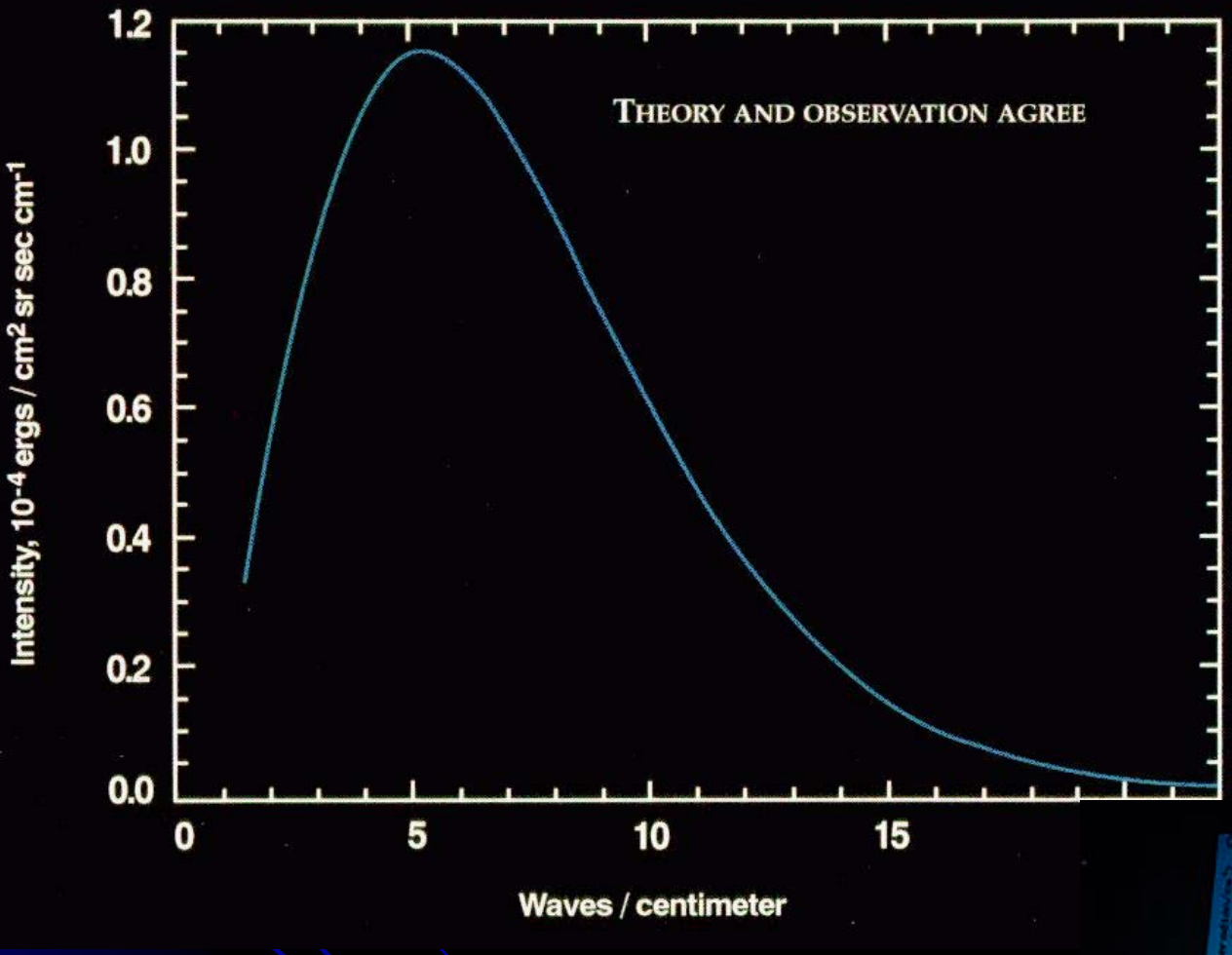
With the light losing energy as space expands, the temperature of these first photons should now be 2.73 degrees.

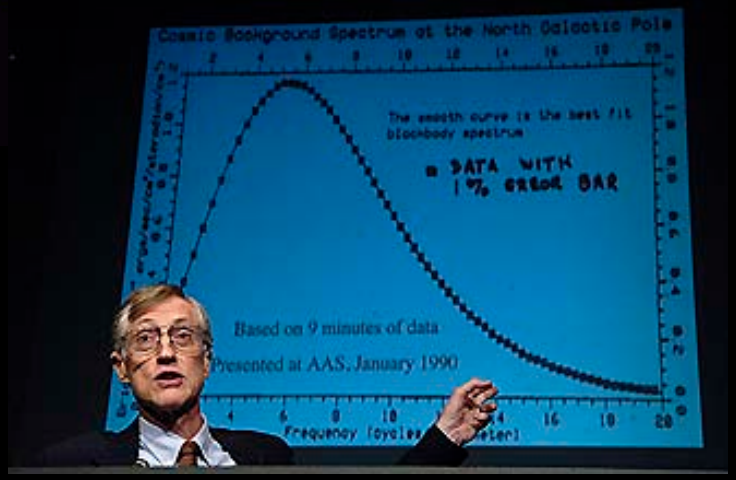
This microwave background predicted by Gamow, Alpher and Herman in 1948

1964: Penzias and Wilson had a problem with pigeons…

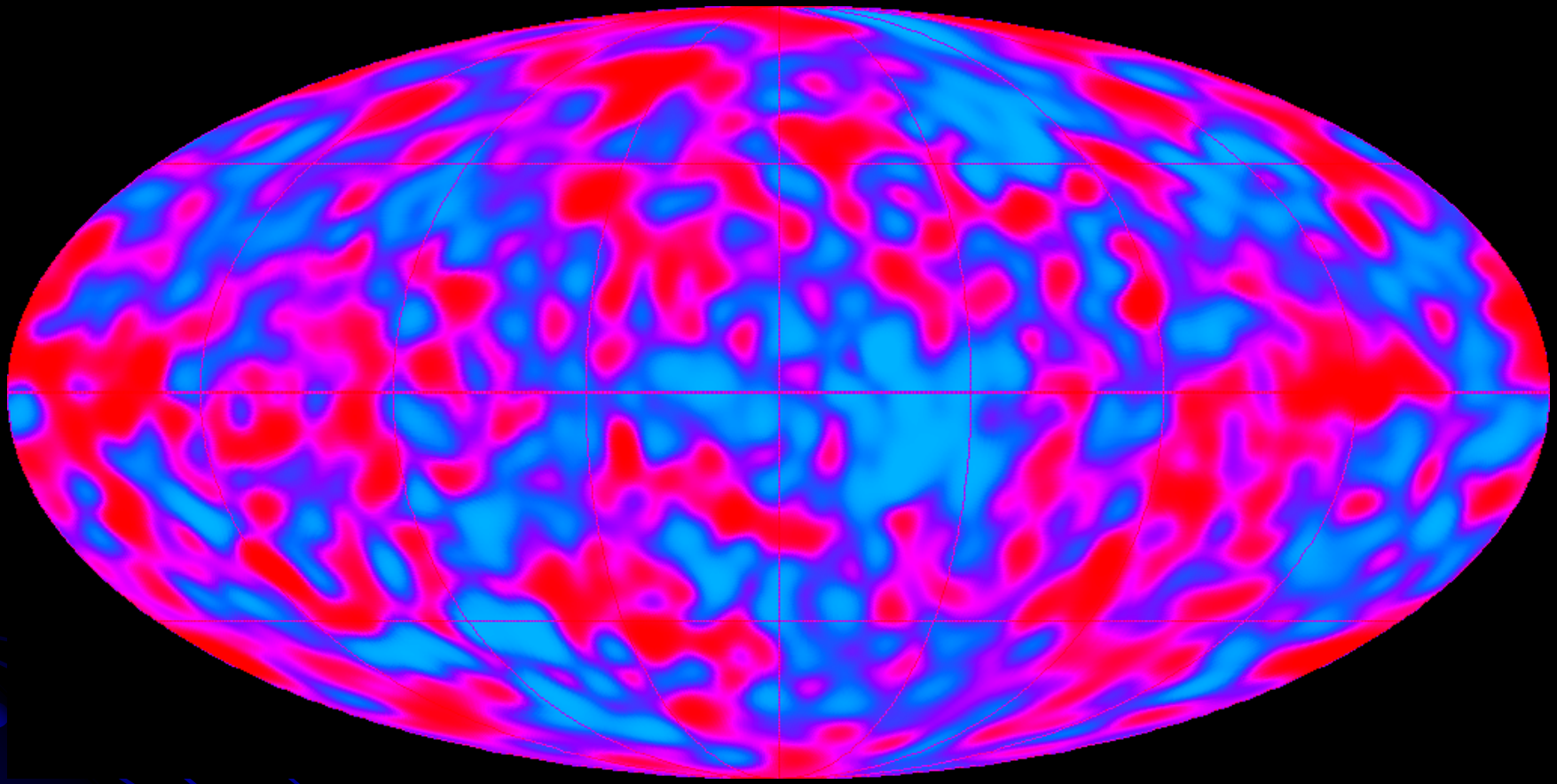

GSFC

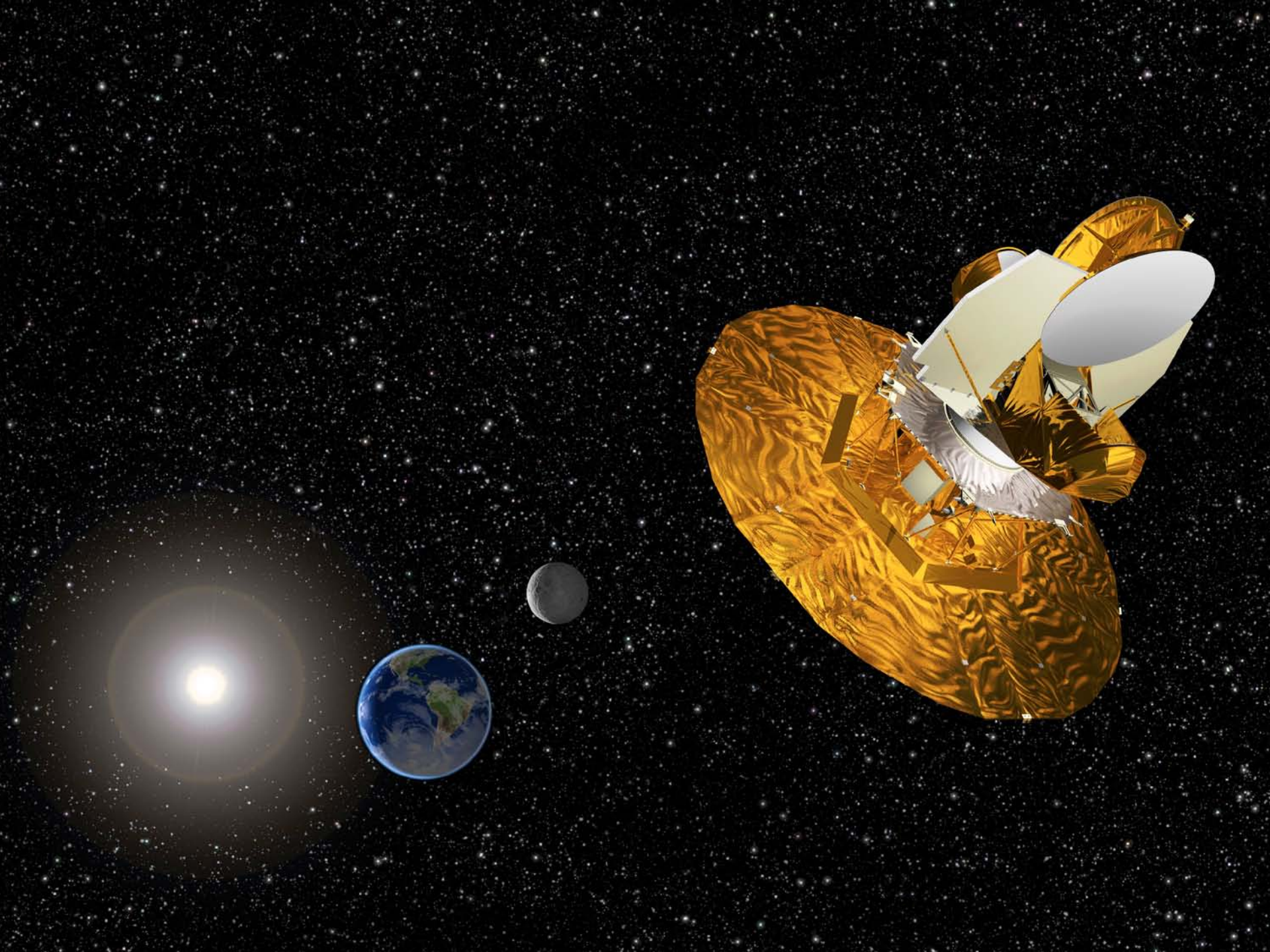
COSMIC MICROWAVE BACKGROUND SPECTRUM FROM COBE

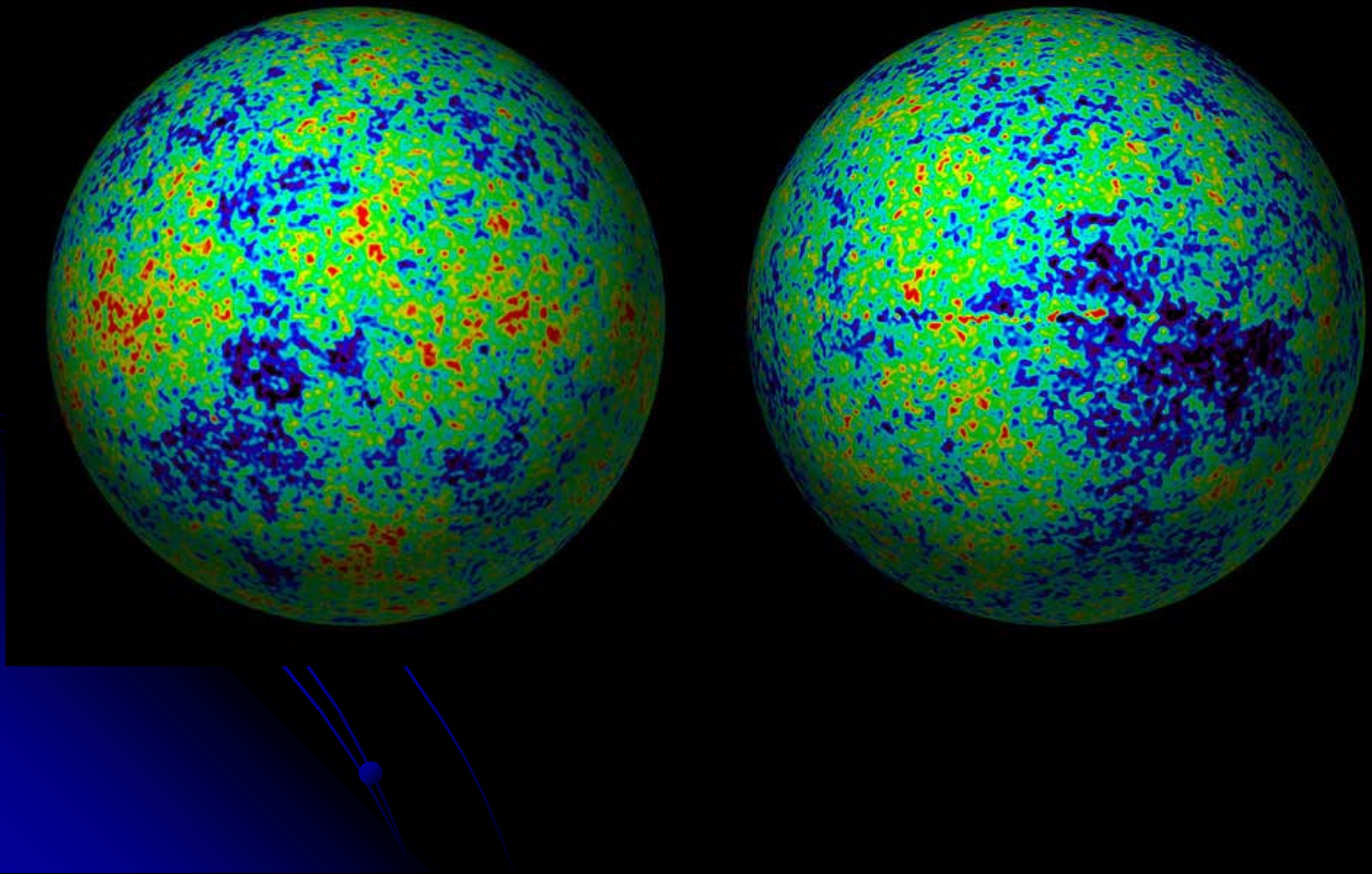


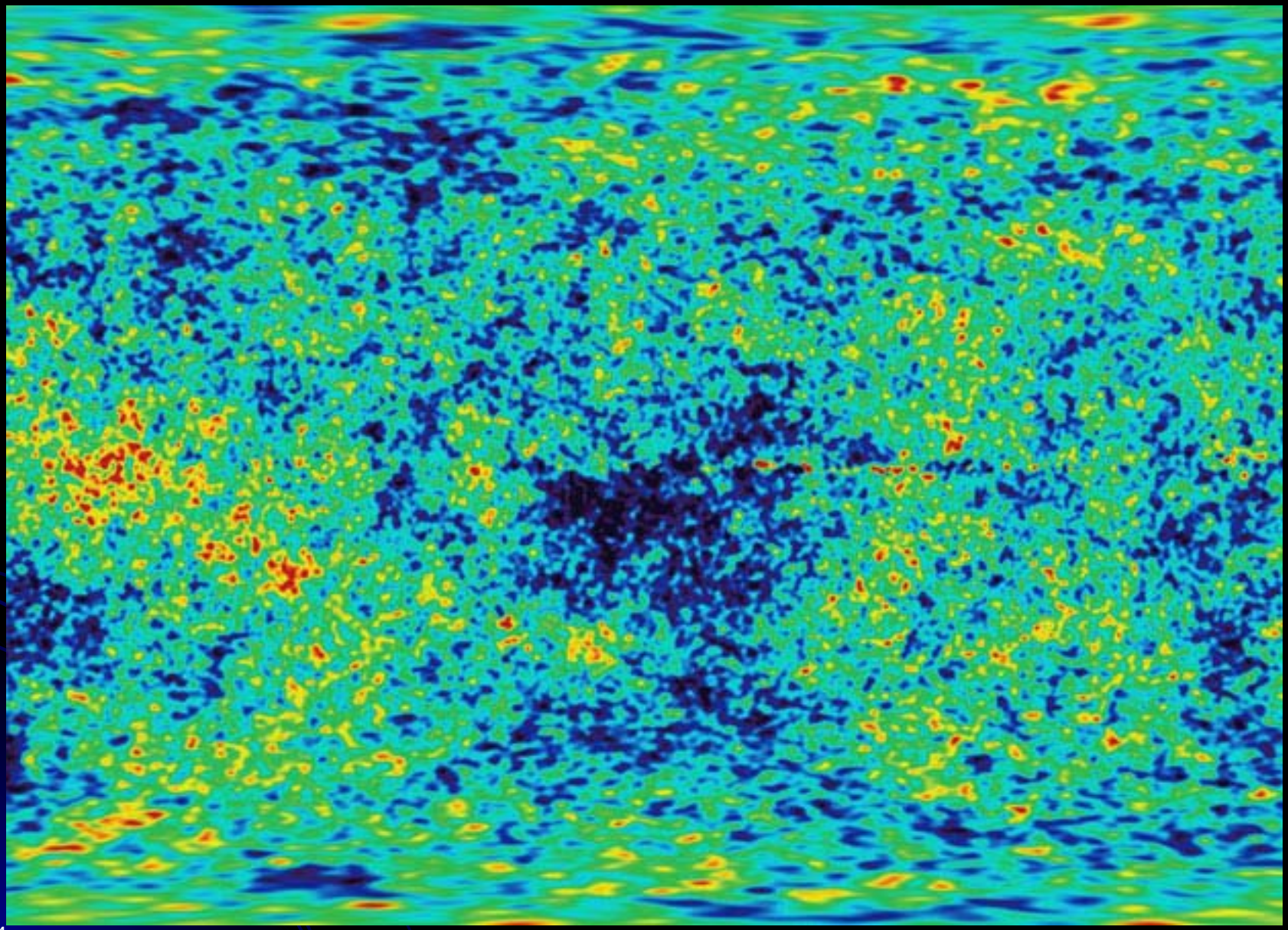


2007 Nobel Prize for Mather and Smoot



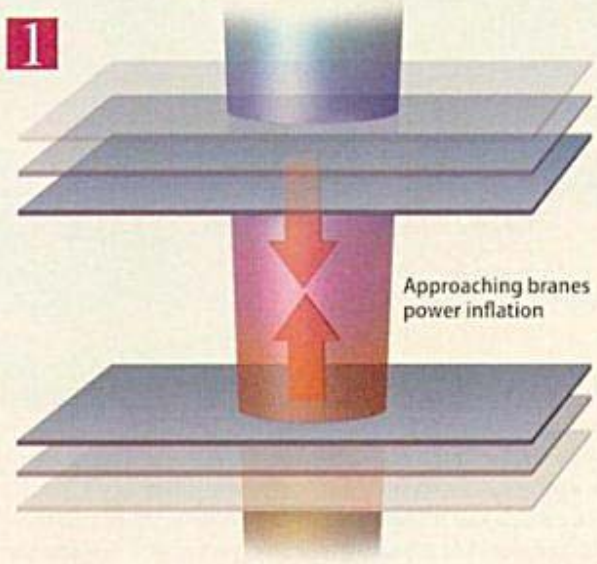




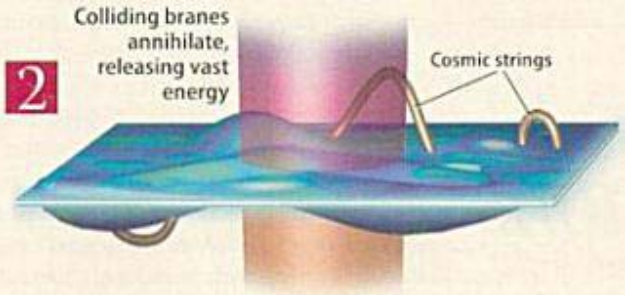


Did annihilating branes trigger the Big Bang?

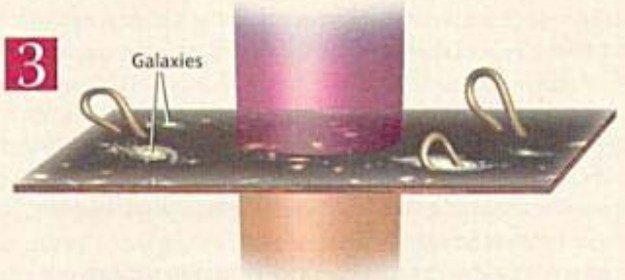
Physicists suggest a brane-antibrane pair interacted to create the Big Bang. Here's how it might have worked:



A brane and an anti-brane spanning our universe's three spatial dimensions move together. As they approach, inflation begins. The size of the universe grows a trillion trillion times and possibly creates ripples in space-time called gravitational waves.



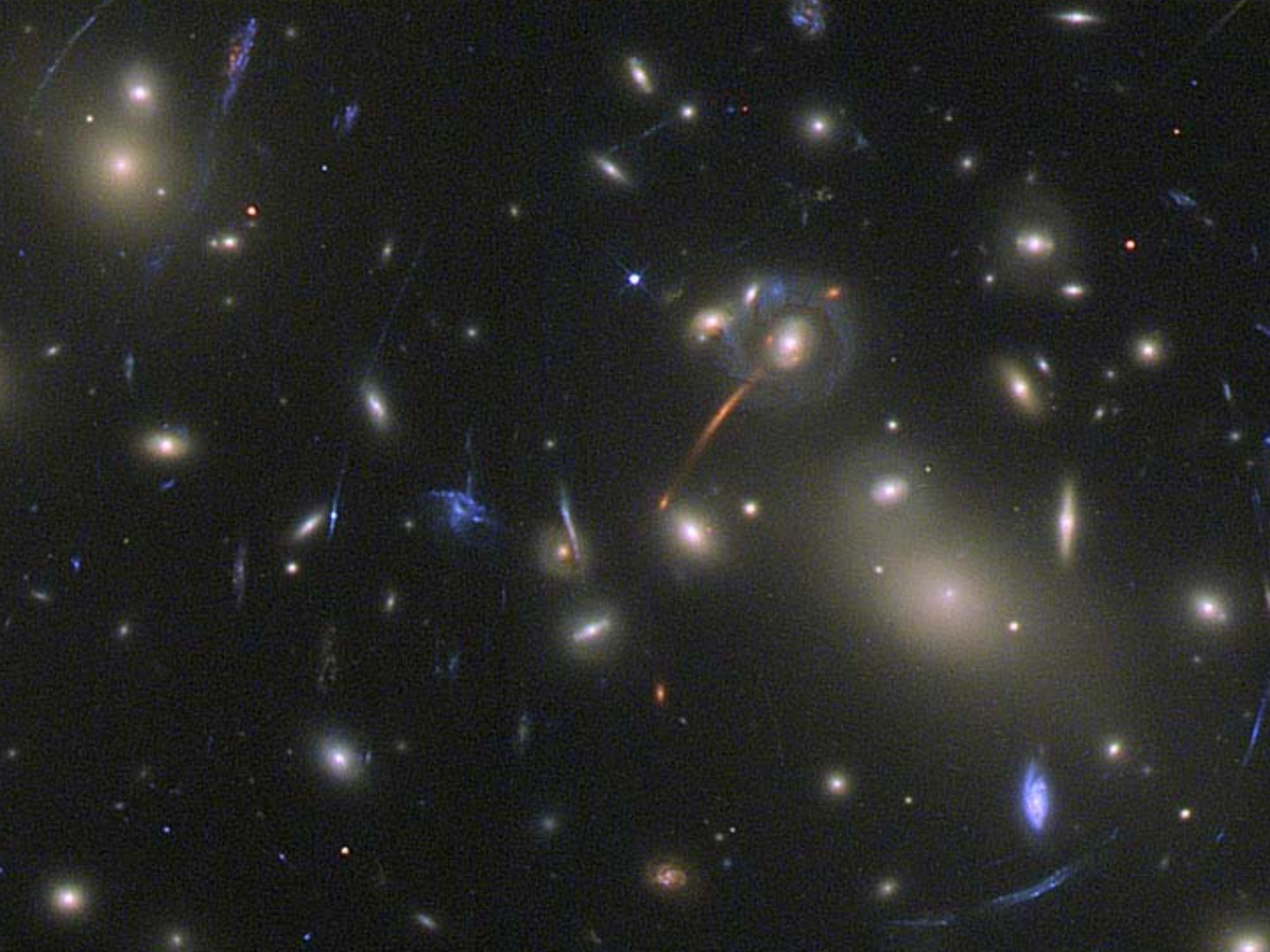
Inflation ends when the branes collide and annihilate each another. The energy release heats up our universe, initiating the hot Big Bang. The collision may also create cosmic strings. Such structures may reveal themselves by gravitational lensing of distant background objects or by polarizing the CMB.

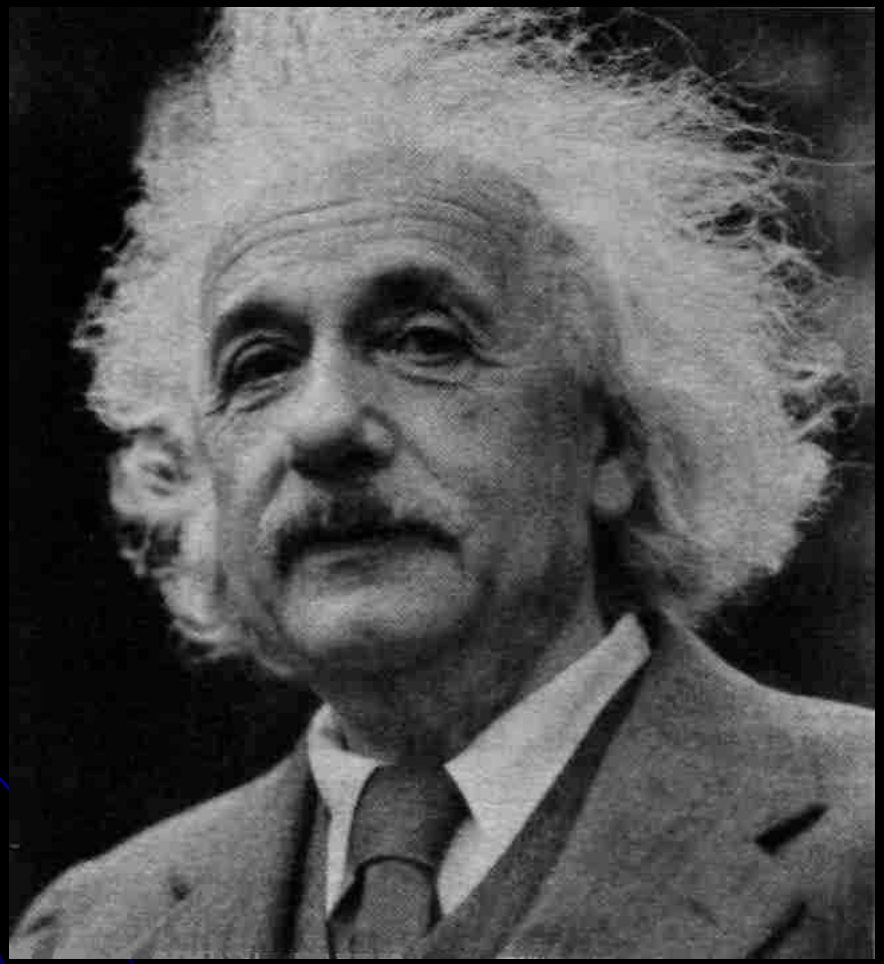


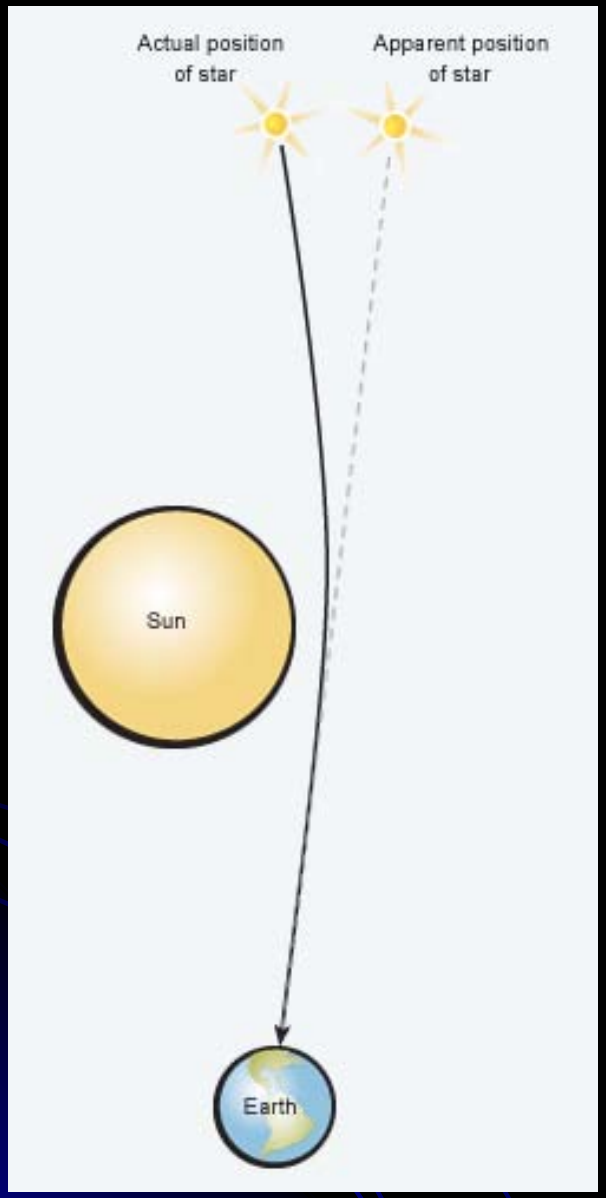
Density fluctuations produced during inflation become the seeds for today's cosmic structures. They also created the temperature fluctuations now being mapped in the CMB. ASTRONOMY: ROEN KELLY

Come to the dark side…

1934: Fred Zwicky notices that galaxies act like they have more mass then the stars can account for.
(A LOT more: about 400 times in the Coma Cluster).







General relativity a huge success (but never got a Nobel Prize)

One problem: the equations suggested that the universe must be either expanding or contracting.

This was obviously wrong, so Einstein added the “cosmological constant”

Age of the Universe:

Infinite

COSMIC TIMES

1919

Size of the Universe:

300,000 Light Years

SUN'S GRAVITY BENDS STARLIGHT

Einstein's Theory Triumphs

"One of the greatest—perhaps the greatest—of achievements in the history of human thought" was what Sir Joseph Thomson, President of the Royal Society of London, called Dr. Albert Einstein's prediction, which was apparently verified during the total eclipse of the Sun May 29 last.

Sir Joseph made his pronouncement during a discussion of the results from observations of the solar eclipse at a joint meeting of the Royal Society and the Royal Astronomical Society in London on Thursday evening, November 6, before a large attendance of astronomers and physicists. The excitement in the air was almost palpable as it seemed generally accepted that the observations were decisive in verifying the prediction of Dr. Einstein, Professor of Physics at the University of Berlin and Director of the Kaiser Wilhelm Physical Institute.

The prediction

According to the gravitational principles enunciated by Sir Isaac Newton in his classic work *Optics* some two centuries ago, a ray of light from a distant star just grazing across the edge of a massive object should be bent by an amount that depends on the object's mass and thus its gravitational field. Newton thought of gravity as a force that pulls things toward an object: the bigger the object, the stronger the pull.

The most massive object in the vicinity of the Earth is the Sun. So according to Newtonian principles, a light ray from a distant star grazing the edge of the Sun should be attracted or bent by the Sun's gravity by an amount equal to 0.87 seconds of arc. To be sure, that angle is very small, about equivalent to a human hair at 75 feet; but it is actually measurable on today's astronomical photographic plates if adequate care is taken.

Dr. Einstein's general theory of relativity, however, conceives of gravitation as indistinguishable from inertia. The "force" of gravity one feels pressing one down into a chair is the same as the "force" one feels when pulled forward in an automobile when the driver brakes.

According to Dr. Einstein, gravity, like inertia, doesn't pull. Instead, a mass warps or curves space and time surrounding the object. The amount of curvature is proportional to the amount of mass. The curvature of space then curves the paths taken by rays of light.

Dr. Einstein's theory, which is highly mathematical, predicts that the curvature of space around the Sun should bend starlight by twice

Herr Einstein in Berlin

the Sun and the stars to be photographed at the same time.

Prof. Eddington himself decided to lead an expedition to the island of Principe, in the Gulf of Guinea close to the coast of West Africa, near the end of the path of totality (see map). He also convinced the Astronomer Royal—Sir Frank Dyson, Director of the Royal Observatory, Greenwich—to send another expedition elsewhere, to minimize the chances of clouds interfering with the observations. Led by Dr. Andrew Crommelin from the Royal Observatory, it set up instruments at Sobral in northern Brazil, near the beginning of the path of totality.

At each of these places, if the weather were propitious on the day of the eclipse, it would be possible to take during totality a set of photographs of the obscured Sun along with a number of bright stars which happened to be in the vicinity.

actly as arranged, but out of the 16 plates taken, only two showed as many as five stars each. Prof. Eddington was also unable to stay several more months to take check-photographs of the star field.

Sir Frank explained in detail the apparatus both expeditions had employed, the way the photographic plates were measured back at the Greenwich Observatory, the corrections that had to be made for various disturbing factors, and the methods by which comparison between the theoretical and observed positions had been made. He convinced the meeting that the results were definite and conclusive, and that deflection did take place. He also asserted that the measurements showed that the extent of the deflection was in close accord with the theoretical amount predicted by Dr. Einstein, as opposed to half of that amount, the amount that would follow if the principles of Newton were correct.

"After a careful study of the plates I am prepared to say that there can be no doubt that they confirm Einstein's prediction," Sir Frank declared. "A very definite result has been obtained that light is deflected in accordance with Einstein's law of gravitation."

"For the full effect that has been obtained, we must assume that gravity obeys the new law proposed by Einstein," added Prof. Eddington. "This is one of the most crucial tests between Newton's law and the proposed new law."

WHY A TOTAL SOLAR ECLIPSE?

According to predictions by both Sir Isaac Newton and Dr. Albert Einstein, a ray of light from a star nearly behind the Sun (as seen from Earth) will be deflected—bent toward the Sun—as it passes by the limb (edge) of the Sun. Such a deflection would make the star look slightly farther away from the edge of the Sun than it really is.

Dr. Einstein's theory of relativity, however, predicts that the amount of the deflection should be double that predicted by Newtonian mechanics. The maximum shift, for a star whose ray of light just grazes the limb of the Sun, would be 1.75 seconds of arc, twice the amount Newton predicted (0.87 arcsecond). The apparent positions of stars closer to the Sun's limb would be shifted more than those of stars farther away.

The more stars around the Sun during a solar eclipse, and the more photographs astronomers can take, then the more accurately the differences between Dr. Einstein's predictions and Sir Isaac's

MT. WILSON ASTRONOMER ESTIMATES MILKY WAY TEN TIMES BIGGER THAN THOUGHT

But Disputes Suggestions that Spiral Nebulae are Other "Island Universes"

The Milky Way is a "discoidal" (disc-shaped) galaxy of stars 10 times bigger than astronomers had previously conceived, according to Mt. Wilson astronomer, Dr. Harlow Shapley. Moreover, he claims, the Sun exists nearer to its edge than to its center. But he disputes the hypotheses of other astronomers that scores of spiral nebulae seen in the starry heavens are other galaxies, or "island universes", that resemble the Milky Way.

In his tour-de-force series of papers throughout 1918 and 1919, the prolific Dr. Shapley examines other recent astronomical work in astonishing detail, as well as presenting the results of his own astronomical photography using the 60-inch reflector of the Mount Wilson Observatory in southern California. His particular subject of interest is globular star clusters—nearly spherical clusters of hundreds of stars that have long puzzled astronomers because of their peculiar positions in only certain parts of the sky. When Dr. Shapley began his study in 1914, 69 globular clusters were known; by the time he completed his work in 1918, he had added another 17 to the list.

In addition to pinpointing the exact position of each globular cluster in the sky, he also spread out their light into spectra to determine their motions, specifically whether they were approaching the Sun or receding from it. From these data, Dr. Shapley sought to calculate the gravitational forces on the clusters, to learn whether they were revolving around a common center, and if so, the location of that center. He also sought to determine the distances of the globular clusters from the Sun using the novel method of Cepheid variables pioneered by Miss Henrietta Leavitt of Harvard Observatory. He also looked at irregularly-shaped clusters of stars, the so-called "open clusters", as well as other individual stars and types of objects.

After four years of diligent study, often assisted by his wife Martha B. Shapley, Dr. Shapley has published a number of astonishing conclusions.

Dr. Shapley has concluded that "our galactic universe appears as a single, enormous, all-comprehending unit, the extent and form of which seem to be indicated through the dimensions of the widely extended assemblage of globular clusters." The center of our discoidal sidereal system "is distant from the Earth some twenty thousand parsecs"—more than 60,000 light-years—"in the direction of the constellation Sagittarius," Dr. Shapley continued.

His conclusions fly in the face of generally accepted astronomical wisdom. "Until the last year or so, most students of stellar problems believed rather vaguely that the Sun was not far from the center of the universe, and that the radius of the galactic system was of the order of 1,000 parsecs," he said (1,000 parsecs is more than 3,000 light-years). Some astronomers thought the galactic system might be as large as 10,000 to 20,000 light-years across. But according to Dr. Shapley, the positions of globular clusters in the arrangement of sidereal objects suggest "that the actual diameter of the galactic system is of the order of 100,000 parsecs", This is a staggering distance, larger than 300,000 light-years across, more than 10 times larger than any other astronomer had hypothesized.

"This newer conception greatly embarrasses the interpretation of spirals as stellar organizations of a size comparable to that of the Galaxy," Dr. Shapley said, because such a size would imply that the spirals were inconceivable distances away in space. "For example," he pointed out, "if any bright spiral of 10 minutes of arc in angular measure has an actual diameter directly comparable with that of the galactic system, its distance must be greater than a hundred million light-years.". Similarly, the average proper motions suggested by the careful observational measurements of several astronomers "would indicate appalling velocities in space."

In short, Dr. Shapley concludes, many observations "all seem definitely to oppose the "island universe" hypothesis of the spiral nebulae."

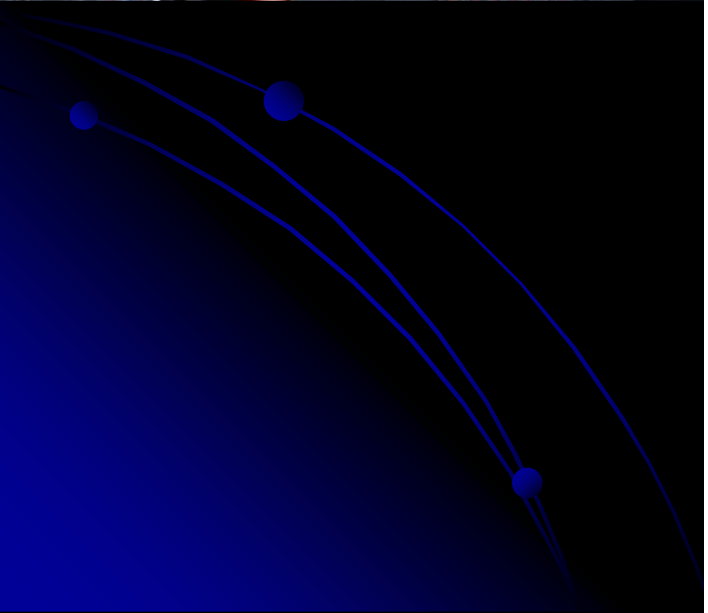
EXPANDING OR CONTRACTING?

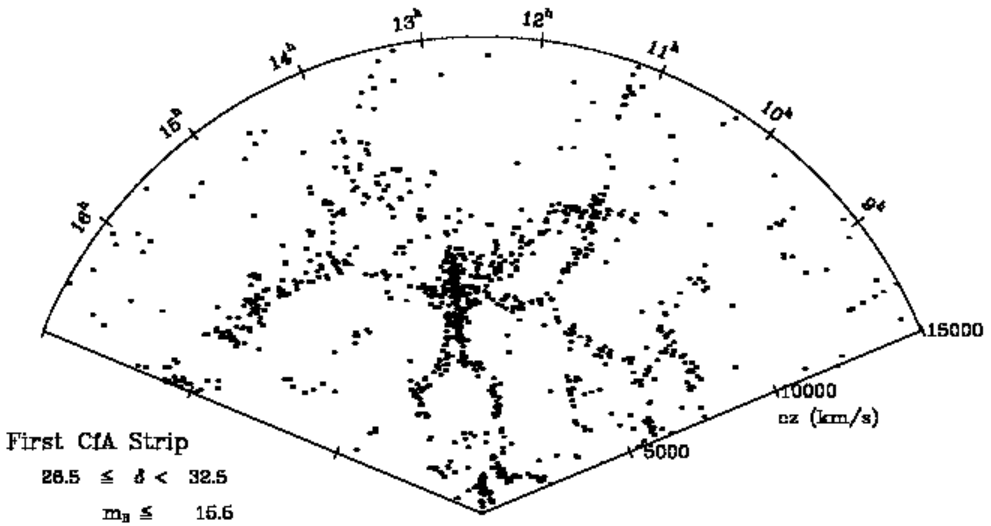
Einstein's Theory Predicts Universe Must be Doing One or the Other

Einstein Says Neither

In 1917, Albert Einstein and the Dutch astronomer Willem de Sitter showed that Einstein's general theory of relativity could describe a highly simplified universe.

But when it was applied to the real universe full of stars, there was a difficulty.

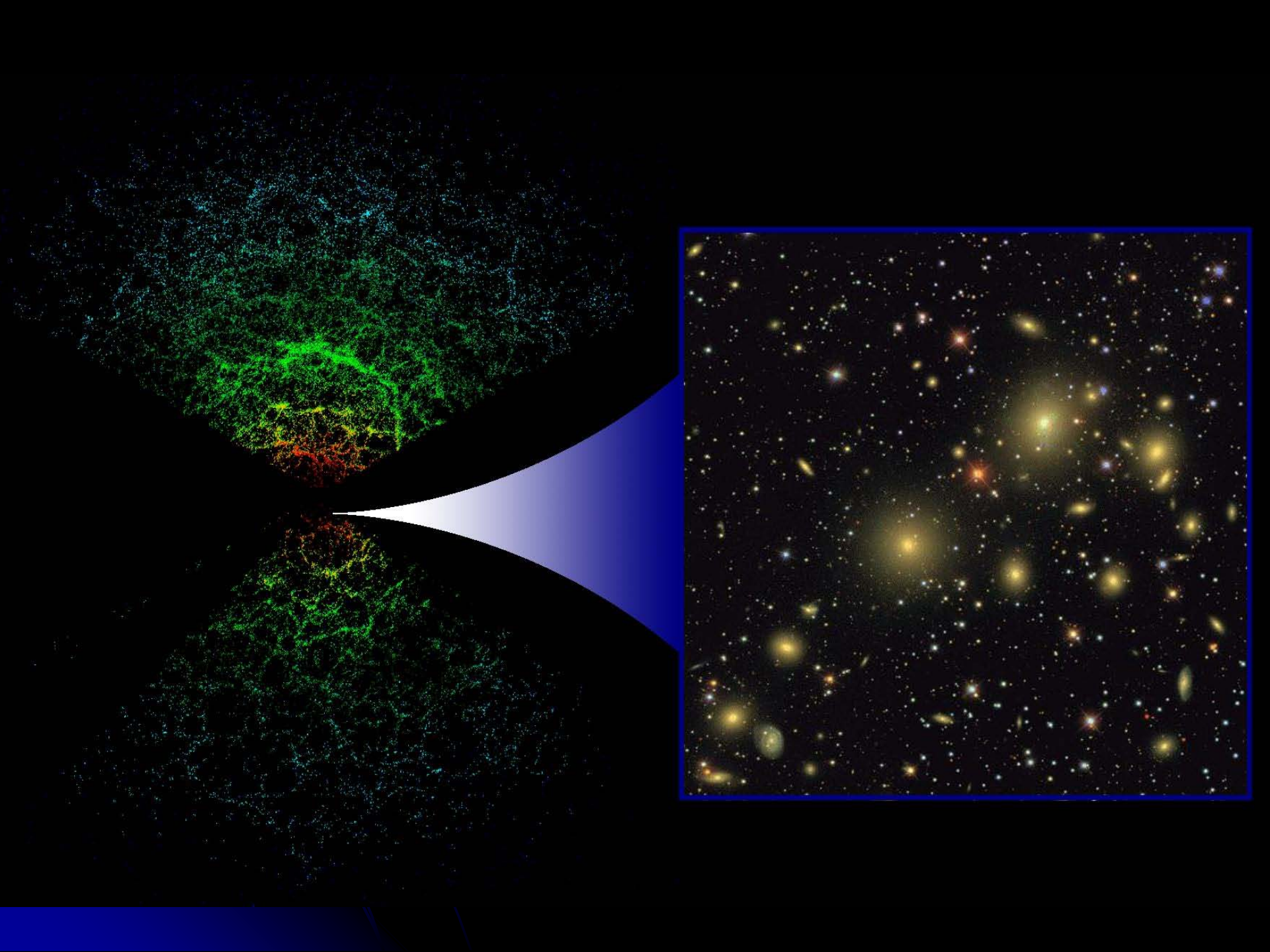


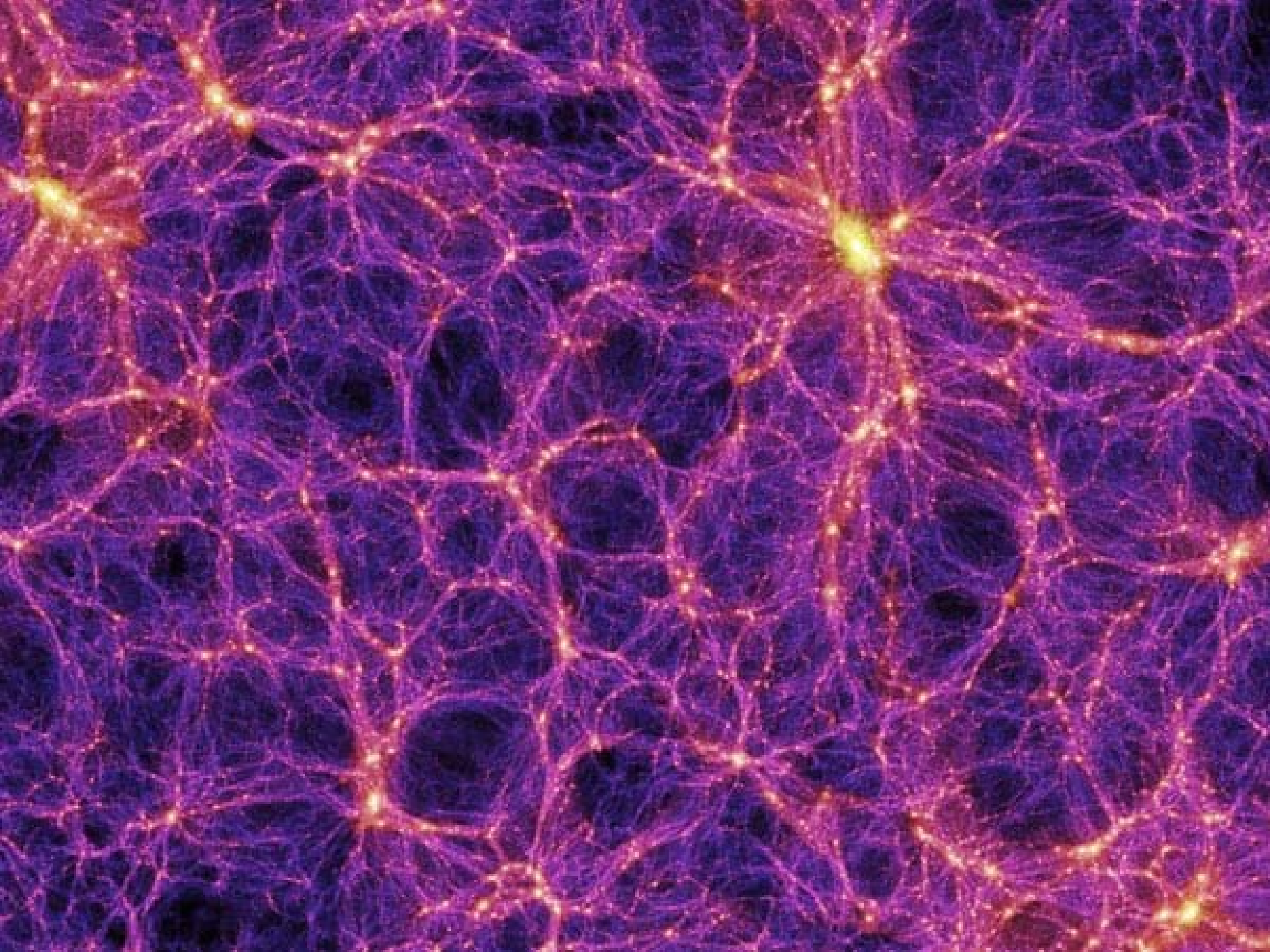


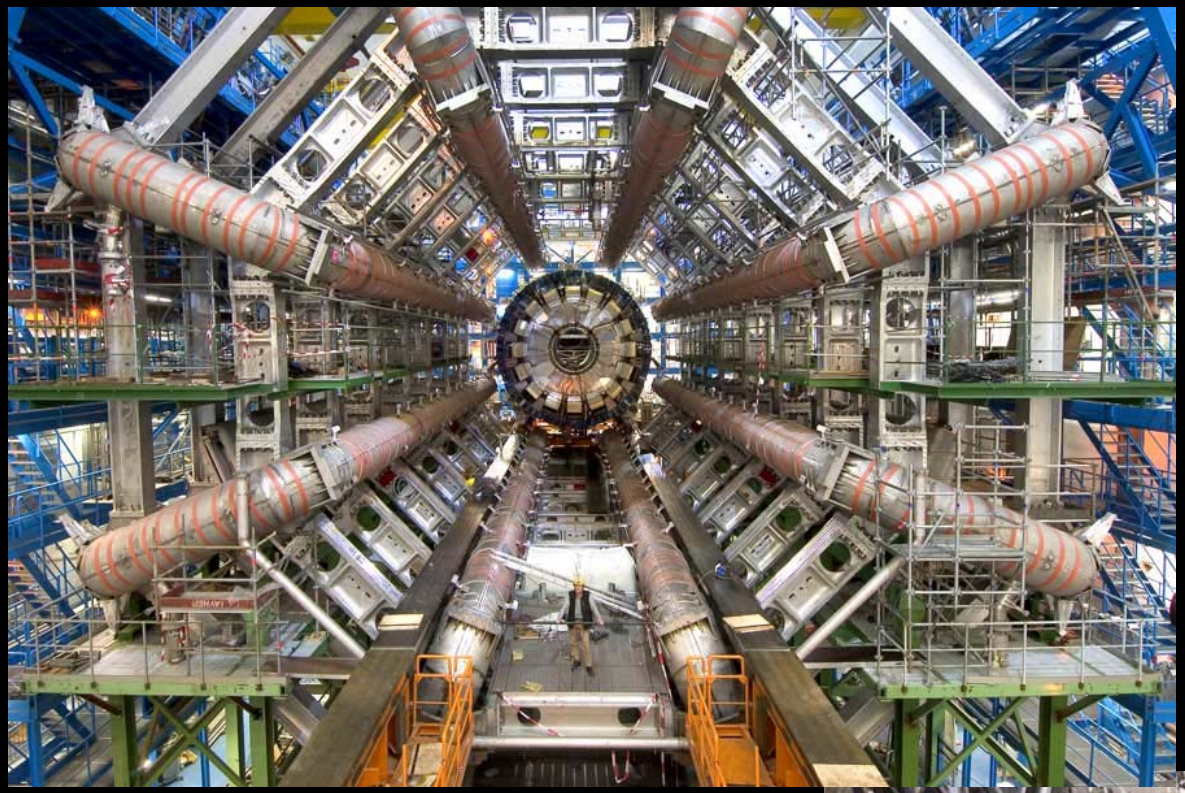
First CfA Strip

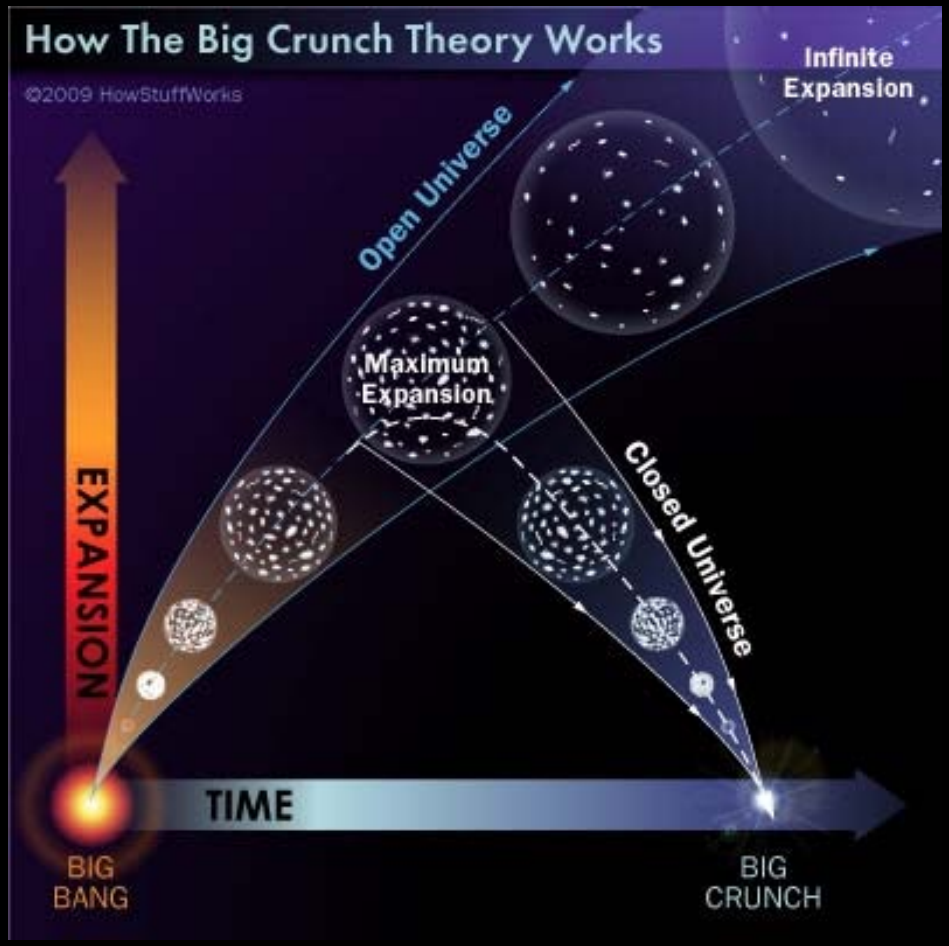
$26.5 \leq \delta < 32.5$

$m_B \leq 15.6$

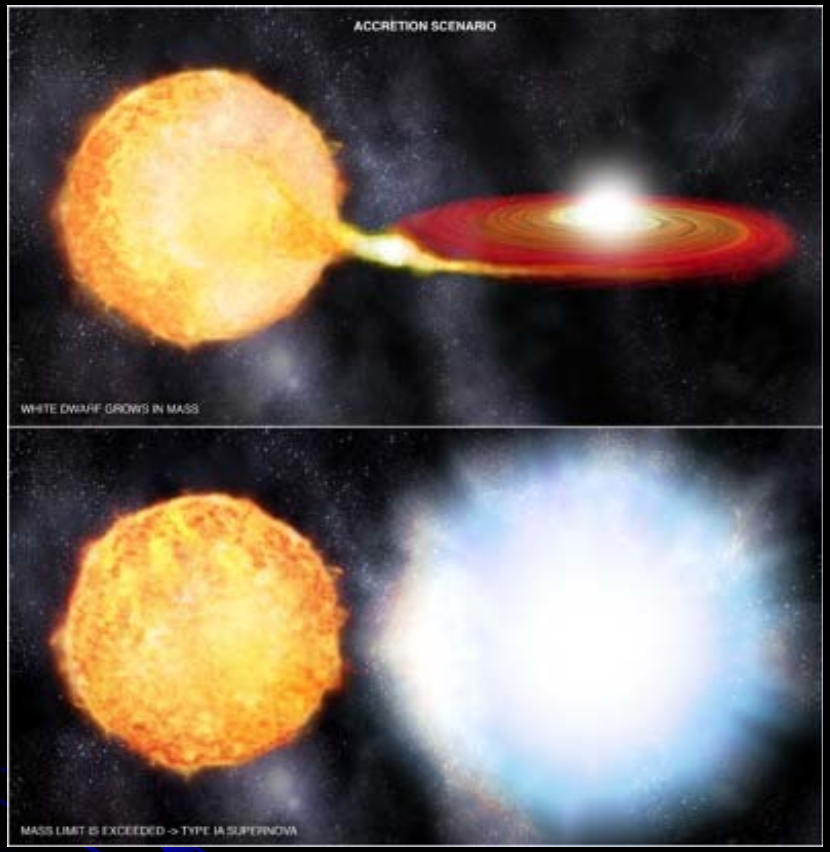


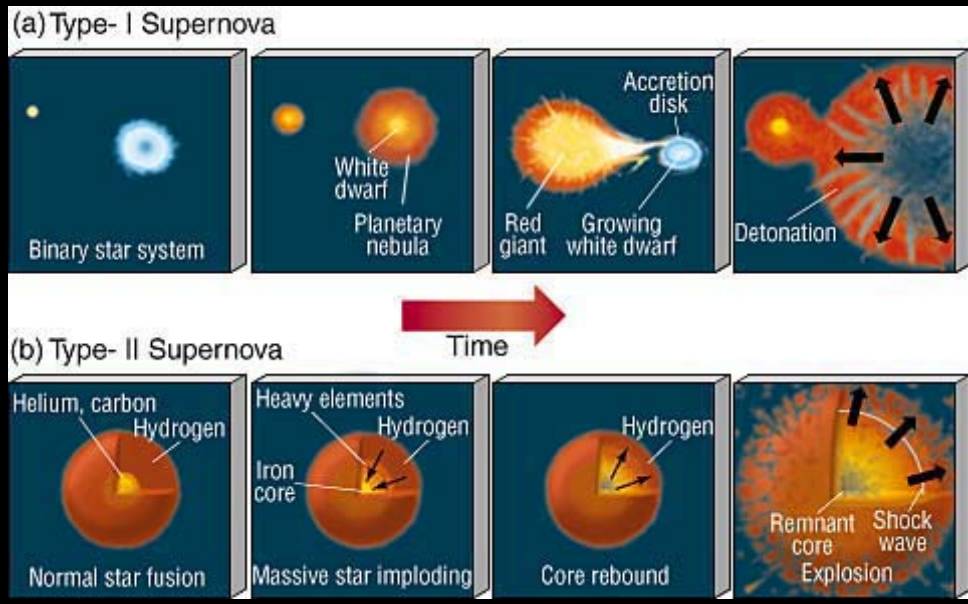


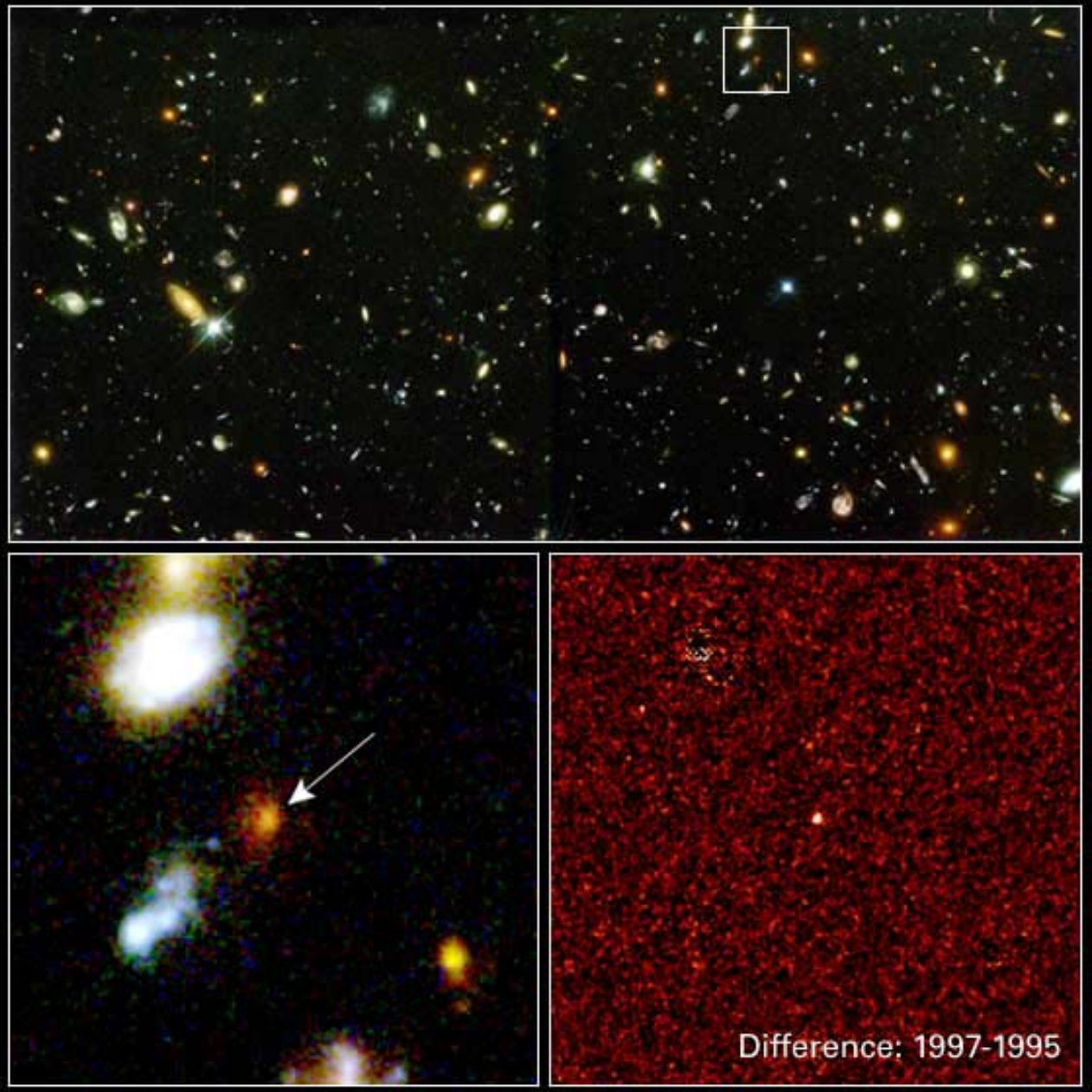




Maybe the Hubble Constant isn’t really constant…

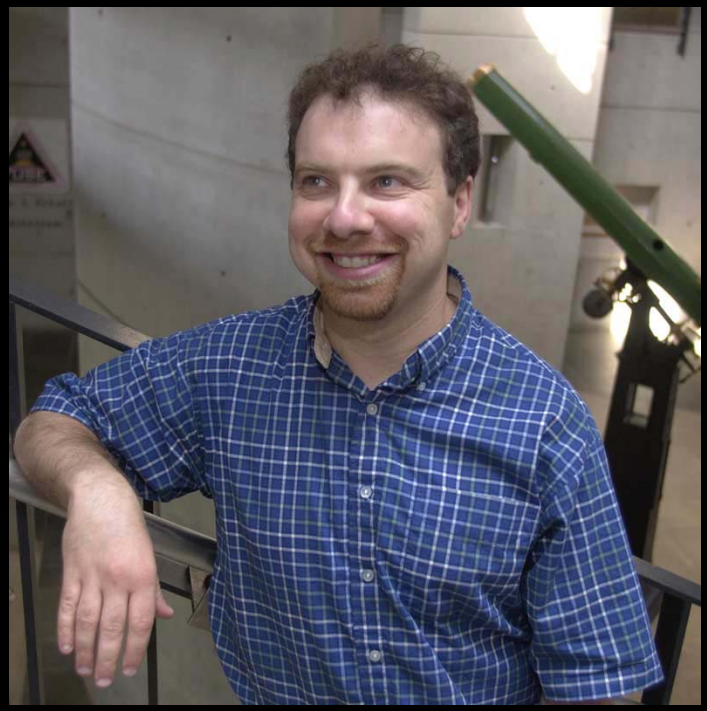

ACCRETION SCENARIO
WHITE DWARF GROWS IN MASS
MASS LIMIT IS EXCEEDED -> TYPE IA SUPERNOVA


(a) Type- I Supernova
Binary star system
White dwarf
Planetary nebula
Red giant
Accretion disk
Growing white dwarf
Detonation
Time
(b) Type- II Supernova
Helium, carbon
Hydrogen
Normal star fusion
Heavy elements
Hydrogen
Iron core
Massive star imploding
Hydrogen
Core rebound
Remnant core
Shock wave
Explosion



Distant Supernova in the Hubble Deep Field **HST • WFPC2**

NASA and A. Riess (STScI) • STScI-PRC01-09

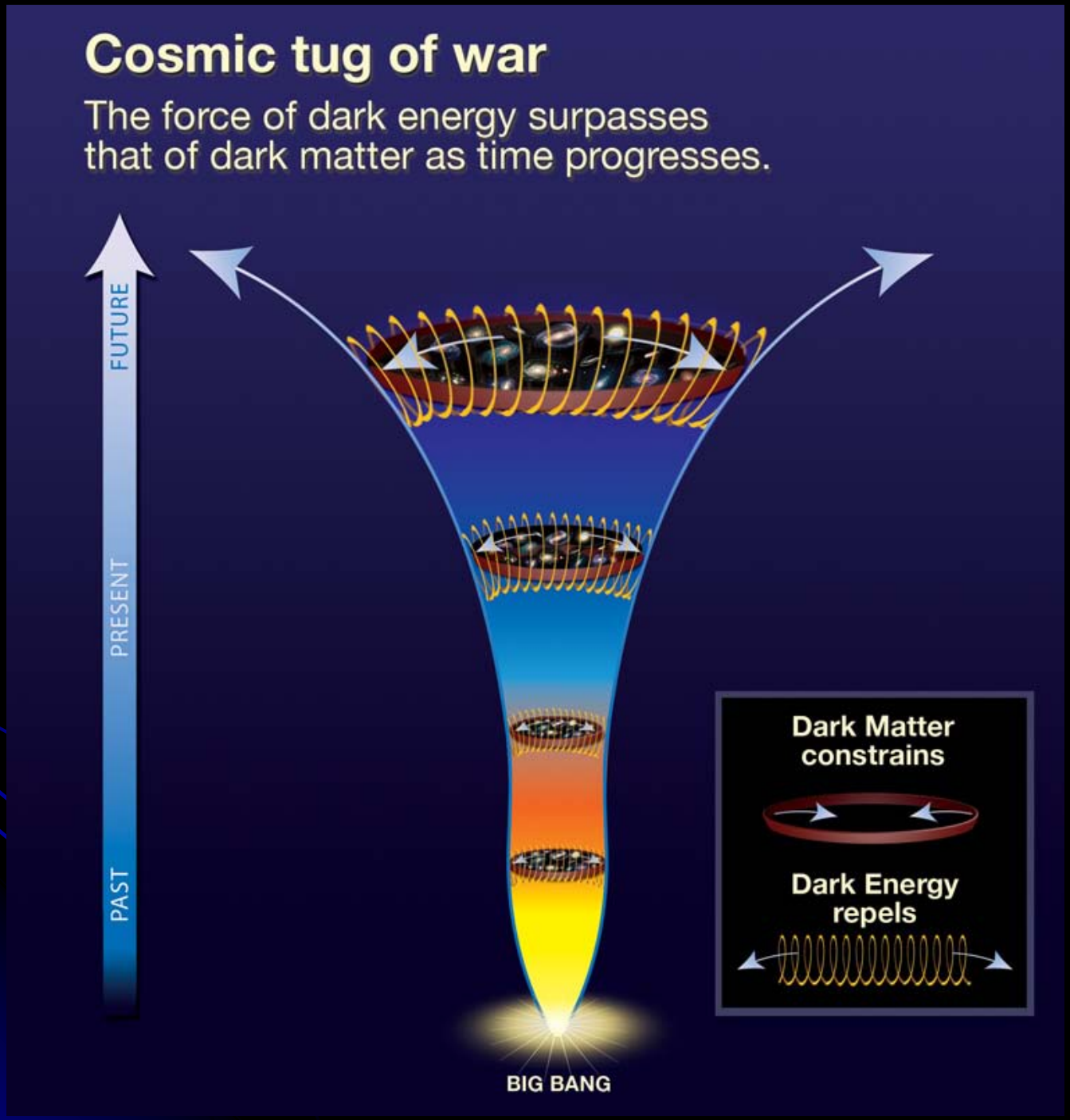


Host Galaxies of Distant Supernovae

HST ▪ ACS/WFC

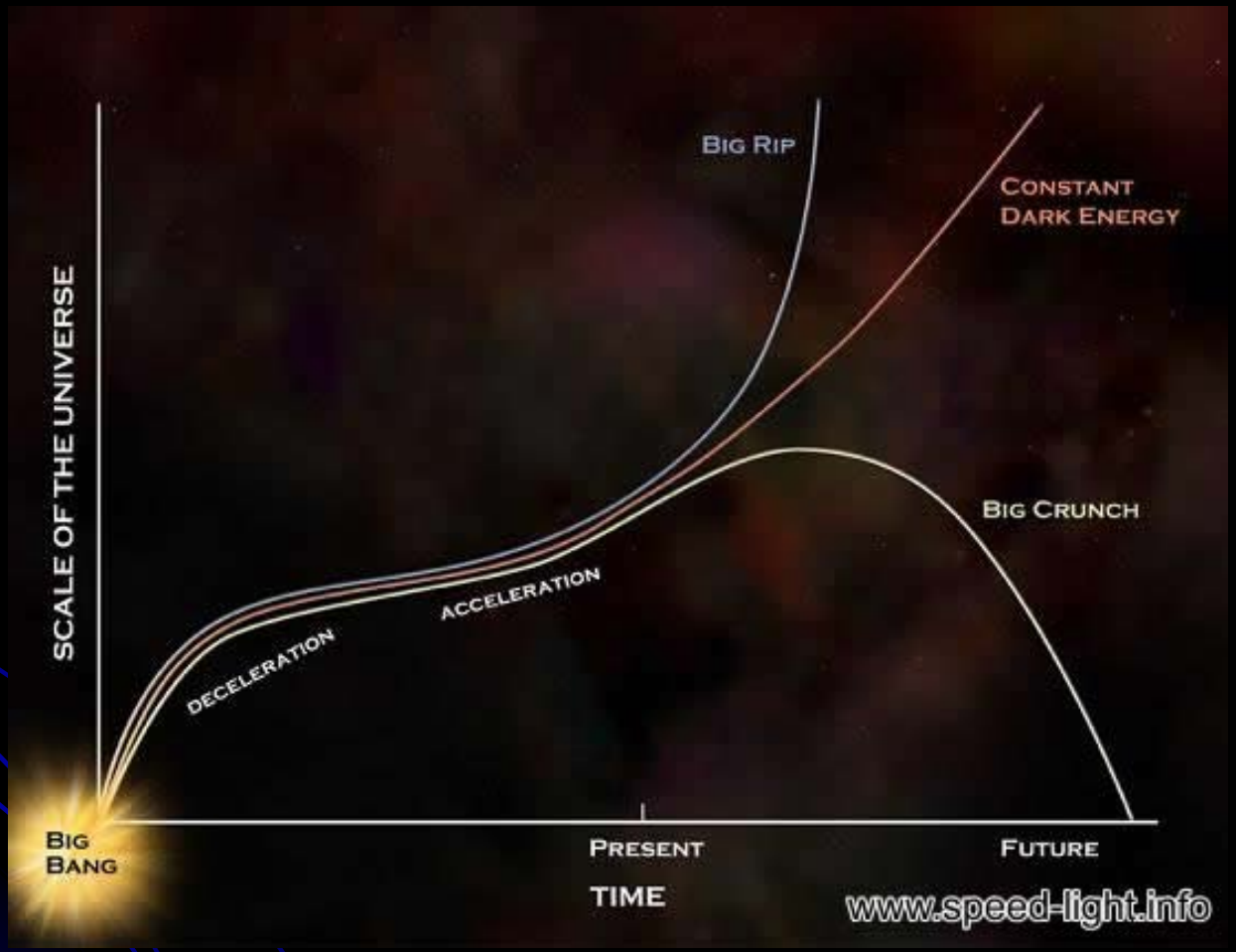
NASA, ESA, and A. Riess (STScI)

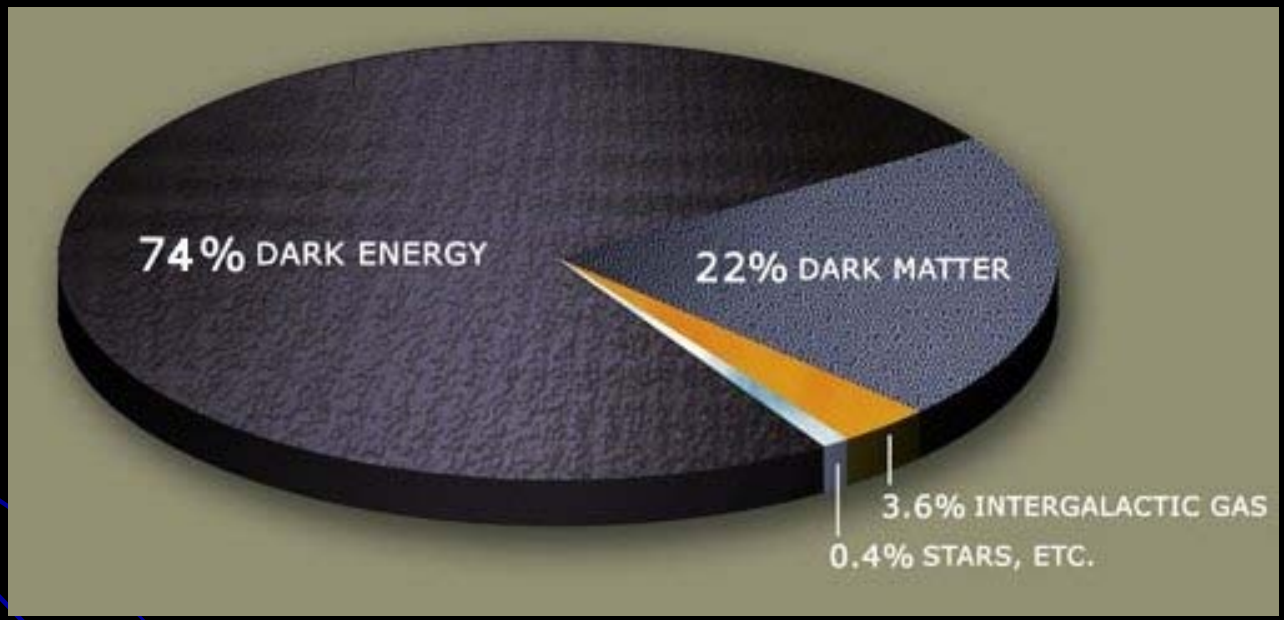
STScI-PRC06-52

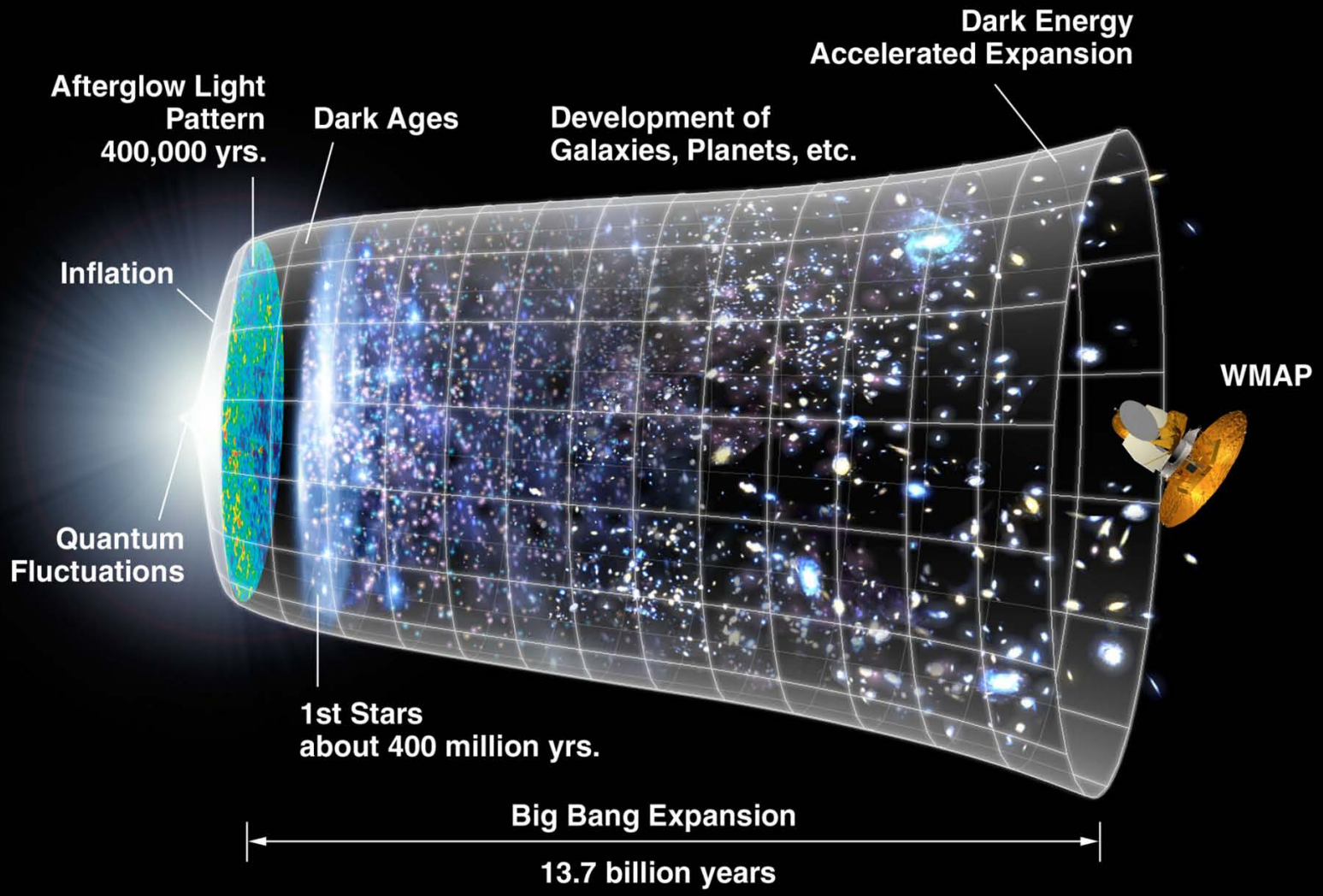

Cosmic tug of war
The force of dark energy surpasses that of dark matter as time progresses.
FUTURE
PRESENT
PAST
BIG BANG
Dark Matter constrains
Dark Energy repels

Saul Perlmutter, Adam Riess and Brian Schmidt accept the 2006 Shaw Prize

The End of the Universe?




74% DARK ENERGY
22% DARK MATTER
3.6% INTERGALACTIC GAS
0.4% STARS, ETC.


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years