

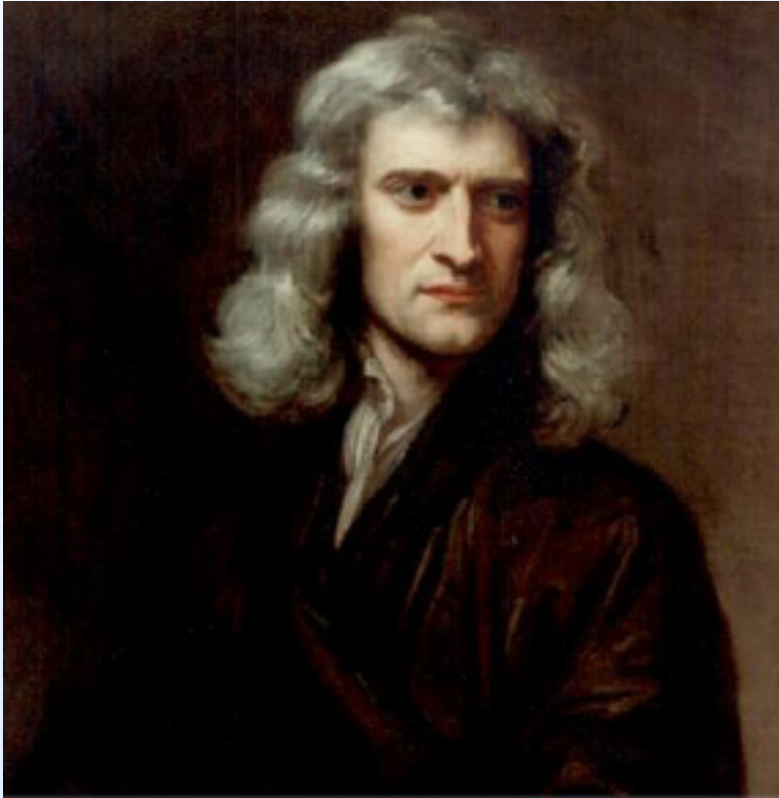
Cosmic Times

Inquiring into the Nature of the Universe

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Perkiomen Valley School District, PA

Cosmic Times



Newton



Space Foundation Teacher Liaison
Workshop



Einstein



<http://cosmictimes.gsfc.nasa.gov/>

Cosmic Times

“Cosmic Times” traces the understanding of the nature of the universe through the 20th century.

Start in 1919 with confirmation of Einstein’s theory of gravity (and its implications for the nature of the universe).

Continue through to discovery of Dark Energy, our current state of knowledge, and stepping stones to future.

Will Consist of 6 Posters, with Classroom Lessons

Lessons at Middle School and High School level, covering topics in physics, astronomy and interdisciplinary

This workshop samples topics and lessons in first four Cosmic Times.

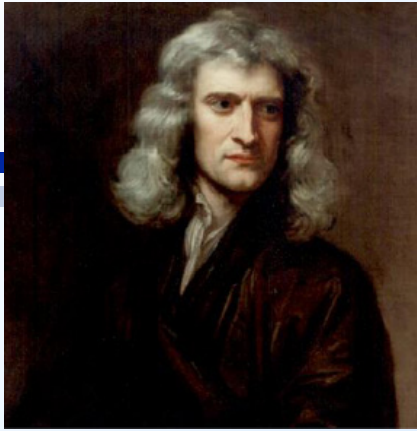
Science is about Questions and Tools

Our understanding of the nature of the Universe has changed as our questions and technology have changed.

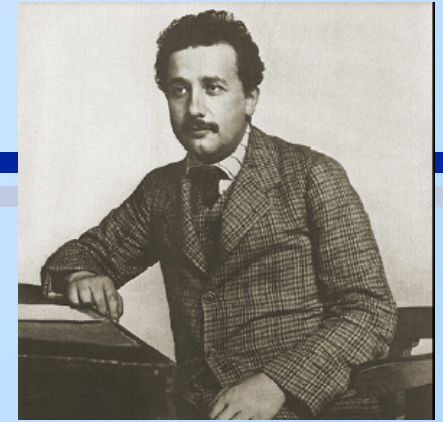
What are some questions we might ask?

What are the tools we might use?

What is Gravity?



Information Exchange (1918)



1. How was the theory developed?
2. Give a description of the theory.
3. How does it explain the motions of the planets?
4. How does it solve the problem of Mercury's orbit?
5. What prediction does it make for the bending of light, and the upcoming eclipse in 1919?

1919

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 a prediction of Dr. Albert Einstein that 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 the solar eclipse at a joint meeting of both the Royal Society along with 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.

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, 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



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 degree predicted by Dr. Einstein, as opposed to half of that degree, 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

What is Gravity?

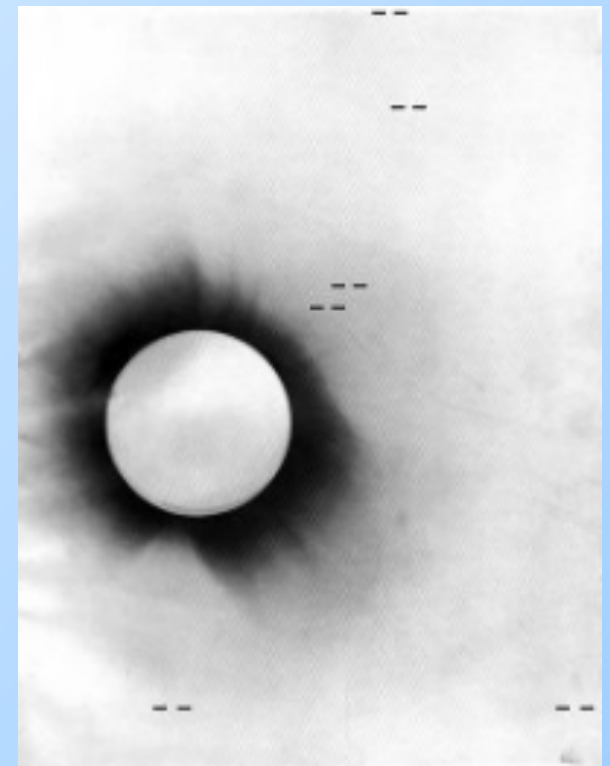
Einstein asked about the nature of gravity.

He discovered that gravity is curved space-time.

His theory predicted that light would bend when passing near a massive object.

Amount of deflection differed from prediction in Newton's gravity.

1919 Solar Eclipse verified Einstein's prediction.



How Far Away are “Spiral Nebulae”?

In 1920, astronomers pondered the distance to the “spiral nebulae.”



Harlow Shapley and Heber Curtis debated whether they were within our own Galaxy or outside our Galaxy.

The question was settled when Edwin Hubble determined the distance to Andromeda Galaxy.

Tools for answering “How Far Away are Spiral Nebulae?”

Apparent vs Absolute Magnitude

Apparent Magnitude measures how bright a star appears to us in the night sky.

Ranges from -4 (for Venus) to ~ 30 (for distant galaxies)

Absolute Magnitude is the apparent magnitude of the object if it was 10 parsecs (32.6 light years) away.

It measures the intrinsic brightness of the object.

$$L_o \propto L_i / r^2$$

But we usually don't know the Absolute Magnitude

Tools for answering “How Far Away are Spiral Nebulae?”

How can we know
a star’s intrinsic brightness?

Cepheid Variable Stars

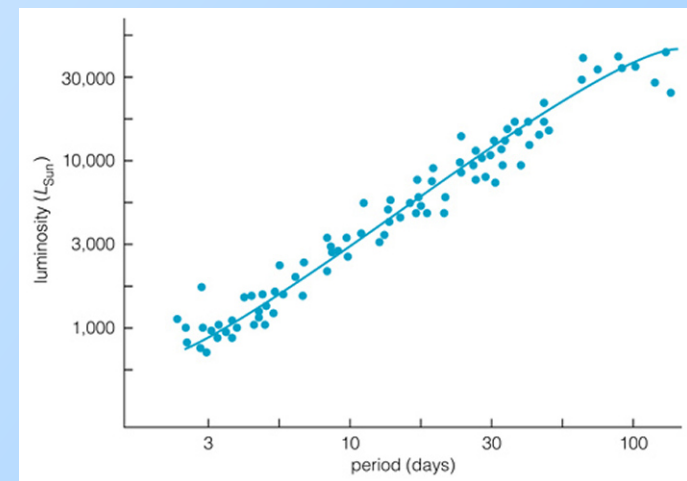
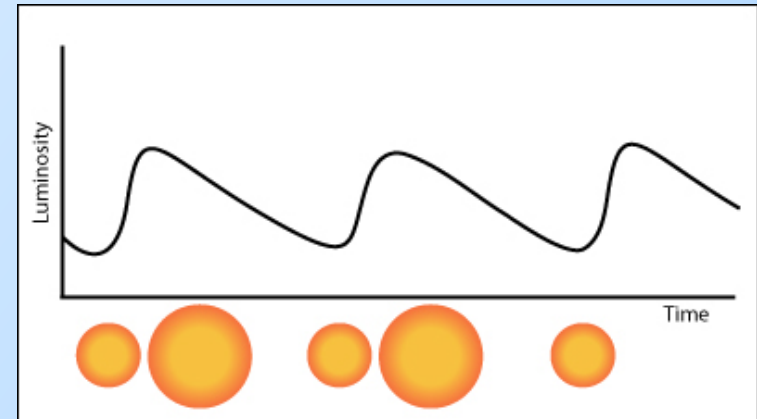
Discovered in 1784 by John Goodricke.

These stars vary in brightness due to pulsations.

In 1908, Henrietta Leavitt discovered this relationship:

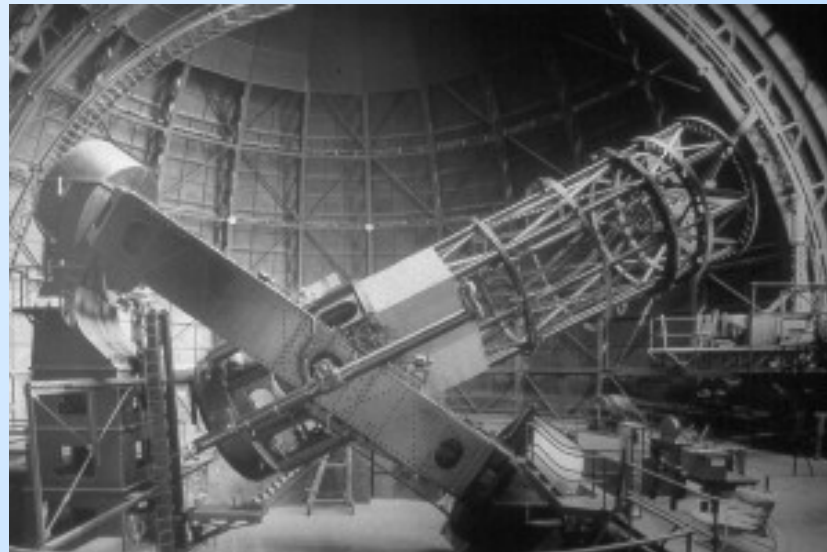
The period of brightness variation is related to star’s intrinsic brightness.

Hence we can use $L \propto P^2$



Tools for answering “How Far Away are Spiral Nebulae?”

100” Telescope at Mt Wilson, CA (commissioned 1917)
provided the added aperture and resolution to resolve the stars.



Hubble determined distance to Andromeda to be 800,000 LY

Age of the Universe:

2 Billion Years

COSMIC TIMES

1929

Andromeda Nebula Lies Outside Milky Way Galaxy Spiral Nebulae are indeed "Island Universes"



Universe is Expanding

"Red Shift" is Proof of Einstein's General Theory

Using the 100-inch Hooker Telescope at Mount Wilson Observatory, Dr. Edwin Powell Hubble has studied a variety of spiral nebulae and established that they are moving away from us at a rapid pace -- strong evidence of an expanding universe. He has further determined that the speed of motion increases with greater distance.

Hubble and colleague Milton Humason measured the radial velocities and distances for twenty-four of these nebulae. Because they are moving so quickly, their light waves are stretched out. This shifts their energy signals - as we detect them - toward the red end of the electromagnetic spectrum, a phenomenon known as "redshift". The team noticed that dimmer, more distant objects have a larger redshift than objects closer to Earth. As reported in a recent paper, Hubble's measurements led him to a useful velocity-distance relationship: redshifts increase in direct proportion to their distance from us.

Dr. Hubble's initial analysis reveals that for every million parsecs of distance, the velocity of

verse, one big question remains. How far out into the Universe does his model hold? The 100-inch telescope can resolve Cepheids in only the nearest nebulae. In nebulae where Cepheids are barely visible, Hubble has identified the most luminous individual stars, some 50 to 100 times brighter than the Cepheids. He uses these luminous stars as standard candles for more distant objects.

But today's telescopes, and the stars they see, will only take Dr. Hubble so far. To measure even greater distances, astronomers will need a larger telescope and new types of standard candles.

One new instrument may hold the key. Last year the Rockefeller Foundation agreed to provide the six million dollars needed to fund the construction of a new observatory with a 200-inch telescope. When completed, this telescope will hold four times the light-gathering power of the instrument Hubble currently uses.

What is the Nature of Universe?

Is the motion of galaxies static?

Is the motion of galaxies random?

Are the galaxies getting closer or further apart?

What data do we need to answer this question?

How do we determine the motion of a galaxy?

Early observations showed the “nebulae” were red-shifted.
I.e. moving very fast away from us.

Understanding Doppler Effect helps in understanding
Redshift of light.

Students can always predict what a siren sounds like when it
approaches and then passes.

Connect to the prior knowledge and transfer from sound to light.

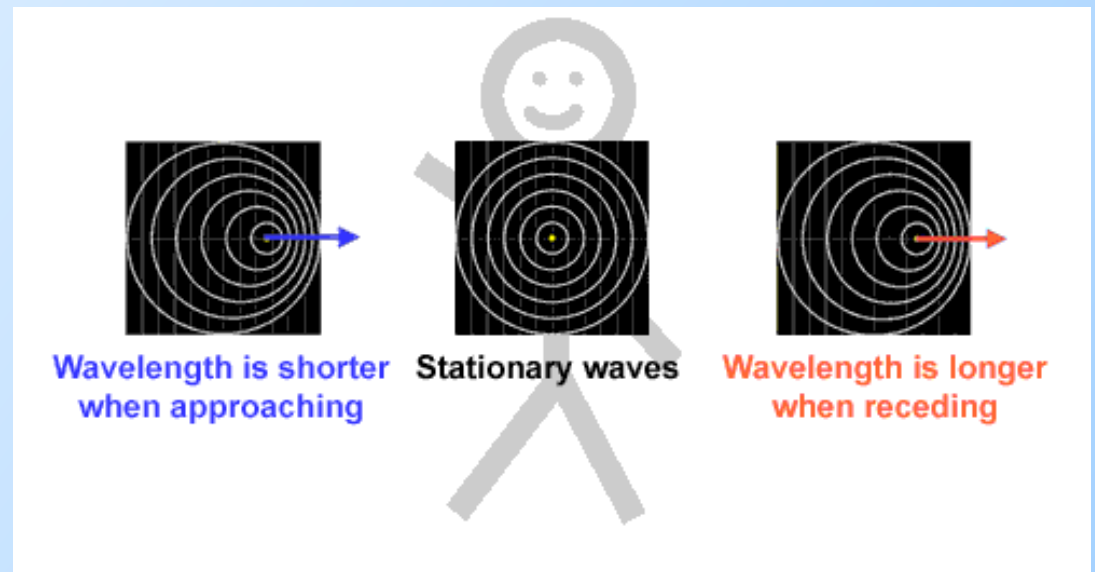
What is Doppler Effect?

Wavelengths bunch up
and get shorter as a
wave approaches.

Higher pitch or bluer light

Wavelengths spread out
and get longer as wave
recedes.

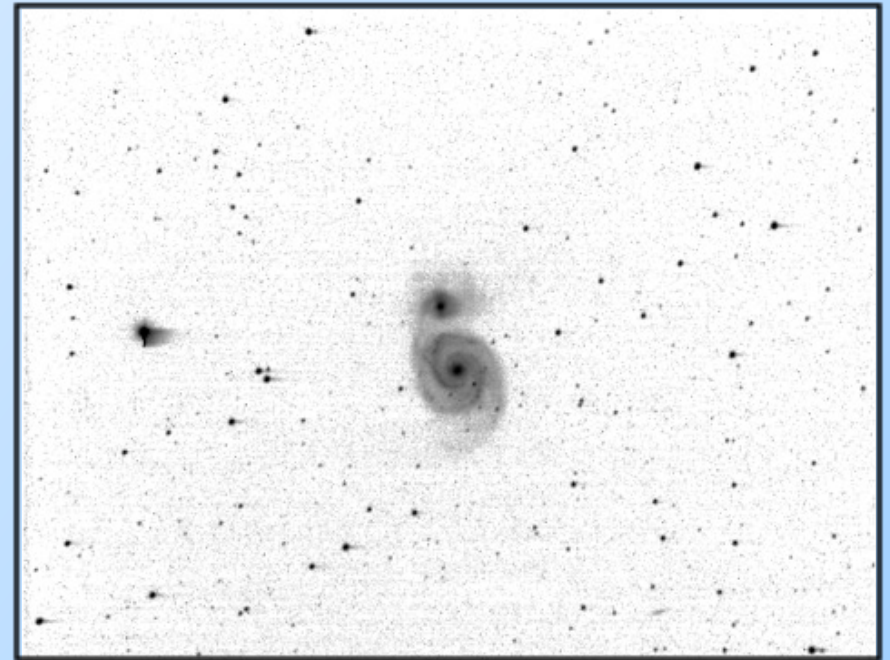
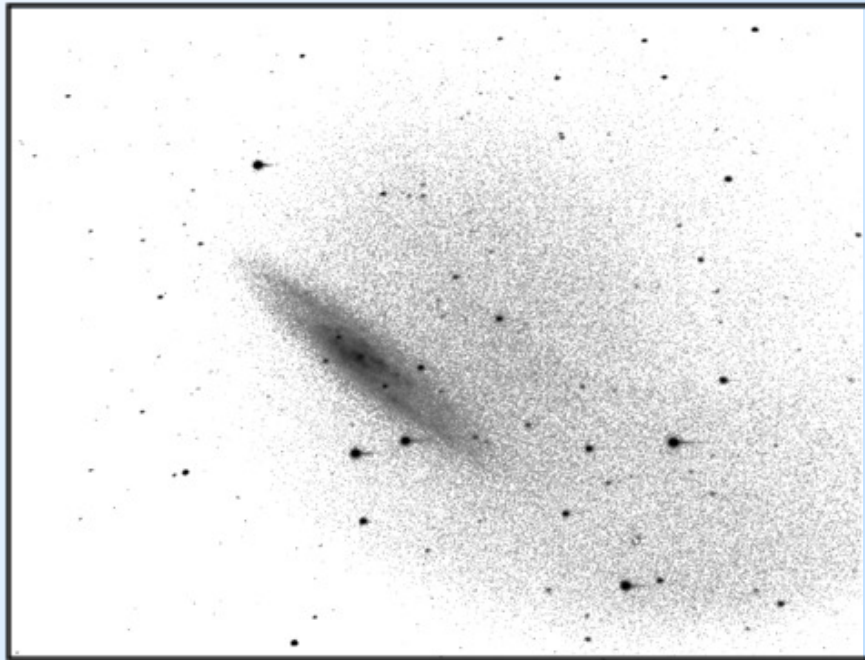
Lower pitch or redder
light.



<http://www.astrocappella.com/>

Determining the Motions of the Galaxies

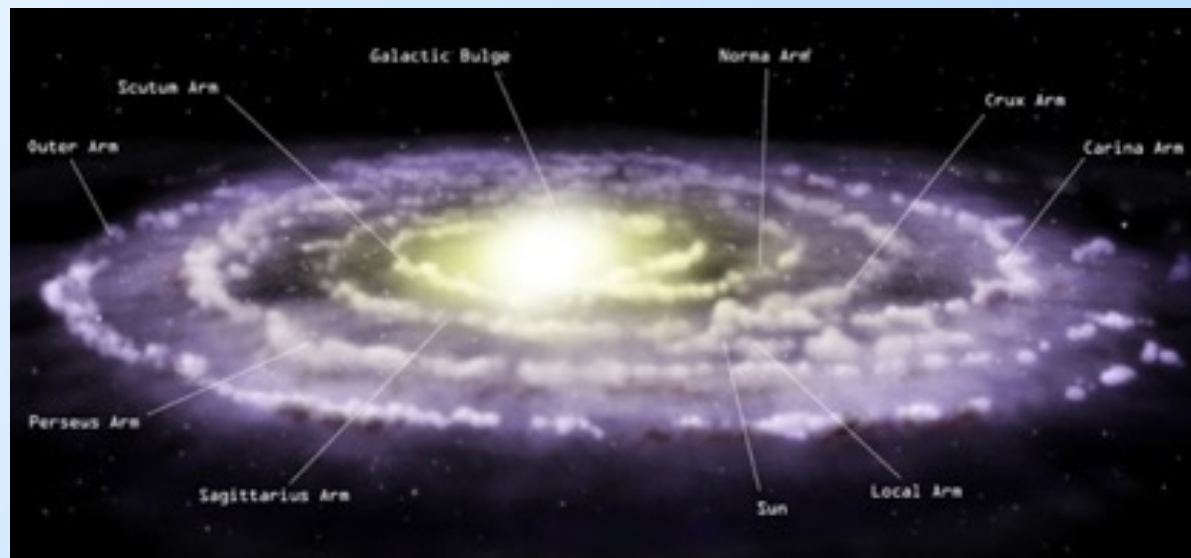
Use images of galaxies to determine their distances



Put this together with their redshift data

Determining the Universe

Size of galaxy

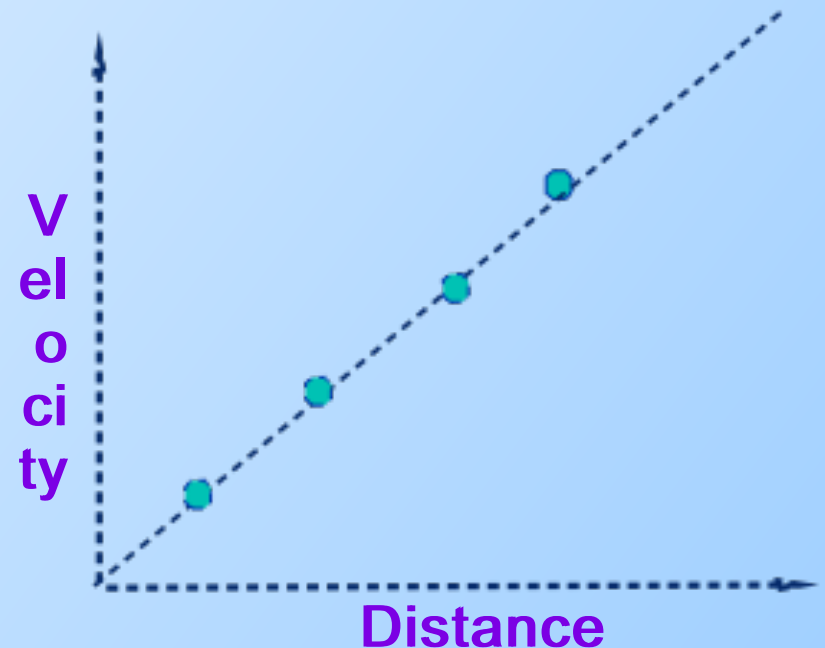


← 100,000 light years →

Galaxies are moving farther apart!

Hubble put together the redshifts with their distances.

Universe is expanding !



Age of the Universe:

2 Billion Years

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Break

Two Types of Cepheids!

During the wartime blackouts in California, Walter Baade discovered two different populations of stars in Andromeda

This led to realizing there are two types of Cepheids, with two different period-luminosity relationships.

Hubble had unknowingly used the wrong relationship.

Yardstick vs Metersticks

Age of the Universe:

6 Billion Years

COSMIC TIMES

1955

'Yardsticks' in Neighbor Galaxy Double Universe's Size

The Universe is twice as large as we thought says Caltech astronomer Walter Baade, who has now employed the giant 200-inch glass reflecting telescope at Mount Palomar to confirm the scale of the cosmos.

Baade's discovery hasn't come from simply reading mile markers in space, of course. To properly divine the distance of stars and the scale of the Universe first he had to discover that Nature has created more than one kind of mile marker, or yardstick, if you will. Until a few years ago, there was just one cosmic yardstick known to astronomers, and it was being used incorrectly. Oddly enough, it took the wartime blackouts in Los Angeles to begin setting things straight.

That first universal yardstick was discovered around the turn of the century. It is a type of pulsating, variable star called a Cepheid. Henrietta S. Leavitt of the Harvard Observatory was surveying the Magellanic Clouds, those junior galaxies outside of the Milky Way, when



The telescope that confirmed the scale of the cosmos: Mount Palomar's 200-inch Hale Telescope was completed in 1949.

either the globular clusters in Andromeda are basically different animals than those in our own Milky Way, or Andromeda must be further than originally calculated.

As chance would have it, the solution came during

Origin of E Hot Bang or Ag

It's difficult to imagine a deeper mystery than the one being addressed recently at the meeting of the National Academy of Sciences in Pasadena, California: Is the Universe eternal or does it have a beginning, middle and an end?

The case for an ageless, steady-state Universe which forever looks much as it does today was presented at the conference by astrophysicists Jesse L. Greenstein and physicist William A. Fowler of the California Institute of Technology. The steady state theory rivals the "evolutionary" theory of the Universe which calls on an initial brew of hot particles exploding at the dawn of time and making all the Universe's hydrogen and perhaps helium on one fell swoop.

Both theories explain – in entirely different ways – the inescapable fact that the Universe is expanding. This cosmic expansion was first detected in 1914, when American astronomer Vesto Melvin Slipher surveyed some galaxies and noticed the light from all of them was "red-shifted." This is essentially the broadening and

Is Universe a “Steady State” or Did it originate from a “Big Bang?”

Steady State Theory: As universe expands, matter is created.

Big Bang: running expansion backwards leads us to a point of high density and high temperature from which universe originated. (Create everything all at once)

COSMIC TIMES

1955

*Size of the Universe:
4-8 Billion Light Years*

Neighbor Galaxy Universe's Size



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Origin of Everything: Hot Bang or Ageless Universe?

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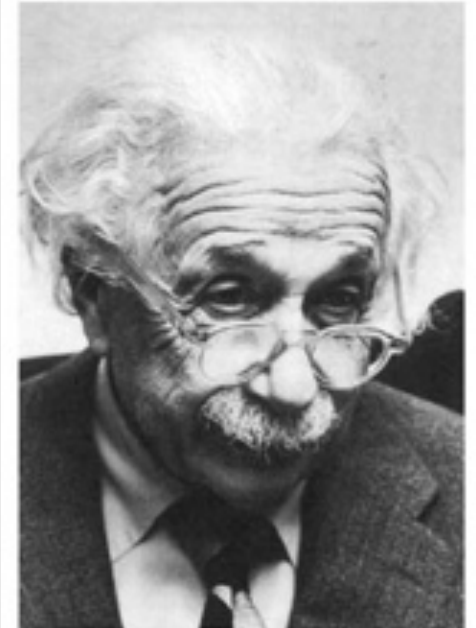
out and the Universe cools down to a vast, frigid stellar graveyard. Or the gravity of all matter might eventually pull everything back together again in an gigantic collapse that rebounds and starts the Universe all over – the endlessly exploding and collapsing Universe described by the late Caltech physicist Richard Tolman.

Which theory will prevail? Only more research with bigger and better telescopes will tell.



Fred Hoyle and William Fowler in Fowler's office in the W. K. Kellogg Lab at Caltech

Death of a Genius



Albert Einstein in 1950.

The world has just lost its greatest scientific mind. Albert Einstein died in his sleep on April 18th from complications of a lingering gall bladder infection. He was 76. There is no doubt

Steady State Universe

Fred Hoyle, Hermann Bondi and Thomas Gold see the movie *The Dead of Night*, in which the end of the story circles back to its beginning.



Unchanging situations need not be static

New matter can be created spontaneously as the universe expands (a few hundred atoms per year per galaxy)

Expansion of universe and creation of new matter balanced via a negative energy.

The universe is constant in its overall density

Evolutionary Universe

Starting from earlier work, George Gamow & Ralph Alpher worked out the conditions in the early universe

Universe is expanding from a state of high density and pressure.

Hydrogen & Helium were formed as universe cooled.

There should be left over a background radiation with a temperature of ~ 5 Kelvin

Hoyle scoffed at this theory and coined the term “Big Bang”

What is the Evidence?

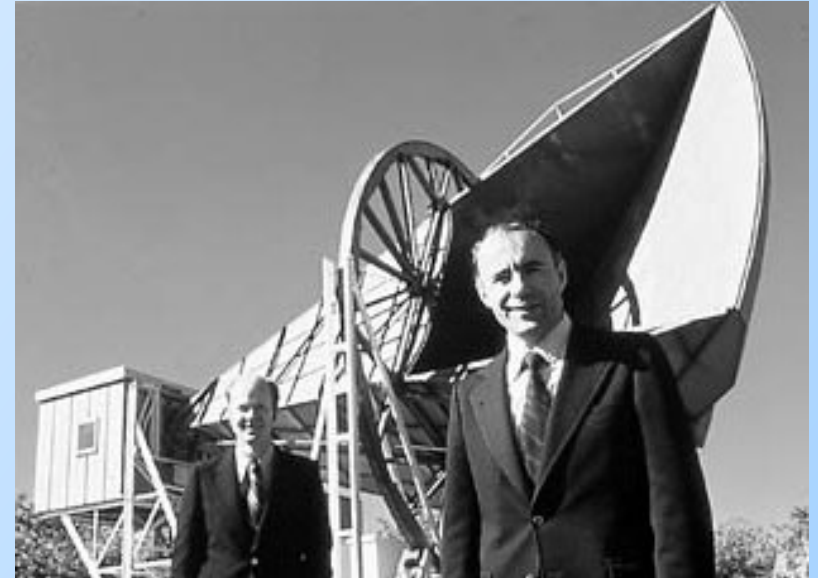
Scientists Sort through Theories by examining Evidence
and making Inferences

Bowl of Evidence

Tool for Determining “Steady State” vs. “Big Bang”

Penzias and Wilson were using a 20-foot horn detector to make radio observations of the Milky Way.

Effort to reduce noise in the detector left them with a 3 K residual. But they didn't know its origin.



Tool for Determining “Steady State” vs. “Big Bang”

Peebles and Dicke (Princeton) had just calculated an estimate for the temperature of the residual background temperature, and found it was detectable in the microwave region.

Peebles and Dicke were convinced that Penzias and Wilson had found it.

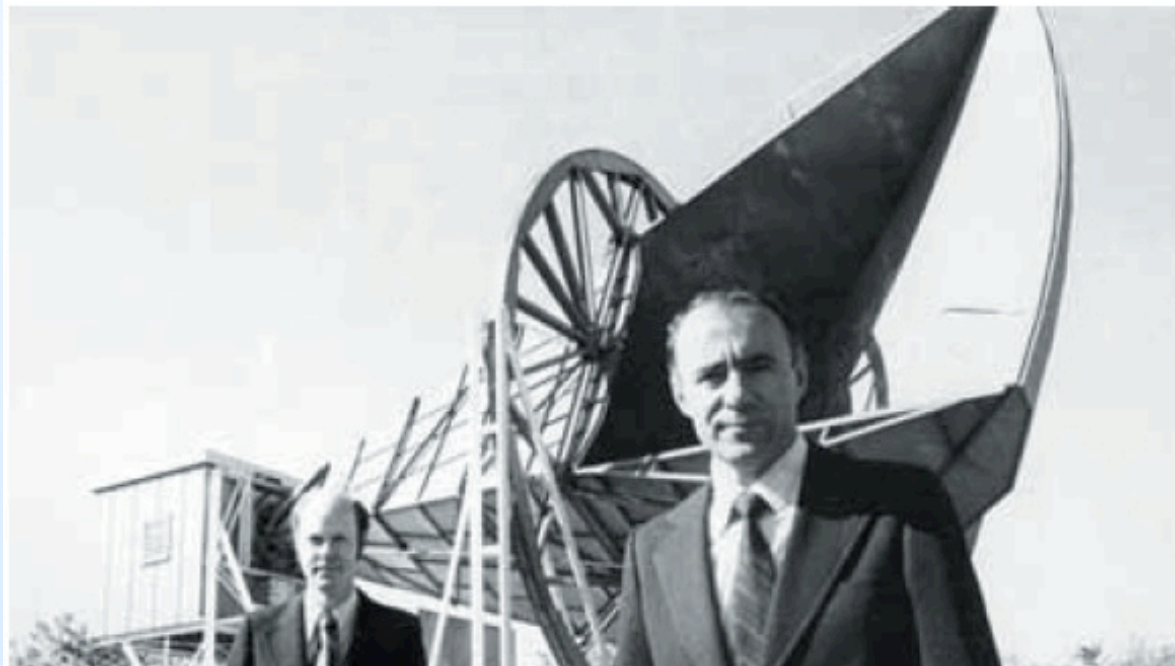
This solved the Steady State vs Big Bang question.

Age of the Universe:

15 - 25 Billion Years

1965 COSMIC TIMES

MURMUR OF A BANG



Big Hiss Missed By Others

One of the biggest surprises from the recent discovery of the Big Bang's faded thunder is how many times others have missed it.

Just last year, Russians Andrei Doroshkevich and Igor Novikov published a study that calculated correctly that, if the Big Bang happened, the remnant heat would now be between 1 and 10 degrees Kelvin. They even proposed searching for the signal in sky temperature measurements made by Edward Ohm in 1961.

Ironically, Ohm had gathered that data using the same Holmdel horn antenna used by Arno Penzias and Robert Wilson this year at Bell Laboratories to identify the 3.5 degrees Kelvin background radiation of the Big Bang. But Ohm found a 3.3 degree Kelvin noise that he

Modeling an expanding universe

How can we envision an expanding universe?

1965 CMB Activity

Cosmic Times

- 1919 - Confirmation of Einstein's Theory of Gravity
- 1929 - Hubble's discovery of Expanding Universe
- 1955 - Debate between Big Bang and Steady State
- 1965 - Discovery of the Cosmic Microwave Background
- 1993 - COBE Results; Development of Inflation Theory
- 2006 - Grappling with Dark Energy.

Cosmic Times: Scientific Themes

Our understanding of the Expansion of the Universe
Nature of Supernovae
The size and scale of the Universe

A number of other themes also appear.

Impact of improved technology.

Role of Women in early astronomy.

Unsung Heroes: Women in Early Astronomy

Objectives: The students identify and describe unfamiliar scientist “heroes” that contributed to the field of science up to the year 1929.

Summary:

identify the women scientists of the Harvard College Observatory

use the world wide web to complete a product on one of the these unfamiliar scientific “heroes” that they discovered in their research.

Pickering's Harem



A print of this Harvard College Observatory photograph was found in an album that had once belonged to Annie Jump Cannon.

These women assisted Pickering in measuring stars and features on the photographic plates.

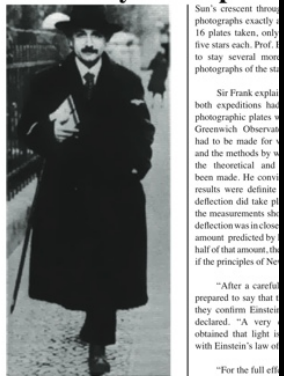
Age of the Universe: Infinite

COSMIC

SUN'S GRAVITY BENDS STARS 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 recently 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. President of Physics at the University of Berlin and Director of the Kaiser Wilhelm Physical Institute.



Here Einstein in Berlin

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 that depends on just grazing across the edge of a massive object should be bent by an amount that is proportional to 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, most 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, it 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 as much as Newton's theory predicts: 1.75 seconds of arc. Thus, Dr. Einstein predicts that a ray of light from a distant star, grazing the edge of the Sun on its way to the Earth, would suffer twice the deflection predicted by Newtonian principles.

The amount by which starlight is deflected by the Sun is thus regarded by astronomers and physicists as one of the crucial tests in determining the validity of the Dr. Einstein's Theory of Relativity versus Newtonian physics.

May's solar eclipse

Dr. Einstein made his prediction in a paper published in 1916, in the midst of the First Great War between England and Germany. He used a neutral Dutch newspaper to publish a copy of Dr. Einstein's paper. The paper was sent to Europe by England. Professor Arthur Eddington and Professor Professor of Astronomy at Cambridge University at Cambridge University—the pioneer who first showed that the Sun would be very favorably placed amongst a group of bright stars at that

time. Moreover, the Sun's light would be totally blocked by the Moon for over five minutes (see sidebar: Why a Total Solar Eclipse?)

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.

Results discussed

At the joint meeting, Sir Frank described the work of the two expeditions. Their purpose was to ascertain whether the light from these stars as it passed by the Sun came as directly toward the Earth as if the Sun were not there, or if there was a deflection due to the Sun's presence. "The effect of the predicted gravitational bending of the ray of light is to throw the apparent position of the star away from the Sun," said Sir Frank. If a deflection were to occur, measurements would be made of how far the stars would appear on the photographic plates from their theoretical positions.

The Royal Observatory party arrived in Brazil in ample time to prepare for the eclipse and photograph stellar fields. The day of the eclipse opened cloudy, but cleared later, and the observations were carried out with almost perfect success. The stars were clearly visible. The only time a star was obscured was during the eclipse of 1919 took place.

The Cambridge University party arrived on Principe on April 23. The island is about 10 miles long by 4 miles wide. "We soon realized that the prospects of a clear sky at the end of May were very good," recounted Prof. Eddington. The sky was completely cloudy at the beginning of the eclipse, but about half an hour before totality they caught glimpses of the

Age of the Universe: 6 Billion Years

COSMIC

'Yardsticks' in Neighbor Galaxy Double Universe's Size

The Universe twice as large as we thought says Caltech astronomer Walter Baade, who has now employed the giant 200-inch glass reflecting telescope at Mount Palomar to confirm the scale of the cosmos.

Baade's discovery hasn't come from simply reading mile markers in space, of course. To properly divine the distance of stars and the scale of the Universe first he had to discover that Nature has created more than one kind of mile marker, or yardstick, if he will. Until a few years ago, there was just one cosmic yardstick known to astronomers, and it had been used incorrectly. Oddly enough, it took the wartime biologist in Los Angeles to begin setting things straight.



The astronomer who confirmed the true size of the cosmos Mount Palomar's 200-inch Hale Telescope was completed in 1949.

Either the globular clusters in Andromeda are basically different animals than those in our own Milky Way, or Andromeda must be further than originally calculated.

As chance would have it, the solution came during the wartime blackout of 1943 in California. Doctor Baade took advantage of the darkened skies and the power of the 100-inch Hooker telescope at the Mount Wilson Observatory near Los Angeles to re-examine Andromeda's globular clusters. Using special red-sensitive photographic plates Dr. Baade discovered two populations of stars: redder, fainter "Type II" stars near Andromeda's center and its outlying halo (the same arrangement as in the Milky Way) and bluer, brighter "Type I" variable stars located in the outer spiral arms as well as in abundance in the Magellanic Clouds. So, Dr. Baade realized that there must be two populations of Cepheids—those Type I Cepheids more common in the disk of a galaxy and those Type II Cepheids more common in the globular clusters.

Each type of Cepheid, it turns out, has a different way of encoding its actual brightness into its pulsing light. It was as if the measuring stick for one type of Cepheid was measured in feet, i.e., a good old American yardstick, and the other was in cubits. The problem was Shapley had treated them both as regular 36-inch yardsticks.

"...[I]f, knowingly Shapley had made a fatal step when he linked the cluster-type variables to the type I Cepheids through the type II Cepheids in globular clusters and that in reality were dealing with two different period-luminosity relations," explained Dr. Baade.

Recently at Mount Palomar, Baade and his computer assistant Henrietta Swape confirmed that both types of Cepheids are very different stellar animals. After recalibrating his measuring sticks, Dr. Baade started his peep in 1952 at the 800-meeting of the International Astronomical Union by announcing that Andromeda was not 810,000 light-years away, as Hubble thought, but 1.8 million light-years distant. Likewise, with the two measuring sticks sorted out, the Universe we knew in 1929 to be one billion light-years wide has now doubled to two billion light-years across.

It's a Star! It's a Nova! It's Super-Nova!

There's more than one sort of "new" star in the heavens, say astronomers. The evidence has been building for decades that new—those stars which light up suddenly to great brightness, then fade away—actually come in at least two distinct classes. On one hand there are pedestrian, Clark Kent-like novae and on the other there are truly Super-Novae.

The first clue that there were two super-novae lurking in the stars was 35 years ago by the fully fledged astronomer Edwin Hubble, who was celebrating his 55th birthday in 1924. He had just discovered that the stars in the Andromeda galaxy, which is 2.5 million light-years away, were not novae, but true super-novae.

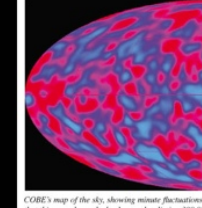
Forty years later, in 1934, physicist Walter Baade and Fritz Zwicky coined the term "super-nova" when they suggested these were not only far brighter than normal novae, but rare, once-in-a-millennium, events in any given galaxy. The most recent super-novae in our own galaxy, they speculated, were those recorded by Germanic astronomer Johannes Kepler in 1604, and another seen by a Dutch astronomer Tycho Brahe in 1572.

A new wrinkle to the matter was added in 1941 by astronomer Rudolph Minkowski. He split the light from 14 distant galaxy super-novae into their component colors and found that nine of these spectra contained no telltale lines for hydrogen (Type I) and five did (Type II). The possible reason for this, speculates British cosmologist Fred Hoyle, is that in the superlative violence of their death throes, the giant stars that become supernovae might be capable of fusing hydrogen and helium to forge heavier elements like carbon and iron. They are, then, they, but bona fide Stars of Steel.

Age of the Universe: 12-20 Billion Years

COSMIC

Baby Universe's 1st Picture



COBE's map of the sky, showing minute fluctuations in the cosmic microwave background. Astronomers estimate that this map shows the background radiation 300,000 years after the Big Bang. (NASA image)

What did the newborn universe look like? In 1965, scientists peered into the distance with a radio telescope, and discovered a microwave background that was rather plain and featureless, or "lumps" in the oldest light in the universe. The COBE data shows the afterglow from the very early universe, only 300,000 years after the Big Bang. The current age of the universe is estimated at 12 to 20 billion years.

"If you're religious, it's like looking at God," said George Smoot, an astrophysicist at the University of California, Berkeley and leader of the research team that unveiled the discovery. He was addressing a room packed with scientists at a meeting of the American Physical Society.

According to the Big Bang theory, the universe expanded from an unbearably small and dense ball of energy, distributing hot radiation - and space itself - outward in all directions. As the universe expanded and cooled, this hot ball of energy produced finely minted particles in the form of quarks and electrons first, then protons and neutrons which combined to make the nuclei of hydrogen and helium. This hot gas also emitted radiation in all directions that gradually shifted into the microwave energy range, which we see today as a cosmic microwave background (CMB). Over time, gravity gathered the denser clumps of gas into the familiar galaxies, stars, and planets of the modern universe.

Data from the 1960s did not show deviations in the CMB energy across the entire sky; however, in 1967, astrophysicists Martin Rees and Dennis Sciama predicted such deviations. The subtlety of the variations, however, made them extremely hard to detect until NASA's Cosmic Background Explorer satellite (COBE) was launched in 1989.

Scientists have now confirmed the existence of very slight - but clearly measurable - energy

Pancake or Oatmeal Universe - What's for Breakfast?

Over its lifetime, the universe started out smooth, but has grown lumpy.

The COBE results present what's been called an isotropic, or smooth, early universe - with measured variations in the cosmic microwave background radiation only 1 part in 100,000. You might say that, at that time, the universe was like the surface of a pancake: smooth at a glance, with a frothy texture seen only if you look closely.

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While the early universe was extremely smooth compared to today, those minuscule lumps in it grew through the action of gravity; they led to the much bigger lumps we see today, the ones that make our very existence possible.

Age of the Universe: 12-20 Billion Years

COSMIC

Inflation in the Universe

The Big Bang theory has a problem, say scientists. It can't get from a tiny ball of energy to the universe we see today without some help - an adjustment called inflation.

Astronomers observe that the overall temperature of the cosmic microwave background (CMB) is nearly smooth and uniform. The temperature can become uniform only if distant regions can interact and exchange energy. The fastest interactions occur at the speed of light. However, at the time the CMB radiation was emitted, two regions that are far apart on the sky today would have been separated by more than the light travel distance in the young universe. So why is the CMB temperature so nearly uniform?

Inflation Theory explains this by stating that shortly after the Big Bang, the universe underwent a very rapid expansion in a very short amount of time. This expansion grew the size of the universe by a factor of 10²⁶ in about 10⁻³² seconds. Thus, regions once in contact with each other are now in far flung regions of the universe. The overall uniformity of the background temperature expanded with inflation. Particle physicists think that inflation might be a natural product of the transition in which the grand-unified force separated into the strong nuclear force and the electro-weak force. If so, it would have occurred 10⁻³⁵ sec after the Big Bang when the universe was 10⁻³⁵ seconds.

After inflation, the expansion of the universe continued, but at a slower rate. As space expanded, the universe cooled and matter formed. Within the first second after the Big Bang, quarks, neutrons, and electrons appeared, then protons and neutrons.

Inflation makes another remarkable prediction: how stars and galaxies in the universe came to be. Since our cosmic neighborhood would have been cosmic in size prior to inflation, quantum fluctuations in the density of matter in this region would be stretched by inflation to astronomical proportions. After inflation, these fluctuations would be faint in contrast, but over time, the slightly over-dense regions would attract neighboring matter through the action of gravity. This would initiate the gradual process of galaxy formation. This inflation simultaneously explains why the CMB is so nearly, but not exactly, uniform, and ultimately how we came to be!

Scientists are now more satisfied that with the addition of inflation, the Big Bang describes the universe we live in.

Princeton astrophysicist David Spergel observed at the meeting: "It's the most important discovery in cosmology in the past 20 years."

Scientists have now confirmed the existence of very slight - but clearly measurable - energy

Pulsar Gravitational Waves Win Nobel Prize

This year's Nobel Prize in Physics was awarded for the amazing discovery of the first evidence, albeit indirect, for the existence of gravitational waves.

In 1974, Princeton University astronomers Russell A. Hulse and Joseph H. Taylor located PSR 1513-16, a binary system made of two super-dense neutron stars locked in a dizzying eight-hour orbit around each other. One of these stars is a pulsar, which emits a radio pulse every 59 milliseconds as it rotates on its axis.

Two years later, after some careful timing measurements, the astronomers discovered that the two stars in the system were orbiting each other in a way that was very different from what was expected. The observed orbital decay was exactly what was predicted by general relativity predictions - strong confirmation of the existence of the gravitational waves predicted by Einstein.

The pulsars won't be colliding any time soon. Although each neutron star is 7 miles in diameter and 1.4 times the mass of the Sun, they are still about a million miles apart. At their present rate, it will take 300 million years for the stars to merge.

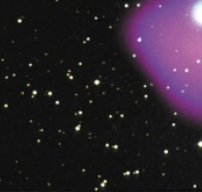
After 18 years of refinement, Taylor has honed down the timing of PSR 1513/16's

Size of the Universe: 30 Billion Light Years

Dark Matter Hunt Heats Up

The mystery of dark matter just deepened with a new report of about 20 trillion suns-worth of the invisible, unexplained stuff hiding out in a small cluster of galaxies.

The vast store of dark matter was found using the ROSAT X-ray satellite. ROSAT detected a gigantic cloud of very hot gas in a very unexpected place: the seemingly empty space between two galaxies. This cloud is a surprise because, according to the standard model of galaxy formation, the gas should have been pulled together into a "Big Crunch," say some researchers.



Astronomer Vera Rubin in 1970, studying the rotation rate of stars in the Andromeda galaxy and found that it just didn't make sense. The stars in the disk further from the galactic center were not rotating more slowly than those closer in, as models predicted they

cause its great heat - detected from its radiation of X-rays - should have made the gas quickly dissipate.

The existence of the hot gas cloud can only be explained by the existence of a gravitational "beast" that is in place. Only dark matter could do the job without being seen, explains Richard Muzibok of NASA's Goddard Space Flight Center.

What's more, the hot gas requires an amazing 30 times more dark matter than visible matter in the cluster to achieve this, said Muzibok. The normal matter ROSAT observed is just a small fraction of what's really there.

If that sort of dark matter ratio holds true throughout the cosmos, dark matter could determine the fate of the universe. Its gravity could be enough to someday reverse the direction of matter and energy flung out by the Big Bang and pull the

Foot-Proofing Galactic 'Candles'

The "standard candle" used for measuring the distance to other galaxies just got a much-needed tune-up.

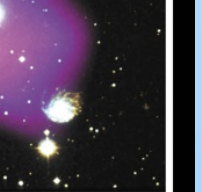
For years, the white super-novae created by the deaths of white dwarf stars in binary systems, known as Type Ia supernovae, have been a standard candle. Wherever they occurred, they were believed to have roughly the same intrinsic brightness. So scientists used them to calculate the distance to the galaxies in which they occur. But recent research has revealed a way to greatly improve the accuracy of these calculations.

But it turns out that not all Type Ia's are equal either. A large sampling of super-novae has revealed that the pattern of brightening and fading over days - known as a light curve - varies a great deal. Astronomer Mark Phillips at the Cerro Tololo Interamerican Observatory in Chile found that the infrared light curves of some brighter Type Ia's fade more slowly over the first 15 days than do those of dimmer ones.

By sorting out the light, fast-fading super-novae from the bright, slow-fading ones, Phillips arrived at a luminosity-decline relation. It allows calculation of a correction factor for super-novae that are dimmer than the standard Type Ia supernovae. Astronomers can adjust the distance accordingly, and increase the accuracy of the distance measurements.

An earlier case for the existence of dark matter was that made by astronomer Vera Rubin in 1970. She studied the rotation rate of stars in the Andromeda galaxy and found that it just didn't make sense. The stars in the disk further from the galactic center were not rotating more slowly than those closer in, as models predicted they

Some of the most massive objects 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, most equivalent to a human hair at 75 feet, but it is actually measurable on today's astronomical photographic plates if adequate care is taken.



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