Cosmic Times: '
Astronomy History and Science '
for the Classroom '

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May 28, 2009 '
Project ASTRO Site Leaders '

Cosmic Times '

- Curriculum support materials that trace our changing understanding of the expanding Universe over the past century
- Includes:
  - 6 posters resembling newspaper front pages '
  - 2 newsletter versions for ' each poster, one at a differentiated reading level '
  - 4-5 lesson plans for each poster exploring fundamental science, social ' context, and reading skills '


SUN'S GRAVITY BENDS S
Einstein's Theory Triu
Andromeda Nebula Lies Outside Milky Way Galaxy
'Yardsticks' in Neighbor Galaxy Double Universe's Size
MURMUR OF A BANG
Baby Universe's 1st Picture
COSMIC TIMES
Faster Walk On The Dark Side
Journey to Cosmos' Dark Heart
Seeds of Modern Universe
Biggest Mystery: What is Dark Energy?
'First Light' Wins Nobel
Sorting Out the Dark Stuff

You will receive a DVD containing all of these materials at the end of this workshop

The year is 1919… '

- What's going on?
- What's going on in science?
- What is your view of the Universe?

- Infinite
- Unchanging/static
- Ageless '

Enter Einstein '

- ✳ What is Gravity?
- ✳ Gravity is curved space-time.
  - ❊ Gravity bends light.
  - ❊ Amount of deflection differs from Newton's prediction.

➢ 1919 Solar Eclipse verified Einstein's prediction.


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.

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.

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.

Dr. Einstein's model predicted that either all the stars would be expanding or moving apart from one another, as if from a gigantic explosion. Or they had to be contracting, as if they were all collapsing upon one another.

But Dr. Einstein, a devotee of the book *Ethics* by Dutch philosopher Spinoza, quoted from memory Corollary 2 of Proposition 20: "It follows that God is immutable or, which is the same thing, all His attributes are immutable." Dr. Einstein was troubled by the concept of a universe that was not immutable or unchangeable.

"We can add, on the left side of the field equation—for the time being— an unknown universal constant," Dr. Einstein said, explaining the quantity he designates by the Greek letter lambda, and calls the "cosmological constant." He explains: "Not much harm is done thereby… the proposed new universal constant determines the average density of the universe that can remain in equilibrium."

According to Dr. Einstein's beautiful immutable universe, the presumably spherical universe would be neither expanding nor contracting.

In Their Own Words

Periods of 25 Variable Stars in the Small Magellanic Cloud - *Miss Henrietta Leavitt*

A remarkable relation between the brightness of the studied variables and the length of their periods has been noticed. There is a simple relation between the brightness of the variables and their periods: the brighter variables have the longer periods.

Spectroscopic Observations of Spiral Nebulae - *V. M. Slipher*

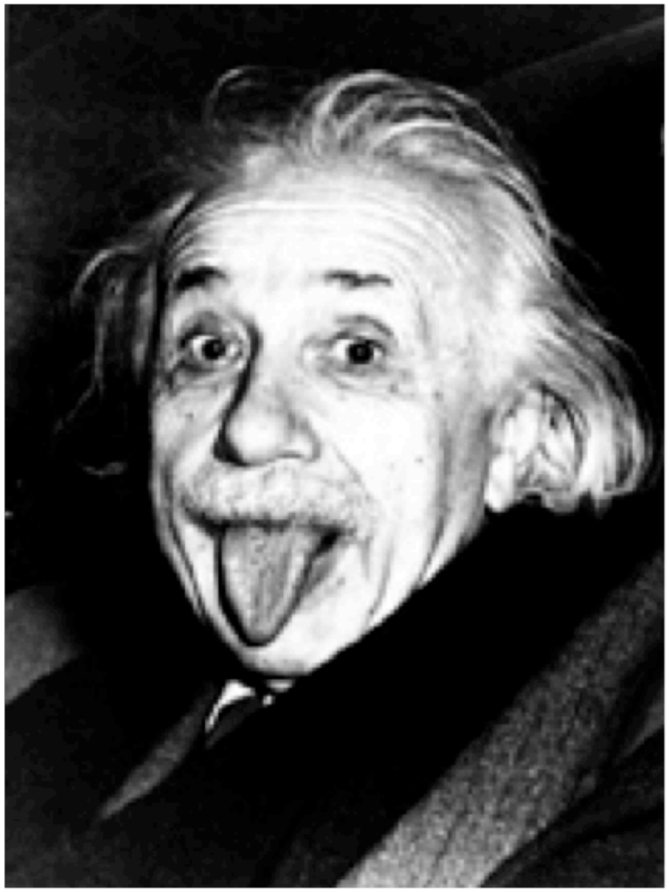
The Relation of the System of Stars to the Spiral Nebulae - *G. F. Paddock*

Why a Solar Eclipse? '

Eclipses and Moon Phases '

Unchanging Universe? '

- Einstein's theory implies universe is not static - it's expanding or contracting.
- Einstein was troubled by a non-static Universe.
- Cosmological Constant keeps the Universe static.



1919 Lessons

- Einstein and His Times
  - Should Einstein be 1919's "Man of the Year" ?
- Two Versions of Gravity
  - Compare Newton's & Einstein's gravity
- Einstein's Gravity
  - Create a model of Einstein's gravity

Other 1919 Stories '

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

Herr Einstein in Berlin

WHY A TOTAL SOLAR ECLIPSE?

MT. WILSON ASTRONOMER ESTIMATES MILKY WAY TEN TIMES BIGGER THAN THOUGHT
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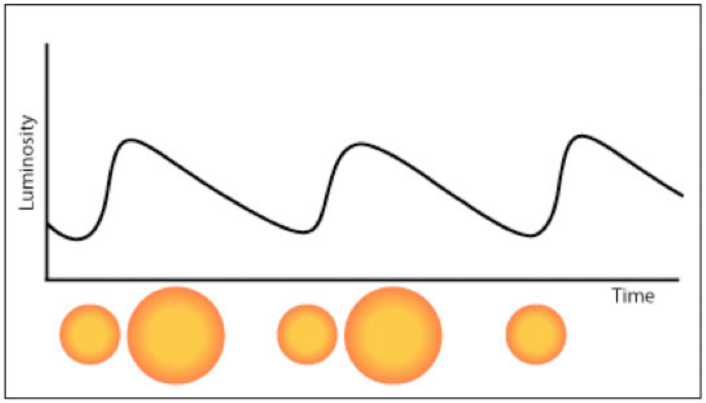
How Far Away are "Spiral Nebulae"?

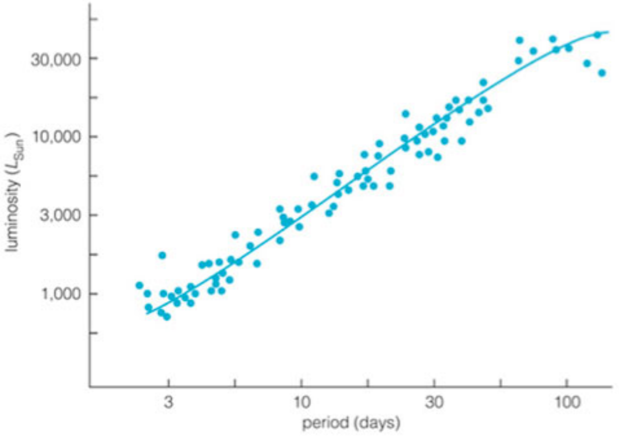
- In 1920, astronomers pondered the distance to the "spiral nebulae."
  - Recall article on Shapley in 1919
- Harlow Shapley and Heber Curtis debated whether they were within our own Galaxy or outside our Galaxy
- Shapely won the debate with his arguments for the spiral nebulae being part of the Galaxy.

Cepheid Variables '

- Henrietta Leavitt observed pattern in the variability of Cepheids - a brighter star had a longer period
- By measuring the observed luminosity, and knowing intrinsic luminosity we can determine distance

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





Using the Standard Candle

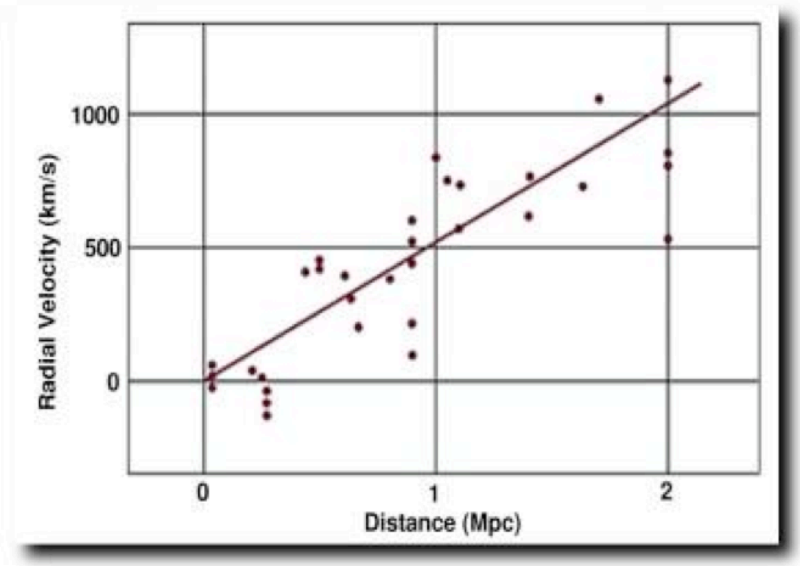
- Hubble used the 100” ' Telescope at Mt Wilson - the first to provide the aperture and resolution to resolve the stars in ' Andromeda '
- Using the Cepheids, he determined distance to Andromeda to be 900,000 ' LY* '
- That distance is too far to ' lie within the Milky Way '

Despite winning the debate, Shapely was wrong! Spiral Nebulae lie outside the Milky Way

* actual dist. is 2.8 million LY

But Wait, There’s more … '

- Vesto Slipher showed the “nebulae” were red-shifted.
  - I.e. moving very fast away from us.
- Hubble put together the redshifts with their distances.



Hubbles' Original Data

Universe is expanding!

"Cosmological Redshift"

- "Doppler" redshift would require the galaxies themselves to be moving at very high speeds.
- Friedmann (1922) and Lamaitre (1927) abandoned Einstein's static universe, and showed that space-time could expand.
  - Then wavelength of light would stretch in response to space-time's stretching.

Scientists Game '

Unsung Heroes: ' Lesser Known Astronomers '

<u>Objectives</u>: The students identify and describe unfamiliar scientist “heroes” that contributed to the field of astronomy.

1929 Lessons

- Discovering the Milky Way
  - Students study the Cepheid P-L relation '
- Just How Far is that Star?
  - Determining distances using apparent and absolute brightnesses
- Cosmic CSI
  - Elemental Composition through Spectra '
- Determining the Universe
  - Students reproduce Hubble's Law

Other 1929 Stories '

Age of the Universe: *2 Billion Years*

COSMIC TIMES

1929

Size of the Universe: *280 Million Light Years*

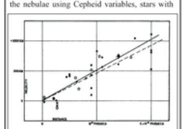
Andromeda Nebula Lies Outside Milky Way Galaxy

Spiral Nebulae are indeed "Island Universes"

Dr. Edwin Hubble found that the Andromeda nebula is the most distant object known and is not part of the Milky Way Galaxy.

Universe is Expanding

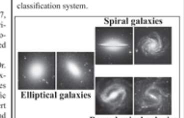
"Red Shift" is Proof of Einstein's General Theory



Einstein's General Theory Holds True

"Great Debate" Resolved

Classifying Nebulae



The Minds Atop Mount Wilson

Athlete-Scholar Unveils the Future of the Universe

Former Mule-Team Driver and Janitor Helps Discover Expanding Universe

In Their Own Words

Problem with the Cepheids?

- Hubble studied globular clusters in Andromeda and M 33 in the early 1930s
  - Equivalence principle says that similar objects found in different parts of the Universe should be similar
  - But … Globular clusters of Andromeda were showing peak luminosities that were 1.5 magnitudes dimmer than those in the Milky Way
  - Either equivalence principle not applicable, or distance scale was wrong
  - Then M 33 showed globular clusters that were dimmer still than Andromeda
  - Problem with the distance scale!

Two Populations!

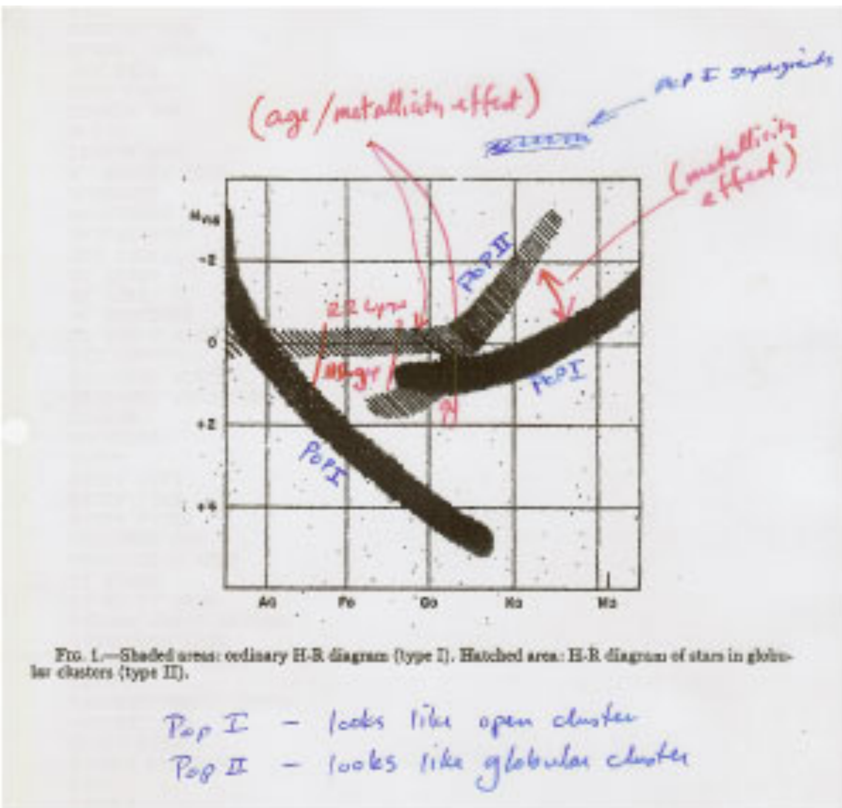


FIG. 1.—Shaded areas: ordinary H-R diagram (type I). Hatched area: H-R diagram of stars in globular clusters (type II).

- In 1944, Walter Baade imaged Andromeda in greater detail than previous studies
- Found definitive evidence of two stellar populations
- Therefore - two types of Cepheids with different Period-Luminosity relationships.

Universe Doubles in Size

- An error in the calibration of the Cepheid period-luminosity relationship led to an under-calculation of the distances to most objects…by half!

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? '

Bowl of Evidence %

Scientists sort through theories by ' examining Evidence and making Inferences '

Steady State vs. Big Bang '

- Resolution of Steady State vs Big Bang won’t come until the mid-to-late 1960s.
- But as a competing theory, the Steady State provides the impetus to make observations to test the theories.

1955 Lessons '

- Cosmic Jeopardy!
- Big Bang Science Fiction
- Discovering Yardsticks are Metersticks
  - An illustration of the recalibration of the Cepheid distance scale
- Hubble's Law Mis-calibration Extension
  - Revisit the 1929 lesson

Other 1955 Stories '

Age of the Universe: 6 Billion Years

COSMIC TIMES

1955

Size of the Universe: 4 Billion Light Years

'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 she noticed that brighter Cepheids pulsed slower than dimmer Cepheids. This was intriguing, since for all practical purposes the stars in the Magellanic Clouds can be considered the same …

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

As chance would have it, the solution came during the wartime blackouts 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 …

Origin of Everything: Hot Bang or Ageless Universe?

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

Hoyle Scoffs at "Big Bang" Universe Theory

Death of a Genius

Albert Einstein in 1950.

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

Radio 'Ear' on the Universe Being Built

Jodrell Bank's Mark I radio telescope under construction.

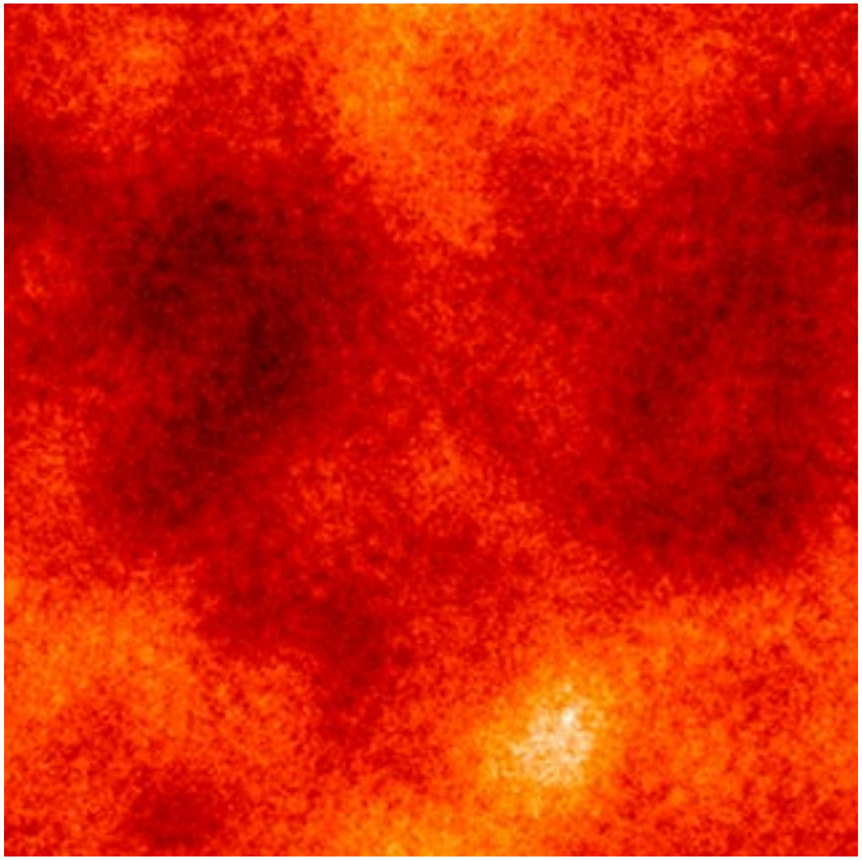
Break '

How Cosmic Times ' Came to Be '

- BE Teacher Focus Group (March 2005) '
- Idea developed by HEASARC E/PO team '
- Survey of Cosmologists
- Trudy Bell sketched out each of the articles '
- PA teachers developed lessons.

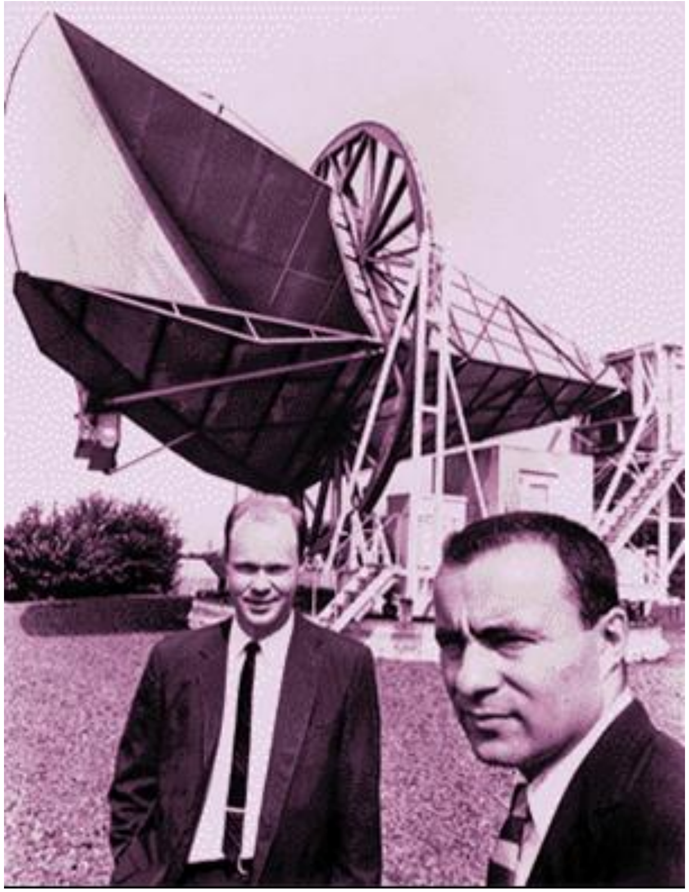
Breaking the Stalemate

- A hot “bang” should leave left-over heat. '
- Where to look in the ' EM spectrum? '
- Many looked. Some concluded it would be ' too faint to detect. '
- Without both the data ' and the theory, the dots could not be connected. '



In 1965, Enter Dumb Luck* '

- Penzias and Wilson were making radio observations of the Milky Way.
- Left with mysterious 3 K residual noise in their detector.
- Peebles and Dicke (Princeton) had just calculated an estimate for the temperature of the residual background in the microwave region.



* Not to imply that the researchers were dumb – quite the opposite, in fact! '

In 1965, Enter Dumb Luck

- The CMB **predicted** by Big Bang theory. '
- Steady State theory has no such prediction. '
- The signal peaks in the microwave, so is called ' the Cosmic Microwave ' Background radiation, or CMB for short. '

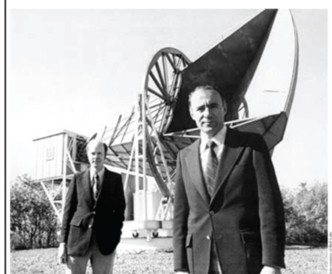
Age of the Universe: 10 - 25 Billion Years

COSMIC TIMES

1965

Size of the Universe: 25 Billion Light Years

MURMUR OF A BANG



Robert Wilson (left) and Arno Penzias stand in front of their horn reflector antenna in Holmdel, New Jersey. They discovered a radiation signal that matches that expected by theorists who proposed that the universe began with a hot explosion called the "big bang". This discovery was made by accident as they tried to track down the source of unwanted noise in their receiver.

Astronomers have identified a faint cosmic radio rumble as the distant roar of the universe's birth. The discovery not only provides the first observational evidence that the universe started with a "big bang," but it also has implications for how it might end.

The faint radio hiss comes in the form of 7.3-centimeter microwaves, which lie on the electromagnetic spectrum between radio waves and infrared light. The microwaves come from every direction in space, without regard to time of day or season. The background radiation signal matches that expected by some theorists who proposed that the universe began with a hot explosion of hydrogen about seven billion years ago and has been cooling ever since.

The discovery of what's being called "cosmic black body radiation," where the wavelength of radiation emitted is directly related to the temperature, was made more or less by accident by Arno Penzias and Robert Wilson of Bell Telephone Laboratories. The two were trying to track down the source of unwanted radio noise in the 20-foot horn reflector antenna at the Crawford Hill Laboratory in Holmdel, N.J. The "Holmdel horn" antenna was built to test telecommunications with the Echo satellite.

When the Holmdel horn was aimed at zenith, Penzias and Wilson found that it picked up the 7.3-centimeter microwave signal consistent with a temperature of 6.7 degrees Kelvin. That is to say, it corresponded to 6.7 degrees above the theoretical value of absolute zero, at which there is no thermal energy at all. After subtracting natural microwave energy emissions from Earth's atmosphere and energy losses in the antenna itself, Penzias and Wilson were left with an unexplained temperature of about 3.5 degrees Kelvin, give or take one degree, coming from empty space.

Luckily, just down the road some Princeton scientists had the solution. Astronomer Robert Dicke and his team were in the process of building a radio telescope for the express purpose of finding the whisper of the Big Bang. When they heard about Penzias' and Wilson's mystery microwave hiss, they knew it was their prey. After conferring, the Bell Lab and Princeton teams announced the discovery in a pair of letters published in the July issue of Astrophysical Journal.

"The presence of thermal radiation remaining from the fireball is to be expected if we can trace the expansion of the universe back to a time when the temperature was of the order of ten billion degrees Kelvin," wrote Dicke and his colleagues. This, they conclude, was the time when the universe began with a Big Bang from a very hot, dense ball of primordial matter and energy.

Stunning and significant as the discovery is, to some astronomers it wasn't a surprise. Theorists including George Gamow, Ralph Alpher and Robert Herman had argued in the late 1940s for a Big Bang and that its remnant heat ought to be still detectable. In 1949, Alpher and Herman reworked some of Gamow's earlier calculations and actually predicted that the remaining radiation would now have a temperature of "a few degrees Kelvin." The new observations of this background radiation support their prediction.

Where Alpher and Herman went wrong, however, is in thinking that the dying thunder of the Big Bang would be drowned out by today's starlight, cosmic ray particles, and the other noisy emissions of an active universe. Instead, it appears that the remnants of the Big Bang have cooled in a way that channels energy into specific bandwidths. This is what Dicke and his team suspected and one reason they were planning to look in the microwave realm. It's also how they knew Penzias' and Wilson's excess microwave noise was a significant discovery.

The discovery of this cosmic black body radiation has driven more nails into the coffin of the "steady-state" universe theory, favored by many astronomers not long ago. Steady-state theory holds that the eternal expansion of the universe is spurred on by the spontaneous creation of particles in empty space. Such a theory does not predict the cosmic black body radiation, making it incompatible with the new data.

The Big Bang implies a range of possible fates for the universe. It will either expand and cool forever as an "open universe," according to Dicke and his team, or it is a "closed universe."

In a closed universe the gravity of all the matter in the universe will pull it back together into another hot ball, breaking down matter and energy into their basic building blocks. Then it will explode again into another, totally new universe. Dicke refers to this version of a closed universe as an "oscillating universe." This option resembles the steady-state model in at least one respect: it has no ultimate beginning or end. Sadly, however, it offers no way of detecting what came before the last bang and no escape from being crushed together into another hot ball before the next.

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 Doroshkevic 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 degrees Kelvin noise that he assumed was coming from the antenna itself. The Bell Laboratories team has been able to say with far more confidence that the faint excess static truly came from space, because they had to weed out the antenna's own noise to arrive at their conclusions.

There were two other near misses as well. Ten years ago Émile Le Roux reported a background radiation of 3 degrees Kelvin, plus or minus 2 degrees, while studying the sky in the 33-centimeter radio wavelength at Paris' Nançay Radio Observatory. In 1957, Russian Tigran Shmaonov nearly made the discovery, reporting that he measured a background temperature of 4 degrees Kelvin, give or take 3 degrees, while looking at the 3.2-centimeter wavelength of microwaves.

The missing piece in both Le Roux's and Shmaonov's work was the connection of what they had seen, to theoretical predictions from the Big Bang made as early as 1948. It was a matter of having the right data, without a theory to make sense of them. Penzias and Wilson would have fared no better had not their neighbors at Princeton helped them recognize the noise as the long-sought remnant radiation.

Galaxies Still Misbehaving

Recent attempts to weigh galaxies still come up a bit short. Two spiral galaxies under study, NGC 3521 and NGC 972, have weighed in at 80 billion and 12 billion suns, respectively. The puzzle is why the amount of starlight from these galaxies doesn't add up to such huge amounts of matter.

The starlight measurements of the two galaxies are based on careful accounting of the galaxy's total luminosity, or magnitude, as recorded on photographic plates. It also takes into account the way the galaxies' stars are arranged from their centers to the edges.

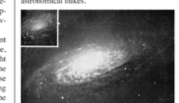
The mass measurement is based on the same idea that long ago allowed astronomers to calculate the mass of the Sun: if a relatively small-mass object orbits a very large-mass object at a known speed, the larger object's mass can be determined mathematically. The same physics applies to stars orbiting a galaxy's center of gravity.

Since the motions of the extremely distant stars are not detectable through any telescope, researchers sampled slivers of galactic starlight from different parts of the galaxies and split the light into spectra – their rainbows of color. These spectra contain patterns of lines, representing different energies, that shift in proportion to the speeds of the stars.

To make comparisons easier, astronomers blend luminosity and mass measurements into a single number called a mass-to-light ratio. Our Sun, for example, has a mass-to-light ratio of one "solar mass" divided by one solar luminosity, which equals 1. A ratio greater than 1 implies more mass than luminosity – which means that some mass is not accounted for.

In the case of NGC 3521, measurements from the University of Texas' powerful 82-inch telescope at McDonald Observatory give it a mass-to-light ratio of 4 or greater. NGC 972 is a bit less worrisome, with a ratio of 1.2. These results were reported in recent issues of Astrophysical Journal by teams of researchers led by Margaret Burbidge of the University of California at San Diego. Other researchers are finding similar mismatches in galaxies everywhere, and no one has yet offered a comfortable explanation.

About the only consolation galactic weight watchers may have is that their missing matter problem is far less extreme than that of Caltech astronomer Fritz Zwicky. In 1933, he pioneered similar measurements, though on a grander scale. Assuming that all the mass in a galaxy contributes to its brightness, he calculated the amount of luminous matter in the entire Coma cluster of galaxies, and then measured the speeds of the galaxies as they orbited the cluster. Zwicky came up with a mass-to-light ratio of about 500, implying that 99 percent of the matter in the cluster is hidden. At the moment, most astronomers dismiss such extreme numbers as astronomical flukes.



McDonald Observatory image of NGC3521. Inset shows detail in the central region (at the same scale).

SUPERNOVAE LEAVE BEHIND COSMIC X-RAY GENERATORS

Two years after discovering that the universe is awash in X-rays, astronomers are starting to pinpoint discrete sources with greater accuracy – and none of which resemble your doctor's X-ray machine.

One source is the Crab nebula, the remnant of a supernova that exploded nearly 900 years ago. Another, designated Ophiuchus XR-1, lies tantalizingly close to the site of another past supernova, SN 1604. In fact, the distribution of X-ray sources in the galaxy mimics that of the known supernova remnants, suggesting that supernovae may leave behind X-ray generators. The exact cause of the X-ray radiation is still a mystery, but if Ophiuchus XR-1 does, indeed, originate from a supernova remnant, then a comparison of these two sources may peel back some of the mystique.

The feat of narrowing down these sources should not be underestimated. Scientists had to develop improvements to astronomical X-ray instruments for rockets and then obtain enough observing time on them for sufficient measurements. Rockets are needed because X-rays cannot penetrate Earth's atmosphere. The atmosphere protects life from dangerous X-rays in space, but it also makes advancing the fledgling field of X-ray astronomy rather difficult and expensive.

The identification of these X-ray sources is the culmination of about three years of rocket flights searching for sources other than the Sun, which is weak in X-rays. The first rocket launch in 1962 used its precious five minutes in space to observe the Moon in X-rays. Riccardo Giacconi and his team at American Science and Engineering, Inc. expected to discover minerals fluorescing in X-rays as a result of being hit by heavy atomic particles from the Sun.

What they found instead was unexpected and far more amazing. A seemingly uniform X-ray hum was coming from every direction in the sky, with a particularly intense X-ray source from the direction of the constellation Scorpius. They named the new spot Scorpius X-1. Unlike the Crab nebula, however, Sco X-1 remains a celestial mystery, as it still has not been tracked to any known heavenly object.

X-ray astronomers hope someday to make their work a little easier by placing instruments in a stable, longer-term orbit that allows more observation time. Until then, the data from those five floating minutes in space is much prized for study.

An Aerobee rocket launches from Wallops Island, Virginia. This rocket is similar to those used in recent discoveries of cosmic X-ray sources such as Scorpius X-1 and, more recently, the Crab nebula and Ophiuchus XR-1.

QUASARS: *Express Trains To Netherworlds*

Astronomers have discovered a quasar racing towards the edge of the known universe at the unprecedented speed of 450 million miles per hour – two-thirds of the speed of light! This and other new-found quasars have more than speed going for them, however. The fact that these strange objects are visible to us from these far distances means they must be fantastically bright.

For years, radio astronomers have seen quasi-stellar objects, or quasars, adding them to a growing list of unexplained "loud" radio sources all over the sky. In 1960, astronomers managed to match a quasar with an object seen by optical telescopes. But it was only two years ago that astronomers Jesse Greenstein and Maarten Schmidt managed to determine the speed of one.

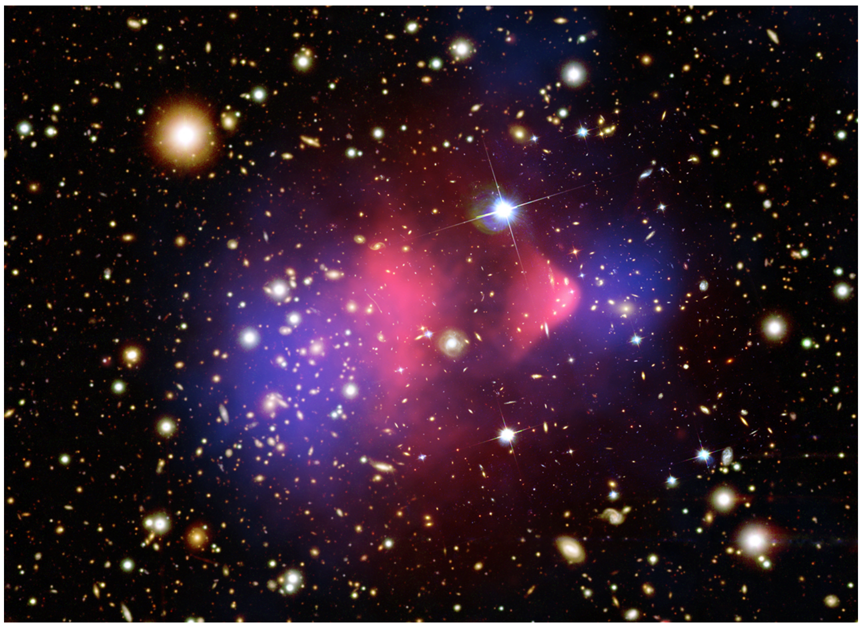
That was when Greenstein and Schmidt split the visible light from quasar 3C 273 into its spectrum of colors. What they found was jaw dropping. The telltale pattern of spectral lines, which signify the presence of specific elements, were shifted dramatically to the red side of the spectrum, the optical equivalent of a train whistle's tone dropping as the train moves away. In the case of 3C 273, the redshift corresponded to an astonishing speed of 16 percent of the speed of light – more than 100 million miles per hour. The same technique was used by Schmidt and Caltech's Allan Sandage to clock the latest record holder, dubbed quasar BSO-1.

No one has yet explained what a quasar is, but Sandage reported, "We do know that [quasars] provide us with the long-sought keys to determine the size and shape of the universe."

Scientists are confident that at least one theory can be ruled out. Quasars are not coded messages from a super-civilization, as has been suggested by Russian astronomer Nikolai Kardashev. It is highly improbable that any civilization could broadcast messages with the power of 10,000 billion suns.

Any message from quasars may be from the universe itself. Astronomers at the 200-inch Mount Palomar telescope hope that, by measuring the distance to more quasars, they can catch sight of some that started shining when the universe was just seven percent of its current age. Some of that light, perhaps 15 billion years old, is only now reaching Earth.

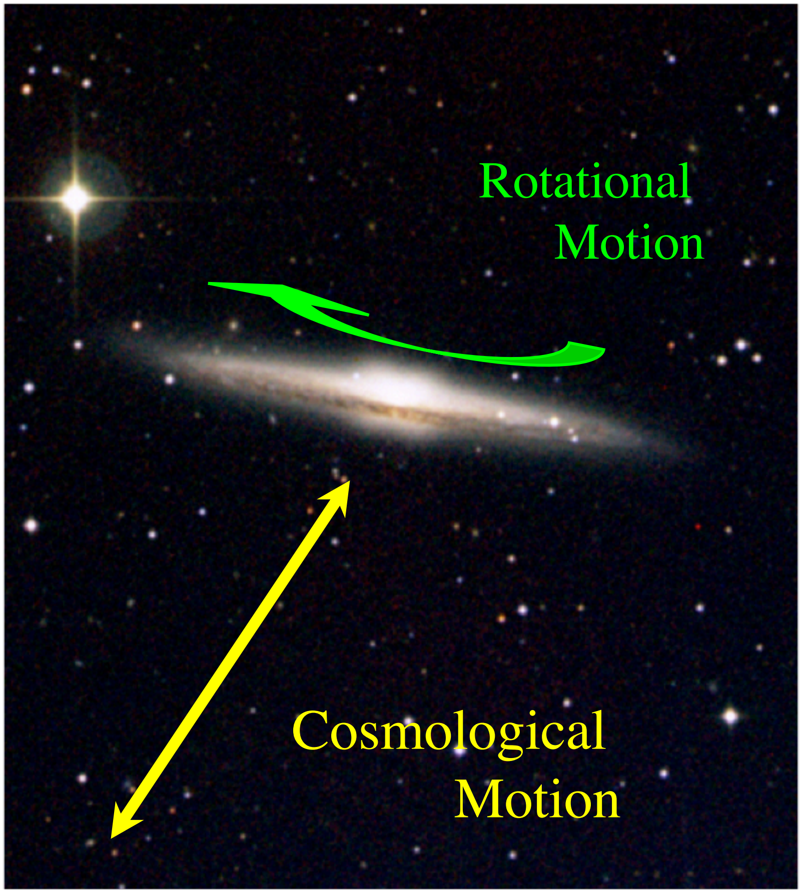
Galaxies still misbehaving



- In the ‘60s, researchers ' start to “weigh” galaxies
- They begin to find that there must be “unseen” matter to account for their observations
- Not the first glimpse at unseen matter - Zwicky ran into trouble when he measured mass in clusters in the ‘30s

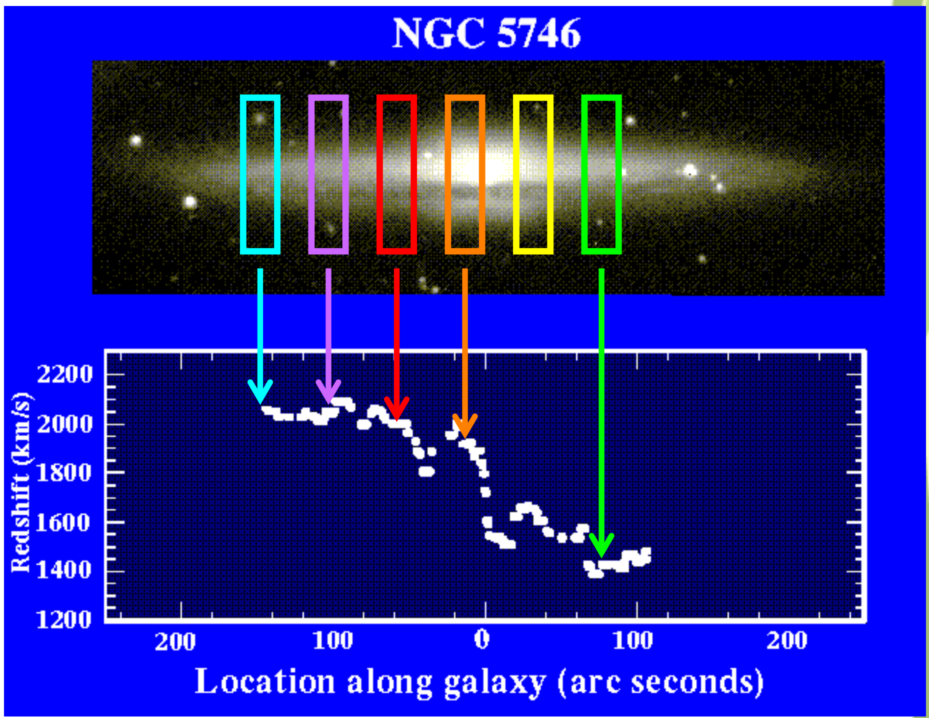
Galaxies still misbehaving '

- Use redshift to map the rotation of a galaxy.
- Here we are interested in the rotational redshift.



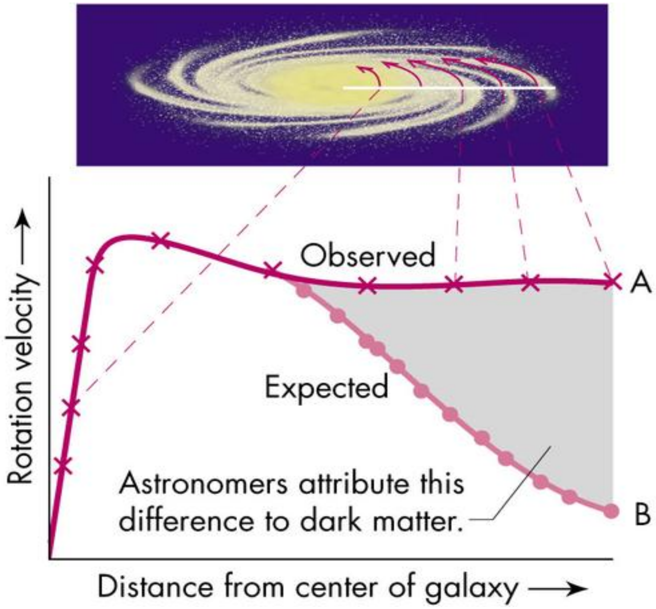
Galaxies still misbehaving

- Use redshift to map the rotation of a galaxy. '
- Here we are interested in ' the rotational redshift. '
- Create a map by ' determining the redshift of ' several slices of the galaxy. '



Galaxies still misbehaving

- Use redshift to map the rotation of a galaxy. '
- Here we are interested in ' the rotational redshift. '
- Create a map by determining the redshift of several slices of the galaxy. '
- Compare the resulting rotation curve to that ' expected if all of the mass were visible as luminous ' matter '



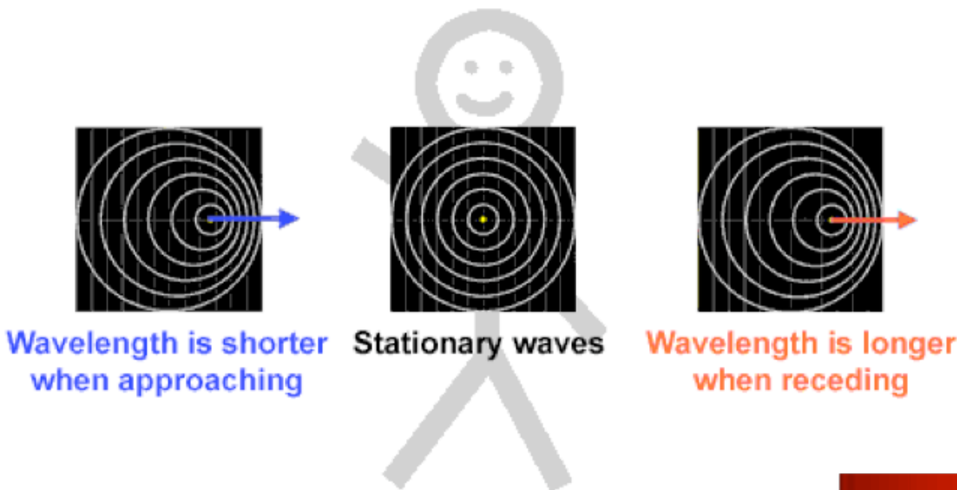
Tornados & Galaxies '

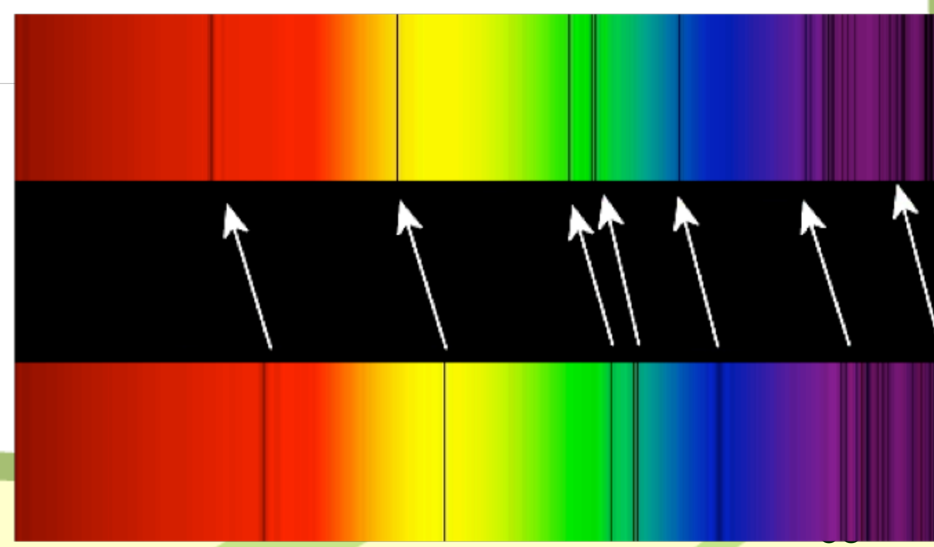
Similar technologies can predict ' tornados and map the rotation of galaxies '

Tornados & Galaxies '

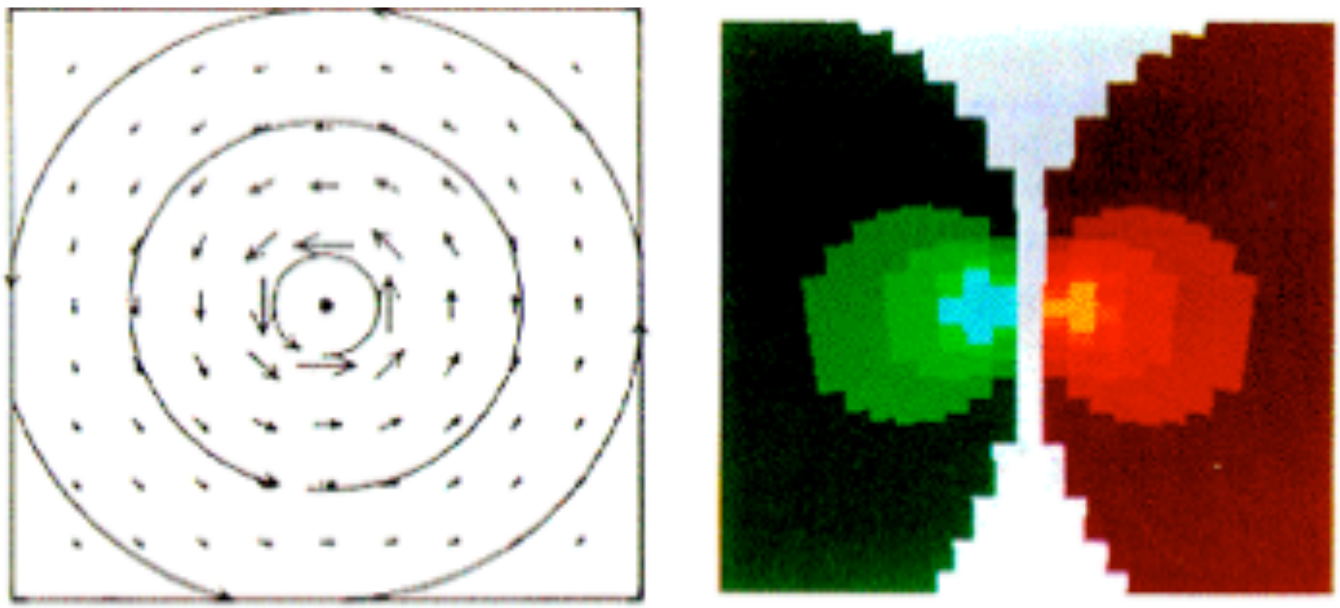
Tornado image from Florencia Guedes on Flickr

Doppler shift '





Doppler mapping '



1965 Lessons

- Reading Strategies
  - Can be applied to any of the articles
- What's the Matter?
  - Modeling dark matter through hidden densities
- Cosmic Microwave Background
  - Illustrating the nature of the CMB '

Other 1965 Stories '

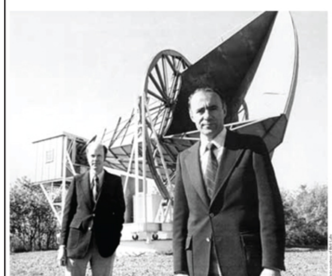
Age of the Universe: *10 - 25 Billion Years*

COSMIC TIMES

1965

Size of the Universe: *25 Billion Light Years*

MURMUR OF A BANG



Robert Wilson (left) and Arno Penzias stand in front of their horn reflector antenna in Holmdel, New Jersey. They discovered a radiation signal that matches that expected by theorists who proposed that the universe began with a hot explosion called the "big bang". This discovery was made by accident as they tried to track down the source of unwanted noise in their receiver.

Astronomers have identified a faint cosmic radio rumble as the distant roar of the universe's birth. The discovery not only provides the first observational evidence that the universe started with a "big bang," but it also has implications for how it might end.

The faint radio hiss comes in the form of 7.3-centimeter microwaves, which lie on the electromagnetic spectrum between radio waves and infrared light. The microwaves come from every direction in space, without regard to time of day or season. The background radiation signal matches that expected by some theorists who proposed that the universe began with a hot explosion of hydrogen about seven billion years ago and has been cooling ever since.

The discovery of what's being called "cosmic black body radiation," where the wavelength of radiation emitted is directly related to the temperature, was made more or less by accident by Arno Penzias and Robert Wilson of Bell Telephone Laboratories. The two were trying to track down the source of unwanted radio noise in the 20-foot horn reflector antenna at the Crawford Hill Laboratory in Holmdel, N.J. The "Holmdel horn" antenna was built to test telecommunications with the Echo satellite.

When the Holmdel horn was aimed at zenith, Penzias and Wilson found that it picked up the 7.3-centimeter microwave signal consistent with a temperature of 6.7 degrees Kelvin. That is to say, it corresponded to 6.7 degrees above the theoretical value of absolute zero, at which there is no thermal energy at all. After subtracting natural microwave energy emissions from Earth's atmosphere and energy losses in the antenna itself, Penzias and Wilson were left with an unexplained temperature of about 3.5 degrees Kelvin, give or take one degree, coming from empty space.

Luckily, just down the road some Princeton scientists had the solution. Astronomer Robert Dicke and his team were in the process of building a radio telescope for the express purpose of finding the whisper of the Big Bang. When they heard about Penzias' and Wilson's mystery microwave hiss, they knew it was their prey. After conferring, the Bell Lab and Princeton teams announced the discovery in a pair of letters published in the July issue of Astrophysical Journal.

"The presence of thermal radiation remaining from the fireball is to be expected if we can trace the expansion of the universe back to a time when the temperature was of the order of ten billion degrees Kelvin," wrote Dicke and his colleagues. This, they conclude, was the time when the universe began with a Big Bang from a very hot, dense ball of primordial matter and energy.

Stunning and significant as the discovery is, to some astronomers it wasn't a surprise. Theorists including George Gamow, Ralph Alpher and Robert Herman had argued in the late 1940s for a Big Bang and that its remnant heat ought to be still detectable. In 1949, Alpher and Herman reworked some of Gamow's earlier calc[illegible] and actually predicted that [illegible] remaining radiation would now have a t[illegible]perature of "a few degrees Kelvin." The [illegible] observations of this background radiatio[illegible] support their prediction.

Where Alpher and Herman went [illegible], however, is in thinking that the dying thunder of the Big Bang would be drowned out by today's starlight, cosmic ray particles, and the other noisy emissions of an active universe. Instead, it appears that the remnants of the Big Bang have cooled in a way that channels energy into specific bandwidths. This is what Dicke and his team suspected and one reason they were planning to look in the microwave realm. It's also how they knew Penzias' and Wilson's excess microwave noise was a significant discovery.

The discovery of this cosmic black body radiation has driven more nails into the coffin of the "steady-state" universe theory, favored by many astronomers not long ago. Steady-state theory holds that the eternal expansion of the universe is spurred on by the spontaneous creation of particles in empty space. Such a theory does not predict the cosmic black body radiation, making it incompatible with the new data.

The Big Bang implies a range of possible fates for the universe. It will either expand and cool forever as an "open universe," according to Dicke and his team, or it is a "closed universe."

In a closed universe the gravity of all the matter in the universe will pull it back together into another hot ball, breaking down matter and energy into their basic building blocks. Then it will explode again into another, totally new universe. Dicke refers to this version of a closed universe as an "oscillating universe." This option resembles the steady-state model in at least one respect: it has no ultimate beginning or end. Sadly, however, it offers no way of detecting what came before the last bang and no escape from being crushed together into another hot ball before the next.

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 Doroshkevic 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 degrees Kelvin noise that he assumed was coming from the antenna itself. The Bell Laboratories team has been able to say with far more confidence that the faint excess static truly came from space, because they had to weed out the antenna's own noise to arrive at their conclusions.

There were two other near misses as well. Ten years ago Émile Le Roux reported a background radiation of 3 degrees Kelvin, plus or minus 2 degrees, while studying the sky in the 33-centimeter radio wavelength at Paris' Nançay Radio Observatory. In 1957, Russian Tigran Shmaonov nearly made the discovery, reporting that he measured a background temperature of 4 degrees Kelvin, give or take 3 degrees, while looking at the 3.2-centimeter wavelength of microwaves.

The missing piece in both Le Roux's and Shmaonov's work was the connection of what they had seen, to theoretical predictions from the Big Bang made as early as 1948. It was a matter of having the right data, without a theory to make sense of them. Penzias and Wilson would have fared no better had not their neighbors at Princeton helped them recognize the noise as the long-sought remnant [illegible]

Galaxies Still Misbehaving

Recent attempts to weigh galaxies still come up a bit short. Two spiral galaxies under study, NGC 3521 and NGC 972, have weighed in at 80 billion and 12 billion suns, respectively. The puzzle is why the amount of starlight from these galaxies doesn't add up to such huge amounts of matter.

The starlight measurements of the two galaxies are based on careful accounting of the galaxies' total luminosity, or magnitude, as recorded on photographic plates. It also takes into account the way the galaxies' stars are arranged from their centers to the edges.

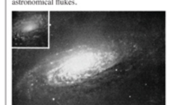
The mass measurement is based on the same idea that long ago allowed astronomers to calculate the mass of the Sun: if a relatively small-mass object orbits a very large-mass object at a known speed, the larger object's mass can be determined mathematically. The same physics applies to stars orbiting a galaxy's center of gravity.

Since the motions of the extremely distant stars are not detectable through any telescope, researchers sampled slivers of galactic starlight from different parts of the galaxies and split the light into spectra – their rainbows of color. These spectra contain patterns of lines, representing different energies, that shift in proportion to the speeds of the stars.

To make comparisons easier, astronomers blend luminosity and mass measurements into a single number called a mass-to-light ratio. Our Sun, for example, has a mass-to-light ratio of one "solar mass" divided by one solar lum[illegible]ty, which equals 1. A ratio greater than 1 [illegible] more mass than luminosity – which m[illegible] that some mass is not accounted for.

In the case of NGC 3521, measurem[illegible]ts from the University of Texas' powerful 82-i[illegible] telescope at McDonald Observatory give it a [illegible] ratio of 4 or greater. NGC 972 is a [illegible] less worrisome, with a ratio of 1.2. These results were reported in recent issues of Astrophysical [illegible] researchers led by Margaret Burbidge of the Univers[illegible] [illegible]lifornia at San Diego. Other researchers are finding similar mismatches in galaxies everywhere, and no one has yet offered a comfortable explanation.

About the only consolation galactic weight watchers may have is that their missing matter problem is far less extreme than that of Caltech astronomer Fritz Zwicky. In 1933, he pioneered similar measurements, though on a grander scale. Assuming that all the mass in a galaxy contributes to its brightness, he calculated the amount of luminous matter in the entire Coma cluster of galaxies, and then measured the speeds of the galaxies as they orbited the cluster. Zwicky came up with a mass-to-light ratio of about 500, implying that 99 percent of the matter in the cluster is hidden. At the moment, most astronomers dismiss such extreme numbers as astronomical flukes.



McDonald Observatory image of NGC3521. Inset shows detail in the [illegible] (at the same scale).

SUPERNOVAE LEAVE BEHIND COSMIC X-RAY GENERATORS

[illegible] years after discovering that the universe is awash in X-rays, [illegible] pinpoint discrete sources with greater accuracy – and none of which resemble your doctor's X-ray machine.

One source is the Crab nebula, the remnant of a supernova that exploded nearly 900 years ago. Another, designated Ophiuchus XR-1, lies tantalizingly close to the site of another past supernova, SN 1604. In fact, the distribution of X-ray sources in the galaxy mimics that of the known supernova remnants, suggesting that supernovae may leave behind X-ray generators. The exact cause of the X-ray radiation is still a mystery, but if Ophiuchus XR-1 does, indeed, originate from a supernova remnant, then a comparison of these two sources may peel back some of the mystique.

The feat of narrowing down these sources should not be underestimated. Scientists had to develop improvements to astronomical X-ray instruments for rockets and then obtain enough observing time on them for sufficient measurements. Rockets are needed because X-rays cannot penetrate Earth's atmosphere. The atmosphere protects life from dangerous X-rays in space, but it also makes advancing the fledgling field of X-ray astronomy rather difficult and expensive.

The identification of these X-ray sources is the culmination of about three years of rocket flights searching for sources other than the Sun, which is weak in X-rays. The first rocket launch in 1962 used its precious five minutes in space to observe the Moon in X-rays. Riccardo Giacconi and his team at American Science and Engineering, Inc. expected to discover minerals fluorescing in X-rays as a result of being hit by heavy atomic particles from the Sun.

What they found instead was unexpected and far more amazing. A seemingly uniform X-ray hum was coming from every [illegible] intense X-ray source from the direction of the constellation Scorpius. They named the new spot Scorpius X-1. Unlike the Crab nebula, however, Sco X-1 remains a celestial mystery, as it still has not been tracked to any known heavenly object.

X-ray astronomers hope someday to make their work a little easier by placing instruments in a stable, longer-term orbit that allows more observation time. Until then, the data from those five floating minutes in space is much prized for study.

An Aerobee rocket launches from Wallops Island, Virginia. This rocket is similar to those used in recent discoveries of cosmic X-ray sources such as Scorpius X-1 and, more recently, the Crab nebula and Ophiuchus XR-1.

QUASARS: *Express Trains To Netherworlds*

Astronomers have discovered a quasar racing [illegible] the edge of the known universe [illegible] unprece[illegible] miles per hour – two-thirds of the speed of light! This and other new-found quasars have more than speed [illegible] for them, however. The fact that these strange [illegible] objects are visible to us from these far distance[illegible] means they must be fantastically bright.

For [illegible], radio astronomers have seen qua[illegible] objects, or quasars, adding them [illegible] a growing list of unexplained "loud" radio sources all over the sky. In 1960, astronomers managed to match a quasar with an object seen by optical telescopes. But it was only two years ago that astronomers Jesse Greenstein and Maarten Schmidt managed to determine the speed of one.

That was when Greenstein and Schmidt split the visible light from quasar 3C 273 into its spectrum of colors. What they found was jaw dropping. The telltale pattern of spectral lines, which signify the presence of specific elements, were shifted dramatically to the red side of the spectrum, the optical equivalent of a train whistle's tone dropping as the train moves away. In the case of 3C 273, the redshift corresponded to an astonishing speed of 16 percent of the speed of light – more than 100 million miles per hour. The same technique was used by Schmidt and Caltech's Allan Sandage to clock the latest record holder, dubbed quasar BSO-1.

No one has yet explained what a quasar is, but Sandage reported, "We do know that [quasars] provide us with the long-sought keys to determine the size and shape of the universe."

Scientists are confident that at least one theory can be ruled out. Quasars are not coded messages from a super-civilization, as has been suggested by Russian astronomer Nikolai Kardashev. It is highly improbable that any civilization could broadcast messages with the power of 10,000 billion suns.

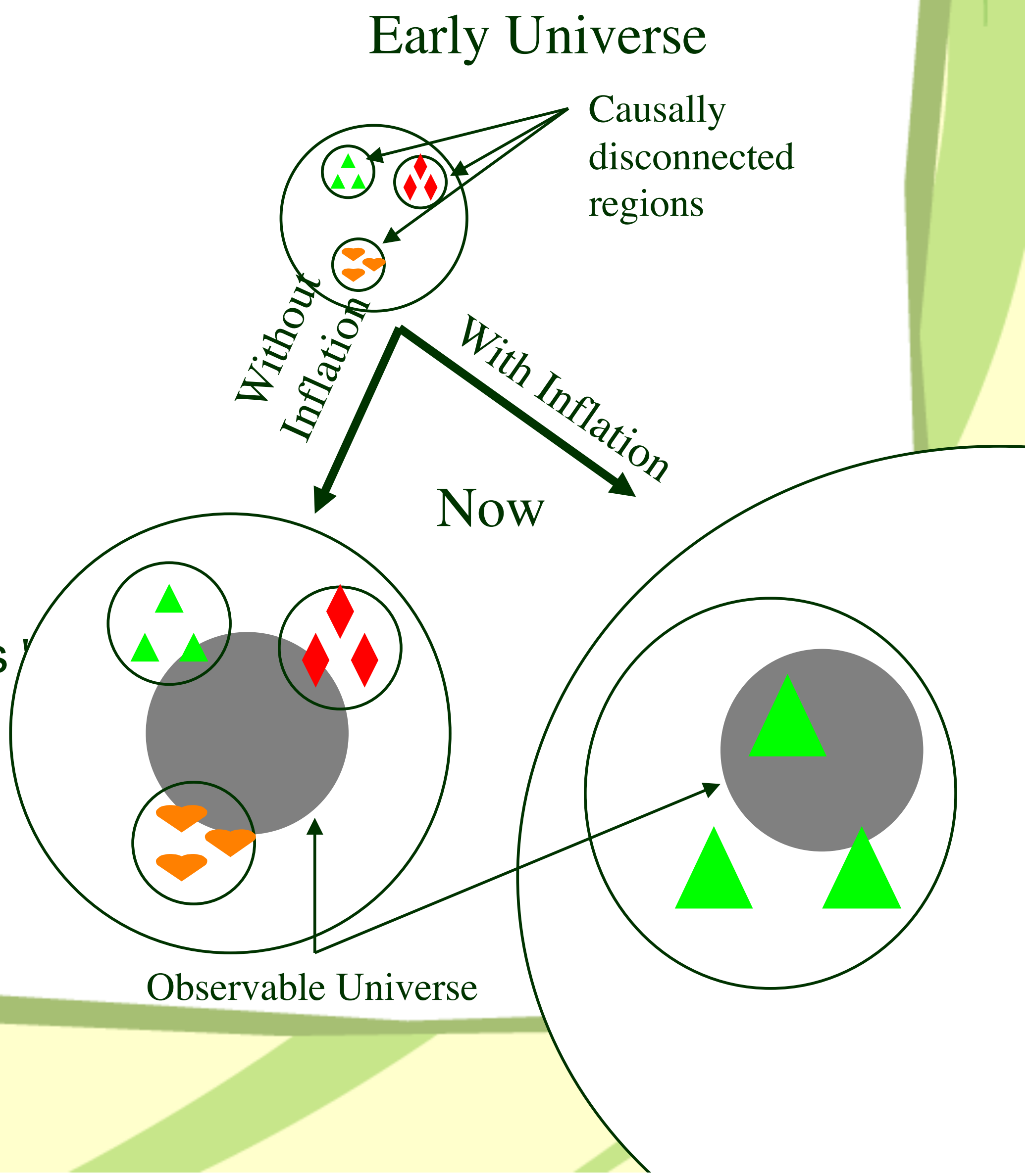
Any message from quasars may be from the universe itself. Astronomers at the 200-inch Mount Palomar telescope hope that, by measuring the distance to more quasars, they can catch sight of some that started shining when the universe was just seven percent of its current age. Some of that light, perhaps 15 billion years old, is only now reaching Earth.

Trouble in the Early Universe '

- By the 1970s, three serious problems ' were emerging with Big Bang Theory '
  - Horizon problem - disparate regions of the Universe should not have been able to “talk”, and yet they look nearly homogeneous.
  - Flatness problem - the Universe is too flat!
  - Magnetic Monopoles - where are they?

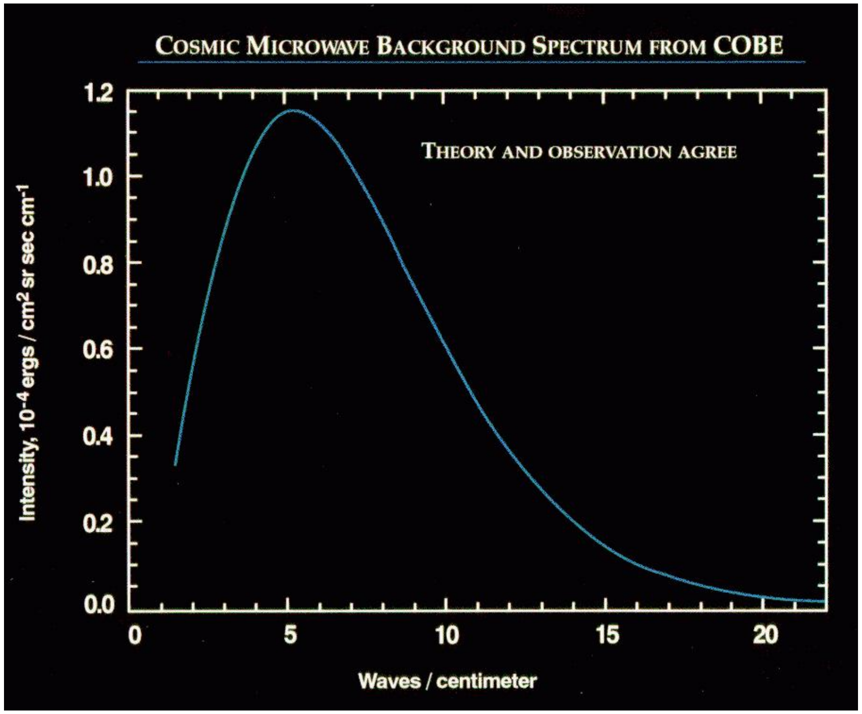
Inflation to the rescue

- Inflation Theory (early '80s) takes care of these issues)
  - The Universe we see all started in a small, "causally-connected" region
  - This region underwent an exponential expansion '
  - The detailed mechanism for this expansion is not currently understood '
  - However, inflationary theory makes predictions that have been shown to be correct '



Perfect Black Body! '
But, where are the lumps? '

- The Cosmic Background Explorer is launched in 1989 to examine the CMB in finer detail '
- The first result was the ' spectrum of the CMB '
- Which was a **perfect** black body (the error bars are contained in the line thickness!) '
- Almost too perfect!

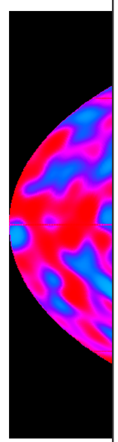


Astronomers hold their breath ' for two years…

- Some “lumps” are needed in the CMB to act as seeds of the structure we see in the Universe today - galaxy clusters, galaxies, stars, everything
- If the lumps were not detected by the limit of COBE’s abilities, the Big Bang and Inflationary theories would all be in trouble

At Last, a Lumpy Universe

- NASA's COBE ' mission finds "lumps" in the CMB! '
- These "lumps" are tiny, consisting of changes on the order of 1 part in 10^5. '
- But they are enough to produce the ' structure we see. '



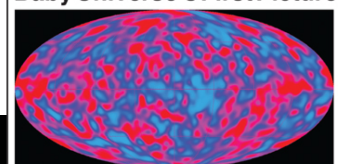
Age of the Universe: *12-20 Billion Years*

COSMIC TIMES

1993

Size of the Universe: *30 Billion Light Years*

Baby Universe's First 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. Today's technology has drawn a more detailed picture of this cosmic microwave background, telling us there's a lot more to the story…and providing further evidence of the Big Bang.

"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 unthinkably 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 freshly minted particles, first in the form of quarks and electrons, then protons and neutrons, which combined to make the nuclei of hydrogen and helium. Over time, gravity gathered the denser clumps of gas into the familiar galaxies, stars, and planets of the modern universe. All the while, the radiation that was emitted in all directions by that early hot gas gradually shifted into the microwave energy range as the universe expanded. We see this radiation today as a cosmic microwave background (CMB).

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- just 30 millionths of a degree - 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 these very slight – but now clearly measurable – energy differences. Smoot and his team created an all-sky map of these microwave variations, illustrating for the first time these anisotropies, 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.

COBE excited scientists three years ago with data that exactly matched what they had expected from a Big Bang universe. COBE measured the spectrum of light from the CMB and found that it was, as predicted, in the form of a perfect blackbody curve. These data were collected by COBE on an instrument designed by John Mather of NASA's Goddard Space Flight Center, who also headed the COBE project. With the addition of the latest findings, the eight-decade-old Big Bang theory, with the addition of inflation, is now firmly the lead model for how the universe began. Other models either cannot account for COBE's results or must undertake some difficult and unsavory contortions to do so.

The lumps in the map do not correlate with anything particular in the night sky today, but they are of distinct importance, say the researchers. If the CMB was perfectly uniform, according to theory, we could not exist! So while the greatest variations in the CMB are only at a level of one part in 100,000, they are sufficient to ultimately lead to the current structures in the universe.

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

Inflation in the Universe

The Big Bang theory has a problem, say scientists. It can't go 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 10^{26} in about 10^{-33} 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 by-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^{27} kelvins.

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, neutrinos, and electrons appeared, then protons and neutrons.

Inflation makes another remarkable prediction: how stars and galaxies formed in the universe. Since our cosmic neighborhood would have been microscopic 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. Thus 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.

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 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 force to hold it in place. Only dark matter could do the job without being seen, explains Richard Mushotzky 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, says Mushotzky. 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 universe back together into a "Big Crunch," say some researchers.

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 disc further from the galactic center were not rotating more slowly than those closer in, as models predicted they should be. The simplest explanation is that matter is a lot more evenly spread through the galaxy than it appears. In other words, dark matter is tugging at these stars and keeping them in the galaxy.

Hot X-ray emitting gas (shown in purple) was discovered by the ROSAT satellite to be present in this group of galaxies. The presence of the gas provides evidence for the existence of dark matter. (NASA image)

Despite the new ROSAT discovery and its enormous implications, scientists haven't been very successful in figuring out what exactly dark matter is. Some think it might be a type of subatomic particle that has mass but only interacts with normal matter through gravity. These Weakly Interacting Massive Particles (WIMPs) could be shooting harmlessly through us right now, a million per second, and we wouldn't know it.

Another possibility is that the there are a lot of dark, cold dead stars out there that can't be detected with our current technology. These MAssive Compact Halo Objects (MACHOs) would probably be concentrated in the halo of stars found immediately above and below the galactic disk.

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 1913+16, which is a special type of super-dense neutron star called a pulsar. This pulsar emits a radio pulse every 59 milliseconds as it rotates on its axis. It is locked in a dizzying eight-hour orbit with another star, which is likely to be another neutron star.

Four years later, after some careful timing measurements of the pulsar, they found that the two stars are spinning closer to each other by about three millimeters per orbit. That could only happen if something was pulling energy out of the system. But what was it?

Einstein's theory of general relativity provides the answer. It predicts that two massive objects tearing around in a strong gravitational field radiate gravitational waves out into space. This extracts energy from their orbits, and causes them to drop in closer to each other. The 8-hour orbit should be 75 microseconds shorter every year.

After 18 years of refinement, Taylor has honed down the timing of PSR 1913+16's orbital periods to within 0.3 percent of 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.

Russell A. Hulse and Joseph H. Taylor, both of Princeton University, shared the 1993 Nobel Prize in Physics for their discovery of evidence of gravitational waves, confirming the prediction by Einstein in 1916.

Fool-Proofing Galactic 'Candles'

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

For years, the bright supernovae 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.

In the 1940s, astronomers realized supernovae came in two flavors: some (later called Type I) did not show any evidence of containing hydrogen, while others (denoted Type II) did. The lack of hydrogen means that the star has used up the basic fuel that drives nuclear reactions in stars. Type II's were found to result from the death of a single, massive star. In the 1980s, however, it became clear that some Type I's also come from the death of a massive star. The remaining Type I's, now called Type Ia, were found instead to result from the collapse of a white dwarf star in a binary star system.

In a binary system, a white dwarf can gain mass from its companion star. With sufficient mass gained from the companion, the white dwarf reaches a critical mass at which nothing can counteract the inward crush of gravity of the star on itself. The white dwarf collapses and explodes as a Type Ia supernova.

Since all Type Ia's are created by the explosion of a white dwarf star as it exceeds a critical mass, astronomers believed they should all have the same intrinsic brightness. and be useful as a measuring stick to distant galaxies. In addition, Type Ia's may be visible at distances greater than the Cepheid variable stars, identified as standard candles in 1912 by Henrietta Leavitt.

But it turns out that not all Type Ia's are equal either. A large sampling of supernovae 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 the dim, fast-fading supernovae from the bright, slow-fading ones, Phillips arrived at a luminosity-decline relation. It allows calculation of a correction factor for supernovae that are dimmer than the standard Type Ia supernova. Astronomers can adjust the distance accordingly, and increase the accuracy of the distance measurements.

Pancake or Oatmeal Universe – What's for Breakfast?

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

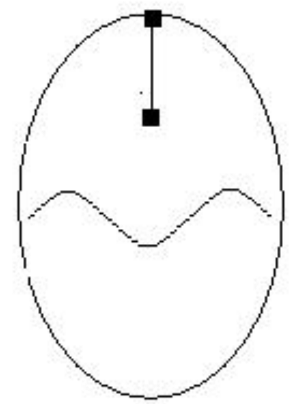
The COBE results present what's been called an isotropic, or smooth, early universe – with measured variations in the cosmic microwave background radiation of only 1 part in 100,000! You might say that, at that time, the universe was like the surface of a pancake: smooth at a glance, with differences in texture seen only under closer inspection.

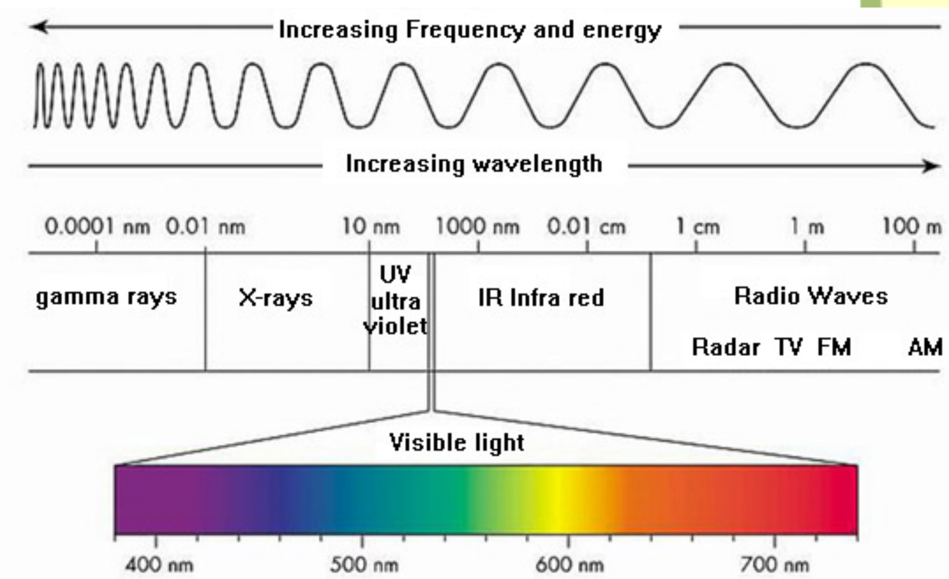
The universe today is more like a bowl of oatmeal, with real "lumps" and clumps of matter and energy. Objects from planets and stars to galaxies and galaxy clusters are easily detectable. Nonetheless, overall the universe is much smoother than was predicted by the original Big Bang. This problem has been solved by inflation.

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

Let's Explore the CMB '

- Take balloon and draw a line connecting two dots and a wavy line, as pictured
- The "dots" represent galaxies.
- The "wave" represents the wavelength of light emitted in the Big Bang.



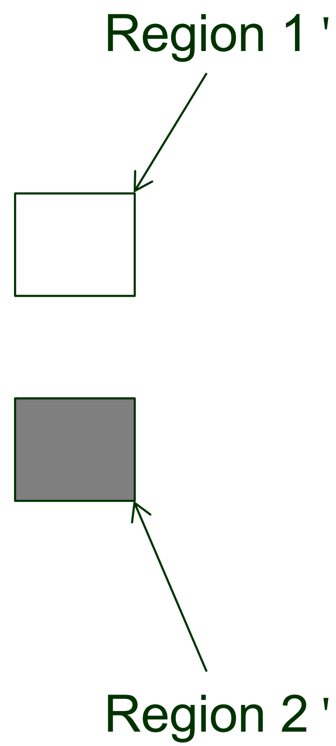


Characteristics of the CMB?

- We've seen that the CMB is
  - isotropic – observed in all directions
  - smooth – similar in all directions
- What does our Universe look like ' today? '
  - Lumpy/structured, not smooth!
  - Problem!! We need *some* lumpiness – some "anisotropies"

Explore CMB Anisotropy '

- Go back to your balloon, turn it to the other side and draw two regions.
- Imagine that gray is one temperature, pink (or balloon color) another temperature.



Supernovae as Standard Candles? '

- Minkowski (1941) identifies two types of SN '
- In late 60's, early 70's - Type I recognized as implosion of a white dwarf, and became candidates as standard candles.
- 1985 - distinction arises between Type Ia and Ib based on spectral properties. Ia's ' continue to be candidates for std candles. '
- 1992 - Phillips provides a correction which makes Ia's more robust as std candles.

1993 Lessons '

- Raisin Bread Universe
  - Cosmology in the kitchen!
- Gravitational Waves
  - Construct a Grav. Wave Demonstrator '
- Melting Ice
  - Carefully designed experiments can yield unexpected results
- Dark Matter NASA Conference

Other 1993 Stories '

Age of the Universe: 12-20 Billion Years

COSMIC TIMES 1993

Size of the Universe: 30 Billion Light Years

Baby Universe's First 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)

Dark Matter Hunt Heats Up

Hot X-ray emitting gas (shown in purple) was discovered by the ROSAT satellite to be present in this group of galaxies. The presence of the gas provides evidence for the existence of dark matter. (NASA image)

Pulsar Gravitational Waves Win Nobel Prize

Russell A. Hulse and Joseph H. Taylor, both of Princeton University, shared the 1993 Nobel Prize in Physics for their discovery of evidence of gravitational waves, confirming the prediction by Einstein in 1916.

Fool-Proofing Galactic 'Candles'

Inflation in the Universe

Pancake or Oatmeal Universe – What's for Breakfast?

Cosmology's End? '

- By the mid-90s, cosmologists thought that they had only to "fill in the details".
- Remaining questions:
  - Will the expansion continue forever, or will Universe eventually collapse back on itself?
  - What is the mass-density of the Universe (which would answer the above)?

Cosmology's End?

- Things may not be what they seem.
- When we see odd behavior, we look more carefully at what's going on.

Not the End '

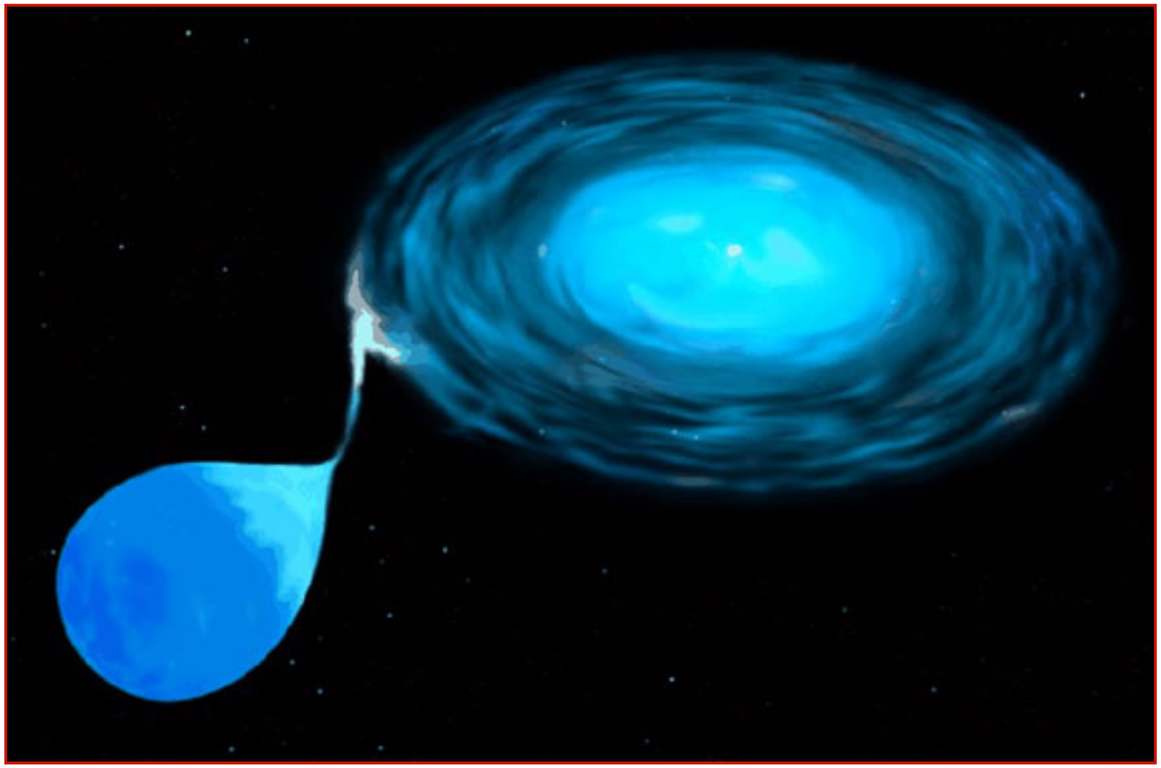
In 1997 …

- Recall, we were looking to “fill in the details” of the Universe’s expansion. '
- Given that gravity is the longest-reaching force according to physics, the expansion of the Universe should be slowing down…

1. Create a White Dwarf

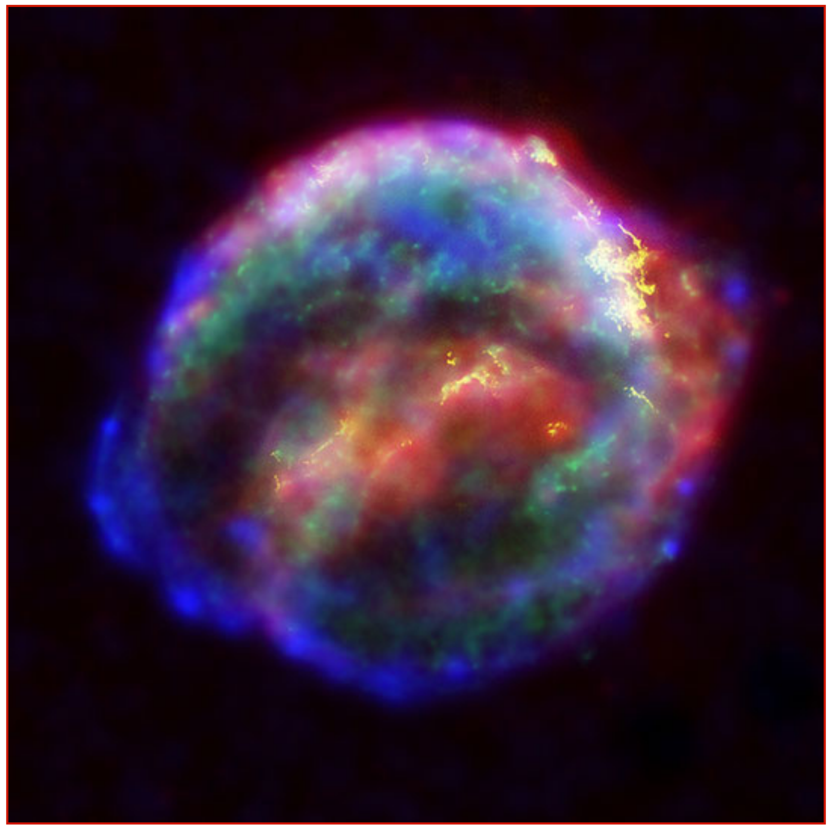
A dying star becomes a white dwarf.

2. Dump more mass onto it



The white dwarf strips gas from its stellar companion….

3. *Until it explodes*

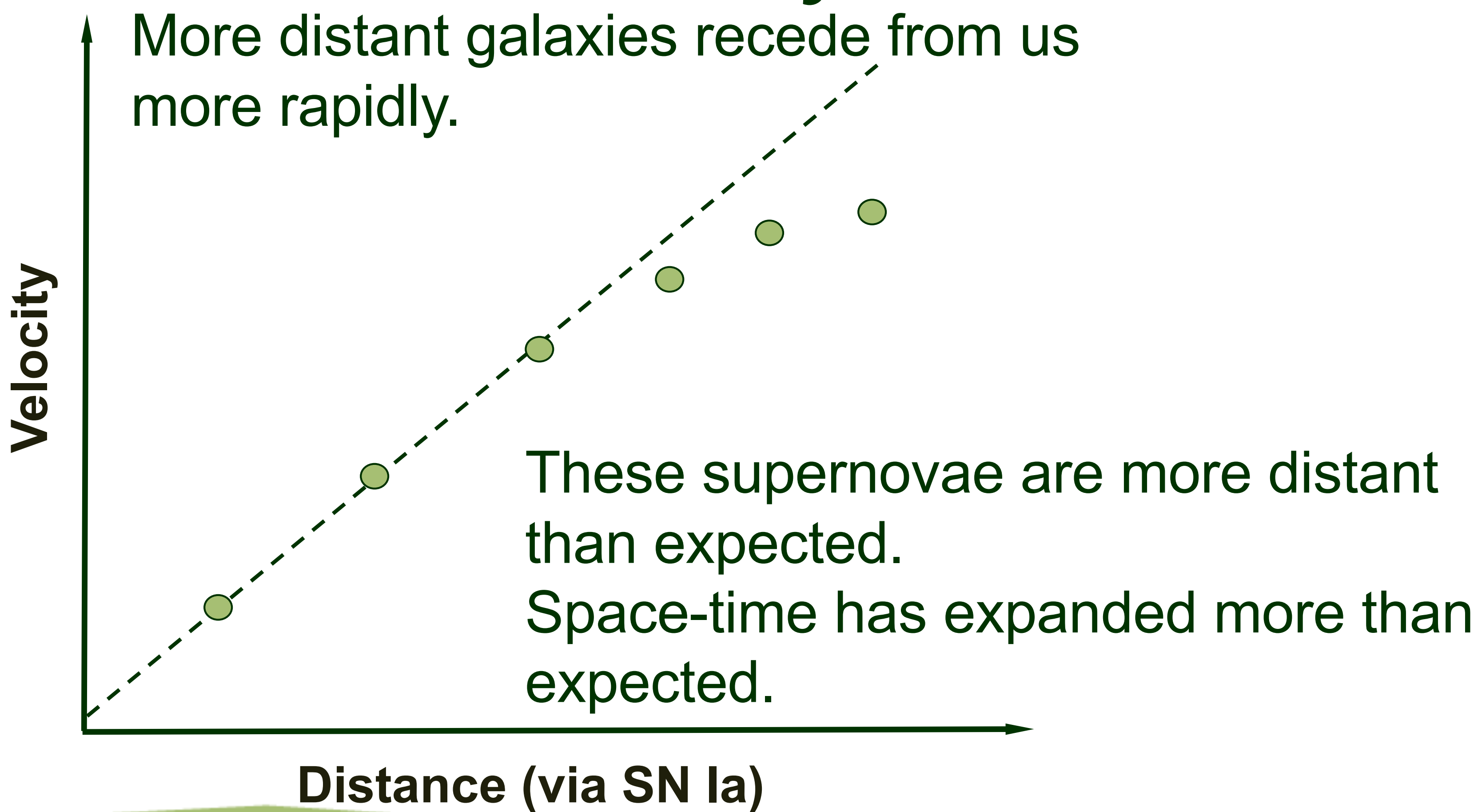


….and uses it to become a hydrogen bomb. Bang!

4. Observe in a distant galaxy

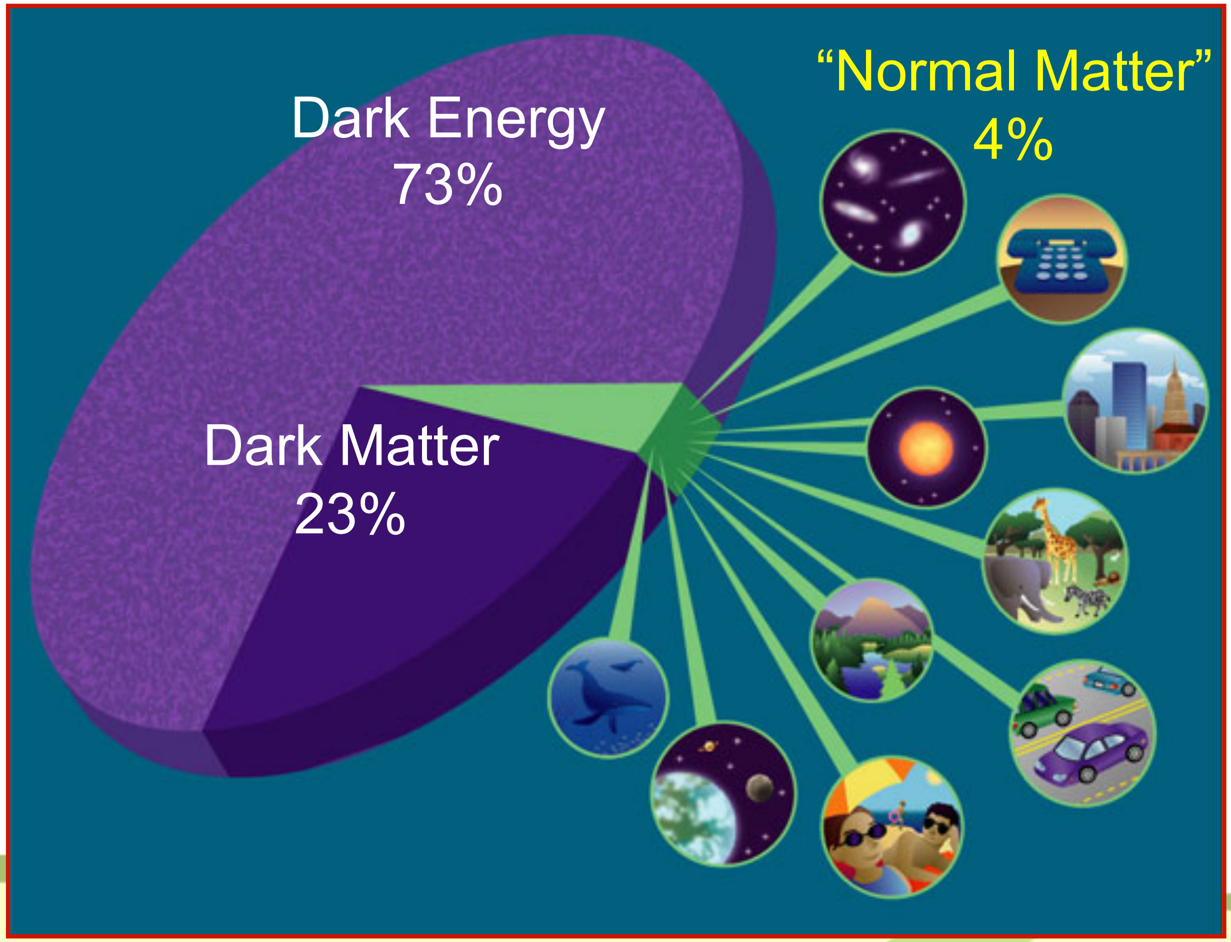
The explosion is as bright as an entire galaxy of stars….
…..and can be seen in galaxies across the universe.

5. Compare its distance to its velocity



History of the Universe's Expansion

Dark Energy Comprises 73% of Universe



Century Timeline

Put together the Cosmic Times timeline with events in:

- Other Science
- Arts/Entertainment/Culture
- World History/Politics

Opportunities for cross-disciplinary collaboration

2006 Lessons

- Measuring Dark Energy
  - Use SN data to see evidence for Dark Energy
- Tools of the Trade
  - Satellites for investigating the cosmos
- Cosmic Times 2019
  - Students predict our state of knowledge and create their own CT edition

Other 2006 Stories

The year is 1919…

- What's going on?
- What's going on in science?
- What is your view of the Universe?

- Infinite
- Unchanging/static
- Ageless

The year is 2009…

- What's going on?
- What's going on in science?
- What is your view of the Universe?

- Finite
- Changing
- 13.7 Billion Years Old

Cosmic Times

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

Posters, Newsletters, Teacher Guide, Lessons