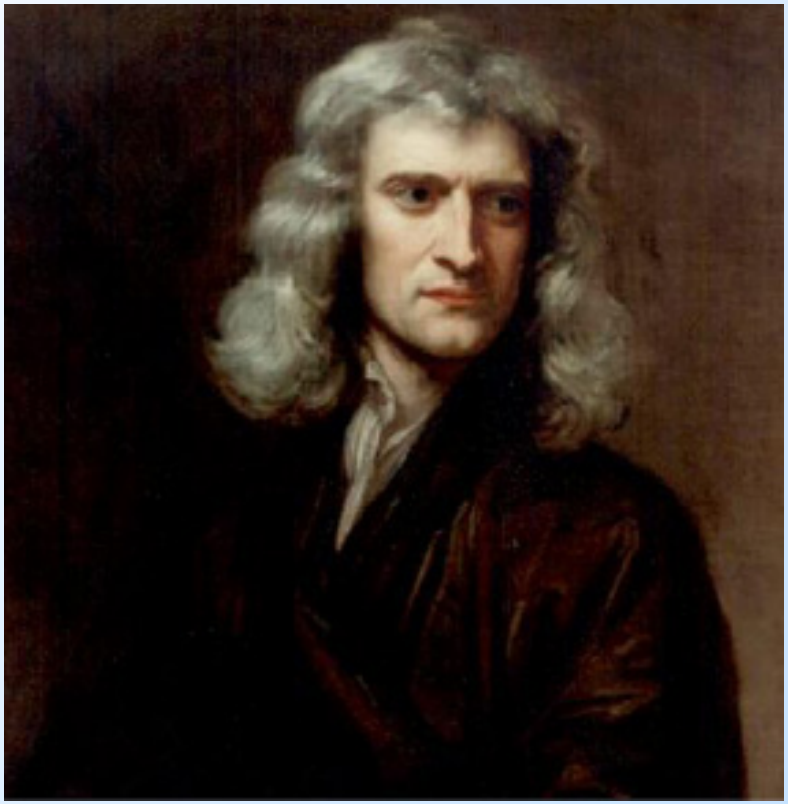
Cosmic Times

Inquiring into the Nature of the Universe

Dr. James Lochner
USRA & NASA/GSFC

Sandra Sweeney, Joseph Petsko
Perkiomen Valley School District, PA

Cosmic Times



Newton

Einstein

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

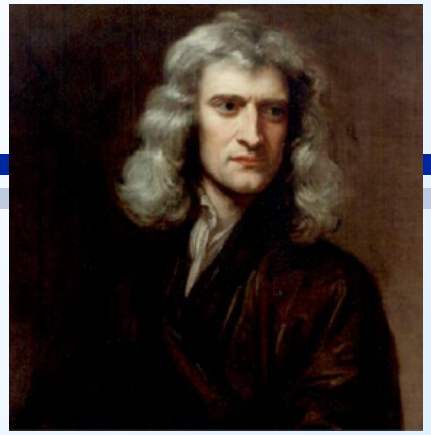
This workshop samples topics and lessons in first four Cosmic Times.

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

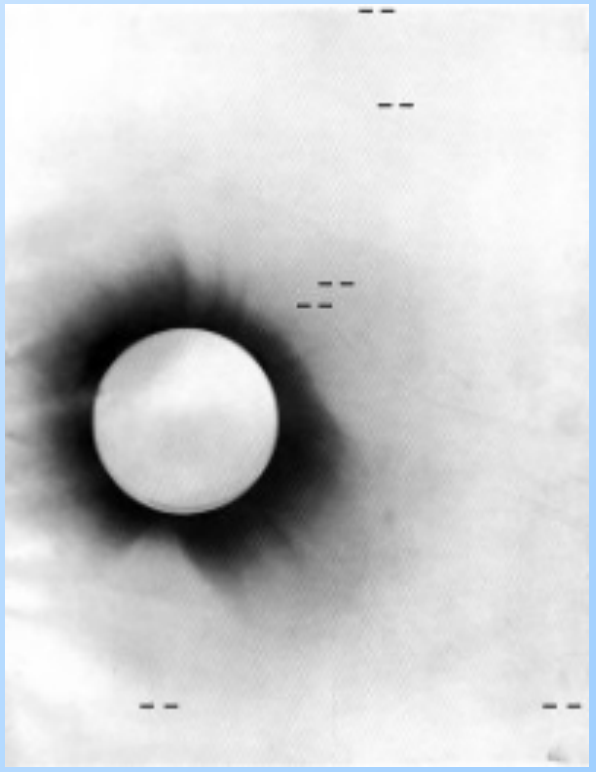
What is Gravity?

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.

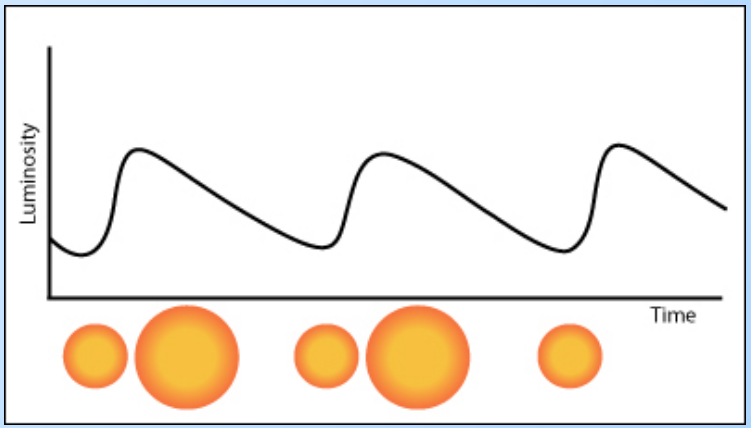
$$Lo \mu Li / r2$$

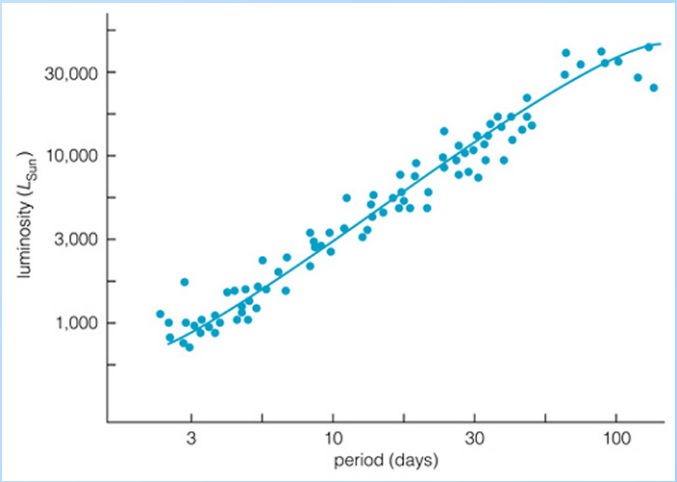
But we usually don't know the Absolute Magnitude

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.

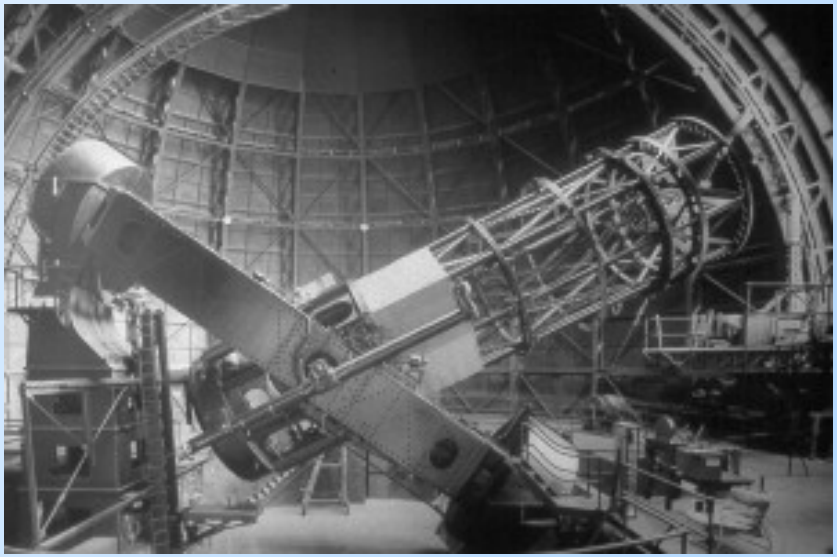
In 1908, Henrietta Leavitt discovered this relationship:

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

Hence we can use $Lo \mu Li / r2$

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.

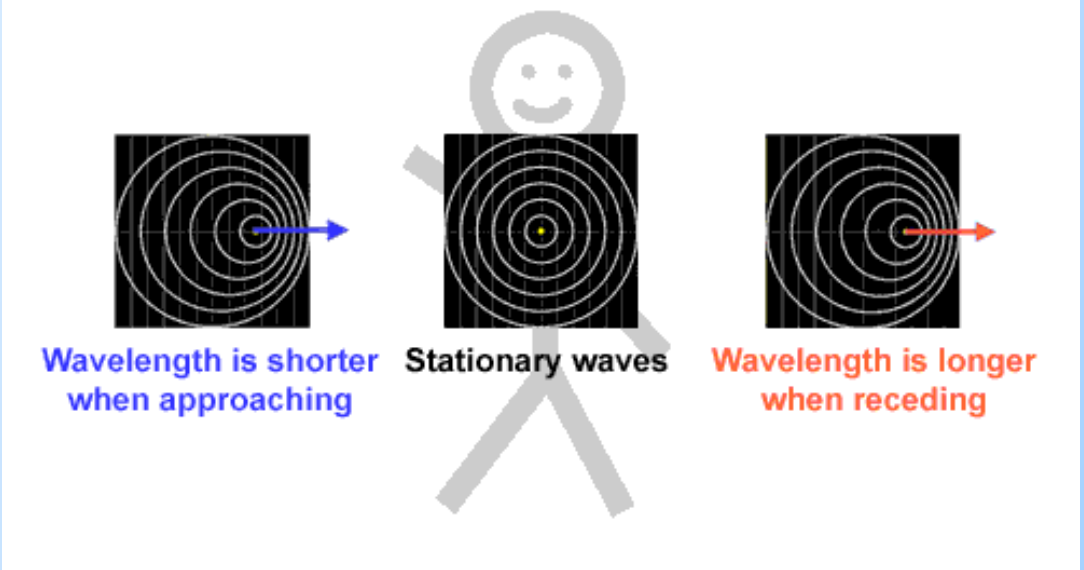
What is Doppler Effect?

Wavelengths bunch up and get shorter as a wave approaches.

- Higher pitch or bluer light

Wavelengths spread out and get longer as wave recedes.

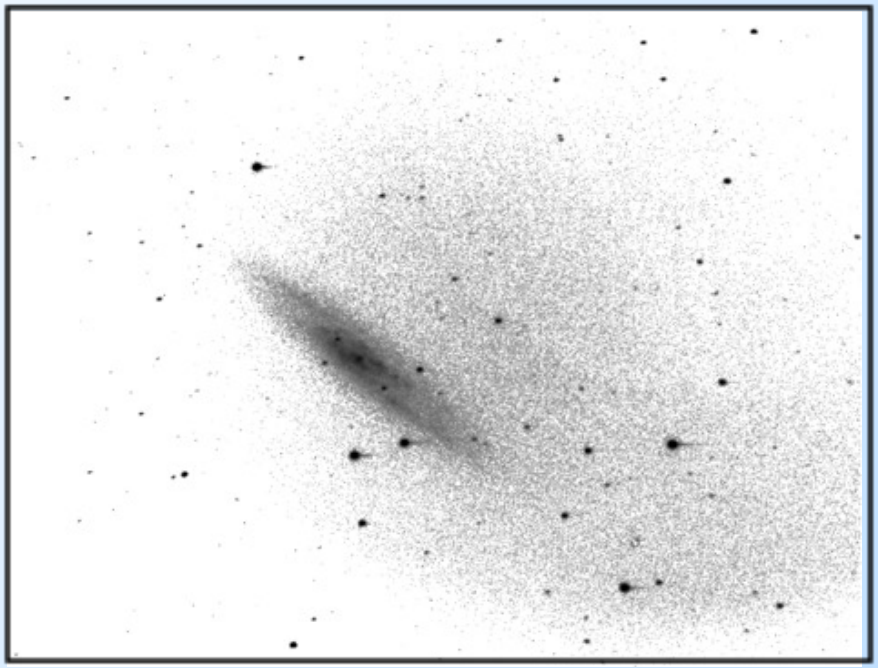
- Lower pitch or redder light.

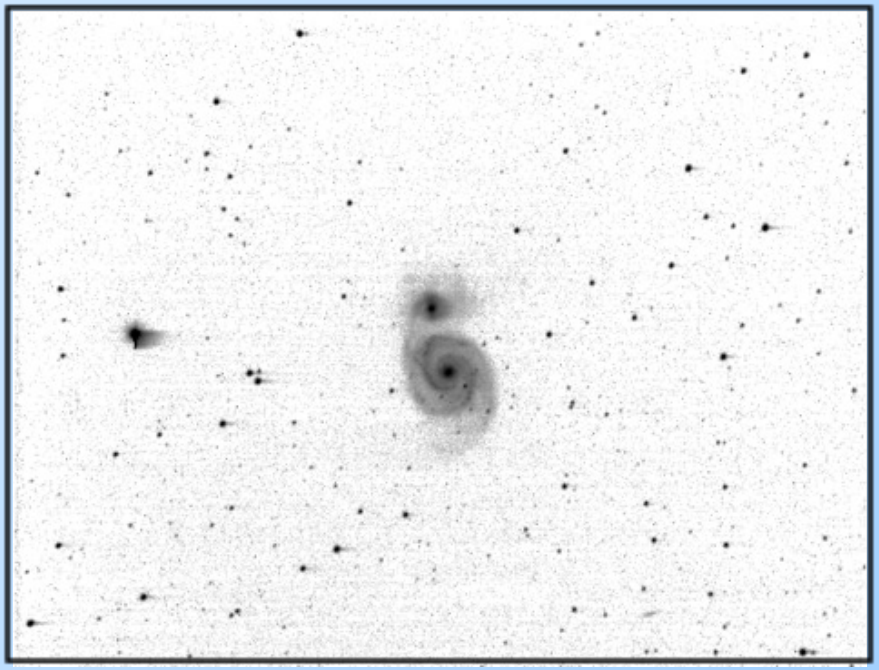


http://www.astrocappella.com/

Determining the Motions of the Galaxies

Use images of galaxies to determine their distances

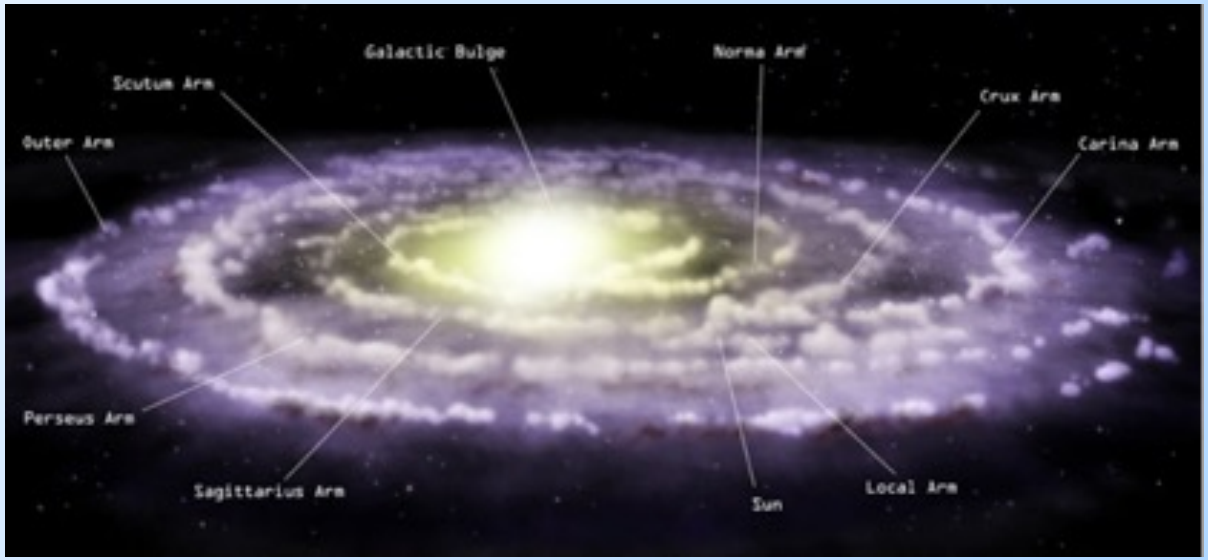




Put this together with their redshift data

Determining the Universe

Size of galaxy

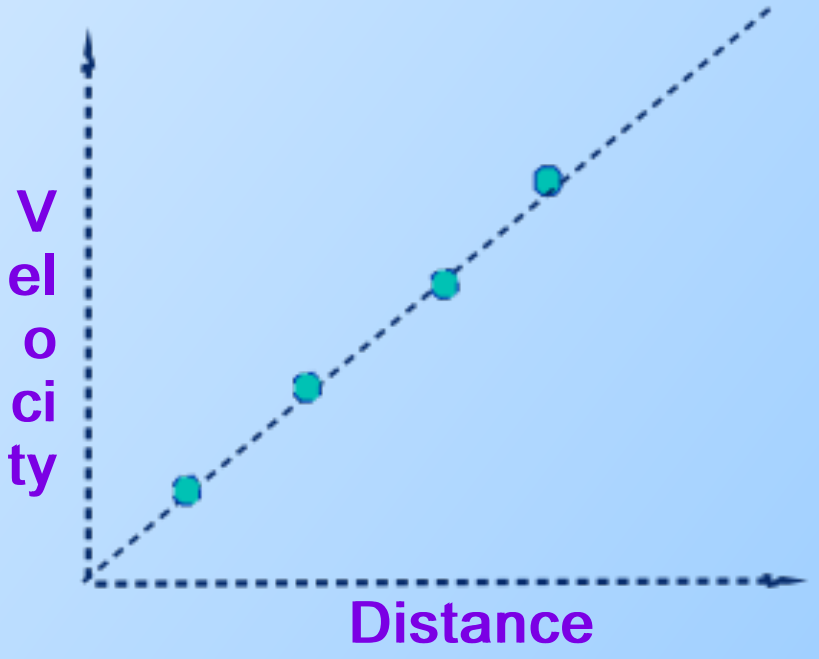


100,000 light years

Galaxies are moving farther apart!

Hubble put together the redshifts with their distances.

Universe is expanding !



Age of the Universe:

2 Billion Years

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.

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 TI

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 telecsope 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)

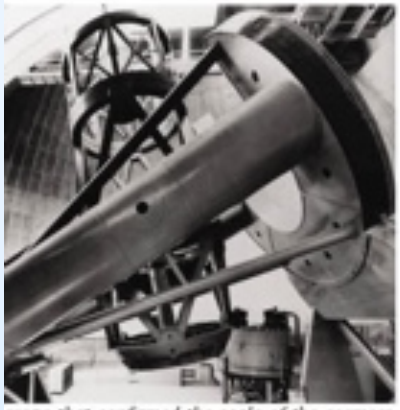
COSMIC TIMES

1955

Size of the Universe:

4-8 Billion Light Years

ghbor Galaxy
rse's Size



cope that confirmed the scale of the cosmos: Palomar's 200-inch Hale Telescope was com- 1949.

the globular clusters in Andromeda are ly different animals than those in our own Way, or Andromeda must be further than lly calculated.

nce would have it, the solution came during rtime blackouts of 1943 in California.

Origin of Everything:
Hot Bang or Ageless Universe?

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.

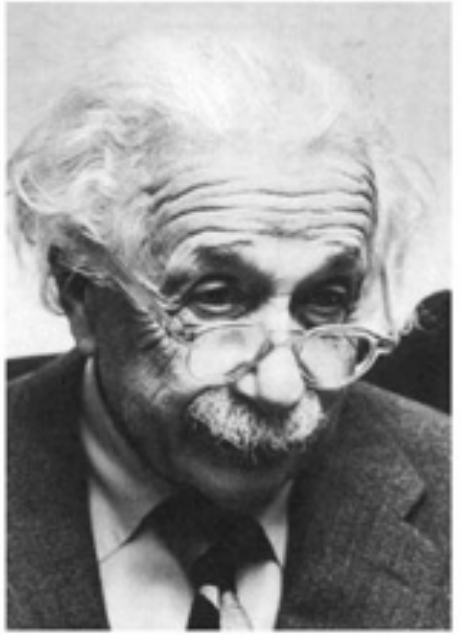
Both theories explain – in entirely different ways – the inescapable fact that the Universe is expanding. This cosmic expansion was first detected in 1914, when American astronomer Vesto Melvin Slipher surveyed some galaxies and noticed the light from all of them was "red-shifted." This is essentially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

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”

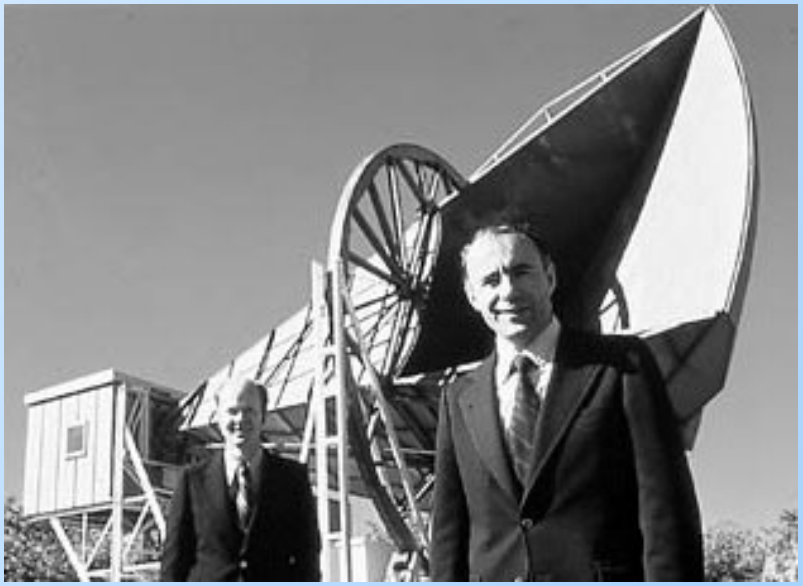
What is the Evidence?

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 TI

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 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

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:

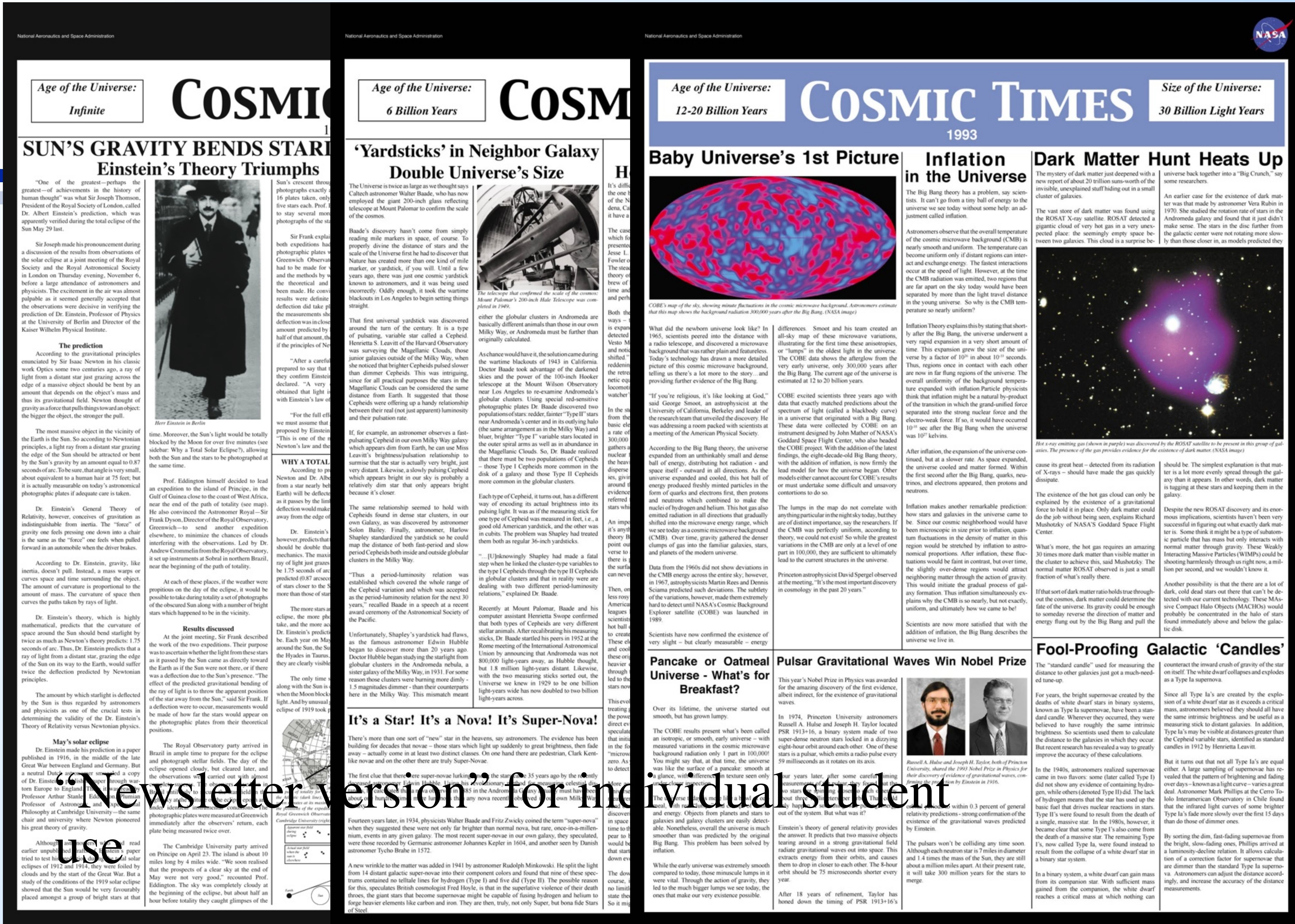
identify the women scientists of the Harvard College Observatory

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.



National Aeronautics and Space Administration

Age of the Universe: Infinite

COSMIC TIMES

SUN'S GRAVITY BENDS STARLIGHT
Einstein's Theory Triumphs

Herr Einstein in Berlin

National Aeronautics and Space Administration

Age of the Universe: 6 Billion Years

COSMIC TIMES

'Yardsticks' in Neighbor Galaxy Double Universe's Size

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

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

National Aeronautics and Space Administration

Age of the Universe: 12-20 Billion Years

COSMIC TIMES

1993

Size of the Universe: 30 Billion Light Years

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)

Inflation in the Universe

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)

Pancake or Oatmeal Universe - What's for Breakfast?

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'

"Newsletter version" for individual student use

Workshop

Cosmic Times Web Site

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

1919 & 1929 Posters and Lessons now Available
This presentation is available (with links to lessons)
1955 materials available soon.
Sign up for email updates