How Telescopes Have Changed Our View of the Universe

A Century of Cosmic Surprises
Presenter: Dr. James Lochner

Tuesday, December 08, 2009
International Year of Astronomy 2009 (IYA)

World-wide celebration of astronomy, its contribution to society and culture

400th anniversary of first use of astronomical telescope by Galileo

NASA IYA objectives include:
• strengthen interest in science and science education
• increase awareness of astronomy

Learn more at: astronomy2009.nasa.gov
How Telescopes Have Changed Our View of the Universe

What this series offers you:

• use science from cutting edge NASA telescopes to illustrate to your students the process of discovery and scientific investigation;

• learn about telescopes across the electromagnetic spectrum and how advances in technology enable leaps in science;

• trace how our understanding of the physical universe has progressed over history.
How Telescopes Have Changed Our View of the Universe

Web seminar series:

I. Anti-matter Eyes on the Gamma-Ray Skies
   Nov 12

II. A Century of Cosmic Surprises
    Dec 08

III. From Sound Waves to Microwaves: "Listening” to the Oldest Light of the Universe with the Planck Mission
    Dec 16
A Century of Cosmic Surprises

Over the past century, the model we use to describe the universe has changed from static to expanding to accelerating. In this workshop we trace some of the questions scientists have asked about the universe, and describe the tools they used to answer those questions. We show how in many cases these led to surprising, unforeseen answers which have shaped our current understanding of the nature of the universe.

Presented by:

Dr. James Lochner
Lead, Education and Public Outreach
High Energy Astrophysics Science Archive Research Center
NASA Goddard Space Flight Center
Classroom Connections

The Big Idea
We develop tools to answer our science questions. These tools may be either physical (e.g. telescopes) or techniques (e.g. improving how we determine distances). Sometimes the resulting answers are surprising.

Connection to Standards
National Science Education Standards (partial list):
• Origin and Evolution of the Universe
• Science as a Human Endeavor
• Nature of Science Knowledge
• Science and Technology
Electromagnetic Spectrum

Note: wavelengths go from short to long from left to right

Telescopes & the Universe
A Century of Cosmic Surprises

Dr. James Lochner
USRA & NASA/GSFC
Acting Education Lead for the Astrophysics Science Division
Cosmic Times

Curriculum support materials that trace our changing understanding of the Universe over the past century.

From Einstein’s Theory of Gravity to Dark Energy
Section I

Questions and Tools
Understanding the Nature of the Universe

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

• What are some questions we might ask?

Type questions in the chat!
Understanding the Nature of the Universe

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?

Type tools in the chat!

Telescopes & the Universe
How Far Away are “Spiral Nebulae”?

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

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

 Archer The question was settled when Edwin Hubble determined the distance to Andromeda Galaxy.
Tools for answering “How Far Away are Spiral Nebulae?”

Cepheid Variables

- These stars vary in brightness due to pulsations.
Tools for answering “How Far Away are Spiral Nebulae?”

Cepheid Variables

1. The period of brightness variation is related to star’s intrinsic luminosity.
2. By measuring the observed luminosity, and knowing intrinsic luminosity we can determine distance

\[ L_0 \propto \frac{L_i}{r^2} \]
Tools for answering “How Far Away are Spiral Nebulae?”

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

Hubble determined distance to Andromeda to be 800,000 LY
(actual distance is 2.8 million LY)
Early observations showed the "nebulae" were red-shifted.

If the spectrum is red-shifted, the galaxy is

A. Moving toward us
B. Moving away from us
C. Standing still
Trivia Question: Which of the following Galaxies is moving toward us?

A. Pinwheel Galaxy  
B. M87 (Giant Elliptical)  
C. Andromeda Galaxy
Consequence of asking “How Far Away are Spiral Nebulae?”

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

Universe is expanding!
Lets Pause for Two Questions from the Audience
Section II

The ‘State’ of the Universe
Is Universe a “Steady State” or Did it originate from a “Big Bang?”

• Steady State Theory: As universe expands, matter is created.
  – Creation rate - a few hundred atoms per year per galaxy
• 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)
Inference vs. Observation

• How would you define an inference?

1) 

2) 

• How would you define an observation?

1) 

2) 

Raise your hand to volunteer
Inference vs. Observation
Let’s Practice!

<table>
<thead>
<tr>
<th>1. In 1929 Hubble observed that every galaxy exhibited a red shift proportional to its distance from us.</th>
<th>2. Hoyle proposed a C-field which would have negative pressure to drive the expansion of the universe.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. In an expanding universe, it would be necessary to create matter at $1 \text{ atom/m}^3/10^9 \text{ years}$ to keep density constant.</td>
<td>4. Hubble concluded that all the galaxies were moving away from us at a speed proportional to their distance.</td>
</tr>
</tbody>
</table>

Which is an observation? 😊 an Inference? √
<p>| | |</p>
<table>
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<tr>
<td>1. A hot big bang would produce radiation, which would be redshifted as the universe expands.</td>
<td>2. The cosmic background was possibly caused by light from distant galaxies scattered by galactic dust.</td>
</tr>
<tr>
<td>3. The microwave background discovered in 1965 was very uniform and coming from all directions.</td>
<td>4. The microwave background produces a perfect black body spectrum at 2.73K</td>
</tr>
</tbody>
</table>

Which represents steady state? 🤔 and big bang? 🎈
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.
- P & D were convinced P & W had found it.
  This solved the Steady State vs Big Bang question.
Let’s Pause for Two Questions from the Audience
Section III

Determining the Fate of the Universe
How Fast is the Expansion Slowing Down?

• Saul Perlmutter (UC Berkeley) wanted to determine the deceleration rate of the expansion.
  • Amount of deceleration depends on average mass density.
    – So we’d be “weighing the universe”
  • This would lead to determining the fate of the universe - expand forever, or contract.
Tools for Determining “How Fast is the Expansion Slowing Down?”

• Compare a galaxy’s measured distance with its redshift.
• Get distance by comparing observed and intrinsic luminosity of an object in the galaxy.

Enter Supernovae!
(But we need a special kind of supernova)
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!
The explosion is as bright as an entire galaxy of stars and can be seen in galaxies across the universe.

4. Observe it in a distant galaxy
5. Compare its distance to its velocity

Place the next three points (with increasing distance) on the graph, if the expansion is slowing down.
5. Compare its distance to its velocity

More distant galaxies recede from us more rapidly.

These supernovae are more distant than expected.
Space-time has expanded more than expected.
Let’s Pause for Two Questions from the Audience
History of the Universe’s Expansion

http://imagine.gsfc.nasa.gov/Videos/cosmic_times/expanding_univ.mov
Section IV

Dark Energy and Beyond
Dark Energy Comprises 73% of Universe
Dark Energy is an Unfinished Story

WE DON’T KNOW WHAT IT IS!

But this story of our understanding of the nature of the universe illustrates the process of science.

- Science is alive and on-going.
- Our ideas change as the data changes.
- Scientific debate differs from social/political debate.
- Progress in science results from both individual and group efforts.
Other Themes in Cosmic Times

- 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.
- Lesser known astronomers.
- Impact of improved technology.
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