Supernovae and cosmology

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Outline

• Structure of the universe

• Dynamics of the universe

• Type 1a supernova

• Michigan Science Supernova Search
Solar system

Length scale: Earth-Sun distance
93 million miles (93x10^6 miles)=1 a.u.
Nearby stars (Orion arm)

Length scale: Light year
\(~6 \times 10^{12} \) miles = 1 ly
Galaxy (Milky Way)

Length scale: Diameter
100,000 ly

Image from: ucsd.edu
Clusters

Image from: nasa.gov
Superclusters

Length scale: Separation/size
100,000,000 ly
Large scale structure

Length scale: Wall length
1,400,000,000 ly

Image from: wikipedia.com (via W. Schaap)

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Universe

Length scale: size of the universe
150,000,000,000 ly (plus or minus)

Image from: nasa.gov
How do we measure distance?
• *Parallax* can be used to find the distance to close objects (~300 ly).

• Astronomers often measure cosmic distance using *apparent luminosity* measurements on *Cepheid variables* and *Type 1a supernovae*.

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Cepheid variable
“Pulsing” star
works to ~60 Mly

Type 1a supernova
“Exploding” star
works to >3000 Mly
Cepheid Variables

• Period of variable luminosity (brightness) is related to actual brightness of star (Henrietta Leavitt, 1908).

• Problems: This estimate is affected by space dust, and these stars are not bright enough to see huge distances.
Type 1a supernova

These supernovae are believed to follow a standard intensity vs time curve (after taking into account well-known “fudge factors”).

Problems: There are not too many Type 1a supernovae known.
Dynamics

How did the universe start?

Where will it end up?

These are hard questions, because we only have an instantaneous snapshot of the universe.
**Big Bang**

- 15 billion years ago, the universe was very small, very hot ball of matter and energy.

- In the intervening time, the universe has expanded, but this original energy can be seen in the *cosmic microwave background*.

In 1963 *isotropic* background radio waves were measured. These could be fit to 2.7 degree background radiation, and proved strong evidence for the *Big Bang* theory.
Cosmic microwave background
History of the Universe

(Inflation)

Matter/antimatter annihilate (0.001 sec)

Protons/neutrons form (3 minutes)

Neutral atoms form (380,000 years)

First galaxies form (1 billion years)

Today (15 billion years)

2.7 K

3000 K

2.7 degrees Kelvin

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Future of the Universe

Open Universe
Expands forever

Closed Universe
Collapses
Hubble’s Law

\[ v = H_0 d \]

\( H_0 = 70 \text{ km s}^{-1}/\text{Mpc} \)

Age of the universe is \( 1/H_0 \), or about 13 billion years.

Note: 1 Mpc \( \approx \) 3,000,000 ly
• Elements in distant stars emit light at very specific wavelengths (spectrum).

• The wavelength of light we measure on Earth ($\lambda_{\text{measured}}$) will be different than the wavelength emitted by the star ($\lambda_{\text{star}}$) if the star is moving relative to the Earth (just like a Doppler shift).

• This shift in wavelength is parameterized by “$z$” defined by:

\[
1 + z = \frac{\lambda_{\text{measured}}}{\lambda_{\text{star}}} \quad \text{If } z\ll 1 \text{ then } z = \frac{v}{c}
\]
The intensity of the most distant objects is smaller than we expect using Hubble’s Law, so they must be moving away faster.

NOTE: The redshift parameter “z” is a measure of distance.
This plot allows astronomers to analyze the microwave background, and gives information about the geometry (flat, open, closed) and matter and energy density of the universe.
Will the universe keep expanding forever?

Einstein put an extra term (called the *cosmological constant*) in his equations for General Relativity to produce a static universe.

Universe expands forever

Universe collapses
Type 1a supernova
Stellar Evolution Review (All masses in units of solar masses.)

- Gas Cloud (Nebula) → Protostar and Pre-Main-Sequence Star
  - M < 0.01 → Planet
  - 0.01 < M < 0.08 → Brown Dwarf
  - M > 0.08 → Main-Sequence Star
    - Lifetime: 1 million to 100 trillion years
    - H fusion
  - 0.8 < M < 4 → Helium White Dwarf
  - 4 < M < 8 (?) → Red Giant
  - M > 8 → White Dwarf (in binary systems) → Nova
  - Type II Supernova → Neutron Star
    - Synchrotron Radiation (Radio Pulses) → Pulsar
    - M > 40 originally
    - M > 2.5 remaining → Black Hole
      - Event Horizon
      - Singularity
  - Type I Supernova
    - No Remnant
      - Accretion Disk

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Type 1a supernova evolution

A red giant star (many, many times larger than the sun) can evolve into a white dwarf (about the mass of the sun, but the size of the earth) composed mainly of oxygen and carbon.

If this white dwarf increases in mass, perhaps by gaining matter from a neighboring star, carbon fusion can be ignited.

This puts out a huge amount of energy ($\sim 10^{44}$ J) in only a few seconds, causing a supernova explosion (as bright as a galaxy).

Because the white dwarf mass is about constant, the actual peak brightness is about the same, so the apparent peak brightness can be used to estimate distance.
The shape of the light curve reflects the composition of the white dwarf.
Gallery of SDSS Supernovae

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Michigan Science Supernova Search

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Finding Supernovae

• Do not need good images to find supernovae.

• Rate is 1/galaxy/century

• Thus in a year observe 100 galaxies once/week to find one!
School based supernovae search

• Easy to use, fast to set up telescope plus sensitive camera (provided as part of the project) means that from start to taking images in 30 minutes or less.

• Takes about 5 minutes to gather an image.

• 10 participants in Detroit metro area = 100 galaxies being monitored. Good chance of finding a supernova.
Search procedure

• Each school would be responsible for taking images of 10 galaxies once per week (about 1 hour total).

• Galaxies to be imaged listed on central website.

• Images will also be uploaded to this website for analysis.

• Pictures from all participants will be available to all the different schools.

• Telescopes would be available for other projects the rest of the week.
Modern GoTo Telescopes

- Celestron NexStar 8 SE (for example)
- Limiting magnitude is 14
- According to HyperLeda galaxy catalog there are more than 4500 galaxies in the sky brighter than this.
Sample images

Pictures of M106 taken with 12” telescope at WSU.