Cosmology with Type Ia Supernova: The Sloan Digital Sky Survey Supernova Search

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on behalf of SDSS SN team and spectroscopic partners
Outline

• The Golden Age of Cosmology (1992-Present)
  - Cosmic Microwave Background
  - Supernovae and Dark Energy
  - Galaxy Clustering

• SDSS Supernova Search
  - Cosmology
  - Type Ia Rate

• Conclusion
Reminder: Big Bang Cosmology

- Expansion observed in 1929 using 25 nearby galaxies, \( v = Hd \) (Hubble’s Law).
- CMB Predicted in 1948 (Gammow and Alpher), observed in 1965 (Penzias and Wilson)
- Universe mostly Hydrogen (Alpher, Bethe, Gammow) in late ‘40’s and observed in ‘70’s through 90’s.
Cosmic Microwave Background

- Snap shot of matter density of the universe at the photon surface of last scattering
Cosmic Microwave Background

- First precision measurement from COBE in 1992
  - Spectrum is a blackbody (CMB compared to on board blackbody)
  - Anisotropies observed at few in $10^5$
  - Start of Golden Age
Cosmic Microwave Background: WMAP

Raw data shows two prominent features:
- Dipole (motion of WMAP wrt to CMB) Easily subtracted
- Milky Way. More complex subtraction, but main conclusion is robust.
Cosmic Microwave Background: WMAP

- Describe data as sum of spherical harmonics and fit for coefficients. Each amplitude corresponds to an angular scale.
Cosmic Microwave Background: WMAP

- Peak position sensitive to the geometry of the Universe
Cosmic Microwave Background: WMAP

- Relative heights of peaks are sensitive to mass density.
Cosmic Microwave Background: WMAP

- Weak sensitivity to a cosmological constant from details of shape.
Cosmic Microwave Background: WMAP

- Geometry of the Universe is very likely flat
- Matter density between 10% and 40% of recollapse density
- Favors Dark Energy
Stellar Evolution Review (All masses in units of solar masses.)

Gas Cloud (Nebula) → Protostar and Pre-Main-Sequence Star

M < 0.1 → Planet
0.1 < M < 0.8 → Brown Dwarf
M > 0.8 → Main-Sequence Star

Lifetime: 1 million to 100 trillion years

0.8 < M < 4 → Helium White Dwarf
4 < M < 8(?) → Red Giant
M > 8 → Supergiant

8 < M < 40 originally
1.4 < M < 2.5 remaining

Type II Supernova → Neutron Star

M > 40 originally
M > 2.5 remaining

Black Hole

Synchrotron Radiation (Radio Pulses) → Pulsar

"Onion" Core

Event Horizon

Singularity

Type I Supernova

No Remnant

Accretion Disk

Black Dwarf → Carbon White Dwarf

Planetary Nebula → White Dwarfs in binary systems

Nova
Type Ia Supernovae

- Easy to identify
- No Hydrogen or Helium but Silicon in spectra
- Light curve is unique
Type Ia Supernovae

- Key observation by Phillips in early 1990’s of the Stretch-Luminosity relation
- Qualitative understanding that this is related to how much metal is in the White Dwarf
- Scatter on distance from ~20% to ~7%
- Standardizable Candle
Type Ia Supernovae

- Still an amazement from 1998-1999
- Clear observation of Dark Energy
- Subsequent observations (more, higher redshift) rule out alternative explanations
- Note the “redshift desert” 0.1-0.4
Type Ia Supernovae

- Combination of CMB and Type Ia SN is unambiguous
- Geometry is flat
- ~70% Dark Energy
- ~30% Matter
- There was a Big Bang
- There will be a Big Chill
Galaxy Clustering

![Graph showing the mass profile of perturbation against radius (Mpc) for different components including dark matter, gas, photon, and neutrino. The graph is labeled with a time of 110 years and a redshift of 82507.]
Galaxy Clustering

![Graph showing mass profile of perturbation vs. radius in Mpc, with curves labeled Dark Matter, Gas, Photon, Neutrino, and a time of 0.23 Myrs, z=1440.]
Galaxy Clustering

![Graph showing the mass profile of perturbation over radius (Mpc) with curves for Dark Matter, Gas, Photon, Neutrino at 1.45 Myrs and z=478.](image)

- Dark Matter, Gas, Photon, Neutrino
- 1.45 Myrs
- z=478
Galaxy Clustering

![Graph showing mass profile of perturbation over radius (Mpc). The graph compares dark matter, gas, photon, and neutrino profiles at a redshift of 10.]
Galaxy Clustering

- Observe this with the galaxy two point function
- Number of galaxies at distance $x$ normalized by volume.
- Large galaxy surveys such as SDSS
Matter to Dark Matter ratio from CMB and Galaxy Clustering
Sloan Digital Sky Survey
Supernova Search

• World’s sample of Supernovas is quite small (100’s)
• More would allow tests of Dark Energy (Is it constant in time? Is it constant in space?)
• Sloan Digital Sky Survey ideal for this work
  (www.sdss.org)
Sloan Digital Sky Survey

• Goal is to map 1/4 of the sky
• 100 Million Objects will have brightness and position
• 1 Million Galaxies will have distances
• 100,000 Quasar distances
• Telescope in New Mexico (Apache Point Observatory)
Sloan Digital Sky Survey

- 15 TB of data
- Supernova search done by repeat viewing of the sky and looking for new bright objects. Today 100’s found by all searches.
- One more run planned in 2007.
Supernova Candidate
Asteroid
Bright Star
Dipole
Photometric Typing

- Good candidates are analyzed further
- Light versus time
- Simple spectrum
- Fit sensitive to type of supernova (Ia/b/c, II), redshift, extinction
- After 3 Epochs type is 95% accurate
- Supernova then have detailed spectrum from partner telescopes
MDM 2.4m
NOT 2.6m
APO 3.5m
NTT 3.6m
KPNO 4m
WHT 4.2m
Subaru 8.2m
HET 9.2m
Keck 10m
SALT 10m
452 Supernovae

Spectroscopic Ia

Probable Ia

Core-Collapse
w gives the Dark Energy equation of state $w = \frac{\text{Pressure}}{\text{Density}}$

- $w = 0$ for matter
- $w = 1/3$ for radiation
- $w = -1$ for Einstein’s Cosmological Constant
similar method and systematics; a few better stats could show rate evolution
Conclusion

- Cosmologies Golden Age Continues
- SDSS Supernova Search doing very well, over 300 SN Ia filling the redshift desert, should finish with 400+. World’s largest homogenous sample.
- Preliminary Cosmology (w to ±0.15) and low redshift SN Ia rate
- Much more science than I covered here including KBO’s, Core Collapse SN, Peculiar SN,…