Supernovae Observations of the Expanding Universe

Kevin Twedt

PHYS798G

April 17, 2007

Overview

- How do we measure expansion?
- Use of supernovae 1a as a good measuring stick
- Techniques for observing supernovae
- Discovery of acceleration
- Theoretical implications and Dark Energy

History and Motivation

- 1929 – discovery of expansion by Edwin Hubble.
- The Hubble constant, H_0, gives the current rate of expansion.
- H_0 can be measured by looking at how "nearby" objects move.
- Measurement of acceleration rate requires use of much more distant objects.

Motivation – Acceleration measurements give mass and energy density values for the universe. Needed to distinguish between cosmological models.

Expanding History

- How do we measure expansion rates?
  - Measure magnitude of astronomical standard candles to get accurate distance measurements
  - This gives the look back time (t = distance to Earth / c) - the amount of time that has elapsed since the light left the standard candle.
  - Also measure the amount of redshift

    $$z = \Delta\lambda/\lambda$$

    which gives the amount of expansion of space, α.
  - Measure magnitude and redshift for many standard candles over a wide range of distances.
  - Construct α(t)

$$H_0 = \left.\frac{d\alpha}{dt}\right|_{present} \qquad acceleration = \frac{d^2\alpha}{dt^2}$$

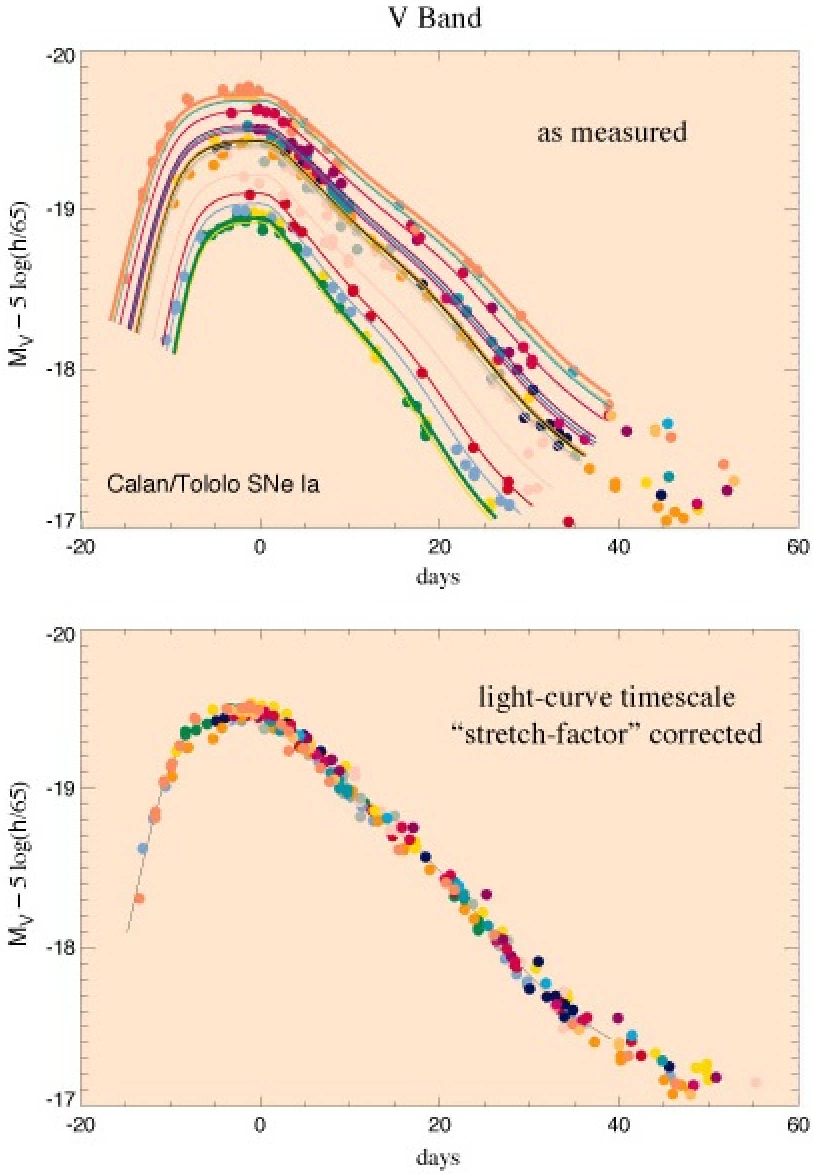
Search for a Standard Candle

- Standard Candle - any distinguishable class of astronomical objects of known intrinsic brightness that can be identified over a wide distance range.
- Early attempts (Hubble and others) tried to use galaxies as standard candles. – Too much variation.
- Supernovae
  - Simple radiative properties
  - Intrinsically bright
  - Found everywhere in early and recent universe
- Subclass SNe type 1a provide best standard candle.

Supernovae 1a

- Nearby type 1a SNe show a simple relationship between their peak brightness and the time scale of their light curve.

- Determine distance by comparing observed magnitude of distant supernovae to absolute magnitude.



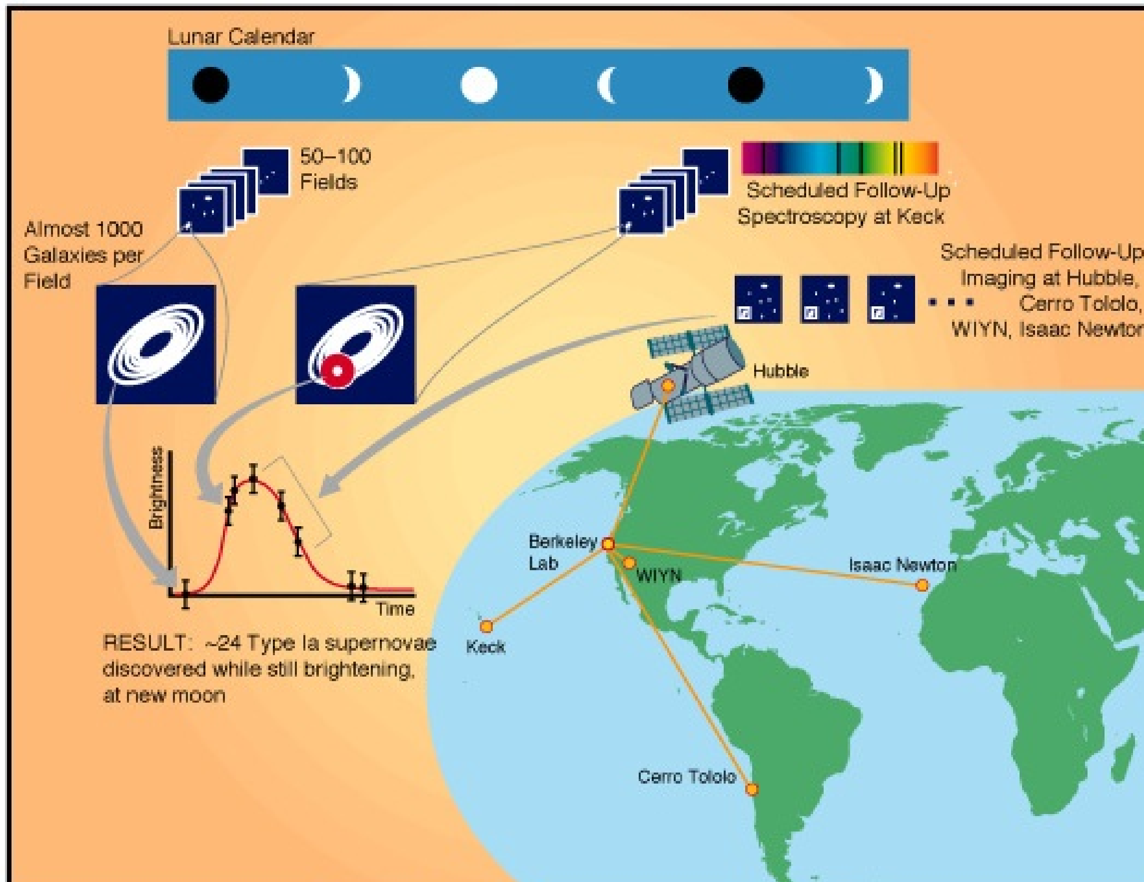
The Great Supernovae Hunt

- Problems –
  - Supernovae are rare (only 1 or 2 per galaxy per millennium)
  - Unpredictable
  - Need to be measured immediately after they are found, as they will pass their peak of brightness within a period of a few weeks.
- But, telescope time is assigned months in advance on the basis of research proposals.
- Often, supernovae measurements had been made on other people's telescope time.

The Great Supernovae Hunt

- 1990's – astronomers developed systematic discovery process.
  - Supernovae Cosmology Project (SCP) of LBL
  - High-Z Supernovae Search of Australia's Mount Stromlo observatory

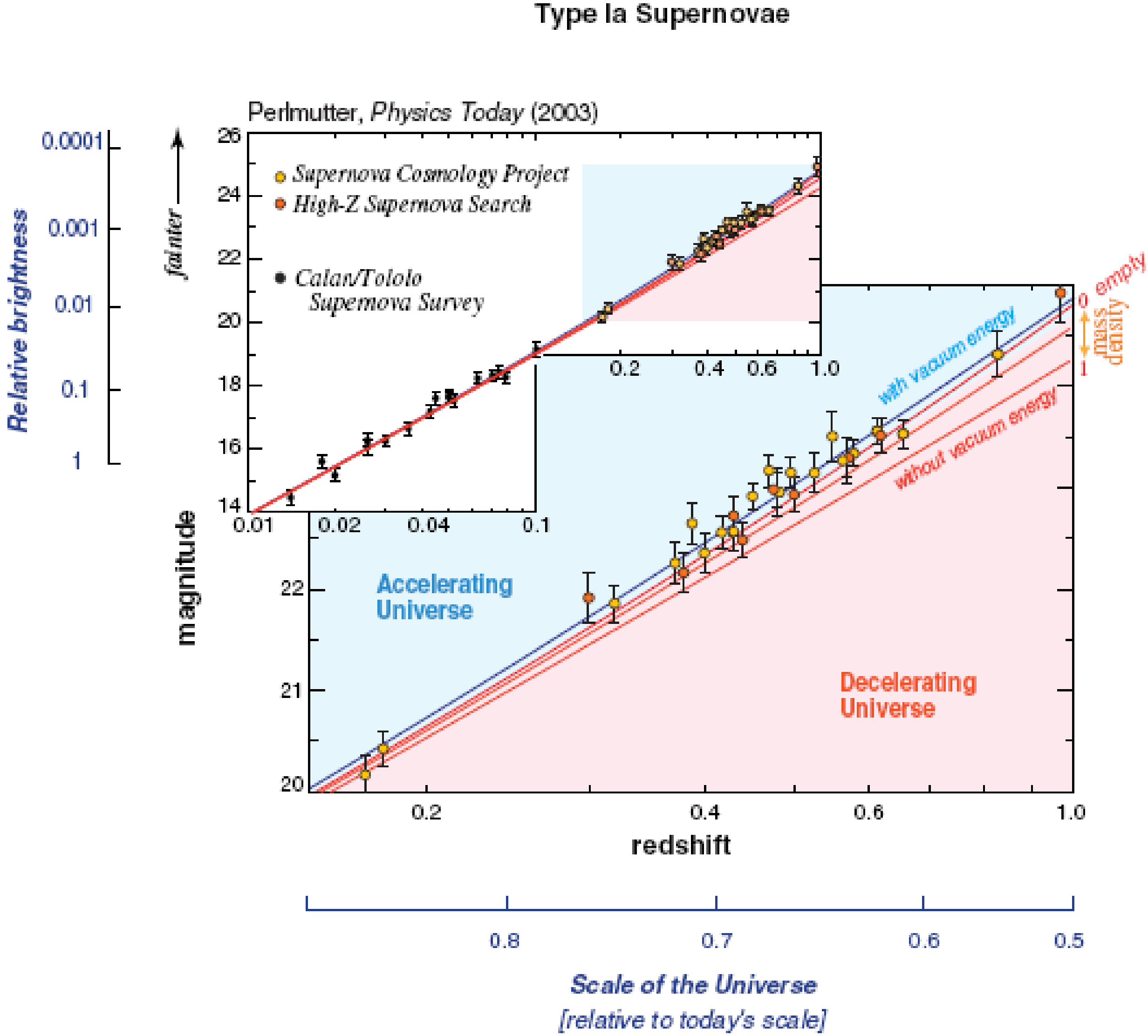
- Used wide-field imagers to view a large section of sky in one night.
- Can search up to a million galaxies a night – ensure discovery of at least a few supernovae.



Perlmutter, et al., in Thermonuclear Supernovae, NATO ASI, v. 486 (1997)

Discovery of Acceleration

1998 – Results published by SCP and HZSNS



Systematic Errors

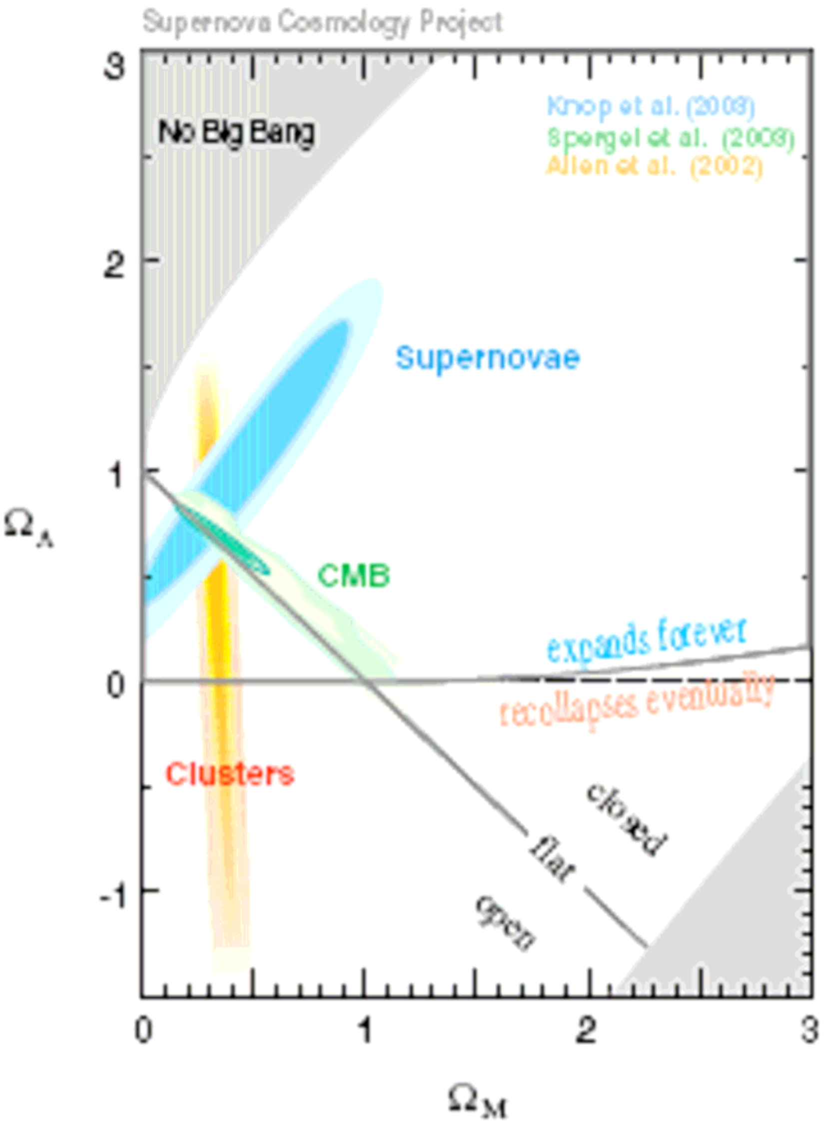
- Dust extinction – At high redshift, dust in host galaxies can dim the light in unpredictable ways.
- Malmquist Bias – selection bias due to the fact that brighter supernovae are more likely to be observed.
- Gravitational Lensing
- K-Correction – uncertainty involved with fitting observed light curves to templates.
- Due to the relatively small number of supernovae measured to date, statistical errors are still dominant – need more data!

Theoretical Implications

- The supernovae measurements are consistent with the results of galaxy cluster and CMB measurements:

$$\Omega_0 = \Omega_M + \Omega_\Lambda$$
$$1 = 0.3 + \Omega_\Lambda$$

- $\Omega_\Lambda > 0$ implies the existence of dark energy.
- ΛCDM theory predicted the expansion acceleration.



Dark Energy

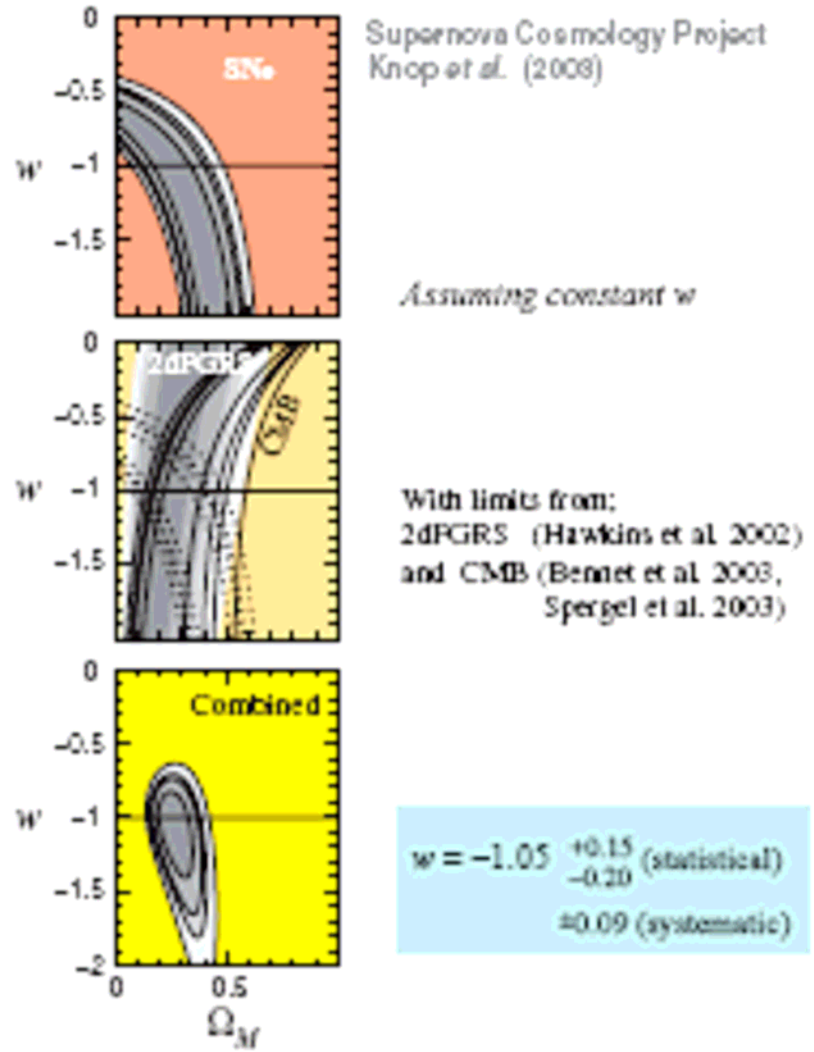
- Even distribution and limited interactions – no laboratory detection.
- give different expansion rates, so Dark energy equation of state:

$$w = p/\rho$$

$$\rho \sim 1/R^{3(1+w)}$$

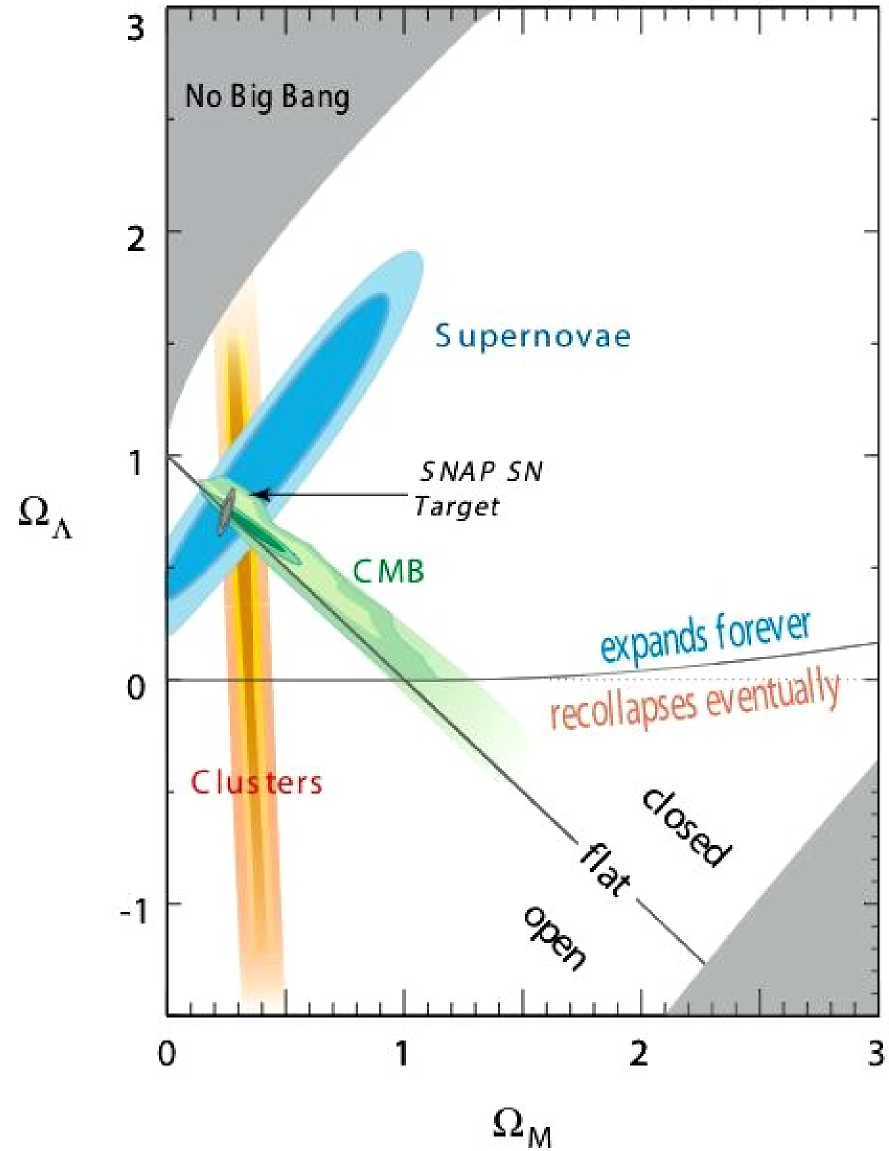
- Different values of w would more precise acceleration measurements would differentiate dark energy theories.

- Note: w = -1 is the equation of state for the vacuum energy.



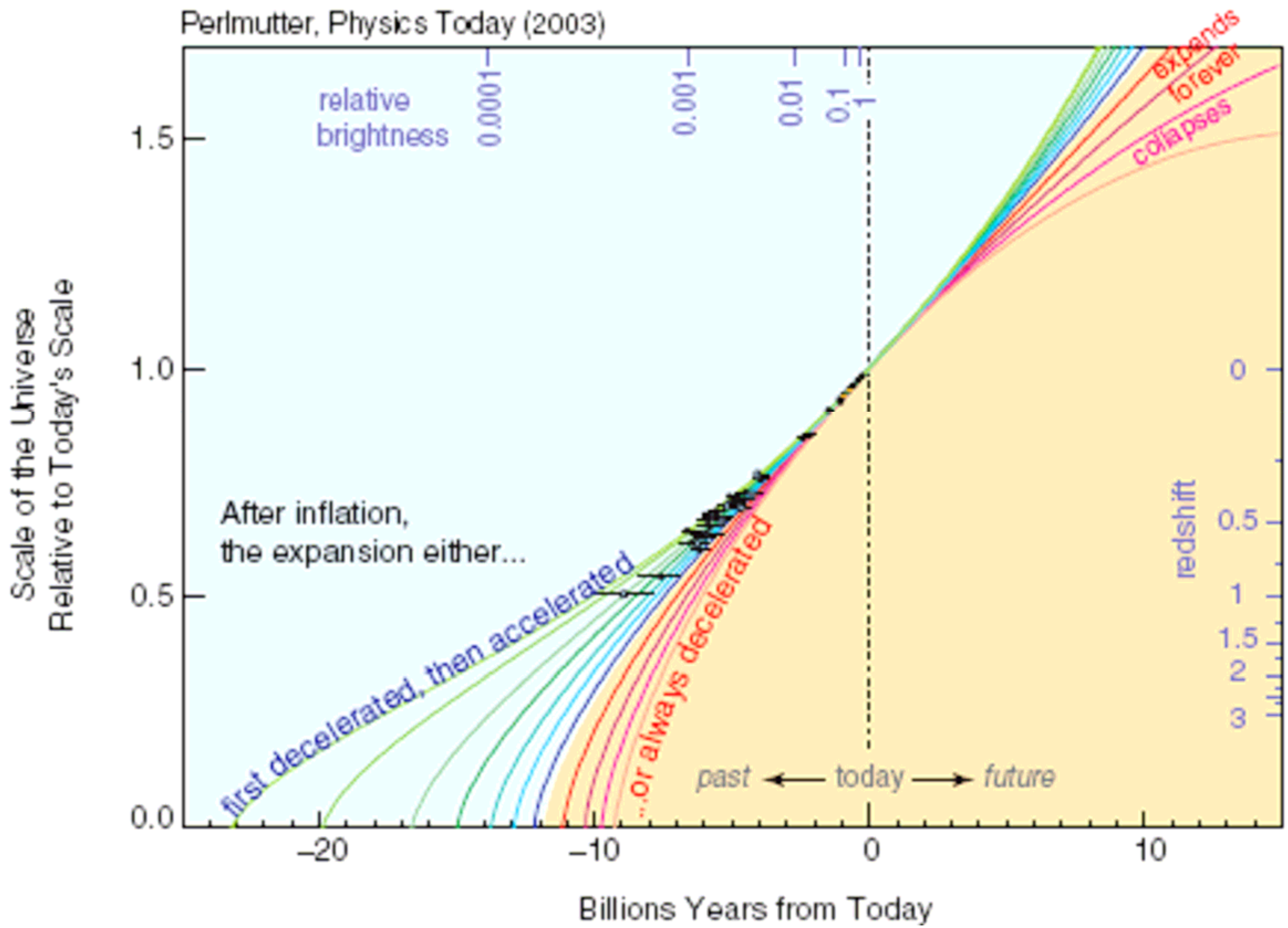
Future Experiments

- SNAP (SuperNovae Acceleration Probe) - DOE proposed satellite
  - Increase discovery rate to 2000 / year
  - Able to find more distant supernovae (z~1.7).
  - Use of large arrays of CCD's
- Search for deceleration epoch.



Expansion History of the Universe

Perlmutter, Physics Today (2003)



Summary

- Supernovae 1a make good standard candles
- Use wide-field imaging to discover distant supernovae
- Magnitude and redshift measurements indicate an accelerating rate of expansion
- Acceleration implies the existence of some form of dark energy