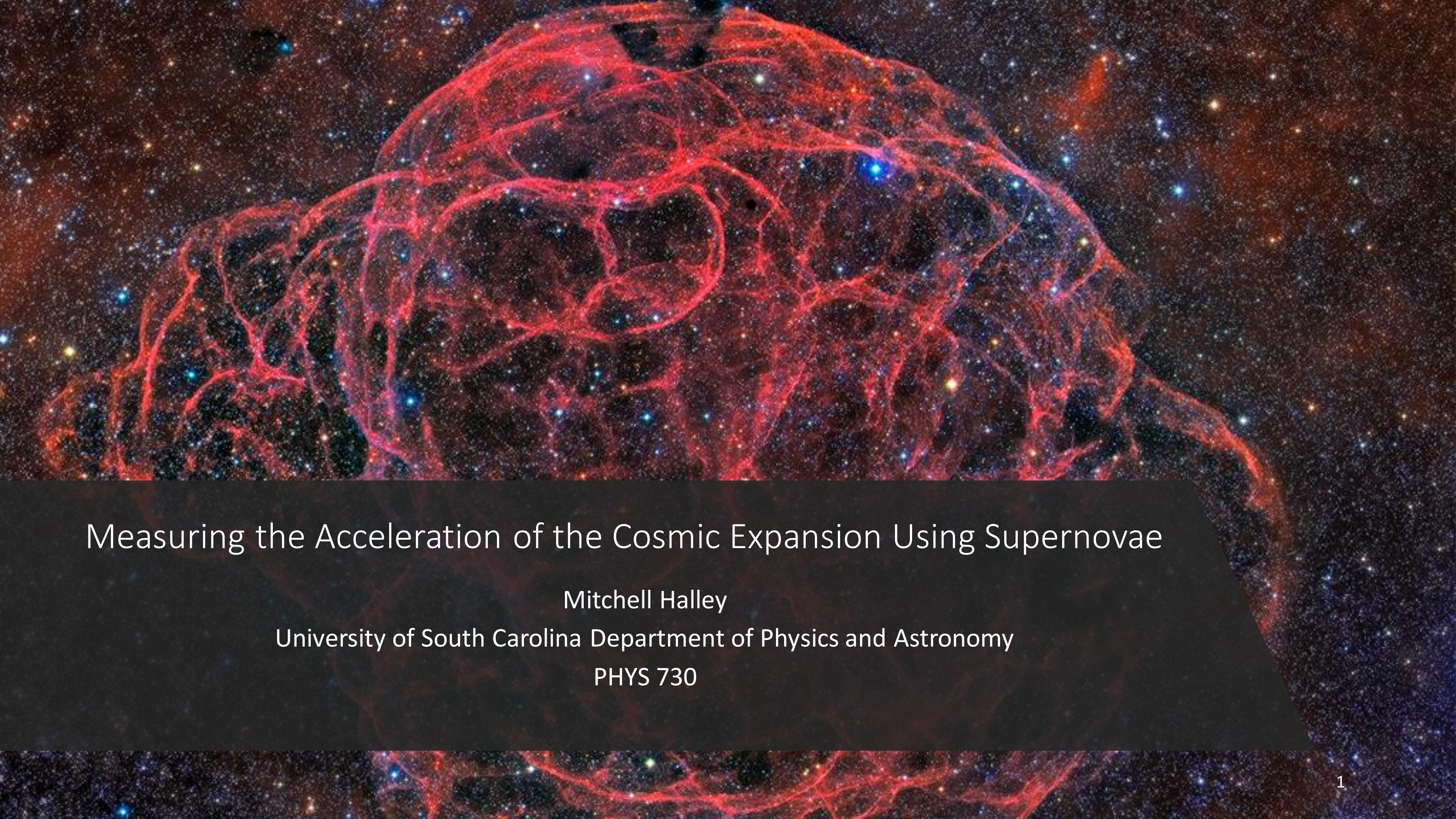

Measuring the Acceleration of the Cosmic Expansion Using Supernovae

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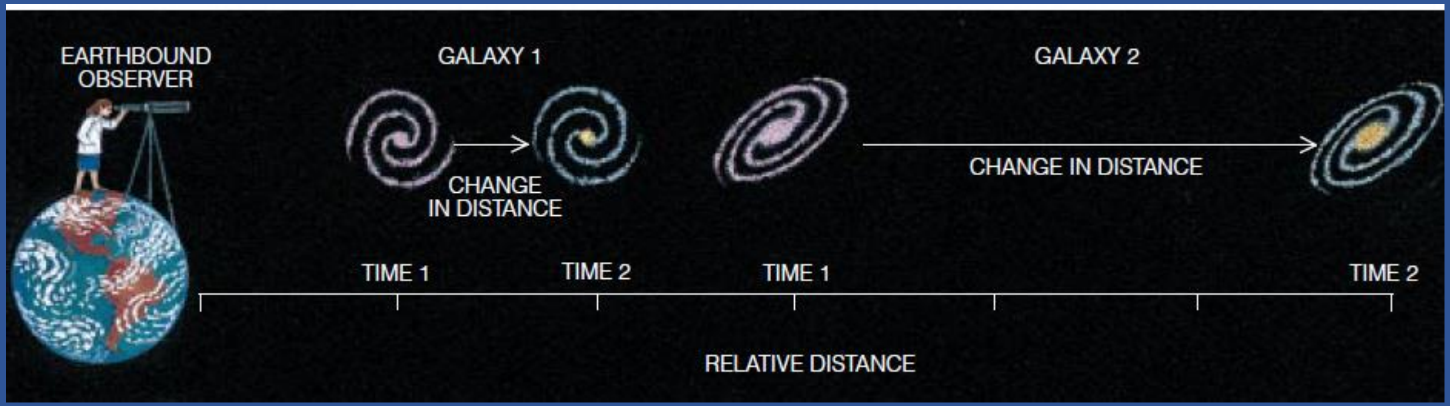
PHYS 730

Structure

Through this presentation I will:

- Explain what we are measuring (the Hubble Constant) and why it is important
- Discuss different methods of measurement why supernovae are good choices
- How one derives the Hubble Constant from the spectra/brightness

Edwin Hubble (1889 – 1953)



Osterbrock, D. (1993).

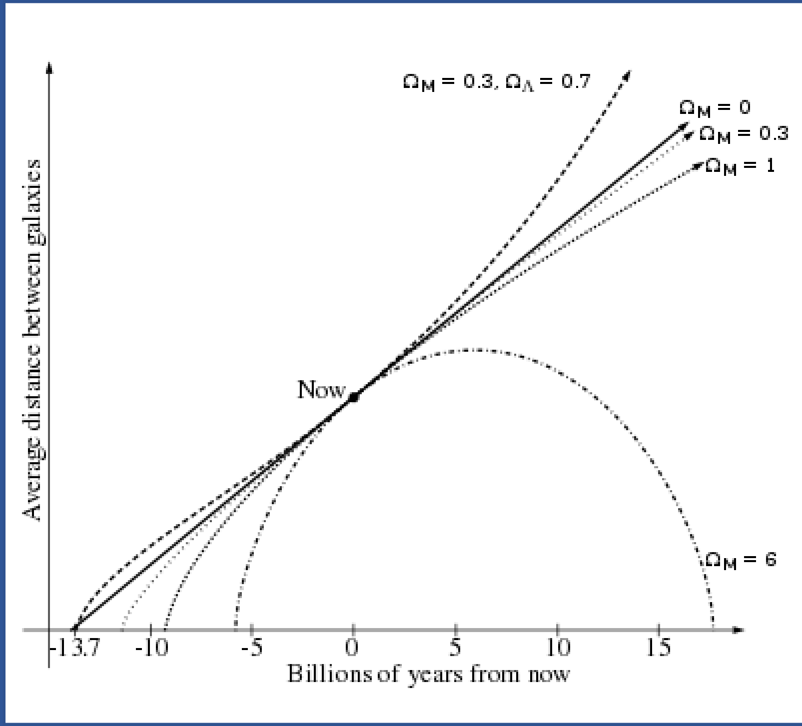
$$v = H_0 D$$ (Hubble's Law – 1929)

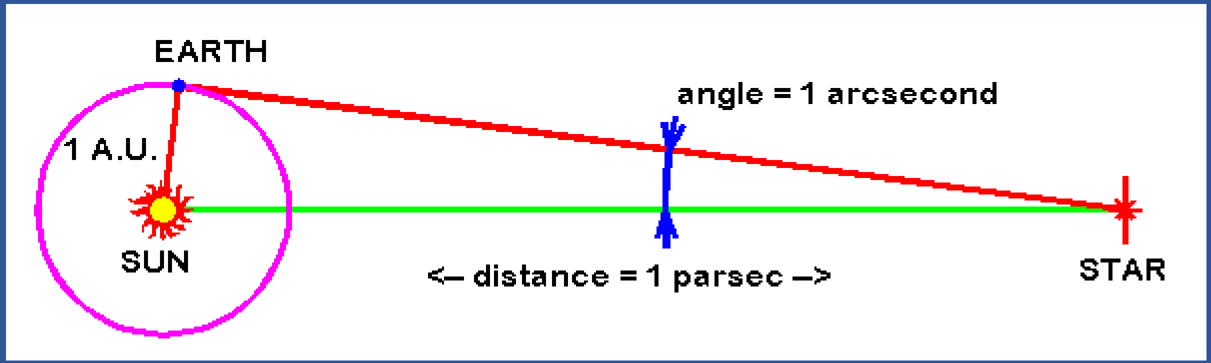
v = Recessional velocity (taken from redshift)

D = Proper distance (taken from brightness)

H_0 = Hubble Constant (expressed in km/s/Mpc)

The Expansion





The universe is not only expanding, the expansion itself is *accelerating.*

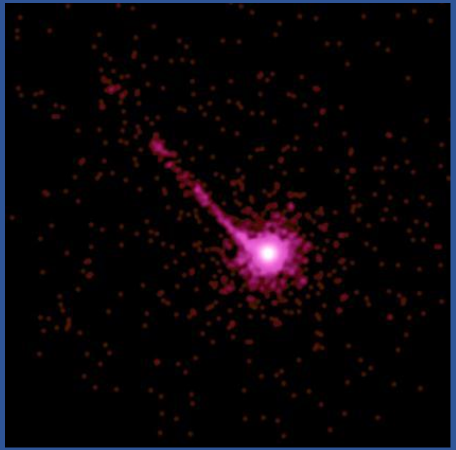
Hubble Constant is estimated between 50 and 100 km/s/Mpc (some estimates give around 73 or 67 km/s/Mpc) (1 Mpc = 3.26 million ly) (Freedman, W. 1992) (NASA, 2014).

Hubble Time = 14.4 billion years (different from 13.8 billion years!)

Critical Density: $\rho_c = \frac{3H_0^2}{8\pi G} = 10^{-29} g/cm^3 = 10\ atoms/m^3$

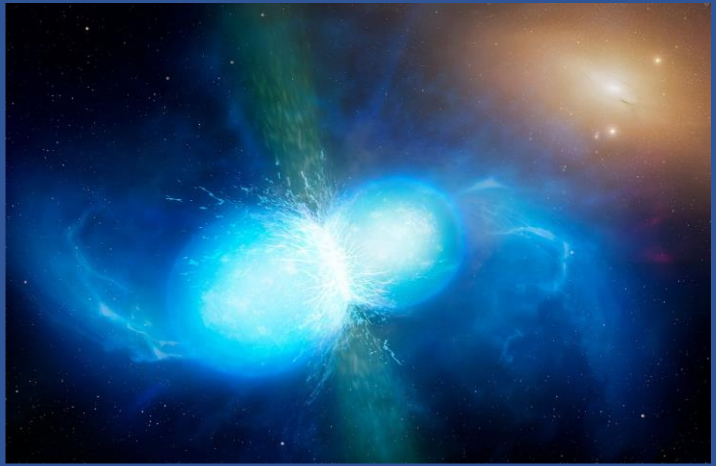
How do we measure the expansion rate?

- Using a standard candle
  (bright objects)



Bechtold. J (2008)

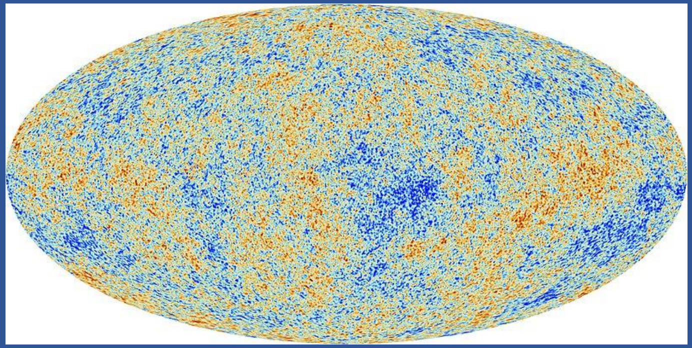
- Gravitational Lensing



Garlic, M. (2017)

- Using the Cosmic Microwave Background

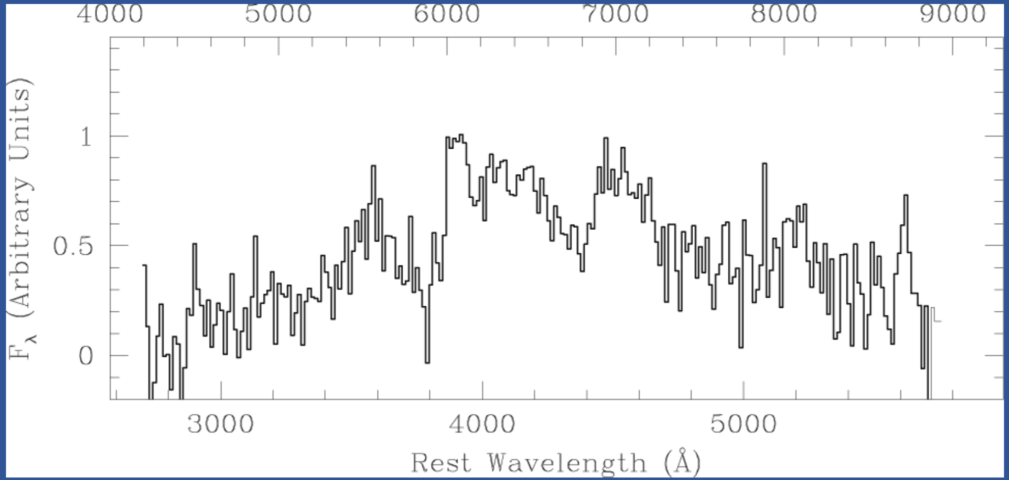
- Using a standard siren
  ("loud" objects)



ESA (2013)

Why are supernovae a good way to measure the expansion?

- We know what the spectra look like
  (Type Ia Supernova come from white dwarfs beyond 1.4 M_{Sun})



Perlmutter, S. (2011)

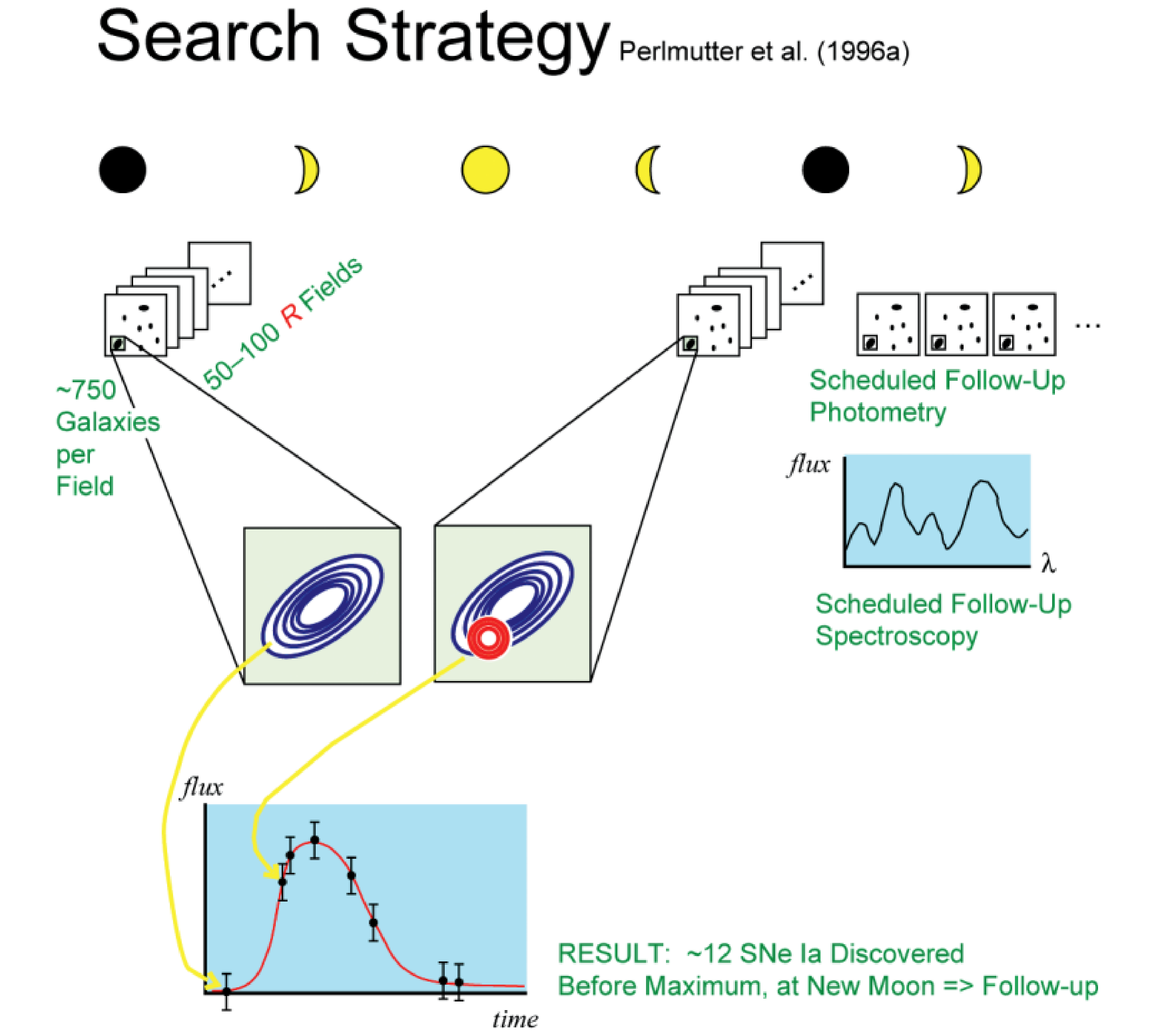
- Given a large field of view, they are frequent
  (2 – 3 per century per galaxy!)

F/1 Wide-field CCD camera for Anglo-American 4-m telescope

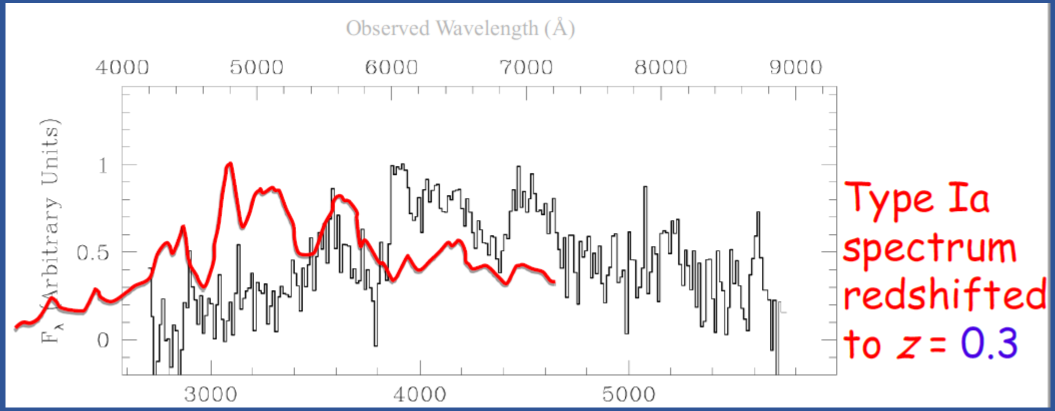
Perlmutter, S. (1987, 2011)

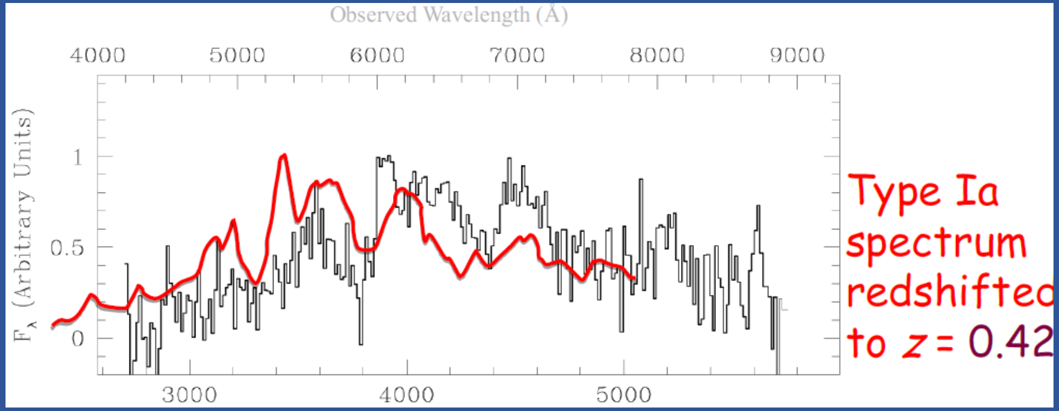
- They are very bright (but short lived)

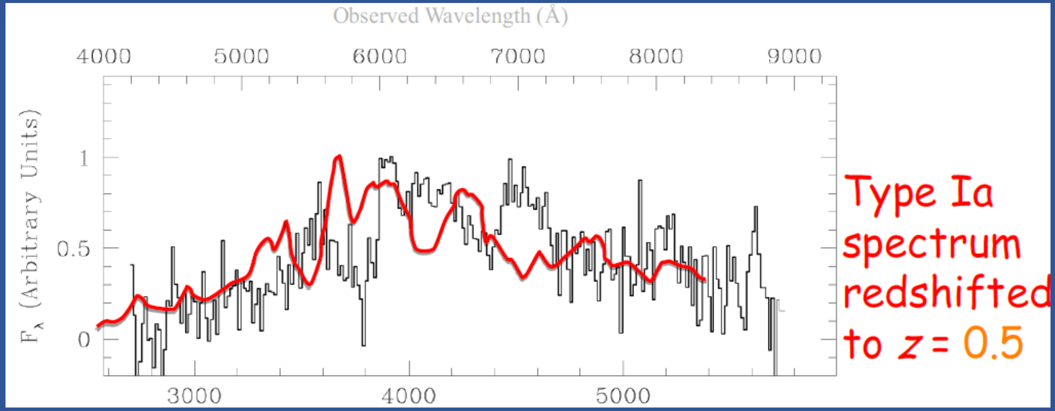
How do we look for distant supernovae?

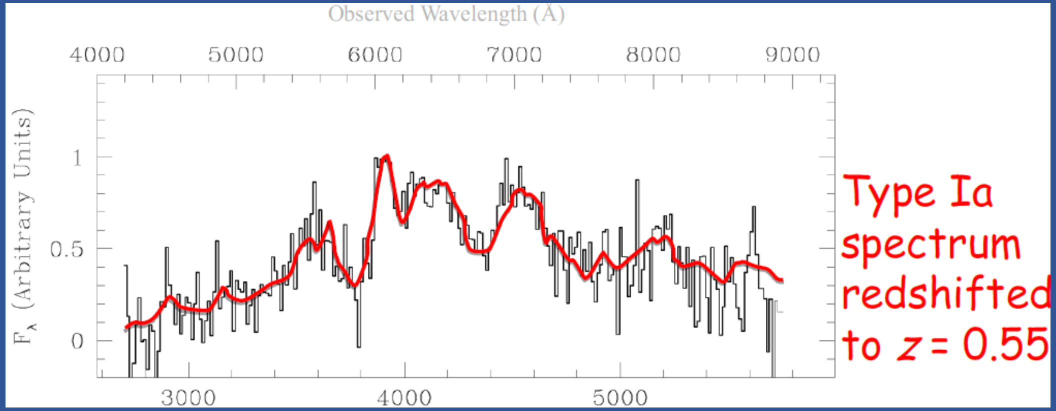


Perlmutter, S. (2011)





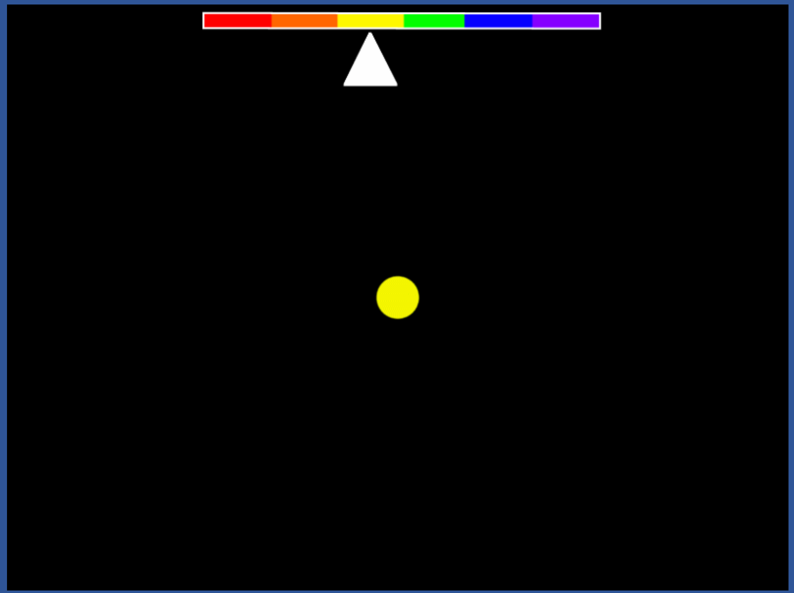


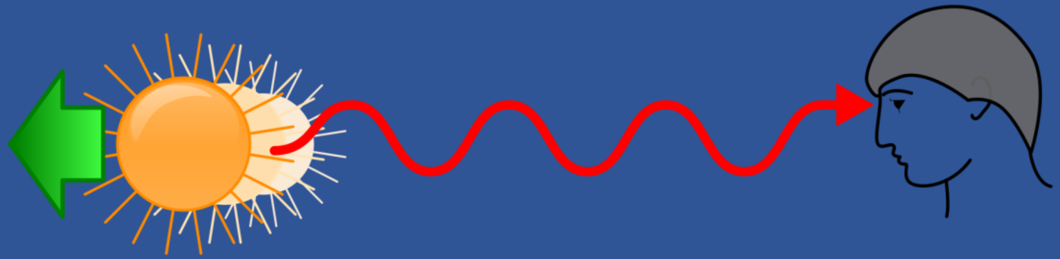


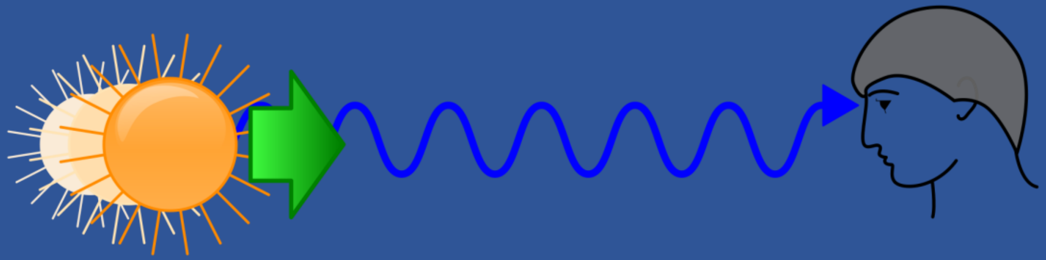
Perlmutter, S. (2011)

Velocity

$$z = \frac{\lambda_{obsv} - \lambda_{emit}}{\lambda_{emit}} = \frac{v}{c}$$







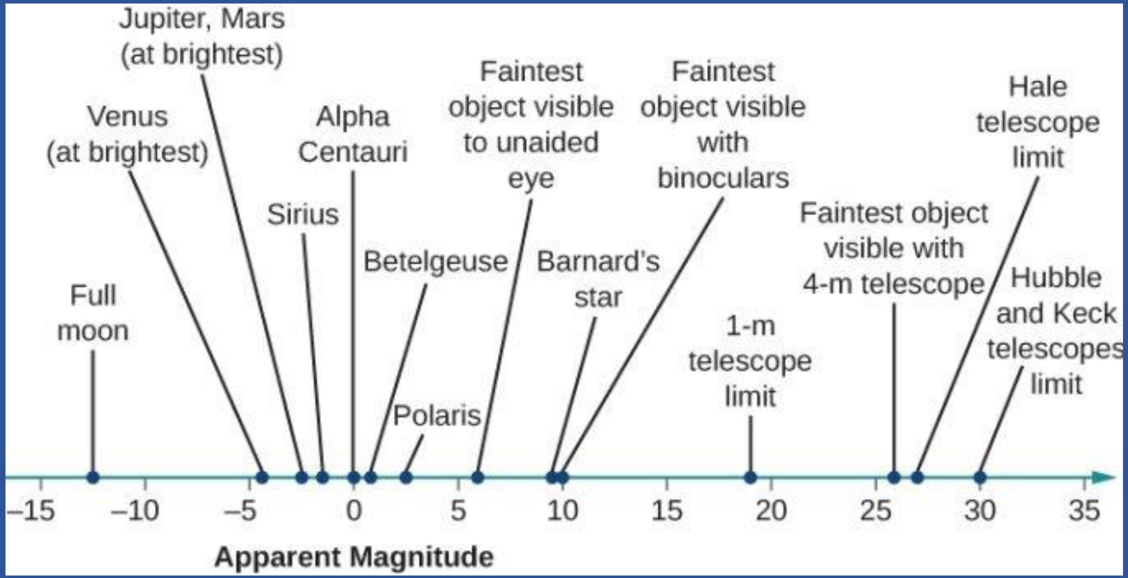
Distance

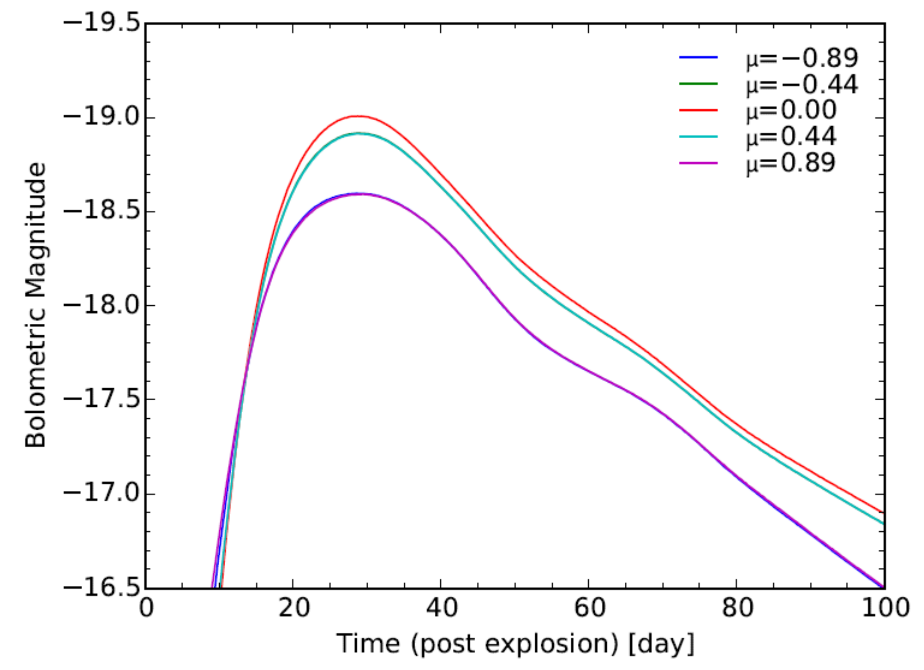
$$M = m - 5(log_{10}(d) - 1)$$

OR

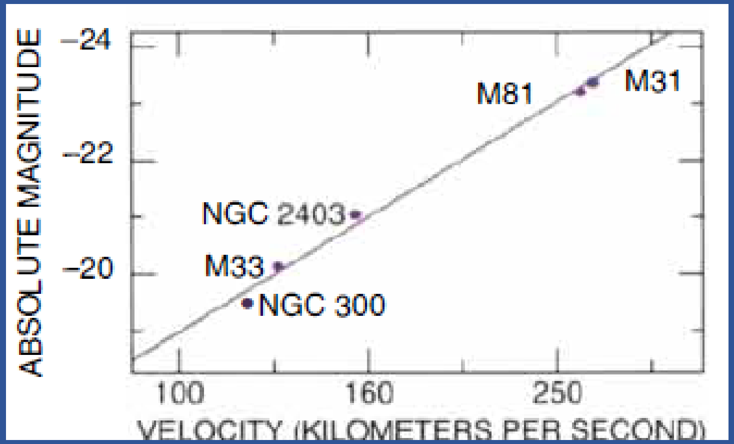
$$M_{bol,*} - M_{bol,Sun} = -2.5log_{10}(\frac{L_*}{L_{Sun}})$$

$$L \propto \frac{1}{d^2}$$



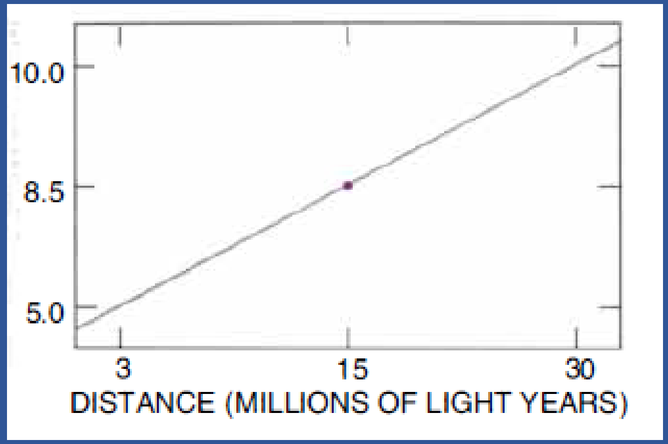


Distance cont'd.



Freedman, W. (1992)

Galaxy magnitude as a function of velocity

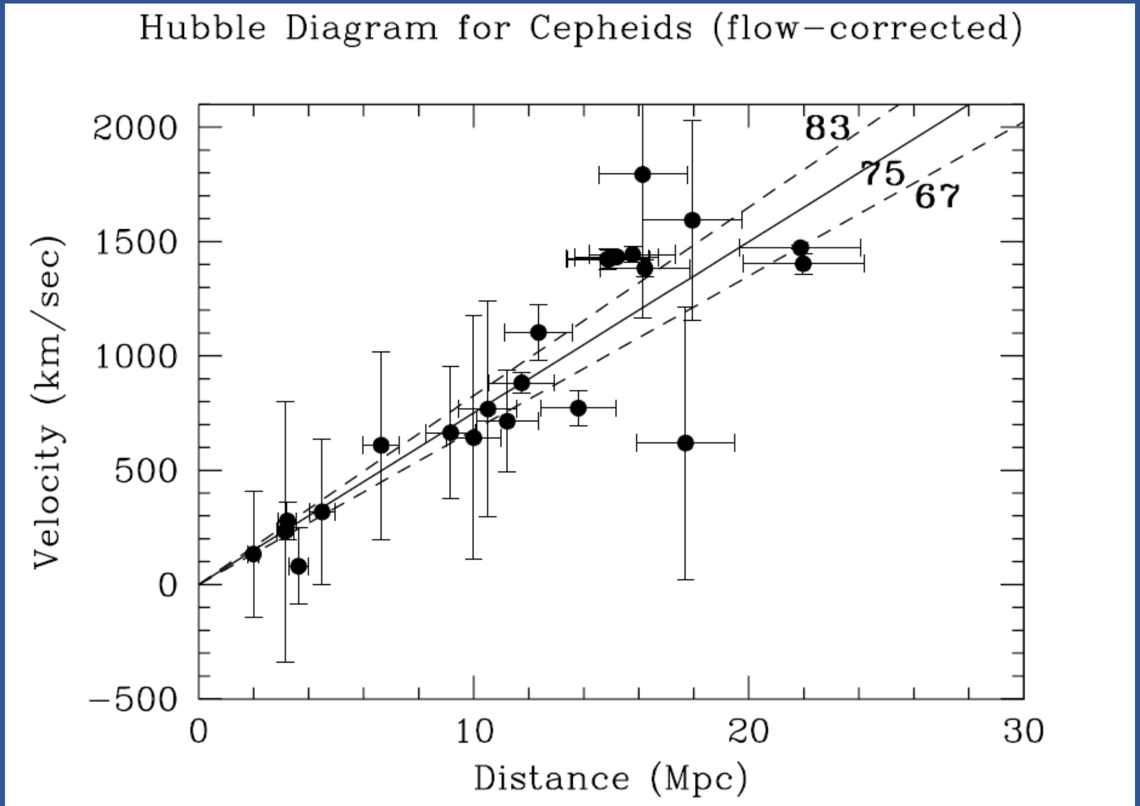


Freedman, W. (1992)

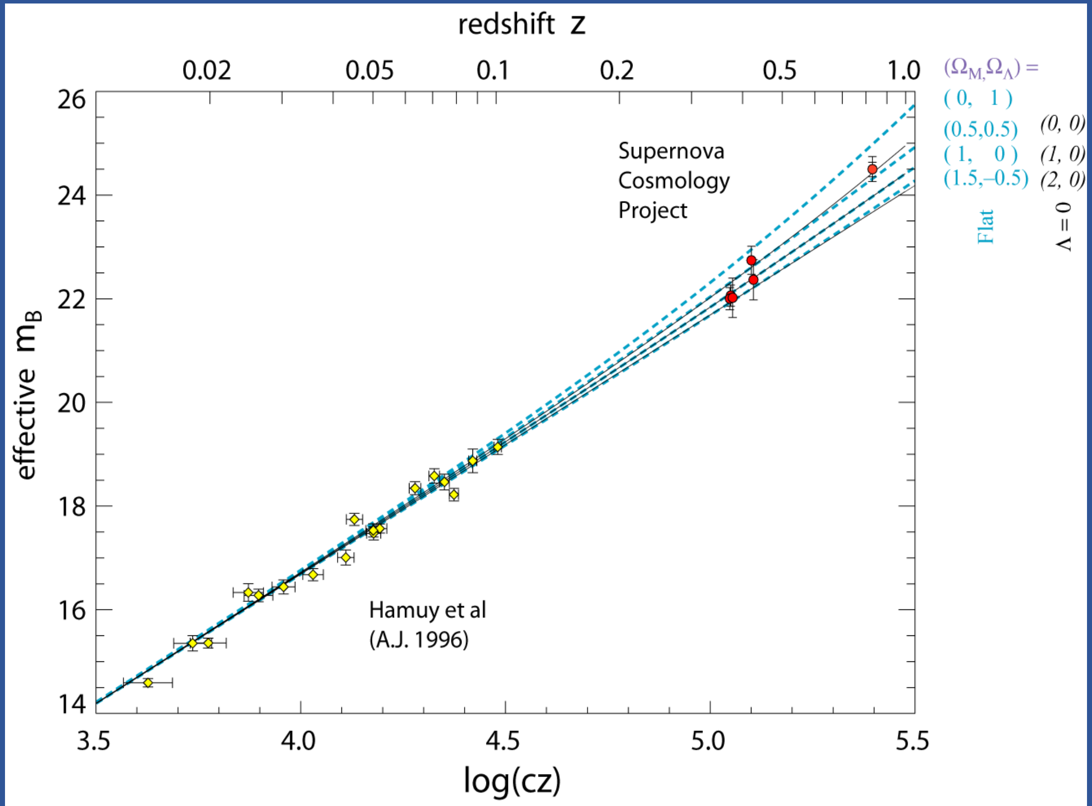
Type Ia Supernova in 1992

- The brightness of an object is directly related to its distance

- Modern charge-coupled devices (CCDs) are capable of measuring this brightness now



Freedman, W. et al. (2000)



Perlmutter, et al. (1998)

Future Developments and Questions

- New technology allows probing of other objects
- Are old supernovae any different than modern ones?
- The accelerating universe implies a positive Λ, what is its cause?

Sources

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