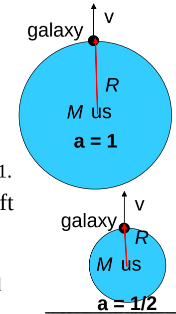
Discovery of Dark Energy—2 Dec

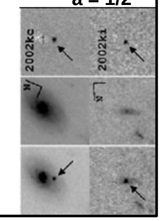
- How do scientists make discoveries?
- Characteristics
  - New ideas
    - Einstein's cosmological constant ca. 1920
  - New instruments
    - Large CCDs to search for SN
  - New wavelengths (NA)
  - Careful design
    - SN are clean, not messy.
  - Serendipity
    - Did not expect to find dark energy
  - Courage to make the measurement (NA)

In a fair sample with R=Moon's orbit
Ordinary matter: 4%, 3oz
Dark matter: 27%, 1lb
Dark energy: 73%, 3 lb

Weighing the universe: summary

- Method for astronomical weighing:
  - Define a motion
    - Universe expands by a factor of 2, from a=1/2 to 1.
  - Time the motion: Use supernova with redshift z = 1.
    - If supernova is brighter, then distance is less, and time is shorter (light travels at speed of light), and mass density of U is greater.
  - If the motion takes longer, the mass is less.
    - For a greater mass density, the time for U to expand by a factor of two is smaller, because gravity is a bigger effect: proxy galaxy must have been moving faster in the past for it to have slowed to its present speed.



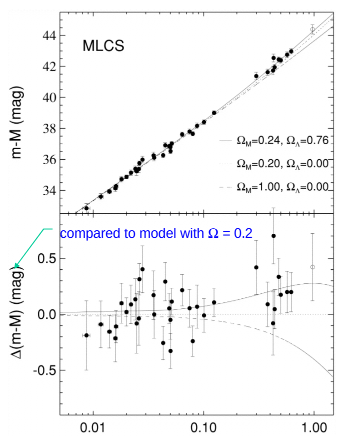


Observations

- Distant SN from Riess et al, 1998, ApJ 116, 1009. Nearby SN from several surveys

2. On upper plot, nearest SN is at
   a. upper right.
   b. upper left.
   c. lower right
   d. lower left.
3. For the most distant SN, the wavelength of light has increased by a factor of ___ since the SN emitted it.

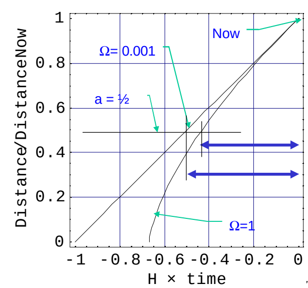
- Lower plot compares data to a model with density parameter
  - Ω = PE/KE = 0.2

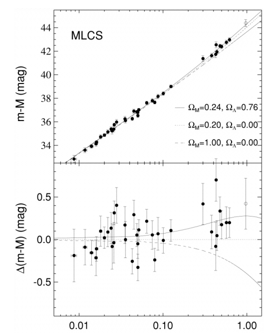


a=0.99 a=0.9 a=0.5

Observations meet models

- What does SN at z=0.4 tell us about U?





Observations

- Distant SN are 20% fainter than model with $\Omega = 0.2$.
- Distant SN are 15% fainter than model with $\Omega = 0$!
  - Longer time to expand than universe having no mass at all!
  - Shorter time means expansion slowed down; longer time means expansion sped up.