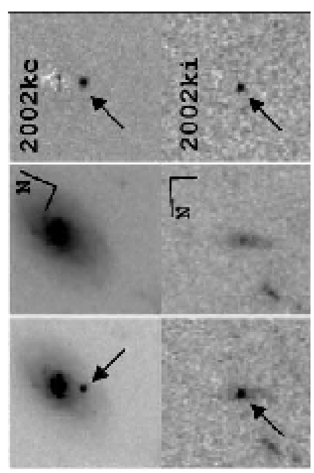
Weighing the Universe with Supernovae. Discovery of Dark Energy/ Cosmological Constant—9 Dec

- Final exam
  - Covers entire course with emphasis on 20th century cosmology (Oct 28 to end of term, Hwk 7–10)
  - One 8.5×11” cheat sheet
  - Mon, 14th, 3:00-5:00, 1410 BPS (large classroom next door)
- Please fill out on-line SOCT http://rateyourclass.msu.edu
  - Will close when grades are submitted.
- Last class: Review

- Weighing the universe means to find mass density
- What we will find: Expansion of universe speeds up!
  - “Dark energy” is dominant. Dark energy repulses whereas matter and radiation attract.

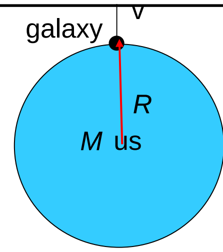
Supernova

- A Type II supernova is a massive star that explodes when it runs out of fuel and pressure is insufficient to counter gravity.
- A Type I supernova is a white dwarf that explodes.
  - A WD and giant orbit each other.
  - Mass moves from the giant to the WD.
  - WD explodes when it gets so much mass from the giant that degeneracy pressure can no longer oppose gravity.
- Type I supernovae are “standard candles.” They have the same luminosity.
- How to find supernovae
  - Look at many galaxies.
  - Look again later. Find objects that were not there earlier.



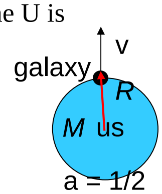
Distant supernovae
Riess et al, 2004, ApJ 607, 665.

Weighing Universe



- Principle for astronomical weighing:
  - Define a motion
  - Time the motion
  - If the motion takes longer, the mass is less.
- Consider a big sphere centered on us, which contains many galaxies
- Mass inside sphere pulls on galaxy & slows expansion.
- Present speed & present distance are fixed by Hubble's Law.
- To find mass density of the universe, measure the time it takes for the U to expand by a factor of 2 by looking at galaxies for which the wavelength has expanded by a factor of 2. (Other factors are OK too.)

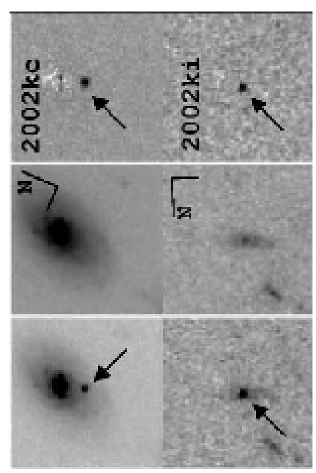
5. Consider now & time when radius of sphere is ½ present radius. If the time to expand by a factor of 2 is long, the mass density of the U is <u>low</u>.



1. When the U was half of its present size, a supernova in a galaxy emitted some light, which we see. What do we measure to determine that the U was half its present size when the light was emitted?
   - A. Measure flux of supernova.
   - B. Measure flux of galaxy.
   - C. Measure wavelength of a spectral line emitted by the galaxy.
2. In a universe with a higher mass density, the supernova will be ___.
   - A. brighter
   - B. same
   - C. fainter

- Ideas:
  - Why would the brightness of a SN depend on mass density of the universe?
  - Flux = Luminosity / Distance^2.
  - What affects distance to SN?
  - If time for U to expand is shorter, distance is shorter.

    Distance = time × speed of light



Distant supernovae

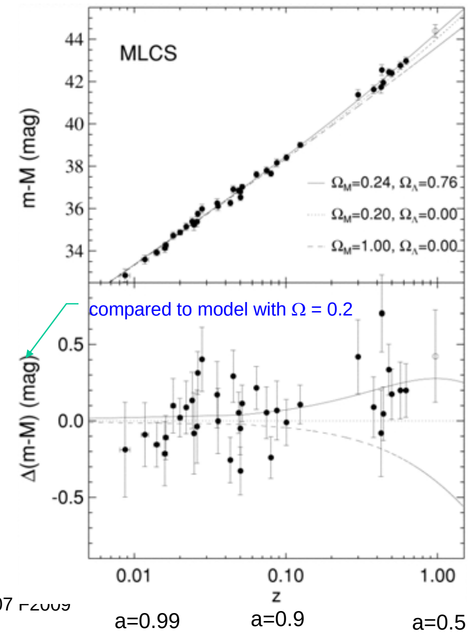
Riess et al, 2004, ApJ 607, 665.

Observations

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

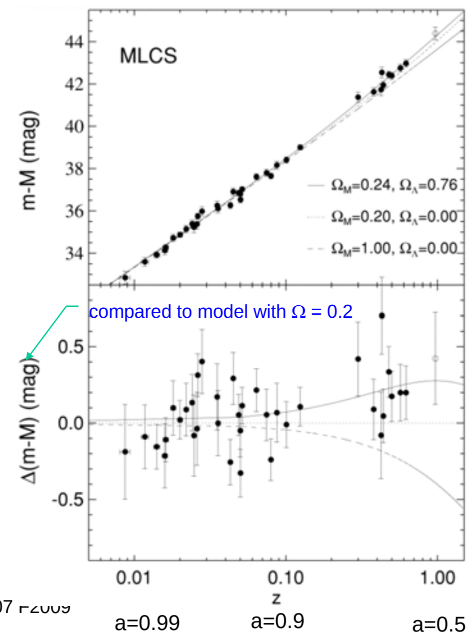
2. On upper plot, nearest SN is at
   a. upper right.
   b. lower left.
3. For the most distant SN, the wavelength of light has increased by a factor of ___ since the SN emitted it.
   A. 1.00
   B. 0.5
   C. 0.99
   D. 0.01
   E. 2

- Ideas
  - Magnitudes are more positive for fainter SN.
  - Expansion parameter $a = D/D_{now}$
  - Redshift $a=1/(1+z)$ $z = (\lambda - \lambda_{lab})/\lambda_{lab}$.



Observations

- Lower plot compares data to a model with density parameter
  $\Omega = PE/KE = 0.2$
- 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 for a universe having no mass at all!
  - Shorter time means expansion slowed down; longer time means expansion sped up.
- Einstein (about 1920): I thought of a kind of stuff where gravity repels.
- Thomas Hardy: “Though a good deal is too strange to be believed, nothing is too strange to have happened.”



What is the Universe Made of?

- Spherical sample of universe. R=moon's orbit. Sample has
  - 3 oz of ordinary matter
  - 1 lb of dark matter
  - 3 lb of dark energy
- Ordinary matter—protons, neutrons, electrons
  - Stars, gas, dust, planets, us
  - Ω_{matter} = 4%
- Dark matter—not detected except through gravity
  - $\Omega_{dark\ matter}$ = 23%
- Light
  - Mass density is small now. Dominant before universe was 1 Million years old
- Dark energy
  - Repulsive
  - $\Omega_{dark\ energy}$ = 73%
- $\Omega_{matter} + \Omega_{dark\ matter} + \Omega_{dark\ energy} = 1$

Summarizing questions

- What is the evidence for dark energy? What was measured. If the result of the measurements were ___, there would be no evidence for dark energy.
- Ideas needed to answer the question:
  - SN are fainter than if U had no dark energy.
  - Flux of SN is related to distance.
  - With no DE, distance to SN is shorter.
  - Redshift of SN determines the amount U expands.
  - SN have the same luminosity: They are standard candles.
  - Astronomers can model flux vs redshift for different density parameters.
  - What plot did we look at? What about the plot indicated DE.