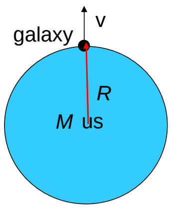
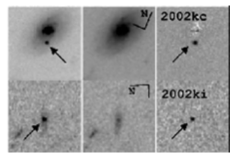
Weighing Univ.: Timing Expansion of Universe—1 Dec



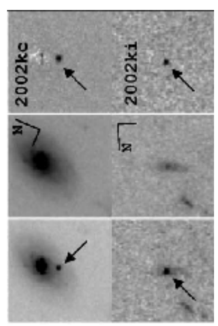
- The force of gravity between galaxies should slow the expansion of the universe. What we will find: Expansion of the universe speeds up!
  - There is a large amount of "dark energy," which is repulsive whereas matter and radiation are attractive.
- "Though a good deal is too strange to be believed, nothing is too strange to have happened." —Thomas Hardy



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

- Schedule:
  - Today: Finish Weighing the universe
  - Wed: Einstein's theory of gravity, which includes a cosmological constant (dark energy)
- Review and Missouri Club
  - Big questions: "Where Do We Come From? What Are We? Where Are We Going?"
- Final exam: Wed, Dec 10th, 3:00-5:00, 1410 BPS
  - Test from 2005 will be on the web.
  - 4 cheat sheets.
- Test 3 will be done on Wed.

- The astronomical "bathroom scale:"
  - Define a motion.
  - Measure how long the motion takes.
  - If the motion takes a short time, the mass is greater.
1. With a higher mass density, the time for U to expand by a factor of two is <u>shorter</u>.
2. A supernova in a galaxy emitted some light when the U was half of its present size. We see that light. In a universe with a higher mass density, the supernova will be <u>brighter</u>.
3. By looking a supernova, how do we know the expansion parameter of the U when the SN emitted the light that we now see? What quantity do we need to measure? <u>Wavelength of light.</u>
- We want to weigh the universe with supernovae.
  - Supernovae from collapsing white dwarfs are "standard candles."
4. We want to weigh the universe with supernovae. What motion do we use? How do we measure how long the motion takes? If a supernova is __, the universe has more mass.
- Ideas & questions
  - If there is more mass, there are more electrons. Light will be dispersed. U is transparent.
  - We need to measure the flux.



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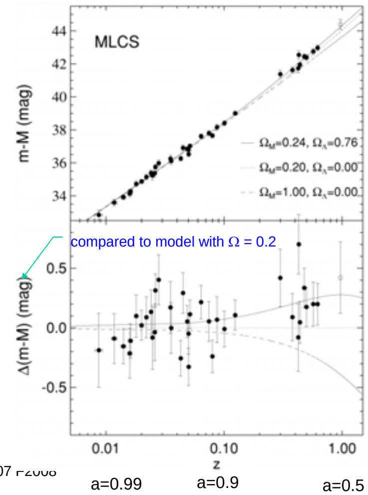
4. We want to weigh the universe with supernovae. What motion do we use? How do we measure how long the motion takes? If a supernova is __, the universe has more mass.
   Ideas:
4. The measured quantity __ defines the motion. The measured quantity _ defines how long the motion takes. If a supernova is __, the universe has more mass.
   A. flux, redshift, brighter
   B. redshift, flux, brighter
   C. flux, redshift, fainter
   D. redshift, flux, fainter

Observations

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

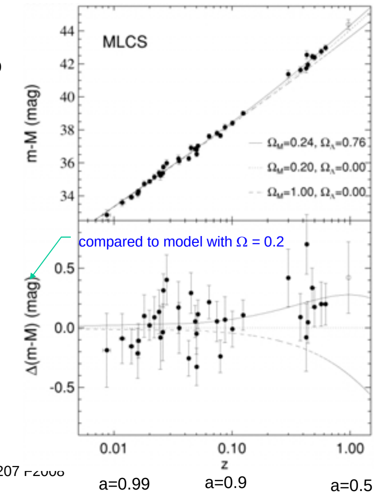
2. On upper plot, nearest SN is at
   a. upper right.
   b. <u>lower left</u>.
3. For the most distant SN, the wavelength of light has increased by a factor of ___ since the SN emitted it.
   A. 1.00
   B. 0.5
   C. 0.99
   D. 0.01
   E. <u>2</u>

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



Observations

- Lower plot compares data to a model with density parameter
  Ω = PE/KE = 0.2
- Distant SN are 20% fainter than model with Ω = 0.2.
- Distant SN are 15% fainter than model with Ω =0!
  - Longer time to expand than universe having no mass at all!
  - Shorter time means expansion slowed down; longer time means expansion sped up.



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
  - $\Omega_{matter} = 4\%$
- 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.