

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

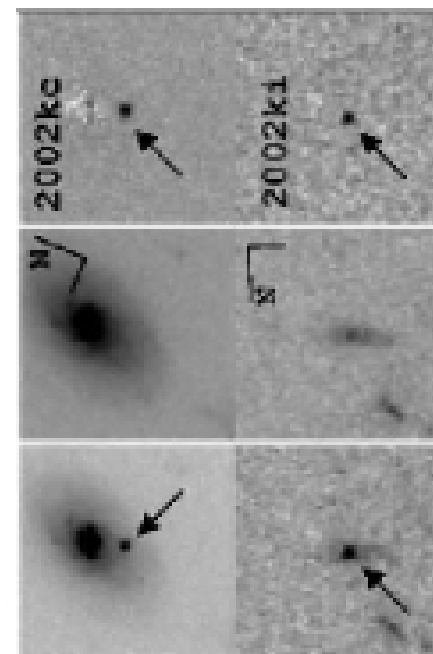
- Final exam
 - Covers entire course with emphasis on 20th century cosmology (Oct 28 to end of term, Hwk 7–10)
 - One 8.5×11” cheat sheet
 - Mon, 14th, 3:00-5:00, 1410 BPS (large classroom next door)
- Please fill out on-line SOCT <http://rateyourclass.msu.edu>
 - Will close when grades are submitted.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

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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.

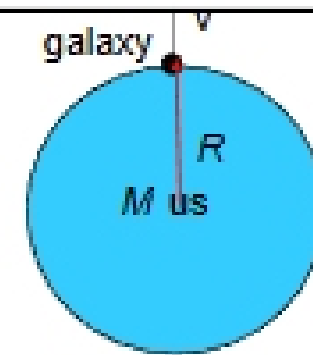


Distant supernovae

Riess et al, 2004, ApJ 607, 665.

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Weighing Universe

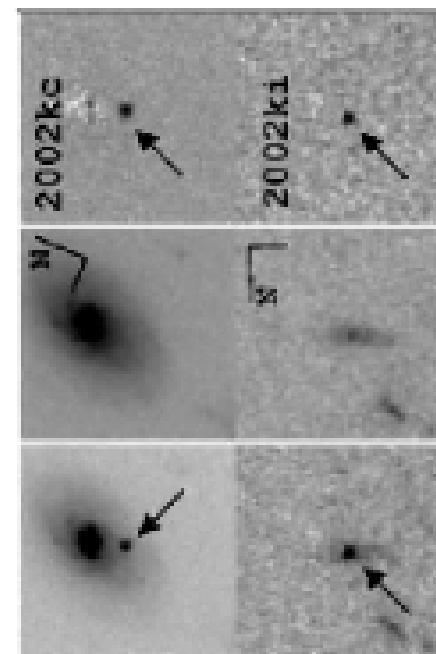


- Principle for astronomical weighing:
 - Define a motion
 - Time the motion
 - If the motion takes longer, the mass is less.
- Consider a big sphere centered on us, which contains many galaxies
- Mass inside sphere pulls on galaxy & slows expansion.
- Present speed & present distance are fixed by Hubble's 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 $\frac{1}{2}$ present radius. If the time to expand by a factor of 2 is long, the mass density of the U is low.



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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 / Distance².
 - What affects distance to SN?
 - If time for U to expand is shorter, distance is shorter.
- Distance = time \times speed of light



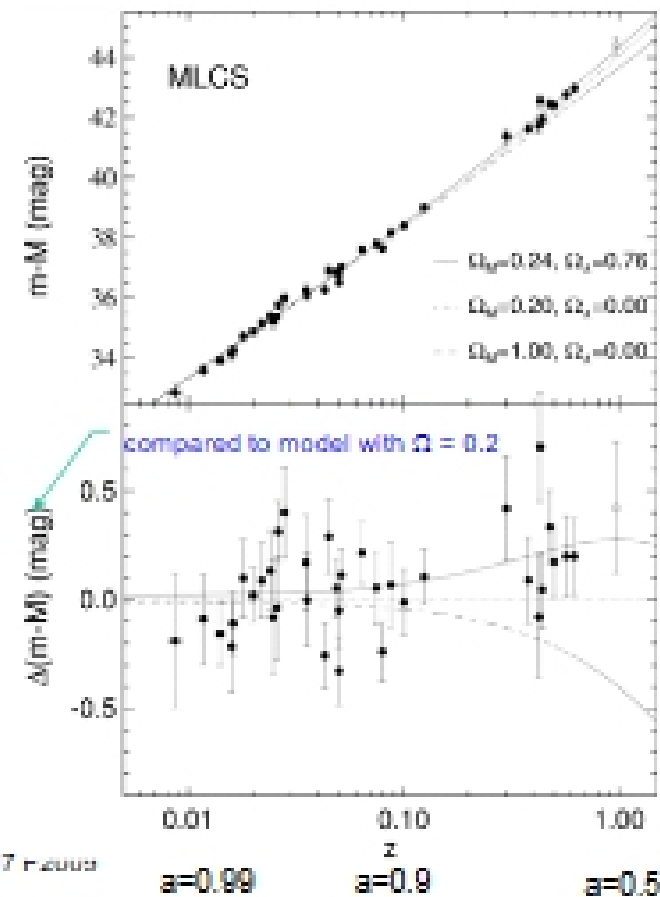
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Observations

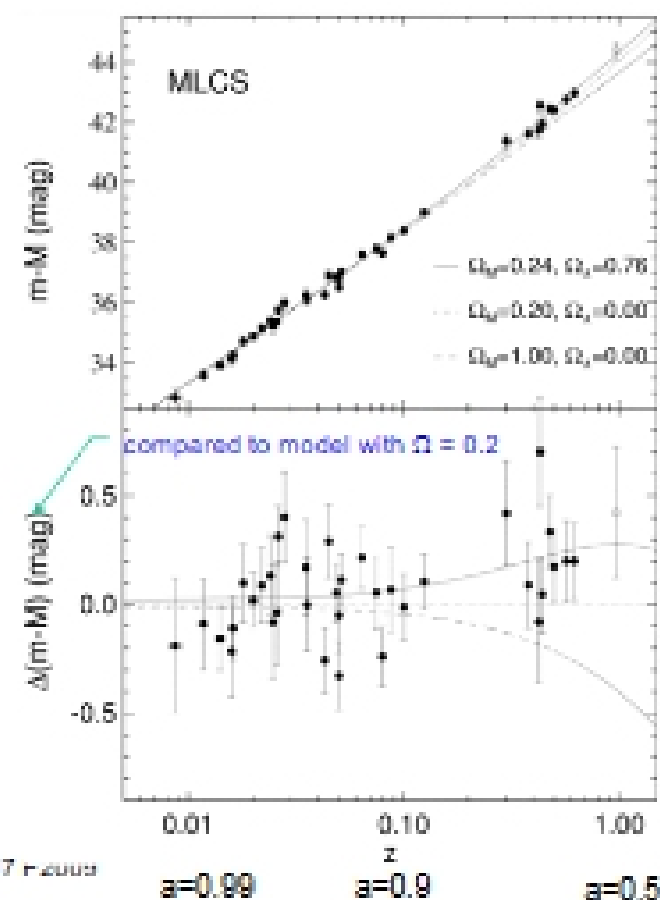
- Distant SN from Riess et al, 1998, ApJ 116, 1009. Nearby SN from several surveys.
- 2. On upper plot, nearest SN is at
 - a. upper right.
 - b. lower left.
- 3. For the most distant SN, the wavelength of light has increased by a factor of ___ since the SN emitted it.
 - A. 1.00
 - B. 0.5
 - C. 0.99
 - D. 0.01
 - E. 2
- Ideas
 - Magnitudes are more positive for fainter SN.
 - Expansion parameter $z = D/D_{\text{now}}$
 - Redshift $z = 1/(1+z)$
 - $z = (\lambda - \lambda_{\text{obs}}) / \lambda_{\text{obs}}$



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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."



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