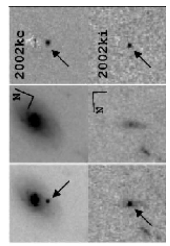
Weighing the Universe—30 Nov

- Weighing the universe means to find mass density or density parameter
  - Ω = PE/KE = $8\pi G/3$ mass density / H^2
- Why?
  - What is the universe made of? Is there mass that we cannot see?
  - What is the fate of the universe? Will it expand forever or fall back on itself?
    - Expand forever if $\Omega \leq 1$
- How?
  - Mass in a large sphere surrounding us pulls on a galaxy on the surface
  - Measure how much the galaxy slows.
  - Use supernovae
- What we will find: Galaxies speed up!
  - "Dark energy" is repulsive whereas matter and radiation are attractive.



Distant supernovae

Riess et al, 2004, ApJ 607, 665.

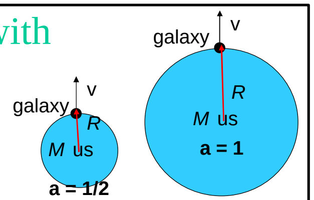
What is the Universe Made of?

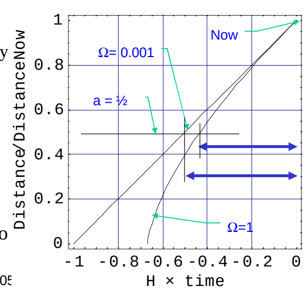
- Spherical sample of universe. R=moon's orbit. Sample has
  - 3 oz of ordinary matter
  - 1 lb of dark matter
  - 3 lb of dark energy
- Ordinary matter—protons, neutrons, electrons
  - Stars, gas, dust, planets, us
  - Ω_{matter} = 4%
- Dark matter—not detected except through gravity
  - $\Omega_{dark\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

Timing the motion with supernovae

- Method for astronomical weighing:
  - Define a motion
    - Universe expands by a factor.
  - Time the motion
  - If the motion takes longer, the mass is less.
- Look at Type I supernova in a distant galaxy.
  - Type I supernovae have same luminosity

3. For which model is the density higher?
4. For the universe with Ω=1, how much time does it take for the universe to expand by a factor of 5? Same question with Ω=0.001. Express time in units of 1/H=14Byr.
5. Identify these events on the graph: (1) SN at z=4 or a=1/5 emits some light in higher density universe. (2) Light gets to a=1/2. (3) We see that light.





Timing the motion with supernovae

- Method for astronomical weighing:
  - Define a motion
    - Universe expands by a factor.
  - Time the motion
  - If the motion takes longer, the mass is less.
- Distance to SN is greater if time for light to travel is longer.

6. Suppose you discovered a supernova at z=2 and found it to be faint. Then is the density parameter Ω bigger or smaller. What on the graph gave you the answer?