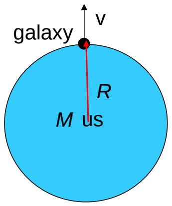
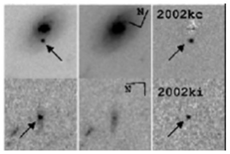
Weighing Univ.: Timing Expansion of Universe—21 Nov



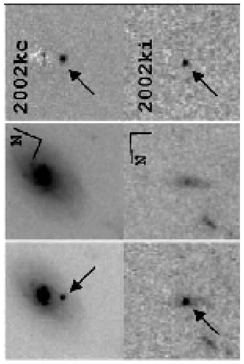
- "Though a good deal is too strange to be believed, nothing is too strange to have happened." —Thomas Hardy
- How to weigh universe
  - Mass in a large sphere surrounding us pulls on a galaxy on the surface
  - Measure how much the galaxy slows.
  - Use supernovae
- What we will find: Galaxies speed up!
  - "Dark energy" is repulsive whereas matter and radiation are attractive.



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

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. By looking the supernova, how do we know the U was half its present size? In a universe with a higher mass density, the supernova will be ___.
   A. brighter
   B. same
   C. fainter

- Ideas:
  - What makes SN brighter? It is closer.
    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



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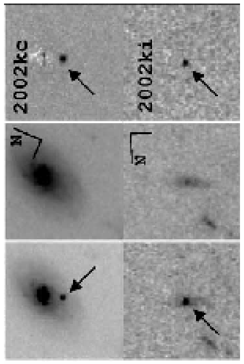

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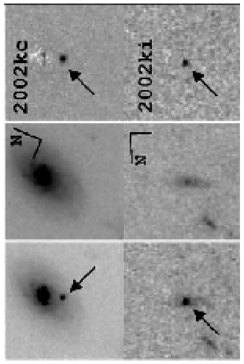
1. With a higher mass density, the time for U to expand by a factor of two is <u>shorter</u>.
2. A supernova in a galaxy emitted some light when the U was half of its present size. (Expansion parameter is ½.) We see that light. In a universe with a higher mass density, the supernova will be <u>brighter</u>.
3. By looking at 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?

- Ideas:
  - Expansion parameter
    a = (Distance between two objects) / (Distance at present time)
  - Amount the wavelength has shifted.
  - Redshift determines expansion parameter.



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1. With a higher mass density, the time for U to expand by a factor of two is shorter.
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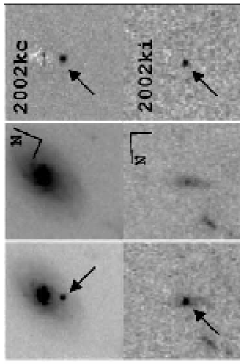
3. By looking a supernova, how do we know the expansion parameter of the U when the SN emitted the light that we now see? What quantity do we need to measure? Wavelength of light.

- Ideas:
  - Expansion parameter
    a = (Distance between two objects) / (Distance at present time)
  - Wavelength of light expands by the same factor as the universe.
  - Other ideas



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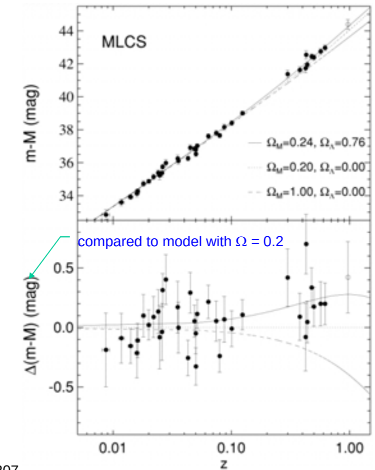
Observations

- 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
    a= D/D_{now}
  - Redshift a=1/(1+z)
    $z = (\lambda - \lambda_{lab})/\lambda_{lab}$.



a=0.99 a=0.9 a=0.5