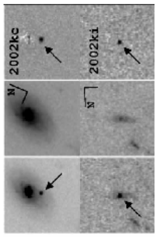
Weighing the Universe with Supernovae—7 Dec

- 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.
- Test answers are on angel.
- Last class: Review or SOAR Telescope?



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

- Weighing the universe means to find mass density
- Why?
  - What is the universe made of? Is there mass that we cannot see?
- How?
  - Mass in a large sphere surrounding us pulls on a galaxy on the surface
  - Measure how much the galaxy slows.
  - Use supernovae to measure the time for the universe to expand.
- What we will find: Expansion of universe speeds up!
  - "Dark energy" is dominant. Dark energy repulse whereas matter and radiation attract.

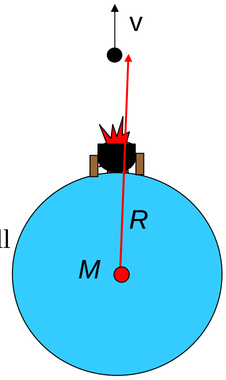
Cannon Ball

- Cannonball is shot out of cannon at speed v.
  - Kinetic energy is ½ v^2.
- Gravity pulls on cannonball to slow the motion.
  - Potential energy is G M /R
- Cannonball will escape if shot fast enough so that

  KE ≥ PE
- Define "Density parameter"

  $\Omega = PE / KE = 2 G M / (R v^2)$

1. A cannonball is shot with Ω=0.7. Will the cannonball escape? Same question for Ω=1.1. Do this on your own.
   A. YY
   B. YN
   C. NY
   D. NN



Universe & "Density Parameter"

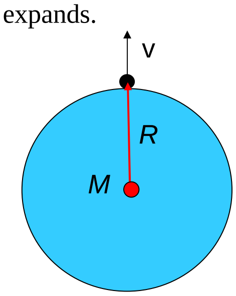
- Sphere expands and galaxy moves because universe expands.
- Galaxy is moving at speed v.
  - Kinetic energy is $\frac{1}{2} v^2$.
- Gravity pulls on galaxy to slow the motion.
  - Potential energy is G M /R
- Galaxy will escape if moving fast enough

  KE ≥ PE
- Define "Density parameter"

  Ω = PE/KE = 2 G M / (R v^2)
- Use Hubble's Law v=HR

  Ω = PE/KE = 2 G M / ($R^3 H^2$)
- Mass/volume is mass density ρ. M=volume ρ = 4/3 π R^3 ρ.

  Ω = PE/KE = $(8\pi/3)$ G ρ / H^2.
- Does not depend on particular galaxy

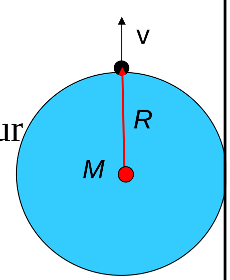


Does universe expand forever?

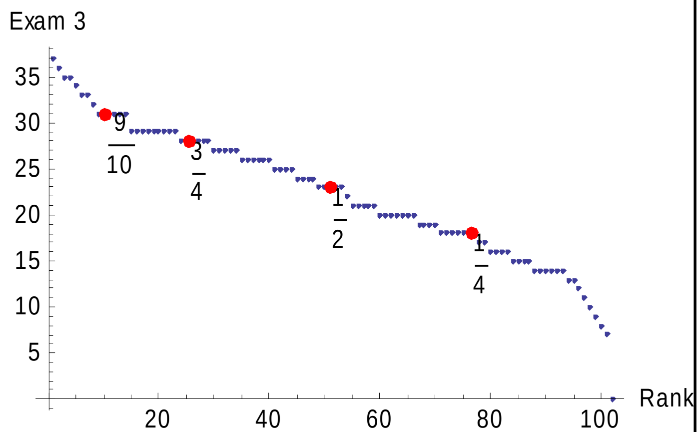
- Density parameter

  Ω = PE/KE = $8\pi/3$ G ρ / H^2.

2. If the density parameter Ω=0.7, will the universe expand forever? Do this on your own.
   A. Y
   B. N



Exam 3



- Top 1/10 31/39 (80%)
- Top quartile 28/39 (72%)
- Median 23/39 (59%)
- Bottom quartile 18/39 (46%)

Course grade

- Grades are on angel
- Includes
  - Tests
  - Homework 1-9
  - Clickers 9/2 – 12/4
- Weights adjusted so that weights of tests:hwk:clicker is same as at end of term
- Grade curve may change slightly at the end of the term.
- Use your grade on angel as guidance. Final exam is 31% of the course grade.

Grade	Min	% of class
0.0		3
1.0	40%	8
1.5	46%	5
2.0	51%	7
2.5	57%	8
3.0	63%	17
3.5	69%	22
4.0	76%	31

Difficult Problems: (Key idea is underlined.)

- 1a. (1 pt.) At the present time, does the value of Hubble's constant depend on the galaxy in which the observations are made? (2 pts.) Explain your reasoning.
  - "1/H gives the present age of the universe… If we consider only the present time, 1/H should not change with the galaxy we are observing from."—K Garafoli
  - We measure the speed v and distance D of another galaxy and find H=v/D. On the other galaxy, the speed and distance of the Milky Way have the same values v and D. Therefore Hubble's constant is the same on the other galaxy.
  - Most incorrect answers addressed different questions.
    - Does speed depend on distance? Is Hubble's Law valid on other galaxies?

Difficult Problems: (Key idea is underlined.)

- 2b. (1 pts.) In the inner part of the galaxy (R<4 kpc), how does the rotational velocity depend on R? (2 pts.) How does the mass enclosed within R depend on R?
  - The rotational velocity depends linearly on R, v=constant R. v=R (if I leave out the constants)
  - $M(R)=v^2R=R^3$. (Kelper's 3rd law)

Difficult Problems: (Key idea is underlined.)

- 3b. (3 pts.) Compute the expansion parameter a of the universe when 0024+1654 emitted the light that we see now.
  - The key idea is that the wavelength of light expands as the universe. The wavelength of Hβ line expands by the factor 6757/4861=1.39. The universe was smaller by that factor when the light was emitted. The expansion parameter is 1/1.39= 0.719
- 3c. (3 pts.) What was the temperature of the radiation of the Big Bang when 0024+1654 emitted the light that we see now?
  - The key idea is that the wavelength of light expands as the universe and therefore by Wien's Law the temperature of the radiation is inversely proportional to the expansion parameter. T=2.7K/a = 2.7/0.719 = 3.75K.