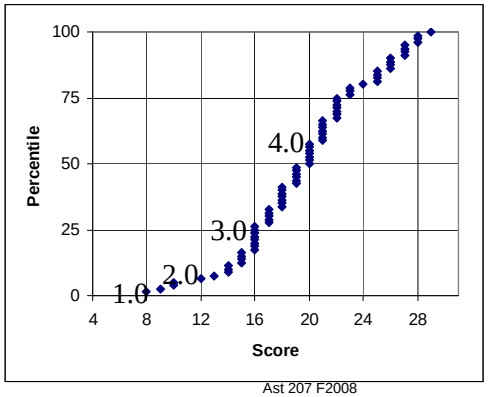
Weighing a Galaxy—31 Oct

- Change in syllabus
  - What are galaxies made of? (Today & next week)
  - Important events in the history of the universe
    - Formation of helium (Done)
    - Universe becomes unionized (Later)
    - Galaxies and stars form (Later)
- Wed, Nov 26: No class

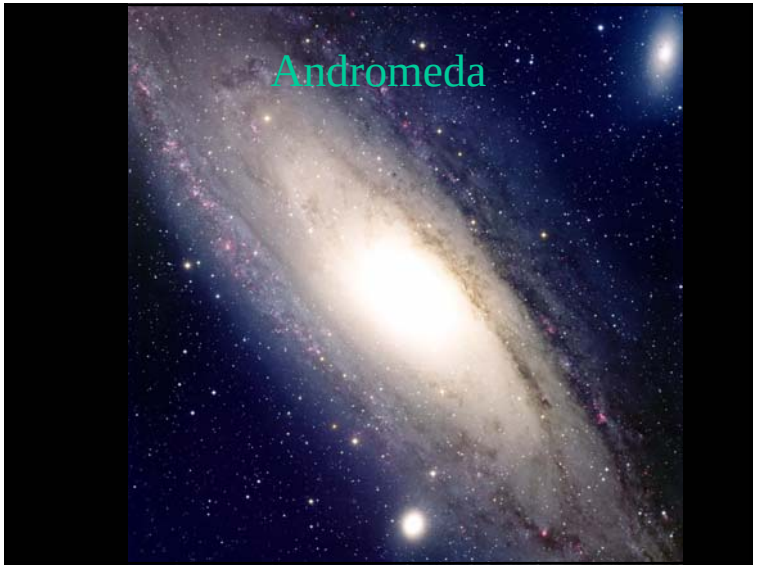
Test 2

Average on test 2: 19.7/31 = 64%

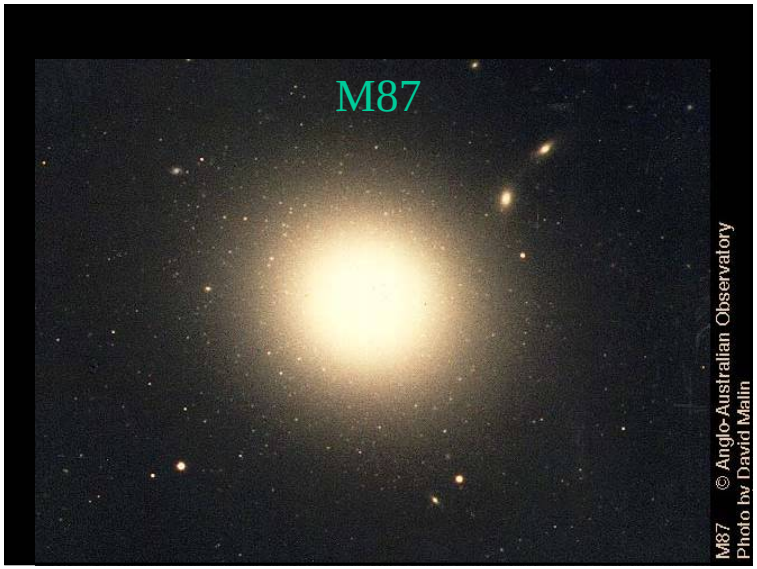
Average on test 1: 61%



Andromeda



Sombrero



Galaxies

- The Milky Way is our galaxy.
  - The sun is halfway from the center of the Milky Way.
  - We see the Milky Way as a band of light.
- Spiral galaxies are made of
  - billions of stars
  - gas
  - dust
  - dark matter
- The sky is covered by distant galaxies.

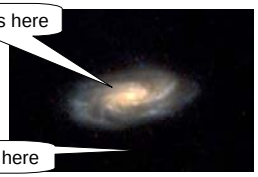
Ast 207 F2008

Weighing a Galaxy

- What is the mass of a galaxy?
  - Answer before 1974: Mass is that of stars & gas
  - Actual answer: Most mass is not that of star & gas
    - Most mass is dark
    - Dark mass is less concentrated.
- Today: How to measure mass

Fritz Zwicky 1898-1974
www.astrosurf.org/lombry/Images/zwickyf.jpg

Vera Rubin 1928-
cwp.library.ucla.edu/images/rubin.1.jpg



NGC 3672
www.astro.princeton.edu/~frei/Gcat_htm/Catalog/CJpeg/n3672.jpg

Weighing Eros

- Near Earth Rendezvous (NEAR) orbited the asteroid Eros (and landed). http://near.jhuapl.edu
- Eros
  - 20mi long, 8mi wide (size of Lansing)
- Gravity is 1000 times weaker
  - You can leap 1000 times farther
    - $\frac{1}{2}v^2 = g\ h$
  - Speed limit is 20mph
    - $v^2 = g\ R$
- On Earth, a ball dropped 1m takes 0.45s. How long would that take on Eros?
  - $\frac{1}{2}v^2 = g\ h$; $v = g\ t$; $t = (2h/g)^{1/2}$
  - $t = 0.45s\ (1000)^{1/2} = 14s$

1. How can you measure the mass of Eros with the satellite (without landing)?

Weighing the Sun

- To find mass of sun, measure period T & size R of a planet's orbit.
  - Kepler's 3rd Law
    $GM = 4\pi^2 R^3 / T^2$
  - $M = R^3 / T^2$ for R in AU, T in years, and M in solar masses.

2. Under influence of the gravity of the sun, a planet moves a given distance. If the time is short, the mass of the sun is
   A. greater.
   B. less.

Mass	Test object	Motion	Behavior if more massive
Sun	Earth	An orbit	
Eros			
Earth	A ball	Drops 1m	Time is shorter
Galaxy			

Weighing a Galaxy

- To find mass of sun, measure period T & size R of a planet's orbit.
  - Kepler's 3rd Law
    $GM = 4\pi^2 R^3 / T^2$
  - $M = R^3 / T^2$ for R in AU, T in years, and M in solar masses.

3. Under influence of the gravity of the sun, a planet moves a given distance. If the time is short, the mass is greater. Write an equivalent statement for the galaxy NGC 3672

Mass	Test object	Motion	Behavior if more massive
Sun	Earth	An orbit	Year is shorter
Eros			
Earth	A ball	Drops 1m	Time is shorter
Galaxy			

Use Doppler effect

- Kepler's Law needs modification since period of sun's motion around Milky Way is 200 Myr.

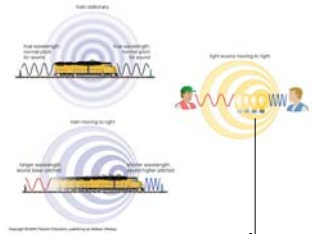
  Mass = $R^3 / T^2 = R (R/ T)^2$

  Mass = $R v^2$
- Doppler effect for measuring speed.
  - No need to wait to see motion.
  - Speed is imprinted in the light.

Most mass here.
not where stars are.

Doppler Effect: Measuring velocities

- Recall redshift & expansion of U
  - Wavelength changes b/c U expands
  - Wavelength changes if light source is moving
  - $v = c (\lambda_{received} / \lambda_{emitted} - 1)$
  - If motion is away (v>0),
    - $\lambda_{received} > \lambda_{emitted}$, redshift
  - If motion is toward (v<0),
    - $\lambda_{received} < \lambda_{emitted}$, blueshift
- Motion across line of sight cannot be measured with Doppler effect. Key idea.



Line of sight

Viewed from here,
λ unchanged.

Weighing using Doppler effect

- Measure period T & size R of a planet's orbit to find the mass M
  - Kepler's 3rd Law
  - $GM \propto 4\pi^2 R^3 / T^2$
  - $M= R^3 / T^2$ for R in AU, T in years, and M in solar masses.
    - $M \propto R v^2$
      - Measure velocity with Doppler effect. Useful in astronomy.
      - Periods of sun's orbit is 200Myr.
- Under influence of the gravity of a mass, a test object moves a given distance. If the time is short, the mass is greater.

1. Alien astronomers want to measure the mass of the sun using the Doppler effect of light emitted by Jupiter. If the mass of the sun is greater, they would measure a shift in wavelength.

   A. smaller
   B. bigger

Mass	Test object	Motion	Behavior if more massive
Sun	Earth	An orbit	Year is shorter
Eros			
Earth	A ball	Drops 1m	Time is shorter
Galaxy			