Galaxies

- Test 3 (New date)
  - Thurs, 9 April
  - One cheat sheet
  - Study guide & practice test
    - Link on syllabus
    - Add Jovian planets
    - Ignore neutron stars & black holes
  - Class of 3/26 (history of low and high-mass stars) is included.

- How do astronomers measure the mass of galaxies?
- Most of the mass of galaxies is "dark matter."
- What clue indicates the presence of newly formed stars?
- Other galaxies: Elliptical, spiral, & Irregular

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. A planet moves under influence of the gravity of the sun. The planet moves once around the sun in a specified orbit. If the time is short, the mass of the sun is
   A. greater.
   B. less.
3. Astronomers measure the mass of the sun by
   A. putting the sun on bathroom scales.
   B. measuring the motion of something that orbits it.
   C. figuring out how much gas is in the sun.

Mass	Test object	Motion	Behavior if more massive
Sun	Earth	An orbit	Period is shorter
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. A planet moves under influence of the gravity of the sun. The planet moves once around the sun in a specified orbit. If the time is short, the mass of the sun 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	A gas cloud		

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. A gas cloud moves under influence of the gravity of the galaxy. The gas cloud moves once around the galaxy in a specified orbit. If the time is short, the mass of the galaxy is greater. Write an equivalent statement for the galaxy NGC 3672

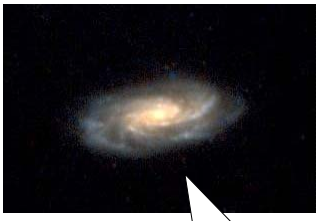
Mass	Test object	Motion	Behavior if more massive
Sun	Earth	An orbit	Year is shorter
Eros			
Earth	A ball	Drops 1m	Time is shorter
Galaxy	A gas cloud		

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.



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.
    - $M = R\ v^2$
      - Measure velocity with Doppler effect. Useful in astronomy.
      - Periods of sun's orbit is 200Myr.

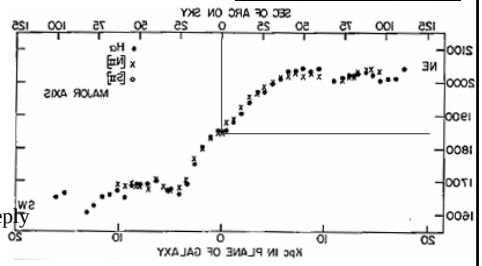
1. Alien astronomers want to measure the mass of the sun using the Doppler effect of light emitted by Jupiter. If the mass of the sun is greater, they would measure a ___ shift in wavelength.

   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	A gas cloud		

Dark Matter

- Vera Rubin & colleagues measured the speed of gas orbiting NGC3672.
- M(R) is mass enclosed within radius R.
- K's 3rd Law
  M(R) is proportional to v^2 R
- NGC3672
  - v(R) rises from 0 to 7 kpc.
  - v(R) is constant beyond 7kpc.
- Mass M(R).
  - Between center and 7 kpc, M(R) rises steeply because both v and R increase.
  - Between 7 & 16 kpc, M(R) rises linearly.
  - There is little light beyond 7 kpc.
  - **Where there is mass there is not necessarily light from stars & gas.**
  - Extrapolate M(R) is linear beyond visible part of galaxy.
- For the Milky Way Galaxy, this extrapolation was tested with satellites of Milky Way.
- **Surprising conclusion: Most of mass of galaxies is not in stars & gas.**



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

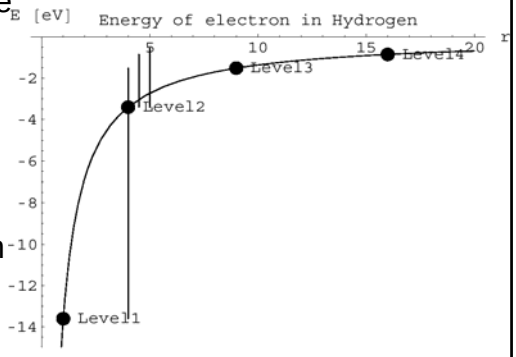
HII region—gas cloud with O stars

1. Which is the hottest star?
   A. G
   B. O
   C. F
   D. M
2. Which type of star has the shortest life?
3. Which type of star emits light with the most energy?

- Wein's Law: $\lambda_{peak}T$=const
- Energy of a photon is proportional to 1/λ.

Hydrogen

- Visible emission line of H
  - Red line is jump 3→2
  - Cyan line is jump 4→2
  - Blue line is jump 5→2
- In a cool cloud of hydrogen, the electrons are in level 1.
- If there is a nearby O star, there are lots of photons with enough energy to ionize hydrogen.
- Proton captures electron in a high energy level.
- Electron falls to a lower level.
- Falling from 3 to 2 causes red light to be emitted.
- Presence of red line of H indicates O stars.
  - Stars have been forming very recently. (O stars live only 20Myr.)



Other Galaxies

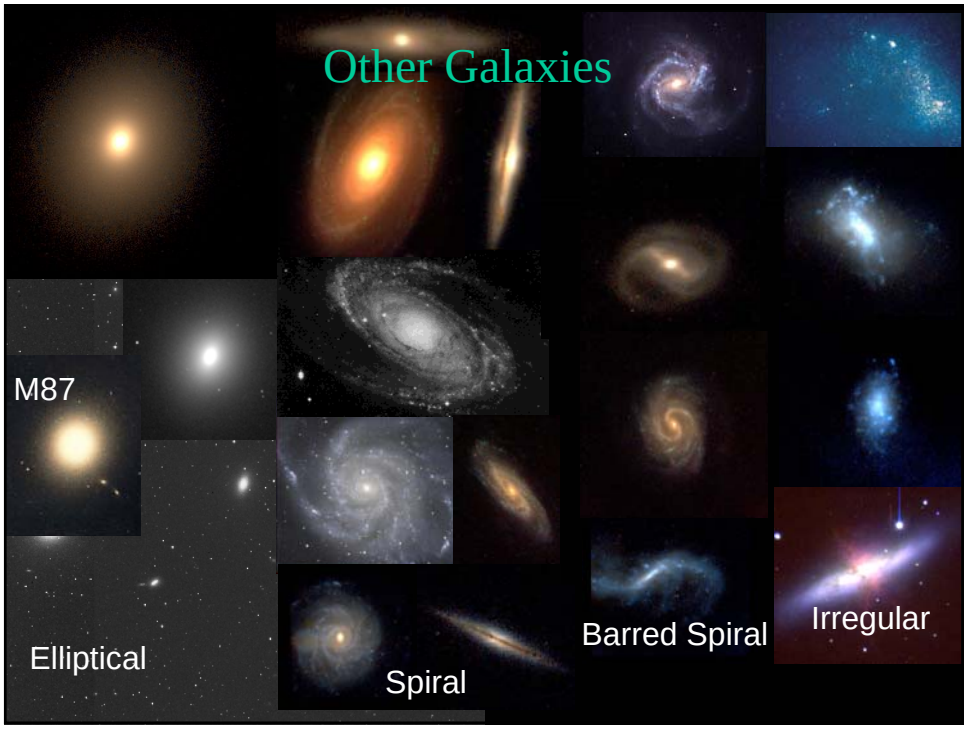
- Our Milky Way
  - Young stars, dust, & gas in disk. Circular orbits.
  - Old stars in halo. Elongated orbits
- How are other galaxies different from the Wilky Way?
  - Type of star? Gas? Dust?
  - Orbits
  - Dark matter
- How did M87, the central galaxy in the Virgo Cluster come to its present form?
  - History of galaxies

Elliptical

Spiral

Barred Spiral

Irregular



1. Which type of galaxies have no young stars?
   a. Elliptical
   b. Spiral
   c. Barred spiral
   d. Irregular
2. Which type of galaxy has the most gas?

- Stars form out of gas.
- For there to be O stars, there must have been gas 20 Myrs ago. (Compare to age of the sun, 4.5Byrs.)

Elliptical Galaxy: M87

- M87 in center of Virgo Cluster
- Virgo Cluster has hundreds of galaxies
- No gas
- No young stars
- No dust
- Halo
- Globular clusters
- Dark matter

M51: Spiral Galaxy

- Gas
- Young stars
- Dust
- Halo
- Globular clusters
- Dark matter

3. In this picture, what is evidence that this galaxy has young stars?
   a. Blue color
   b. Bright center
   c. Spiral structure
   d. Dark regions
   e. Red clouds

Large Magellanic Cloud: Irregular Galaxy

- Gas
- Young stars
- Dust
- Globular clusters
- Dark matter

4. In this picture, what is evidence that this galaxy has dark matter?
   a. Blue color
   b. Bright center
   c. Red clouds
   d. Dark regions
   e. None