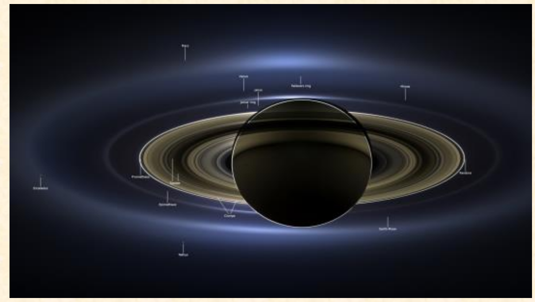
ASTR 1020: Stars & Galaxies

November 13, 2013

- Reading: Chapter 23, sections 23.1-23.2.
- *Mastering Astronomy* Homework on Galaxy Evolution is due Nov. 15th.

Astronomy Picture of the Day



On July 19, 2013, NASA's Cassini spacecraft slipped into Saturn's shadow and turned to image the planet, seven of its moons, its inner rings -- and, in the background, our home planet, Earth.

Reading Clicker Question: Which of the following is **not** true about dark matter?

A. Evidence for dark matter has been building for many decades.
B. Dark matter and dark energy are two aspects of the same phenomenon.
C. Dark matter is inferred based on unseen gravitational effects in galaxies.
D. Dark matter is the dominant source of gravity in the universe.

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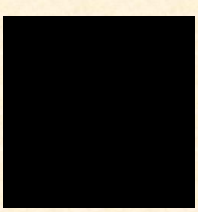
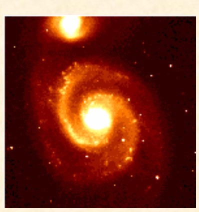
Today

- Chapter 22: Evidence for Dark Matter



Dark Matter



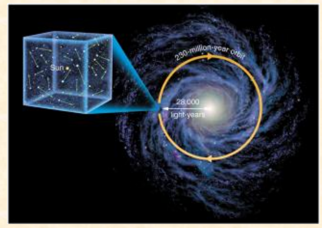
Not Dark Matter

The Case for Dark Matter

- Only ≈4% of the mass/energy of the Universe is baryonic (you and me). The rest is something dark.
- Dark matter is detectable ONLY via its gravitational forces on “light” matter (gas and stars)
- Note- this dark matter is NOT the same as black holes, brown/black dwarfs, or dust

Contents of Universe

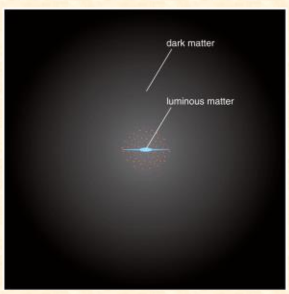
- "Ordinary" (baryonic) matter: ~ 4%
  - Ordinary matter inside stars: ~ 0.5%
  - Ordinary matter outside stars: ~ 3.5%
- Dark matter: ~ 23%
- Dark energy ~ 73%



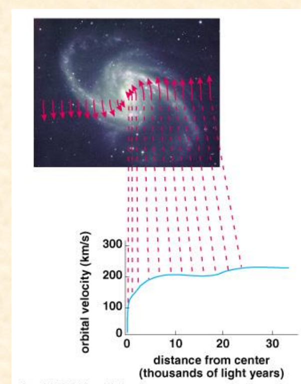
- Mass within the Sun's orbit: $1.0 \times 10^{11} M_{Sun}$
- Total mass: $\sim 10^{12} M_{Sun}$

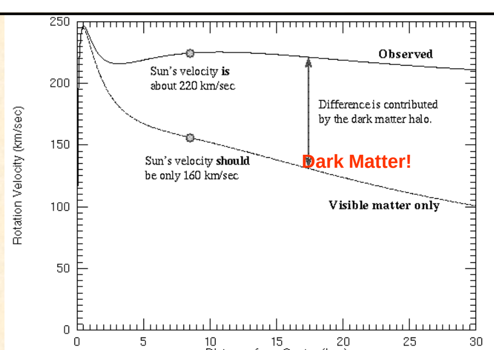
Evidence from Galaxies

- Rotation curves
- Motions of stars & gas in the Galaxy
- → dark matter extends beyond visible part of the galaxy, mass is 10x stars and gas



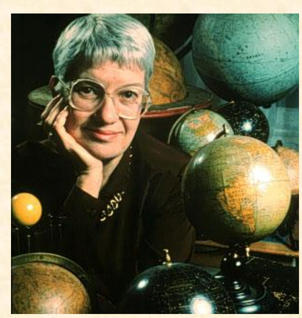
- "Flat rotation curves"
- High speeds far from the luminous center means that there is dark matter in the outer regions



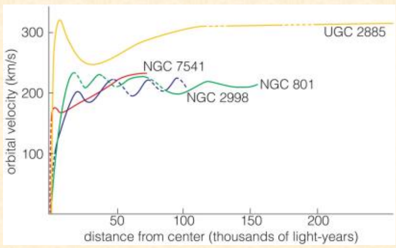


The gravity of the visible matter in the Galaxy is not enough to explain the high orbital speeds of stars in the Galaxy. For example, the Sun is moving about 60 km/sec too fast. The part of the rotation curve contributed by the visible matter only is the bottom curve. The discrepancy between the two curves is evidence for a **dark matter halo.**

- Discovered by Vera Rubin in the 1970's
- Highly controversial until many rotation curves were confirmed



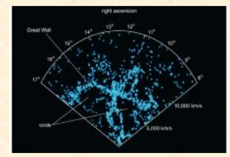
- Very little gas or stars at large radii → not much to measure
- Still don't know the extent of the dark matter
- Possibly outweigh stars by factor of 10!



How much dark matter IS there?

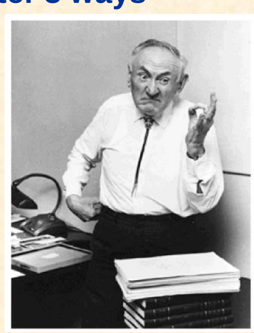
- Galaxies: difficult to see the full extent of dark matter because we run out of light matter to measure!

- Galaxy clusters: probably made by gravity pulling together galaxies and all nearby dark matter
  - A more representative measure of dark matter?



Galaxy Clusters: Dark Matter 3 ways

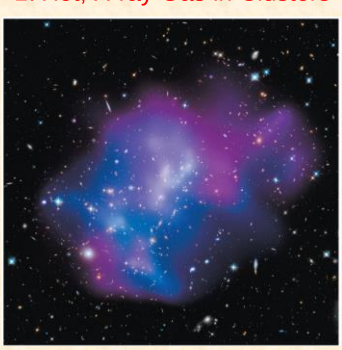
1. Galaxy Velocities



- Galaxy velocities within clusters are too large to be explained by gravity of the galaxies
- Expected 300 km/sec for a typical cluster, saw 1000 km/sec!
- First seen in 1930's by Fritz Zwicky (they didn't believe him, either)

- We can measure the velocities of galaxies in a cluster from their Doppler shifts.
- The mass we find from galaxy motions in a cluster is about ***50 times*** larger than the mass in stars!

2. Hot, X-ray Gas in Clusters



Clusters contain large amounts of X-ray emitting hot gas.

Temperature of hot gas ($10^{7\text{-}8}$ K) tells us cluster mass:

85% dark matter
13% hot gas
2% stars

- Temperature and concentration of the X-ray gas tell us the mass of the cluster:
  =>Hotter means more mass
- Also too much mass to be explained by the gas and galaxies!

Clicker Question

Galaxies in two galaxy clusters are studied. Cluster A has typical velocities of 300 km/sec, cluster B is 1000 km/sec. Which is most likely?

a) Cluster A has more galaxies than cluster B

b) Cluster A is more massive than cluster B

c) Gas between galaxies in cluster A will have a lower temperature than gas in cluster B

d) Cluster B galaxies are more likely to be spirals

- **C)**
  The lower velocities in “A” mean that there is less mass overall in that cluster. This probably means fewer galaxies. Less mass also means a cooler gas temperature

3. Gravitational Lenses

- Dark matter warps space → acts like a lens and distorts and magnifies the view of more distant galaxies