ASTR 1020: Stars & Galaxies

April 7, 2008

- Reading: Chapter 22, sections 22.3.
- *MasteringAstronomy* Homework on Dark Matter is due April 14th.
- Meet at Planetarium on Friday!
- Last midterm Exam next week – Wednesday, April 16th: Chapters 19.3-22.3.

Astronomy Picture of the Day

South of Orion

Credit & Copyright: Johannes Schedler (Panther Observatory)

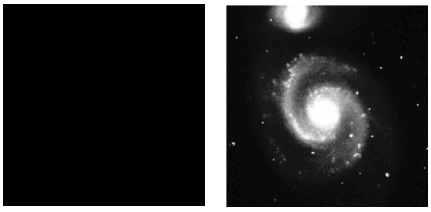
Explanation: This tantalizing array of nebulae and stars can be found about 2 degrees south of the famous star-forming Orion Nebula. The region abounds with energetic young stars producing jets and outflows that push through the surrounding material at speeds of hundreds of kilometers per *second*.

Hubble expansion within the solar system

- H = 70 km/sec/Mpc = 70 mm/sec/pc
  = 0.0003 mm/sec/AU,
  where 1 pc = 2.1 x 10^5 AU.
- Over 1 year, Hubble expansion distance is ΔD = 10.5 meters for Earth-Sun distance, or $\Delta D/D = 7 \times 10^{-11}$ (about 1 part in 10 billion!).

Today

- Chapter 22: Evidence for Dark Matter



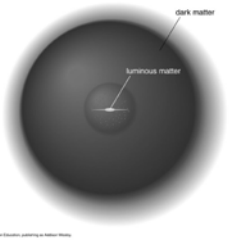
Dark Matter | Not Dark Matter

The Case for Dark Matter

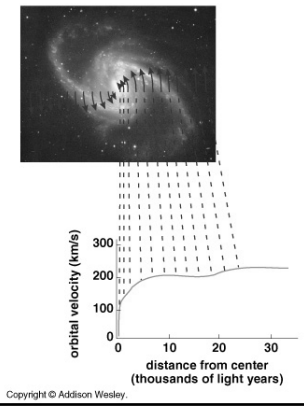
- > 90% of the mass of the Universe is dark (missing matter)
- Detectable ONLY via its gravitational forces on "light" matter (gas and stars)
- Note- this dark matter is NOT the same as black holes, brown/black dwarfs, or dust

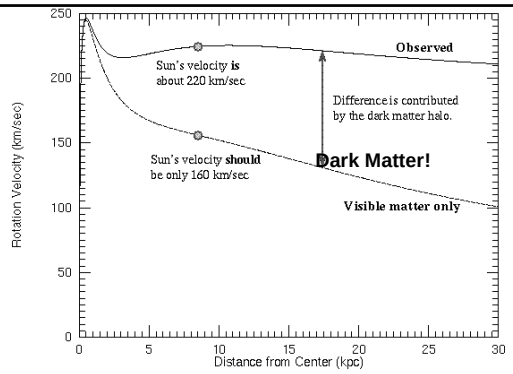
Evidence from Galaxies

- Rotation curves
- Motions of stars 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





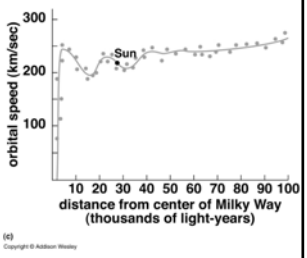
The gravity of the visible matter in the Galaxy is not enough to explain the high orbital speeds of stars in the Galaxy. For example, the Sun is moving about 60 km/sec too fast. The part of the rotation curve contributed by the visible matter only is the bottom curve. The discrepancy between the two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

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

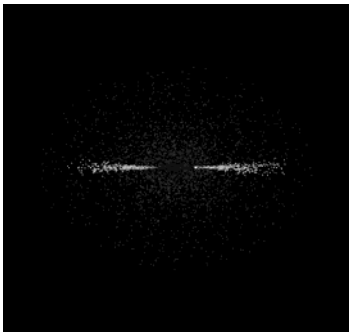
Very little gas or stars at large radii → not much to measure

Still don't know the extent of the dark matter

Possibly outweigh stars by factor of 10!

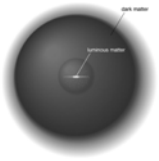


- Stars and gas are embedded in a much larger Dark Matter Halo??
- Don't know what dark matter is yet….

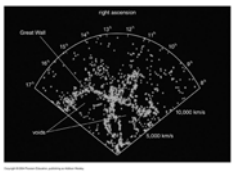


How much dark matter IS there?

- 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



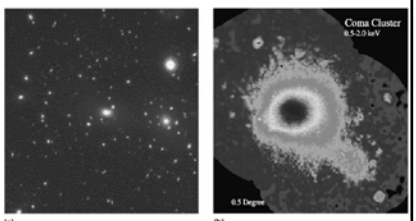
- A more representative measure of dark matter?

Galaxy Clusters: Dark Matter 3 ways

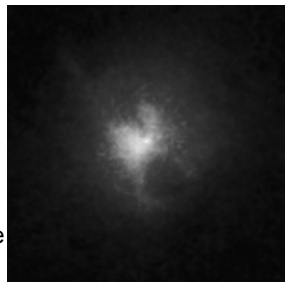
- Galaxy velocities within clusters are too large to be explained by gravity of the galaxies
- Expected 300 km/sec for a typical cluster, saw 1000 km/sec!
- First seen in 1930's by Fritz Zwicky (they didn't believe him, either)

Hot, X-ray emitted gas

- Gas in between galaxies is also moving because of the gravity of dark matter
- 1000 km/sec → 100 million degrees K
- Emits X-rays!



- 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

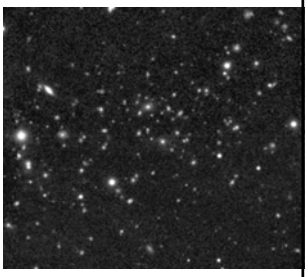
Galaxies in two galaxy clusters are studied. Cluster A has typical velocities of 300 km/sec, cluster B is 1000 km/sec. Which is most likely?

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

Gravitational Lenses

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