Announcements

- Webwork due on Wednesday!
- Group A: Last lab this week!
- Hopefully will hand back tests on Wednesday
- I'm pushing out new grade reports (with Test 3 results) today
- Polling: `rembold-class.ddns.net`

APOD!

Link to Video

Review Question

You observe two Type II Cepheid variable stars to have the same peak apparent brightness from Earth. Star A has a period of 5 days and Star B has a period of 10 days. Which star is further from the Earth?

A. Star A
B. Star B
C. They are the same distance
D. You can't say without knowing their temperatures

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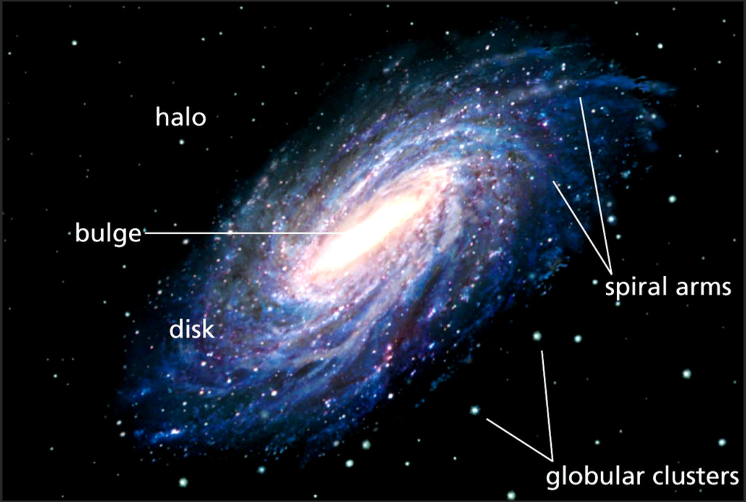

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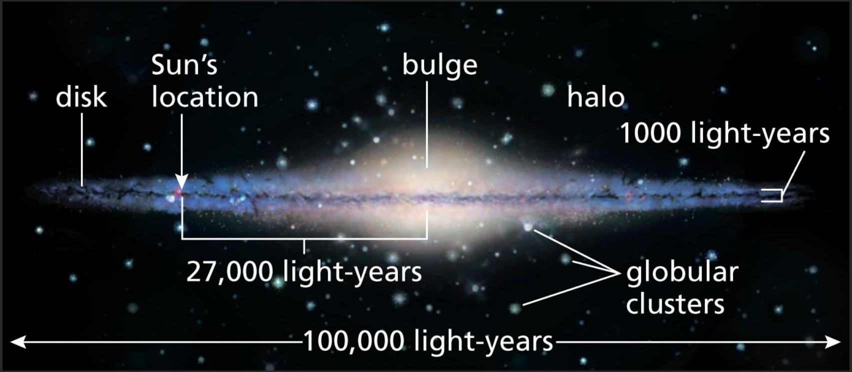
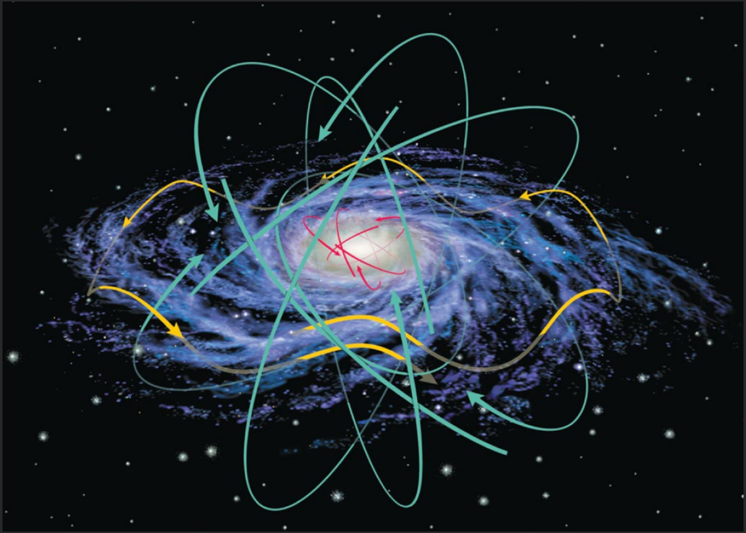


Orbital Paths



The Scales Don't Lie

- By observing nearby stars, we know that we orbit the center of the Milky Way at about 220 km/s
  - Gives an orbital period of about 230 million years
- We know the distance. We know the period.
  - Kepler's Third Law! (Newton's Form)
  - Gives a mass of about 2×10^{41} kg

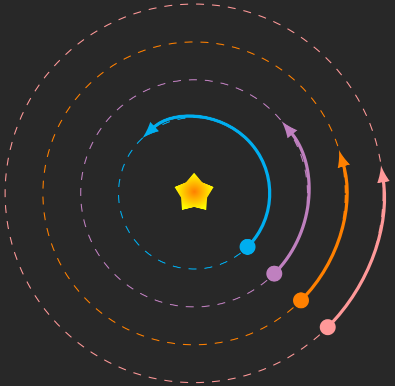
Calculation!

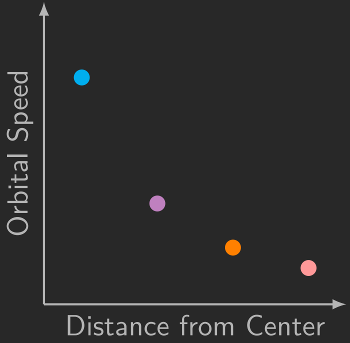
$$
\begin{aligned}
\frac{P^2}{a^3} &= \frac{4\pi^2}{GM} \\
\Rightarrow M &= \frac{4\pi^2 a^3}{GP^2} \\
&= \frac{4\pi^2 \left(2.6 \times 10^{20}\,\mathrm{m}\right)^3}{(6.67 \times 10^{-11})(7.258 \times 10^{15}\,\mathrm{s})} \\
&= 1.97 \times 10^{41}\,\mathrm{kg}
\end{aligned}
$$

Where is all the Mass?

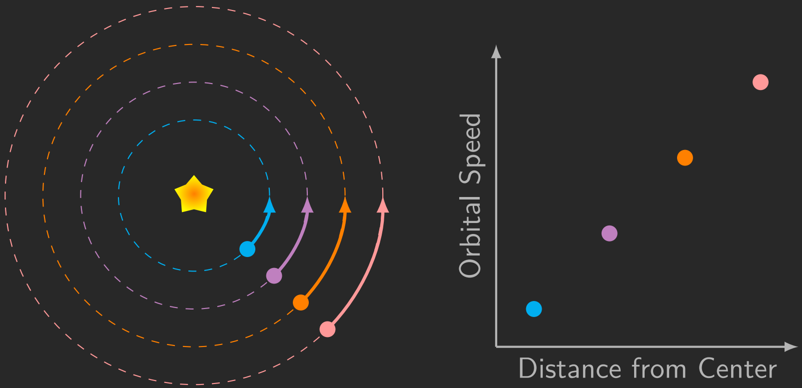
- Most of the mass we know of in the universe (or galaxy) is in stars
- Most of the stars are near the center of the galaxy
- Rotation curves tell us differently however!

Rotation Curves: Planets

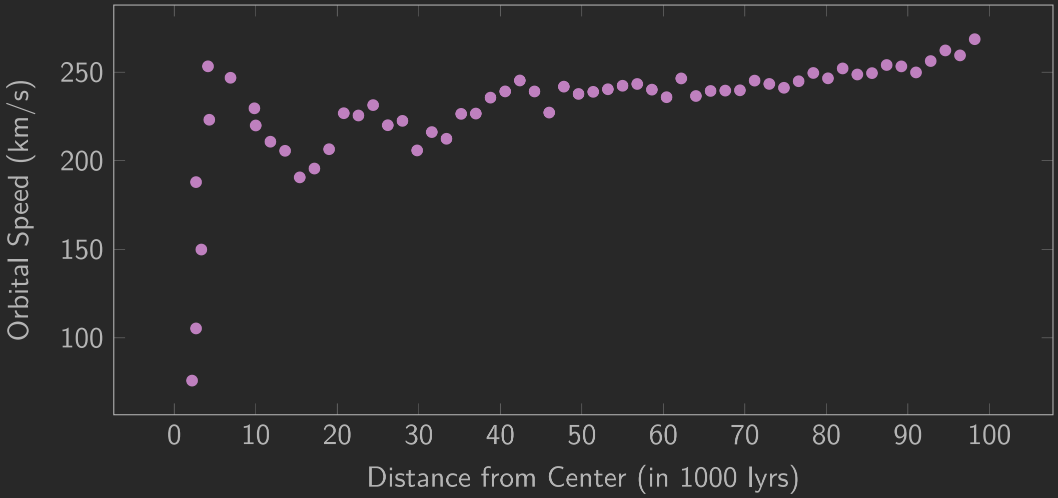




Rotation Curves: Wheel

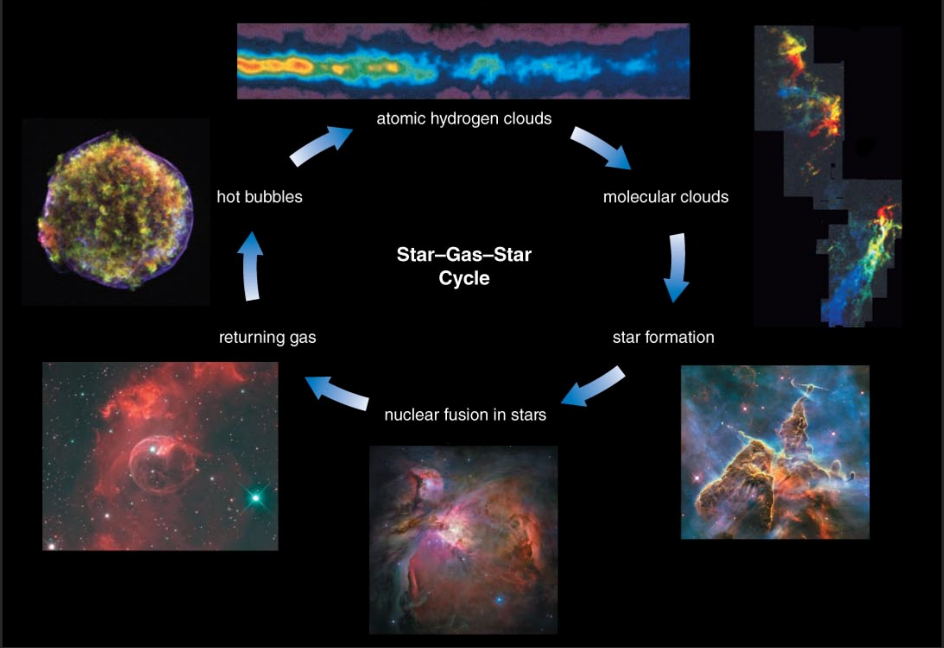


Rotation Curves: Milky Way



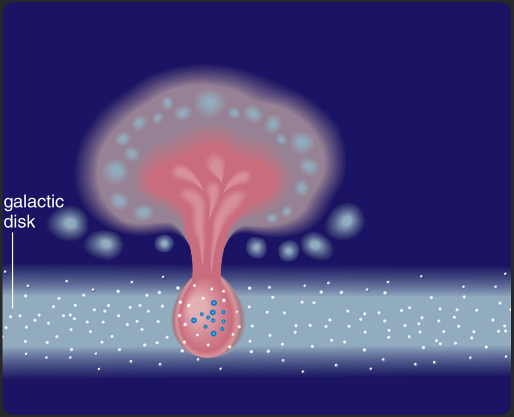
Conclusions

- The Milky Way as a whole contains:
  - 5-10 times as much mass as can be seen at any wavelength
  - Spread throughout the galaxy and beyond
- Decidedly does NOT have the mass concentrated in the center


atomic hydrogen clouds
molecular clouds
star formation
nuclear fusion in stars
returning gas
hot bubbles
Star–Gas–Star
Cycle

Reduce, Reuse, Recycle!

- We a pretty solid already with the star formation through lifetime side of things
- What about the backside of the cycle?
  - Mainly a question of cooling
    - High speed gas from star outflows or explosions sweeps up ISM
    - Creates hot bubbles
    - Cool as they expand and run into surrounding ISM
    - Possible to "blowout" of the galactic disk



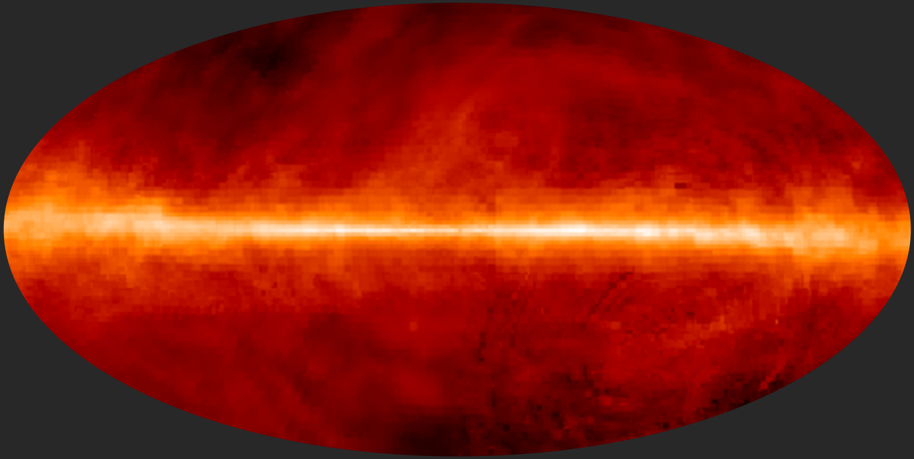
Atomic Hydrogen

- Further cooling causes the gas to become un-ionized
- Left with atomic hydrogen gas
  - Along with the normal mixture of helium and other trace elements
- Can “see” atomic hydrogen in Radio waves
- Gravity slows draws gas together into clumps
  - Radiate heat better, so they cool
  - Form molecular clouds
- And the process repeats!

Seeing the Star-Gas-Star Cycle

- Different wavelengths of light give us information on different points in the cycle!
  - 21 cm Radio – Shows atomic hydrogen gas
  - 1.3 mm Radio – Shows molecular gas
  - 90 µm Far Infrared – Shows dust
  - 2 µm Near Infrared – Shows stars
  - 650 nm Visible Light – Light emmitted and scattered
  - 1.6 nm X-Ray – Hot gas bubbles and X-Ray binaries
  - 10 pm Gamma Ray – Cosmic Ray collisions

Pretty Pictures!



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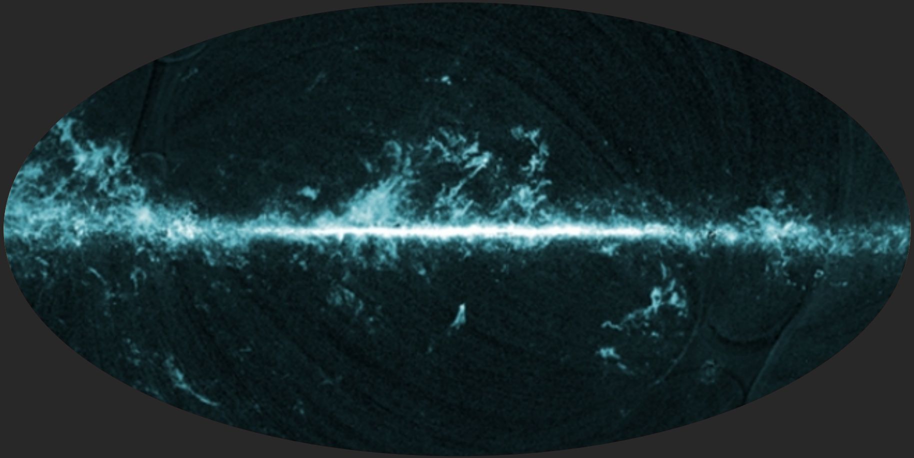
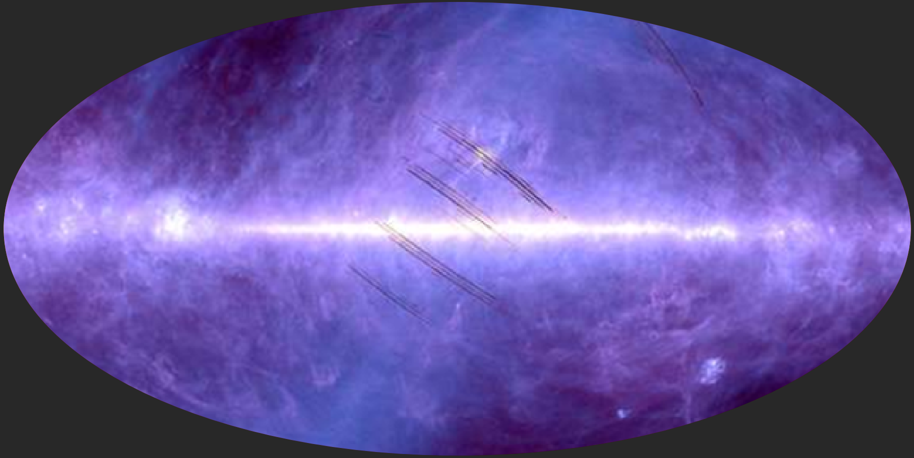


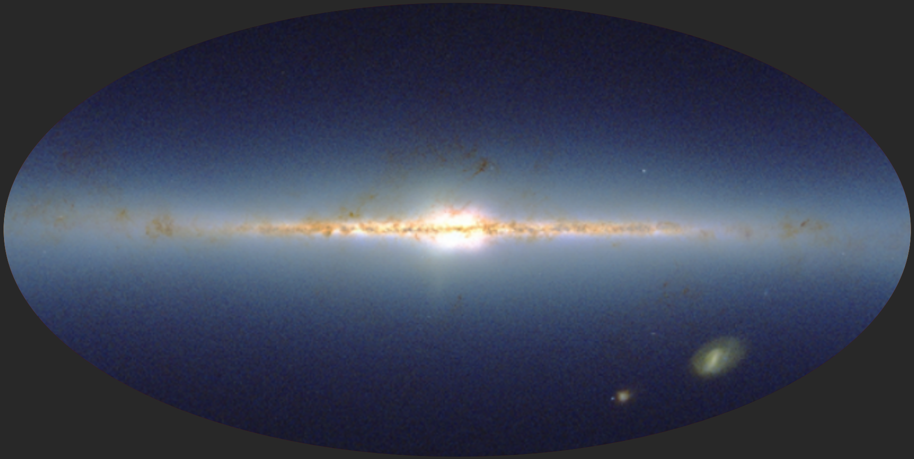
Molecular Clouds

Pretty Pictures!



Interstellar Dust

Pretty Pictures!

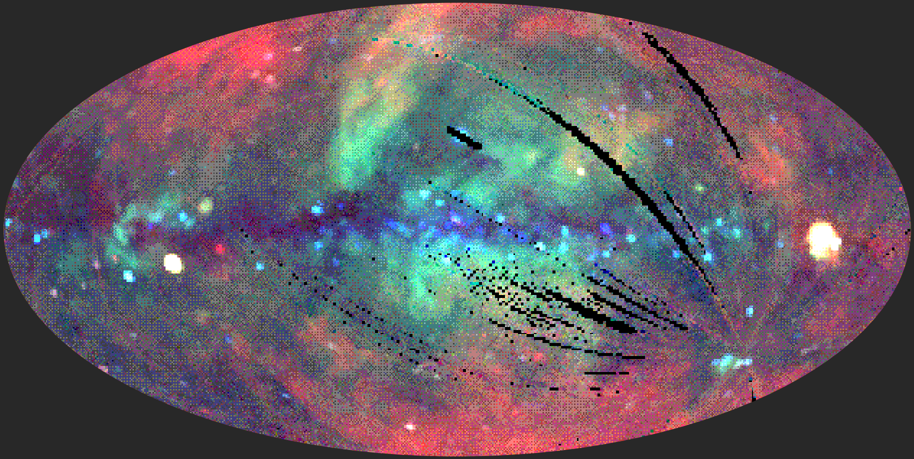


Stars!

Pretty Pictures!

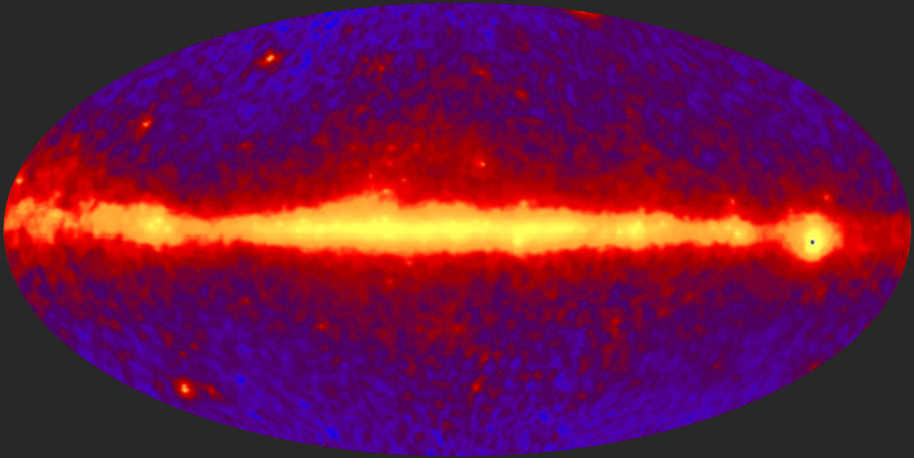
Our Visible View

Pretty Pictures!



Hot gases and X-ray binaries

Pretty Pictures!



Cosmic rays interacting with atomic nuclei

Phases of the ISM

Gas State	Primary Component	Temperature	Density (atoms per cm^3)	Description
Hot Bubbles	Ionized hydrogen	1 000 000 K	0.01	Pockets of gas heated by supernova shock waves
Warm Atomic Gas	Atomic hydrogen	10 000 K	1	Fills much of the galactic disk
Cool atomic clouds	Atomic hydrogen	100 K	100	Intermediate stage
Molecular clouds	Molecular hydrogen	30 K	300	Star forming regions

- So temperature decreases as the cloud cools (duh)
- Density increases as the cloud cools

Spiral Arms

- Bright blue regions indicate star forming regions
- Galaxy rotates at same speed, so inner bits have shorter periods
- If arms moved with stars, they would get all wound up!
- Spiral Density Waves
    - Pinches everything together in that region
    - Doesn't effect normal stars much
    - Gives molecular clouds a chance to start star formation

Regions of the Milky Way

- The Disk
  - Younger generation of stars
  - Contains gas and dust
  - Location of open clusters
- The Bulge
  - Mixture of young and old stars
- The Halo
  - Older generation of stars
  - Contains no gas or dust
  - Location of globular clusters