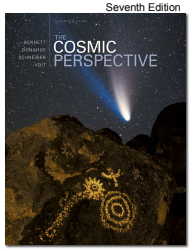
Chapter 19 Lecture

The Cosmic Perspective

Seventh Edition



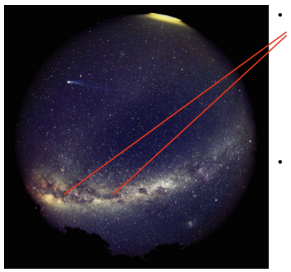
Our Galaxy

Our Galaxy

19.1 The Milky Way Revealed

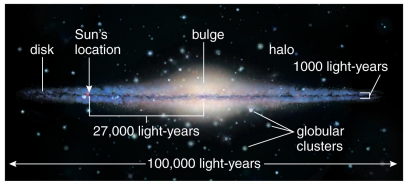
- Our goals for learning:
  - **What does our galaxy look like?**
  - **How do stars orbit in our galaxy?**

What does our galaxy look like?

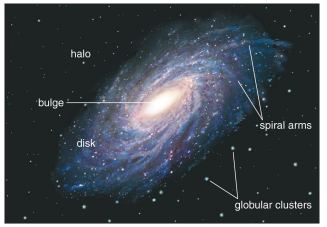


- Dusty gas clouds obscure our view because they absorb visible light.
- This is the ***interstellar medium*** that makes new star systems.

- All-Sky View

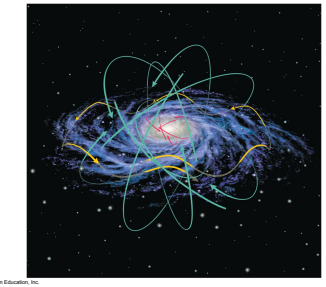


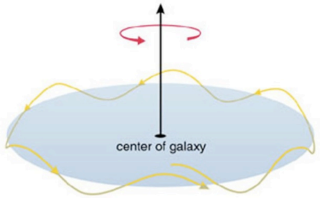
- We see our galaxy edge-on.
- Primary features: disk, bulge, halo, globular clusters



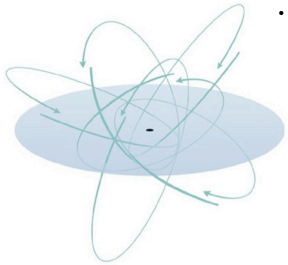
- If we could view the Milky Way from above the disk, we would see its spiral arms.

How do stars orbit in our galaxy?

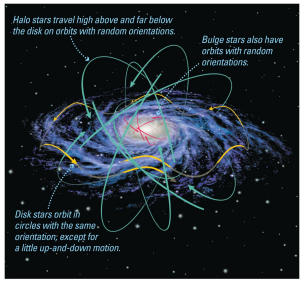




- Stars in the disk all orbit in the same direction with a little up-and-down motion.



- Orbits of stars in the bulge and halo have random orientations.



Thought Question

Why do orbits of bulge stars bob up and down?

A. They're stuck to interstellar medium.
B. Gravity of disk stars pulls them toward the disk.
C. Halo stars knock them back into the disk.

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- The Sun's orbital motion (radius and velocity) tells us the mass within Sun's orbit:

$1.0 \times 10^{11} M_{\text{Sun}}$

That is $1.9 \times 10^{41} kg!$

Or,
190,000,000,000,000,000,000,000,000,000,000,
000,000,000 kg.

Orbital Velocity Law

$$M_r = \frac{r \times v^2}{G}$$

- The orbital speed (v) and radius (r) of an object on a circular orbit around the galaxy tell us the mass (M_r) within that orbit.

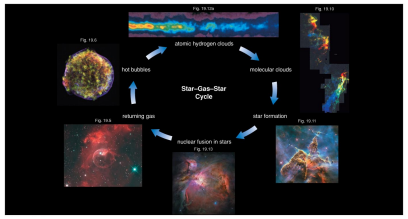
What have we learned?

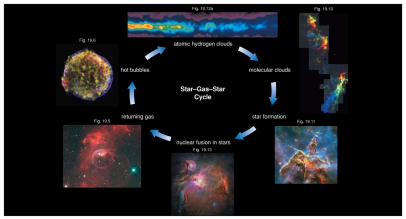
- **What does our galaxy look like?**
  - Our galaxy consists of a disk of stars and gas, with a bulge of stars at the center of the disk, surrounded by a large spherical halo.
- **How do stars orbit in our galaxy?**
  - Stars in the disk orbit in circles going in the same direction with a little up-and-down motion.
  - Orbits of halo and bulge stars have random orientations.

19.2 Galactic Recycling

- Our goals for learning:
  - **How is gas recycled in our galaxy?**
  - **Where do stars tend to form in our galaxy?**

How is gas recycled in our galaxy?

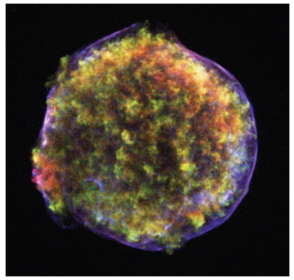




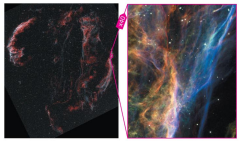
- ***Star–gas–star cycle***
- Recycles gas from old stars into new star systems.

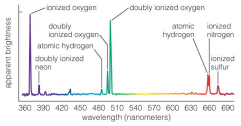
- High-mass stars have strong stellar winds that blow bubbles of hot gas.

- Lower mass stars return gas to interstellar space through stellar winds and planetary nebulae.

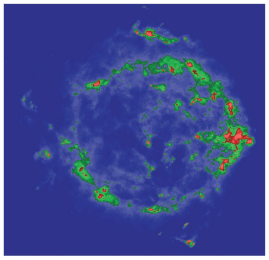


- X rays from hot gas in supernova remnants reveal newly made heavy elements.

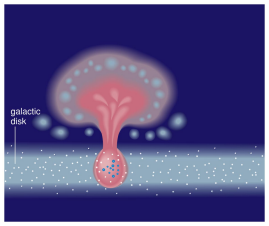




- A supernova remnant cools and begins to emit visible light as it expands.
- New elements made by a supernova mix into the interstellar medium.

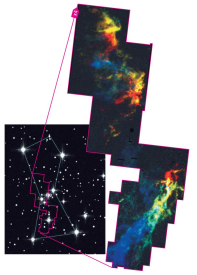


- Radio emission in supernova remnants is from particles accelerated to near light speed.
- Cosmic rays probably come from supernovae.

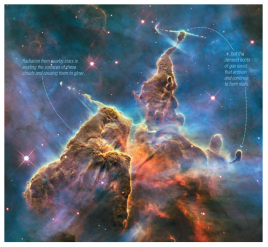


- Multiple supernovae create huge hot bubbles that can blow out of the disk.
- Gas clouds cooling in the halo can rain back down on the disk.

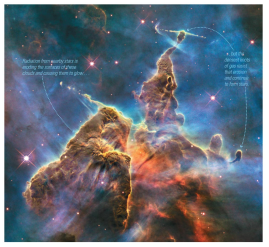
- ***Atomic hydrogen gas*** forms as hot gas cools, allowing electrons to join with protons.
- ***Molecular clouds*** form next, after gas cools enough to allow atoms to combine into molecules.



- Molecular clouds in Orion
- Composition:
  - Mostly H_2
  - About 28% He
  - About 1% CO
  - Many other molecules



- Gravity forms stars out of the gas in molecular clouds, completing the star–gas–star cycle.



- Radiation from newly formed stars is eroding these starforming clouds.

Summary of Galactic Recycling

Gas Cools

- Stars make new elements by fusion.
- Dying stars expel gas and new elements, producing hot bubbles (~10^6 K).
- Hot gas cools, allowing atomic hydrogen clouds to form (~100–10,000 K).
- Further cooling permits molecules to form, making molecular clouds (~30 K).
- Gravity forms new stars (and planets) in molecular clouds.

Thought Question

Where will the gas be in 1 trillion years?

A. blown out of galaxy
B. still recycling just like now
C. locked into white dwarfs and low-mass stars

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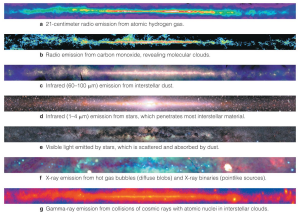
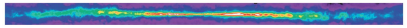


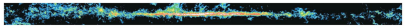
- We observe the star–gas–star cycle operating in Milky Way's disk using many different wavelengths of light.



Radio (atomic hydrogen)

Visible

- 21-cm radio waves emitted by atomic hydrogen show where gas has cooled and settled into disk.



Radio (CO)

Visible

- Radio waves from carbon monoxide (CO) show the locations of molecular clouds.

Infrared (dust)

Visible

- Long-wavelength infrared emission shows where young stars are heating dust grains.

Infrared

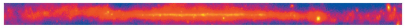
Visible

- Infrared light reveals stars whose visible light is blocked by gas clouds.

X-ray

Visible

- X rays are observed from hot gas above and below the Milky Way's disk.

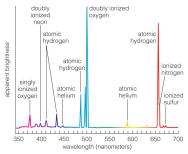


Gamma-ray

Visible

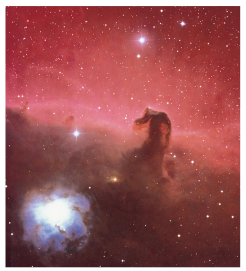
- Gamma rays show where cosmic rays from supernovae collide with atomic nuclei in gas clouds.

Where do stars tend to form in our galaxy?



- ***Ionization nebulae*** are found around short-lived high-mass stars, signifying active star formation.

- ***Reflection nebulae*** scatter the light from stars
- Why do reflection nebulae look bluer than the nearby stars?
- For the same reason that our sky is blue!

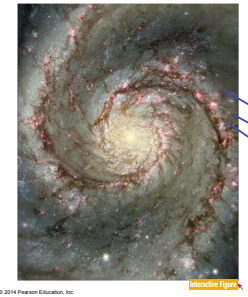


- What kinds of nebulae do you see in this photo?

Halo: no ionization nebulae, no blue stars
⇒ no star formation

Disk: ionization nebulae, blue stars ⇒ star formation

- Much of the star formation in the disk happens in the spiral arms.
- Whirlpool Galaxy

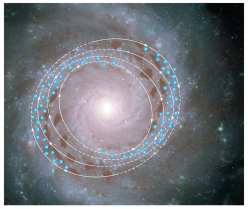


- Much of the star formation in the disk happens in the spiral arms.

Ionization nebulae
Blue stars
Gas clouds

- Whirlpool Galaxy

- Spiral arms are waves of star formation.



Spiral arms are waves of star formation.

1. Gas clouds get squeezed as they move into spiral arms.
2. Squeezing of clouds triggers star formation.
3. Young stars flow out of spiral arms.

What have we learned?

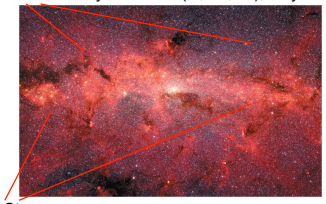
- **How is gas recycled in our galaxy?**
  - Gas from dying stars mixes new elements into the interstellar medium, which slowly cools, making the molecular clouds where stars form.
  - Those stars will eventually return much of their matter to interstellar space.
- **Where do stars tend to form in our galaxy?**
  - Active star-forming regions contain molecular clouds, hot stars, and ionization nebulae.
  - Much of the star formation in our galaxy happens in the spiral arms.

19.3 The History of the Milky Way

- Our goals for learning:
  - **What clues to our galaxy's history do halo stars hold?**
  - **How did our galaxy form?**

What clues to our galaxy's history do halo stars hold?

Halo Stars:
0.02–0.2% heavy elements (O, Fe, …), only old stars



Disk Stars:
2% heavy elements, stars of all ages

Halo Stars:
0.02–0.2% heavy elements (O, Fe, …), only old stars

- Halo stars formed first, then stopped.

Disk Stars:
2% heavy elements, stars of all ages

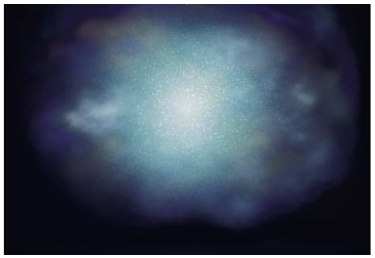
Halo Stars:
0.02–0.2% heavy elements (O, Fe, …), only old stars

- Halo stars formed first, then stopped.
- Disk stars formed later, kept forming.

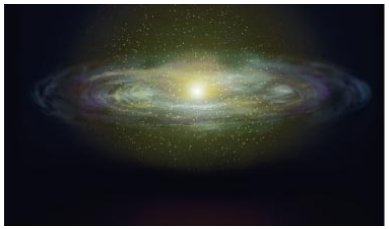
Disk Stars:
2% heavy elements, stars of all ages

How did our galaxy form?

- Our galaxy formed from a cloud of intergalactic gas.



- Halo stars formed first as gravity caused gas to contract.

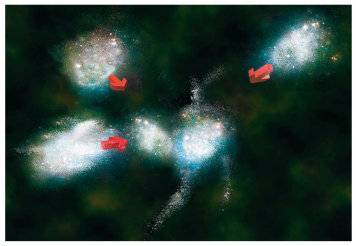


- Remaining gas settled into a spinning disk.

- Stars continuously form in disk as galaxy grows older.

Warning: This model is oversimplified!

- Stars continuously form in disk as galaxy grows older.



- Detailed studies show that halo stars formed in clumps that later merged.

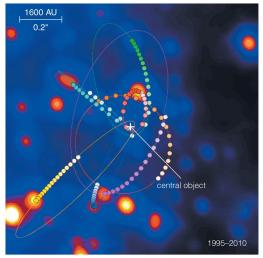
What have we learned?

- **What clues to our galaxy's history do halo stars hold?**
  - Halo stars are all old, with a smaller proportion of heavy elements than disk stars, indicating that the halo formed first.
- **How did our galaxy form?**
  - Halo stars formed early in the galaxy's history; disk stars formed later, after much of the galaxy's gas settled into a spinning disk.

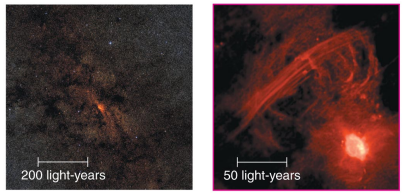
19.4 The Mysterious Galactic Center

- Our goals for learning:
  - **What lies in the center of our galaxy?**

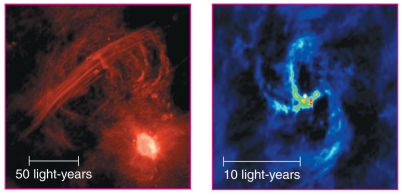
What lies in the center of our galaxy?



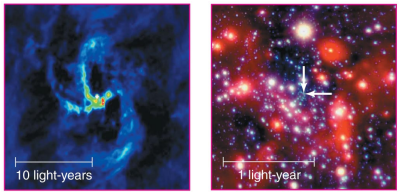
Infrared light from center | Radio emission from center

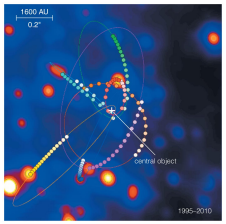


Radio emission from center | Swirling gas near center

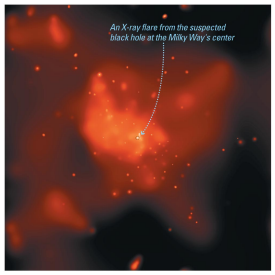


Swirling gas near center | Orbiting stars near center





- Stars appear to be orbiting something massive but invisible … ***a black hole?***
- Orbits of stars indicate a mass of about 4 million M_{Sun}.



- X-ray flares from galactic center suggest that tidal forces of suspected black hole occasionally tear apart chunks of matter about to fall in.

What have we learned?

- **What lies in the center of our galaxy?**
  - Orbits of stars near the center of our galaxy indicate that it contains a black hole with 4 million times the mass of the Sun.