Chapter 19
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?

Dusty gas clouds obscure our view because they absorb visible light

This is the ***interstellar medium*** that makes new star systems

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

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

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

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

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 tells 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?

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

Supernova remnant cools and begins to emit visible light as it expands

New elements made by supernova mix into 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 disk

Gas clouds cooling in the halo can rain back down on 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 to 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 star-forming 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

Interactive Figure

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

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

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

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

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

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

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

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?

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!

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

Disk: Ionization nebulae, blue stars ⇒ star formation

Much of star formation in disk happens in spiral arms

Ionization Nebulae
Blue Stars
Gas Clouds

Whirlpool Galaxy

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?

Halo Stars:

Halo stars formed first, then stopped

Disk Stars:

Disk stars formed later, kept forming

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?
  - Our galaxy formed from a huge cloud of gas, with the halo stars forming first and the disk stars forming later, after the gas settled into a spinning disk

19.4 The Mysterious Galactic Center

Our goals for learning

- What lies in the center of our galaxy?

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Stars appear to be orbiting something massive but invisible … ***a black hole?***

Orbits of stars indicate a mass of about 4 million M_{Sun}

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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