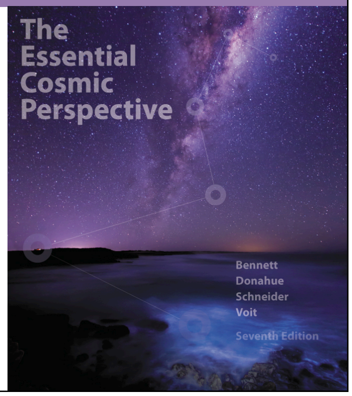
Lecture Outline

Chapter 15: Our Galaxy

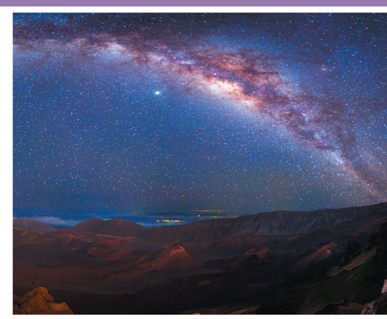


15.1 The Milky Way Revealed

Our goals for learning:

- What does our galaxy look like?
- How do stars orbit in our galaxy?

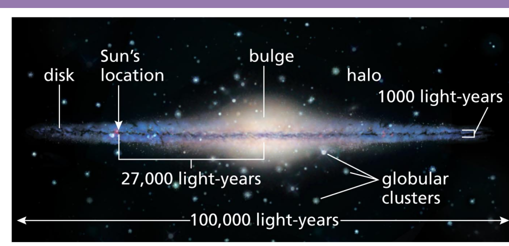
•What does our galaxy look like?



The Milky Way Galaxy appears in our sky as a faint band of light.

Dusty gas clouds obscure our view because they absorb visible light.

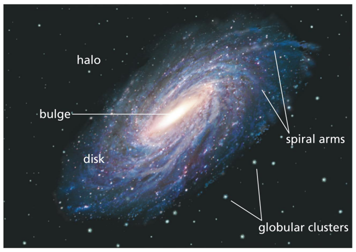
This is the ***interstellar medium*** that makes new star systems.



b Edge-on schematic view of the Milky Way.

We see our galaxy edge-on.

Primary features: disk, bulge, halo, globular clusters

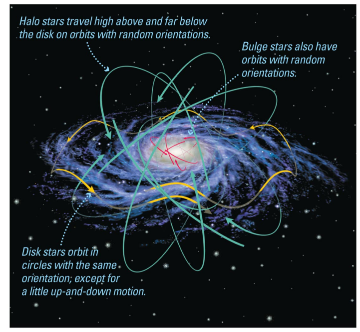


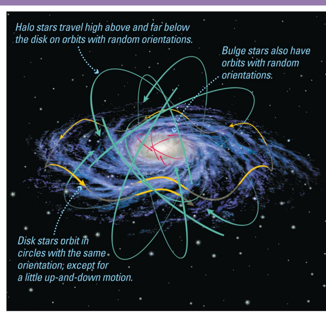
a Artist's conception of the Milky Way viewed from the outside.

MA INTERACTIVE FIGURE

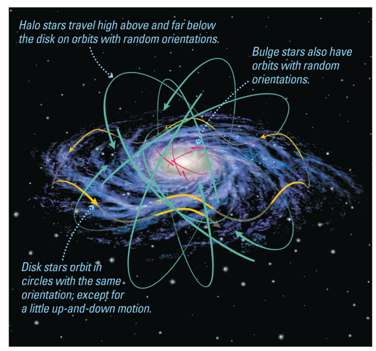
If we could view the Milky Way from above the disk, we would see its spiral arms.

•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 the interstellar medium.
B. The gravity of disk stars pulls them toward the disk.
C. Halo stars knock them back into the disk.

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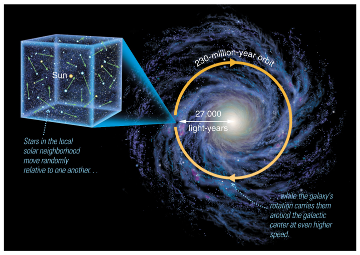


Sun's orbital motion (radius and velocity) tells us mass within Sun's orbit:

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

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 tell us the mass (M_r) within that orbit.

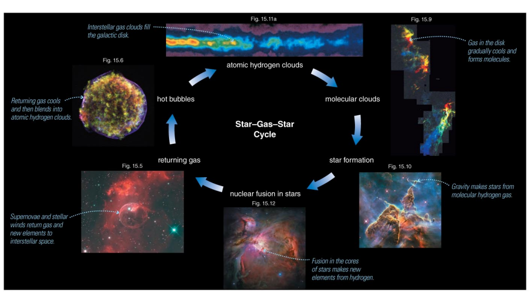
What have we learned?

- 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.

15.2 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?



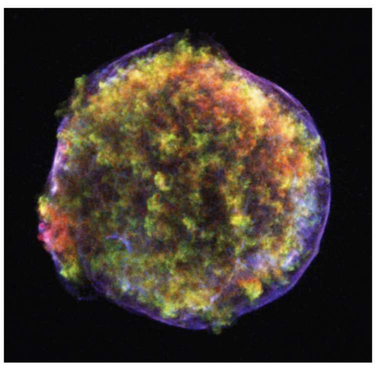
Star–gas–star cycle

Recycles gas from old stars into new star systems.

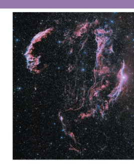
MA INTERACTIVE FIGURE

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.

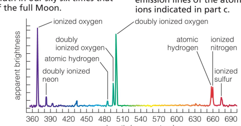


X rays from hot gas in supernova remnants reveal newly made heavy elements.



a This visible-light image shows the entire supernova remnant, which is about 130 light-years across and spans an angular width in our sky six times that of the full Moon.

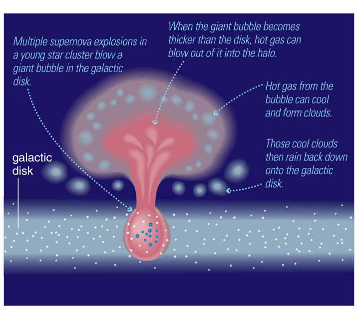
b This Hubble Space Telescope image shows fine filamentary structure in a small piece of the remnant. The colors come from emission lines of the atoms and ions indicated in part c.



c A visible-light spectrum from the Cygnus Loop shows the strong emission lines that account for the distinct colors in the Hubble Space Telescope image.

A supernova remnant cools and begins to emit visible light as it expands.

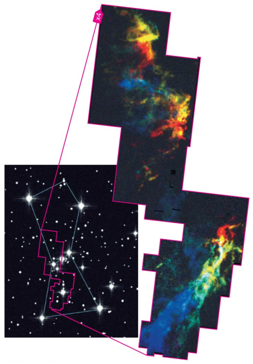
New elements made by supernova mix into interstellar medium.



Multiple supernovae create huge hot bubbles that can blow out of disk.

Gas clouds cooling in the halo can rain back down on disk.

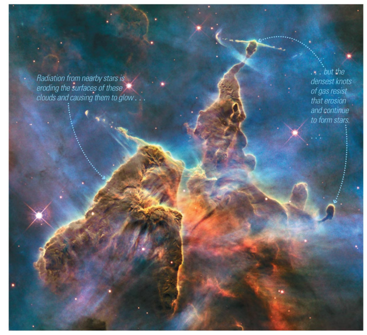
- ***Atomic hydrogen (H_2) gas*** forms as hot gas cools, allowing electrons to join with protons.
- ***Molecular clouds*** form next, after gas cools enough to allow atoms to combine into molecules.



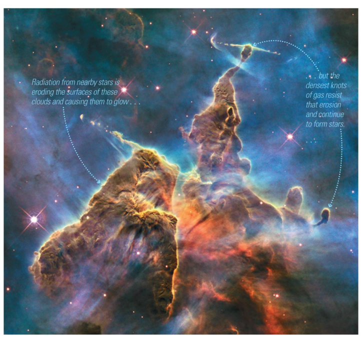
Molecular clouds in Orion

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 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.

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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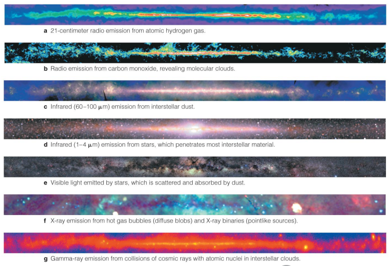
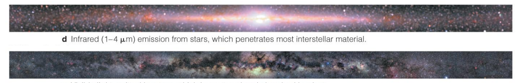
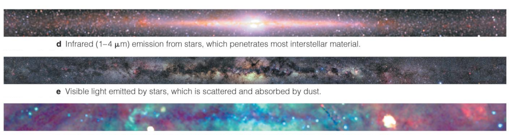


MA INTERACTIVE FIGURE

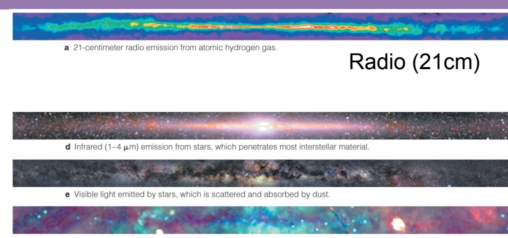
We observe the star–gas–star cycle operating in Milky Way's disk using many different wavelengths of light.



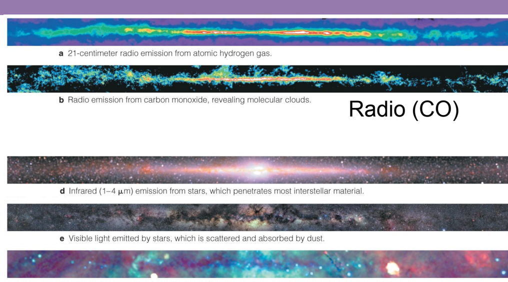
Infrared light reveals stars whose visible light is blocked by gas clouds.



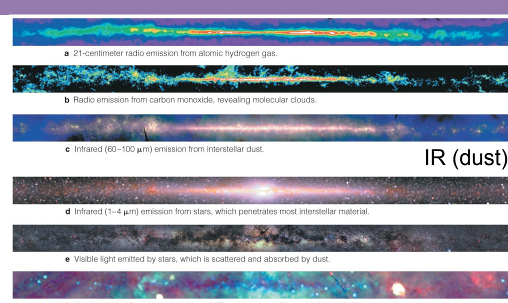
X rays are observed from hot gas above and below the Milky Way's disk.



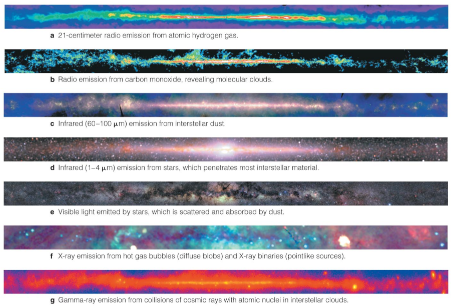
21-cm radio waves emitted by atomic hydrogen show where gas has cooled and settled into disk.



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

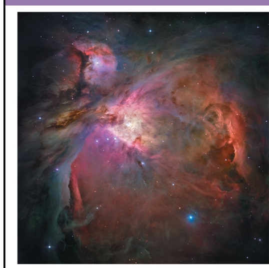


Long-wavelength infrared emission shows where young stars are heating dust grains.

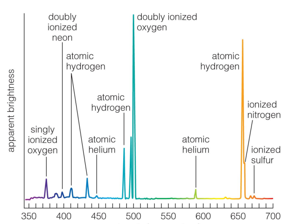


Gamma rays show where cosmic rays from supernovae collide with atomic nuclei in gas clouds.

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?

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?

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.

Whirlpool Galaxy

Much of star formation in disk happens in spiral arms.

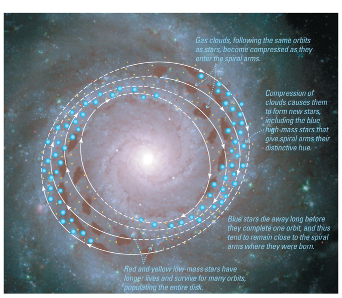
Ionization nebulae
Blue stars
Gas clouds

PLAY Spiral Arms

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. The squeezing of clouds triggers star formation.
3. Young stars flow out of spiral arms.

What have we learned?

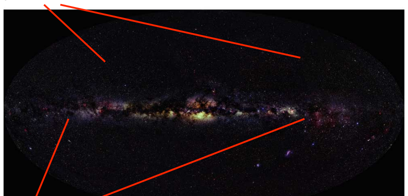
- How is gas recycled in our galaxy?
  - Gas from dying stars mixes new elements into the interstellar medium, which slowly cools, making the molecular clouds where stars form.
  - Those stars will eventually return much of their matter to interstellar space.
- Where do stars tend to form in our galaxy?
  - 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.

15.3 The History of the Milky Way

Our goals for learning:
- What do halo stars tell us about our galaxy's history?
- How did our galaxy form?

What do halo stars tell us about our galaxy's history?

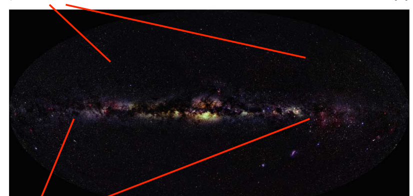
Halo Stars:
0.02–0.2% heavy elements (O, Fe, …), only old stars



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.



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Disk Stars:
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Disk stars formed later, and kept forming.

Halo Stars:
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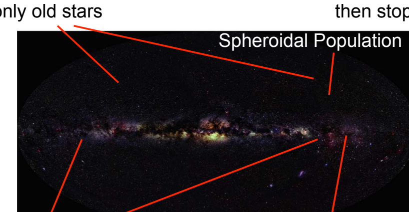
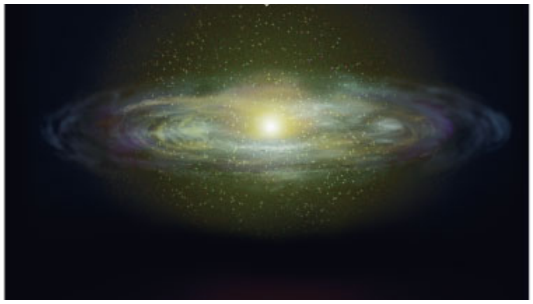
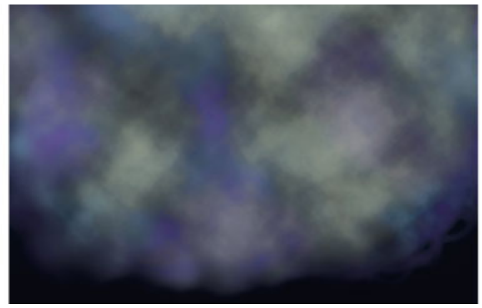


Disk Stars:
2% heavy elements, stars of all ages

Disk Population:
Disk stars formed later, and kept forming.

How did our galaxy form?





Our galaxy probably formed from a giant gas cloud.

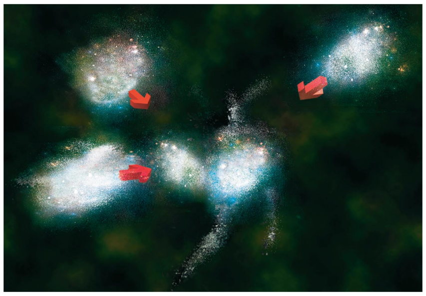
Halo stars formed first as gravity caused the cloud to contract.

The remaining gas settled into a spinning disk.

Stars continuously form in the disk as the galaxy grows older.

Warning: This model is oversimplified.

Stars continuously form in the disk as the galaxy grows older.



Detailed studies: Halo stars formed in clumps that later merged.

What have we learned?

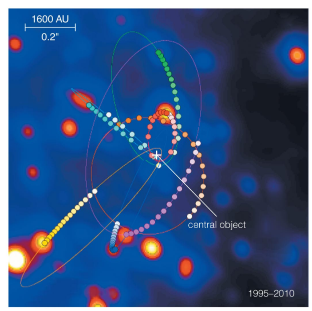
- What do halo stars tell us about our galaxy's history?
  - Halo stars are all old, with a smaller proportion of heavy elements than disk stars, indicating that the halo formed first.
- How did our galaxy form?
  - Our galaxy formed from a huge cloud of gas, with the halo stars forming first and the disk stars forming later, after the gas settled into a spinning disk.

15.4 The Galactic Center

Our goals for learning:

- What is the evidence for a black hole at our galaxy's center?

What is the evidence for a black hole at our galaxy's center?



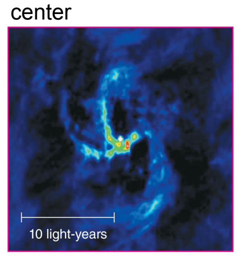
Infrared light from center

a This infrared image shows stars and gas clouds within 1000 light-years of the center of the Milky Way.

Radio emission from center

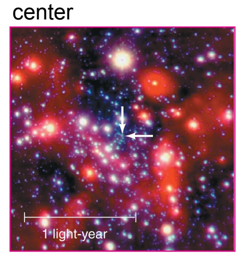
b This radio image shows vast threads of emission tracing magnetic field lines near the galactic center.

Radio emission from center



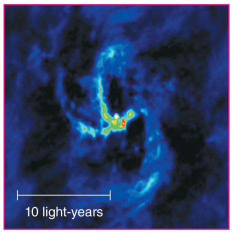
c This radio image zooms in on gas swirling around the radio source Sgr A* (marked by the white dot), suspected to contain a very massive black hole.

Swirling gas near center



d This infrared image shows stars within about 1 light-year of Sgr A*. The two arrows point to the precise location of Sgr A*.

Swirling gas near center



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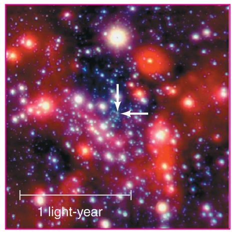
Orbiting stars near center



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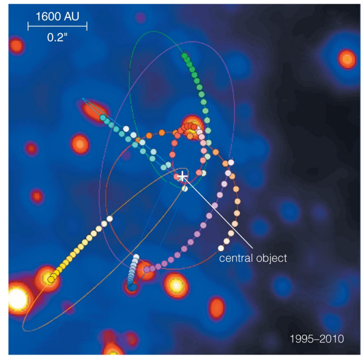
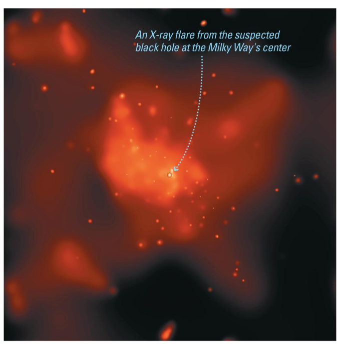


Stars appear to be orbiting something massive but invisible …

a black hole?

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



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 is the evidence for a black hole at our galaxy's center?
  - 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.