Assignments

• For Mon. Oct. 26:
  – **Read Ch. 13 + Do** Online Exercise 10 ("H-R Diagram" tutorial)
Stellar Properties Review

**Luminosity:** from brightness and distance

\[(0.08 M_{\text{Sun}}) \times 10^{-4} L_{\text{Sun}} - 10^6 L_{\text{Sun}} (100 M_{\text{Sun}})\]

**Temperature:** from color and spectral type

\[(0.08 M_{\text{Sun}}) \times 3000 \text{ K} - 50,000 \text{ K} (100 M_{\text{Sun}})\]

**Mass:** from period \((p)\) and average separation \((a)\) of binary-star orbit

\[0.08 M_{\text{Sun}} - 100 M_{\text{Sun}}\]
What is the minimum mass of a star?

A. 0.001 times the mass of the Sun
B. 0.03 times the mass of the Sun
C. 0.08 times the mass of the Sun
D. 0.2 times the mass of the Sun
E. 0.5 times the mass of the Sun
What is the minimum mass of a star?

A. 0.001 times the mass of the Sun
B. 0.03 times the mass of the Sun
C. 0.08 times the mass of the Sun
D. 0.2 times the mass of the Sun
E. 0.5 times the mass of the Sun
About how massive are the most massive stars?

A. 18 times the mass of the Sun
B. 30 times the mass of the Sun
C. 50 times the mass of the Sun
D. 200 times the mass of the Sun
E. 1000 times the mass of the Sun
About how massive are the most massive stars?

A. 18 times the mass of the Sun
B. 30 times the mass of the Sun
C. 50 times the mass of the Sun
D. 200 times the mass of the Sun
E. 1000 times the mass of the Sun
Luminosity-Mass for main sequence stars

\[ \frac{L}{L_{\text{Sun}}} \approx \left( \frac{M}{M_{\text{Sun}}} \right)^3 \]

e.g. if \( M = 10 M_{\text{Sun}} \)

\[ L = 10^3 L_{\text{Sun}} \]
Sun's life expectancy: 10 billion years

Life expectancy of a $10M_{\odot}$ star:

10 times as much fuel, uses it $10^3$ times as fast

100 million years $\sim$ 10 billion years $\times 10/10^3$

Life expectancy of a $0.1M_{\odot}$ star:

0.1 times as much fuel, uses it 0.001 times as fast

1000 billion years $\sim$ 10 billion years $\times 0.1/0.001$
Main-sequence lifetime

\[ \frac{t}{t_{\text{sun}}} = \frac{M/M_{\text{sun}}}{L/L_{\text{sun}}} \]

\[ = \left( \frac{M/M_{\text{sun}}}{L/L_{\text{sun}}} \right)^3 \]

\[ \frac{t}{t_{\text{sun}}} = \left( \frac{M_{\text{sun}}}{M} \right)^2 \]
Main-Sequence Star Summary

High-mass:
- High luminosity
- Short-lived
- Large radius
- Blue

Low-mass:
- Low luminosity
- Long-lived
- Small radius
- Red
12.3 Star Clusters

Our goals for learning:

• What are the two types of star clusters?
• How do we measure the age of a star cluster?
What are the two types of star clusters?
Open cluster: A few thousand loosely packed stars
**Globular cluster:** Up to a million or more stars in a dense ball bound together by gravity
How do we measure the age of a star cluster?
The main-sequence turnoff point of a cluster tells us its age.
Detailed modeling of the oldest globular clusters reveals that they are about 13 billion years old.
Chapter 13: Star Stuff
How do stars form?

Newborn stars produce white patches in the cloud where starlight illuminates surrounding gas.

The cloud looks dark where dust particles block the light from more distant stars.
Star-Forming Clouds

- Stars form in dark clouds of dusty gas in interstellar space.
- The gas between the stars is called the interstellar medium.
Gravity Versus Pressure

- Gravity can create stars only if it can overcome the force of thermal pressure in a cloud.
- Gravity within a contracting gas cloud becomes stronger as the gas becomes denser.
Mass of a Star-Forming Cloud

• A typical molecular cloud ($T \sim 30$ K, $n \sim 300$ particles/cm$^3$) must contain at least a few hundred solar masses for gravity to overcome pressure.

• The cloud can prevent a pressure buildup by converting thermal energy into infrared and radio photons that escape the cloud.
Fragmentation of a Cloud

- This simulation begins with a turbulent cloud containing 50 solar masses of gas.

The simulation begins with a turbulent gas cloud 1.2 light-years across, containing $50M_{\text{Sun}}$ of gas.
Fragmentation of a Cloud

- The random motions of different sections of the cloud cause it to become lumpy.

Random motions in the cloud cause it to become lumpy, with some regions denser than others. If gravity can overcome pressure in these dense regions, they can collapse to form even denser lumps of matter.
Fragmentation of a Cloud

- Each lump of the cloud in which gravity can overcome pressure can go on to become a star.
- A large cloud can make a whole cluster of stars.

The large cloud therefore fragments into many smaller lumps of matter, and each lump can go on to form one or more new stars.
Glowing Dust Grains

- As stars begin to form, dust grains that absorb visible light heat up and emit infrared light.
- In visible light, as in this image, the star forming regions still appear dark.

This visible-light image from the Hubble Space Telescope shows part of the Eagle Nebula, a gas cloud in which stars are currently forming.
Glowing Dust Grains

• Long-wavelength infrared light is brightest from regions where many stars are currently forming.
Thought Question

What would happen to a contracting cloud fragment if it were not able to radiate away its thermal energy?
A. It would continue contracting, but its temperature would not change.
B. Its mass would increase.
C. Its internal pressure would increase.
Thought Question

What would happen to a contracting cloud fragment if it were not able to radiate away its thermal energy?

A. It would continue contracting, but its temperature would not change.
B. Its mass would increase.
C. Its internal pressure would increase.
Solar system formation is a good example of star birth.

The original cloud is large and diffuse, and its rotation is imperceptibly slow. The cloud begins to collapse.

Because of conservation of energy, the cloud heats up as it collapses. Because of conservation of angular momentum, the cloud spins faster as it contracts.
Cloud heats up as gravity causes it to contract due to **conservation of energy**. Contraction can continue if thermal energy is radiated away.

The original cloud is large and diffuse, and its rotation is imperceptibly slow. The cloud begins to collapse.

Because of conservation of energy, the cloud heats up as it collapses. Because of conservation of angular momentum, the cloud spins faster as it contracts.
As gravity forces a cloud to become smaller, it begins to spin faster and faster, due to *conservation of angular momentum*.
Gas settles into a spinning disk because spin hampers collapse perpendicular to the spin axis.

The original cloud is large and diffuse, and its rotation is imperceptibly slow. The cloud begins to collapse. Because of conservation of energy, the cloud heats up as it collapses. Because of conservation of angular momentum, the cloud spins faster as it contracts. Collisions between particles flatten the cloud into a disk.
Rotation of a contracting cloud speeds up for the same reason a skater speeds up as she pulls in her arms.
Flattening

Collisions between particles in the cloud cause it to flatten into a disk.

The original cloud is large and diffuse, and its rotation is imperceptibly slow. The cloud begins to collapse.

Because of conservation of energy, the cloud heats up as it collapses. Because of conservation of angular momentum, the cloud spins faster as it contracts.
Formation of Jets

Rotation also causes jets of matter to shoot out along the rotation axis.

A contracting cloud fragment always has some small, overall rotation.

Conservation of angular momentum ensures that the rotation speeds up as the cloud shrinks and flattens.

In the late stages of collapse, the central protostar may fire jets of high-speed gas along its rotation axis.
Jets are observed coming from the centers of disks around protostars.

a This photograph shows two jets of material being shot in opposite directions by a protostar. The structures to the left and right of the protostar are formed as the jet material rams into surrounding interstellar gas.
b This photograph shows a close-up view of a jet (red) and a disk of gas (green) around a protostar. We are seeing the disk nearly edge-on. The top and bottom surfaces of the disk are glowing, but we cannot see the darker middle layers of the disk.
Thought Question

What would happen to a protostar that formed without any rotation at all?

A. Its jets would go in multiple directions.
B. It would not have planets.
C. It would be very bright in infrared light.
D. It would not be round.
Thought Question

What would happen to a protostar that formed without any rotation at all?

A. Its jets would go in multiple directions.
B. It would not have planets.
C. It would be very bright in infrared light.
D. It would not be round.
Protostar to Main Sequence

• A protostar contracts and heats until the core temperature is sufficient for hydrogen fusion.
• Contraction ends when energy released by hydrogen fusion balances energy radiated from the surface.
• It takes 30 million years for a star like the Sun to become a main sequence star (less time for more massive stars).
Summary of Star Birth

1. Gravity causes gas cloud to shrink and fragment.
2. Core of shrinking cloud heats up.
3. When core gets hot enough, fusion begins and stops the shrinking.
4. New star achieves long-lasting state of balance
How massive are newborn stars?

a Artist’s conception of a brown dwarf, orbited by a planet (to its left) in a system with multiple stars. The reddish color approximates how a brown dwarf would appear to human eyes. The bands are shown because we expect brown dwarfs to look more like giant jovian planets than stars.

b An infrared image showing brown dwarfs (circled) in the constellation Orion. They are easier to spot in star-forming regions like this one than elsewhere in our galaxy, because young brown dwarfs still have much of the thermal energy left by the process of gravitational contraction. They therefore emit measurable amounts of infrared light.
A cluster of many stars can form out of a single cloud.