Star Birth
16.1 Stellar Nurseries

- Our goals for learning:
  - Where do stars form?
  - Why do stars form?
Where do stars form?
Star-Forming Clouds

- Stars form in dark clouds of dusty gas in interstellar space.
- The gas between the stars is called the interstellar medium.
We can determine the composition of interstellar gas from its absorption lines in the spectra of stars.

70% H, 28% He, 2% heavier elements in our region of Milky Way
Molecular Clouds

- Most of the matter in star-forming clouds is in the form of molecules ($\text{H}_2$, CO, etc.).
- These *molecular clouds* have a temperature of 10–30 K and a density of about 300 molecules per cubic centimeter.
Most of what we know about molecular clouds comes from observing the emission lines of carbon monoxide (CO).
Interstellar Dust

- Tiny solid particles of *interstellar dust* block our view of stars on the other side of a cloud.

- Particles are < 1 micrometer in size and made of elements like C, O, Si, and Fe.
Interstellar Reddening

- Stars viewed through the edges of the cloud look redder because dust blocks (shorter-wavelength) blue light more effectively than (longer-wavelength) red light.
Interstellar Reddening

- Long-wavelength infrared light passes through a cloud more easily than visible light.

- Observations of infrared light reveal stars on the other side of the cloud.
Observing Newborn Stars

Visible light from a newborn star is often trapped within the dark, dusty gas clouds where the star formed.
Observing Newborn Stars

Observing the infrared light from a cloud can reveal the newborn star embedded inside it.
Observing Newborn Stars

A visible-light image shows immense pillars of dark molecular gas.

The pillars are being sculpted by ultraviolet radiation from nearby stars (not seen in this image) that heats and erodes the dark gas.

Infrared light passes through the dark gas, so the pillars become almost transparent, allowing us to see newborn stars that were hidden in the visible-light image.

Images of longer-wavelength infrared light show the glow of thermal radiation from the pillars.
Glowing Dust Grains

- Dust grains that absorb visible light heat up and emit infrared light of even longer wavelength.
- Long-wavelength infrared light is brightest from regions where many stars are currently forming.
Glowing Dust Grains
Why do stars form?
Mass of a Star-Forming Cloud

- Gravity can create stars only if it can overcome the force of thermal pressure in a cloud.

- Emission lines from molecules in a cloud can prevent a pressure buildup by converting thermal energy into infrared and radio photons that escape the 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.
Resistance to Gravity

- A cloud must have even more mass to begin contracting if there are additional forces opposing gravity.
- Both magnetic fields and turbulent gas motions increase resistance to gravity.
Fragmentation of a Cloud

- Gravity within a contracting gas cloud becomes stronger as the gas becomes denser.
- Gravity can therefore overcome pressure in smaller pieces of the cloud, causing it to break apart into multiple fragments, each of which may go on to form a star.
Fragmentation of a Cloud

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

The random motions of different sections of the cloud cause it to become lumpy.
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.
Isolated Star Formation

- Gravity can overcome pressure in a relatively small cloud if the cloud is unusually dense.
- Such a cloud may make only a single star.
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.
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The First Stars

- Elements like carbon and oxygen had not yet been made when the first stars formed.

- Without CO molecules to provide cooling, the clouds that formed the first stars had to be considerably warmer than today's molecular clouds.

- The first stars must therefore have been more massive than most of today's stars, for gravity to overcome pressure.
Simulations of early star formation suggest the first molecular clouds never cooled below 100 K, making stars of \(~100M_{\text{Sun}}\).
What have we learned?

- **Where do stars form?**
  - Stars form in dark, dusty clouds of molecular gas with temperatures of 10–30 K.
  - These clouds are made mostly of molecular hydrogen (H$_2$) but stay cool because of emission by carbon monoxide (CO).

- **Why do stars form?**
  - Stars form in clouds that are massive enough for gravity to overcome thermal pressure (and any other forms of resistance).
  - Such a cloud contracts and breaks up into pieces that go on to form stars.
16.2 Stages of Star Birth

Our goals for learning:

- What slows the contraction of a star-forming cloud?
- What is the role of rotation in star birth?
- How does nuclear fusion begin in a newborn star?
What slows the contraction of a star-forming cloud?
Trapping of Thermal Energy

- As contraction packs the molecules and dust particles of a cloud fragment closer together, it becomes harder for infrared and radio photons to escape.

- Thermal energy then begins to build up inside, increasing the internal pressure.

- Contraction slows down, and the center of the cloud fragment becomes a protostar.
Growth of a Protostar

Matter from the cloud continues to fall onto the protostar until either the protostar or a neighboring star blows the surrounding gas away.
What is the role of rotation in star birth?
Evidence from the Solar System

The nebular theory of solar system formation illustrates the importance of rotation.

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.
Conservation of Angular Momentum

The rotation speed of the cloud from which a star forms increases as the cloud contracts.

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.
Rotation of a contracting cloud speeds up for the same reason a skater speeds up as she pulls in her arms.
Collisions between particles in the cloud cause it to flatten into a disk.
Collisions between gas particles in cloud gradually reduce random motions.
Collisions between gas particles also reduce up and down motions.
The spinning cloud flattens as it shrinks.
Formation of Jets

- Rotation also causes jets of matter to shoot out along the rotation axis.
Jet phenomena are observed coming from the centers of disks around protostars. Jets are caused by ionized particles traveling along strong magnetic field lines.
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.
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