The Birth of Stars

Chapter Twenty
Guiding Questions

1. Why do astronomers think that stars evolve?
2. What kind of matter exists in the spaces between the stars?
3. In what kind of nebulae do new stars form?
4. What steps are involved in forming a star like the Sun?
5. When a star forms, why does it end up with only a fraction of the available matter?
6. What do star clusters tell us about the formation of stars?
7. Where in the Galaxy does star formation take place?
8. How can the death of one star trigger the birth of many other stars?
Understanding how stars evolve requires both observation and ideas from physics

- Because stars shine by thermonuclear reactions, they have a finite life span
  - That is, they fuse lighter elements into heavier elements
    - When the lighter elements are depleted, there is nothing left to fuse

- The theory of stellar evolution (not in the same sense as biological evolution, but more like life cycle development, like growing up) describes how stars form and change during that life span
(a) A wide-angle view of Orion. (b) A closeup of the Orion Nebula.
Interstellar gas and dust is ubiquitous the Galaxy

- Interstellar gas and dust, which make up the interstellar medium (ISM), are concentrated in the disk of the Galaxy
- Clouds within the interstellar medium are called nebulae
- Dark nebulae are so dense that they are opaque
  - They appear as dark blots against a background of distant stars
- Emission nebulae, or H II regions, are glowing, ionized clouds of gas
  - Emission nebulae are powered by ultraviolet light that they absorb from nearby hot stars
- Reflection nebulae are produced when starlight is reflected from dust grains in the interstellar medium, producing a characteristic bluish glow
As light from a distant object travels through interstellar space...

...short-wavelength blue light is scattered or absorbed by dust grains...

...while red light passes through.

How dust causes interstellar reddening
Reddening depends on distance
We see spiral galaxy M83 nearly face-on.
Dust is concentrated in the galaxy's midplane

We see spiral galaxy NGC 891 nearly edge-on
Protostars form in cold, dark nebulae

- Star formation begins in dense, cold nebulae, where gravitational attraction causes a clump of material to condense into a protostar.
- As a protostar grows by the gravitational accretion of gases, Kelvin-Helmholtz contraction causes it to heat and begin glowing.
Protostars evolve into main-sequence stars

- A protostar’s relatively low temperature and high luminosity place it in the upper right region on an H-R diagram.
- Further evolution of a protostar causes it to move toward the main sequence on the H-R diagram.
- When its core temperatures become high enough to ignite steady hydrogen burning, it becomes a main sequence star.
The more massive the protostar, the more rapidly it evolves.

(a) Mass more than about 4 $M_{\odot}$: Energy flows by convection in the inner regions and by radiation in the outer regions.

(b) Mass between about 4 $M_{\odot}$ and 0.8 $M_{\odot}$: Energy flows by radiation in the inner regions and by convection in the outer regions.

(c) Mass less than 0.8 $M_{\odot}$: Energy flows by convection throughout the star's interior.
During the birth process, stars both gain and lose mass

- In the final stages of pre–main-sequence contraction, when thermonuclear reactions are about to begin in its core, a protostar may eject large amounts of gas into space.
- Low-mass stars that vigorously eject gas are called T Tauri stars.
A circumstellar accretion disk provides material that a young star ejects as jets.
Clumps of glowing gas called Herbig-Haro objects are sometimes found along these jets and at their ends.
Circumstellar accretion disk

Magnetic field lines thread through the disk
As the disk contracts toward the protostar, it pulls the magnetic field lines with it.
Swirling motions in the disk distort the field lines into helical shapes.

Some infalling disk material is channeled outward along the helices.
Young star clusters give insight into star formation and evolution

- Newborn stars may form an open or galactic cluster
- Stars are held together in such a cluster by gravity
- Occasionally a star moving more rapidly than average will escape, or “evaporate,” from such a cluster
- A stellar association is a group of newborn stars that are moving apart so rapidly that their gravitational attraction for one another cannot pull them into orbit about one another
1. This emission nebula (about 2200 pc away and about 20 pc across) surrounds the star cluster M16.

2. Star formation is still taking place within this dark, dusty nebula.

3. Hot, luminous stars (beyond the upper edge of the closeup image) emit ultraviolet radiation: This makes the dark nebula evaporate, leaving these pillars.

4. At the tip of each of these “fingers” is a cocoon nebula containing a young star.

5. Eventually the cocoon nebulae evaporate, revealing the stars.
(a) The star cluster NGC 2264

(b) An H-R diagram of the stars in NGC 2264

This star cluster is so young that most of its cool, low-mass stars have not yet arrived at the main sequence.
(a) The Pleiades star cluster

(b) An H-R diagram of the stars in the Pleiades

This star cluster is old enough that all of its cool, low-mass stars have arrived at the main sequence; hydrogen fusion has begun in their cores.
Star birth can begin in giant molecular clouds

The spiral arms of our Galaxy are laced with giant molecular clouds, immense nebulae so cold that their constituent atoms can form into molecules.
• Star-forming regions appear when a giant molecular cloud is compressed.

• This can be caused by the cloud’s passage through one of the spiral arms of our Galaxy, by a supernova explosion, or by other mechanisms.
O and B Stars and Their Relation to H II Regions

- The most massive protostars to form out of a dark nebula rapidly become main sequence O and B stars
- They emit strong ultraviolet radiation that ionizes hydrogen in the surrounding cloud, thus creating the reddish emission nebulae called H II regions
- Ultraviolet radiation and stellar winds from the O and B stars at the core of an H II region create shock waves that move outward through the gas cloud, compressing the gas and triggering the formation of more protostars
Star formation progresses in this direction.

Shell of hydrogen that has not yet been ionized.

Older cluster

Old cluster

Expanding region of ionized hydrogen (H II)

Young cluster

New stars being formed

Giant molecular cloud

Shock wave spreads into molecular cloud
Star formation progresses in this direction.

Shell of hydrogen that has not yet been ionized.

Older cluster

Old cluster

Expanding region of ionized hydrogen (H II)

Young cluster

Giant molecular cloud

Shock wave spreads into molecular cloud

New stars being formed

Radiation and stellar winds from this massive, luminous star...

...may have triggered the formation of these stars.
Supernovae can compress the interstellar medium and trigger star birth.

A shock wave spreads away from the site of a supernova explosion.

This interstellar gas was compressed and heated by the shock wave, making it glow.
<table>
<thead>
<tr>
<th>Key Words</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>accretion</td>
<td>interstellar medium</td>
</tr>
<tr>
<td>Barnard object</td>
<td>interstellar reddening</td>
</tr>
<tr>
<td>bipolar outflow</td>
<td>nebula (plural nebulae)</td>
</tr>
<tr>
<td>Bok globule</td>
<td>nebulosity</td>
</tr>
<tr>
<td>circumstellar accretion disk</td>
<td>OB association</td>
</tr>
<tr>
<td>cluster (of stars)</td>
<td>open cluster</td>
</tr>
<tr>
<td>cocoon nebula</td>
<td>protoplanetary disk (proplyd)</td>
</tr>
<tr>
<td>dark nebula</td>
<td>protostar</td>
</tr>
<tr>
<td>dust grains</td>
<td>recombination</td>
</tr>
<tr>
<td>emission nebula</td>
<td>reflection nebula</td>
</tr>
<tr>
<td>evolutionary track</td>
<td>stationary absorption lines</td>
</tr>
<tr>
<td>fluorescence</td>
<td>stellar association</td>
</tr>
<tr>
<td>giant molecular cloud</td>
<td>stellar evolution</td>
</tr>
<tr>
<td>H II region</td>
<td>supernova remnant</td>
</tr>
<tr>
<td>Herbig-Haro object</td>
<td>supersonic</td>
</tr>
<tr>
<td>interstellar extinction</td>
<td>T Tauri star</td>
</tr>
</tbody>
</table>