# Discovering the Essential Universe 

CHAPTER 11
The Lives of Stars from Birth Through Middle Age


Chapter 12 Opener

## TABLE 12-1 Composition of the Interstellar Medium

## Particle number

Mass (\%)

## Hydrogen

(atoms and molecules) Helium
Metals*

90
74
25
1
*Metals are all elements except hydrogen and helium.

Table 12-1
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Figure 12-2a
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Figure 12-2b
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As light from a distant object travels through interstellar space...


Distant object

## ...short-wavelength blue

light is scattered or absorbed by dust grains...

1 ...while red light passes through.

Observer

## How dust causes interstellar reddening



## Reddening depends on distance



Figure 12-5c
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Cygnus Loop - supernova remnant,
Exploded 20,000 years ago, distance 120 ly

a

## O: blue S: red <br> H: green



Figure 12-7
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Figure 12-8
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a A dark nebula
b A hidden protostar within the dark nebula
Figure 12-9
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## >300 protostars

## 2 pre-main-sequence stars




## Figure 12-11

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Supermassive star, originally $\mathrm{M} \sim 100$ to $200 \mathrm{M}_{\text {sol }}$


Figure 12-14a
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1.This emission nebula (about 2200 pc away and about 20 pc across) surrounds the star cluster M16.


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Star formation progresses in this direction

Shell of hydrogen that has not yet been ionized

Older cluster


Expanding region of ionized hydrogen (H II)

Young cluster


Shock wave spreads into molecular cloud

New stars being formed


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## Stars about to burn H




In this cold, dark nebula, gas atoms and dust particles move so slowly that gravity can draw them together.

In the T Tauri stage, the young star ejects mass into space in a opposite directions. A stellar wind blows away the remaining parts of the nebula that surround the star, exposing the star to space.

Gas and dust begin to condense into clumps, forming the cores of protostars.



As the cores condense, their density and temperature both increase.


When accretion stops, the protostar becomes a pre-main-sequence star. Its core heats to 107 K and fusion begins there. The mass that is continuing to fall onto the star forms an accretion disk.

Protostellar cores within the dark nebula


As the protostars continue to heat up and accrete matter from the nebula, they begin to glow due to their increasing temperature. If the core is rotating, some gas and dust in it forms a disk around the protostar.


The ejected mass can induce a shock wave in the surrounding interstellar material, triggering the formation of additional stars.

Processes that cause the star to lose or gain mass come to an end, and the star stabilizes as a main-sequence star in hydrostatic equilibrium. A system of planets often forms around the star in the disk of gas and dust.

Figure 12-19
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## TABLE 12-2 Main-Sequence Lifetimes

|  | Surface <br> temperature (K) | Luminosity (L $\odot$ ) | Time on main <br> sequence <br> $\left(10^{6}\right.$ years) | Spectral <br> class |
| :--- | :--- | :---: | :--- | :--- |
| 25 | 35,000 | 80,000 | 3 | O |
| 15 | 30,000 | 10,000 | 15 | B |
| 3 | 11,000 | 60 | 500 | A |
| 1.5 | 7000 | 5 | 3000 | F |
| 1.0 (Sun) | 6000 | 1 | 10,000 | G |
| 0.75 | 5000 | 0.5 | 15,000 | K |
| 0.50 | 4000 | 0.03 | 200,000 | M |

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## $\mathrm{Lt}=\mathrm{fMc}^{2}$

$\mathrm{t} \alpha \mathrm{Mc}^{2} / \mathrm{L}$
$\mathrm{L} \alpha \mathrm{M}^{3.5}$
$\mathrm{t} \alpha \mathrm{M}^{-2.5}$

## Evolution of low-mass stars

## Red dwarfs

$85 \%$ of all stars
$0.08 \mathrm{M}_{\text {sol }}$ to
$0.4 \mathrm{M}_{\text {sol }}$

Burn all H to He , then cool and move down the main sequence


## Early and middle evolution of stars with more than $0.4 \mathrm{M}_{\text {sol }}$

## Outer layers: no thermonuclear reactions



Hydrogen-fusing
core
Main-sequence star Young red-giant star
fusing shell


Helium-fusing core

Red-giant star after helium fusion begins

C

## The Sun as a main-sequence star (diameter $=1.4 \times 10^{6} \mathrm{~km} \approx \frac{1}{100} \mathrm{AU}$ ) <br> The Sun as a red giant (diameter $\approx 1$ AU)

## The Sun today and as a red giant

## Post main-sequence evolution



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Figure 12-25
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## Helium fusion:

${ }^{4} \mathrm{He}+{ }^{4} \mathrm{He}+{ }^{4} \mathrm{He} \rightarrow{ }^{12} \mathrm{C}+\gamma$ ${ }^{12} \mathrm{C}+{ }^{4} \mathrm{He} \quad \rightarrow{ }^{16} \mathrm{O}+\gamma$


## H-R diagram of a globular cluster (M55)



## H-R diagram of a globular cluster (M55)



## Simulation of the evolution of a cluster from 0 to 4.5 billion years



Figure 12-30c-j


## The turnover point gives the age (yr) of the cluster (in red).

## Binaries


a Detached binary: Neither star fills its Roche lobe.


Mass can flow from either star to the other across the boundary point

## c Contact binary: Both stars fill their

 Roche lobes.

Mass can flow from the enlarged star to the smaller one
b Semi-detached binary: One star fills its Roche lobe.

## d Overcontact binary: Both stars overfill their Roche lobes.

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Each star in a binary system has a Roche lobe. Within a Roche lobe, orbital material is bound to the star.

## A companion star can influence the evolution

1 Held in a gravitational embrace, the pair of stars in Phi Persei has lived normal lives for the last 10 million years.

(4) The once-massive star sheds practically all of its mass, leaving its hot, bright core exposed.


2 The duo's quiet lives end when the more massive star enters its twilight years. The aging star swells as it runs out of the fuel-hydrogen-which powers its thermonuclear furnace.

(5) The smaller companion, on the other hand, has captured most of its partner's excess mass and changes its identity from a mildmannered, moderately massive star to a massive, hot, rapidly spinning star.

(3) As the aging star expands, it begins dumping its mass onto its companion.


In fact, the star is spinning so rapidly that its shape is distorted into a flattened spheroid. The rapid rotation also causes the star to dump hydrogen gas, which has settled into a broad ring-like the rings of Saturn-around the star.


Figure 12-34
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