Low-Mass Star

Years in Stage: 10 million

\( T = 10 - 20 \text{ K} \)

\( L = 0 \) (collapsing gas and dust)

\( R = 1 - 3,000 \text{ ly} \)

\( M = 1 \text{ m}\odot \)

Other - Dozens or even hundreds of stars can form in a cloud.

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High-Mass Star

Years in Stage: 1 million

\( T = 10 - 20 \text{ K} \)

\( L = 0 \) (dark gas and dust)

\( R = 1 - 3,000 \text{ ly} \)

\( M = 10 \text{ m}\odot \)

Other - Dozens, even hundreds of stars can form in a cloud.

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Giant Molecular Cloud in Orion.

Portion of Giant Molecular cloud begins collapse by gravitational attractions, perhaps triggered by nearby supernova explosion.

The dark areas in the Orion nebula—giant molecular clouds—are where stars are born.

Supernova shockwave triggers collapse and begins the accumulation of material by gravitational attraction.
Low-Mass Star

An infrared picture of the Elephant Trunk nebula. Proto-stars are seen peeking through their dust clouds.

Heating by gravitational collapse and accretion of particles. No internal fusion.

Years in Stage: 5 million
T = 2 - 3,000 K
L = low (covered by a shell of dust)
R ≈ 5 R☉
M = 1 M☉

High-Mass Star

Massive stars form in clusters. The first stars to form blow away the gas and dust, surrounding them.

Heating by gravitational collapse and accretion of particles. No internal fusion.

Years in Stage: 2 million years
T = 2 - 3,000 K
L = low (covered by a shell of dust)
R = 100 R☉
M = 10 M☉
Low-Mass Star

Initiation of hydrogen fusion in core of star.
\[ ^1_1H \rightarrow ^3_2He + \text{energy} \]

T Tauri Stars

Other - Star is still contracting and often have large accretion disks - with future planets - surrounding them.

High-Mass Star

Fusion begins - CNO cycle produces helium in core.

Rigel - A B star on the main sequence.

Other - Peak wavelength of the star in the ultraviolet.
Low-Mass Star

A yellow main-sequence star.

Hydrogen builds up helium in the core.

Not enough for helium to fuse.

High-Mass Star

Blue main sequence stars go through stages of fusion quickly.

Helium fusion produces C + O in the core.

\[ ^3\text{He} \rightarrow ^{12}\text{C} + \text{energy} \]
\[ ^4\text{He} \rightarrow ^{16}\text{O} + \text{energy} \]

Low-Mass Star

Years in Stage: 8 billion

- \( T = 5,800 \text{ K} \)
- \( L = 1\odot \)
- \( R = 1\text{ R}\odot \)
- \( M = 1\text{ M}\odot \)

Other - Luminosity of the star changes from the time the star arrives on the main sequence until it leaves.

High-Mass Star

Years in Stage: 10 million

- \( T = 9,000 \text{ K} \)
- \( L = 10,000\text{ L}\odot \)
- \( R = 100\text{ R}\odot \)
- \( M = 10\text{ M}\odot \)

Other - No Helium flash; each stage of fusion is faster than the last.
Low-Mass Star

- Hydrogen shell fusion; helium in core not hot enough to fuse.
- Years in Stage: 2 billion
  - $T = 2500 - 3500 \text{ K}$
  - $L = 1,000 - 10,000 \text{ L}$
  - $R = 20 - 500 \text{ L}$
  - $M = 1 \text{ M}_\odot$
- Other - Often variable. Star pulsates and throws off outer layers of gas.

High-Mass Star

- Carbon and oxygen fusion produce magnesium, sulfur, neon, and finally silicon.
- Years in Stage: 1 million
  - $T = 5,000 \text{ K}$
  - $L = 50,000 \text{ L}_\odot$
  - $R = 100 - 200 \text{ R}_\odot$
  - $M = 10 \text{ M}_\odot$
- Other - Very regular pulsations with a period between 1 and 100 days.
**Low-Mass Star**

Yellow Giant Star

Onset of helium fusion in the core as internal temperature = 100 million K.

\[ ^4\text{He} + ^4\text{He} \rightarrow ^{12}\text{C} + \text{E} \]

or: \[ ^4\text{He} \rightarrow ^{16}\text{O} + \text{E} \]

**Betelgeuse** is an M11a red supergiant star 1,000 times the diameter of the sun.

**High-Mass Star**

After a succession of shell burning episodes, silicon fusion produces iron in the core of the star.

**Low-Mass Star**

Years in Stage: 200 million
- \( T = 5 - 6,000 \text{ K} \)
- \( L = 2,000 - 10,000 \text{ L} \)
- \( R = 10 - 400 \text{ R} \)
- \( M = < 1 \text{ M} \)

Other - Sometimes variable, star contracts and gets hotter.

**High-Mass Star**

Years in Stage: 100,000
- \( T = 3,000 \text{ K} \)
- \( L = 50,000 \text{ L} \)
- \( R = 7,500 \text{ R} \)
- \( M = < 10 \text{ M} \)

Other - Iron absorbs energy, outward heat pressure drops dramatically.
Low-Mass Star

2nd Red Giant Stage

The carbon/oxygen core never gets hot enough to fuse.

Years in Stage: 1 billion

T = 3 - 4,000 K
L = 500 - 5,000 L☉
R = 10 - 500 R☉
M = <.9M☉

Other - 2nd red giant phase, usually a variable star with irregular pulsations.

High-Mass Star

Supernova 1987a

Material from supernova expands into space, sometimes colliding with dust shells.

Supernovae release the energy of a billion stars in a few seconds. Elements are fused during the explosion.

Years in Stage: a few seconds

T = billions of degrees
L = 100 billion L☉
R = 19 km core diameter
M = disperses

Other - Star collapses on core and rebounds. Shock wave induces fusion of heavy elements at billions of degrees.
Low-Mass Star

The gas thrown off by dying stars is called a planetary nebula because in small telescopes these objects look like planets.

Low-Mass Star

Fusion stops, core white hot.

Low-Mass Star

Years in Stage: 50,000

- **T** = Up to 100,000 K for central star
- **L** = < .1 L⊙
- **R** = Gas shells dozens to hundreds of light years in diameter.
- **M** = .5 M⊙

Other - Ejected material forms envelope of gas. Central star is Earth-sized.

High-Mass Star

Cassiopeia is a supernova remnant. The neutron star, the leftover core, is the aqua blue dot in the center of the gas cloud.

High-Mass Star

Neutron stars are degenerate matter - a ball of neutrons with an iron crust.

High-Mass Star

Years in Stage: billions of years

- **T** = 1 million degrees
- **L** = invisible to eye, but visible using x-ray and gamma ray detectors.
- **R** = size of the island of Manhattan
- **M** = 1.4 - 2.5 M⊙

Other - Pulsars are neutron stars that spin at an incredible rate of 100 - 5,000 rev/sec!
**Low-Mass Star**

- White dwarf star.
- Heat slowly leaks away as star cools until only a black dwarf - a charcoal briquet in space - remains.

**High-Mass Star**

- A black hole cannot be seen. Only when a black hole is in a binary system can its presence be detected.
- A black hole is an intense gravitational source, a kind of infinitely deep well.

**Low-Mass Star**

- Years in Stage: 50 billion
- $T = 20 - 50,000 \, \text{K}$, eventually less than 10K
- $L = < .01 \, \text{L}_{\odot}$
- $R = \text{size of Earth}$
- Other - The universe is not old enough for any stars to have evolved to black dwarf.

**High-Mass Star**

- Years in Stage: varies
- $T = \text{undefined}$
- $L = 0$
- $R = 0$
- $M = > 3\, \text{M}_{\odot}$