STELLAR AND GALACTIC EVOLUTION

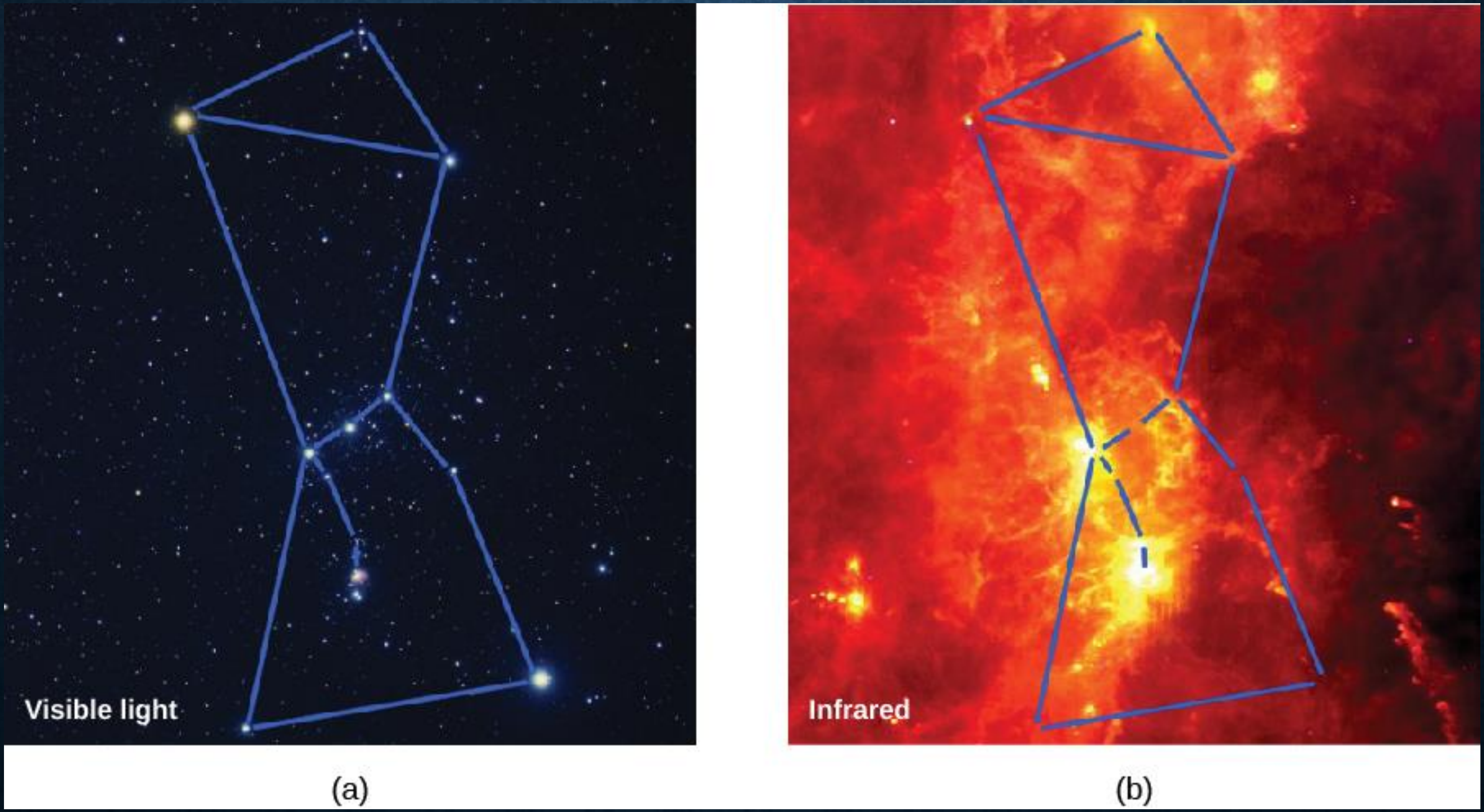
SMS 2019-2020 Science Olympiad

OPENSTAX - ASTRONOMY

MOLECULAR CLOUDS: STELLAR NURSERIES

- The most massive reservoirs of interstellar matter are the giant molecular clouds
- These clouds have cold interiors (only 10-20 K – our Sun is around 5,578 K) with hydrogen gas and dust.
- The molecular clouds have a complex filamentary structure kind of like cirrus clouds on Earth.
- These filaments can be up to 1,000 light years long. Within these clouds are dense regions called "clumps" with a typical mass of 50-500 times the mass of our Sun. Inside of the "clumps" are "cores" that are even denser.
- These "cores" are the embryos of stars.

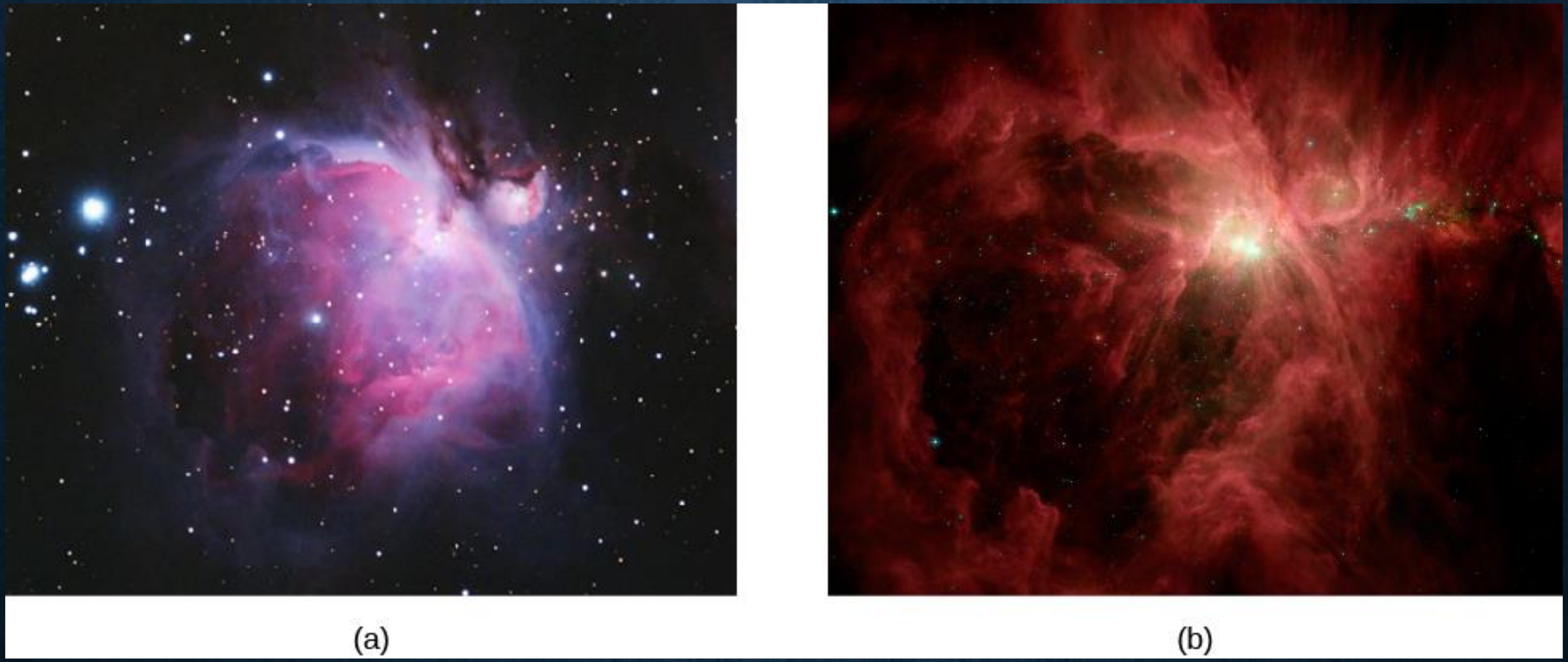
ORION MOLECULAR CLOUD



ORION MOLECULAR CLOUD

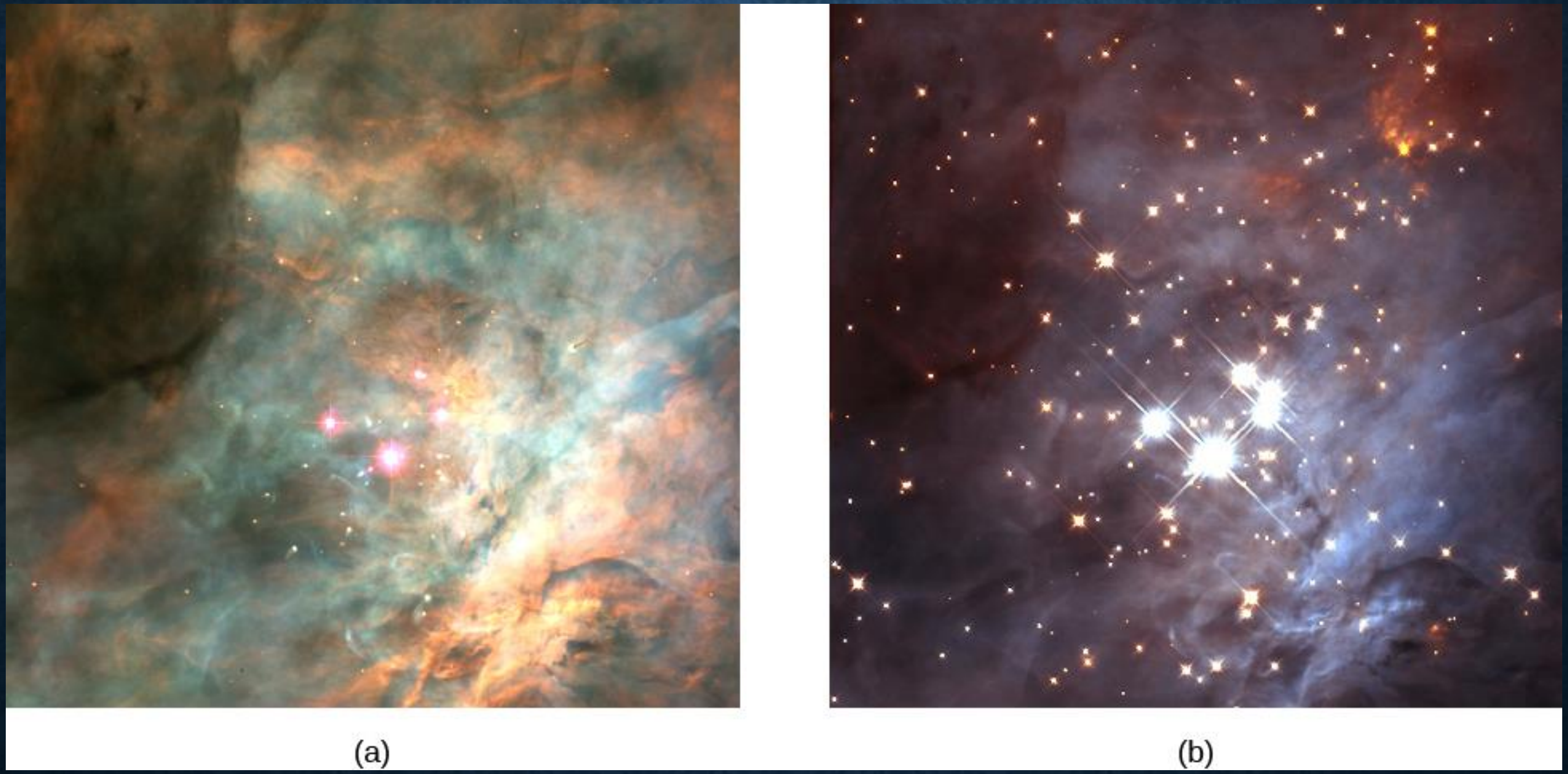
- There's a region about ½ way down Orion's sword where star formation is taking place – The Orion Nebula (M42)
- The Orion Nebula (M42) contains about 2,200 young stars
- In the Central Region of the nebula is a Trapezium Cluster of very bright young stars

ORION NEBULA (M42)



(a) Orion Nebula (M42) shown in visible light
(b) Orion Nebula (M42) with near-infrared radiation. We can see more detail because infrared can penetrate the dust more easily than visible light.

CENTRAL REGION OF THE ORION NEBULA

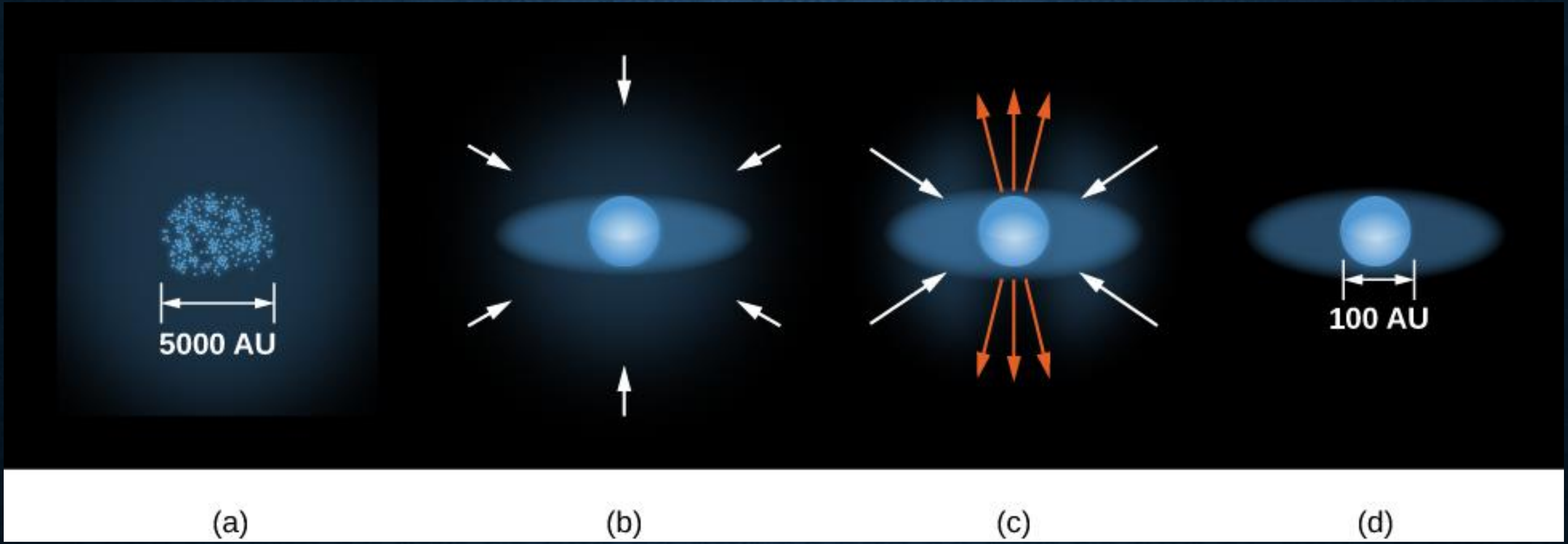


(a) Central Region in visible light
(b) Central Region in infrared light

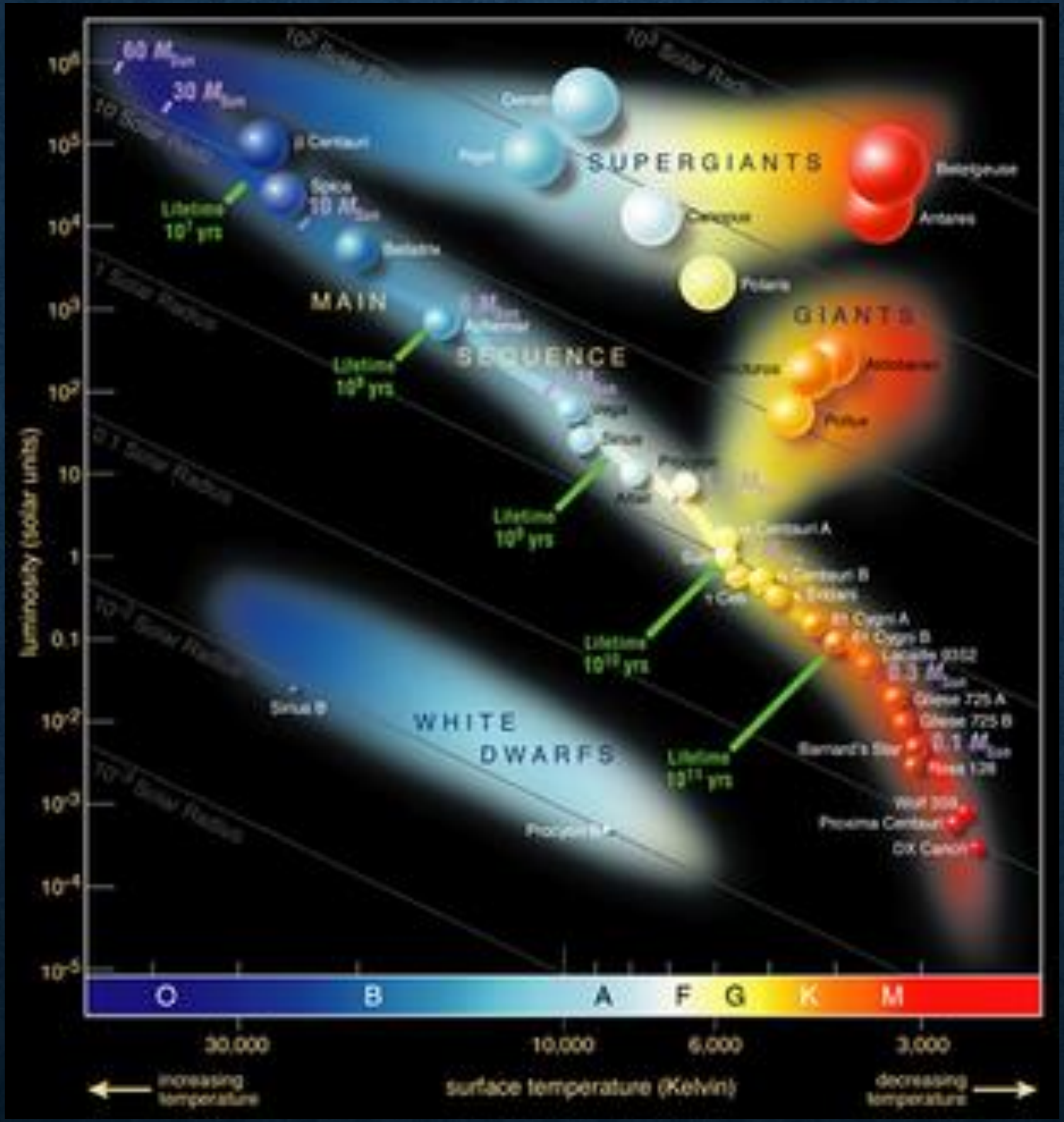
BIRTH OF A STAR – THE PROTOSTAR

- The first step is the formation of a dense core within a clump of gas and dust.
- Gravitational forces begin pulling the gas and dust together until it's strong enough to overwhelm the pressure keeping the molecules apart.
- The material around the baby star rapidly collapses and the density of the core increases greatly.
- Fusion begins – gravitational force the Hydrogen atoms to fuse together into Helium releasing a tremendous amount of energy.
- This is now a "protostar".

BIRTH OF A STAR – THE PROTOSTAR



SO WHAT'S NEXT?



SUPERGIANTS
GIANTS
MAIN
SEQUENCE
WHITE
DWARFS
Betelgeuse
Antares
Polaris
Lifetime 10^7 yrs
Lifetime 10^8 yrs
Lifetime 10^9 yrs
Lifetime 10^{10} yrs
Lifetime 10^{11} yrs
luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
increasing temperature
surface temperature (Kelvin)
decreasing temperature

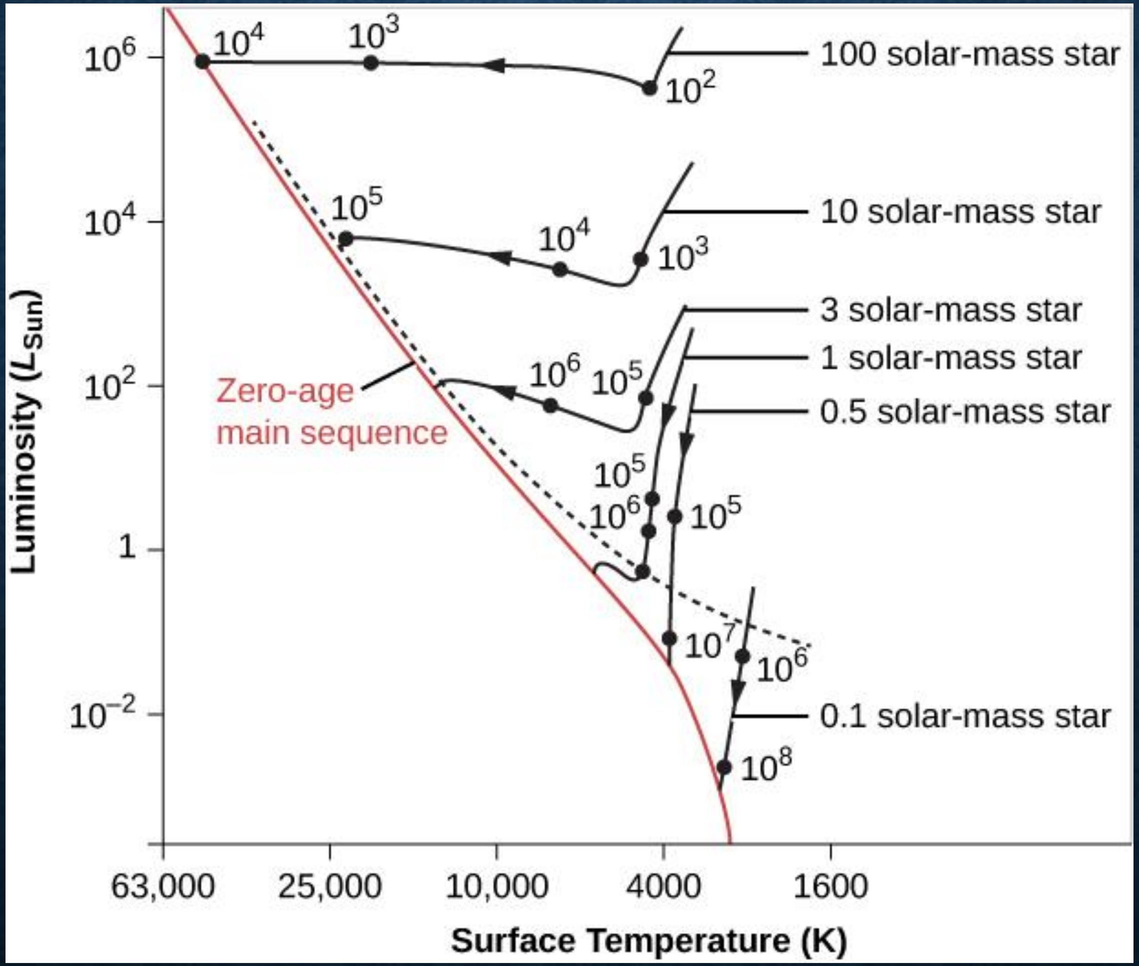
THE HERTZSPRUNG-RUSSEL (H-R) DIAGRAM

- Initially, a protostar remains fairly cool with a large radius and low density
- The heat in its core builds up slowly, so the gas pressure remains low and the outer layers of the star collapse quickly.
- As the surface gets smaller, the total luminosity decreases.
- This contraction stops when the protostar becomes dense enough to trap the heat released. This keeps the luminosity of stars like our Sun roughly constant.
- As the temperature increases, the star moves to the left on the H-R diagram.

THE HERTZSPRUNG-RUSSEL (H-R) DIAGRAM

- When the star's central temperature is high enough (12 million K) to fuse hydrogen into helium, the star is in the Main Sequence.
- The mass of the star determines where it falls on the main sequence.
- Massive stars have high temperatures and luminosity, low-mass stars have low temperatures and low luminosity.

EVOLUTIONARY TRACKS FOR CONTRACTING PROTOSTARS



HOW LONG WILL A STAR LIVE?

- The lifetime of a star depends on how much nuclear fuel it has and how quickly it is using that fuel.
- Large, high mass stars have much higher pressure on their core. The high mass must be balanced by the higher pressure from fusion. This results in higher temperature and faster burning of fuel.

HOW LONG WILL A STAR LIVE?

Lifetimes of Main-Sequence Stars

Spectral Type	Surface Temperature (K)	Mass (Mass of Sun = 1)	Lifetime on Main Sequence (years)
O5	54,000	40	1 million
B0	29,200	16	10 million
A0	9600	3.3	500 million
F0	7350	1.7	2.7 billion
G0	6050	1.1	9 billion
K0	5240	0.8	14 billion
M0	3750	0.4	200 billion

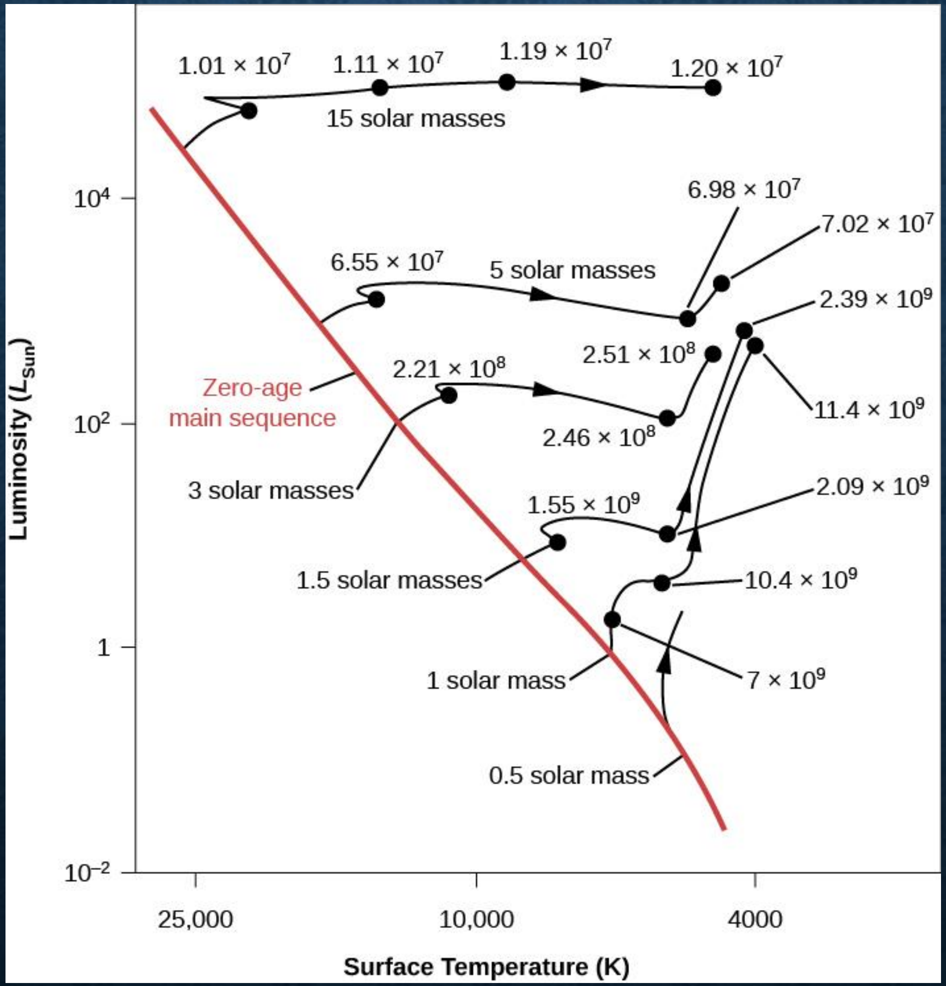
MAIN SEQUENCE TO RED GIANTS

- Eventually the hydrogen in a star gradually depletes and helium accumulates.
- This changes the luminosity, temperature, size and structure of the star.
- The temperature and density of the interior of a star slowly increases as the helium accumulates.
- As it gets hotter, the rate of fusion increases.
- As the rate of fusion goes up, the rate at which energy is generated increases and the luminosity gradually rises.

MAIN SEQUENCE TO RED GIANTS

- The heat from the star flows outward where it is cooler and heats the outer layers of the star causing them to expand.
- As the heat expands, the temperature of the surface begins to cool and the color becomes redder.
- Over time, the massive stars become red super giants.

EVOLUTIONARY TRACKS OF STARS OF DIFFERENT MASSES



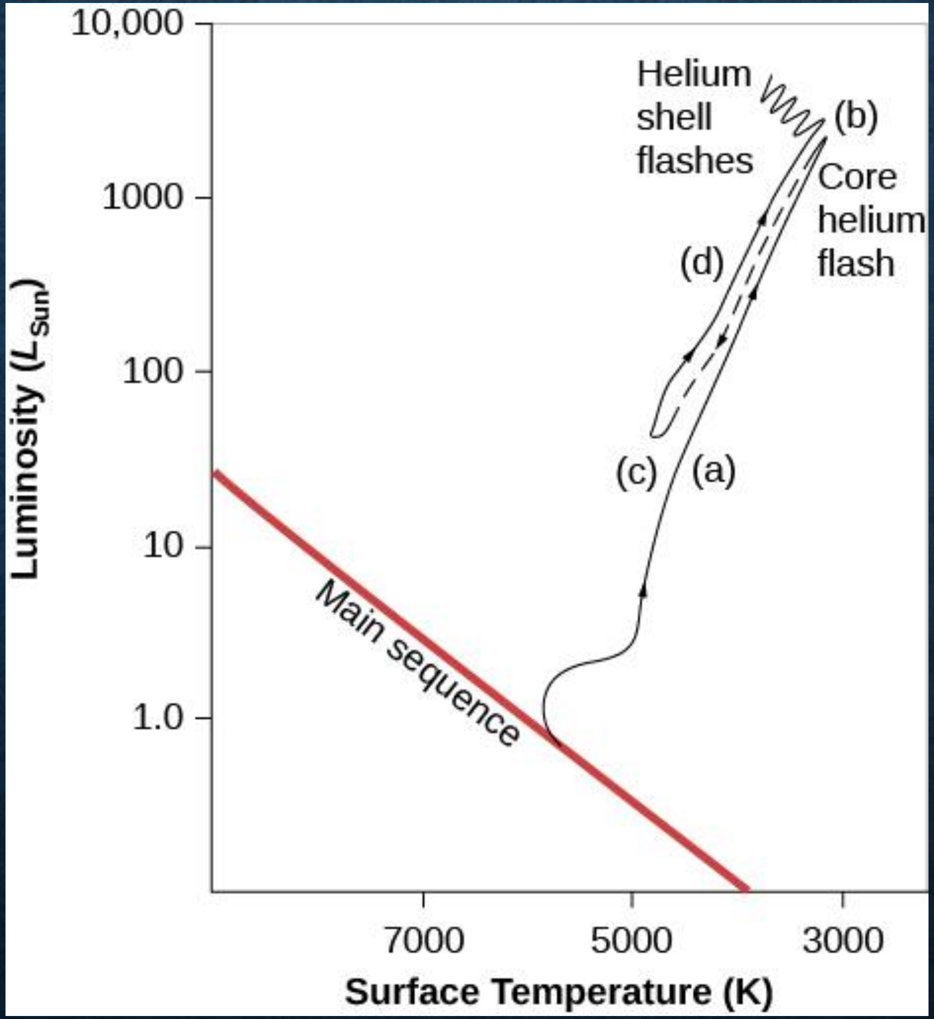
THE DEATH OF STARS

LOWER MASS STARS

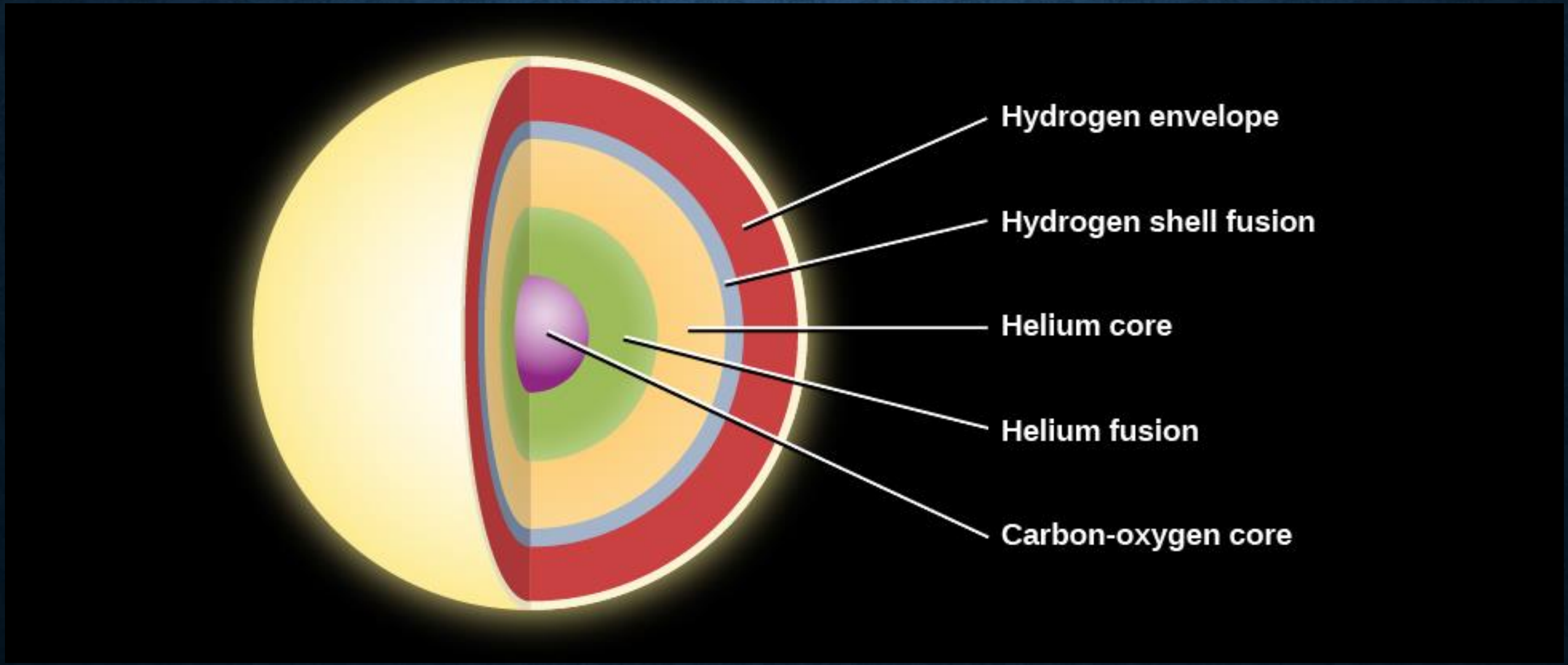
HELIUM FLASH

- If the star had an initial low mass, they may go through another phase.
- The helium core of a red giant can continue to compress and can get extremely hot.
- If it reaches 100 million K, three helium atoms can be fused together into a single carbon atom.
- This ignites the core into a quick burst of fusion called a helium flash.
- Eventually the helium can fuse with the carbon to create oxygen.

HELIUM FLASH



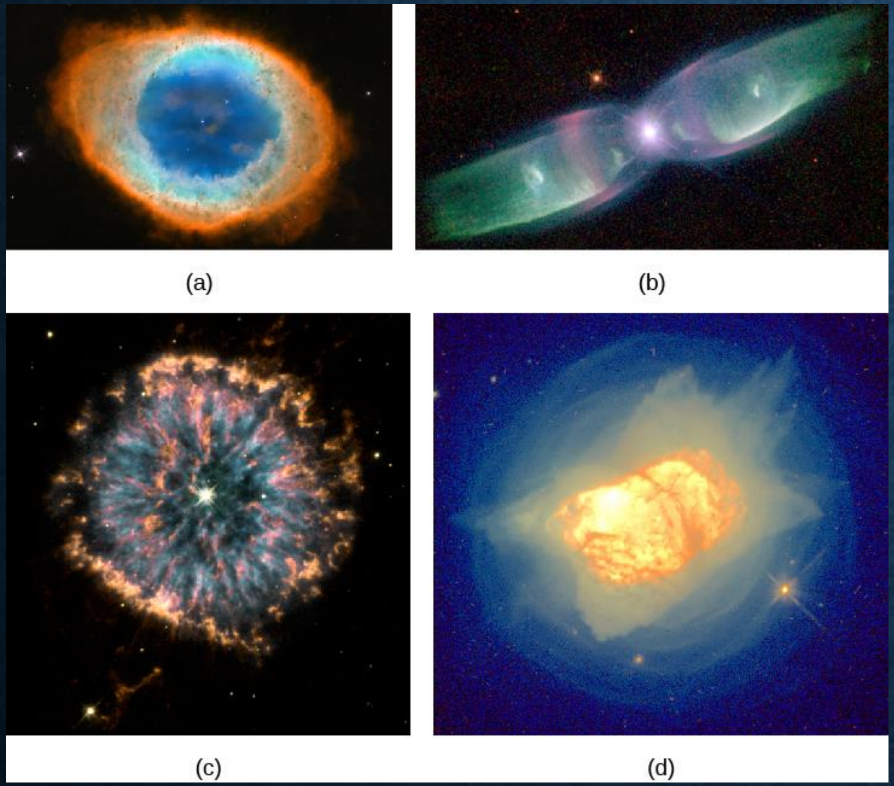
LAYERS INSIDE A LOW-MASS STAR BEFORE DEATH



PLANETARY NEBULAE

- When the nuclear energy generation in the carbon-oxygen core ceases, the core shrinks again and become very hot. The stellar winds from the increase of heat can eject the material away from the core.
- These winds and ultraviolet radiation can heat the materials, ionize them, and set them aglow.
- These are planetary nebulae.

PLANETARY NEBULAE



a) Ring Nebula (M57) – Lyra
b) Butterfly Nebula (M2-9) – Ophiucus
c) Nebula NGC 6751 – Aquila
d) Nebula NGC 7027 - Cygnus

WHITE DWARFS

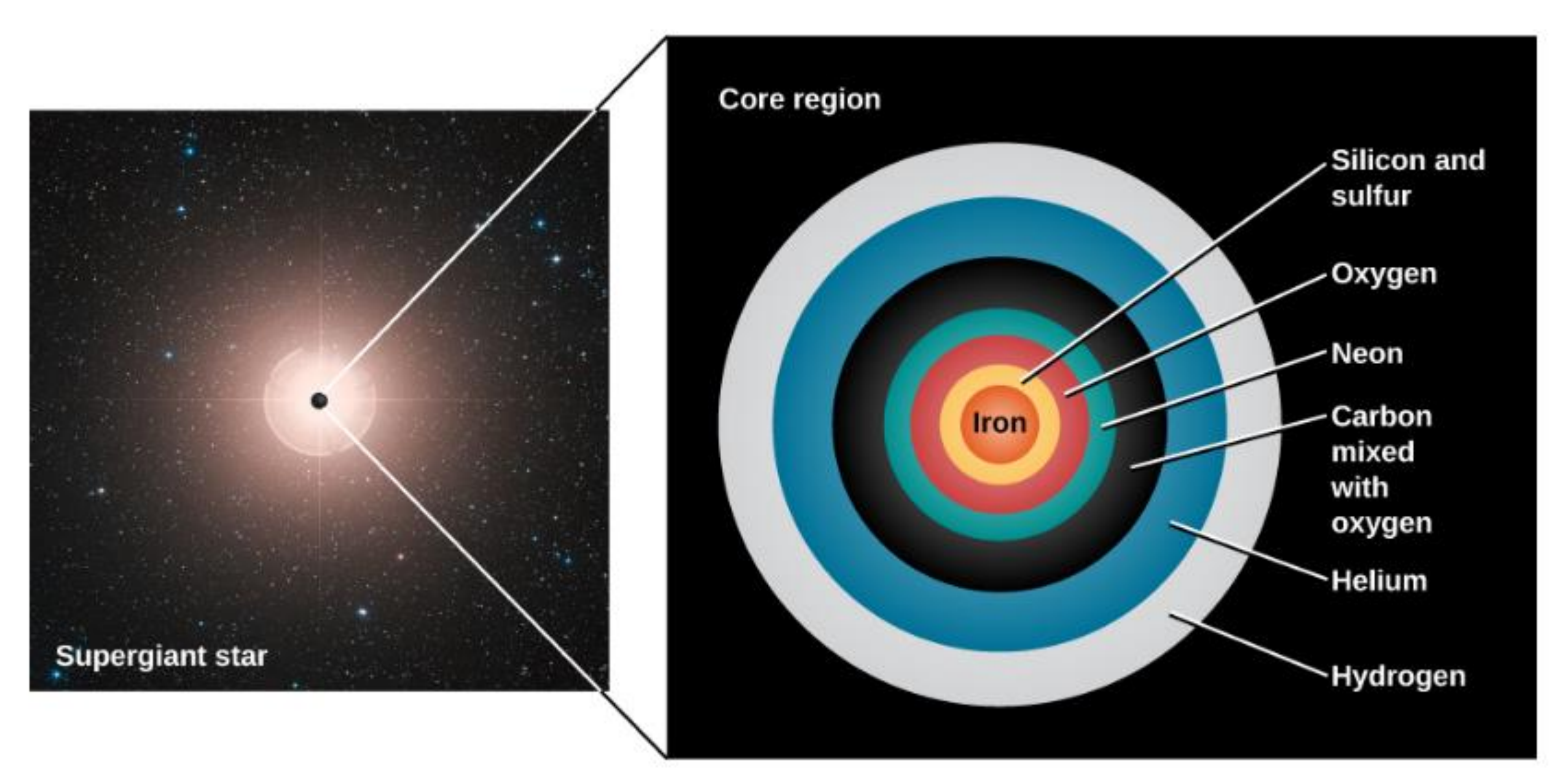
- For lower mass stars, eventually the helium runs out and there’s no more fusion and the core continues to contract.
- The core become incredibly dense (nearly 1,000,000 times the density of water).
- The high density increases its gravity and it shrinks even further.
- The interior temperature becomes so high that the atoms are stripped of virtually all of their electrons.
- The electrons are around the core and eventually stabilizes as a White Dwarf.

MASSIVE STARS

EVOLUTION OF MASSIVE STARS

- After the helium core is exhausted, the evolution of a massive star takes a very different course from that of a low-mass star.
- The weight of the outer layers of a massive star is sufficient in force to contract the carbon core until its hot enough to fuse into oxygen, neon, and magnesium.
- This fusion can reignite the core and begin the cycle again fusing the core into heavier elements like silicon, sulfur, calcium, and argon.
- These elements may even fuse further into iron.
- These stages can happen very quickly – sometimes only months or days!

EVOLUTION OF MASSIVE STARS



NEUTRON STARS

- Remember that electrons can get stripped out in white dwarfs? Well, in massive stars, the collapsing core will be stripped of electrons and neutrons and the neutrons then stabilize the collapsing core and we end up with a neutron star.
- This collapse is very rapid – a core the size of the Earth collapses to a diameter of less than 20 kilometers!
- This shock ejects matter around it creating a supernova.

SUPERNOVA

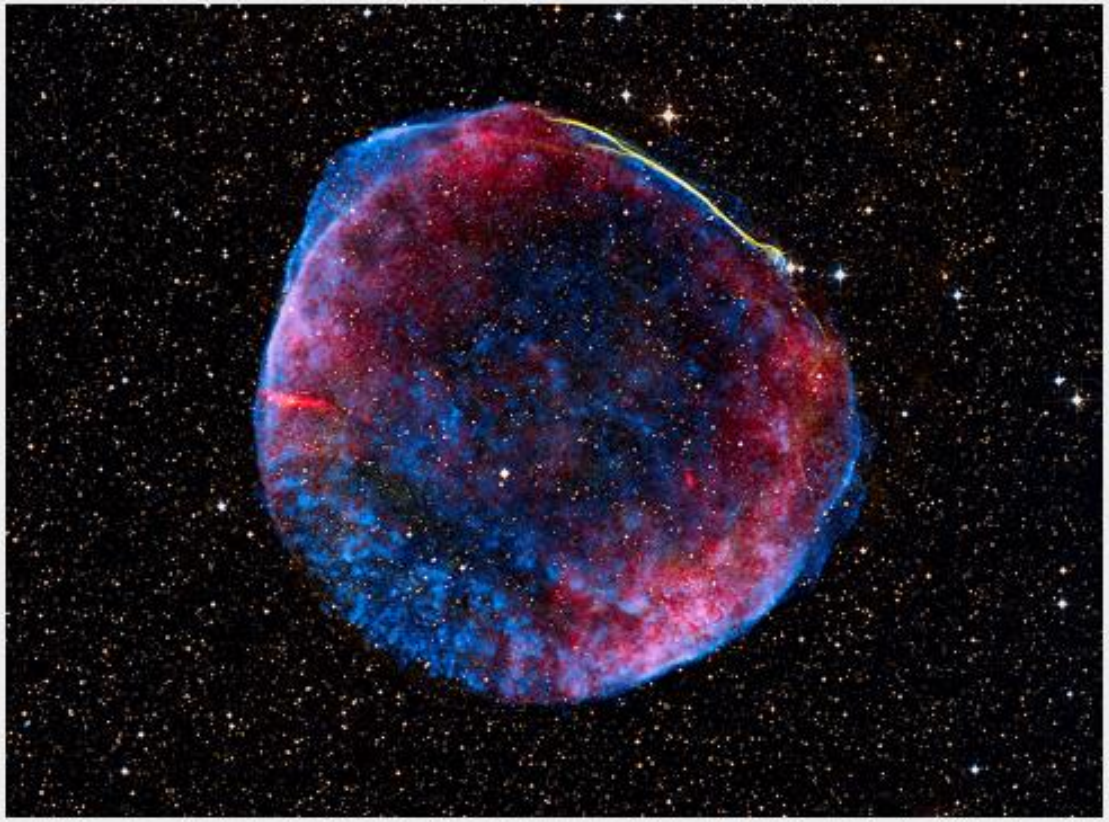


Figure 23.9 Supernova 1006 Remnant. This composite view of SN 1006 from the Chandra X-Ray Observatory shows the X-rays coming from the remnant in blue, visible light in white-yellow, and radio emission in red. (credit: modification of work by NASA, ESA, Zolt Levay(STScI))

SUPERNOVA

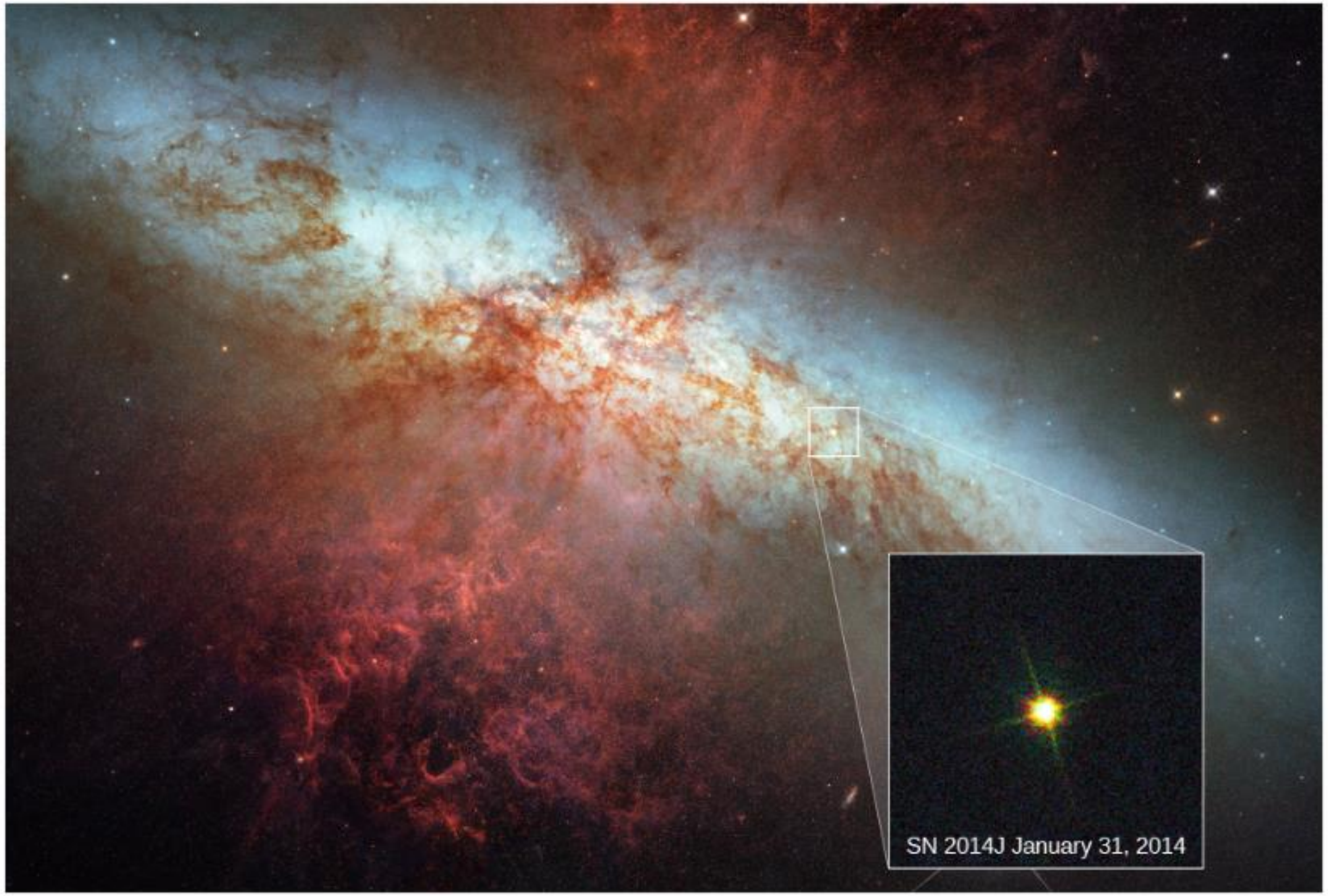


Figure 23.10 Supernova 2014J. This image of supernova 2014J, located in Messier 82 (M82), which is also known as the Cigar galaxy, was taken by the

SUPERNOVA

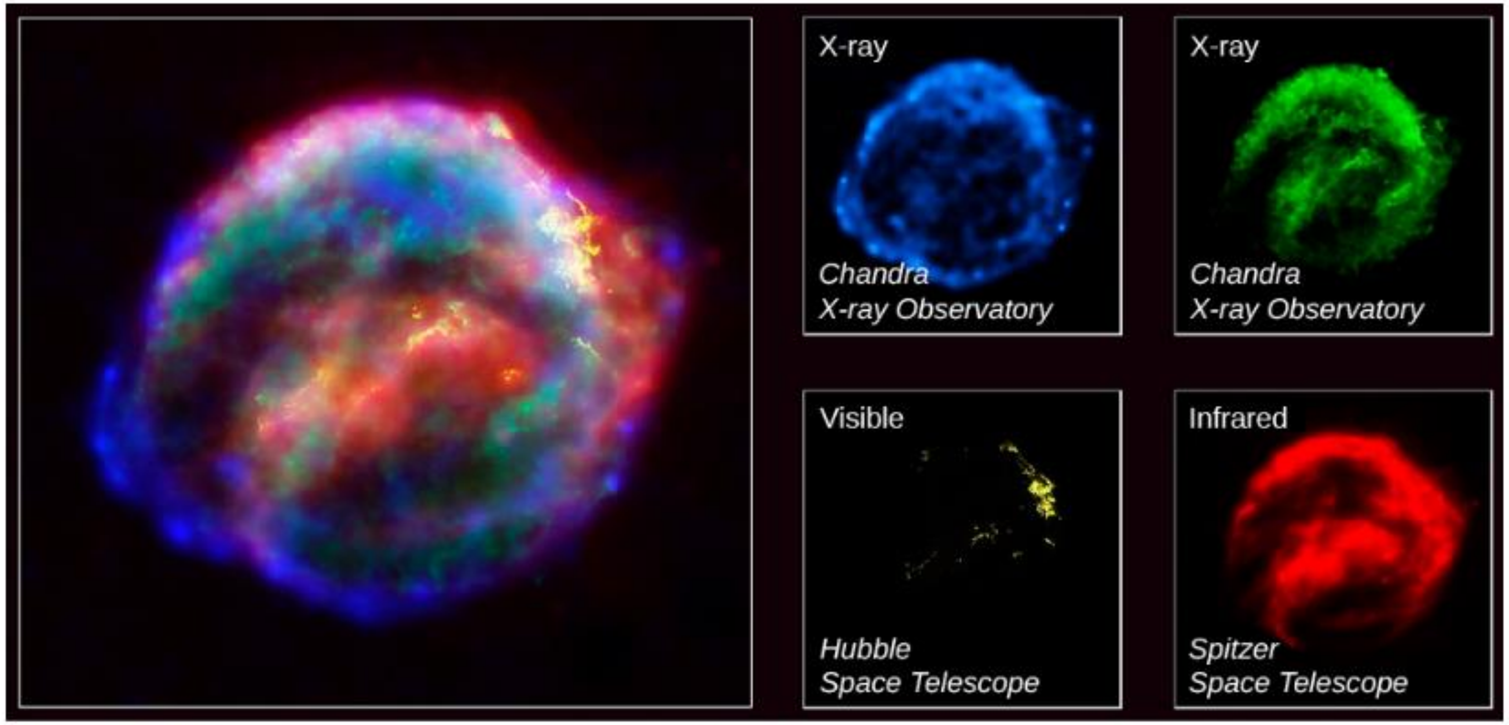


Figure 23.8 Kepler Supernova Remant. This image shows the expanding remains of a supernova explosion, which was first seen about 400 years ago by sky watchers, including the famous astronomer Johannes Kepler. The bubble-shaped shroud of gas and dust is now 14 light-years wide and is expanding at 2,000 kilometers per second (4 million miles per hour). The remnant emits energy at wavelengths from X-rays (shown in blue and green) to visible light (yellow) and into the infrared (red). The expanding shell is rich in iron, which was produced in the star that exploded. The main image combines the individual single-color images seen at the bottom into one multi-wavelength picture. (credit: modification of work by NASA, ESA, R. Sankrit and W. Blair (Johns Hopkins University))

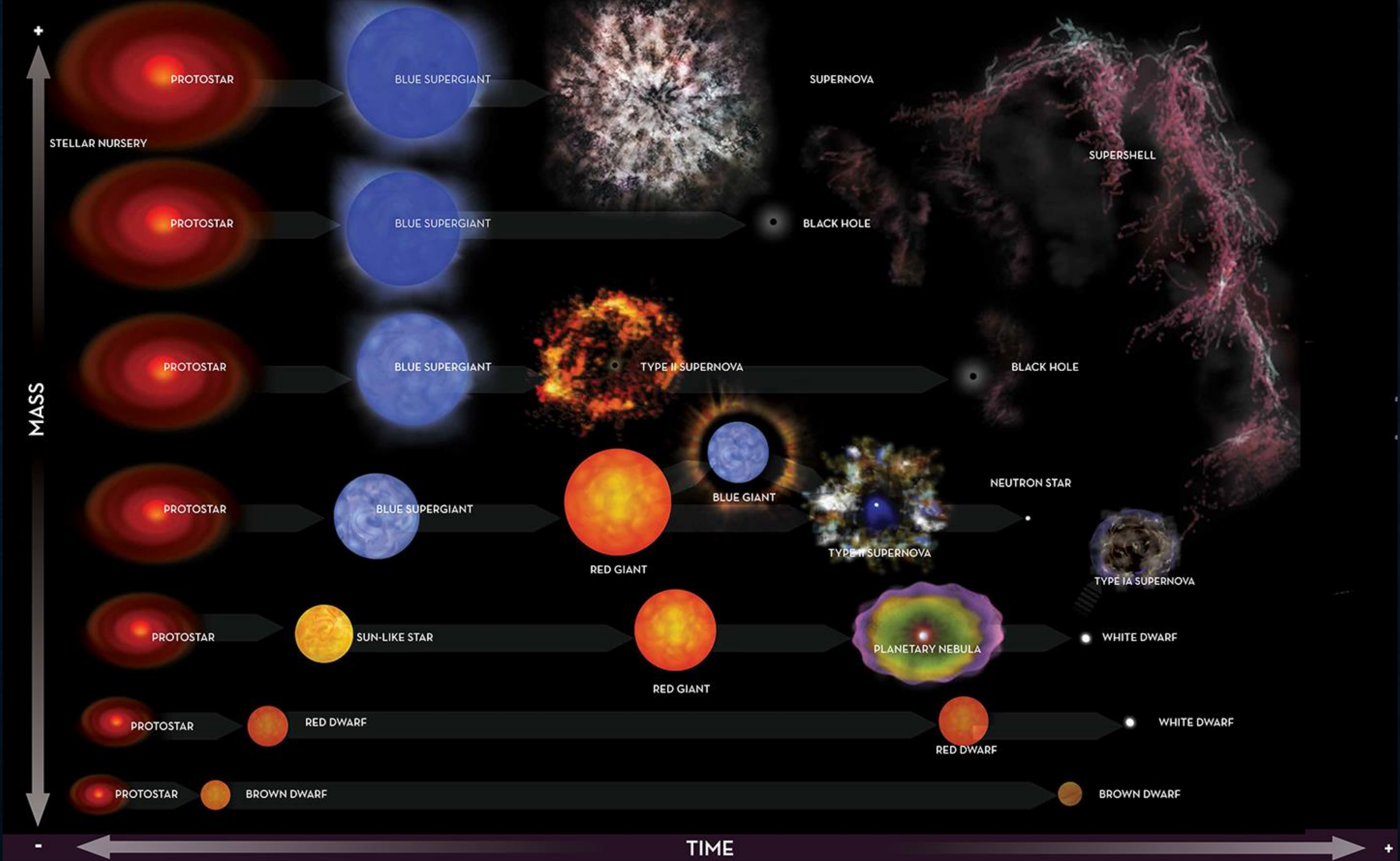
BLACK HOLES

- When a very, very massive star collapses, not even the mutual repulsion of densely packed neutrons can support the core against its own weight.
- If the remaining mass of the star is more than about three times that of the Sun, no known force can stop it from collapsing forever!!
- Gravity overwhelms all other forces and crushes the core until it occupies an infinitely small volume.
- A BLACK HOLE!!!

ULTIMATE FATE OF STARS AND SUBSTELLAR OBJECTS WITH DIFFERENT MASSES

The Ultimate Fate of Stars and Substellar Objects with Different Masses

Initial Mass (Mass of Sun = 1)[1]	Final State at the End of Its Life
< 0.01	Planet
0.01 to 0.08	Brown dwarf
0.08 to 0.25	White dwarf made mostly of helium
0.25 to 8	White dwarf made mostly of carbon and oxygen
8 to 10	White dwarf made of oxygen, neon, and magnesium
10 to 40	Supernova explosion that leaves a neutron star
> 40	Supernova explosion that leaves a black hole


PROTOSTAR
BLUE SUPERGIANT
SUPERNOVA
STELLAR NURSERY
SUPERSHELL
PROTOSTAR
BLUE SUPERGIANT
BLACK HOLE
PROTOSTAR
BLUE SUPERGIANT
TYPE II SUPERNOVA
BLACK HOLE
PROTOSTAR
BLUE SUPERGIANT
RED GIANT
BLUE GIANT
TYPE II SUPERNOVA
NEUTRON STAR
TYPE IA SUPERNOVA
PROTOSTAR
SUN-LIKE STAR
RED GIANT
PLANETARY NEBULA
WHITE DWARF
PROTOSTAR
RED DWARF
RED DWARF
WHITE DWARF
PROTOSTAR
BROWN DWARF
BROWN DWARF
MASS
+
-
TIME
-
+

GALACTIC EVOLUTION

3 TYPES OF GALAXIES

- **Elliptical** – Spherical or oval shaped. Very little star-making gas which makes them appear yellow-red.
- **Normal Spirals** – Flat, rotating disk with a central concentration of stars known as a the bulge. Spiral structures extend from the center of the galaxy which contain ongoing star formation. Tends to have a blueish tinge.
- **Barred Spirals** – Similar to a normal spiral, but the arms attach to a bar-like structure extending from the bulge. About 2/3 of the spiral galaxies are barred galaxies.

TOP-DOWN THEORY

- Disk galaxies form through a collapse of a large gas cloud.
- Matter in the early universe was mostly clumps of dark matter.
- As gravity began to pull the matter together, the matter in the center of the cloud speeds up in its rotation. Then, like a spinning pizza, the matter forms a tight disk.
- As the disk cools, the gas in the disk begins to form into stars.
- This theory is no longer widely accepted.

BOTTOM-UP THEORY

- Instead of a large gas cloud collapsing to form a galaxy containing smaller gas clouds, it is proposed that matter starts out in these smaller clumps and those clumps merge to form galaxies. Gravity pulls them together into the disc-like, spiral pattern.
- Models using this process predict more small galaxies than large ones, which matches observations.

- So what about elliptical galaxies?

GALAXY MERGERS

- Astronomers see elliptical galaxies as the most evolved systems in the universe.
- The main driving force for their evolution is the merger of smaller galaxies.
- If the galaxies are of a similar size, the resulting merger will result in an elliptical galaxy.
- The Milky Way and the Andromeda Galaxy are gravitationally bound and currently approaching each other at high speed. They are expected to collide in less than five billion years and could result in an elliptical galaxy.