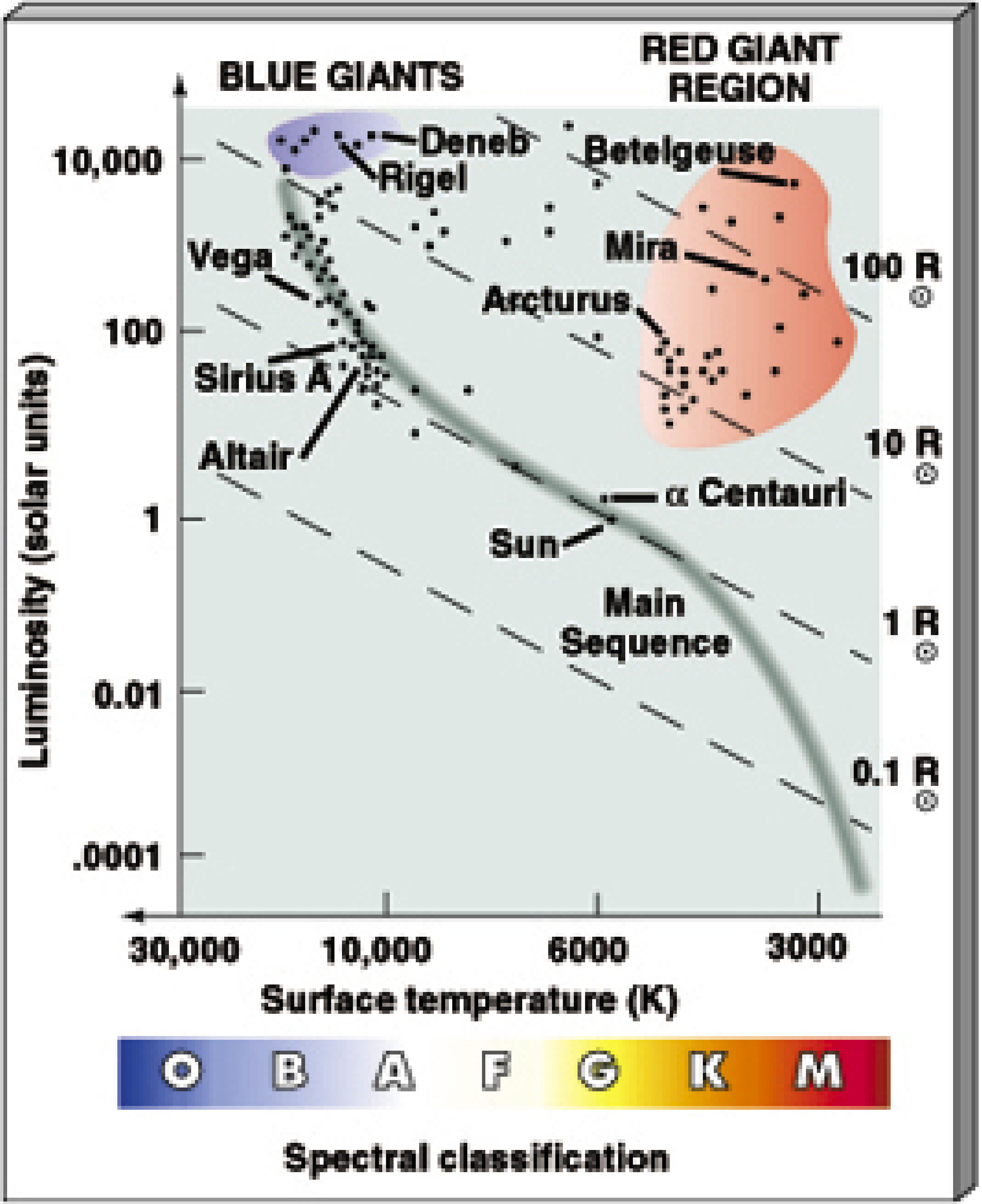
Stellar Evolution

The Life and Death of Stars

The HR-Diagram

- The Hertzsprung-Russel Diagram plots stars on a chart with brightness on the vertical axis and temperature on the horizontal axis
- Stars of the same type (undergoing the same type of core fusion) tend to group together on the HR-Diagram.
- Where a star is on the HR-Diagram gives astronomers information as to where the star is in its evolution.


BLUE GIANTS
RED GIANT REGION
Luminosity (solar units)
10,000
100
1
0.01
.0001
Deneb
Rigel
Betelgeuse
Mira
Arcturus
Vega
Sirius A
Altair
α Centauri
Sun
Main Sequence
100 R☉
10 R☉
1 R☉
0.1 R☉
30,000
10,000
6000
3000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification

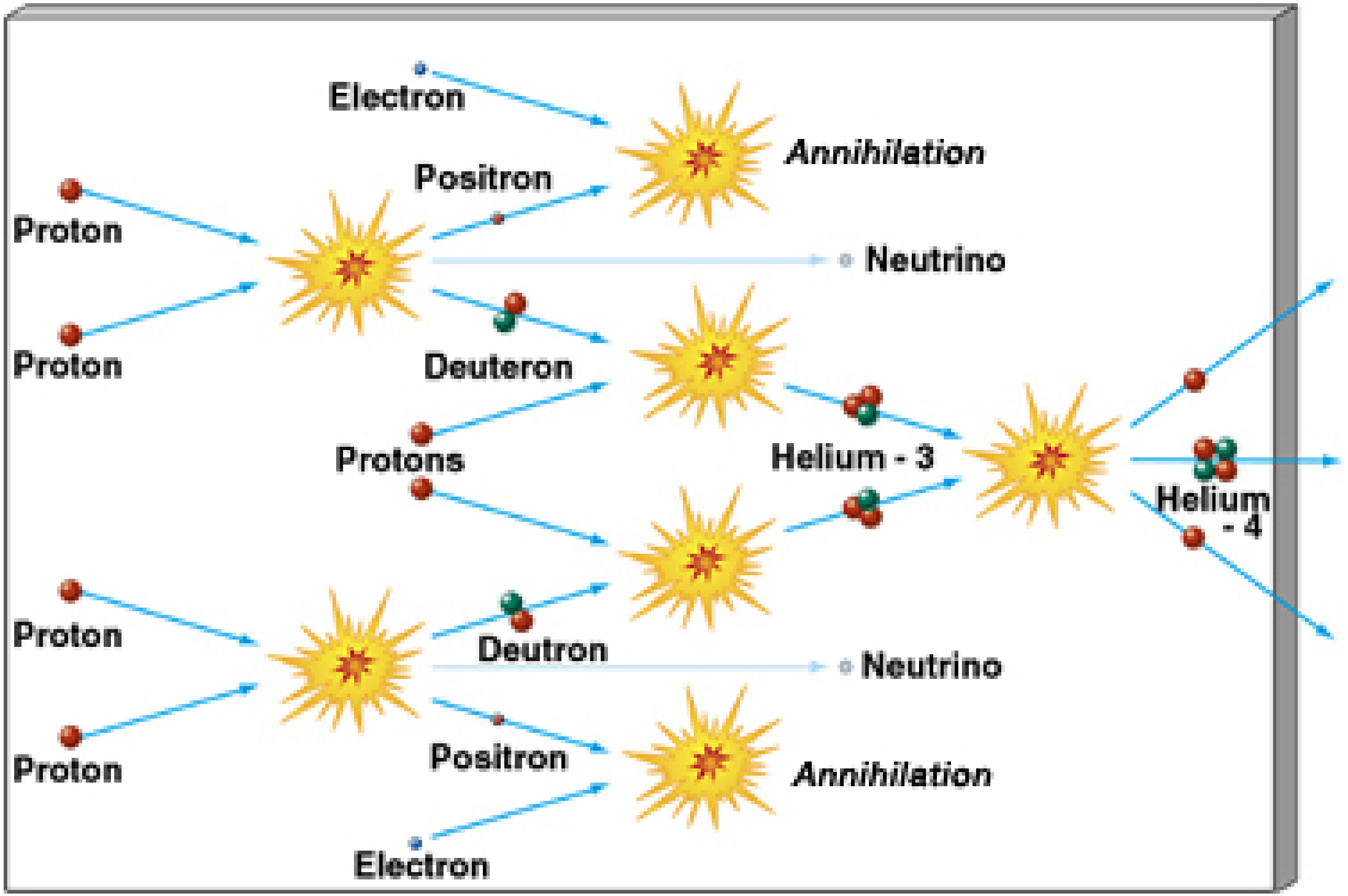
Formation of a Protostar

- As seen in the Solar Nebular Theory, stars are produced from collapsing clouds of interstellar gas and dust.
- As a proplyd condenses due to its own gravity, the majority of material concentrates in the center forming a protostar.
- The protostar is heated as a result of the gravitational compression. Any gas when it is compressed, heats up. The gas forming a protostar is no different.

Entering the Main Sequence

- When the core temperature of a protostar reaches 10 million Kelvin, hydrogen fusion can begin via the proton-proton chain like our Sun.
- More massive stars capable of producing higher temperatures and pressures fuse hydrogen by a process call the CNO Cycle.
- When any protostar begins to fuse hydrogen into helium in its core, it becomes a Main-Sequence Star.

The Proton-Proton Chain



Hydrostatic Equilibrium

- When a star begins nuclear fusion in its core, there is an outward radiation pressure.
- The star’s size is determined by the balance between the inward pull of gravity and the outward push of the radiation pressure.
- When these two forces are balanced, the star is said to be in hydrostatic equilibrium.

Moving Off of the Main Sequence

- Eventually, a star will run out of hydrogen in its core to fuse, and the nuclear reaction will stop.
- When this occurs, gravity begins to squeeze the core even more since the radiation pressure is gone.
- If the core temperature reaches at least 100 million Kelvin, then Helium fusion can begin and the star swells into a Red Giant and moves off of the Main Sequence.

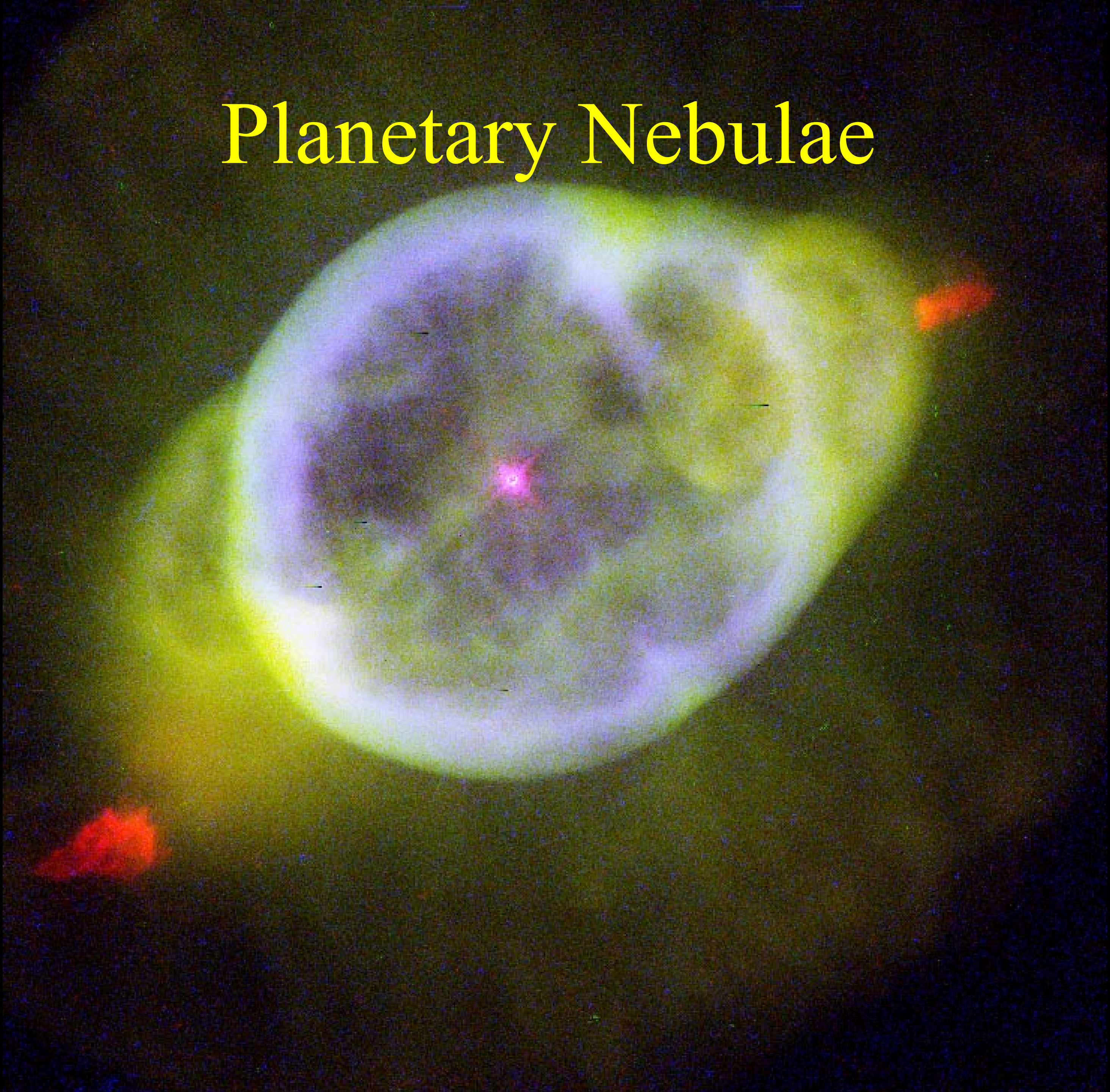
Red Giants

- While a star is fusing helium, the radiation pressure outward is much stronger than when the star was fusing hydrogen.
- This causes the star to swell to immense proportion.
- When our star moves into the Red Giant stage, it will swell to be as large around as the orbit of Mars. The Earth will be inside the Sun’s surface.

The Death of Lightweight Stars

- For lightweight stars, the process of helium fusion produces a radiation pressure that can overcome the inward pull of gravity and push the outer layers of the star off of the core.
- What is produced is a planetary nebula.
- The dead core is left behind and is called a white dwarf.
- This is the fate our Sun will suffer.

Planetary Nebulae



White Dwarfs

- White dwarfs are not really stars since they are not producing their own energy and glow only because they are still hot, sometimes as hot as tens of thousands of Kelvin.
- White dwarfs are highly compressed matter. Atoms packed in just as tightly as they can be.
- One teaspoon of white dwarf material has as much mass as an elephant.
- The upper mass limit for white dwarfs is 1.44 solar masses. Any more mass than that and gravity will crush the atoms of the white dwarf and form a neutron star.

Beyond Helium Fusion

- More massive stars have a large enough gravitational force to balance the increased radiation pressure of helium fusion.
- Eventually, the star will run out of helium to fuse in its core, and the core will become compressed and heated again.
- If the temperature is high enough, the star will begin to fuse carbon.
- This process will continue through heavier and heavier materials through to silicon until the star tries to fuse iron.

The Death of Massive Stars

- Iron fusion absorbs energy rather than producing it.
- This means that the radiation pressure is inward rather than outward causing the star to collapse rapidly.
- The core of the star cannot absorb material at the same rate that material is falling onto it, so most of the material bounces off the core forming a shockwave.

Type II Supernovae

- When the inward falling material of the star bounces off the core, a shockwave it produce that moves outward at nearly the speed of light.
- This shockwave completely destroys what is left of the star and is called a Type II Supernova.
- Along this shockwave, the temperatures and pressures are high enough that all of the heavier elements can be made through fusion.
- All of the gold, silver, lead, uranium and other elements heavier than iron were produced by a supernova explosion.

Stellar Remnants

- There are three types of object that the core of a star can become after a star has died:
  - White Dwarf
  - Neutron Star
  - Black Hole
- Which type of object the core becomes depends upon its mass.

White Dwarfs

- The cores of stars like our Sun will end up as white dwarfs.
- White dwarfs are made of mainly carbon atoms that are packed in as tightly as possible.
- The upper limit for the mass of a white dwarf is 1.44 solar masses.
- White dwarfs are typically about the same size as our planet.

Neutron Stars

- The cores of more massive stars can become neutron stars.
- A neutron star is composed completely of neutrons. The gravitational force is strong enough to force the protons and electrons to fuse into neutrons.
- Neutrons stars have a mass greater than 1.44 but less than 3.0 solar masses.

Pulsars

- Most neutron stars have a magnetic field.
- As material from another star or a nebula is drawn in by the pulsar, it begins to heat up.
- This material often will begin to emit x-rays.
- These x-rays are emitted in a beam along the magnetic axis.
- As the neutron star rotates, this beam of x-rays rotates as well, very similar to a lighthouse beacon.
- If the beam of x-rays happens to sweep by the Earth, then we see a Pulsar, a pulsating x-ray source.

Black Holes

- Black holes are formed by the most massive of stars.
- The minimum mass requirement for a black hole is 3.0 solar masses.
- A black hole has no physical size, it’s a singularity.
- There is a boundary called the Event Horizon, the point at which the escape velocity is equal to the speed of light.