INTRODUCTION

Prerequisite Knowledge

- Basic familiarity with how gravity and pressure balance to achieve hydrostatic equilibrium
- Basic familiarity with the link between stellar energy and nuclear fusion

Goals

- Understand that protostars form in regions of gas and dust
- Understand how temperature and pressure determine the nuclear fusion rate in a star
- Understand how mass and nuclear fusion rate determine the lifetime of a star

Pre-activity Question

1) How does the Sun produce the energy that heats our planet?
   a) The gases inside the Sun are on fire; they are burning like a giant bonfire.
   b) **Hydrogen atoms are combined into helium atoms inside the Sun's core. Small amounts of mass are converted into huge amounts of energy in this process.**
   c) When you compress the gas in the Sun, it heats up. This heat radiates outward through the star.
   d) Magnetic energy gets trapped in sunspots and active regions. When this energy is released, it explodes off the Sun as flares that give off tremendous amounts of energy.
   e) The core of the Sun has radioactive materials that give off energy as they decay into other elements.

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1) **[Move closer]**

2) **[Gravitational attraction]**

   The answer for this question is not obvious to all students. Some discussion about gravitational interactions should occur during the lecture before doing this Lecture-Tutorial*.*

3) **[The temperature will increase.]** As the protostar collapses, its internal pressure increases as does its temperature.

   Many students lack a fundamental understanding of the relationship between pressure and temperature but will nonetheless answer this question correctly based on the knowledge that stars eventually end up very hot. This does not present a barrier to completing the activity.

4) **[Low mass stars]**

5) **[The reaction rate is greater for high mass star.]**
Note: Since high mass stars have more fuel, and they live shorter lifetimes, they must consume it at a greater rate in order to use up that fuel in less time.

6) **[e]** Lower mass stars live longer. As seen in the table, a star 6 times more massive than the Sun has a lifetime that is more than 100 times shorter than the Sun's lifetime.

Initially, students will think that high mass stars must live longer because they want to attribute "most" in every category to them—more massive, bigger, hotter, must live longer. As students start to understand that high mass stars live shorter lives, they then will want a linear relationship between mass and lifetime. That is, if the star is six times more massive, it will have a lifetime that is six times shorter.

[d] A star with twice the mass of the Sun will live less than half the lifetime of the Sun (from the table), so it has to use up its fuel in less than half the time as the Sun. So, its rate of fusion must be more than twice that of the Sun.

INTRODUCTION

Prerequisite Knowledge

- Basic familiarity with the evolutionary states of stars

Goals

- Understand the evolutionary pathways of stars with different masses

Pre-activity Question

1) The eventual fate of our Sun is to
   a) collapse into a black hole.
   b) form a neutron star.
   c) **become a steadily cooling white dwarf.**
   d) explode as a Type I supernova leaving no remnant.

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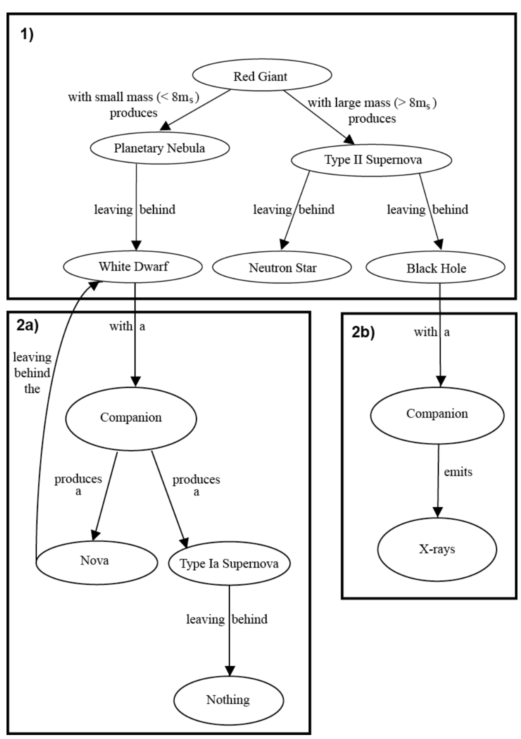
Many students learn the names of the various stages of stellar evolution, but fail to organize these stages into the appropriate sequences. Having students fill in the flowchart with these various stages, and connect them with linking words, helps students organize the information in a visually useful fashion.



Above is one representation of the key stages of stellar evolution. Although students may depict this information in different ways, they should be able to explain how their representations relate the key ideas of the various evolutionary stages. For 2a) it is important that the path that contains the Nova includes an arrow drawn back to the White Dwarf to indicate that this process repeats itself.

Below is a representation of one of the most exhaustive representations a student could create given the information within this Lecture-Tutorial*. For most instructors, having students know each of these stages is not important, and the previous diagram provides sufficient information.*