The Life Cycles of Stars

- Planetary nebula
- Fusion
- Red Giant
- White Dwarf
- Binary Star
- Spectral Class
- H-R Diagram

- Supernova
- Core Bounce
- Nova
- Main Sequence
- Luminosity
Star Birth
Orion Nebula Star Birth

http://jrscience.wcp.muohio.edu/movies/orion.nebula.32.305.mov
Lagoon Nebula-Star Birth

Tornadoes?
Orion Nebula-Close Up
Eagle Nebula-Star Eggs
Star Death
Life Cycle Themes

<table>
<thead>
<tr>
<th>STAR MASS</th>
<th>DESTINY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 4 Solar Masses</td>
<td>White Dwarf (No supernova)</td>
</tr>
<tr>
<td>4 to 8 Solar Masses</td>
<td>Supernova; Pulsars or Neutron Stars</td>
</tr>
<tr>
<td>Greater than 8 Solar Masses</td>
<td>Supernova; Black Holes</td>
</tr>
</tbody>
</table>
Observations in the Night
Properties of Stars

- Stellar Distances and Magnitudes
- Types of Stars - sizes, colors, temperatures, masses, luminosities, numbers
- Stellar Spectra
- Hertzsprung-Russel Diagram
Relative Sizes
Astronomical Distance Units

- **Astronomical Unit** - average distance between Earth and Sun, \( \sim 93 \text{ million } (9.3 \times 10^7) \text{ miles} \).
- **Light year** - distance light travels in one year, \( \sim 6 \text{ trillion } (6 \times 10^{12}) \text{ miles} \), or \( \sim 64,520 \text{ A.U.} \).
- **Parsec** - \( \sim 3.3 \text{ light years} \).
Sun Crosssection

- Corona: $T = 2,000,000$ K
- Chromosphere
- Photosphere (visible surface): $T = 5700$ K
- Center: $T = 15,000,000$ K
- Hydrogen-burning core
- Prominences
- Hydrogen and helium gas: no nuclear reactions
- Convective zone
- Earth at same scale

North Pole

Energy flow
The Earth is as Big as My Cursor!
Our Dynamic Sun

The Sunspot Cycle

Number of Sunspots

Year

1700 1740 1790 1840 1890 1940 1990
Solar Prominences

http://jrscience.wcp.muohio.edu/movies/loopslcn.mov
A Dying Star

Start Stuff-Celestial Fertilizer
Astronomers measure the temperature of stars by

1. Looking at their overall color.
   blue-white : yellow : red
   ----------> decreasing temperature
2. Examining the strength (or darkness) of absorption lines in the star’s spectrum.
Types of Spectra

- **Continuum Spectrum**
- **Emission Line Spectrum**
- **Absorption Line Spectrum**
Spectral Signatures Different Stars
<table>
<thead>
<tr>
<th>COLOR INDEX</th>
<th>SURFACE TEMPERATURE</th>
<th>COLOR</th>
<th>FAMILIAR EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B intensity/V intensity)</td>
<td>(K)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.7</td>
<td>30,000</td>
<td>electric blue</td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>20,000</td>
<td>blue</td>
<td>Rigel</td>
</tr>
<tr>
<td>1.0</td>
<td>10,000</td>
<td>white</td>
<td>Vega, Sirius</td>
</tr>
<tr>
<td>0.8</td>
<td>7,000</td>
<td>yellow-white</td>
<td>Canopus</td>
</tr>
<tr>
<td>0.6</td>
<td>6,000</td>
<td>yellow</td>
<td>Sun, Alpha Centauri</td>
</tr>
<tr>
<td>0.4</td>
<td>4,000</td>
<td>orange</td>
<td>Arcturus, Aldebaran</td>
</tr>
<tr>
<td>0.2</td>
<td>3,000</td>
<td>red</td>
<td>Betelgeuse, Barnard’s Star</td>
</tr>
</tbody>
</table>
Spectral Classes

<table>
<thead>
<tr>
<th>Letter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Blue-white; high temperatures (35,000°K), large masses, high luminosities; lines of ionized helium, nitrogen, oxygen, in addition to hydrogen. Typical examples = Zeta Puppis, Lambda Orionis, 15 Monocerotis.</td>
</tr>
<tr>
<td>B</td>
<td>Blue-white; high luminosities; temperature 20,000°K, large masses. Strong helium lines with greatest intensity at B2, vanishing at AO. Sometimes called &quot;Orion stars&quot;. Typical examples = Rigel, Spica, Regulus, Alpha Eridani.</td>
</tr>
<tr>
<td>A</td>
<td>White- &quot;Sirian&quot; or &quot;hydrogen&quot; stars; temperature 10,000°K; luminosities average 50 to 100 times Sun. Strong hydrogen lines, helium absent. Examples = Sirius, Vega, Altair.</td>
</tr>
<tr>
<td>F</td>
<td>Yellow-white; temperature 7000°K; weaker hydrogen lines, strong lines of calcium with other metallic lines increasing. Examples = Canopus, Procyon, Alpha Persei.</td>
</tr>
<tr>
<td>G</td>
<td>Yellow- &quot;Solar type&quot; stars; temperature 6000°K; weaker hydrogen lines, prominent lines of many metals. Examples = the Sun, Capella, Alpha Centauri.</td>
</tr>
<tr>
<td>K</td>
<td>Orange- &quot;Arcturian&quot; stars; temperature 4000° to 4700°K; complex spectra with many strong lines of metals, faint hydrogen lines, hydrocarbon bands appear. Examples = Arcturus, Pollux, Alpha Ursa Majoris.</td>
</tr>
<tr>
<td>M</td>
<td>Red stars- temperature 2500° to 3000°K; rich spectra showing many strong metallic lines with wide bands produced by titanium oxide. Many M-type variables show bright hydrogen lines, indicated by spectrum &quot;Me&quot;. Examples = Antares, Betelgeuse, Mira.</td>
</tr>
<tr>
<td>N</td>
<td>Deep red- cool giants of temperature 2500°K; peculiar banded spectra showing carbon compounds; mostly variable stars. Examples = S Capheii, R Leporis, Y Canum Venaticorum.</td>
</tr>
<tr>
<td>R</td>
<td>Orange-red; similar to type N, somewhat higher temperature, carbon bands weaker. May form connecting link between classes G and N. Examples = S Camelopardi, RU Virginis.</td>
</tr>
<tr>
<td>S</td>
<td>Red; resembles type M, but titanium oxide bands are replaced by zirconium oxide. Complex spectra, usually variable, with hydrogen emission lines. Example = R Cygni.</td>
</tr>
<tr>
<td>W</td>
<td>Wolf-Rayet Stars; hot blue giants, high temperatures and luminosities, resemble O-type, but show broad emission features caused by expanding gaseous shell, extremely turbulent atmospheres. Temperature 50,000°K and higher. Example = Gamma Velorum.</td>
</tr>
</tbody>
</table>
H-R Diagram - Masses along the Main Sequence
H-R Diagram
Betelgeuse-If this star was our sun, Jupiter would be inside of this Red Giant
Luminosity vs Solar Mass

![Graph showing the relationship between luminosity and solar mass, with points labeled for Vega, Sun, Proxima Centauri.](image)
Life Cycle Themes-The Importance of Mass

<table>
<thead>
<tr>
<th>STAR MASS</th>
<th>DESTINY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1 Solar Masses</td>
<td>White Dwarf (No supernova)</td>
</tr>
<tr>
<td>4 to 8 Solar Masses</td>
<td>Supernova; Pulsars or Neutron Stars</td>
</tr>
<tr>
<td>Greater than 8 Solar Masses</td>
<td>Supernova; Black Holes</td>
</tr>
</tbody>
</table>
Supernova
Supernova Centaurus Video

http://jrscience.wcp.muohio.edu/movies/centaurassupernova.mov
The Onion “Core”
Remember where elements beyond H and some He come from!
Core Bounce & a Big Explosion!

Heavy Elements Synthesized
Supernova
Supernova
Crab Nebula-1054 A.D.
Crab Nebula Pulsar

http://jrscience.wcp.muohio.edu/movies/crabanim.mov

This is what the Crab Nebula Pulsar sounds like
http://jrscience.wcp.muohio.edu/movies/crab.mov
Supernova 1987a
Supernova 1987a
Black Hole Signature-M84

http://jrscience.wcp.muohio.edu/movies/black.hole.31.313.mov
Neutron Stars

Neutron star vs. Chicago

Mass = 1.4 \( M_\odot \), Radius = 10 km
Spin rate up to 38,000 rpm
Density \( \sim 10^{14} \) g/cc, Magnetic field \( \sim 10^{12} \) Gauss
A “Heavy” Companion

Accreting neutron star or black hole

Companion star

Accretion disk
\(~10^{10} \text{ cm}\)

\(~10^6 \text{ cm}\)
NS or black hole

\(~10^{11} \text{ cm}\)
Binary separation

Luminosity \(\sim 10^{36} - 10^{38} \text{ erg s}^{-1} = 200 - 50,000 \text{ L}_\odot\)

Temperature of disk \(\sim 10^7 \text{K} \Rightarrow \text{primarily X-rays}\)
Can you Guess the Relative Ages of These Stars?
Ages of Clusters- Can You Interpret this H-R Diagram
Main Sequence