The Lives of Stars
Cradle to Grave

Seminar Outline

Conception

The Birth of a Star

The “Working” Years

The “Retirement” Years

The Death of a Star

Resurrection

Credits

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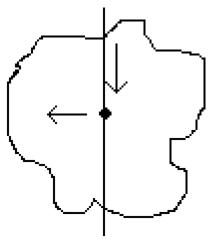
Conception

- Begins as a dense, irregularly-shaped giant molecular cloud of dust and gas.



- Cloud was rotating, causing gas to form "disk."
- Gravitational attraction begins in "center" of rotating disk.
- For the first stars after the Big Bang ("first light", approx. 500 million years), the gas was almost entirely hydrogen (~75%) and helium (~25%). Helium, being heavier, sinks to the center.
- After that, the gas also had heavier elements, which sink to the center.
- As cloud grew smaller, rotation speeds increased.
- The star begins to collapse gravitationally, cause the center of the rotating cloud to heat up.
- "Protostar"
- We now have gravity trying to collapse the cloud, and heat in the center trying to expand it.
- At this point, gravity is winning.

The Birth of a Star

- Gravity is trying to collapse the star, and …
- Heat in the center is pressuring the star to expand.
- Eventually, the heat in the center is enough to ignite nuclear fusion (hydrogen to helium).
- This fusion process is dependent on a sufficiently high temperature as to cause protons to collide and “stick” through the strong nuclear force.

- The fusion increases in intensity until the outward pressure of fusion exactly balances the inward pressure of gravity.
- This is a self-regulating process.

At this point, the star is “born”. Its mass (only!) at this instant determines where it will live on the “main sequence” of the Hertzsprung-Russell diagram (attached). The star will live out its life in this state, with only minor movement on the main sequence.

- How big (massive) can a star be?
- Less than 0.4 solar masses ($M_\odot$), it won’t light.
- Up to ~ 150 $M_\odot$ now.
- At “first light” (first Big Bang stars), ~ 250 $M_\odot$.

The "Working" Years

- The star's job is to make energy.
- Fusing hydrogen into helium releases energy.
- This energy is released as electromagnetic energy.
- Part of this electromagnetic energy is visible light.

- The higher the mass, the hotter the star, and the brighter the star.
- The brightest stars have a blue surface color.
- The lower-mass stars are red – but we can't see *any* of these!

- The working life of the star depends on how much hydrogen it has, and how fast it burns it.
- (Note we say "burning hydrogen" and/or "fusing helium", though this convention is less than universal.)
- The helium, being heavier than hydrogen, migrates to the center of the star, forming an increasing helium core.
- The more massive the star, the *shorter* its life. The life of a star is *inversely* proportional to (roughly) the *cube* of its mass.
- This is because the hydrogen must burn much more quickly to offset the higher gravitational inward pressure.

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The “Retirement” Years

- Eventually, hydrogen gets used up.
- With insufficient outward pressure, the star begins to collapse.
- But outward gasses – least effected by gravity – begin to expand and cool.
- Expanding gasses make the star (visually) bigger. The cooling makes them redder. The increased surface area makes them brighter.
- At this point, the star’s primary life is over, and it leaves the Main Sequence.
- They become red giants ($\leq 8M_\odot$), red supergiants ($10 – 25M_\odot$), or blue supergiants ($\geq 25M_\odot$), puffing out the outer layers to space.
- For stars less than about $0.5M_\odot$, there is no “retirement”.
- More massive stars retire by continuing to burn elements, fusing them into heavier elements (nucleosynthesis).

The Death of a Star

This happens when the star's nuclear fuel is all used up, and all fusion stops.

Stars ≤ $8M_{\odot}$

- Collapse to a White Dwarf.
- Size now comparable to that of Earth.
- Cool and die in this state.
- Contain a residual mass of about 1.4 $M_{\odot}$.
- Finally cool into a "Black Dwarf".

Stars 10 – $25M_{\odot}$

- Produce a Type II Supernova.
- Collapse into a Neutron Star – extraordinarily high mass-density.
- Size now approximately that of a city.
- Cool and die in this state.

Stars ≥ $25M_{\odot}$

- Produce a Type II Supernova.
- Collapse into a Black Hole.
- Size (of the Event Horizon) depends on mass and rotation rate.

Life of a 25 $M_{\odot}$ Star

Stage	Time
H → He	7 million years
He → C, O	500,000 years
C, O → Ne, Mg	600 years
Ne, O → Si, S	6 months
Si → Fe	1 day

Resurrection

A star can be "brought back to life" if it's part of a binary or multiple star system.

- One star is a white dwarf or neutron star.
- Another star is a Main Sequence star that is now going to its giant or supergiant phase.
- The white dwarf or neutron star can gravitationally "steal" the expanding mass from the giant/supergiant.
- This increases its mass.

For a white dwarf:

- This increased mass can reignite fusion.
- This can produce an immediate Type I Supernova, or…
- It can cause the star to re-enter the Main Sequence ("normal life").

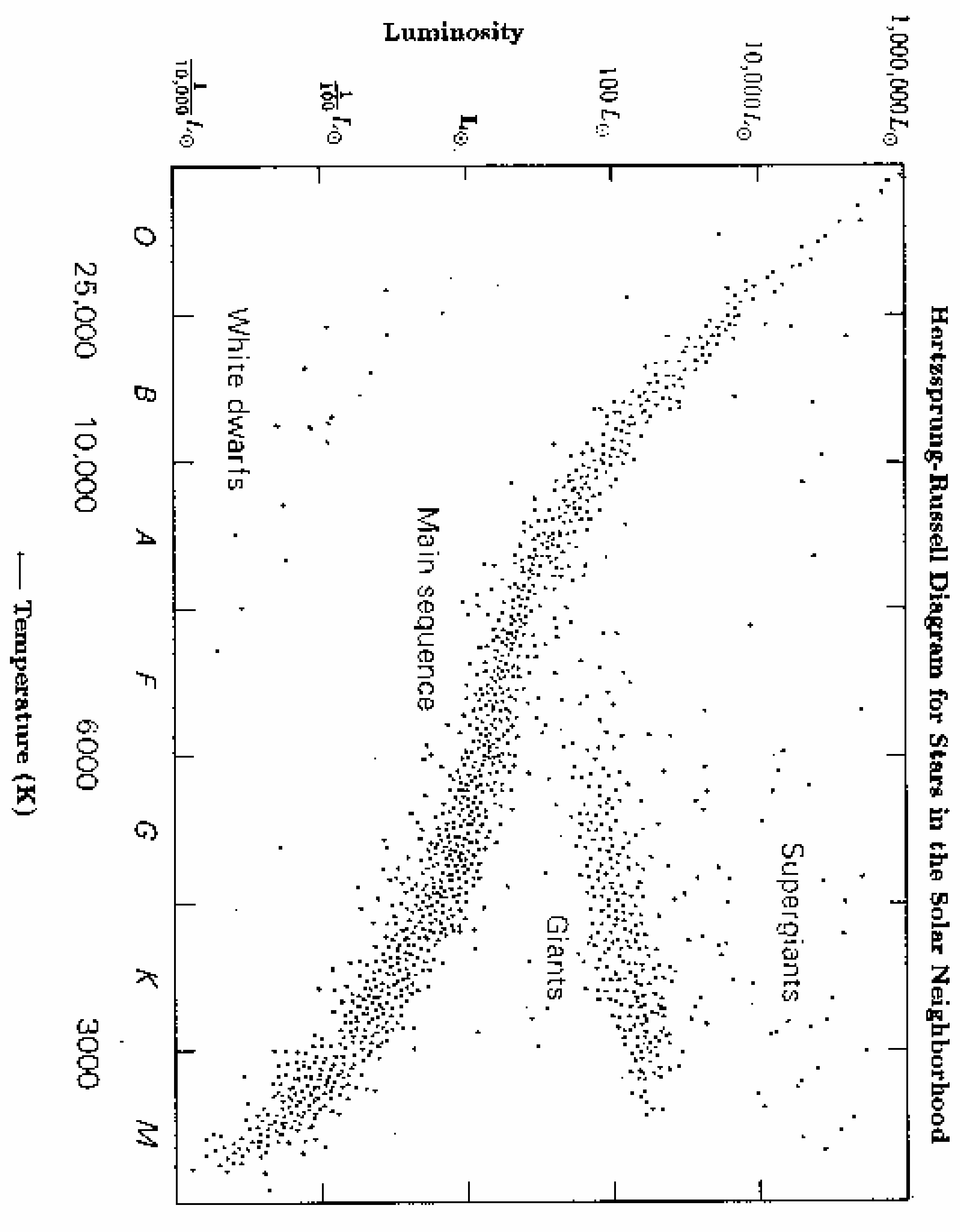
For a neutron star:

- The increased mass can overcome neutron pressure, and cause the star to collapse into a Black Hole.

Credits

- **Prof. Alex Filippenko**, UC Berkeley, and his Teaching Company DVD series "Understanding the Universe: An Introduction to Astronomy"
- **Prof. Neil deGrasse Tyson**, Director of the Hayden Planetarium, and his Teaching Company DVD series "My Favorite Universe"
- **Wikipedia.com**, for more reference material than can be listed.

Tables


Hertzsprung-Russell Diagram for Stars in the Solar Neighborhood
Luminosity
1,000,000 $L_\odot$
10,000 $L_\odot$
100 $L_\odot$
$L_\odot$
$\frac{1}{100}$ $L_\odot$
$\frac{1}{10,000}$ $L_\odot$
Supergiants
Giants
Main sequence
White dwarfs
O
B
A
F
G
K
M
25,000
10,000
6000
3000
← Temperature (K)