Astronomy 114

Lecture 20: Death of stars

Martin D. Weinberg

weinberg@astro.umass.edu

UMass/Astronomy Department
Announcements

- PS#5 posted today (and available up-front)
- Due next Wednesday: 4 Apr
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Today:
- How stars evolve
  - Planetary nebula
  - White dwarfs
  - High-mass evolution
  - Supernovae
- *Stellar Evolution, Chaps. 21 & 22*
Thermal pulsations

- Fusion in shell around the core only creates variability
- More difficult heating through contraction to regulate pressure
- Tends to overshoot

![Graph showing luminosity over time](image)
Envelope ejection

- Core continues to contract
- H and He burning in shell
- Envelope pulsates and eventually becomes unbound from the core!
- Envelope forms a "planetary nebula" around core
- Core moves to the left on HR diagram
- White Dwarf
Planetary nebula

A114: Lecture 20—28 Mar 2007
Read: Ch. 22,23
Astronomy 114—6/19
Planetary nebula
Low-mass evolution: quick review

- Core H exhausted, H shell burning

![Graph illustrating the evolution of a low-mass star, showing the transition from the main sequence to the red giant branch.]
Low-mass evolution: quick review

- Core H exhausted, H shell burning
- Helium flash, He core burning
Low-mass evolution: quick review

- Core H exhausted, H shell burning
- Helium flash, He core burning
- Core He exhausted, He and H shell burning
Low-mass evolution: quick review

- Core H exhausted, H shell burning
- Helium flash, He core burning
- Core He exhausted, He and H shell burning
- Pulsation, envelope ejection
Low-mass evolution: quick review

- Core H exhausted, H shell burning
- Helium flash, He core burning
- Core He exhausted, He and H shell burning
- Pulsation, envelope ejection
- Core moves to the left on HR diagram ⇒ White Dwarf
White dwarf stars

- Cores of low-mass stars collapse after losing their envelopes
- Generate luminosity (Kelvin-Helmholtz mechanism)
  \[ R = 0.01R_\odot \approx R_{\text{Earth}} ! \]
- At these densities, laws of Quantum Mechanics become important, as in Hydrogen atom
Pauli exclusion principle

- Two identical electrons, located in the same region of space, cannot have the same velocity.
- All electrons must have different trajectories.
- The electrons are packed so tightly that some of the electrons are forced to have high velocities → high pressure.
- Pressure depends only on density and is independent of temperature!
  - Pressure of electrons remains constant as the temperature falls or rises.
  - Helium flash!
- Teaspoon of white dwarf stuff weighs as much as SUV!
Maximum mass of a white dwarf

- White dwarfs with larger masses have smaller radii.
- The pressure within a white dwarf depends only on density, not on temperature, so larger density is needed to balance gravity.
- At $M = 1.4M_\odot$, degeneracy pressure can no longer provide enough pressure.
- Radius of white dwarf approaches zero, in other words, a white dwarf can not be more massive than $1.4M_\odot$.
- Known as: Chandrasekhar limit.
Implication for stellar evolution

AGB stars lose mass in winds and envelope ejection

- Star with initial mass $M = 4M_\odot$ loses $2.6M_\odot$
- Leaves $1.4M_\odot$ remnant
- Star with $M > 4M_\odot$ will not lose enough mass to have a remnant white dwarf above the Chandrasekhar limit
Evolution of High-Mass Stars

Stars with mass greater than 4 solar masses: *Burn hot, Live fast, Die young*

- Burns H to He in core
- Builds up a He core in roughly 10 million years
- Giant phase: huge envelope, $R = 5$ AU!
Evolution of High-Mass Stars

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High-Mass Helium Fusion

- Helium burning ignites in core
- Hydrogen burning in shell
- Build up of Carbon (and Oxygen) core
- Star becomes a blue supergiant
High-Mass Helium Fusion

- Helium burning ignites in core
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Carbon burning

- He runs out in core
- He and H burning in shells
- Becomes a red supergiant (again)
- Core collapses and ignites Carbon burning
  - $T_{\text{core}} > 6 \times 10^8$ K!
  - Density $> 1.5 \times 10^5$ g/cc
- This phase lasts for about 1000 years, then Carbon exhausted in core
- Leaves: oxygen, neon, magnesium core
Nearly the end . . .

- White dwarf for stars with $M < 8M_{\odot}$
- Neon burning: few years
- Oxygen burning: 1 year
- Silicon burning: 1 day
Nearly the end . . .

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<table>
<thead>
<tr>
<th>Table 22-1: Evolutionary Stages of a 25-$M_\odot$ Star</th>
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</thead>
<tbody>
<tr>
<td>Stage</td>
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<tr>
<td>Hydrogen fusion</td>
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<td>Helium fusion</td>
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<tr>
<td>Carbon fusion</td>
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<tr>
<td>Neon fusion</td>
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<td>Oxygen fusion</td>
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<tr>
<td>Silicon fusion</td>
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<tr>
<td>Core collapse</td>
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<tr>
<td>Core bounce</td>
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<tr>
<td>Explosive (supernova)</td>
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</tbody>
</table>
The very end: iron core

Star after Silicon burning

- H Burning Shell
- He Burning Shell
- C Burning Shell
- Ne Burning Shell
- O Burning Shell
- Si Burning Shell
- Core Radius: $\sim 1 \text{ } R_{\text{Earth}}$
- Envelope Radius: $\sim 5 \text{ AU}$
The Core of an Evolved Star

- An element factory!
- An "onion skin" of different elements
- Iron core - if the star is massive enough
- Origin of commonly found terrestrial elements
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- Origin of commonly found terrestrial elements

The end is catastrophic!

Core Radius: \( \sim 1 \, R_{\text{Earth}} \)

Envelope Radius: \( \sim 5 \, \text{AU} \)
The most stable element is Iron \( (\text{Fe}^{56}) \)

Need energy to split up Fe or to add to Fe.

For elements lighter than iron:
- Fusion releases energy

For elements heavier than iron:
- Fission releases energy

The universe is slowly turning to iron!
What next?

- The most stable element is Iron ($^{56}\text{Fe}$).
- Need energy to split up Fe or to add to Fe.
- For elements lighter than iron:
  - Fusion releases energy
- For elements heavier than iron:
  - Fission releases energy
- The universe is slowly turning to iron!
Three special cases

1. White Dwarf stars
2. Pulsating stars
3. Supernovae
Three special cases

1. White Dwarf stars
2. Pulsating stars
3. Supernovae
4. Neutron stars
5. Black holes