Astronomy 353
(Spring 2007)

ASTROPHYSICS:
From Black Holes
to the First Stars
(Lecture 6: Stellar Structure and Evolution)

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Stellar Remnants: How do they originate?

- **White Dwarfs**
  - ~10,000 km (Earth)

- **Neutron Stars**
  - Mass: ~1.5 times the Sun
  - Solid crust: ~1 mile thick
  - Diameter: ~12 miles
  - Heavy liquid interior: Mostly neutrons, with other particles
  - ~10 km

- **Black Holes**
  - ~3 km
Basic Structure of a Star

• in hydrostatic equilibrium (pressure = gravity)

• High central pressure

Temperature vs Radius

- High central temperature
Basic Structure of a Star

• Why does a star *have* to evolve?

Luminosity (L) = energy/time

• A: Because it loses energy to radiation!
Basic Structure of a Star

• How does star replace lost energy?

Nuclear fusion (hydrogen burning)

• Radiation (photons) random walk to the surface!
Basic Structure of a Star

• What happens when nuclear fuel is exhausted?

A: Stellar core contracts!

• Compressional heating! Central temperature goes up!

• Further stages of nuclear burning! (e.g., Helium burning)
Stellar Evolution

• core contraction  • envelope expansion ("mirror principle")

• stars evolve to become giants!
The Hertzsprung-Russell Diagram (HRD)

- hydrogen burning stars (main-sequence, MS)

Stars are ~ black-body radiators

\[ L = 4 \cdot \pi \cdot R^2 \cdot \sigma \cdot T^4 \]

Stars obey virial theorem

\[ k_B T \sim GMm_H / R \]
\( (R \sim \text{const for MS stars}) \)

Mass-Luminosity relation

\[ L = f(M) \]
for MS stars
The Life-cycle of a Low-mass Star

- Prototype: Our Sun

- Final outcome (Stellar grave): White Dwarf (WD)
The Life-cycle of a Low-mass Star

• Final Death Throe: Planetary Nebula
The Life-cycle of a High-mass Star

- Final outcome (Stellar grave):
  Neutron Star (NS) or Black Hole (BH)

Supernova (SN)
(stellar masses > 8 M☉)
The Life-cycle of a High-mass Star

- High-mass stars burn nuclear fuel all the way to iron ("onion structure of chemical composition")
- Iron core has to collapse, triggering SN explosion
Supernova (SN) Explosions

- extremely energetic and violent events

SN Remnants (e.g., Crab Nebula)
Summary:

• Evolution of Low-mass stars:
  - Main-sequence  Red Giant  Planetary Nebula  White Dwarf (WD)

• Evolution of High-mass stars (M > 8 M\(_\odot\)):
  - Main-sequence  Red Supergiant  SN explosion  Neutron Star (NS) or Black Hole (BH)