The Bizarre Stellar Graveyard
18.1 White Dwarfs

- Our goals for learning:
  - What is a white dwarf?
  - What can happen to a white dwarf in a close binary system?
What is a white dwarf?
White Dwarfs

- White dwarfs are the remaining cores of dead low mass ($< 2 M_{\text{sun}}$) stars.

- Electron degeneracy pressure supports them against the crush of gravity.
White dwarfs cool off and grow dimmer with time.

White dwarfs are characterized by their atmospheres.
White dwarfs with same mass as Sun are about same size as Earth.

Higher-mass white dwarfs are smaller.
The White Dwarf Limit

- Quantum mechanics says that electrons must move faster as they are squeezed into a very small space.

- As a white dwarf's mass approaches $1.4 M_{\text{Sun}}$, its electrons must move at nearly the speed of light.

- Because nothing can move faster than light, a white dwarf cannot be more massive than $1.4 M_{\text{Sun}}$, the white dwarf limit (or Chandrasekhar limit).
What can happen to a white dwarf in a close binary system?
A star that started with less mass gains mass from its companion.

Eventually, the mass-losing star will become a white dwarf.

What happens next?
Accretion Disks

- Mass falling toward a white dwarf from its close binary companion has some angular momentum.

- The matter therefore orbits the white dwarf in an accretion disk.
Accretion Disks

- Friction between orbiting rings of matter in the disk transfers angular momentum outward and causes the disk to heat up and glow.
Thought Question

What would the gas in an accretion disk do if there were no friction?

A. It would orbit indefinitely.
B. It would eventually fall in.
C. It would blow away.
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Nova

- The temperature of accreted matter eventually becomes hot enough for hydrogen fusion.

- Fusion begins suddenly and explosively, causing a nova.

a Diagram of the nova process.
Nova

- The nova star system temporarily appears much brighter.

- The explosion drives accreted matter out into space.

**b** Hubble Space Telescope image showing blobs of gas ejected from the nova T Pyxidis. The bright spot at the center of the blobs is the binary star system that generated the nova.
Thought Question

What happens to a white dwarf when it accretes enough matter to reach the $1.4M_{\text{Sun}}$ limit?

A. It explodes.
B. It collapses into a neutron star.
C. It gradually begins fusing carbon in its core.
Thought Question

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Two Types of Supernova

- **Massive star supernova (Type II):**
  - Iron core of a massive star reaches white dwarf limit and collapses into a neutron star, causing total explosion.

- **White dwarf supernova (Type Ia):**
  - Carbon fusion suddenly begins as a white dwarf in close binary system reaches white dwarf limit, causing total explosion.
One way to tell supernova types apart is with a **light curve** showing how luminosity changes with time.
Nova or Supernova?

- Supernovae are MUCH MUCH more luminous (about 100 thousand times)!!!
- Nova: H to He fusion of a layer of accreted matter, white dwarf left intact
- Supernova: complete explosion of white dwarf, nothing left behind
Supernova Type:
Massive Star or White Dwarf?

- Light curves differ.

- Spectra differ (exploding white dwarfs don't have hydrogen absorption lines).
What have we learned?

- **What is a white dwarf?**
  - A white dwarf is the inert core of a dead star.
  - Electron degeneracy pressure balances the inward pull of gravity.
What have we learned?

- What can happen to a white dwarf in a close binary system?
  - Matter from its close binary companion can fall onto the white dwarf through an accretion disk.
  - Accretion of matter can lead to novae and white dwarf supernovae.
Our goals for learning:

- What is a neutron star?
- How were neutron stars discovered?
- What can happen to a neutron star in a close binary system?
What is a neutron star?
What is a neutron star?

- A neutron star is the ball of neutrons left behind by a intermediate mass star ($M = 2 - 8 M_{\text{sun}}$) supernova.

- Degeneracy pressure of neutrons supports a neutron star against gravity.
What is a neutron star?

- Electron degeneracy pressure goes away because electrons combine with protons, making neutrons and neutrinos.
- Neutrons collapse to the center, forming a neutron star.
- Compression too rapid to explode as nova.
A neutron star is about the same size as metro Atlanta.
Using a radio telescope in 1967, Jocelyn Bell noticed very regular pulses of radio emission coming from a single part of the sky.

The pulses were coming from a spinning neutron star—a pulsar.
Pulsar at the center of the Crab Nebula pulses 30 times per second.
Pulsars

A **pulsar** is a neutron star that beams radiation along a magnetic axis that is not aligned with the rotation axis.
The radiation beams sweep through space like lighthouse beams as the neutron star rotates.
Why Pulsars Must Be Neutron Stars

Circumference of NS = $2\pi (\text{radius}) \sim 60 \text{ km}$
Circumference of WD = $2\pi (\text{radius}) \sim 6,000 \text{ km}$

Spin rate of fast pulsars $\sim 1000 \text{ cycles per second}$

NS Surface rotation velocity $\sim 60,000 \text{ km/s}$
$\sim 20\% \text{ speed of light}$
$\sim \text{escape velocity from NS}$

WD Surface rotation velocity $\sim 6,000,000 \text{ km/s}$
$\sim 20x \text{ speed of light}$

Anything else would be torn to pieces!
Pulsars spin fast because a stellar core's spin speeds up as it collapses into neutron star.

Conservation of angular momentum
Thought Question

Could there be neutron stars that appear as pulsars to other civilizations but not to us?

A. Yes
B. No
Thought Question

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Supernova Remnants

- The Crab Nebula (M1)
- Named in 1840
- Remnant of supernova in 1054 observed by Chinese astronomers
Supernova Remnants

- Expansion
  - Crab Nebula ~ 1500 km/hr
- Expansion essential for interstellar enrichment.
What can happen to a neutron star in a close binary system?
Matter falling toward a neutron star forms an accretion disk, just as in a white dwarf binary.
Accreting matter adds angular momentum to a neutron star, increasing its spin.
Thought Question

According to the conservation of angular momentum, what would happen if a star orbiting in a direction opposite the neutron's star rotation fell onto a neutron star?

A. The neutron star's rotation would speed up.
B. The neutron star's rotation would slow down.
C. Nothing. The directions would cancel each other out.
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X-Ray Bursts

- Matter accreting onto a neutron star can eventually become hot enough for helium fusion.

- The sudden onset of fusion produces a burst of X rays.
What have we learned?

- **What is a neutron star?**
  - It is a ball of neutrons left over from a massive star supernova and supported by neutron degeneracy pressure.

- **How were neutron stars discovered?**
  - Beams of radiation from a rotating neutron star sweep through space like lighthouse beams, making them appear to pulse.
  - Observations of these pulses were the first evidence for neutron stars.
What have we learned?

- What can happen to a neutron star in a close binary system?
  - The accretion disk around a neutron star can become hot enough to produce X rays, making the system an X-ray binary.
  - Sudden fusion events periodically occur on the surface of an accreting neutron star, producing X-ray bursts.