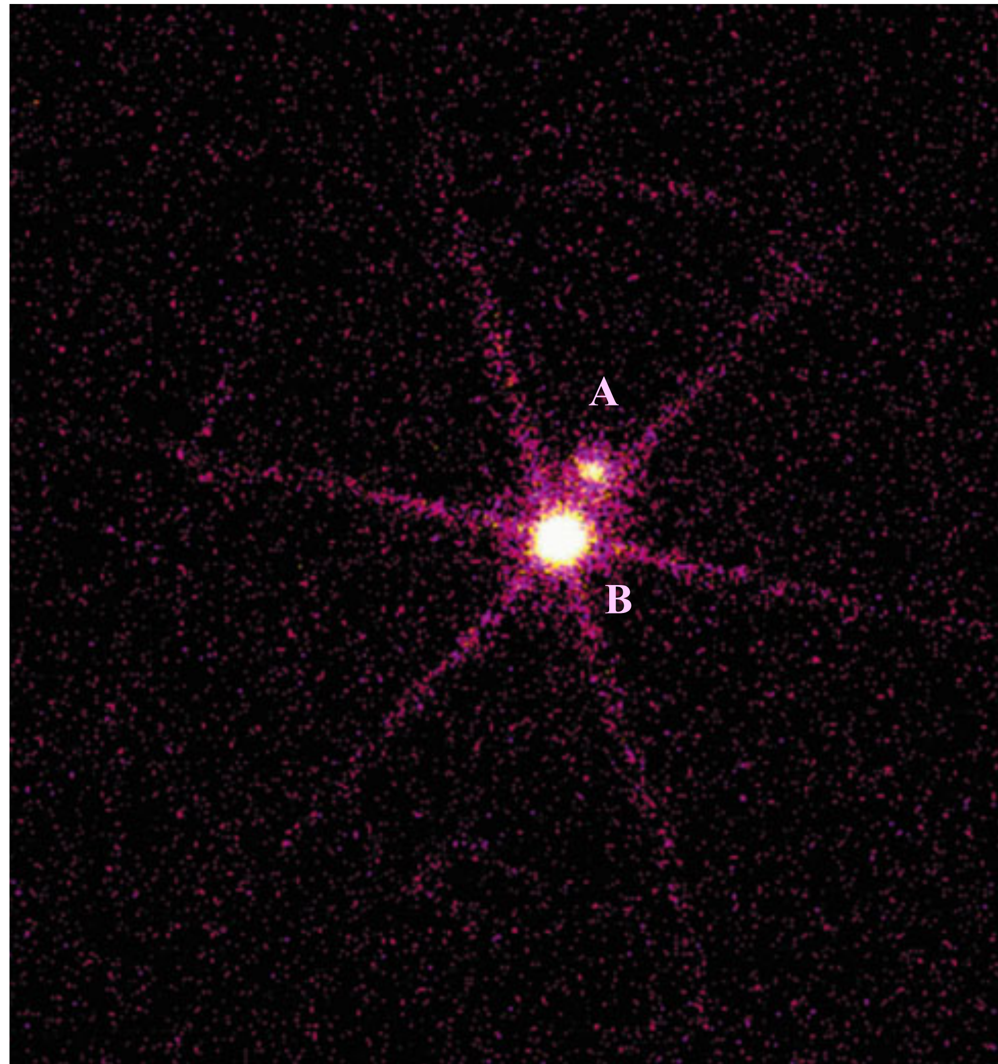
Lecture 19:
White Dwarfs & Neutron Stars

$M = 1.5\ M_{sun}$
$R \approx 10$ km
$V_{esc} \approx 0.7c$

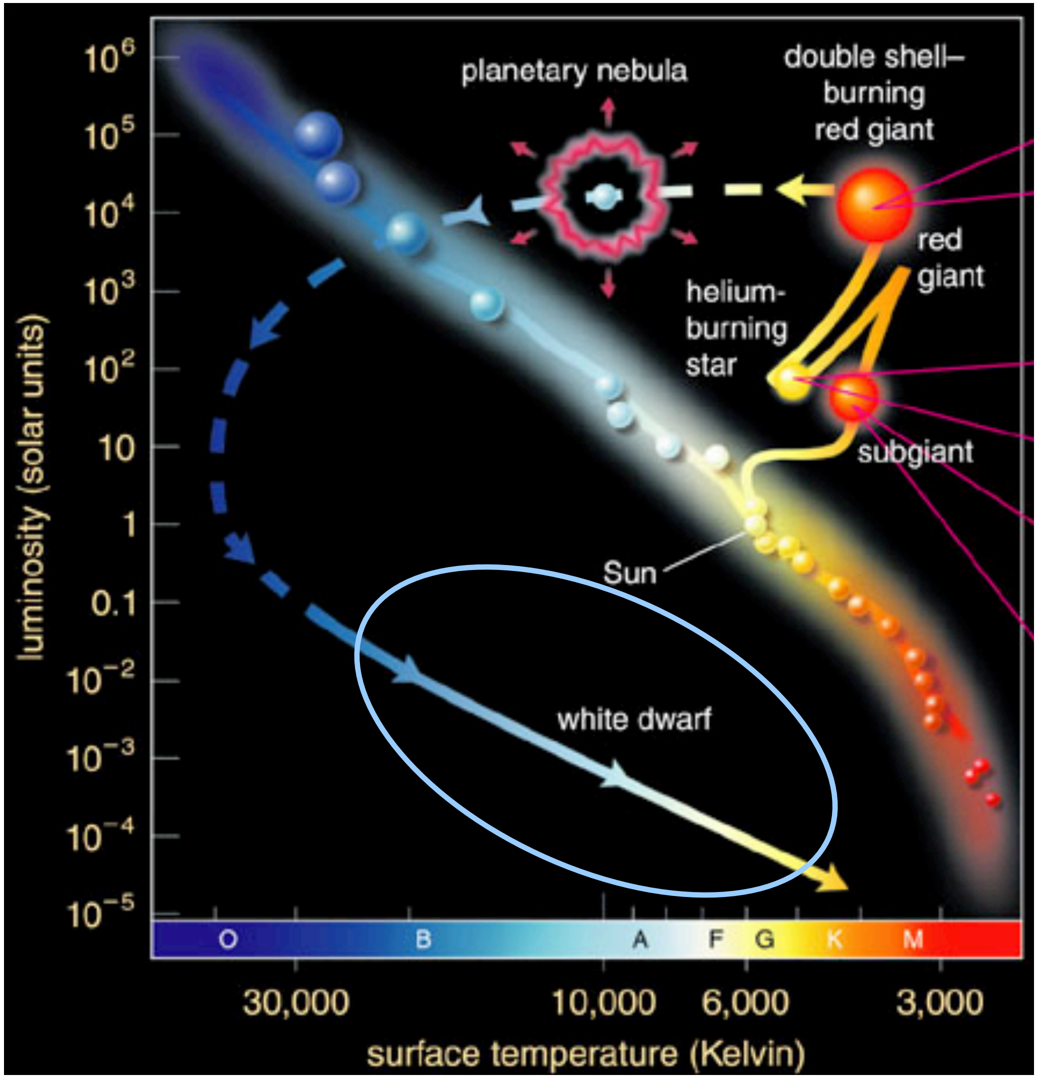
What is a white dwarf?

- White dwarfs are small remaining cores of old, dead, *low-mass* stars.
- Hydrogen and helium burning finished, outer layers ejected as a planetary nebula.
- **Electron** degeneracy pressure supports the white dwarf against gravity.

Sirius B, a tiny white dwarf, is much hotter that Sirius A, a main sequence star, and so much brighter in ultraviolet and x-ray light

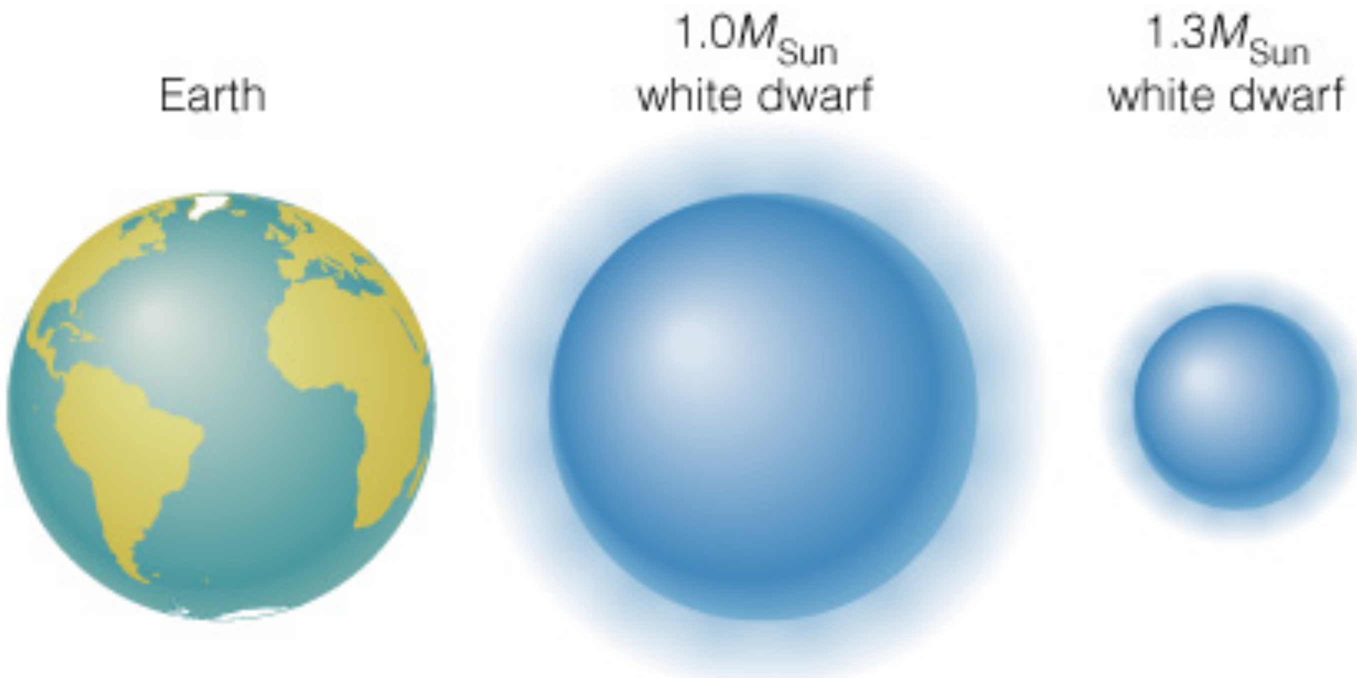


White dwarfs



White dwarfs gradually cool off and grow dimmer over long periods of time.

Size of a White Dwarf

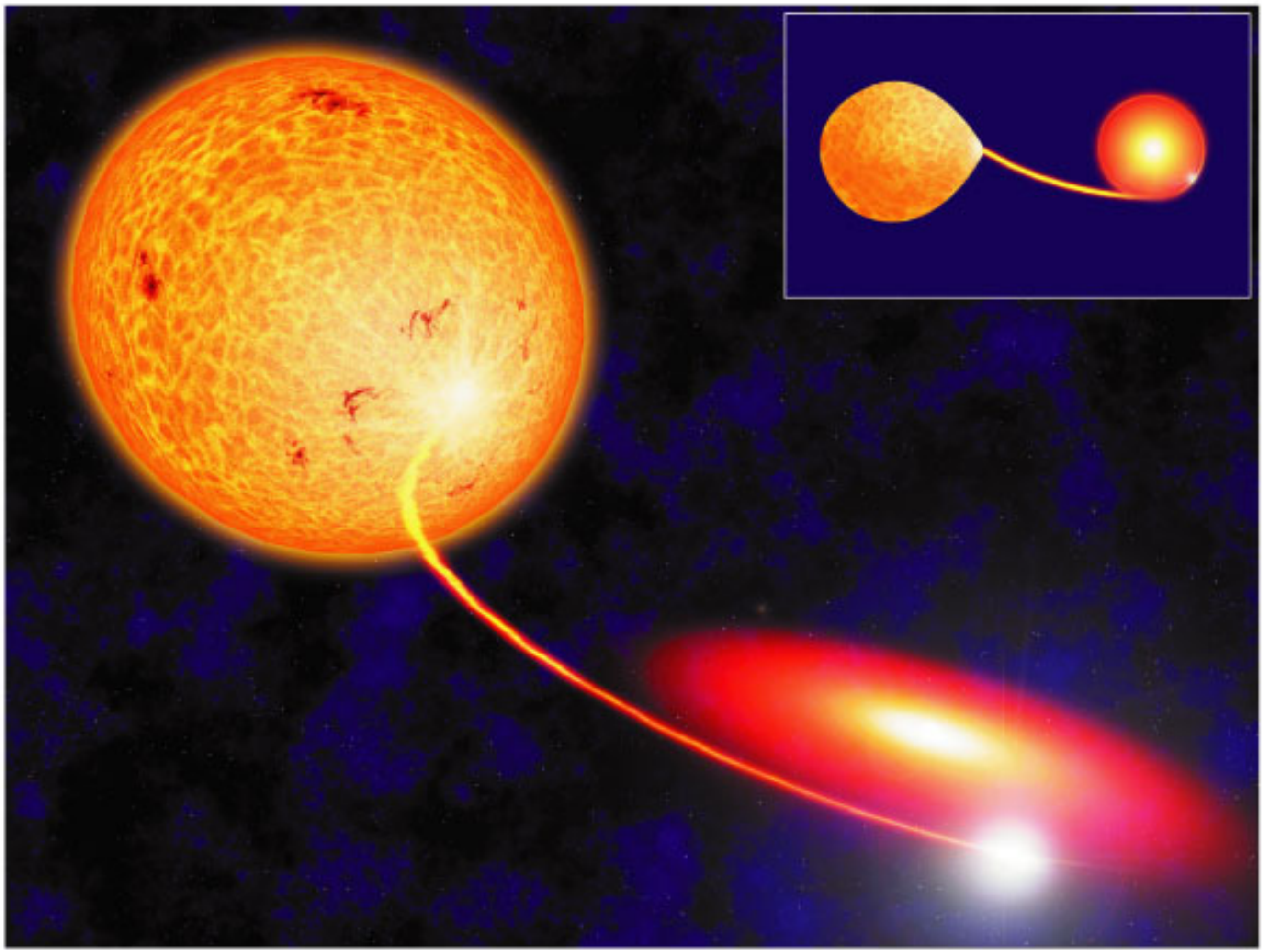


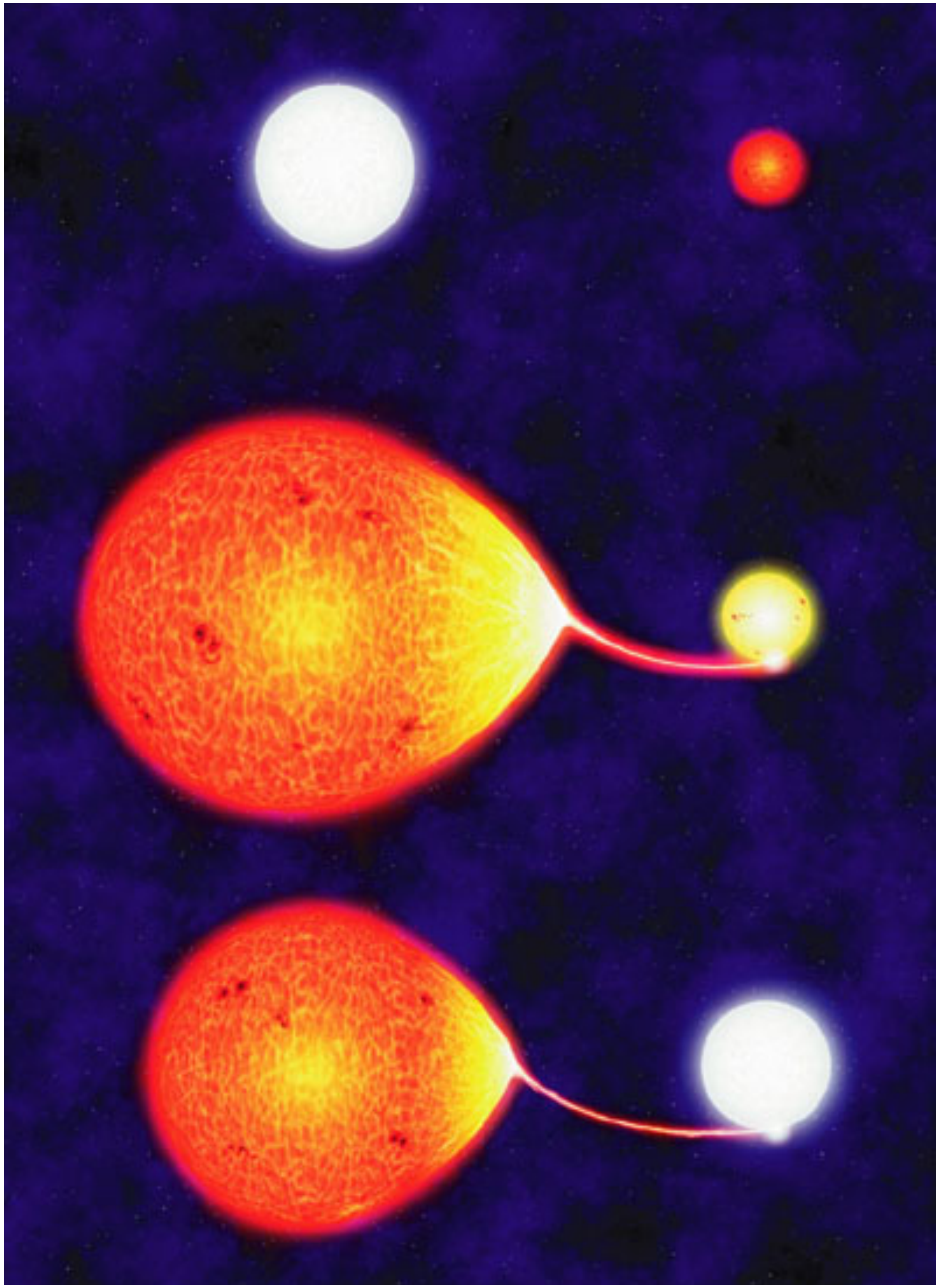
- White dwarfs with the same mass as the Sun are about the same size as Earth!
- Higher-mass white dwarfs are smaller!
- Density ~ 2 tons/cm^3!

The White Dwarf Limit

- Electrons must move faster as they are squeezed into a very small space.
- As a white dwarf's mass approaches $1.4M_{\text{Sun}}$, its electrons must move at nearly the speed of light.
- Because nothing moves faster than light, **a white dwarf cannot be more massive than $\mathbf{1.4}\boldsymbol{M}_{\mathbf{Sun}}$**, the *white dwarf limit* (also known as the *Chandrasekhar limit*).

What can happen to a white dwarf in a close binary system?



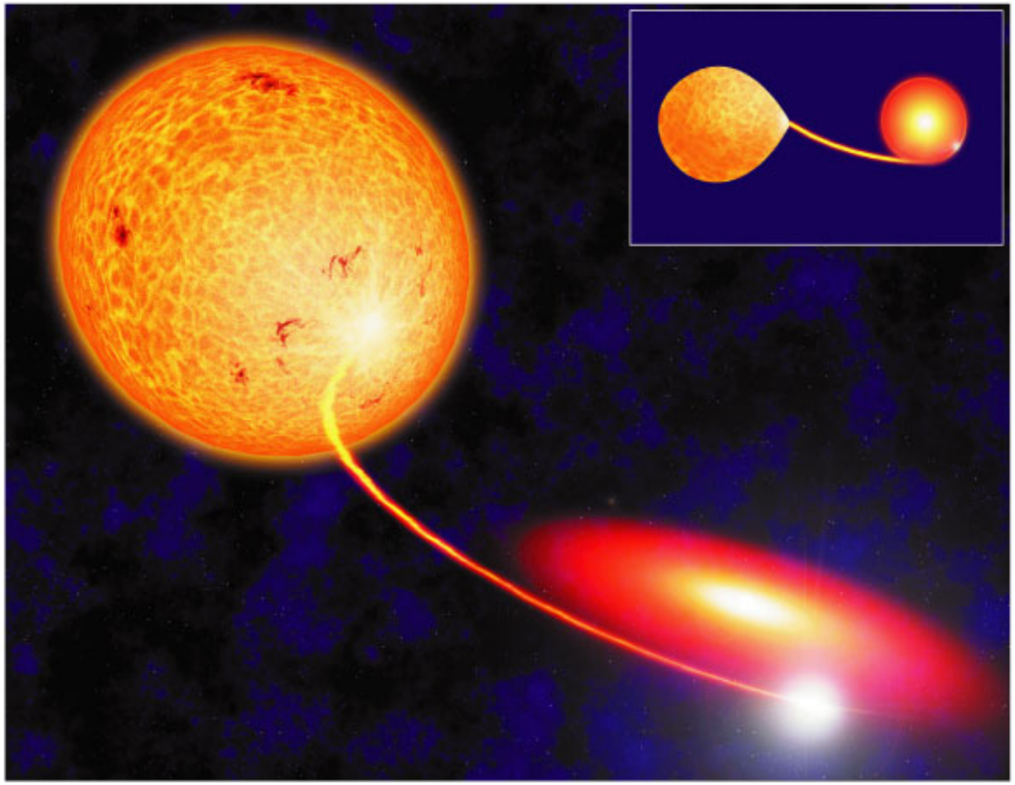


A white dwarf in a close binary system

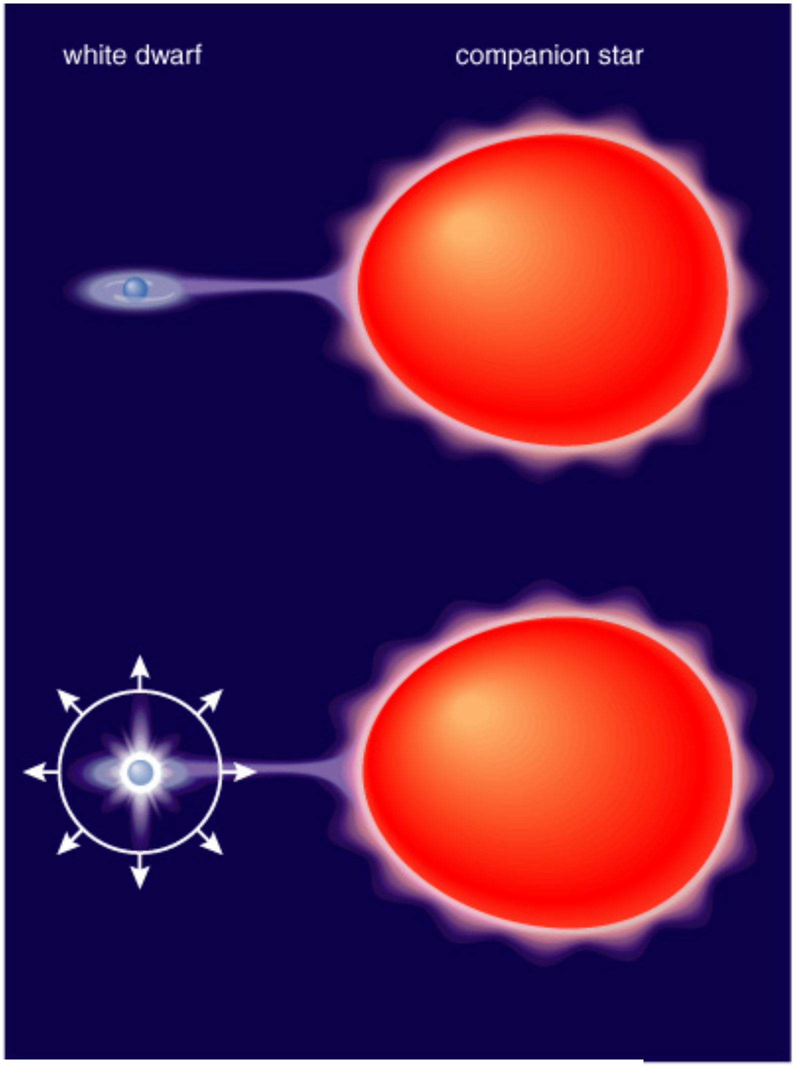
- A star that started with less mass can gain mass from its evolving companion.
- What happens next?

Accretion Disks

- Mass falling toward a white dwarf from its companion has angular momentum, overshoots white dwarf .
- The matter orbits the white dwarf in an *accretion disk.*
- Friction of matter in the disk causes the disk to heat up and glow.



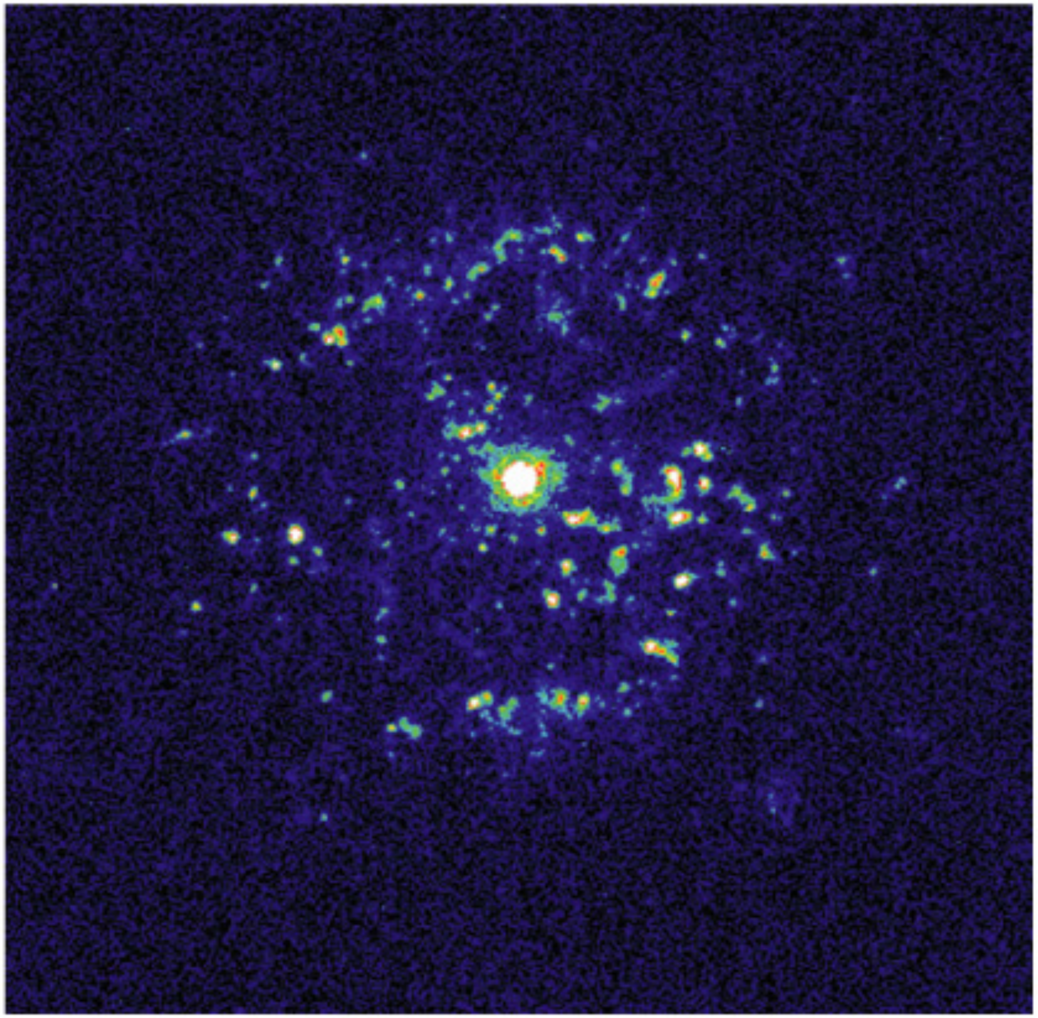
Nova



- The temperature of accreted matter on surface is hot enough for hydrogen fusion *on the surface of the white dwarf*.
- More accreting matter compresses and heats this hydrogen layer.
- Fusion ignites suddenly and explosively, causing a ***nova.***
- The white dwarf brightens dramatically (~10^5 L_{Sun}).

Nova

- The nova star system temporarily appears much brighter.
- The explosion drives accreted matter out into space.
- Accretion resumes so nova can recur.



Think/Pair/Share

What happens to a white dwarf if it accretes enough matter to exceed the 1.4 M_{Sun} limit?

A. It explodes as a supernova.
B. It collapses into a neutron star.
C. It gradually begins fusing carbon in its core.
D. Its radius grows to keep its density constant.

Think/Pair/Share

What happens to a white dwarf if it accretes enough matter to exceed the 1.4 M_{Sun} limit?

A. **It explodes as a supernova!**
B. It collapses into a neutron star.
C. It gradually begins fusing carbon in its core.
D. Its radius grows to keep its density constant

Two Types of Supernova

***White dwarf* supernova *(Type I)*:**

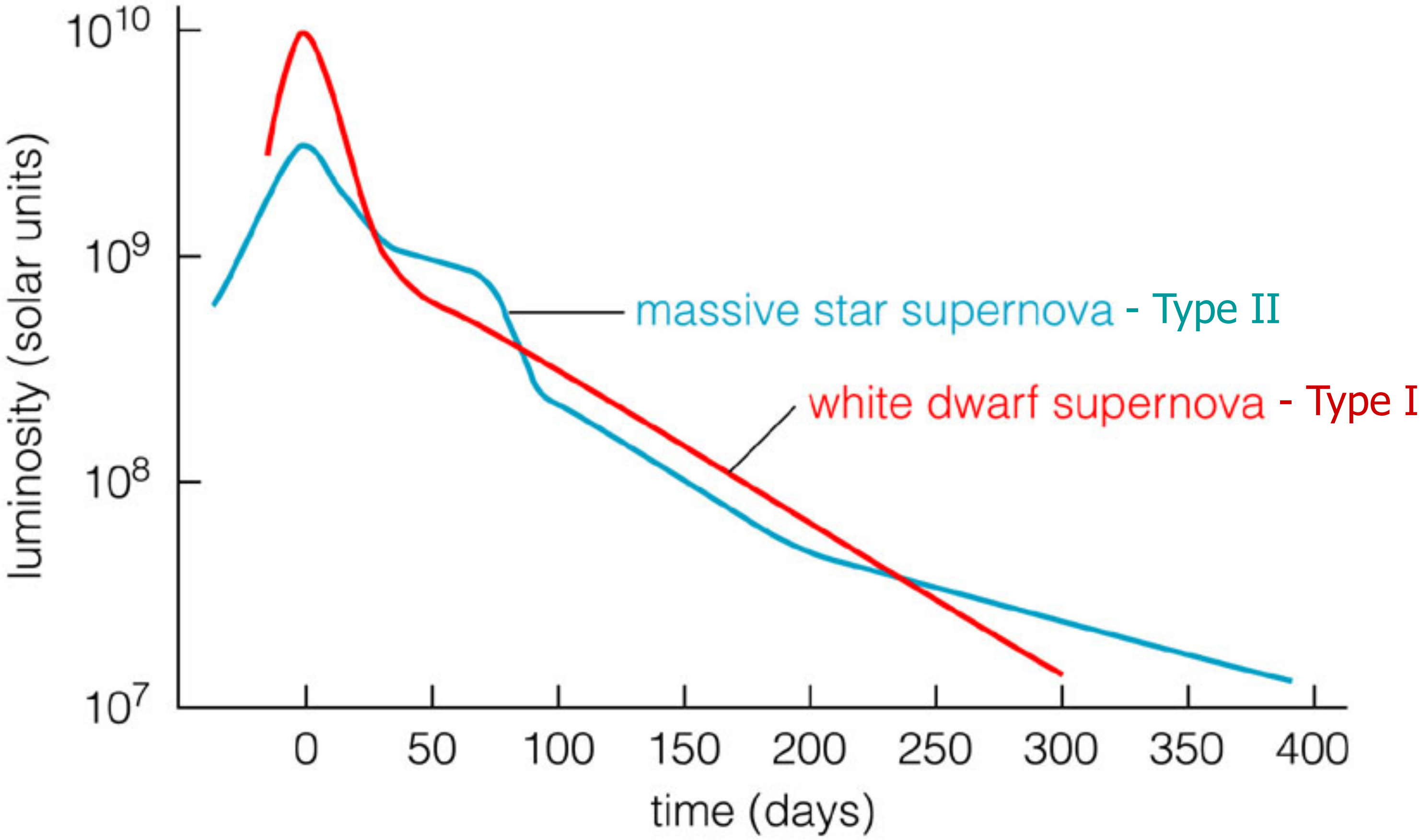
Uncontained carbon fusion suddenly begins in core as white dwarf reaches limit, causing total explosion.

***Massive star* supernova *(Type II)*:**

Iron core of massive star exceeds white dwarf limit and collapses into a neutron star, causing explosion.

Light curves and spectra differ. (Exploding white dwarfs don't have hydrogen absorption lines.)

Two Types of Supernova



One way to tell supernova types apart is with a ***light curve*** showing how luminosity changes with time.

Nova or Supernova?

- Supernovae are MUCH more luminous (about 10 million times) than a nova!!!
- **Nova**: H fusion into He of a *layer* of accreted surface matter, white dwarf left intact.
- **Supernova**: *complete* explosion of white dwarf, nothing left behind.

What have we learned?

Begin 3 minute review

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 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.

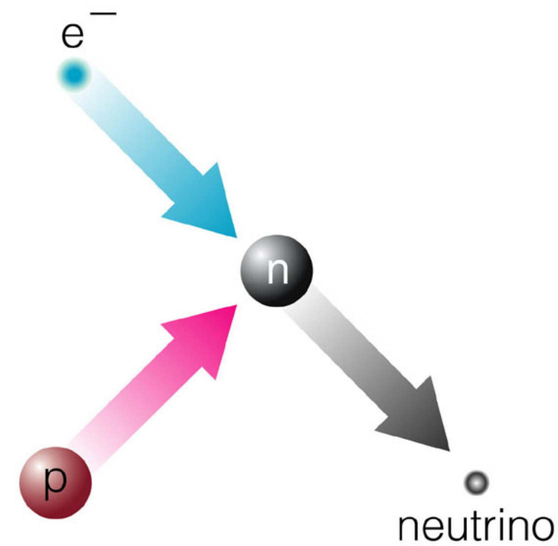
Accretion of matter can lead to novae and white dwarf supernovae.

What is a neutron star?

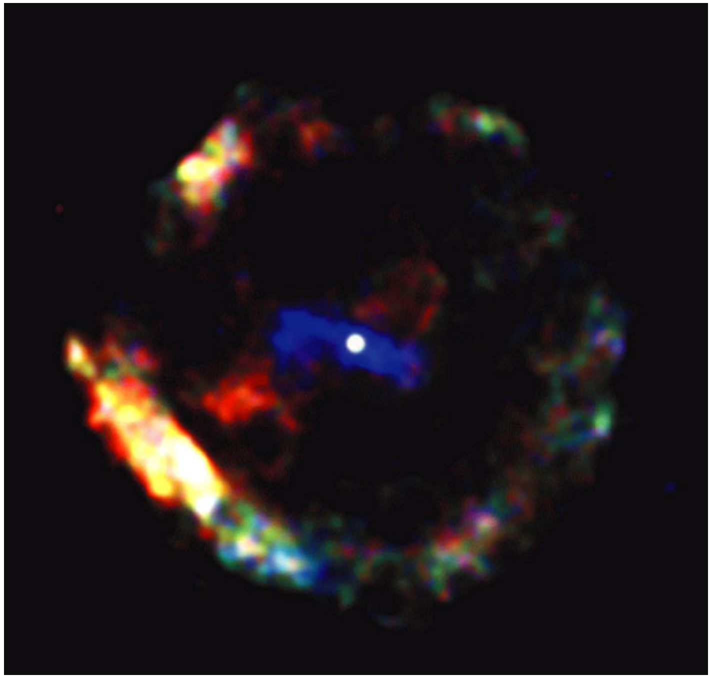
$M=1.5\ M_{sun}$
$R \approx 10$ km
$V_{esc} \approx 0.7c$

- A neutron star is the tiny core of neutrons left behind by a massive-star supernova.
- The degeneracy pressure of **neutrons** supports a neutron star against gravity.

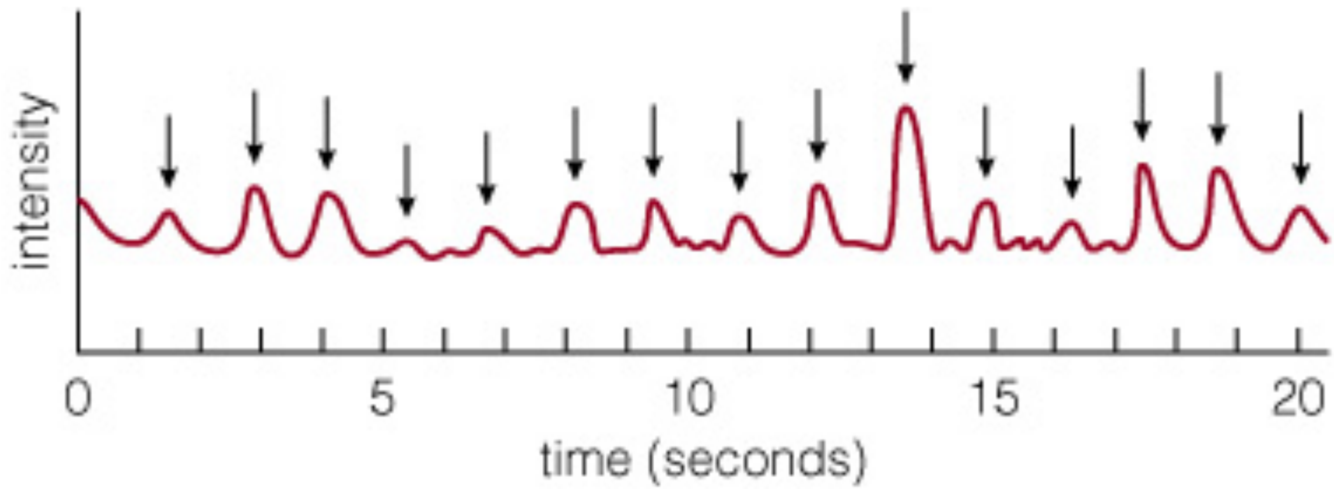
Neutron stars



- Electron degeneracy pressure fails, electrons are crushed into protons, making neutrons and neutrinos.
- Neutrons collapse to the center, forming a ***neutron star.***
- A neutron star has more mass than a white dwarf but is only about 10km across!
- Density ~ 100 million tons/cm^3!

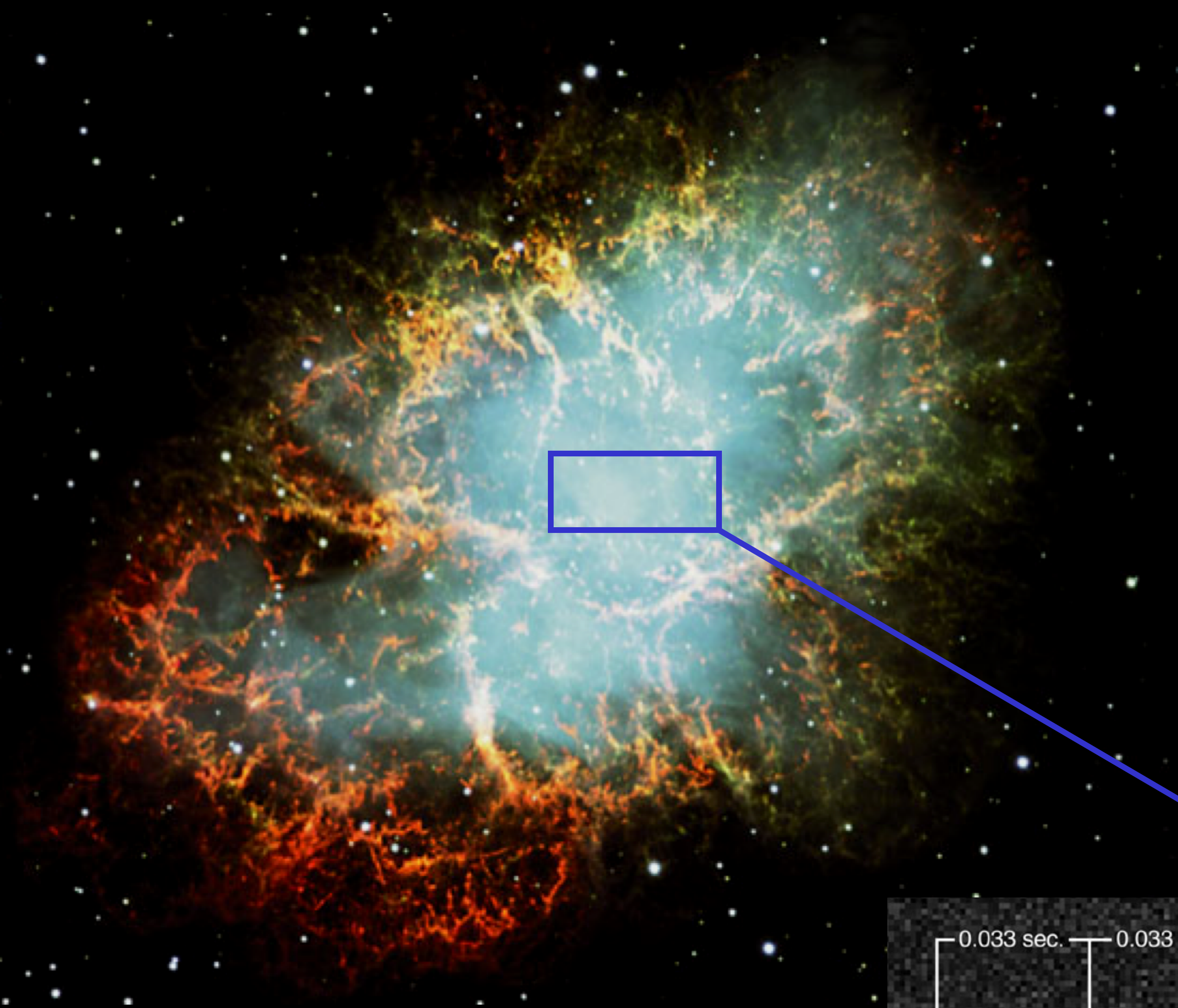


Discovery of Neutron Stars

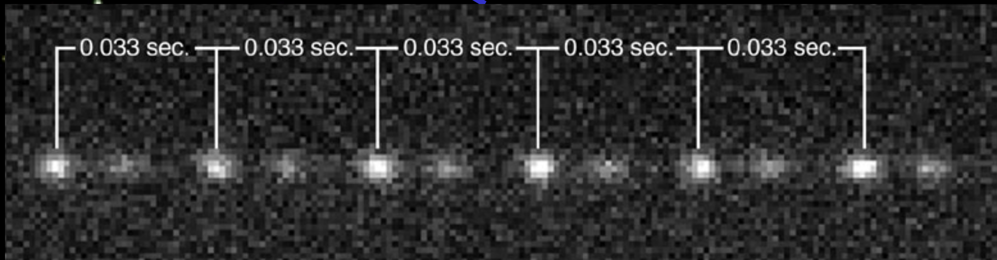


- Using a radio telescope in 1967, Jocelyn Bell noticed very regular pulses of radio emission coming from a an object in the sky.
- The pulses were coming from a rapidly spinning neutron star—a *pulsar*.

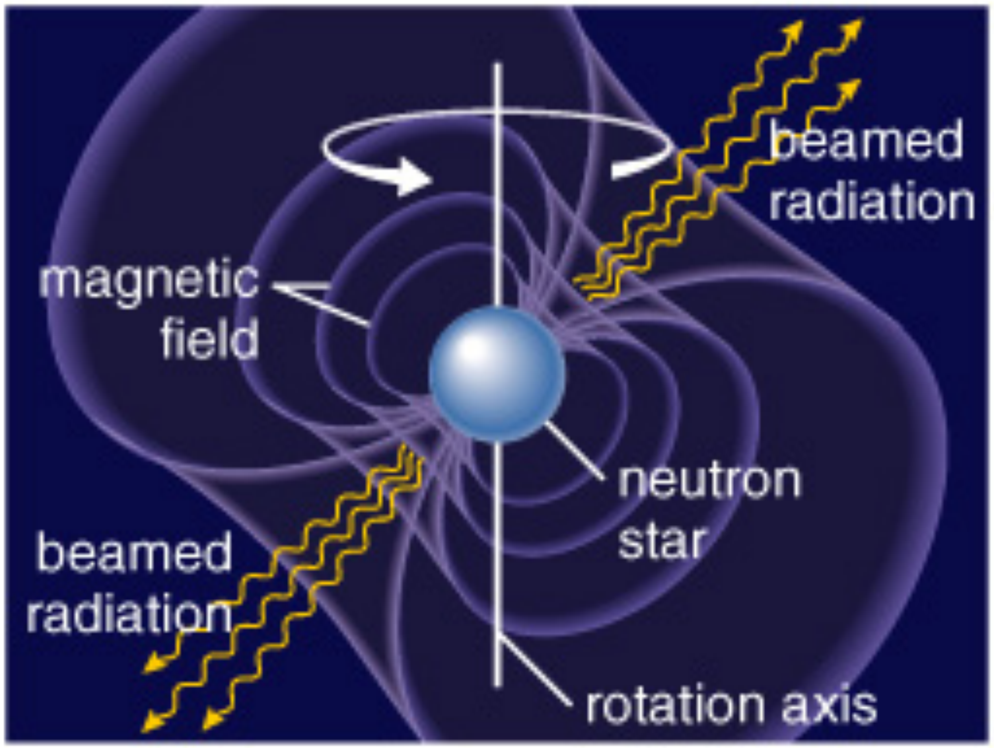
Pulsars



Pulsar at center of Crab Nebula pulses 30 times per second!



What *is* a Pulsar?



- 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.

http://www.youtube.com/watch?v=mXzwtp-KaoI&NR=1

Why Pulsars Must Be Neutron Stars

Pulsars spin fast because *the core's spin speeds up as it collapses* due to ***conservation of angular momentum***

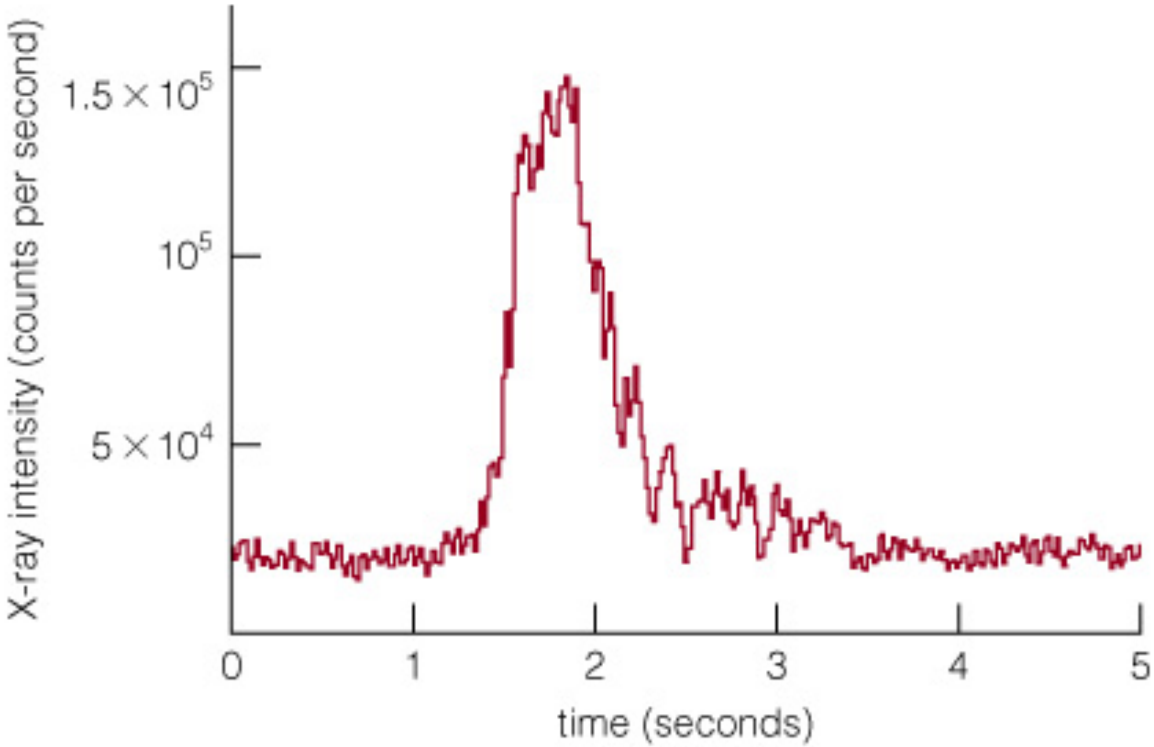
Circumference of Neutron Star = 2π (radius) ~ 60 km

Spin Rate of Fast Pulsars ~ 1,000 cycles per second!

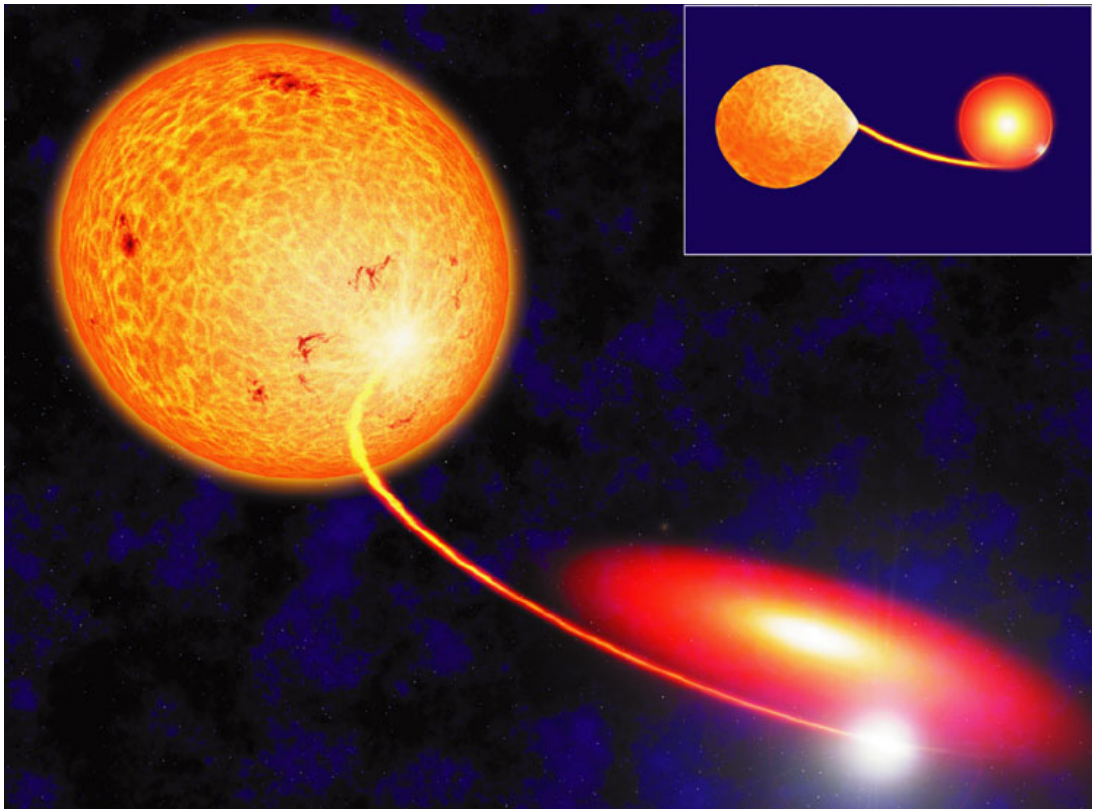
Surface Rotation Velocity ~ 60,000 km/s
~ 20% speed of light
~ escape velocity from NS

Anything else would fly apart !

What can happen to a neutron star in a close binary system?



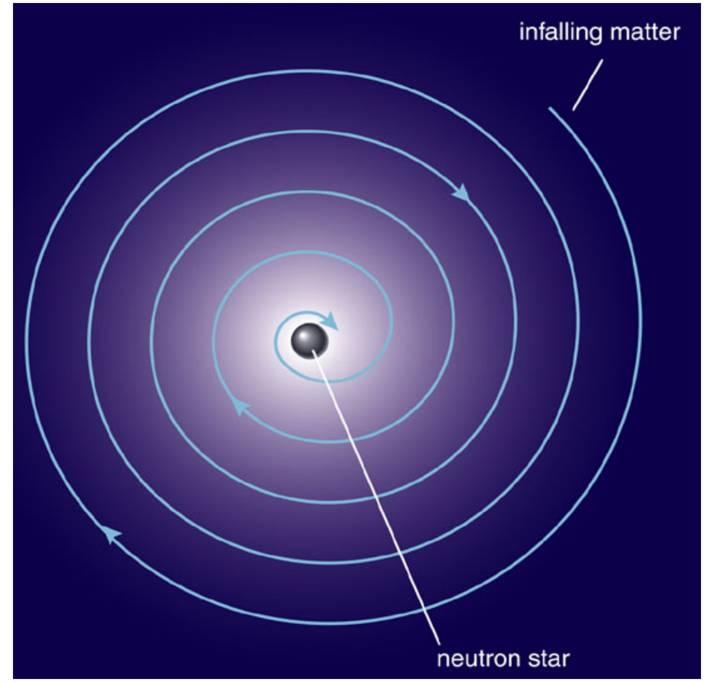
A neutron star in a close binary

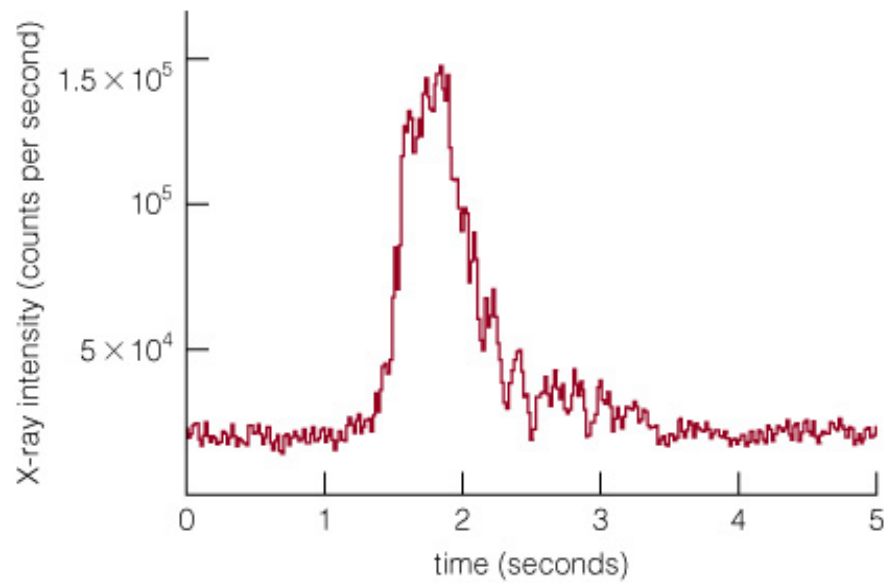


Matter falling toward a neutron star forms an **accretion disk**, just as in a white-dwarf binary, only denser and hotter.

X-ray Bursts

• Accreting matter adds angular momentum to neutron star, increasing its spin and pulse rates.
• Matter accreting onto the disk can become hot enough for helium fusion.
• Fusion on surface leads to powerful X-ray bursts (novae).





What have we learned?

Begin 3 minute review

What have we learned?

What is a neutron star?

A ball of neutrons left over from a massive star supernova supported by neutron degeneracy pressure.

How were neutron stars discovered?

Beams of radiation from a rotating neutron star sweep thru space like lighthouse beams.

As beams sweep over Earth we see pulses.

What happens to a neutron star in a binary system?

The accretion disk around a neutron star gets hot enough to produce X-ray bursts.

Sudden fusion events periodically occur on an accreting neutron star creating x-ray bursts.

Cosmos: https://drive.google.com/file/d/10VeaJVLQvp1qdHlBylOenqaY3kPJKXpB/view