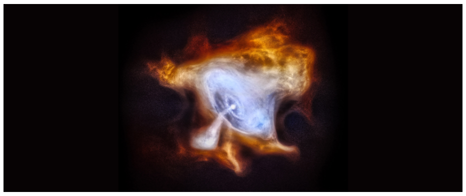
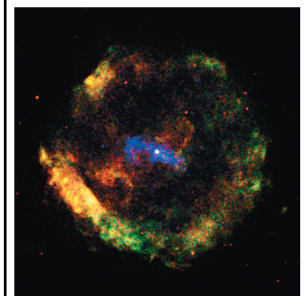
23.4 PULSARS AND THE DISCOVERY OF NEUTRON STARS

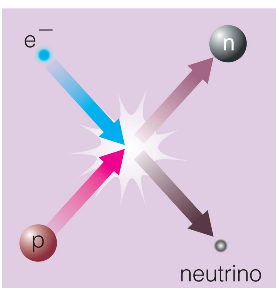


- **Crab Nebula.** This image shows X-ray emmisions from the Crab Nebula, which is about 6500 light-years away. The pulsar is the bright spot at the center of the concentric rings. Data taken over about a year show that particles stream away from the inner ring at about half the speed of light. The jet that is perpendicular to this ring is a stream of matter and antimatter electrons also moving at half the speed of light. (credit: modification of work by NASA/CXC/SAO)



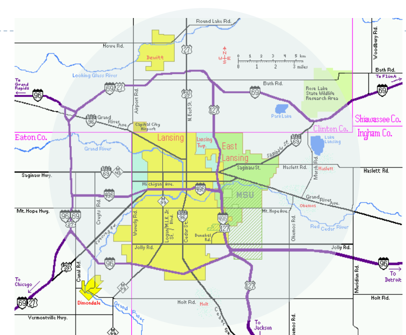
A neutron star is the ball of neutrons left behind by a massive-star supernova.

The degeneracy pressure of neutrons supports a neutron star against gravity.



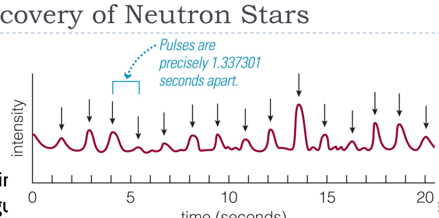
Electron degeneracy pressure goes away because electrons combine with protons, making neutrons and neutrinos.

Neutrons collapse to the center, forming a ***neutron star***.



A neutron star is about the same size as a small city.

Discovery of Neutron Stars

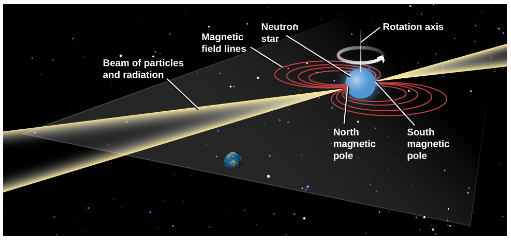


- Usir … very regu… e part of the sky.
- The pulses were coming from a spinning neutron star—a *pulsar*.

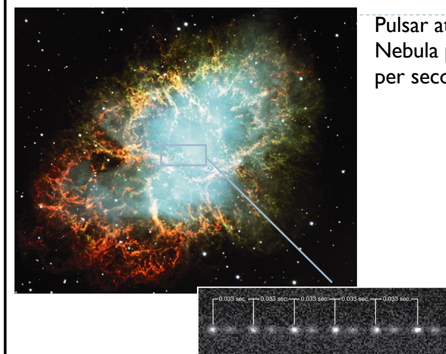
Figure 23.15

- **Lighthouse.** A lighthouse in California warns ships on the ocean not to approach too close to the dangerous shoreline. The lighted section at the top rotates so that its beam can cover all directions. (credit: Anita Ritenour)

Figure 23.16



- **Model of a Pulsar.** A diagram showing how beams of radiation at the magnetic poles of a neutron star can give rise to pulses of emission as the star rotates. As each beam sweeps over Earth, like a lighthouse beam sweeping over a distant ship, we see a short pulse of radiation. This model requires that the magnetic poles be located in different places from the rotation poles. (credit "stars": modification of work by Tony Hisgett)



Pulsar at center of Crab Nebula pulses 30 times per second

Figure 23.17

- **Speeding Pulsar.** This intriguing image (which combines X-ray, visible, and radio observations) shows the jet trailing behind a pulsar (at bottom right, lined up between the two bright stars). With a length of 37 light-years, the jet trail (seen in purple) is the longest ever observed from an object in the Milky Way. (There is also a mysterious shorter, comet-like tail that is almost perpendicular to the purple jet.) Moving at a speed between 2.5 and 5 million miles per hour, the pulsar is traveling away from the core of the supernova remnant where it originated. (credit: X-ray: NASA/CXC/ISDC/L.Pavan et al, Radio: CSIRO/ATNF/ATCA Optical: 2MASS/UMass/IPAC-Caltech/NASA/NSF)

Why Pulsars Must Be Neutron Stars

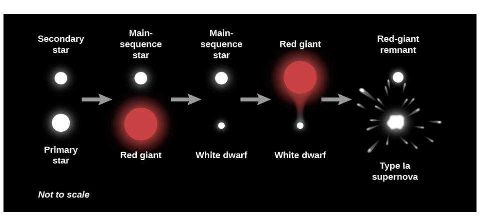
Circumference of Neutron Star = 2π (radius) ~ 60 km

Spin Rate of Fast Pulsars ~ 1000 cycles per second

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

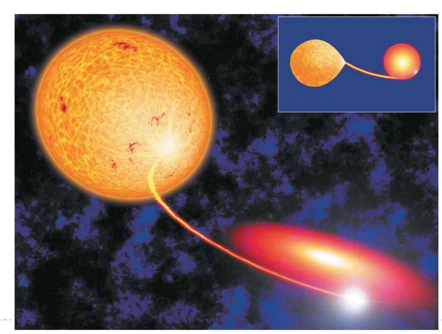
Anything else would be torn to pieces!

23.5 THE EVOLUTION OF BINARY STAR SYSTEMS

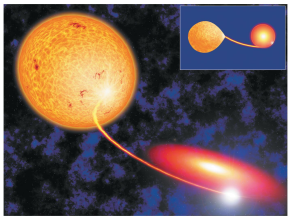


- **Evolution of a Binary System.** The more massive star evolves first to become a red giant and then a white dwarf. The white dwarf then begins to attract material from its companion, which in turn evolves to become a red giant. Eventually, the white dwarf acquires so much mass that it is pushed over the Chandrasekhar limit and becomes a type Ia supernova.

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

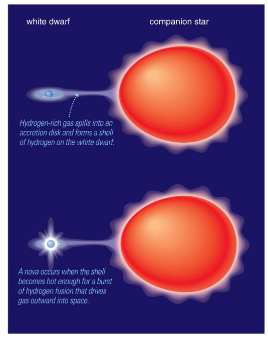


Accretion Disks



- 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*.

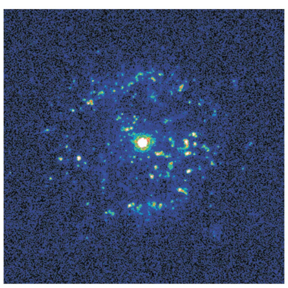
Nova



a Diagram of the nova process.

- The temperature of accreted matter eventually becomes hot enough for hydrogen fusion.
- Fusion begins suddenly and explosively, causing a *nova*.

Nova



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.

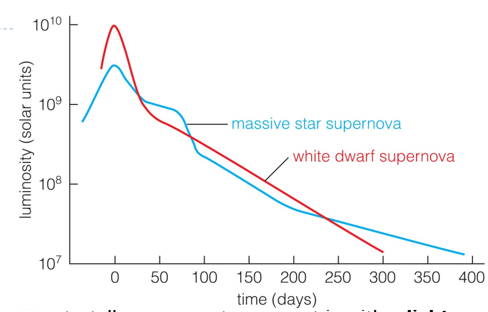
- The nova star system temporarily appears much brighter.
- The explosion drives accreted matter out into space.

Two Types of Supernova

- **Massive star supernova:**
  - Iron core of massive star reaches white dwarf limit and collapses into a neutron star, causing an explosion.
- ***White dwarf supernova:***
  - Carbon fusion suddenly begins as white dwarf in close binary system reaches white dwarf limit, causing a total explosion.

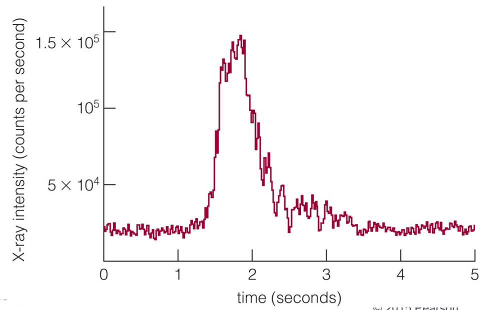
Nova or Supernova?

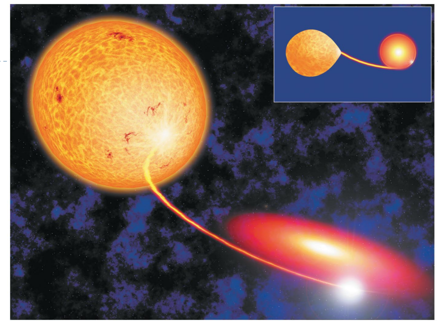
- Supernovae are MUCH MUCH more luminous than novae (about 10 million times)!!!
- Nova: H to He fusion of a layer of accreted matter; white dwarf left intact
- Supernova: complete explosion of white dwarf; nothing left behind



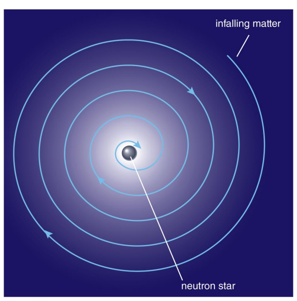
One way to tell supernova types apart is with a ***light curve*** showing how luminosity changes with time.

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





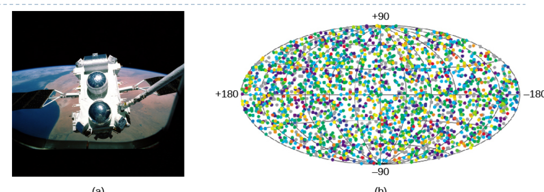
Matter falling toward a neutron star forms an accretion disk, just as in a white dwarf binary.



Accreting matter adds angular momentum to a neutron star, increasing its spin.

Episodes of fusion on the surface lead to X-ray bursts.

23.6 GAMMA RAY BURST

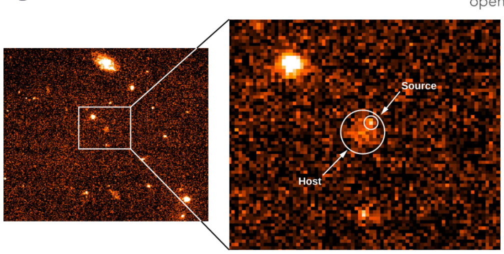


- **Compton Detects Gamma-Ray Bursts.**

(a) In 1991, the Compton Gamma-Ray Observatory was deployed by the Space Shuttle Atlantis. Weighing more than 16 tons, it was one of the largest scientific payloads ever launched into space.

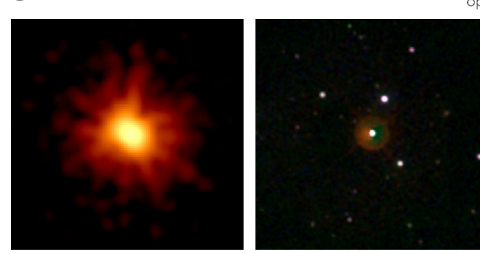
(b) This map of gamma-ray burst positions measured by the Compton Gamma-Ray Observatory shows the isotropic (same in all directions), uniform distribution of bursts on the sky. The map is oriented so that the disk of the Milky Way would stretch across the center line (or equator) of the oval. Note that the bursts show no preference at all for the plane of the Milky Way, as many other types of objects in the sky do. Colors indicate the total energy in the burst: red dots indicate long-duration, bright bursts; blue and purple dots show short, weaker bursts

Figure 23.20



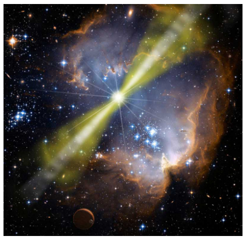
- **Gamma-Ray Burst.** This false-color Hubble Space Telescope image, taken in September 1997, shows the fading afterglow of the gamma-ray burst of February 28, 1997 and the host galaxy in which the burst originated. The left view shows the region of the burst. The enlargement shows the burst source and what appears to be its host galaxy. Note that the gamma-ray source is not in the center of the galaxy. (credit: modification of work by Andrew Fruchter (STScI), Elena Pian (ITSRE-CNR), and NASA, ESA)

Figure 23.21



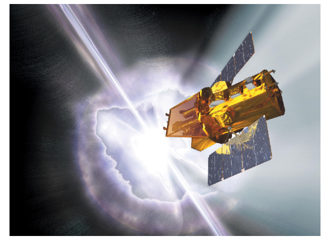
- **Gamma-Ray Burst Observed in March 2008.** The extremely luminous afterglow of GRB 080319B was imaged by the Swift Observatory in X-rays (left) and visible light/ultraviolet (right). (credit: modification of work by NASA/Swift/Stefan Immler, et al.)

Figure 23.22



- **Burst That Is Beamed.** This artist's conception shows an illustration of one kind of gamma-ray burst. The collapse of the core of a massive star into a black hole has produced two bright beams of light originating from the star's poles, which an observer pointed along one of these axes would see as a gamma-ray burst. The hot blue stars and gas clouds in the vicinity are meant to show that the event happened in an active star-forming region. (credit: NASA/Swift/Mary Pat Hrybyk-Keith and John Jones)

Figure 23.23



- **Artist's Illustration of Swift.** The US/UK/Italian spacecraft *Swift* contains on-board gamma-ray, X-ray, and ultraviolet detectors, and has the ability to automatically reorient itself to a gamma-ray burst detected by the gamma-ray instrument. Since its launch in 2005, *Swift* has detected and observed over a thousand bursts, including dozens of short-duration bursts. (credit: NASA, Spectrum Astro)

Links

- gamma ray 6

Reading

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