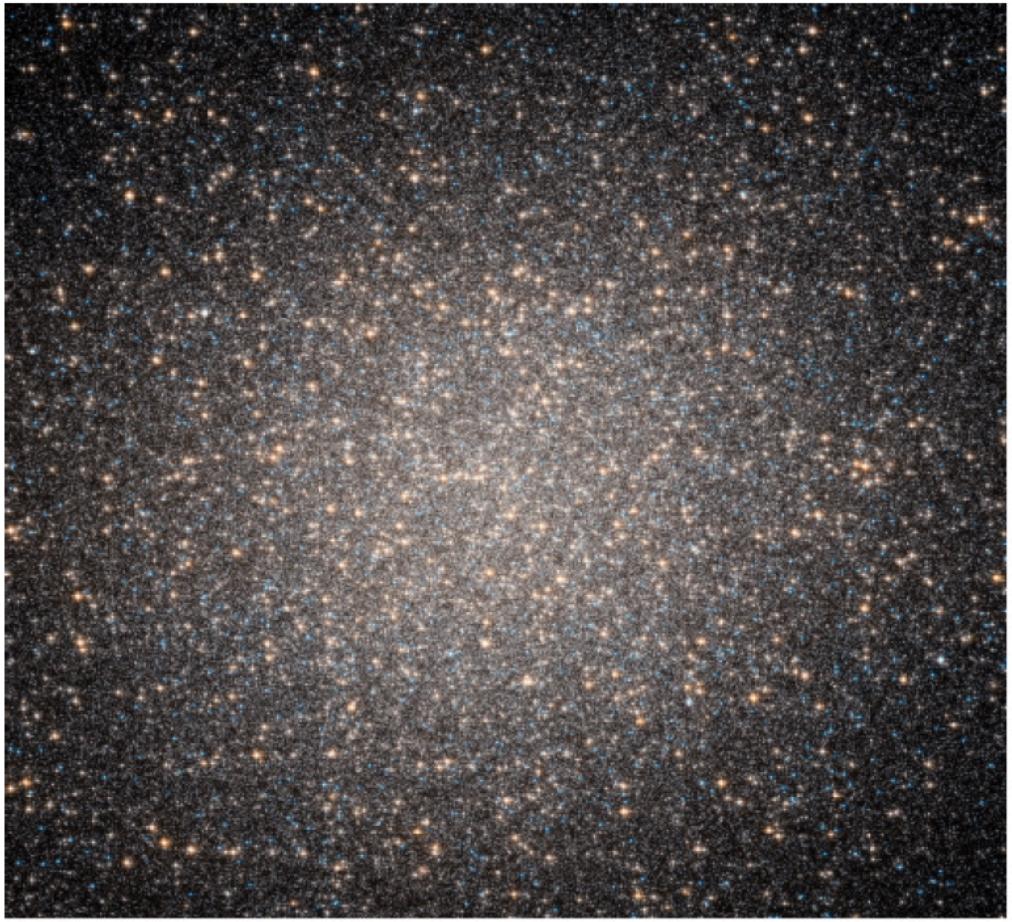
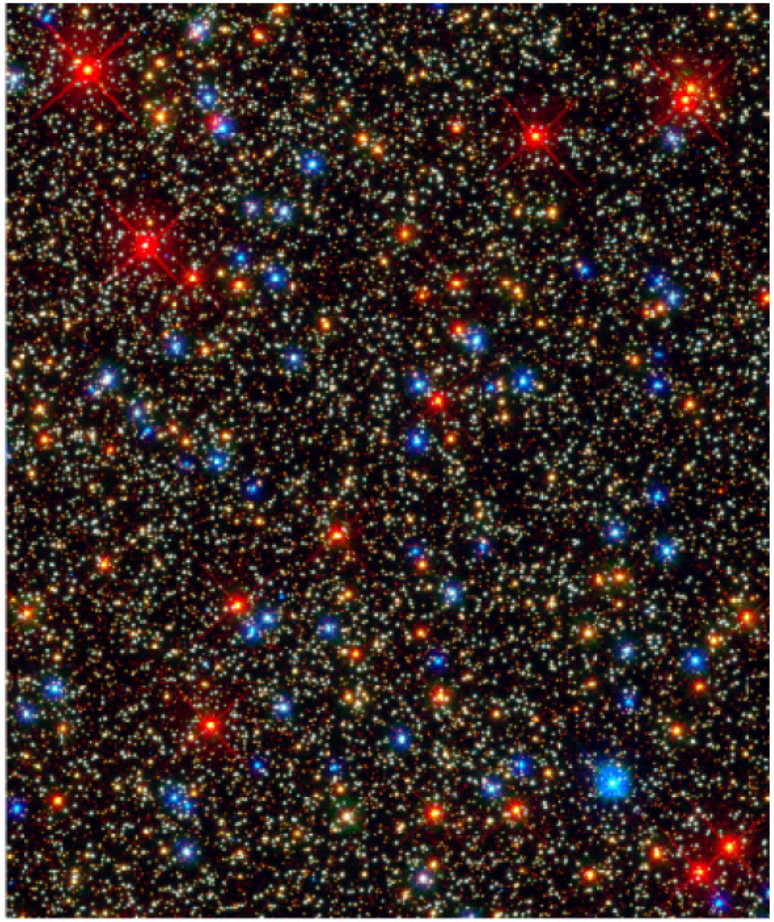
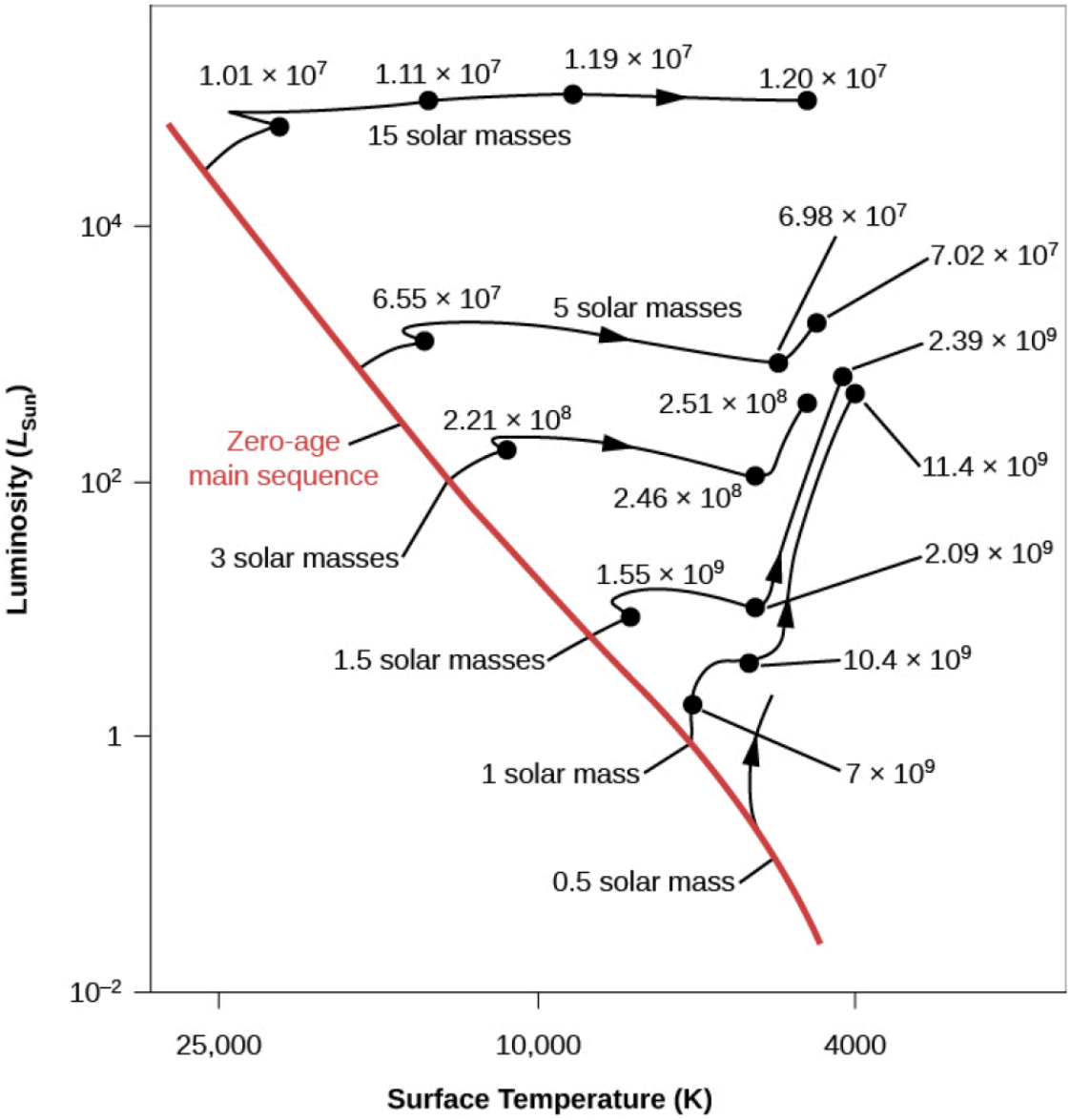
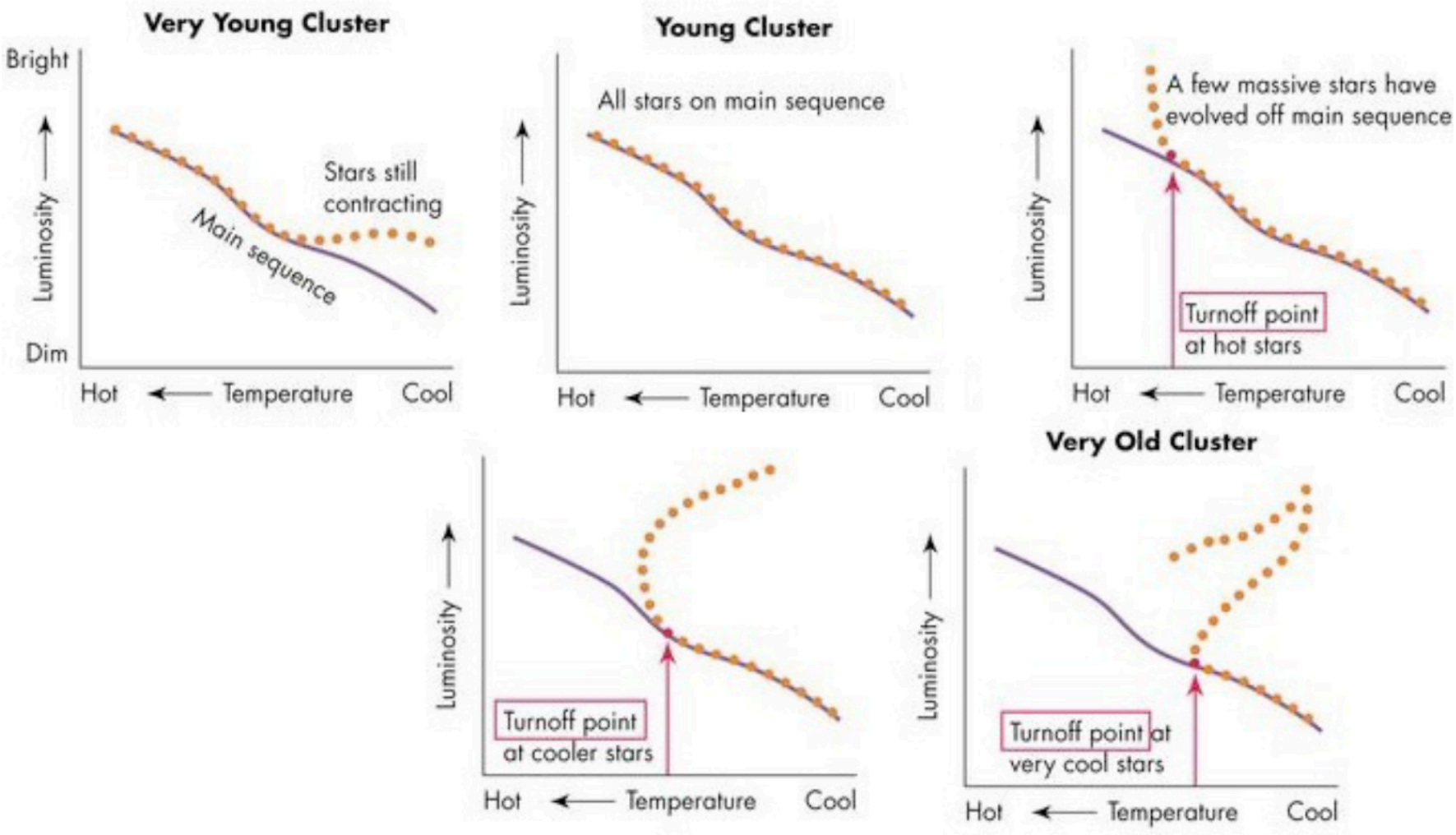
Clusters: stars born at same time





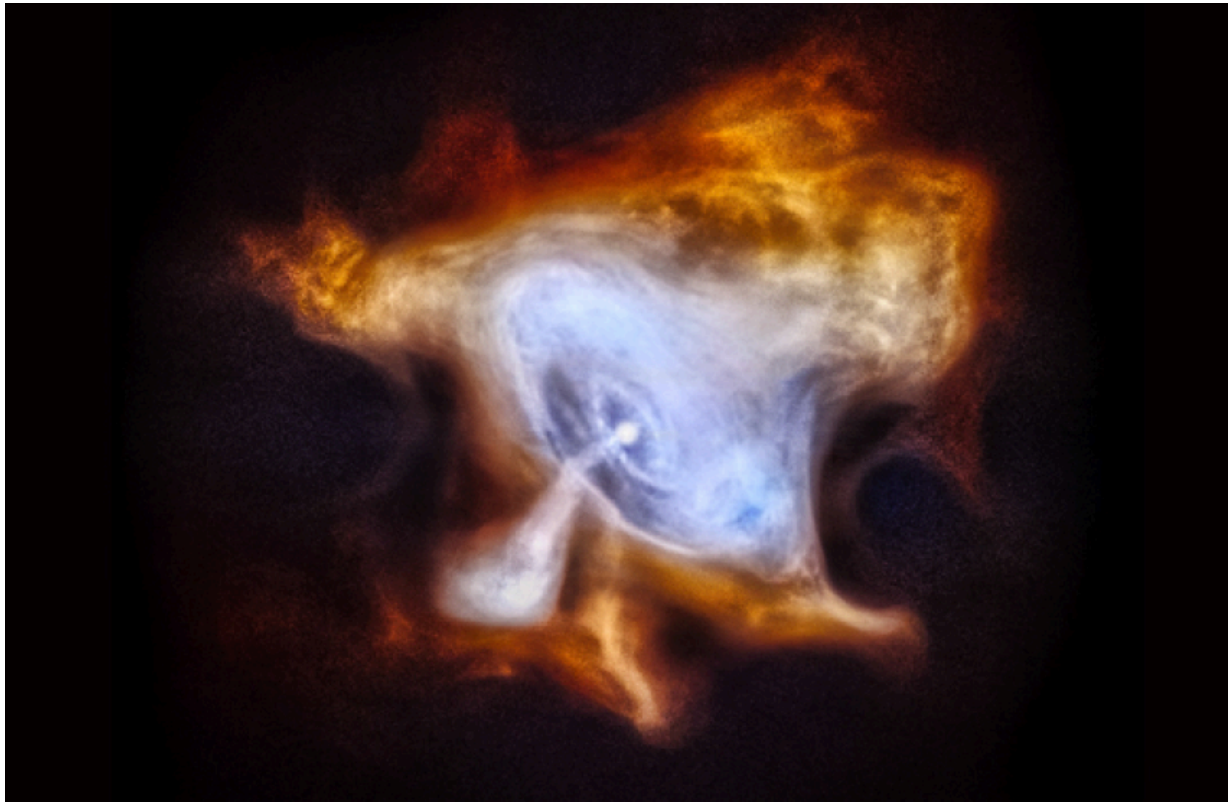
Location of stars tells us age of cluster




Very Young Cluster
Bright
Luminosity
Dim
Stars still contracting
Main sequence
Hot
Temperature
Cool
Young Cluster
All stars on main sequence
Luminosity
Hot
Temperature
Cool
A few massive stars have evolved off main sequence
Luminosity
Turnoff point at hot stars
Hot
Temperature
Cool
Luminosity
Turnoff point at cooler stars
Hot
Temperature
Cool
Very Old Cluster
Luminosity
Turnoff point at very cool stars
Hot
Temperature
Cool

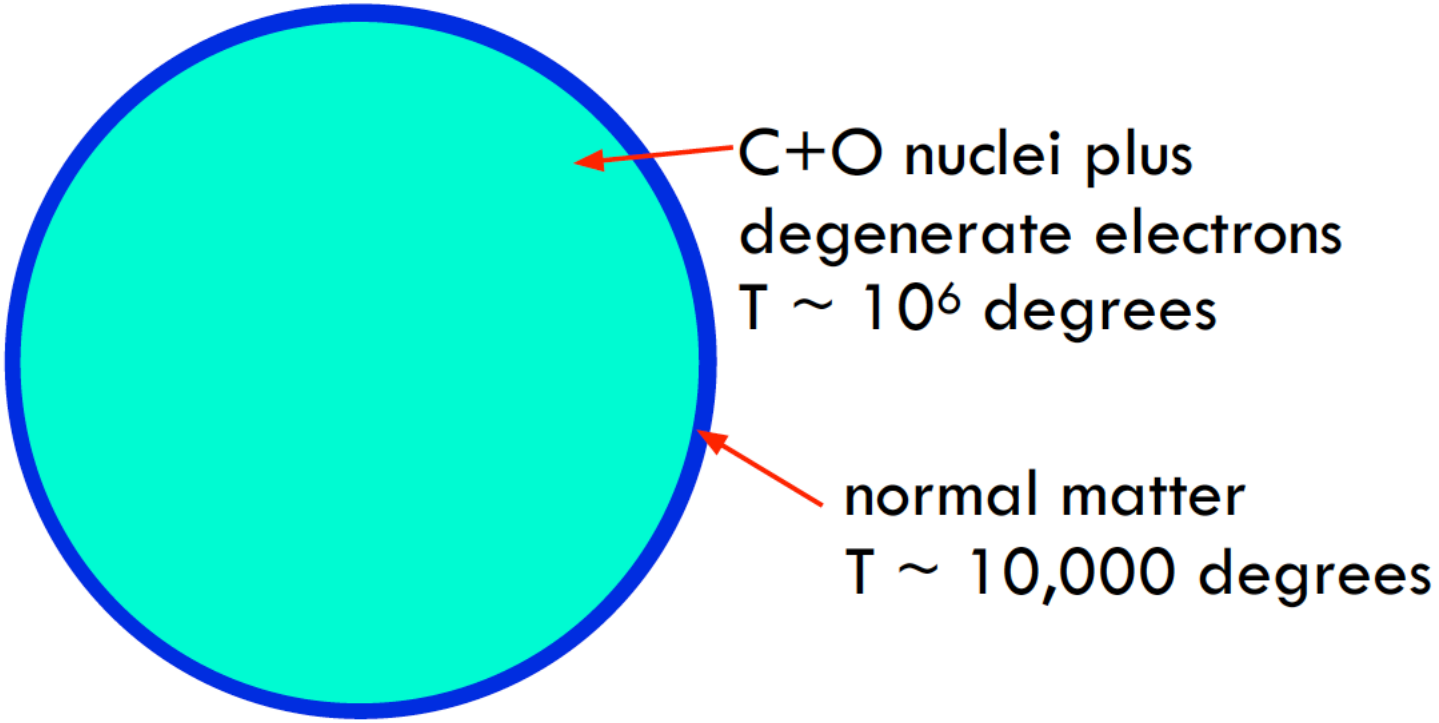
Properties of a Typical White Dwarf and a Neutron Star

Property	White Dwarf	Neutron Star
Mass (Sun = 1)	0.6 (always <1.4)	Always >1.4 and <3
Radius	7000 km	10 km
Density	8×10^5 g/cm^3	10^{14} g/cm^3

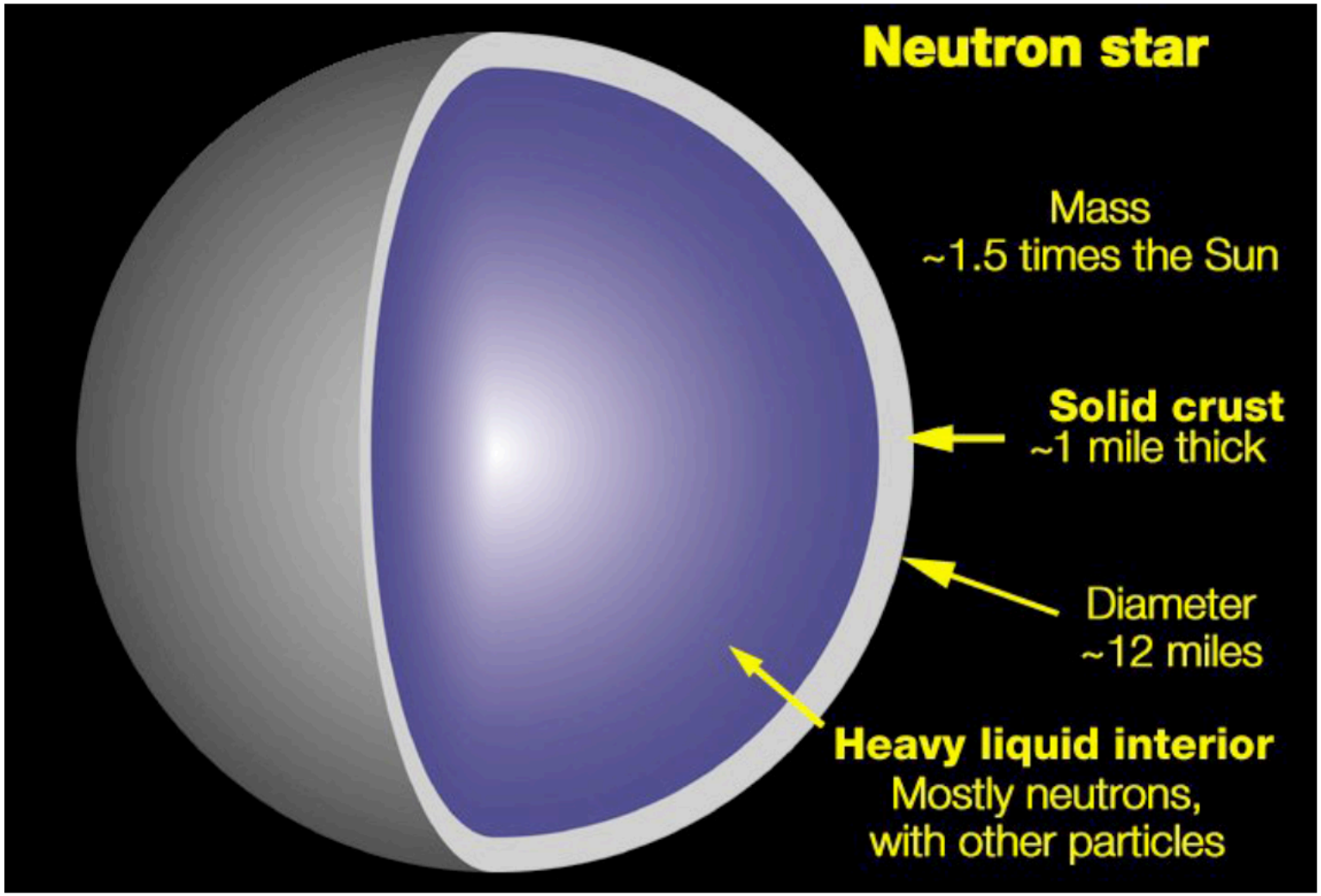


X-ray image of accreting neutron star

White dwarf


C+O nuclei plus
degenerate electrons
T ~ 10⁶ degrees
normal matter
T ~ 10,000 degrees

Neutron star: density of nucleus!



- **white dwarf:** electrons run out of room and halt the collapse of the star

maximum mass
1.4 solar masses

- **neutron star:** neutrons run out of room and halt the collapse of the star

maximum mass
~3 solar masses

- **black hole:** gravity wins: collapse continues

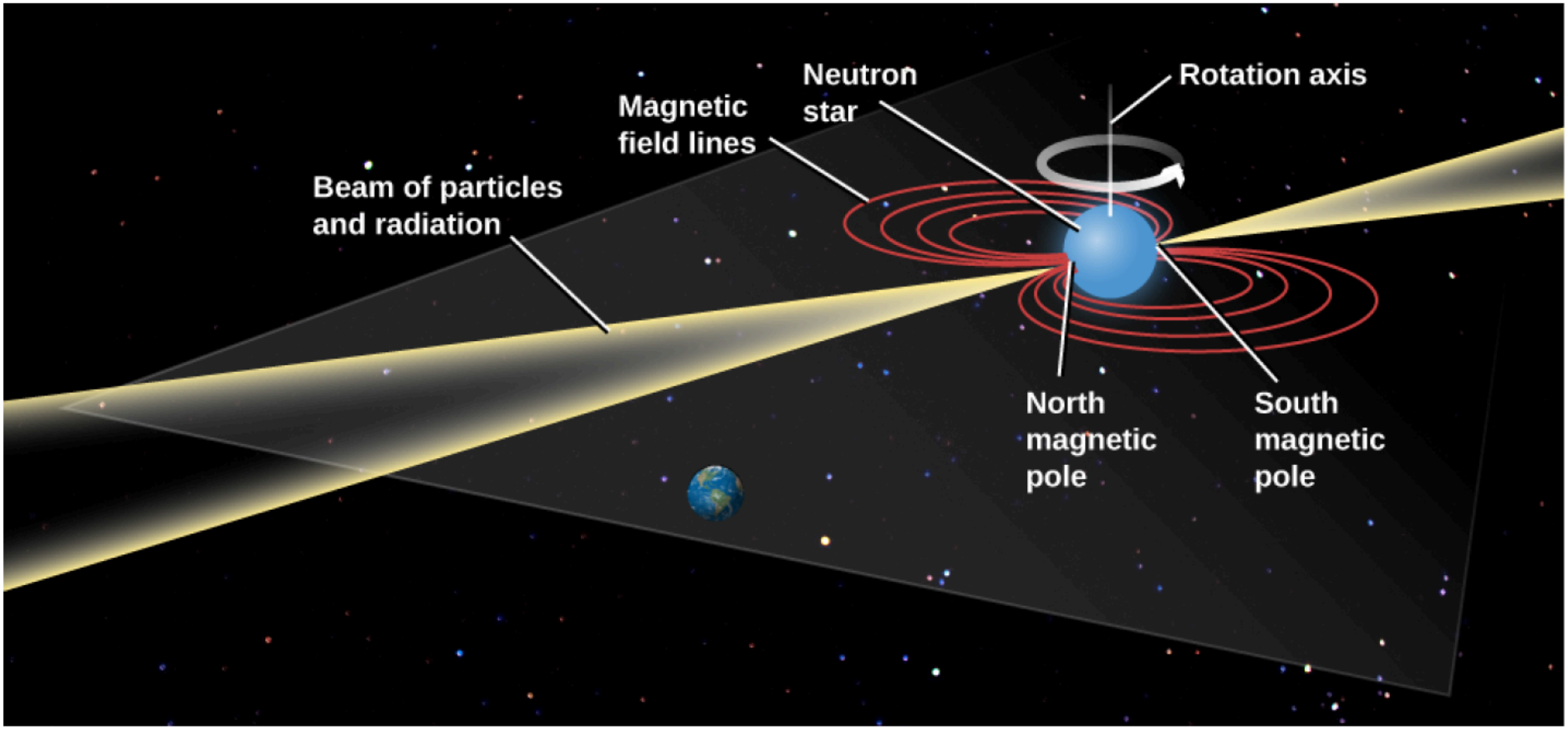
Sun: size 1.4×10^6 km

rotation period 27 days = 2.3×10^6 s

Neutron star: size 14 km = 1 million times smaller

☞ rotation period 1 million times shorter = 2.3 s

Pulsar: neutron star with beamed light pulses from electrons



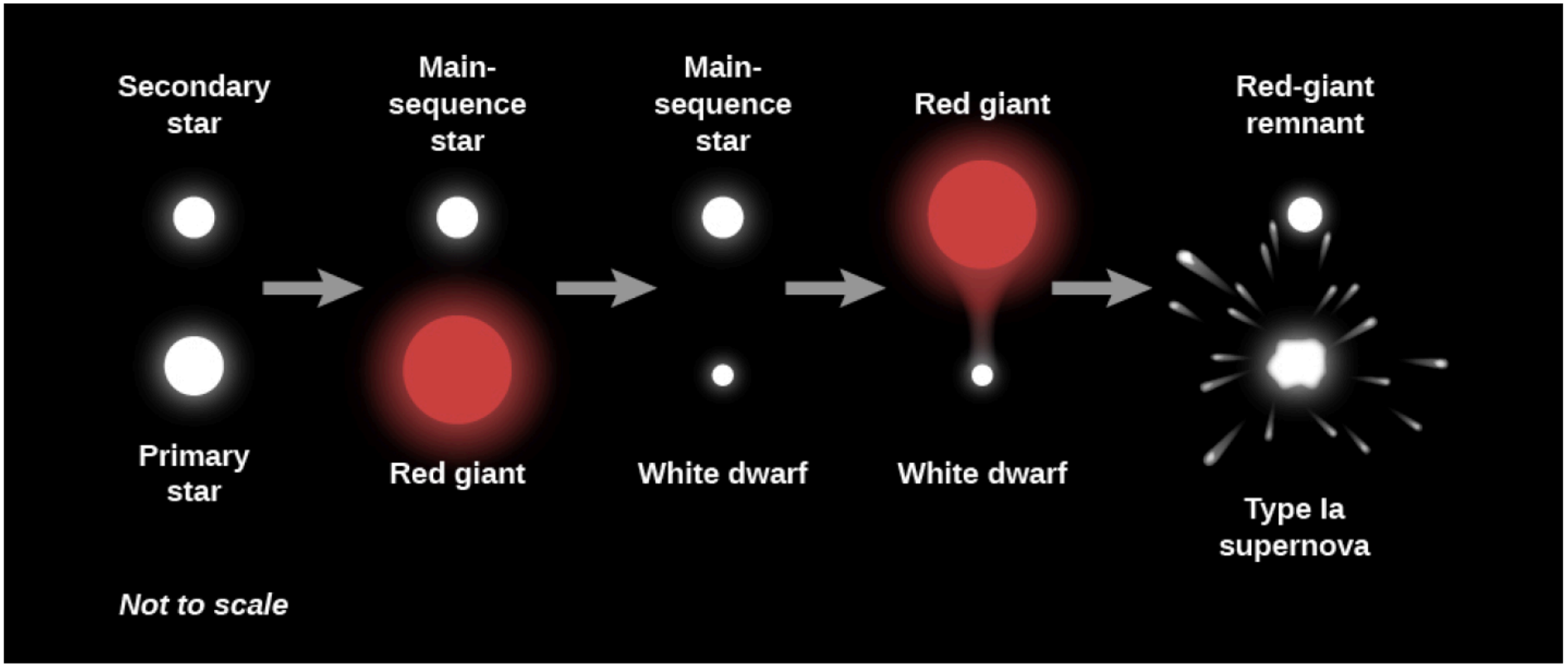
Jocelyn Bell: Found pulsars (discovery won Nobel Prize, but she did not)

In 1982, an *extremely* fast pulsar was discovered, rotating 640 times per second.

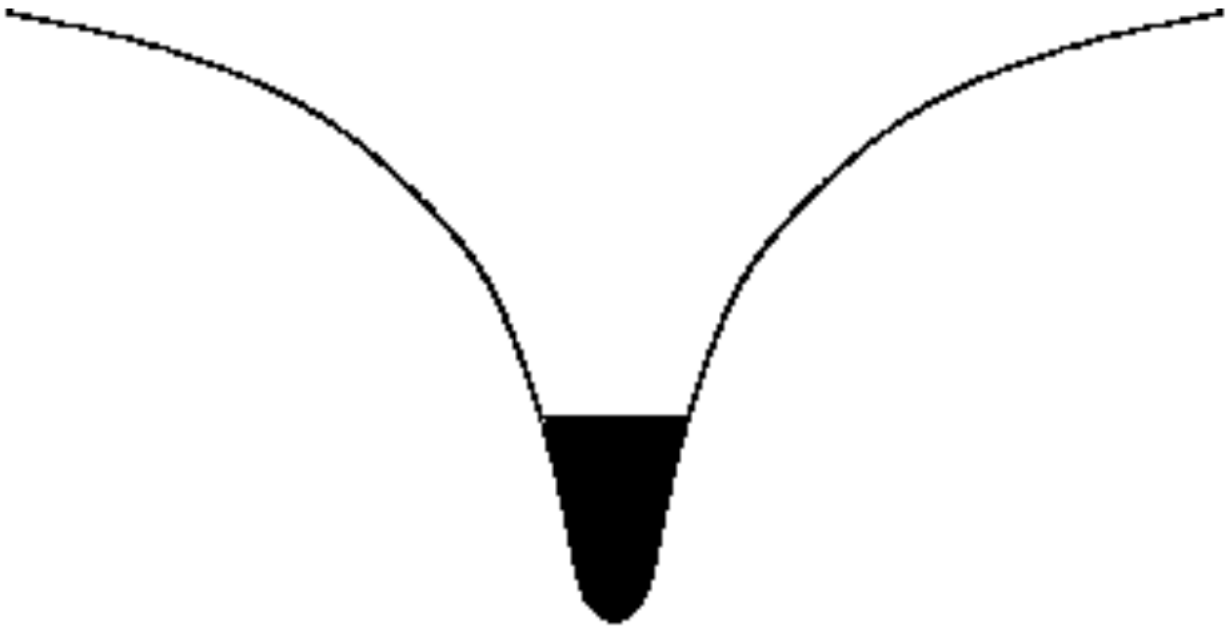
More *millisecond pulsars* were discovered, and 80% are in binary systems (compared to <1% of regular pulsars)

Millisecond pulsars are *old*: other fast pulsars (like the Crab pulsar) are young.

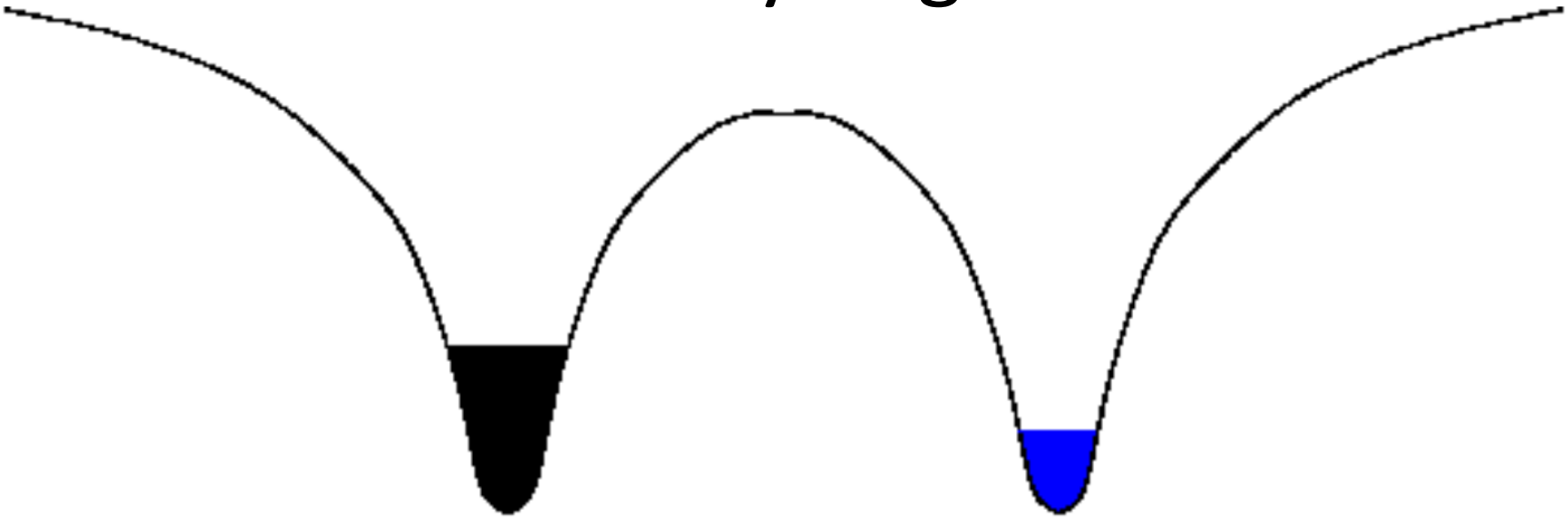
Weird things: binary evolution



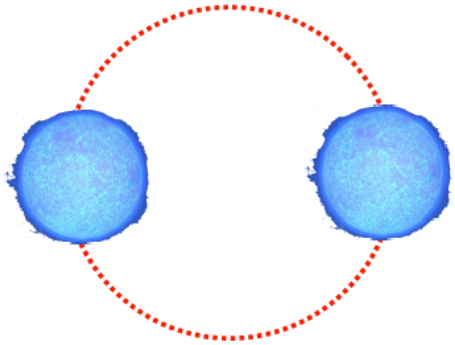
Gravity of single star



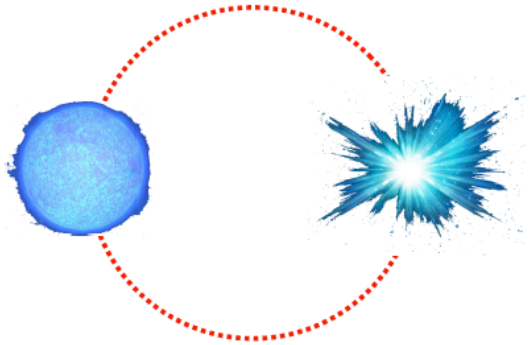
Gravity of binary star
What happens if one star grows very large?



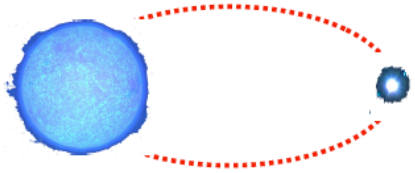
Begin with two massive stars.



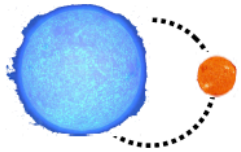
Then one goes supernova



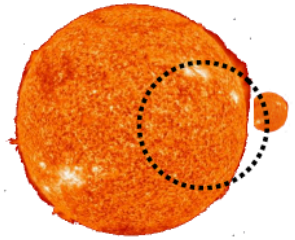
... leaving the other in an elliptical orbit with a neutron star



Begin with a massive star and a light star.

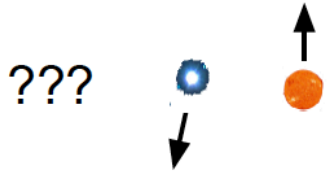


How does the giant star fit inside the orbit?



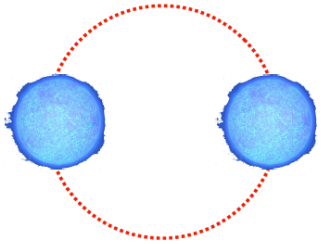
After the supernova explosion,

the binary will be unbound.

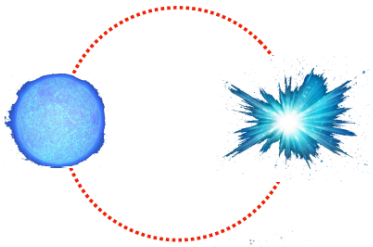


Millisecond pulsars are *recycled* pulsars.

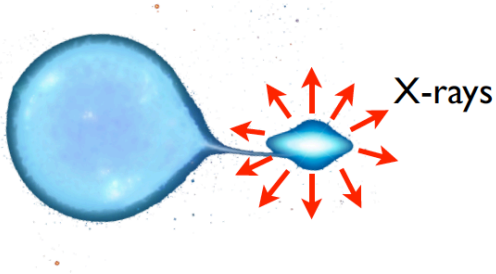
Born in a binary system,



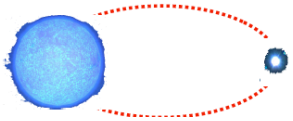
one star goes supernova, then the other evolves and leaves a neutron star.

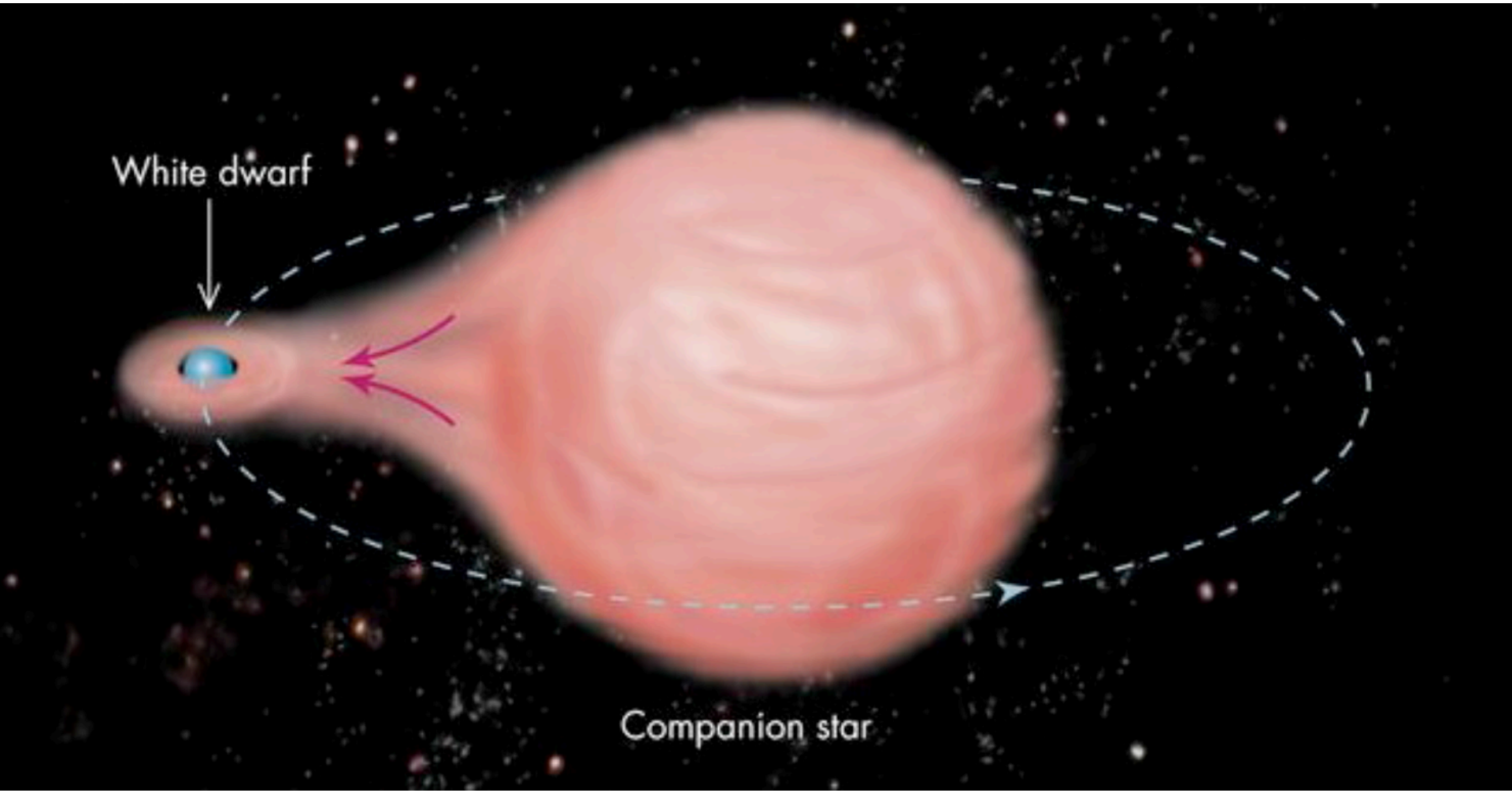


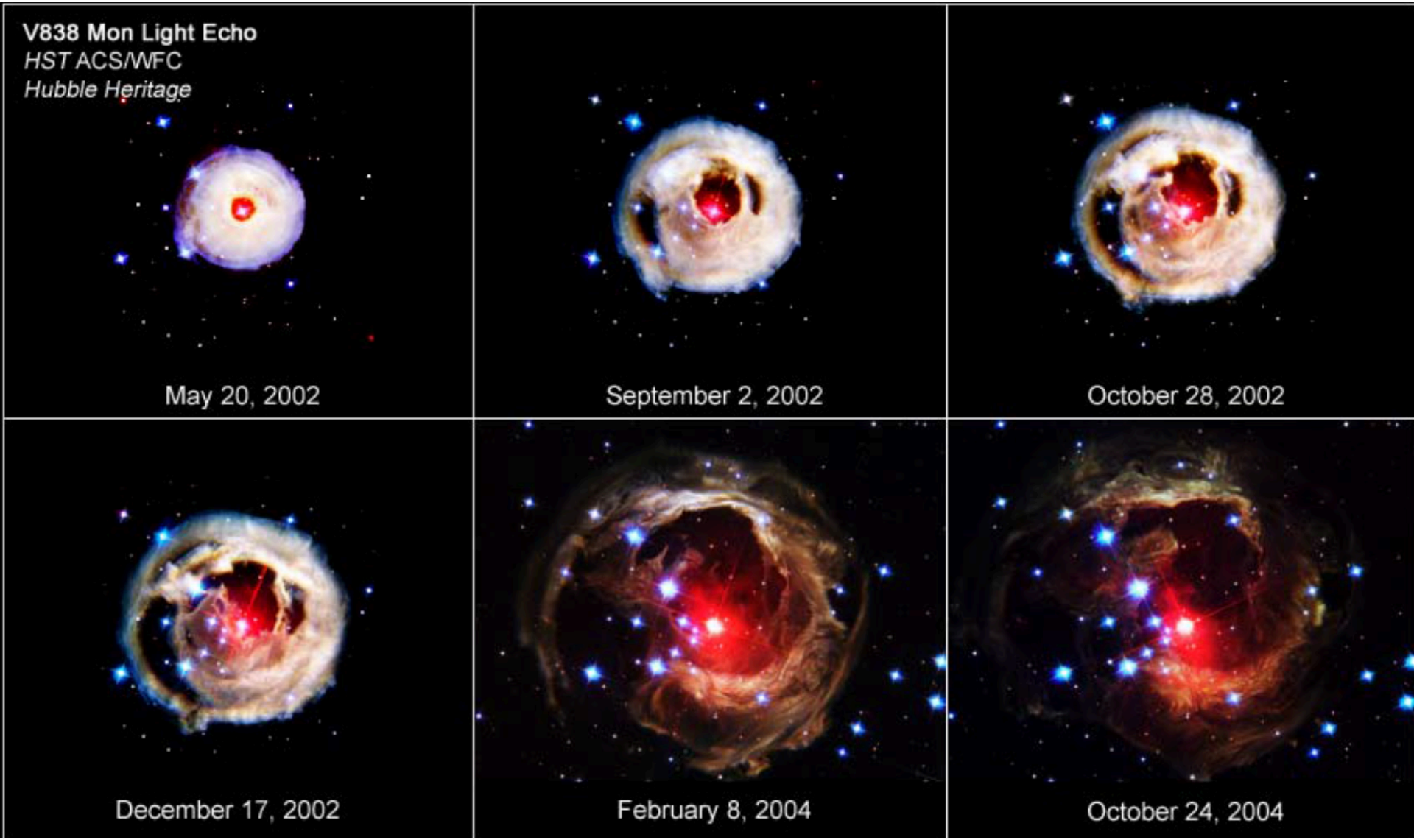
The second star starts spilling matter onto the neutron star, which accretes matter and angular momentum, which spins it up: an *X-ray binary*.



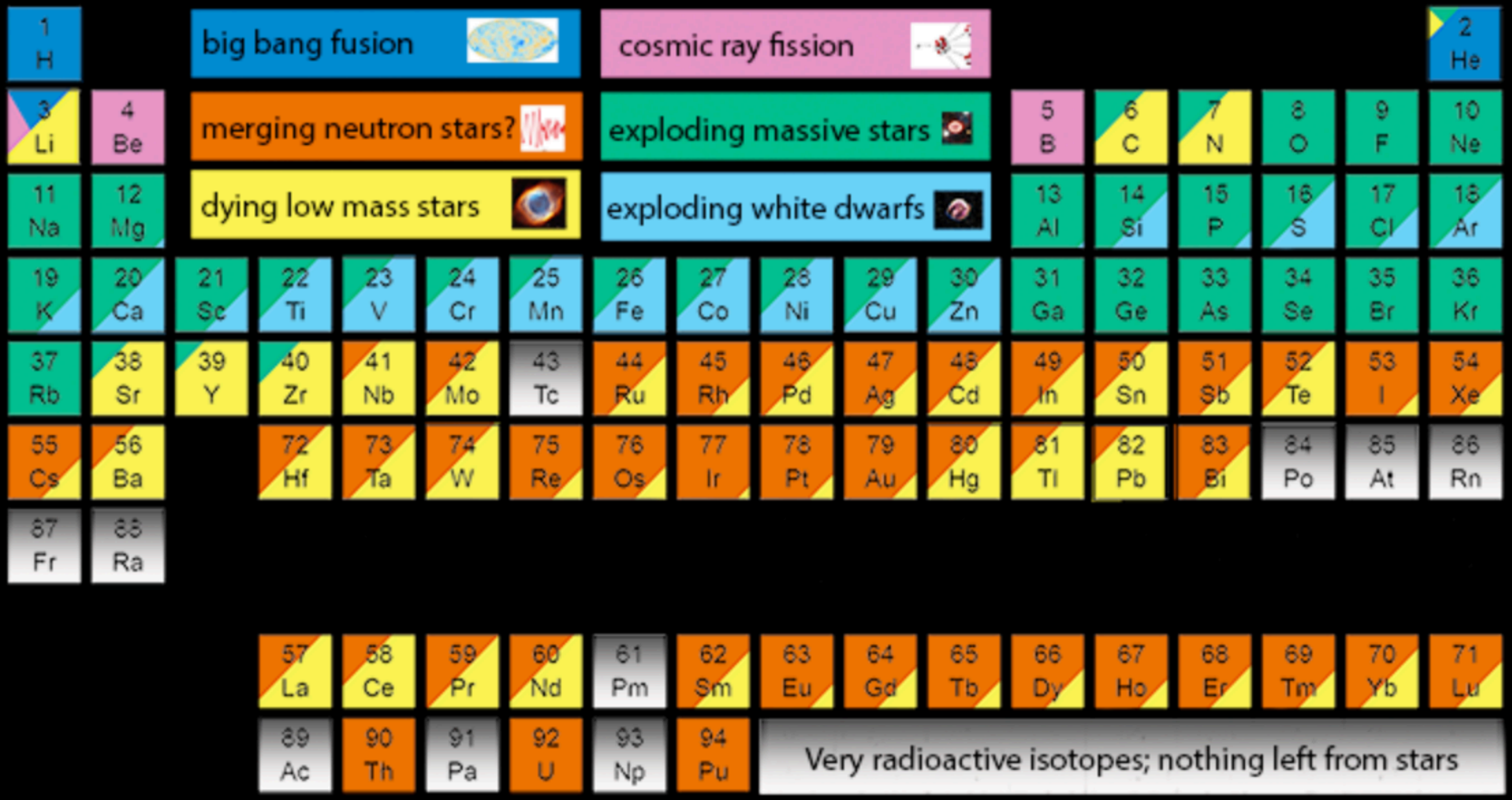
When accretion stops, we have a very fast pulsar in orbit with a neutron star or white dwarf.




White dwarf
Companion star


V838 Mon Light Echo
HST ACS/WFC
Hubble Heritage
May 20, 2002
September 2, 2002
October 28, 2002
December 17, 2002
February 8, 2004
October 24, 2004

The Origin of the Solar System Elements



Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/

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