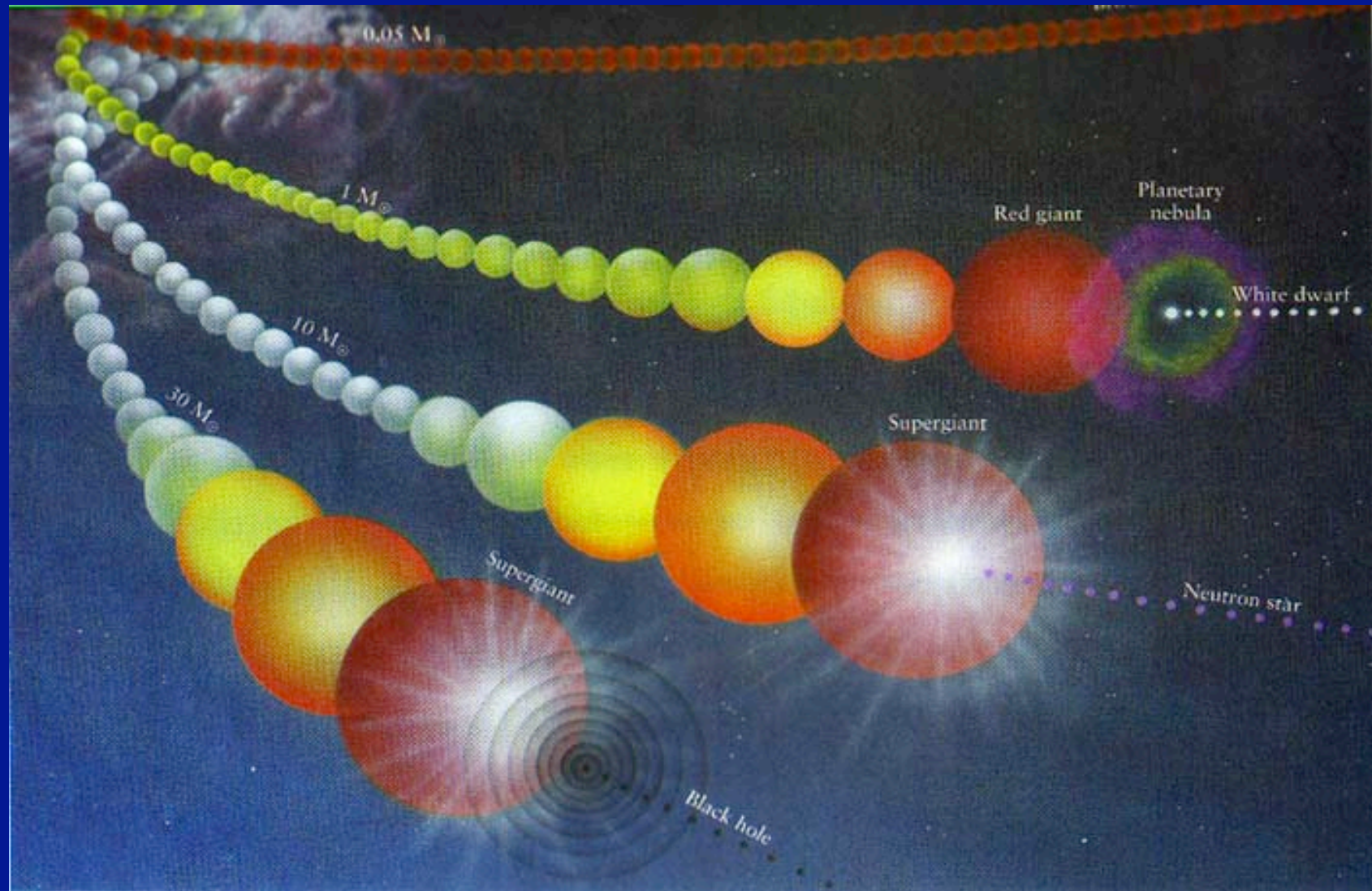


STARS: how they are born, live and die



[Image from "Gravity's fatal attraction" by Begelman & Rees]

HOW STARS ARE BORN

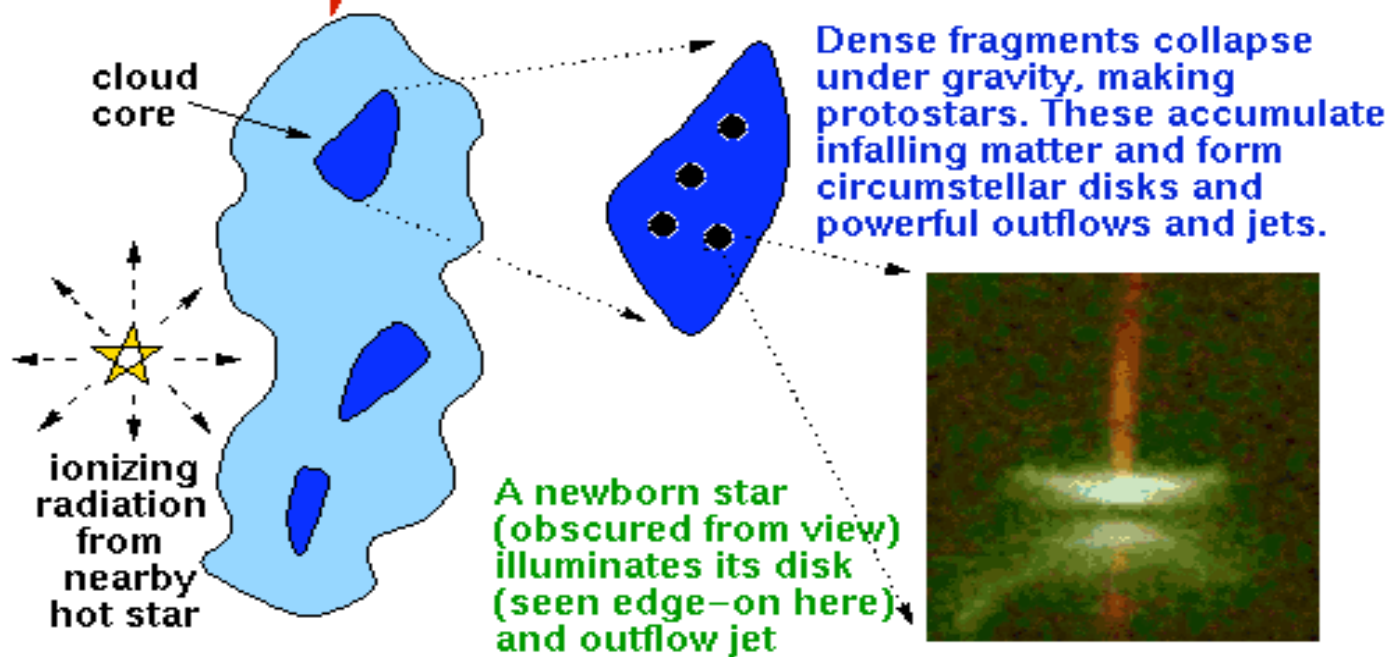


Molecular clouds are cold, dark, giant condensations of dust and molecular gas which serve as "stellar nurseries".

All stars are born in molecular clouds, including our Sun. Molecular clouds are the "stuff" we're made of!

Because of their dusty content, visible light cannot penetrate into a molecular cloud. Thus, infrared and submillimeter observations are needed to "see" the star-forming process.

molecular cloud



[Image from <http://sora.as.arizona.edu/submm-science.html>]

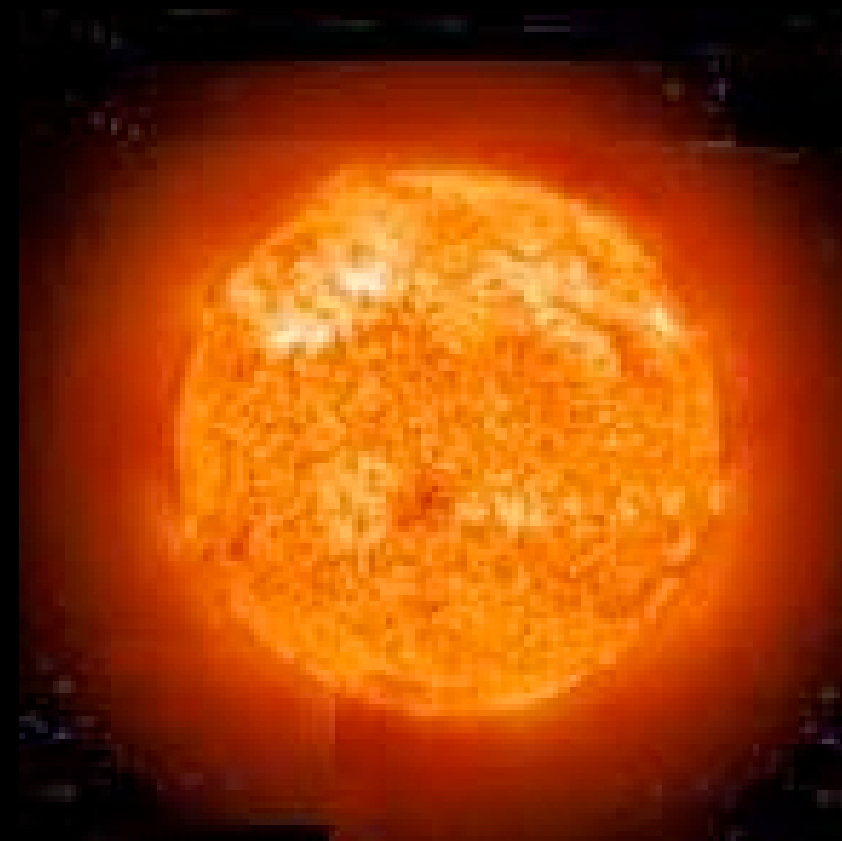
STAR BIRTH CLOUDS IN M16



*[Image by the Hubble
Telescope - NASA]*

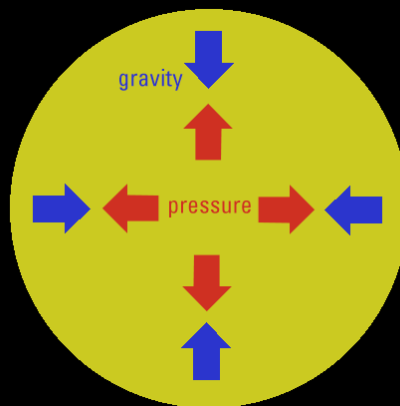
HOW STARS LIVE AND DIE

The life and death of
LOW-MASS STARS (i.e. our beloved Sun)



The life and death of a low-mass star

Start with a normal star like the Sun. Fusion of protons into helium in the star's center generates heat and pressure that can support the weight of the star. The Sun was mostly made of hydrogen (=1 proton + 1 electron) when it was born, and started with enough hydrogen to last like this for about 15 billion years.



*[This and next five slides
courtesy of D. Watson with
a few modifications]*

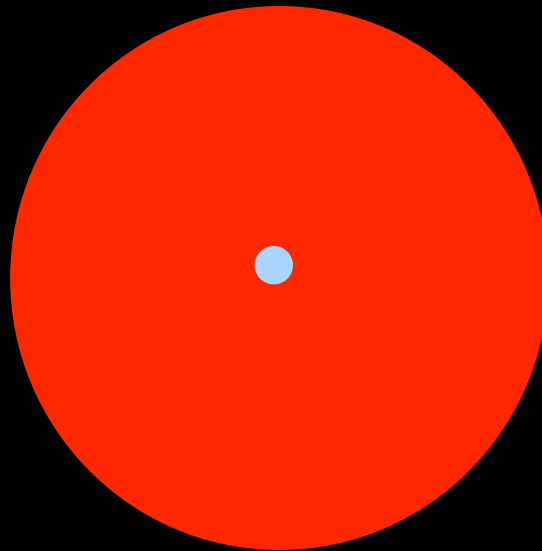
The life and death of a low-mass star (cont.)

When it begins to run out of hydrogen in its center, not enough heat and pressure are generated to balance the star's weight, so the core of the star gradually begins to collapse.



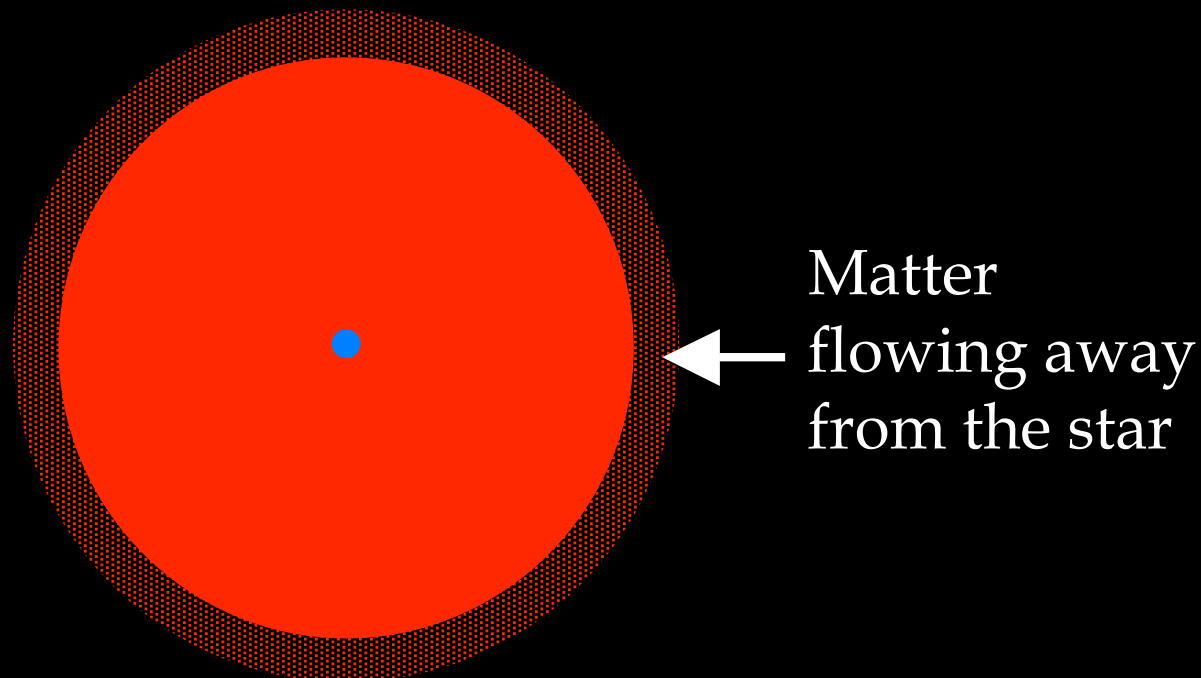
The life and death of a low-mass star (cont.)

As the core collapses it gets hotter, though no extra heat has been generated, just because it compresses. It gets so hot that light from the core causes the outer parts of the star to expand and get less dense, whereupon the star looks cooler from the outside. The star is becoming a **red giant**.



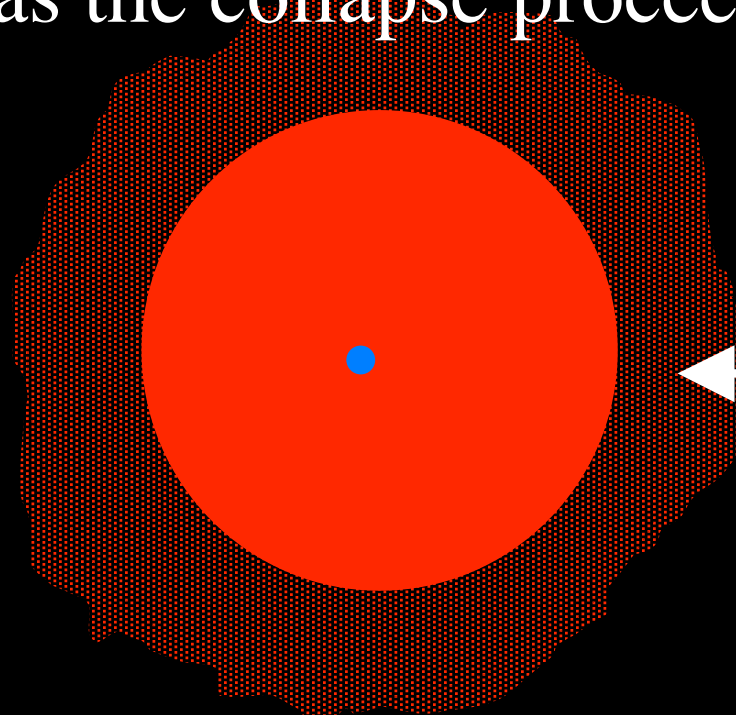
The life and death of a low-mass star (cont.)

Eventually the core gets so hot that it is possible for helium to fuse into carbon and oxygen. Extra heat and pressure are once again generated and the core stops collapsing; it is stable until the helium runs out, which takes a few million years. The outer parts of the star aren't very stable, though.



The life and death of a low-mass star (cont.)

Eventually the core is all carbon and oxygen, no additional heat and gas pressure is generated, and the core begins collapsing again. This time the density is so large – the electrons so close together – that electron degeneracy pressure begins to increase significantly as the collapse proceeds.



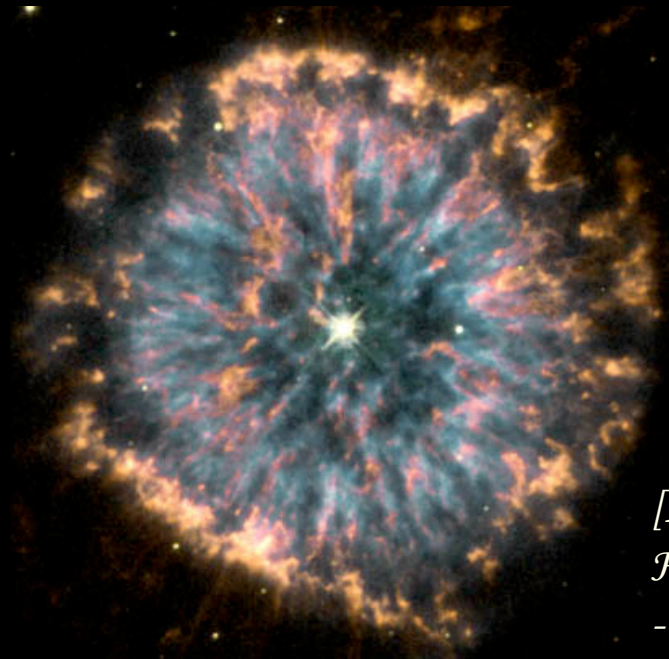
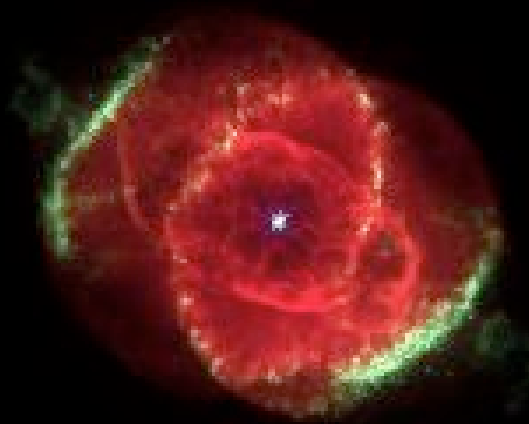
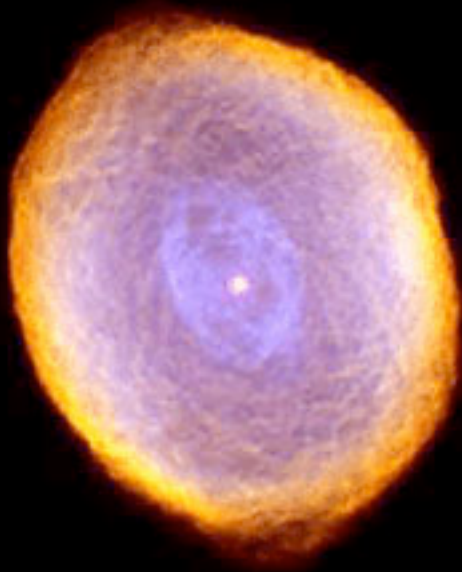
Matter
flowing away
from the star

The life and death of a low-mass star (cont.)

Electron degeneracy pressure eventually brings the collapse of the core to a halt, before it gets hot enough to fuse carbon and oxygen into magnesium and silicon. The unstable outer parts of the star fall apart altogether; they are ejected and ionized by light from the core, producing a **planetary nebula**.



Hubble images of PLANETARY NEBULAE



*[Images by the
Hubble Telescope
- NASA]*

The life and death of a low-mass star (cont.)

The planetary nebula's material expands away from the scene in a few thousand years, leaving behind the hot, former core of the star, now about the size of Earth. Its weight supported against further collapse by electron degeneracy pressure, it will do nothing but sit there and cool off, for eternity.

.

[This and next slide courtesy of D. Watson]

The life and death of a low-mass star (cont.)

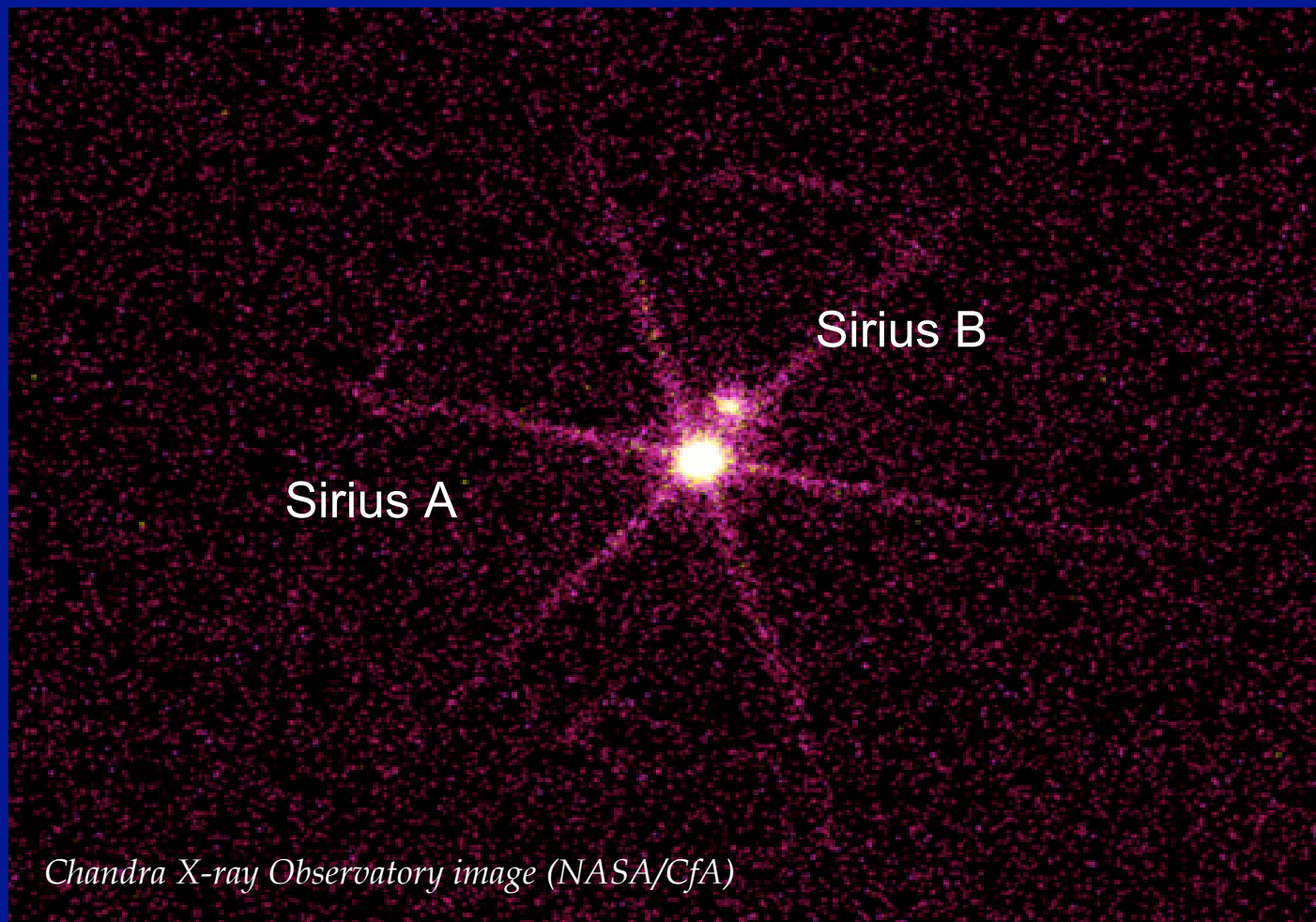
When brand new, this degenerate star is quite hot and looks white (like Sirius B) or even blue in color, leading to the name **white dwarf**. The oldest “white dwarfs” in our galaxy, age about 12 billion years, have had enough time to cool down to temperatures in the few thousands of degrees, and thus look red. (Despite this they are still called white dwarfs.)



A famous white dwarf: **Sirius B**

Distance to us = 8.7 light years

Density = 50,000 times that of water



Chandra X-ray Observatory image (NASA/CfA)

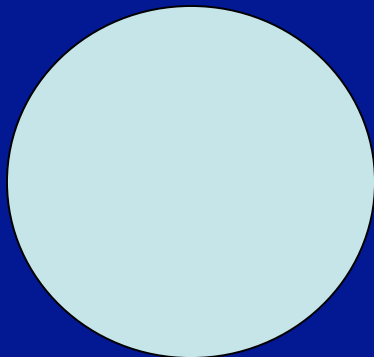
Funky properties of white dwarf material



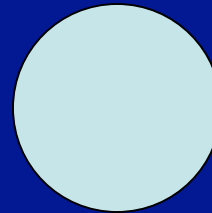
1 Kg chocolate cake



2 Kg chocolate cake



$0.4 M_{\text{sun}}$ white dwarf



$0.8 M_{\text{sun}}$ white dwarf

How heavy can a white dwarf be?



Subrahmanyan Chandrasekar.

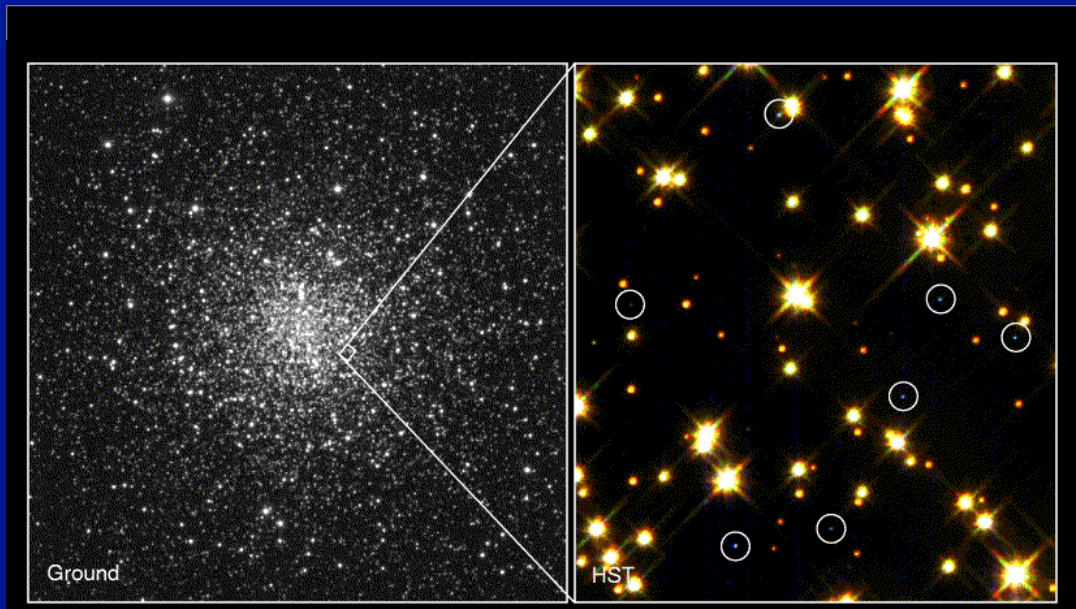
CHANDRASEKAR LIMIT: $1.4 M_{\text{SUN}}$

A star heavier than $1.4 M_{\text{sun}}$ can no longer be supported against gravitational collapse by the degeneracy pressure of electrons.

Experimental confirmation of Chandrasekhar's theory of white dwarfs

Today thousands of white dwarf stars are known. Sure enough, all stellar masses under $1.4 M_{\odot}$ are represented, but no white dwarf heavier than this has ever been found.

For this work, Chandrasekhar was awarded the 1983 Nobel Prize in Physics. The NASA Chandra X-ray Observatory (CXO) is named in his honor.



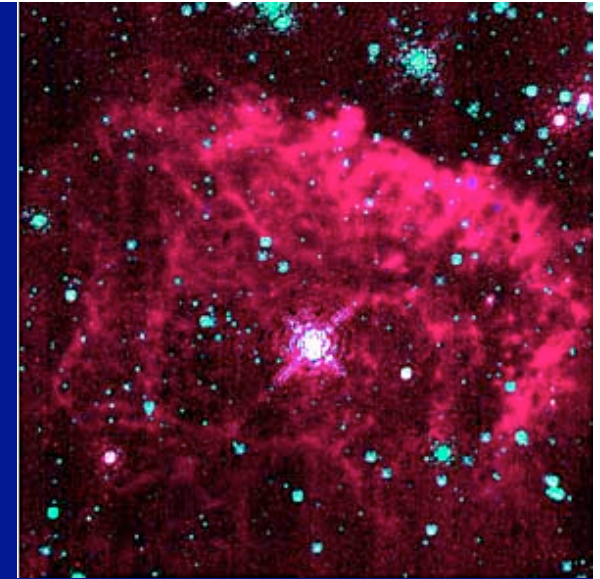
Seven white dwarfs (circled) in a small section of the globular cluster M4 (By H. Richer and M. Bolte. Left: Kitt Peak National Observatory 36"; right: Hubble Space Telescope).

[Slide courtesy of D. Watson]

HOW STARS DIE

HIGH-MASS STARS

Nuclear reactions proceed until core becomes Iron.
Core collapses until density becomes so high that neutrons are packed very tightly and their degeneracy pressure supports against gravity



→ **NEUTRON STAR**

Neutron degeneracy pressure prevents further collapse

$$M_{\text{max}} \sim 2-3 M_{\text{sun}}$$

[Image from "Gravity's Fatal Attraction" by Begelman & Rees]

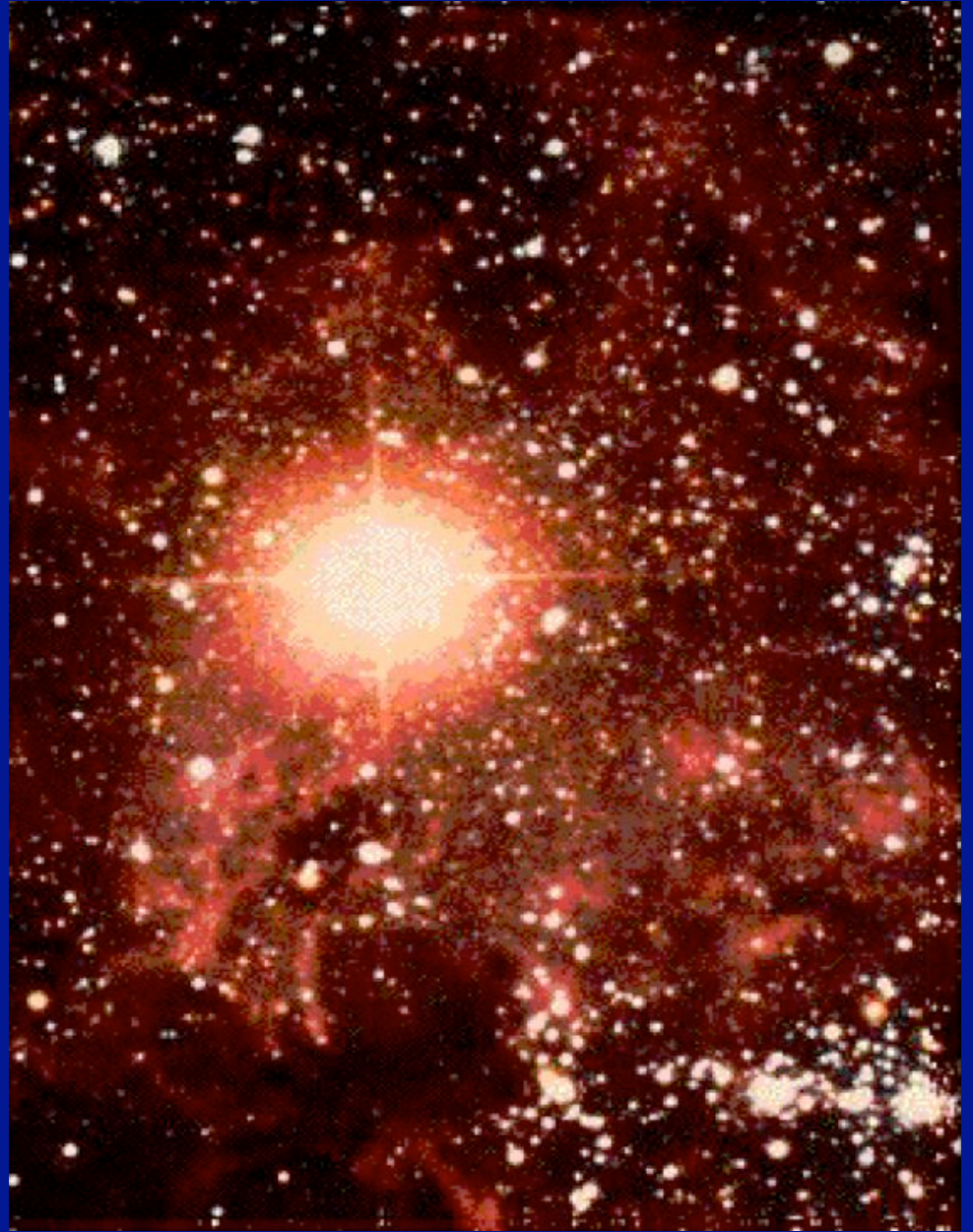


The explosion is dramatic: SUPERNOVA

.... as seen by an artist



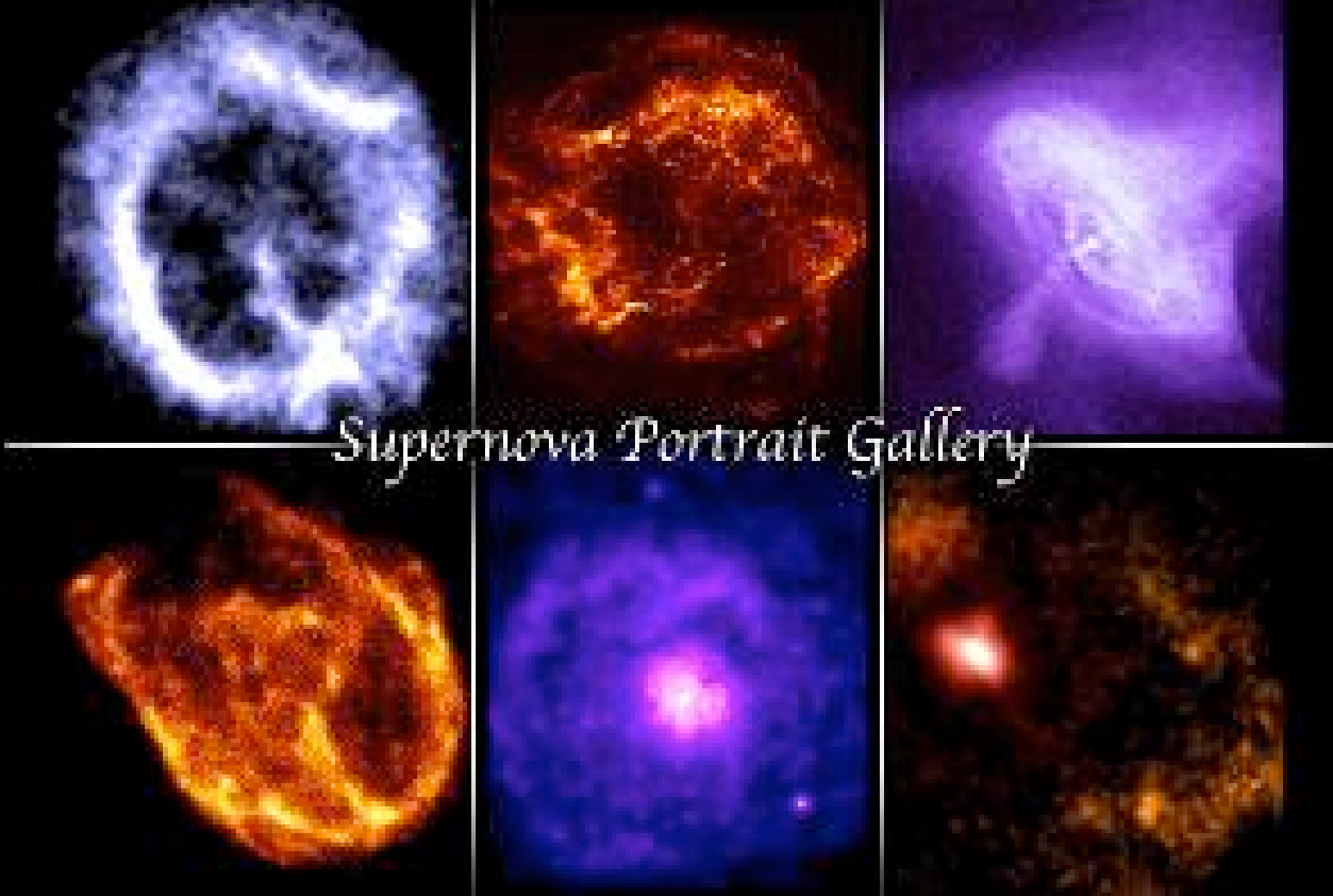
... as seen by a telescope



[Supernova 1987A, Anglo-Australian Observatory]

What is left behind: SUPERNOVA REMNANT

Chandra X-ray Observatory



[Images from the Chandra Observatory]

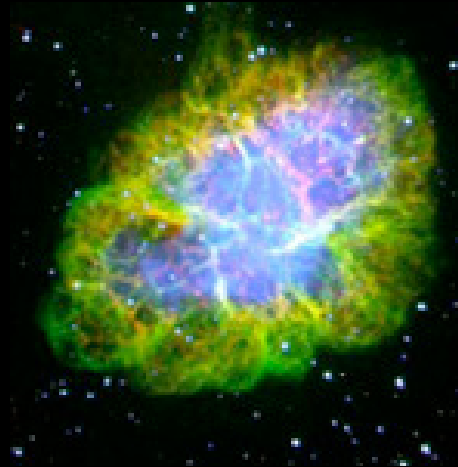
The Crab supernova remnant seen at different wavelengths

X-rays



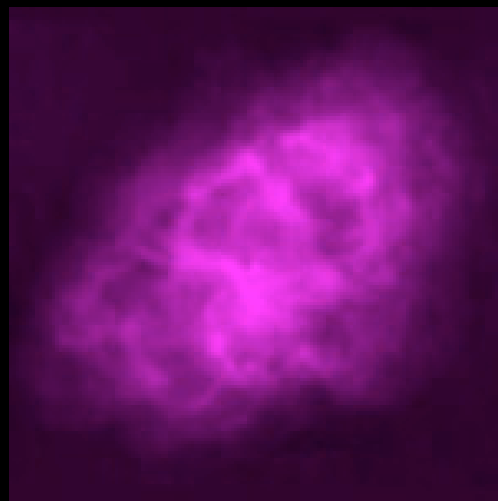
*[NASA/CXC
/SAO]*

Optical



[Palomar Observatory]

Infrared



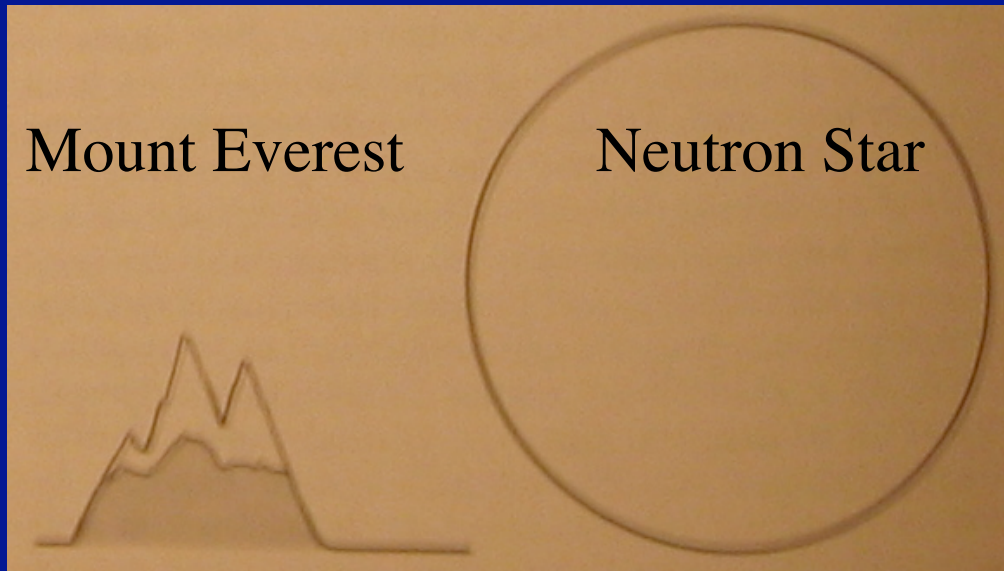
*[2MASS/Umass/
IPAC-Caltech/
NASA/NSF]*

Radio



[VLA/NRAO]

NEUTRON STAR properties

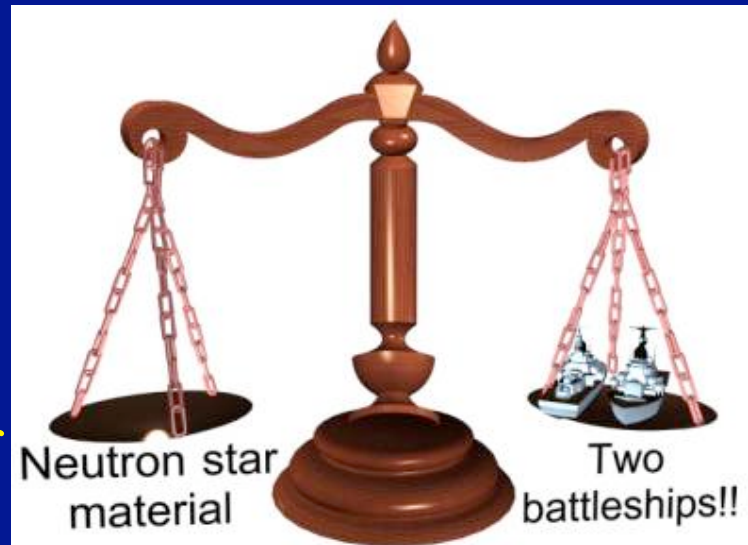


Mount Everest

Neutron Star

**Size of a
neutron star**

Weight of a neutron star



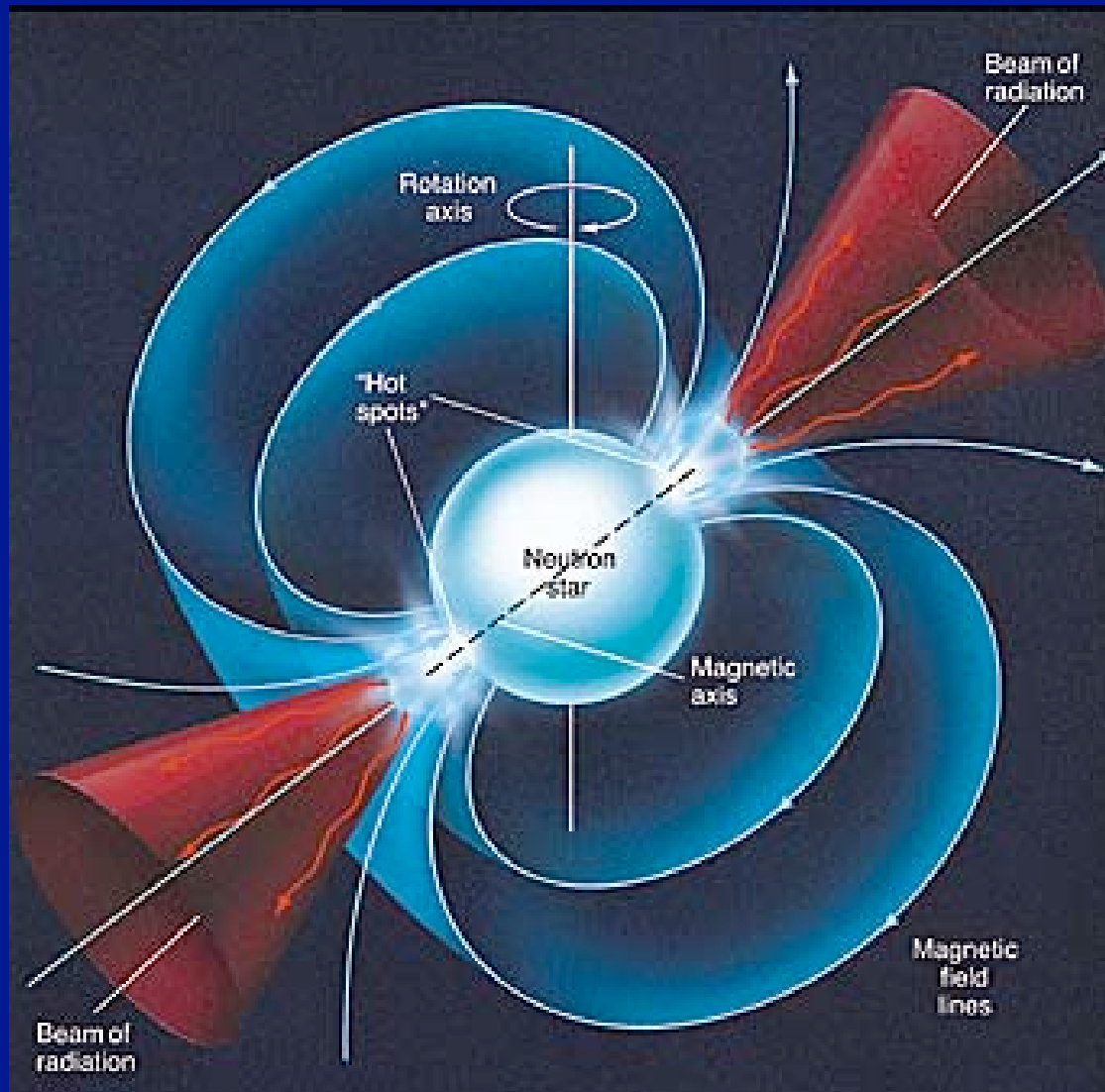
Pinhead of

Neutron star
material

Two
battleships!!

How neutron stars manifest themselves:

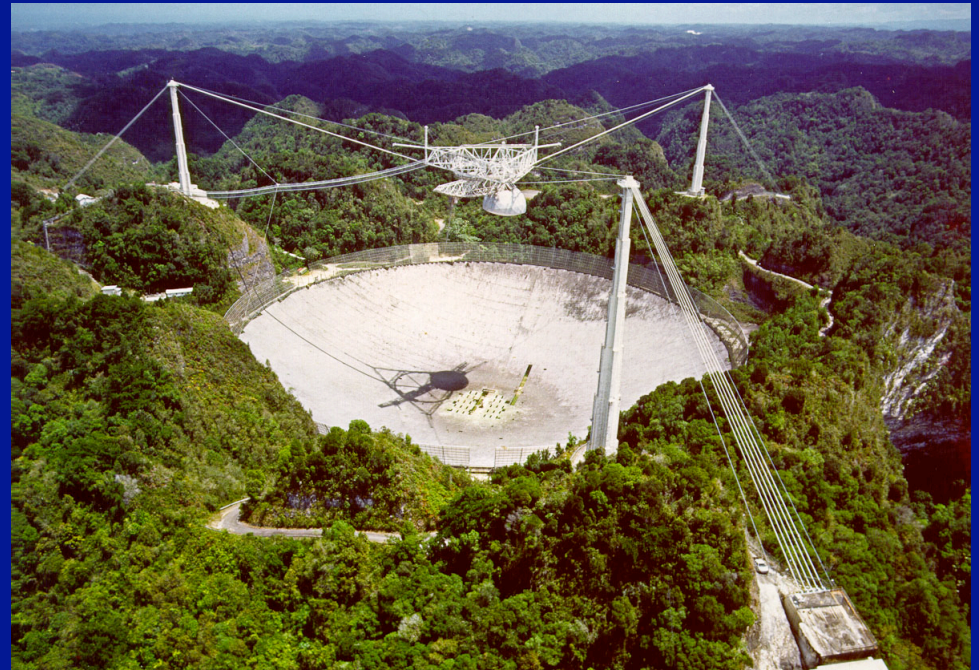
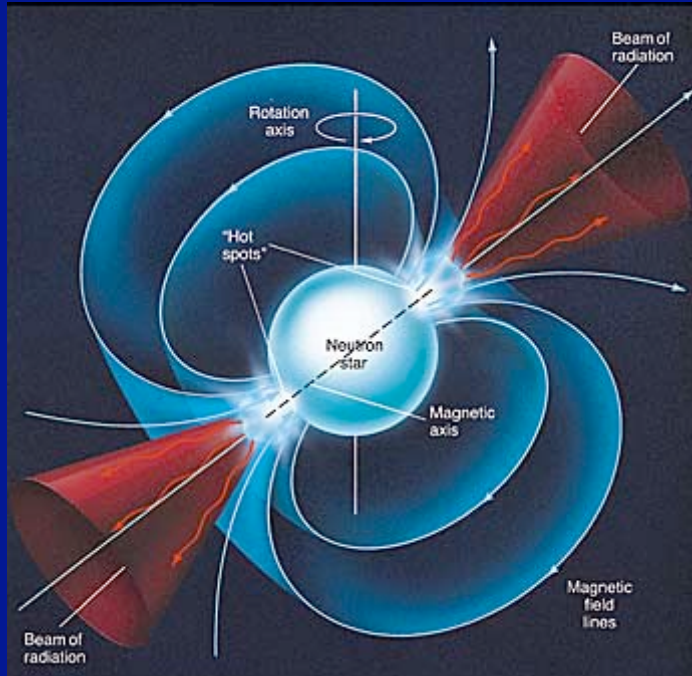
PULSARS



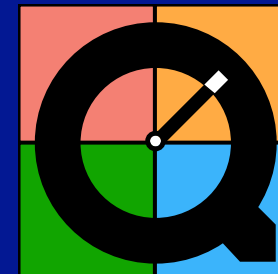
A **pulsar** is a magnetized, spinning neutron star that emits a beam of radiation (mostly radio, but also X-ray and optical). As the star spins, its beam sweeps around.

Any time the beam sweeps by the Earth, telescopes detect a pulse of radiation.

How does a pulsar “sound”?



The Arecibo radio telescope



[Audios courtesy of D. Nice]

What happens if the Iron core of the collapsing star has a mass larger than $2-3 M_{\text{sun}}$?

A BLACK HOLE IS BORN!



[Image from <http://archive.ncsa.uiuc.edu/Cyberia/NumRel/Images/hole.born.gif>]

QUESTIONS TO BE ADDRESSED:

- **Where are these remnant black holes?**
- **Can we identify them? How?**
- **What are the observational signatures that allow us to distinguish a black hole from another remnant such as a neutron star?**
- **Are the stellar remnant BHs the only types of black holes in our Universe?**