Special Stars

Reading: 19.4, 20.1 – 3, 21.1

The mass of stars lead quiet lives
on the Main Sequence.

“The mass of men lead lives of quiet
desperation.”

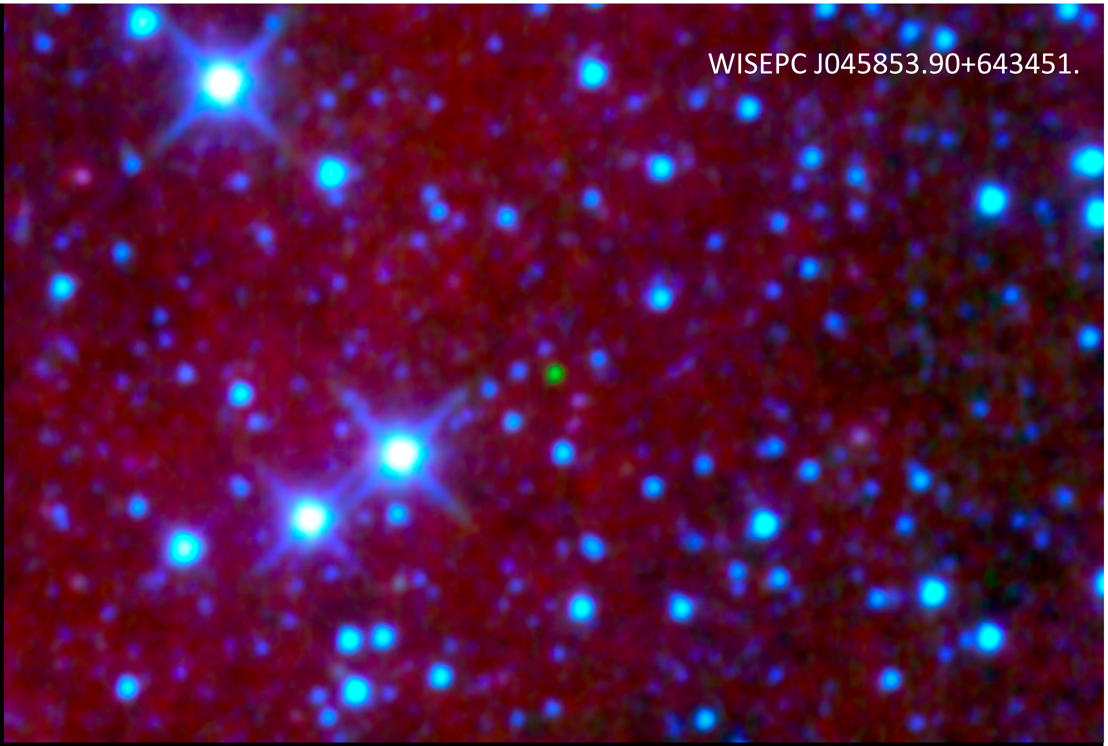
Henry David Thoreau
“Walden” (1854)

Brown Dwarf

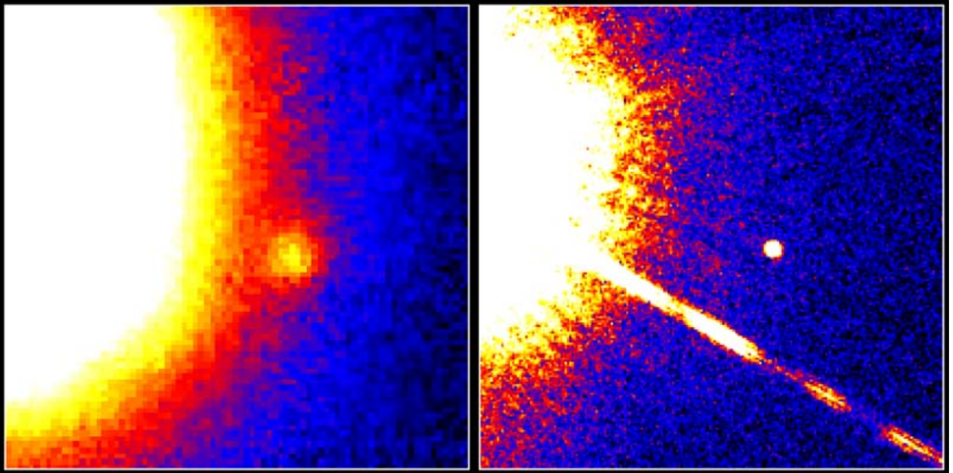
Too big to be a planet.
Too small to be a "real" star.
No nuclear fusion
(at least not ongoing).

Radius almost always the same as that of Jupiter.

Mass from 10 to 80 times the mass of Jupiter


WISEPC J045853.90+643451.

Brown Dwarf Gliese 229B



Palomar Observatory
Discovery Image
October 27, 1994

Hubble Space Telescope
Wide Field Planetary Camera 2
November 17, 1995

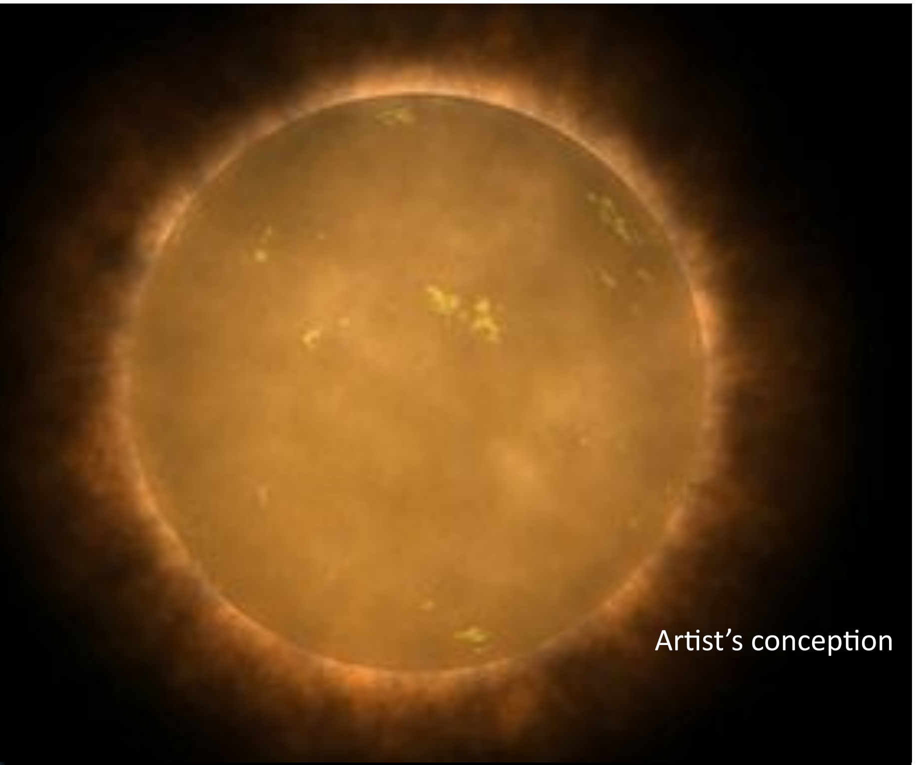
PRC95-48 • ST ScI OPO • November 29, 1995
T. Nakajima and S. Kulkarni (CalTech), S. Durrance and D. Golimowski (JHU), NASA

Red Dwarf

Small, cool star on the main sequence.
Spectral class M or K.

Mass less than 0.5 $M_\odot$
Mass greater than 0.075 $M_\odot$

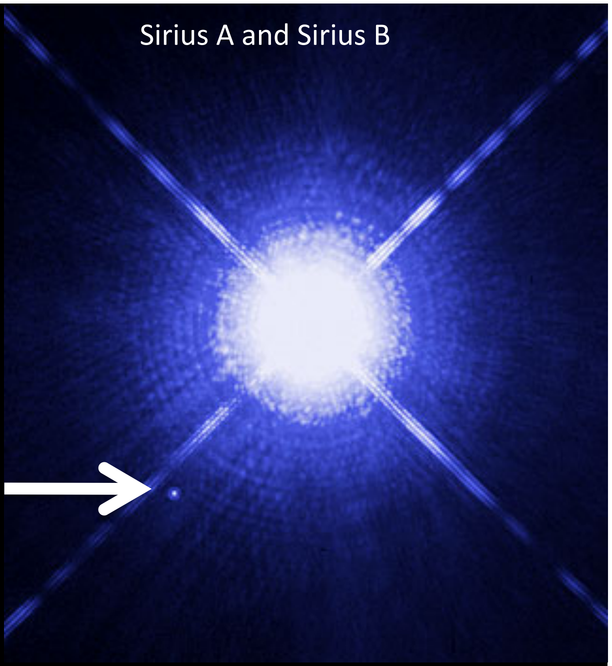
Low luminosity, so not easily observed.



Artist's conception

Proxima Centauri is an M5 Red Dwarf

White Dwarf



Mass of the Sun, in the size of the Earth

Primarily Carbon and Oxygen,
but with a degenerate "gas" of electrons.

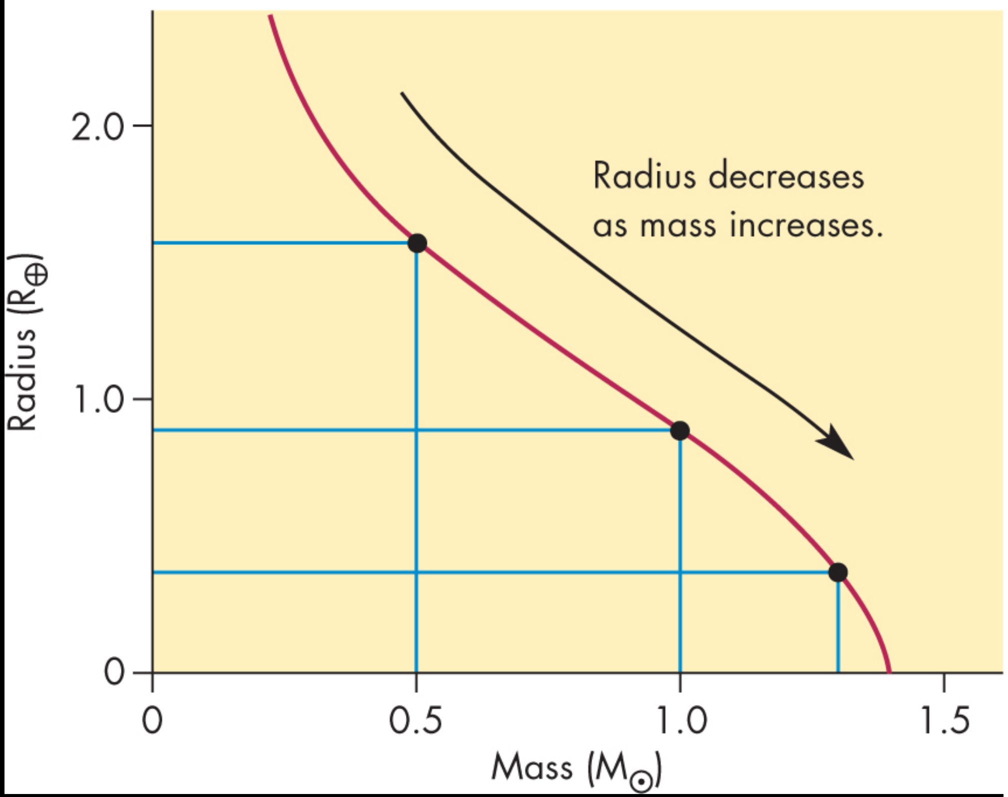
No nuclear "burning",
but still white hot

Main sequence stars with $M < 8\ M_{\odot}$ will become White Dwarf stars, not supernovae.

The Cat's Eye nebula (NGC 6543)
Composite image using optical images from the HST and X-ray data from the Chandra X-ray Observatory

As the mass of a White Dwarf increases, the radius *__decreases__*

As much as half the mass of our galaxy may be dead white dwarfs.

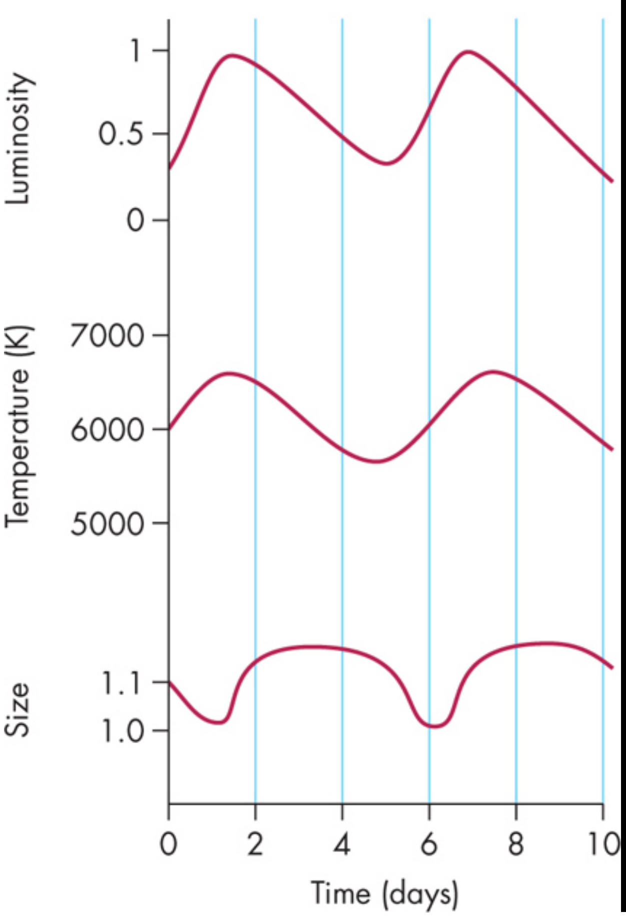


Maximum mass of a White Dwarf is 1.4 $M_\odot$, the "Chandrasekhar limit.

A White Dwarf star will eventually cool to the point that it will emit no visible light, and become a "Black Dwarf", but this will take more than the current age of the Universe, so there are as yet no black dwarf stars (yet, as far as we know). (And black dwarf stars are no the same thing as black holes)

Variable Stars

Some stars show periodic variations in brightness, which changes over hours or days or years

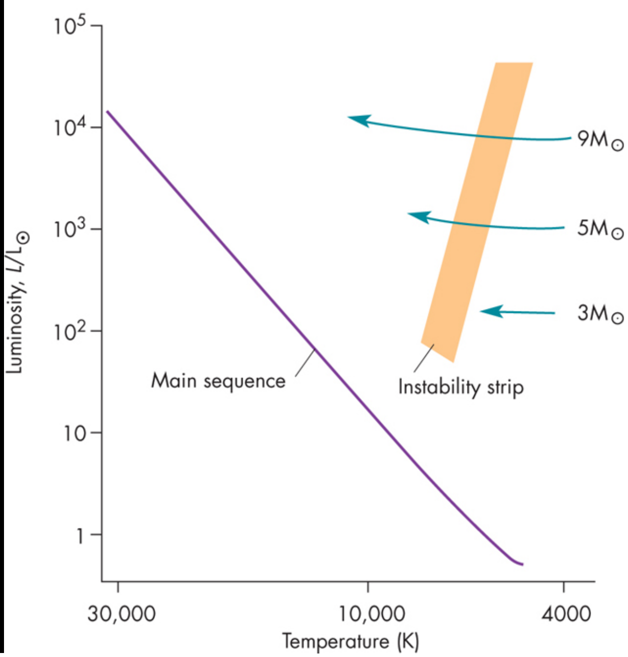


RR Lyrae Stars:
1.5 hrs to 1 day

Cepheid Variables:
1 to 100 days

Mira Variables:
more than 100 days

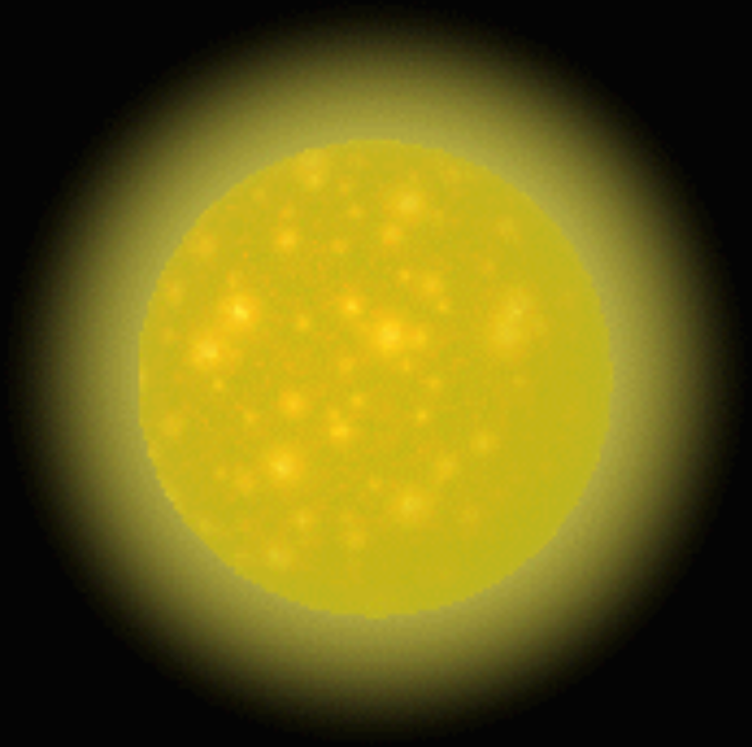
There is an “Instability Strip” in the H-R diagram



Pulsating Stars

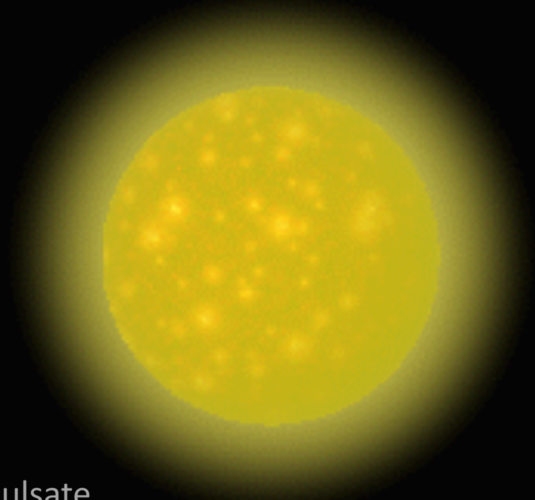
Hot, ionized atmosphere is opaque to light and so radiation pressure pushes it outward.

The expanded atmosphere cools, becomes less ionized, and becomes transparent, so it is no longer pushed outward. It contracts back in.



Atmosphere is heated, ionized, again becomes opaque and is pushed outward.   The process repeats like an oscillator

Analogy: lid on a boiling pot of water

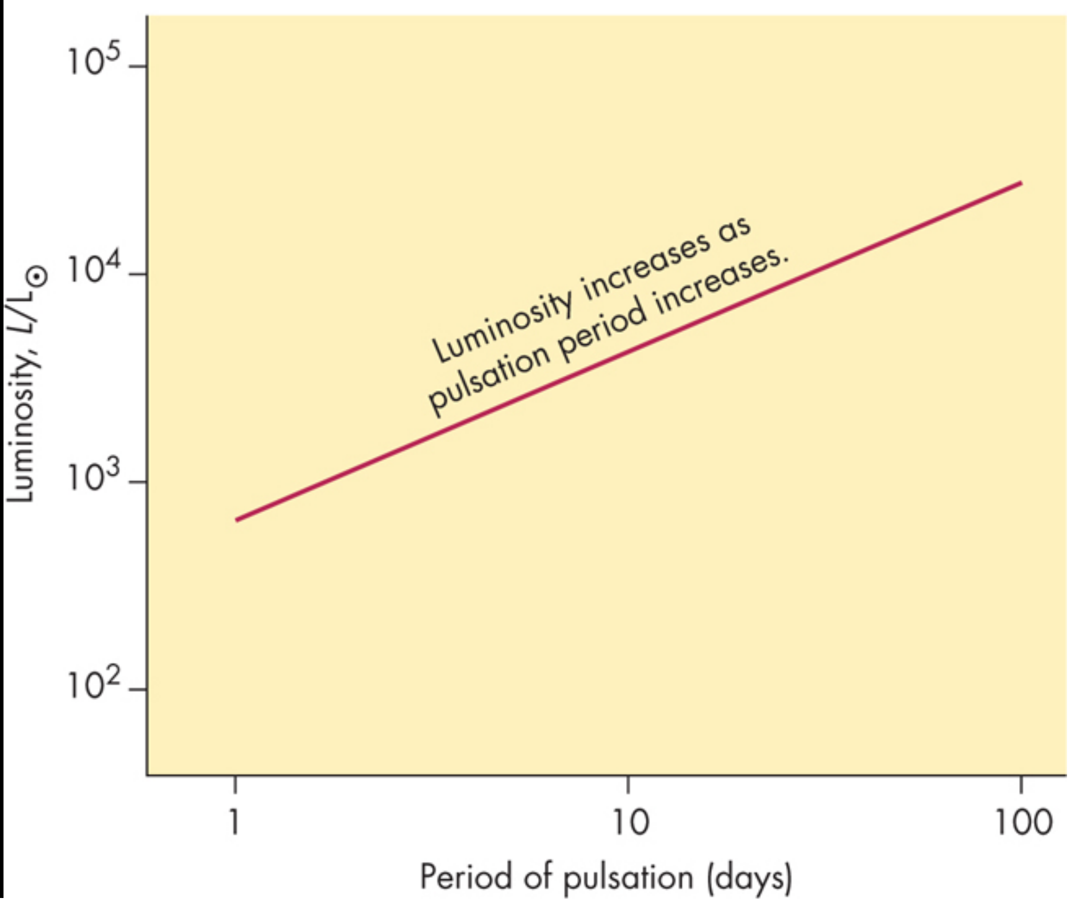


http://www.khanacademy.org/science/cosmology-and-astronomy/v/why-cepheids-pulsate

Cepheid Variables

Cepheid variable stars can be used as *Standard Candles!*

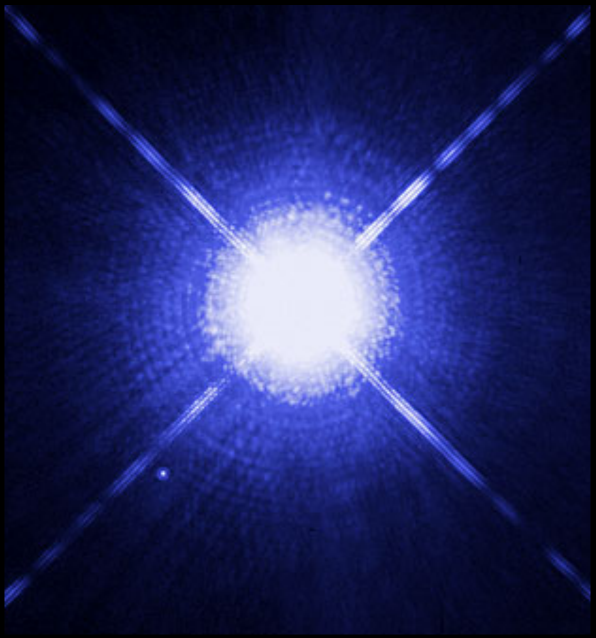
Measure the period, and you can infer the Luminosity of the star. Compare the absolute magnitude to apparent magnitude, and you can compute the distance to the star.



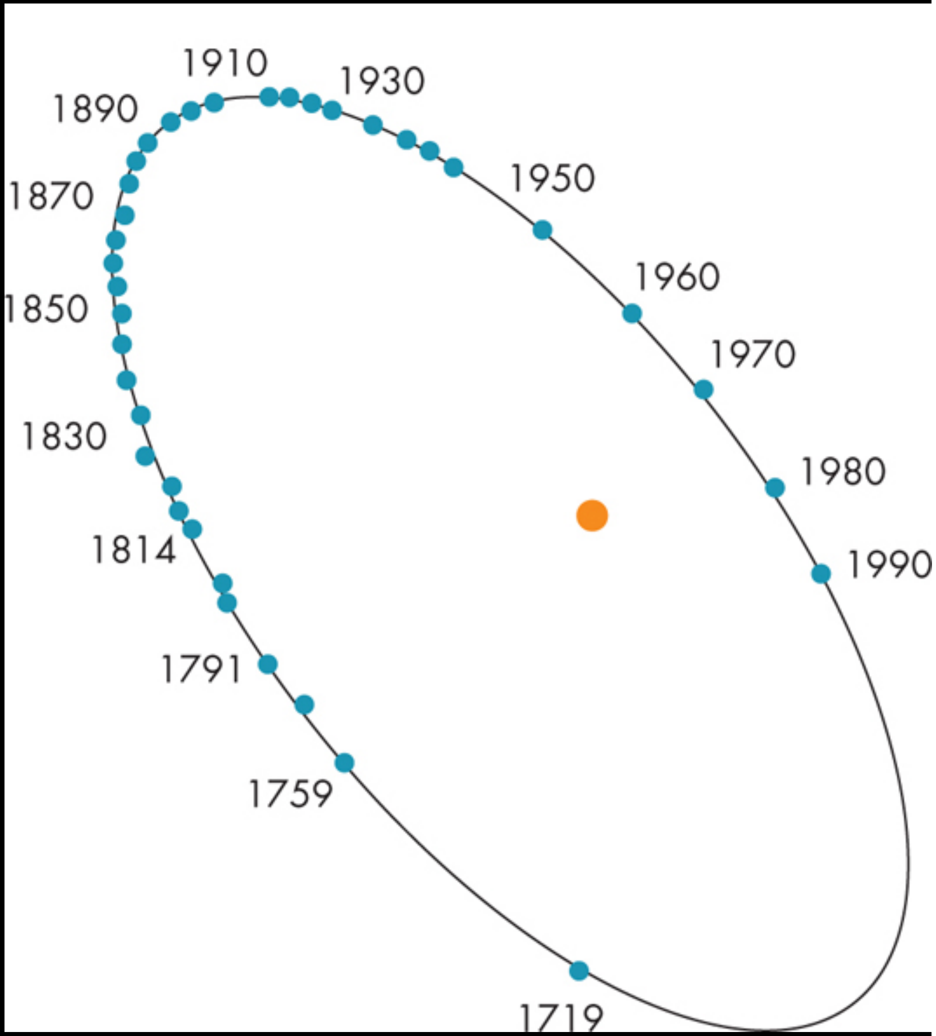
Binary Stars

Perhaps 50% of the stars we see in the night sky are actually binaries.

Visual Binaries:



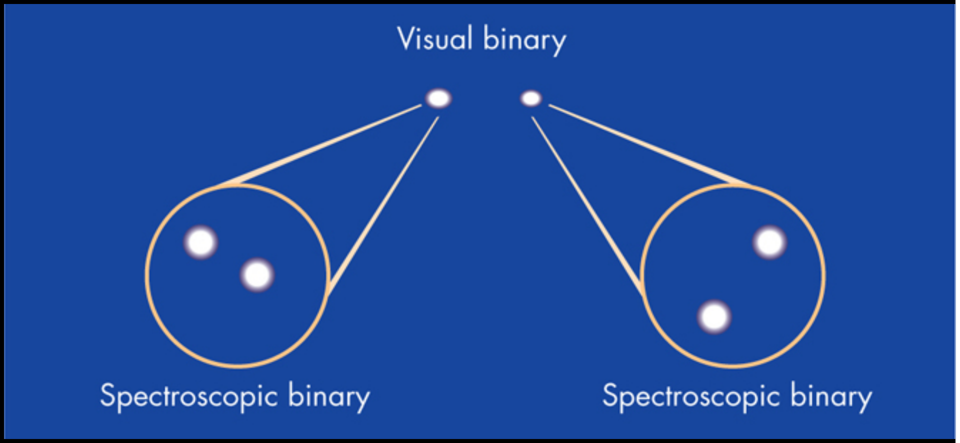
Sirius A and Sirius B



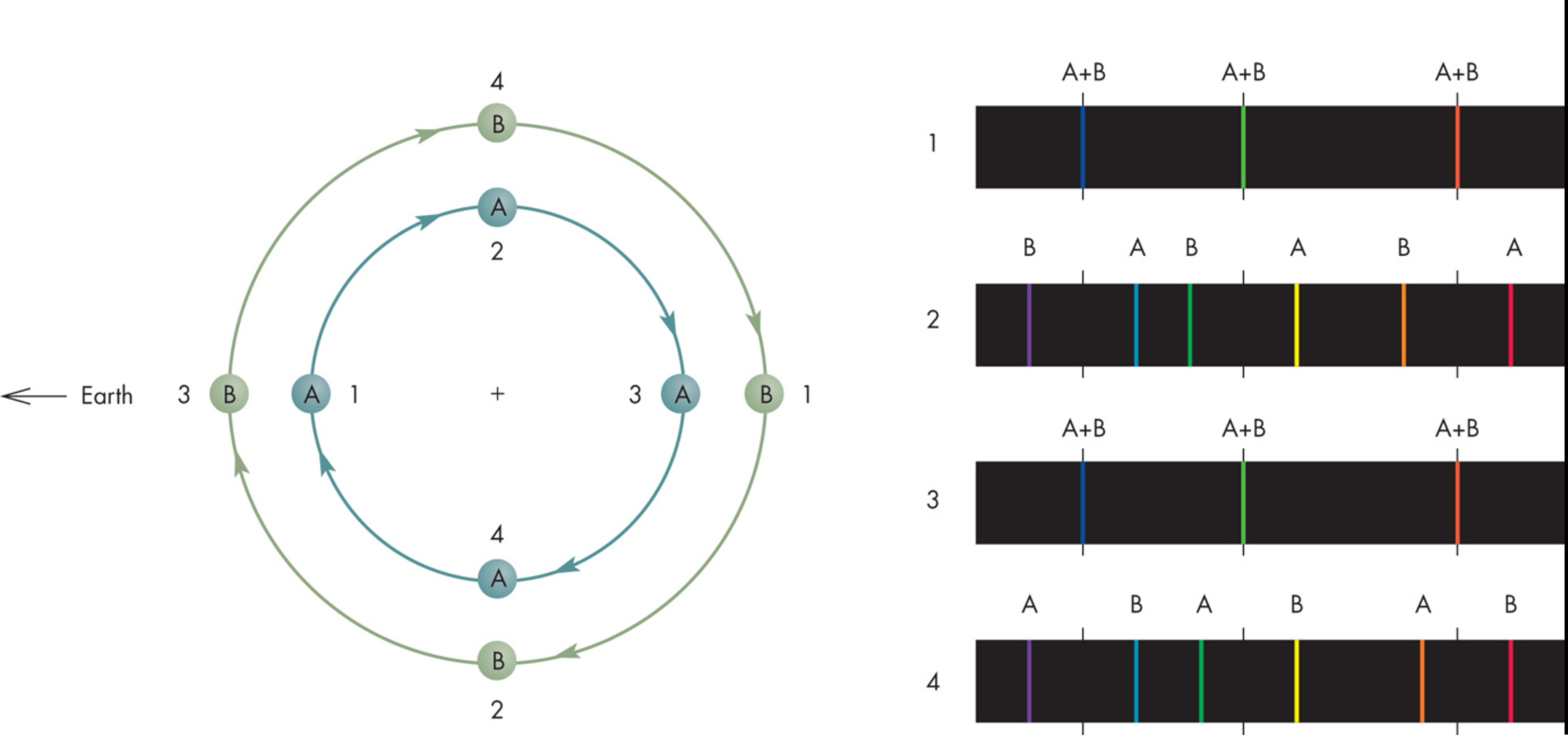
Castor A and Castor B (α Geminorum)

Spectroscopic Binaries

Spectral lines separate periodically due to Doppler shift

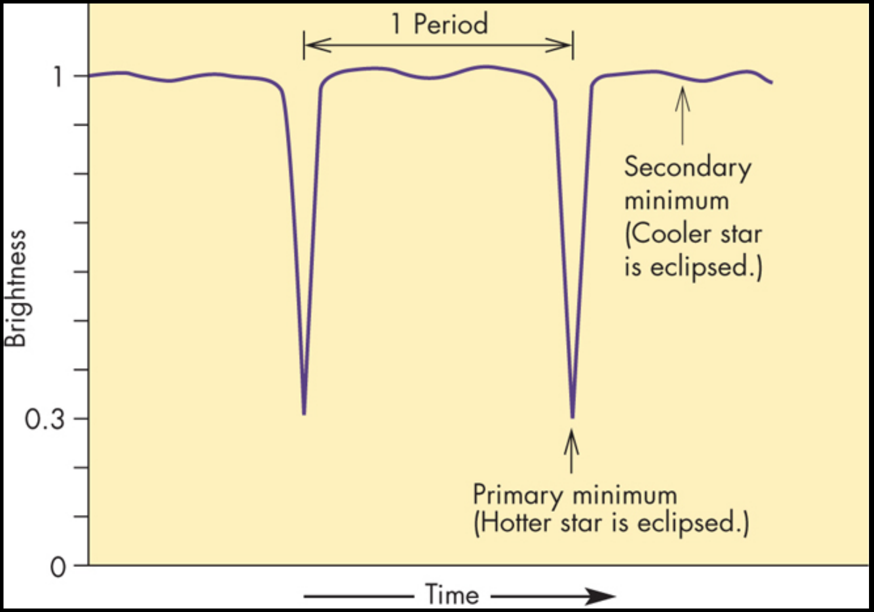


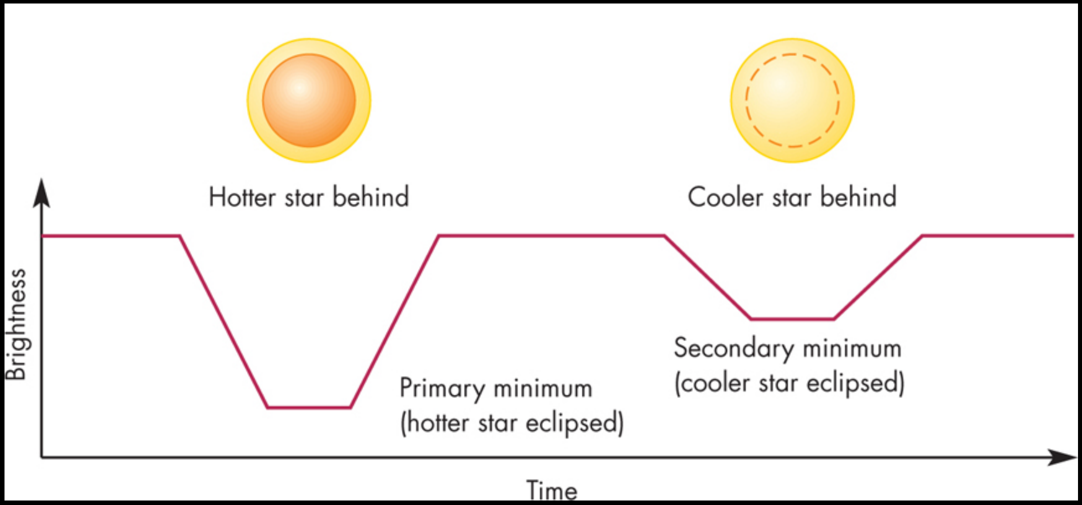
Castor (α Gem) is actually a visual binary of two spectroscopic binaries



Eclipsing Binaries

Algol (β Persei) shows periodic dips in brightness which can be interpreted as a dimmer companion passing in front of the brighter star.

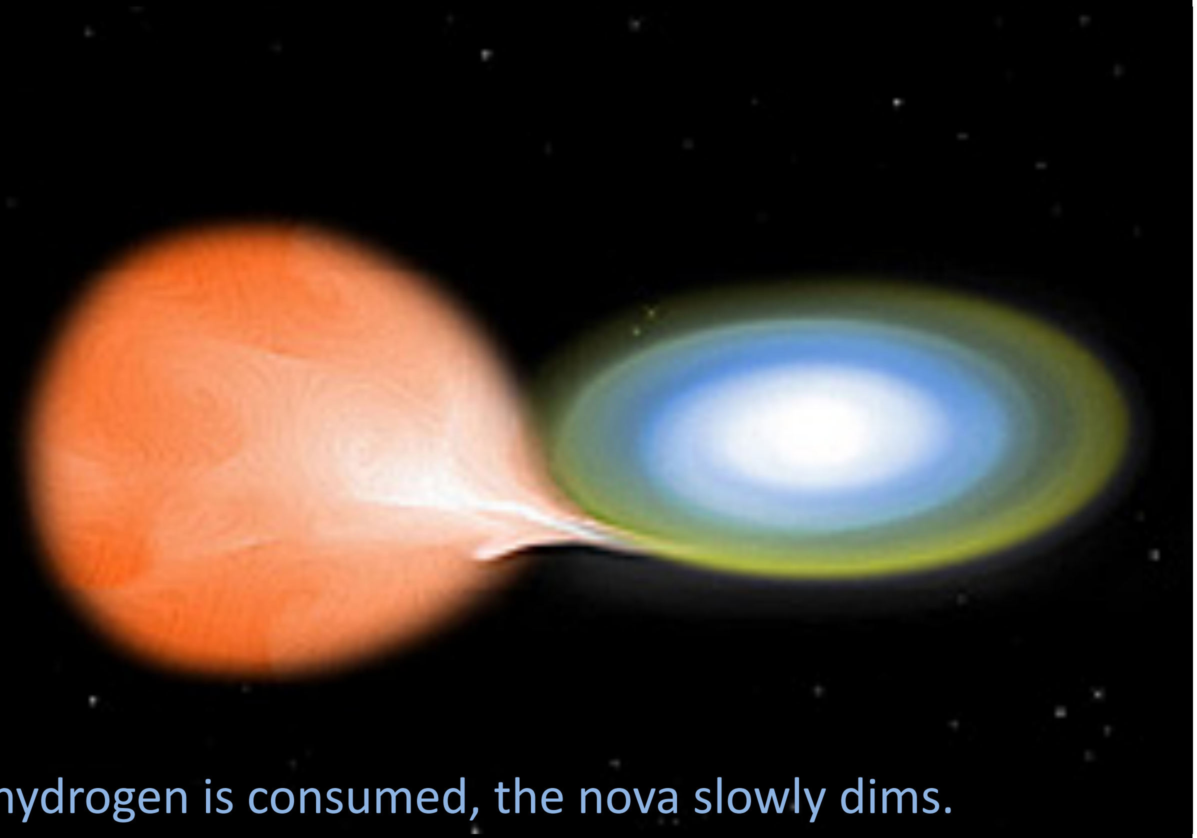




Nova or Supernova?

Originally thought to be a “new” star, a nova is an existing star (which may not have been visible before) which suddenly brightens, then fades over several weeks

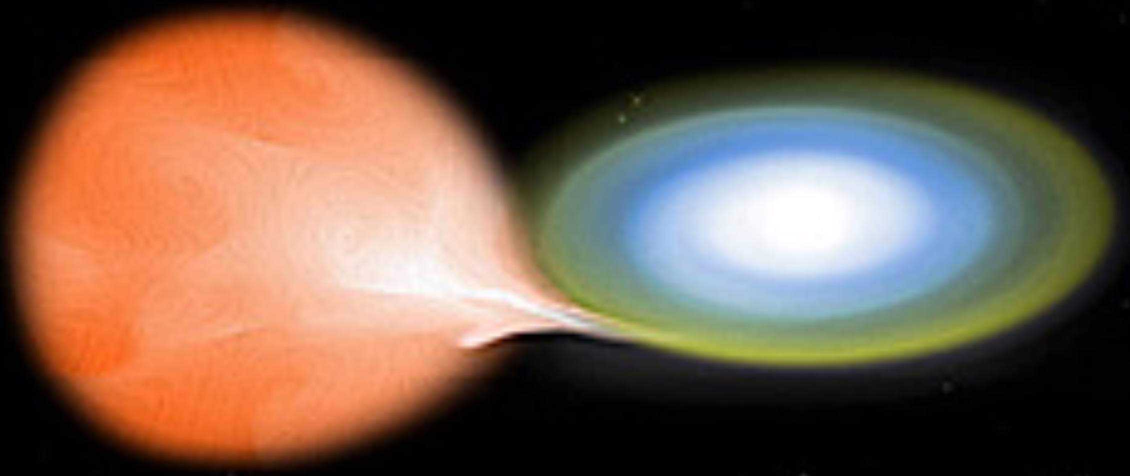
A white dwarf slowly pulls hydrogen off of a normal star. Eventually, when the temperature and pressure build up enough for nuclear fusion the hydrogen “burns” rapidly and the star brightens.



When the hydrogen is consumed, the nova slowly dims.
The white dwarf remains.

Type Ia Supernova

A *Super*nova is brighter than a nova!



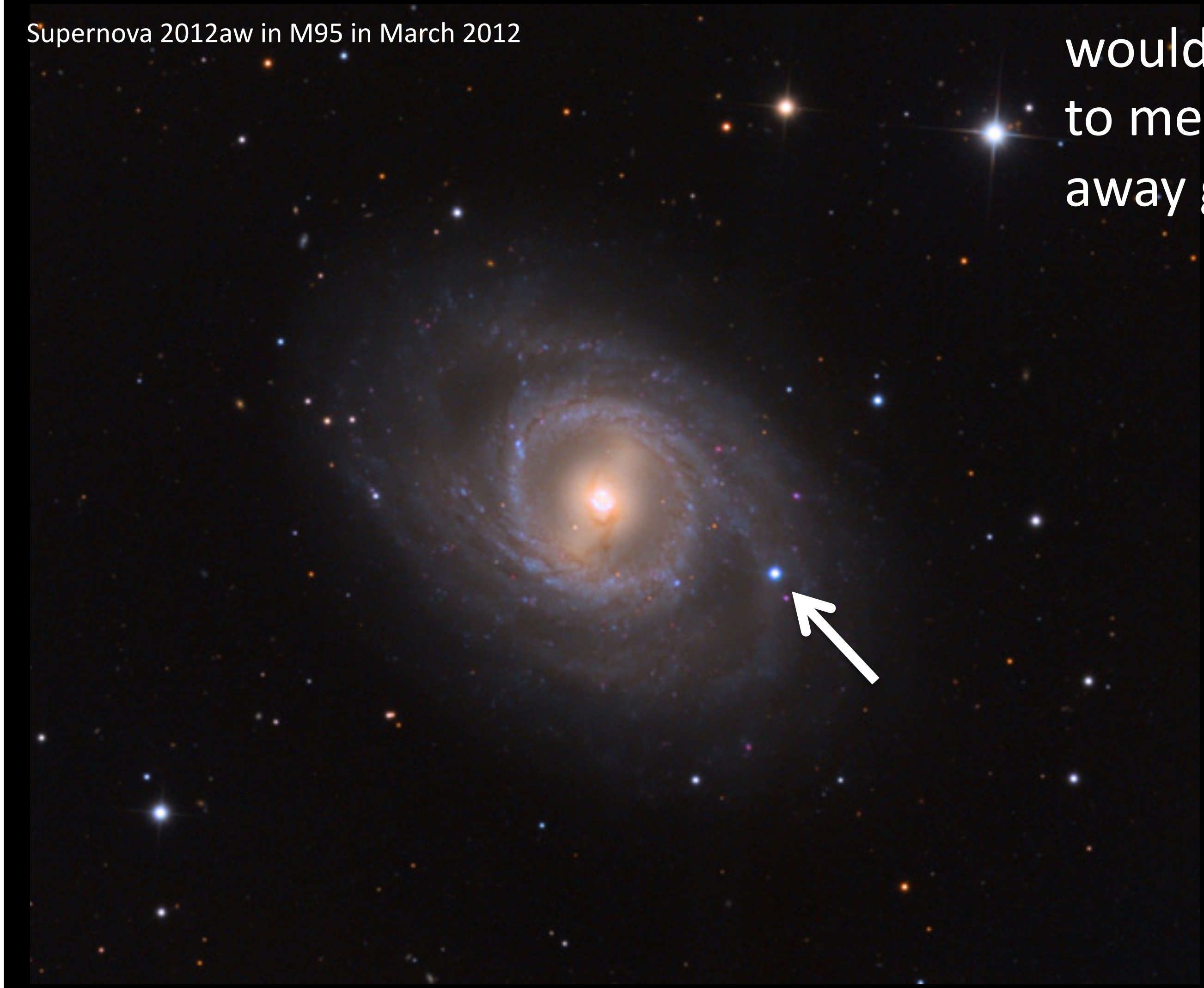
Material from normal star falls onto white dwarf faster, causing fusion to start immediately and continue.

White dwarf center gets smaller and hotter. Eventually Carbon fusion is possible. Explosive release of energy blows the star apart!

The energy released in a type Ia supernova in 1 second is about the same as all the energy released by the Sun in 10 billion years on the Main Sequence.

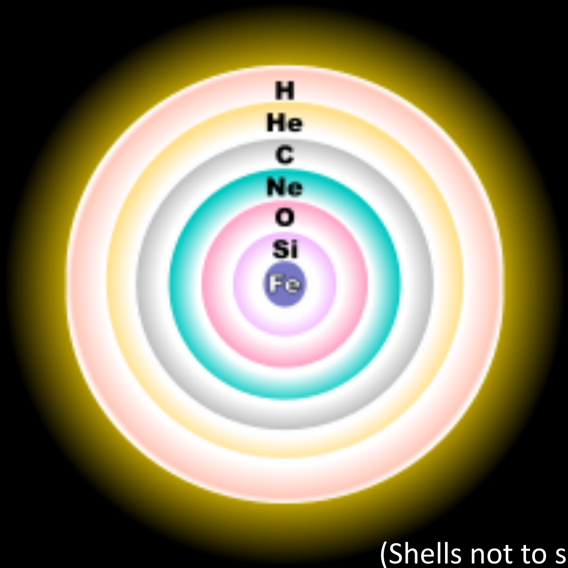
Type Ia supernova

Type Ia supernovae may be *Standard Candles,* which would provide another way to measure distances to far away galaxies



Supernova 2012aw in M95 in March 2012

Type II Supernova



(Shells not to scale)

In a star with M > 8 M$_\odot$ nuclear fusion reactions "burn" to produce He, C, Ne, O, Si, Ni and Fe. Fusion ends at iron.

The star has a nickel and iron white dwarf core. When the core gets larger than 1.4 M$_\odot$ it collapses to form a neutron star.

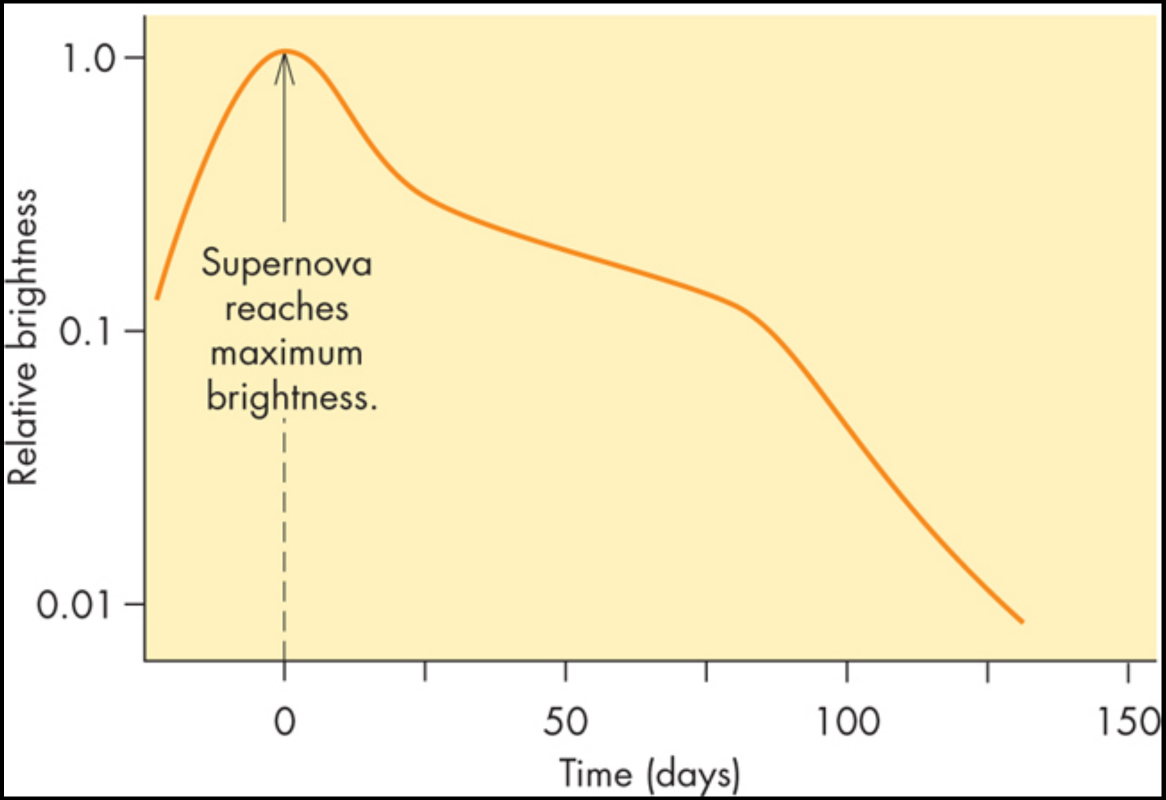
Fusion of protons and electrons produces neutrons and neutrinos:

Rebound from collapse produces outward shock wave.

$$p^+ + e^- \rightarrow n + \nu$$

90% of energy is carried away by neutrinos
1 % comes out as visible light

Light curve of a supernova



Historical Supernovae

SN 1006 – brightest recorded supernova

SN 1054 – visible in daytime

SN 1181 –

SN 1572 – observed by Tycho Brahe

SN 1604 – observed by Kepler

SN 1885A – in the Andromeda galaxy

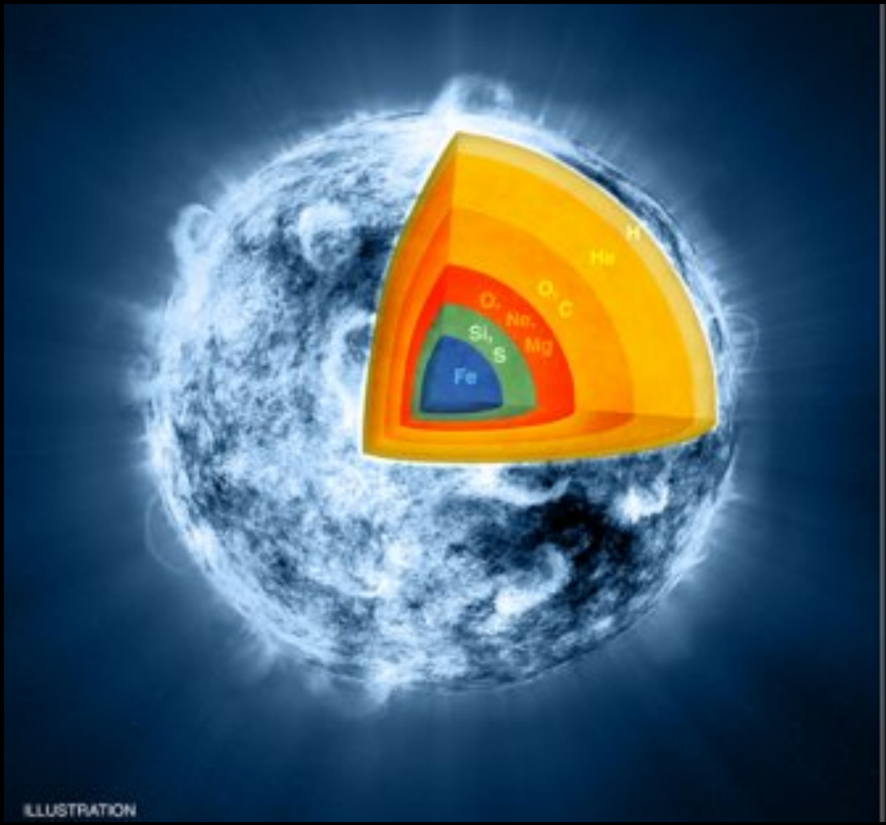
Crab Nebula (M1), remains of SN 1054

SN 1987A in the nearby Large Magellanic Cloud
neutrinos were detected in three terrestrial particle detectors about 3 hours before visible light arrived.

Remains of SN 1987A

Remains of SN 1604

Cassiopeia A - A star turned inside out?



Model of interior of a massive star before it becomes a supernova, showing layers of iron, silicon, sulfur, magnesium, neon, oxygen, carbon, helium and hydrogen

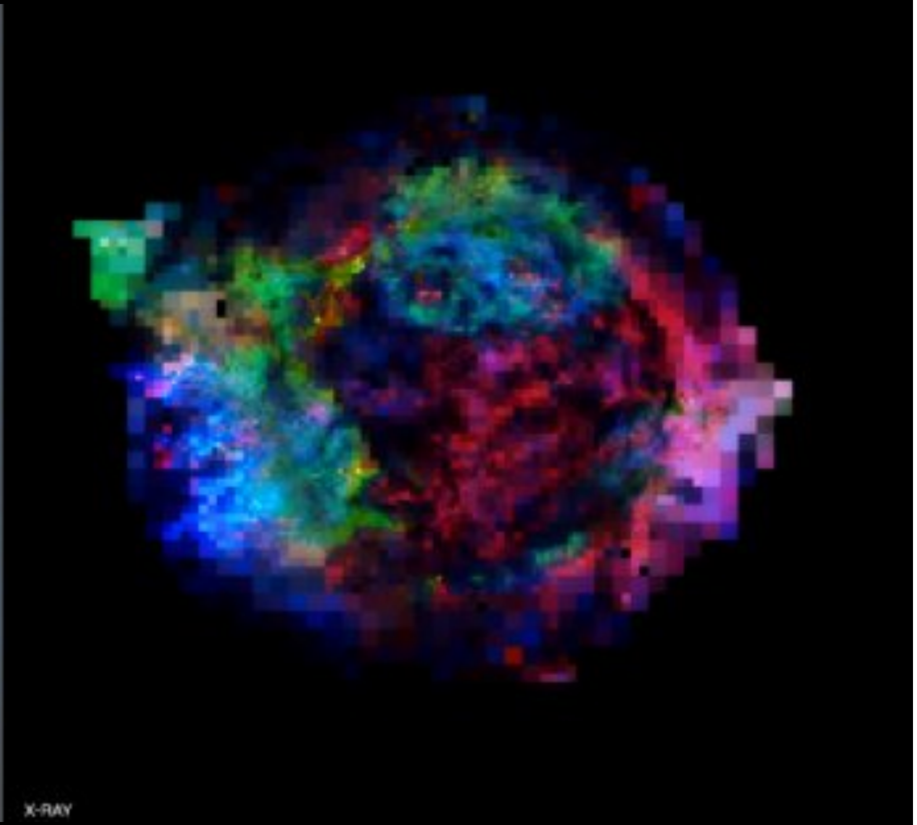


Image from the Chandra X-ray Observatory shows distribution of the same elements (shown in the same colors). The insides now appear to be on the outside.

http://www.nasa.gov/mission_pages/chandra/multimedia/casa2012.html

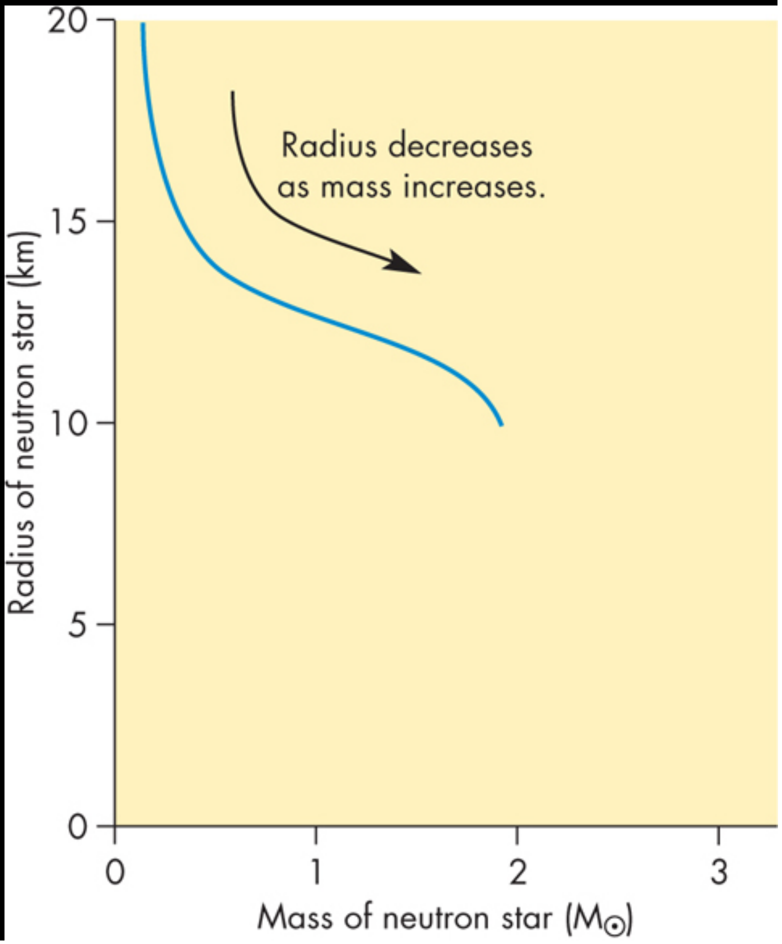
Neutron stars

A star larger than 1.4 $M_\odot$ cannot form a White Dwarf.
Gravity is so strong that even the pressure of electron degeneracy cannot hold the star up.

The great pressure forces electrons into the nuclei, where they combine with protons to form neutrons.

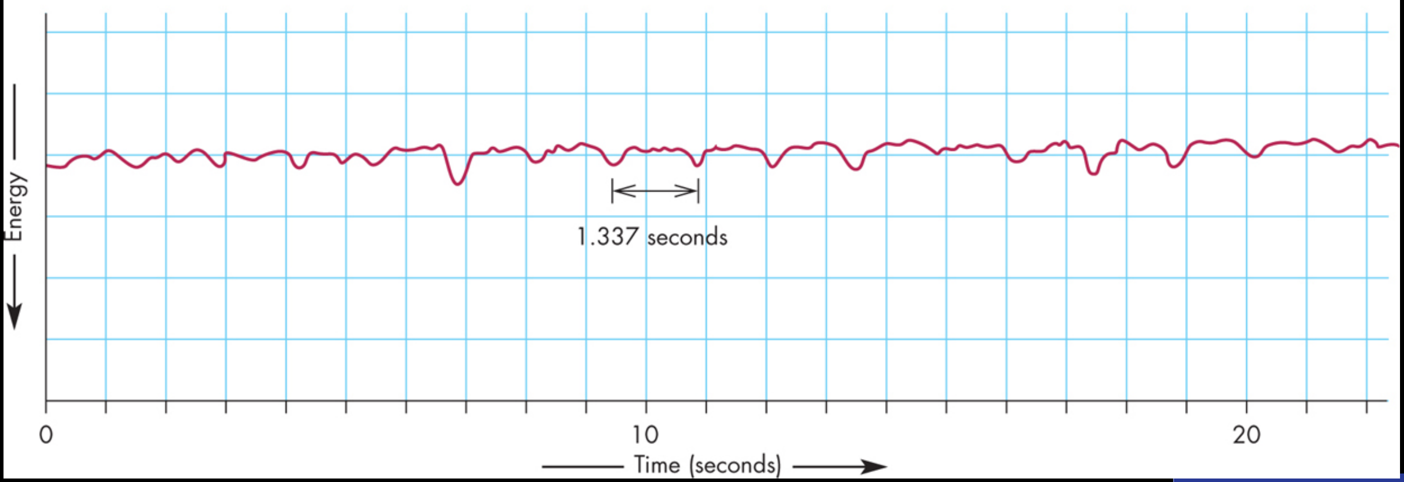
A neutron star with the mass of the sun will have a radius of only about 13 km!

As with a White Dwarf, the radius decreases as the mass increases



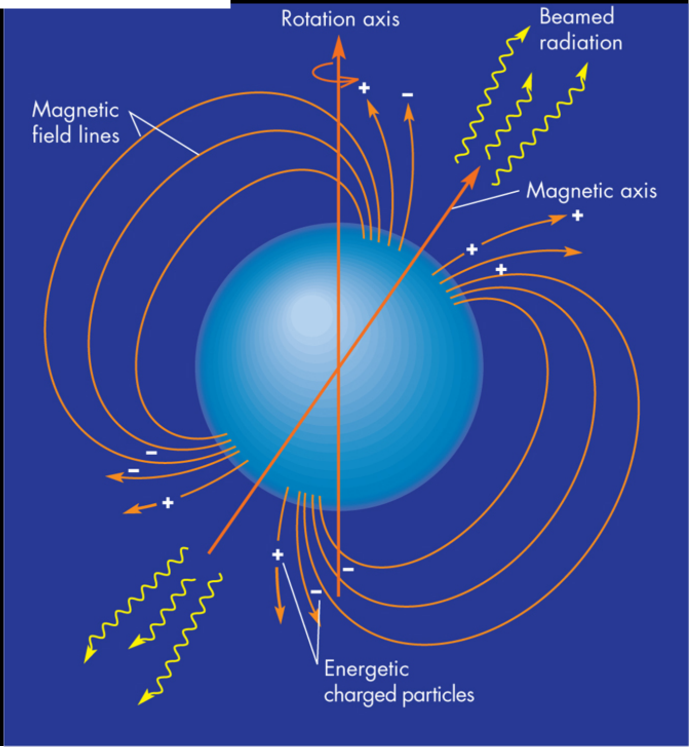
Pulsars

There are over 1000 known pulsars today



In 1967 Bell and Hewish detected periodic radio pulses with a period of 1.337 seconds?

Could it be Little Green Men?



We now think that pulsars are rotating neutron stars with strong magnetic fields which creates beams of radiation which sweep over us periodically, much like the beam of a lighthouse.

Black Holes

A black hole is created by a star so massive and dense that not even light can escape.

Escape speed:

$$v = \sqrt{\frac{2GM}{R}}$$

Set v to the speed of light,
$c \approx 3 \times 10^8$ m/s,
and solve for R:

$$R = \frac{2GM}{c^2}$$

For $M = M_\odot$ the "Schwarzschild radius" is 3 km

The full details require Einstein's General Theory of Relativity

The Theory of Relativity (Albert Einstein)

1905 – The “Special” theory of relativity:

- The speed of light c = 299,792,458 m/s is a constant for all observers
- Space and time are one thing: “*spacetime*”

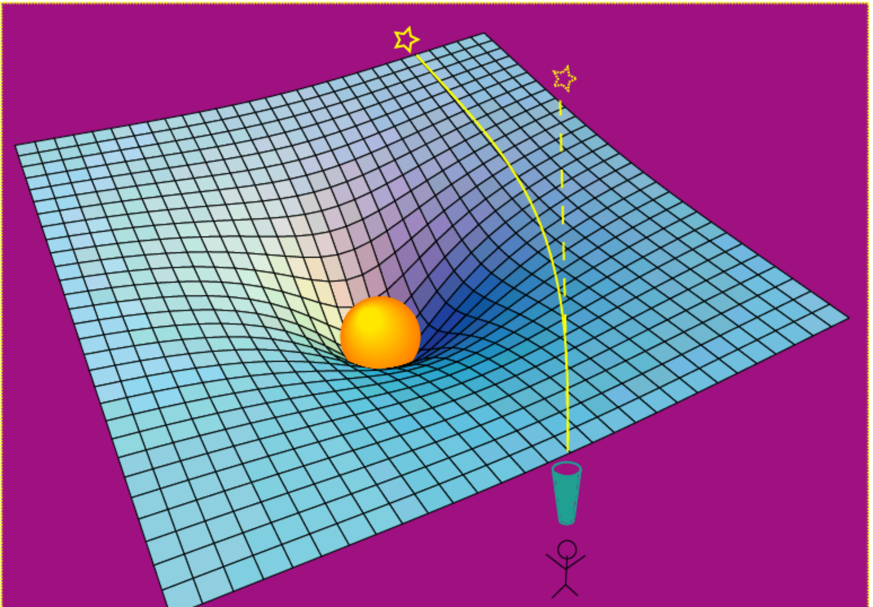
➢ Objects moving near the speed of light appear to be shorter in direction of motion

➢ Objects moving near the speed of light appear to have slower clocks

➢ Objects moving near the speed of light appear to have more mass

1916 – The “General” theory of relativity:

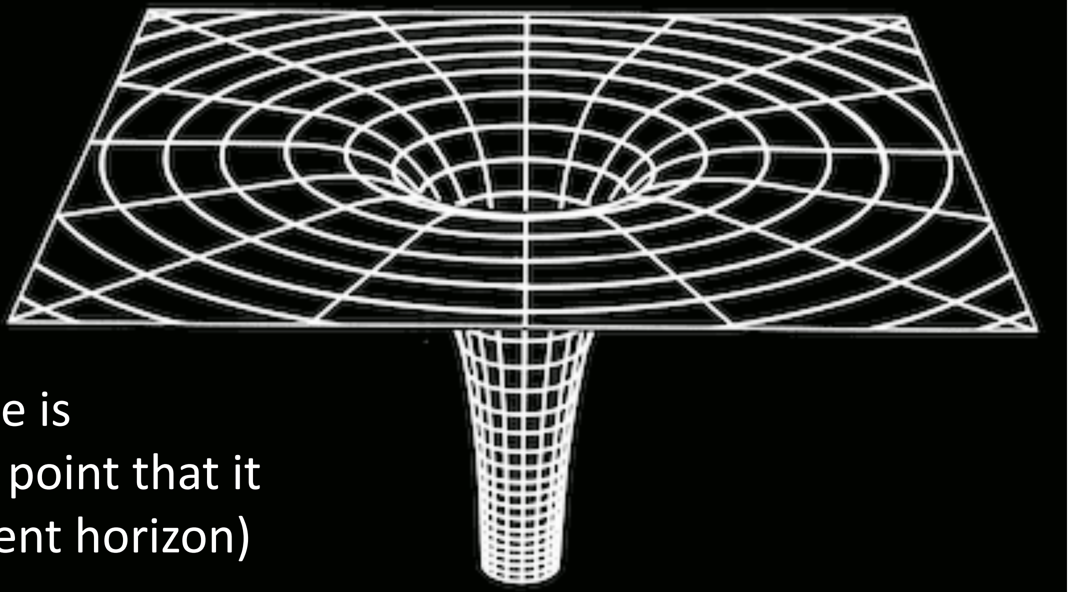
- Spacetime is curved by matter
- Newton’s law of gravitation included as a special case
- Correct amount of precession of perihelion of Mercury (1916)
- Correct predition of bending of starlight by the Sun (1919)
- Gravitational Red-shift of light (1959)
- Time delay of radar reflections from Venus and Mercury (1966)



Matter curves space-time, and objects in “free-fall” (even photons) travel in “straight” paths in the curved space.

Black Holes

The black hole is not the star itself – it is a boundary in space caused by the star, called the "Event Horizon"



Anything, even light, which is inside the event horizon, cannot escape out.

Except…

1. Material falling into a black hole is compressed and heated to the point that it gives off X-rays (outside the event horizon)

2. In 1974 Stephen Hawking showed that due to quantum physics black holes will give off radiation from quantum particle production.