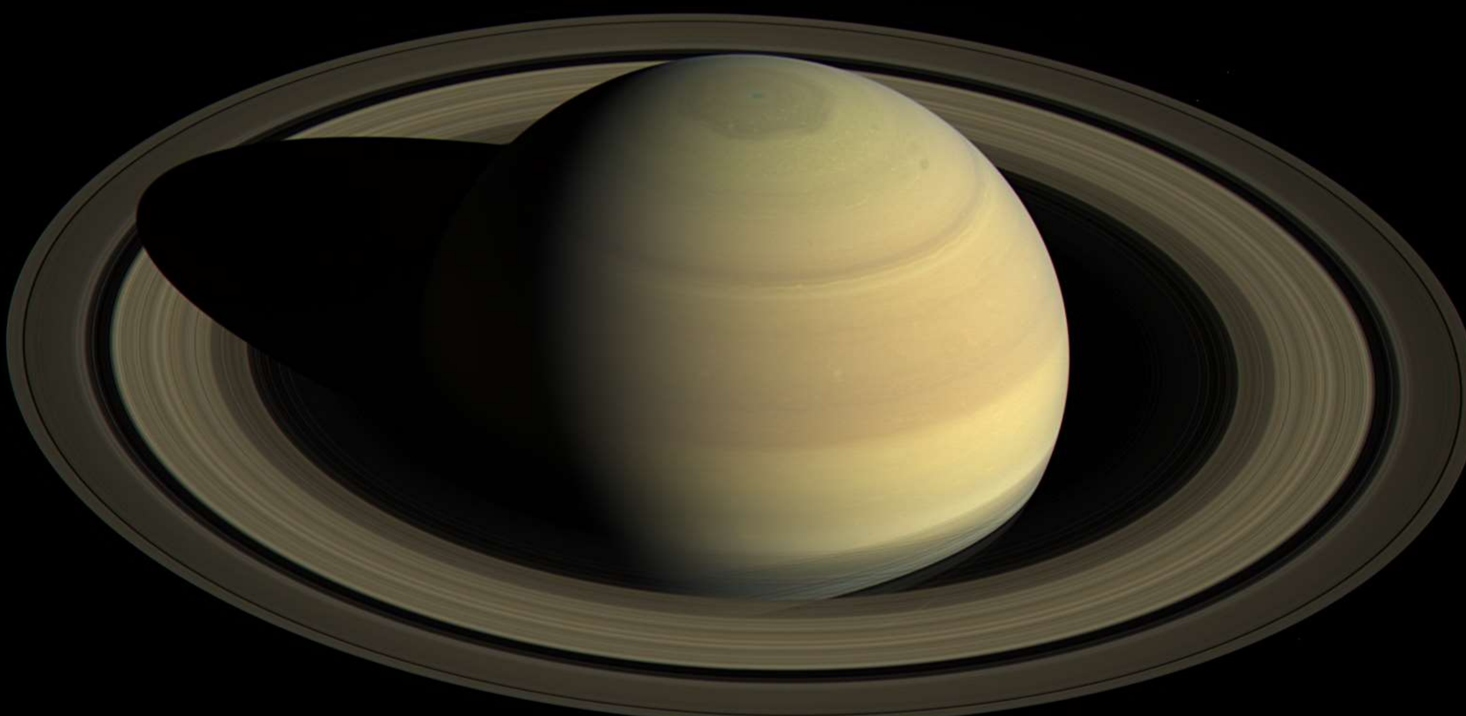
AST 2002
Introduction to Astronomy



A Few Quick Things…

E-mailing me: Must have AST2002 in the subject

Mary Hinkle, Graduate Teaching Assistant:

Office hours: Mon 1:30-3:00pm. PSB 316

My office hours: ~~Mon 3:00-4:00pm. PSB 308~~

~~Tue 3-4 pm. PSB 308~~

I will be in a teleconference next week.
Will switch to Wed/Thur at 3 pm.

I will be in DC the week afterwards… Mon-Thur

Will try to get my Graduate student, Amy to cover Mon/Tue on both weeks… also in PSB316

Mid-term results should be in Fri (Best of 2 will count towards final grade)

Final: Friday 27th April. 7am-9:50 am. (on all chapters; ~ 100 questions. 25:25:25:25)

LAST Knights Under the Stars Event – Thursday 19th April

Opportunity to make up the 1% extra credit that was offered (if you haven't been yet, worth 2%) – Last chance for extra credit..

What’s Next?

Chapter 14: The Bizarre Stellar Graveyard

14.1. White Dwarfs

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

14.2. Neutron Stars

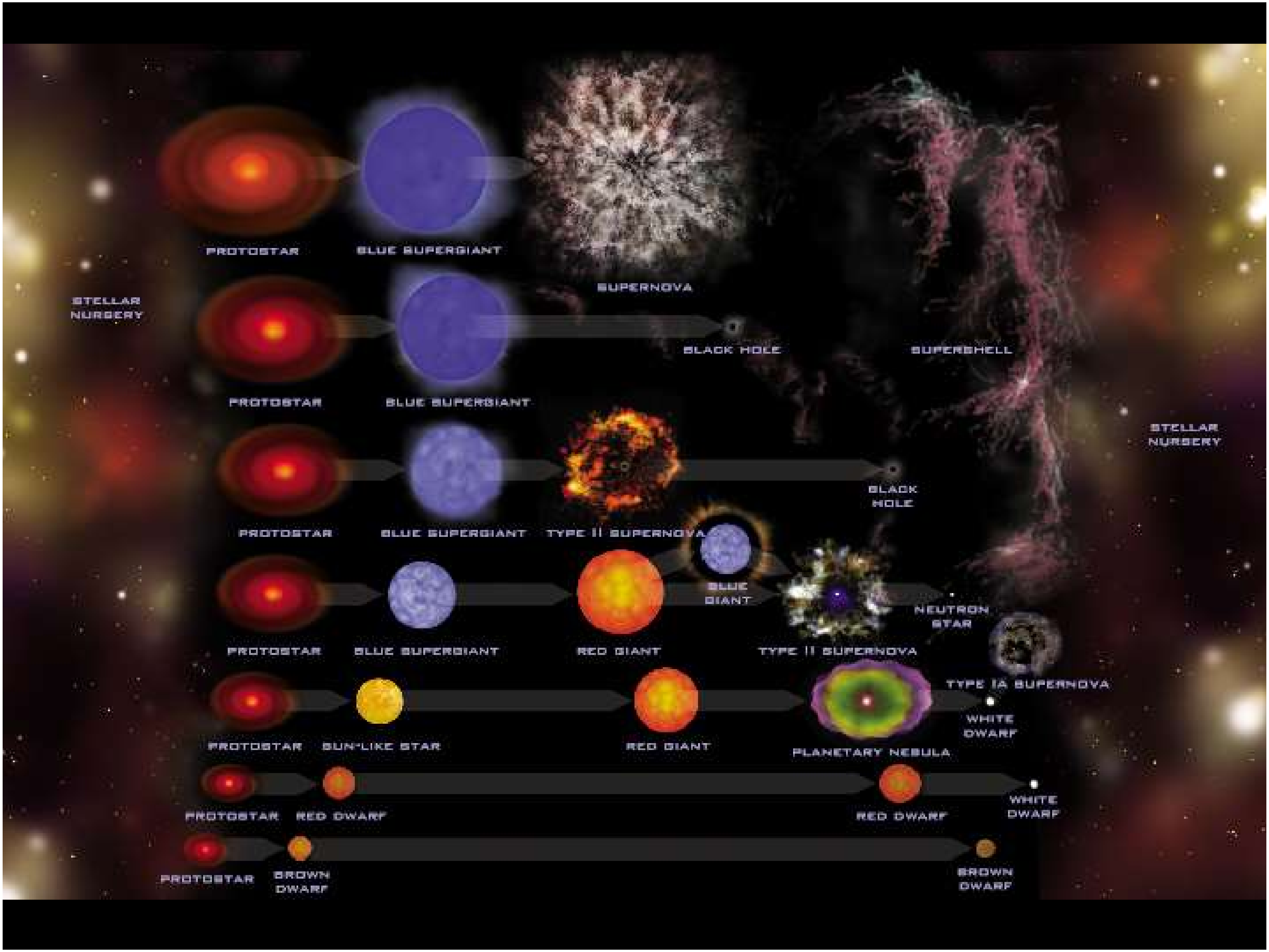
- What is a neutron star?
- How were neutron stars discovered?
- What can happen to a neutron star in a close binary system?

14.3. Black Holes: Gravity’s Ultimate Victory

- What is a black hole?
- What would it be like to visit a black hole?
- Do black holes really exist?

14.4. Stars in Close Binaries

- What causes gamma-ray bursts?
- What happens when black holes merge?



STELLAR NURSERY
PROTOSTAR
BLUE SUPERGIANT
SUPERNOVA
PROTOSTAR
BLUE SUPERGIANT
BLACK HOLE
SUPERSHELL
STELLAR NURSERY
PROTOSTAR
BLUE SUPERGIANT
TYPE II SUPERNOVA
BLACK HOLE
PROTOSTAR
BLUE SUPERGIANT
RED GIANT
BLUE GIANT
TYPE II SUPERNOVA
NEUTRON STAR
TYPE IA SUPERNOVA
PROTOSTAR
SUN-LIKE STAR
RED GIANT
PLANETARY NEBULA
WHITE DWARF
PROTOSTAR
RED DWARF
RED DWARF
WHITE DWARF
PROTOSTAR
BROWN DWARF
BROWN DWARF

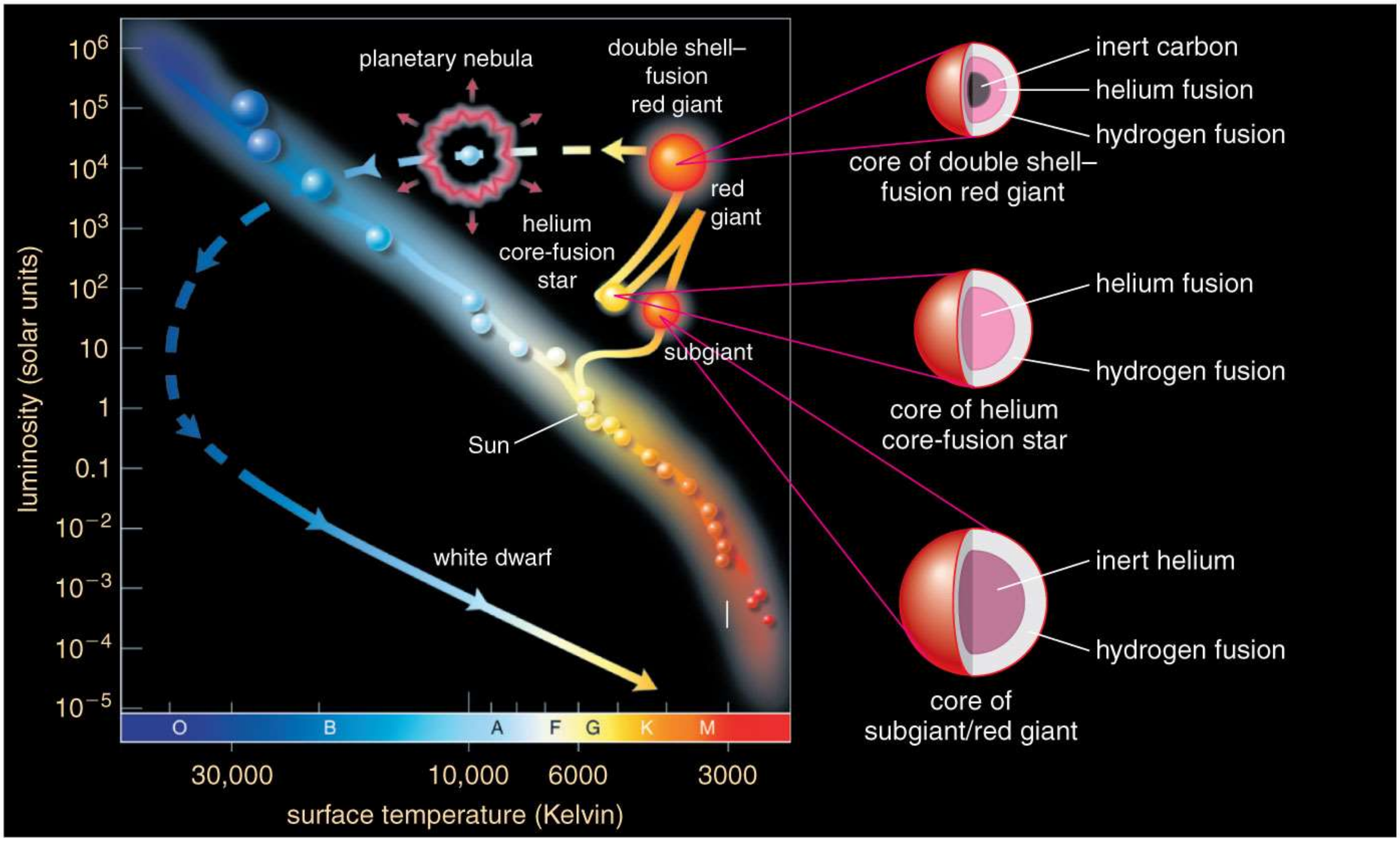
The Fate of Stars Based on Mass

The Ultimate Fate of Stars and Substellar Objects with Different Masses

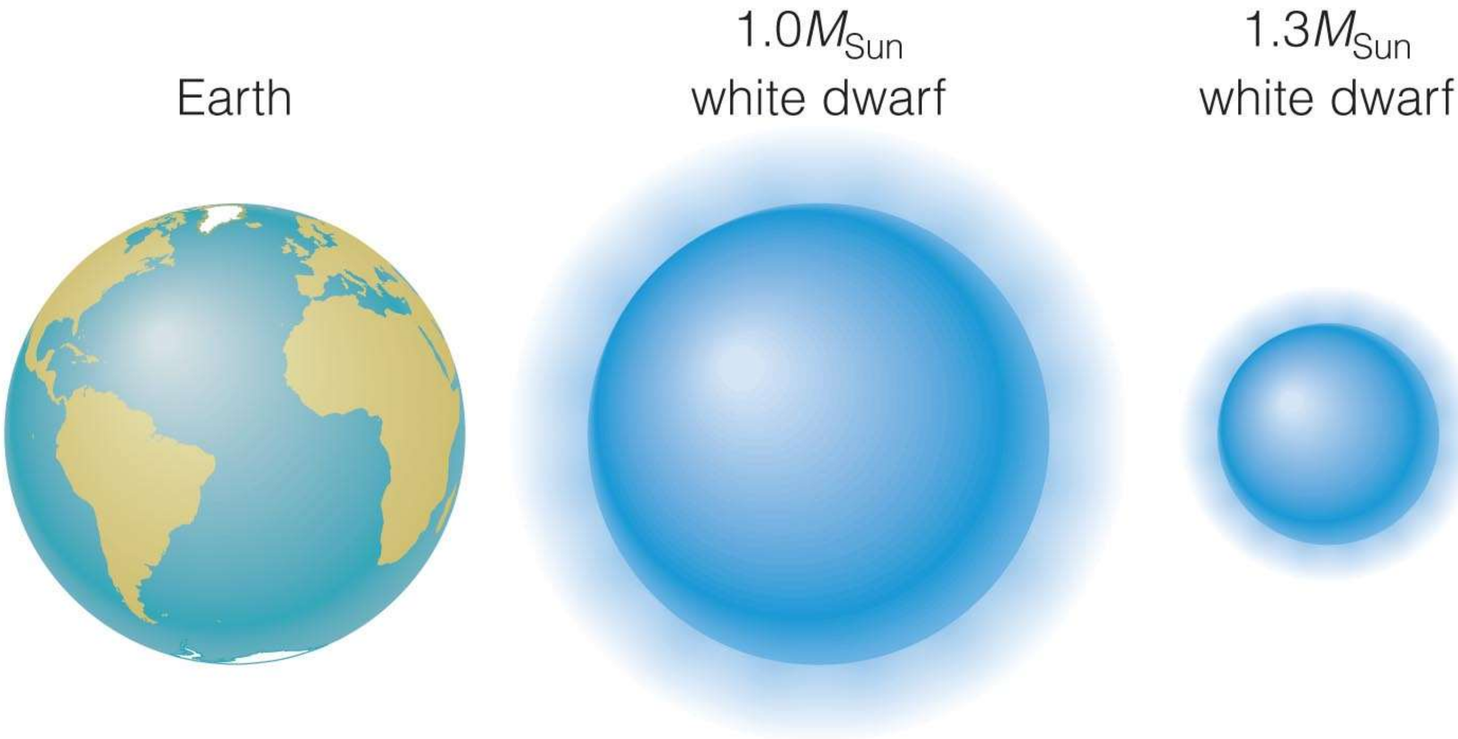
Initial Mass (Mass of Sun = 1)[1]	Final State at the End of Its Life	
< 0.01	Planet	
0.01 to 0.08	Brown dwarf	
0.08 to 0.25	White dwarf made mostly of helium	
0.25 to 8	White dwarf made mostly of carbon and oxygen	
8 to 10	White dwarf made of oxygen, neon, and magnesium	$< 1.4\ M_{Sun}$
10 to 40	Supernova explosion that leaves a neutron star	$> 1.4\ M_{Sun}$
> 40	Supernova explosion that leaves a black hole	$> 3\ M_{Sun}$

More massive stars lose more mass!

Recall the Lifetime of an Sun-like Star



Leaving Behind a White Dwarf…



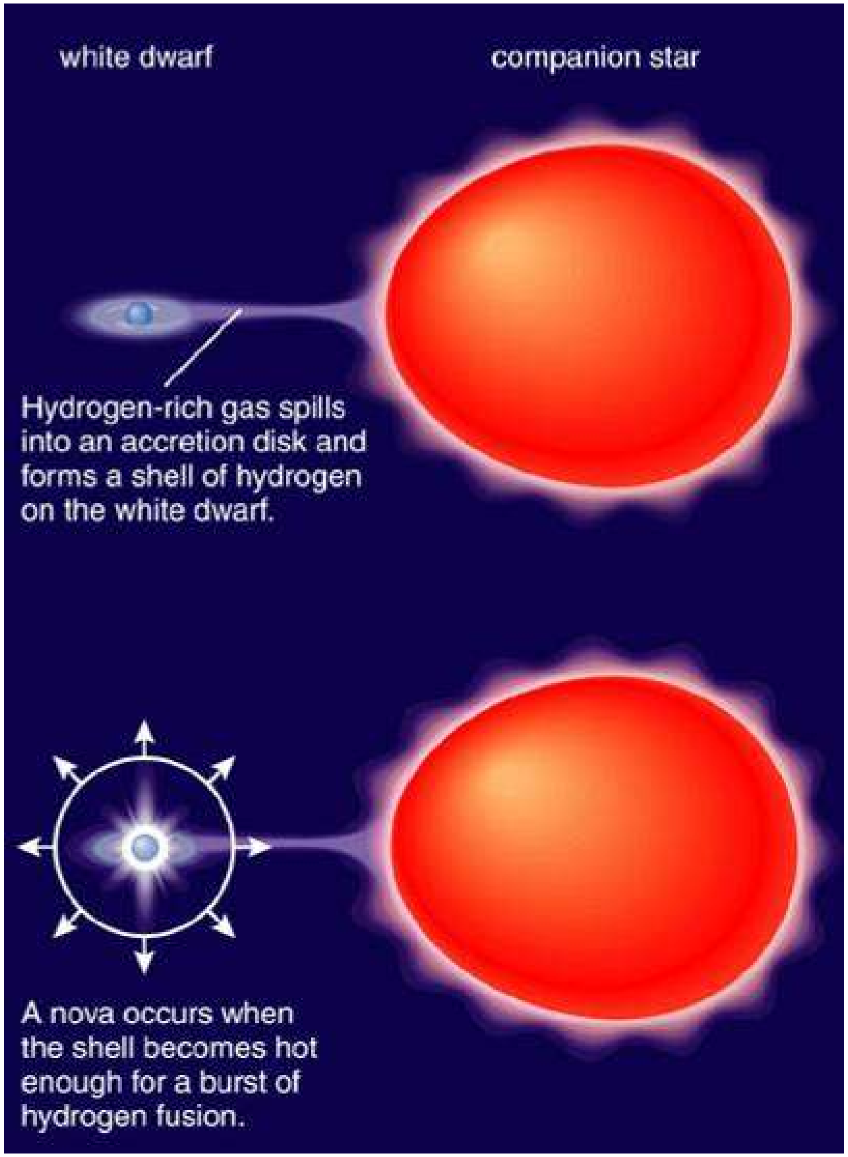
- White Dwarf’s are the remaining cores of low-mass stars
- A 1.0 M_{Sun} white dwarf is about the same size as Earth
- A 1.3 M_{Sun} white dwarf is about half the size of Earth
- *All white dwarfs are supported by electron degeneracy pressure*

The White Dwarf Limit

S. Chandrasekhar

- Einstein's theory of relativity says that nothing can move faster than light
- When electron speeds in white dwarf approach speed of light, electron degeneracy pressure can no longer support it
- Chandrasekhar found (at age 20!) that this happens when a white dwarf's mass reaches 1.4 M_{sun}
- He actually puzzled this out on the boat from India to England before he started his grad studies in physics. (Once at Cambridge his advisor told him he was crazy and to drop this work…. it won him the Nobel Prize)

What is a Nova?



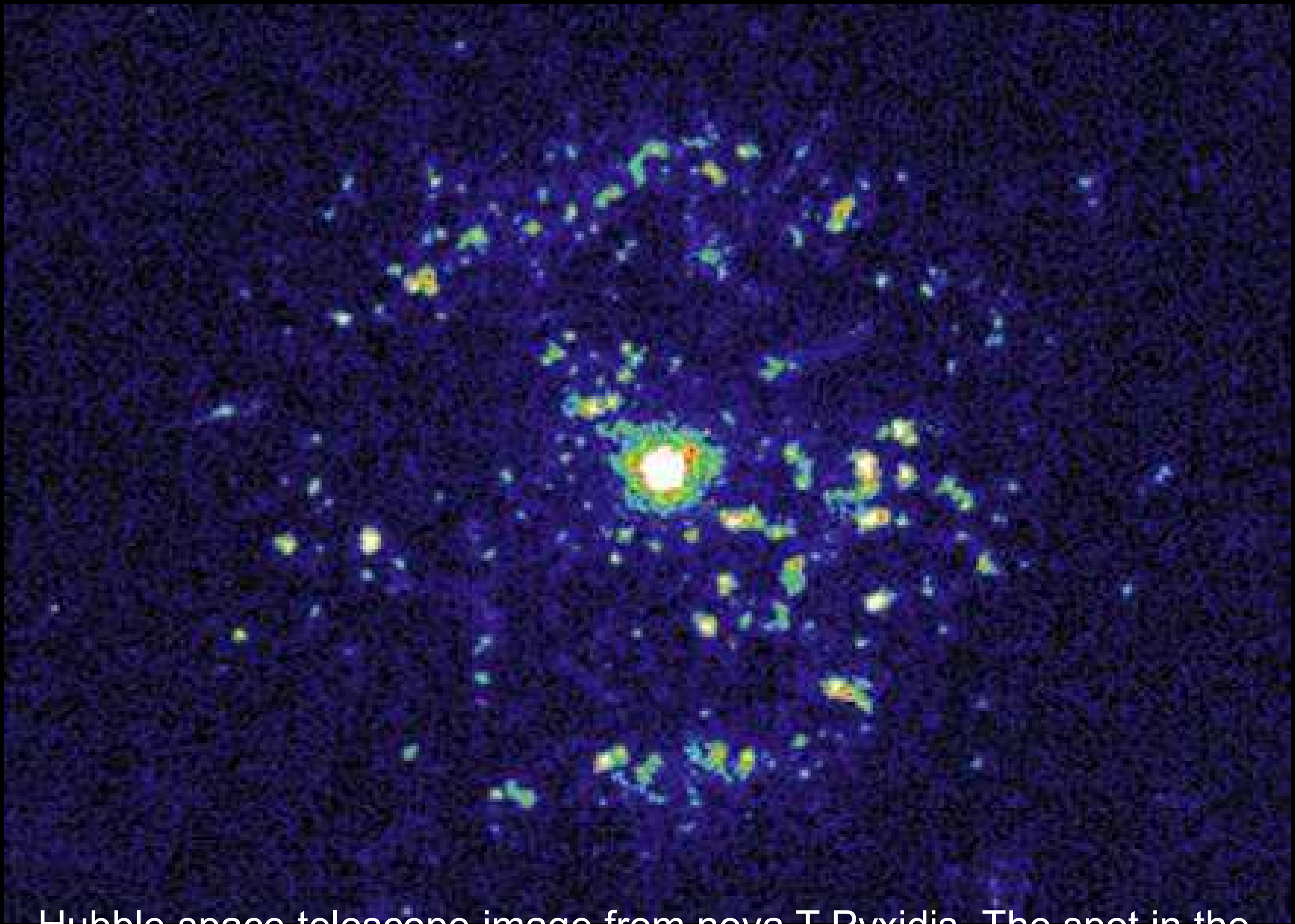
- Increased brightness up to 100,000 times
- Fades over months to years

What's happening?

1. Hydrogen from a neighboring star gets siphoned into an accretion disk around the white dwarf
2. Friction from the accretion disk causes some hydrogen to decay its orbit and build up mass on the hot white dwarf
3. Once sufficient mass is accreted the shell begins a short burst of hydrogen fusion.

Can occur regularly with ~ hundreds to thousands of years between events…

Example of a Nova



Hubble space telescope image from nova T Pyxidis. The spot in the center is a binary star system

Thought Question

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

A. It explodes
B. It collapses into a neutron star
C. It gradually begins fusing carbon in its core

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There are Two Types of Supernova

Massive star supernova: (Type II)

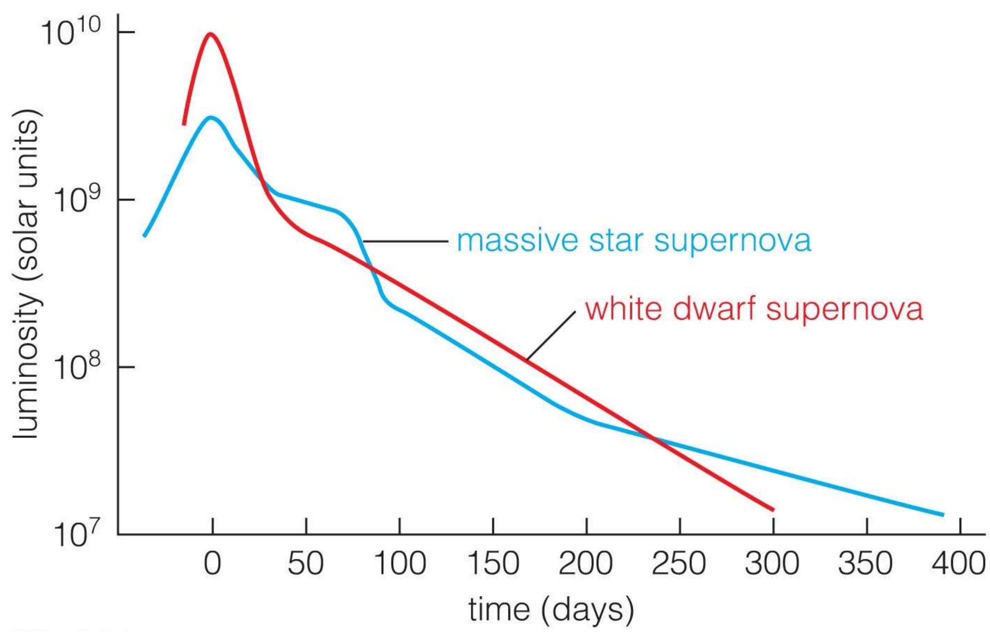
Iron core of massive star reaches white dwarf limit and collapses into a neutron star, causing an explosion. Neutron star or black hole remains

White dwarf supernova*:* (Type 1a)

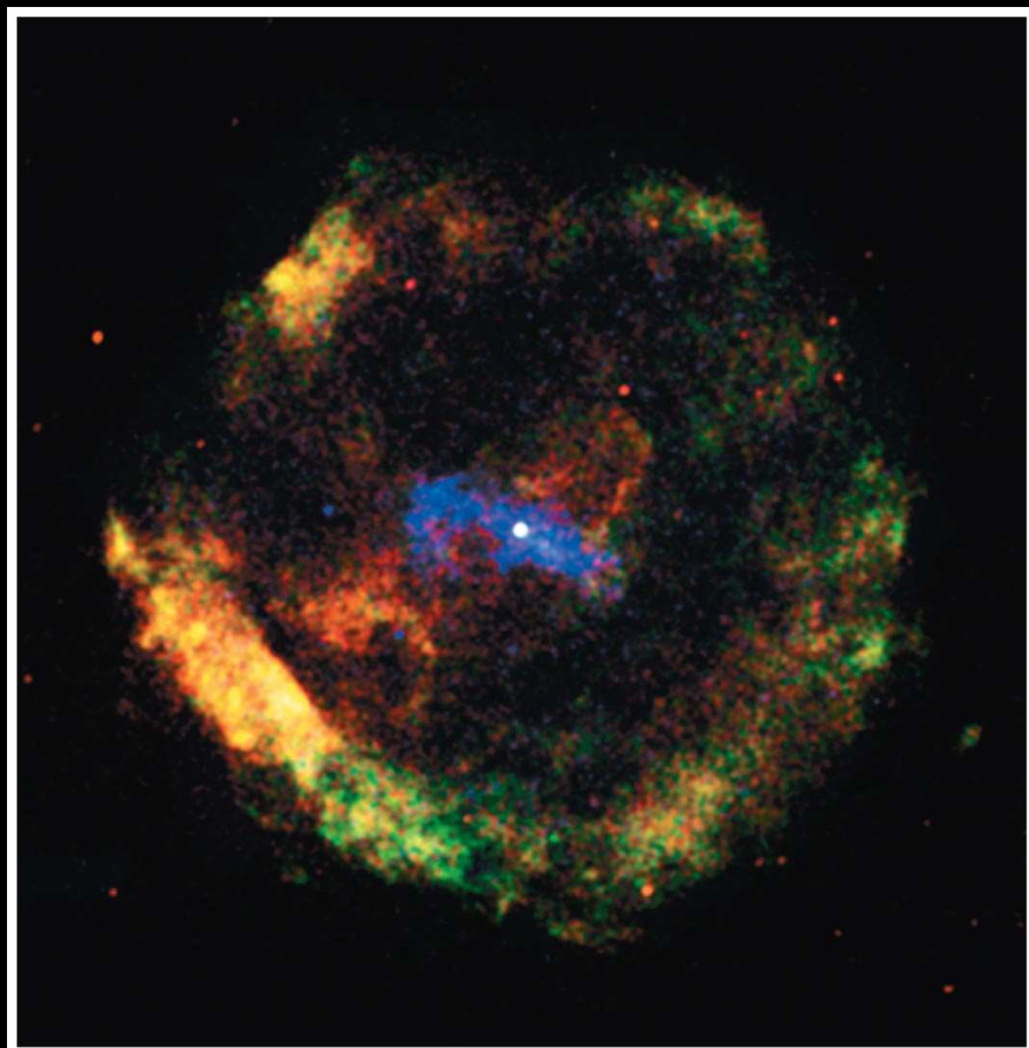
Carbon fusion suddenly begins as white dwarf in close binary system reaches white dwarf limit, causing a total explosion. Nothing remains

Massive star supernovae have additional heat from radioactive decay from unstable elements formed by the r-process…

White dwarf supernovae are very bright and have similar luminosities
→ Act as a standard candle



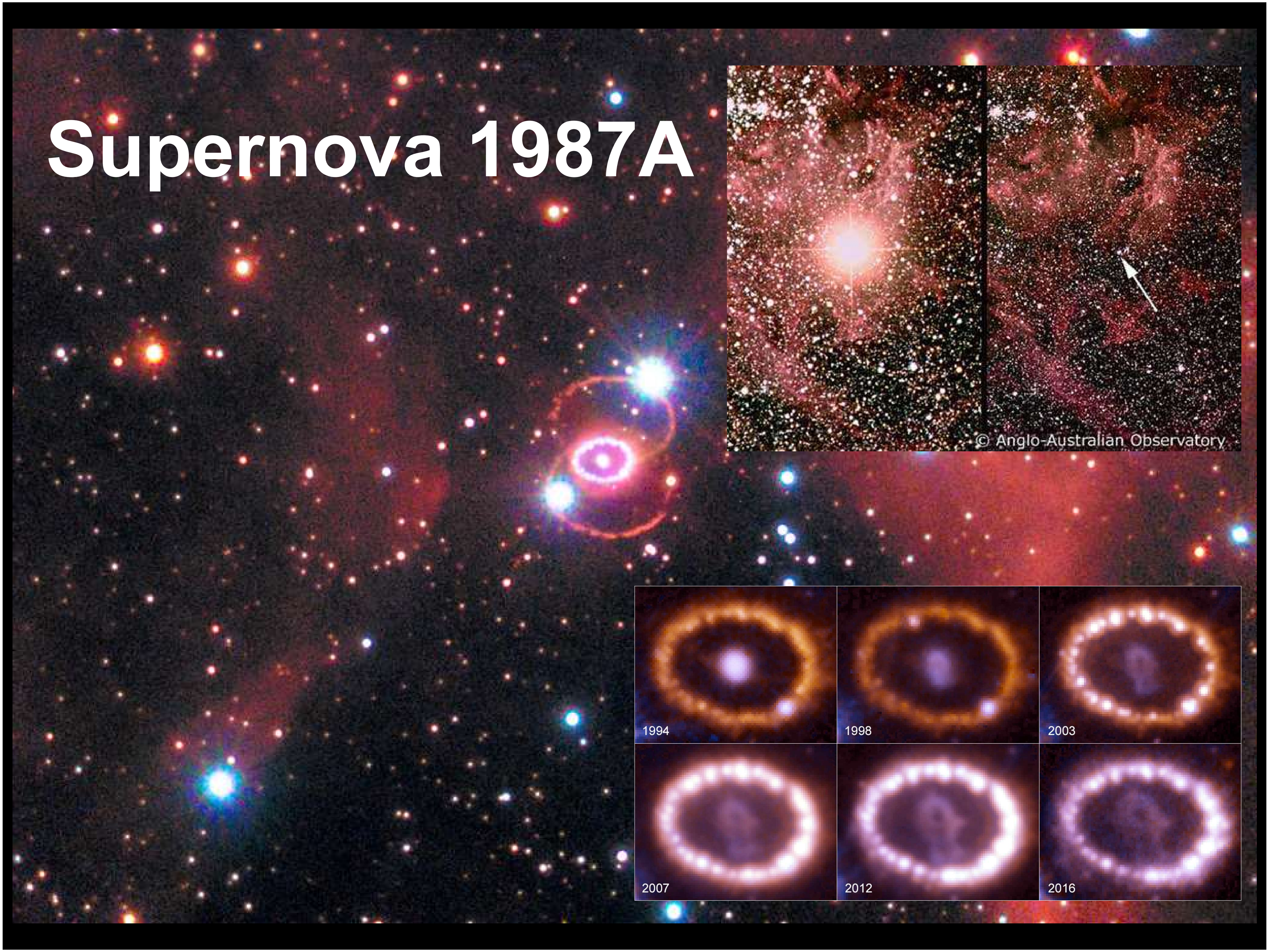
Example of a Supernova



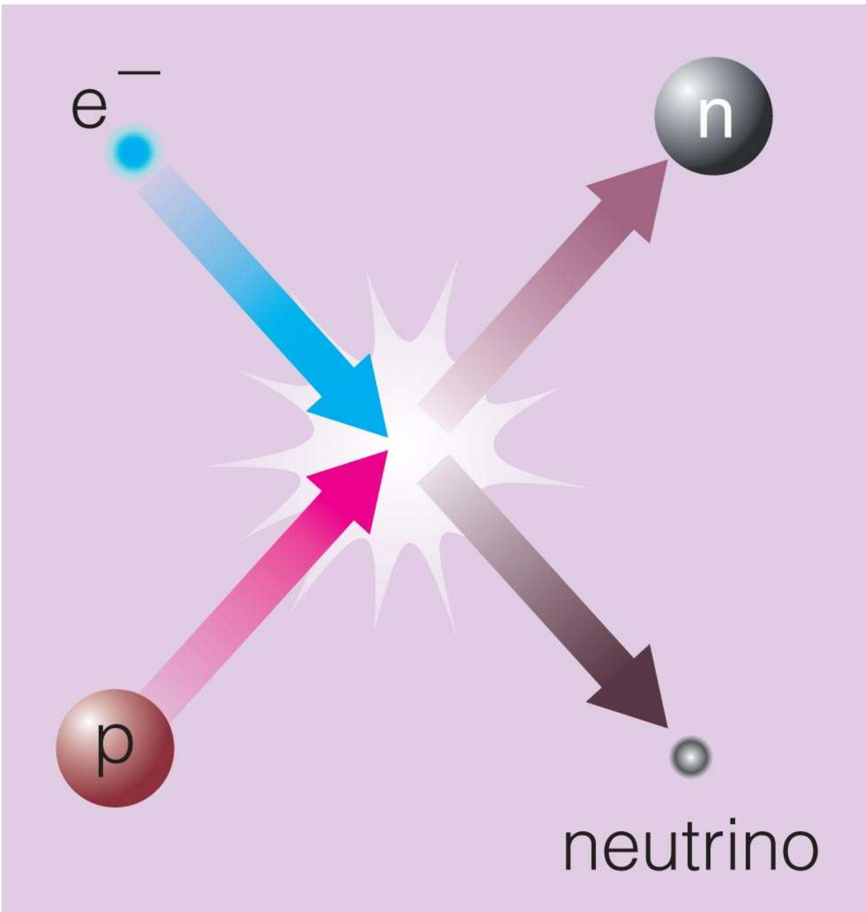
Neutron star in the middle!

X-ray image from the Chandra X-Ray observatory of Supernova Remnant G11.2-03 (observed by Chinese astronomers in 386 A.D.)

Supernova 1987A



What is a Neutron Star?



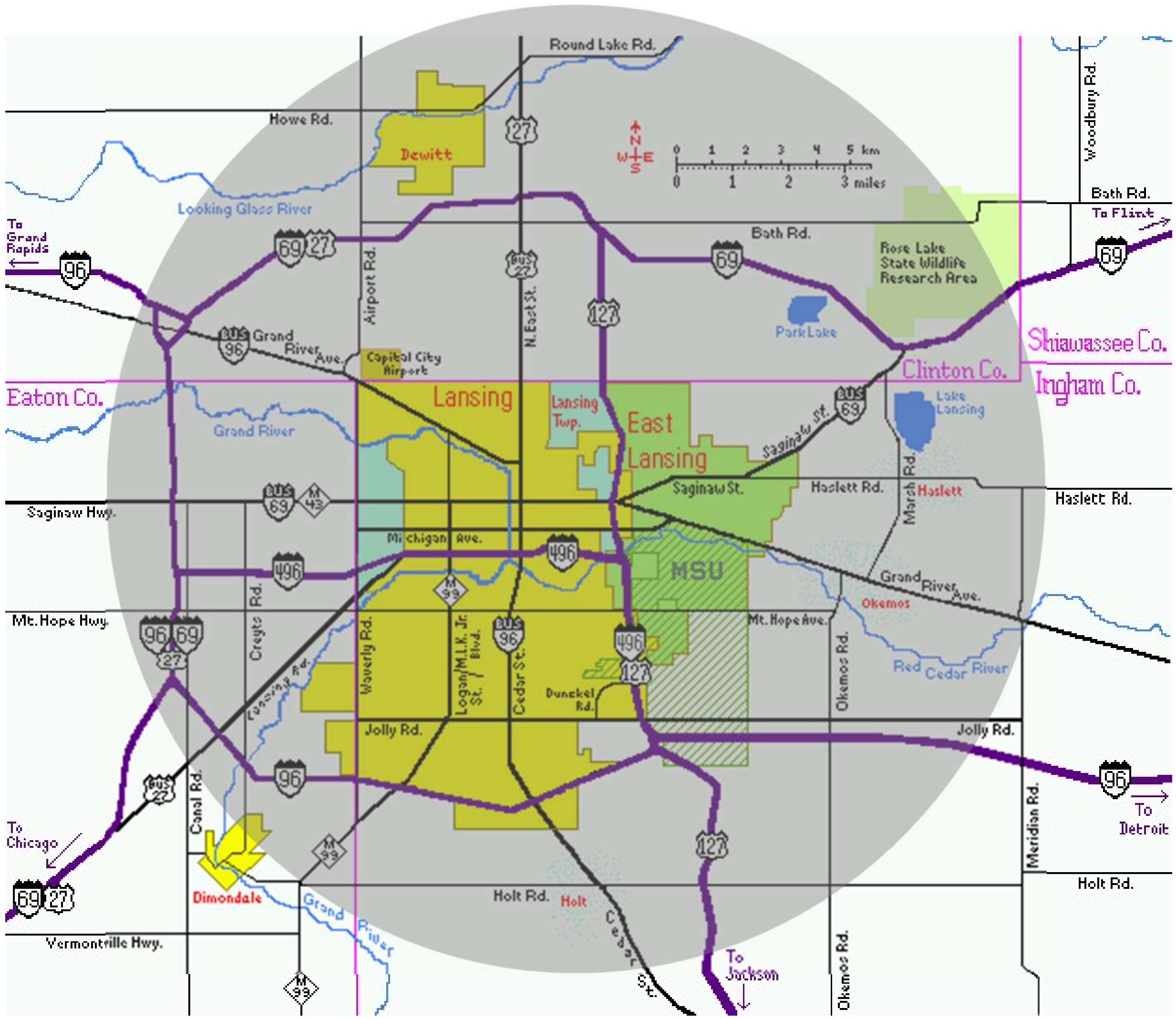
If the pressure within the core of a star exceeds the **electron degeneracy pressure,** electrons and protons recombine to make neutrons and neutrinos.

In a type II supernova, the neutrons may carry away ~10^{46} W of energy…
(more luminous than an entire galaxy)

Neutrons collapse to form a neutron star which is ~ 95% neutrons with some other protons and electrons remaining.

Neutron stars are held from total collapse by **neutron degeneracy pressure**. Neutron star limit ~ 3 M_{Sun}

How Big is a Neutron Star?



A neutron star is about the same size as a small city… but ~1-3 M_{Sun}

Thought Question

What would happen if something with the density of a neutron star were to be dropped onto the surface of the Earth?

A. It would drop with a very loud thud
B. The entire Earth would crush onto the object
C. The object would be attracted to the center of the Earth by gravity with such a force that it would fall through the Earth and come back on the other side over and over again…

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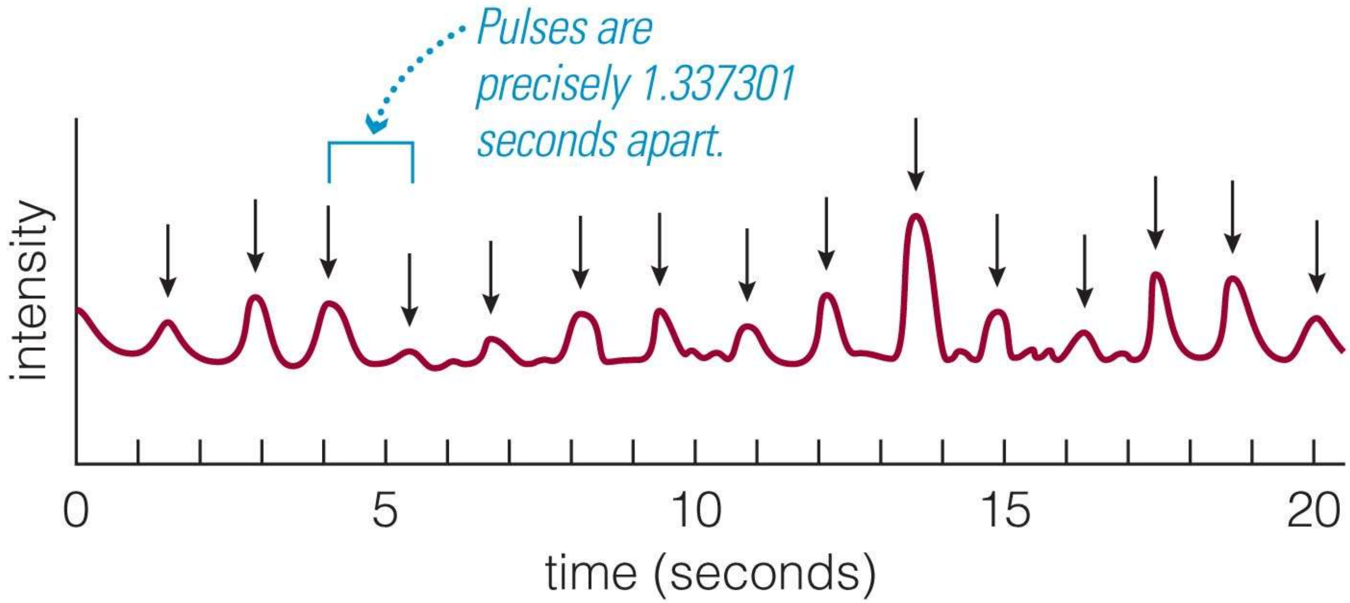
How Were Neutron Stars Discovered?

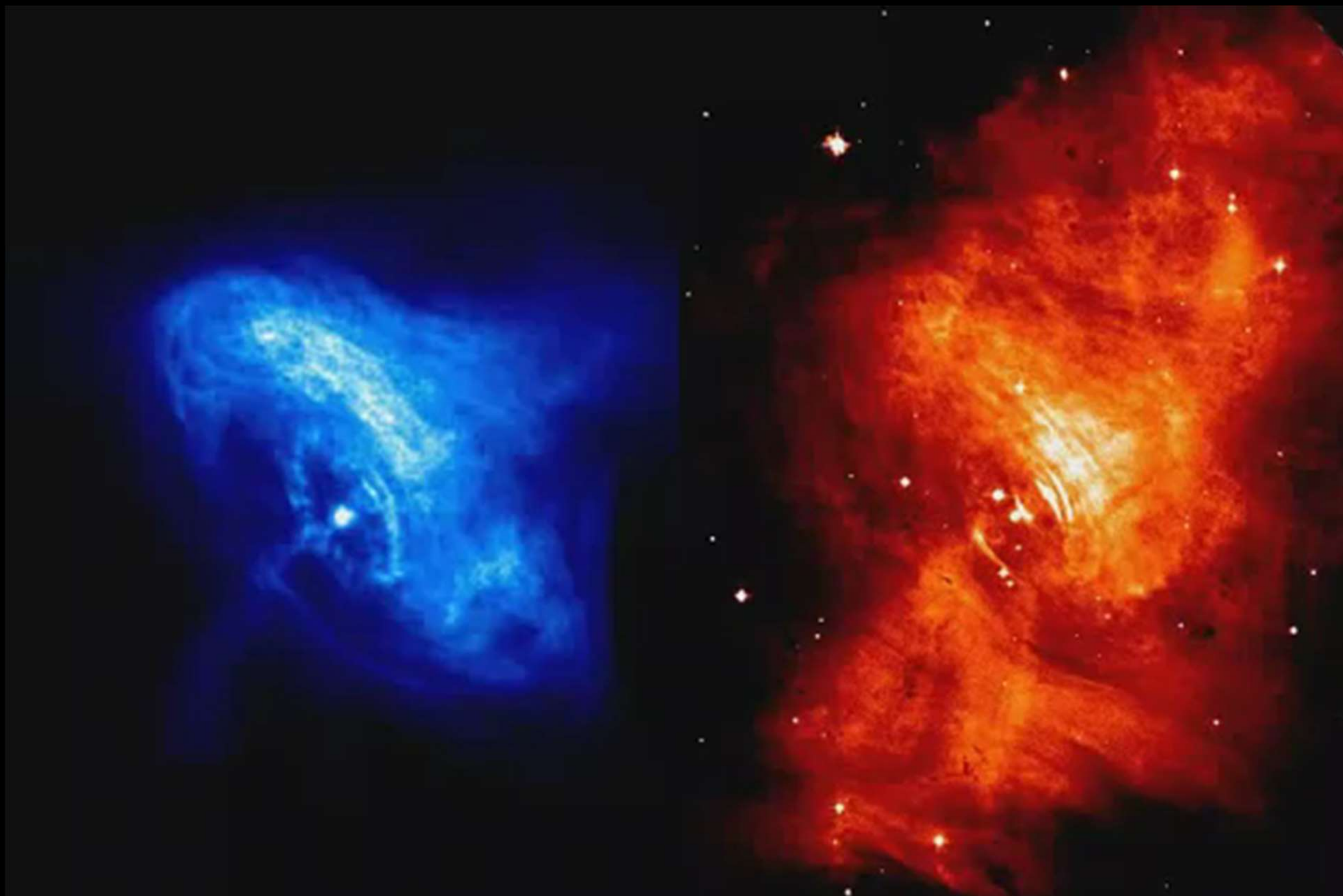


- Using a radio telescope in 1967, Jocelyn Bell noticed very regular pulses of radio emission coming from a single part of the sky.
- The pulses were coming from a spinning neutron star—a *pulsar*.

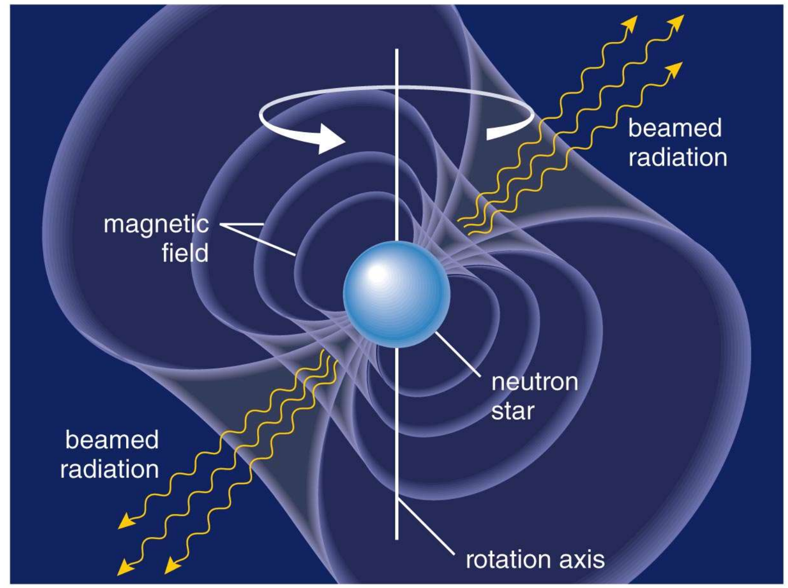
Thought Question

Why do Lighthouses rotate a beam of light around, rather than just shine a light in all directions? What could you do to the light from a 100W bulb to make sure it is seen as far away as possible?

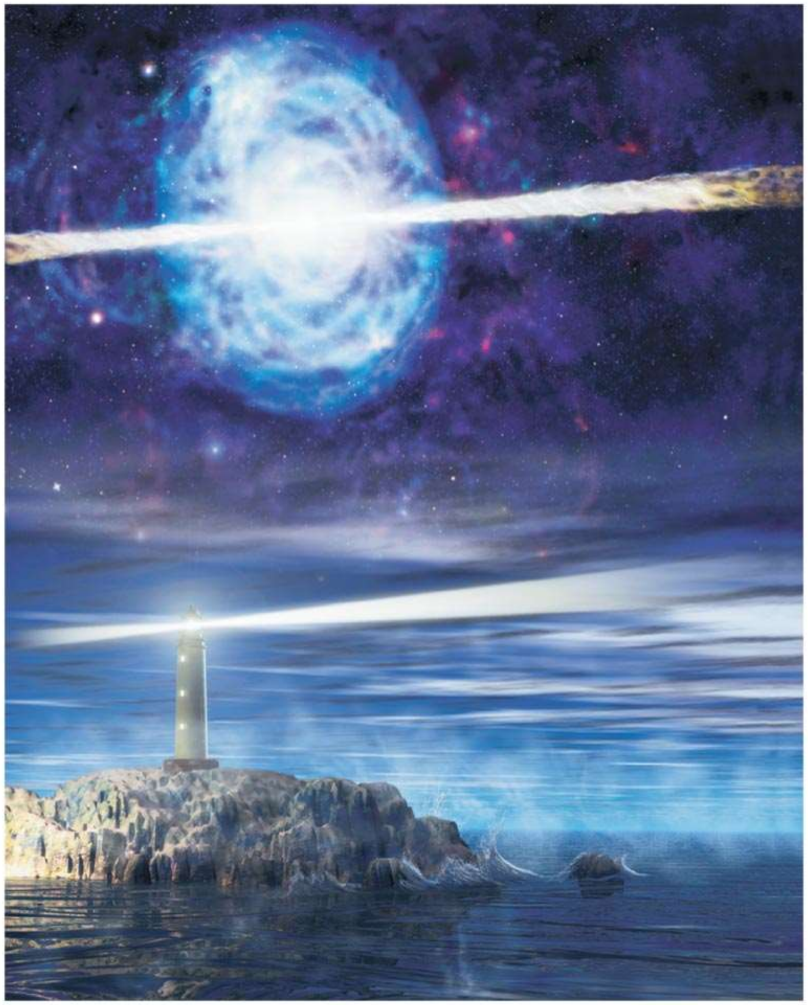
Time-lapse video of Crab Nebula from Chandra X-ray Telescope
X-rays (left) and Visible (right)



What is a Pulsar?



a A pulsar is a rotating neutron star that beams radiation along its magnetic axis.



b If the magnetic axis is not aligned with the rotation axis, the pulsar's beams sweep through space like lighthouse beams. Each time one of the pulsar's beams sweeps across Earth, we see a pulse of radiation.

- The magnetic field from the star is trapped within a very small space…
- Magnetic axis not necessarily aligned with rotation axis…
- Radiation sweeps across the Universe like a lighthouse – observed by Bell.

More Evidence these Stars are small and made from Neutrons

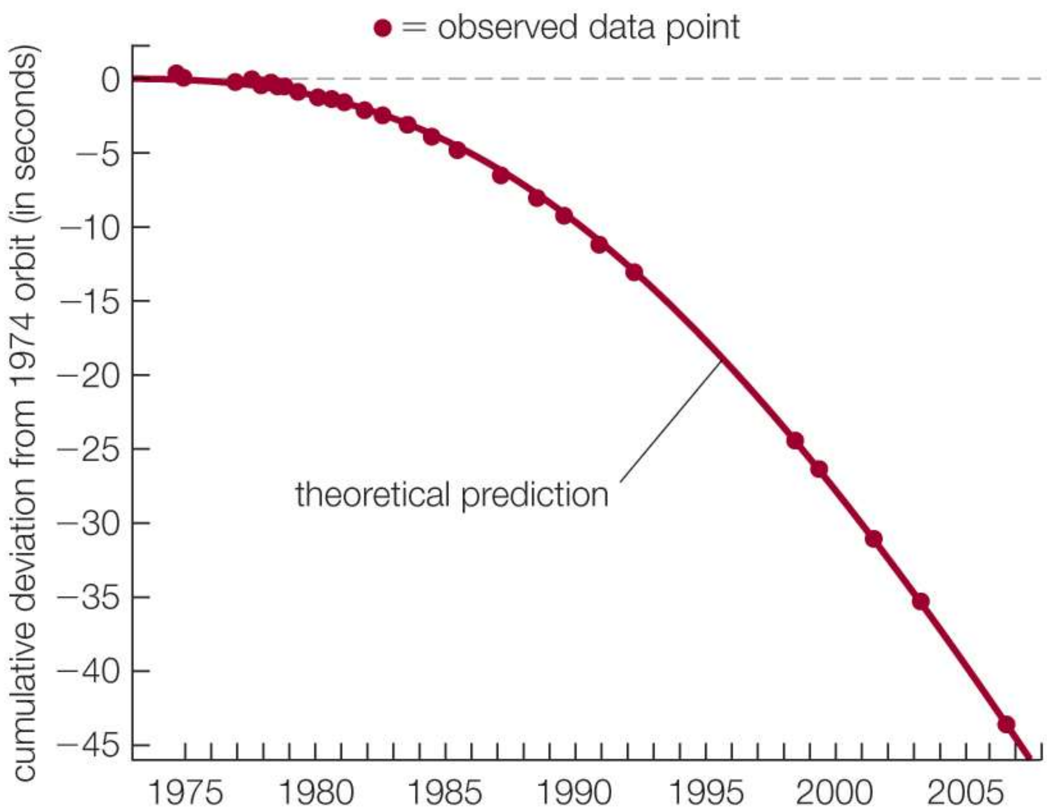
Circumference of Neutron Star = 2π (radius) ~ 60 km

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 much larger would be torn to pieces!

Neutron Stars & Gravity Waves



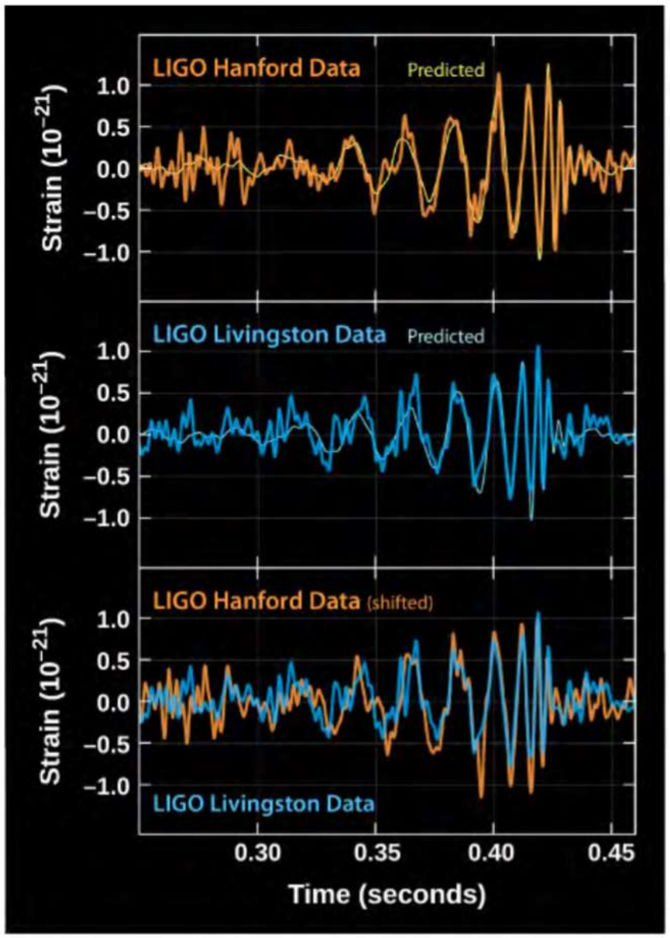
Two neutron stars in a close orbit will emit gravitational waves and spiral together.

The figure shows theory vs. observation for one such system.

Detection of Gravity Waves
(from Merging Neutron Stars & Black Holes)

Figure 24.17 Gravitational Wave Telescope. An aerial view of the LIGO facility at Livingston, Louisiana. Extending to the upper left and far right of the image are the 4-kilometer-long detectors. (credit: modification of work by Caltech/MIT/LIGO Laboratory)

Detection of Gravity Waves
(from Merging Neutron Stars & Black Holes)



Merger of two black holes 20 and 36 times the mass of the Sun

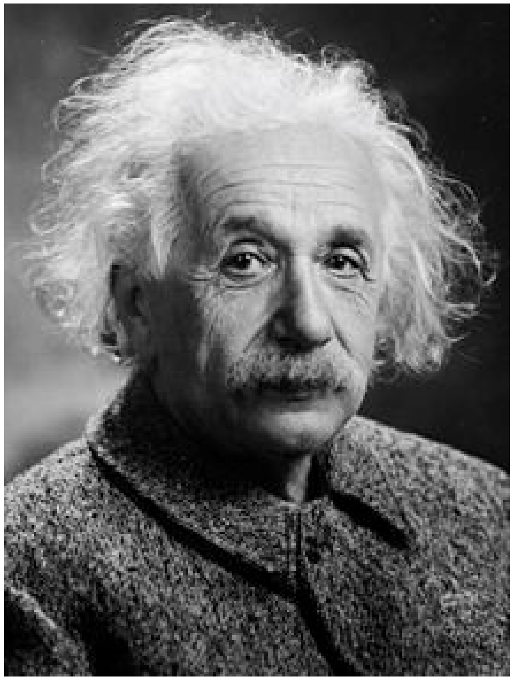
But Wait, what are Black Holes?

Aside: What is Special Relativity?

The speed of light is constant relative to your reference frame…

Example for an astronaut…

$E=mc^2$



- Mass changes as a function of velocity

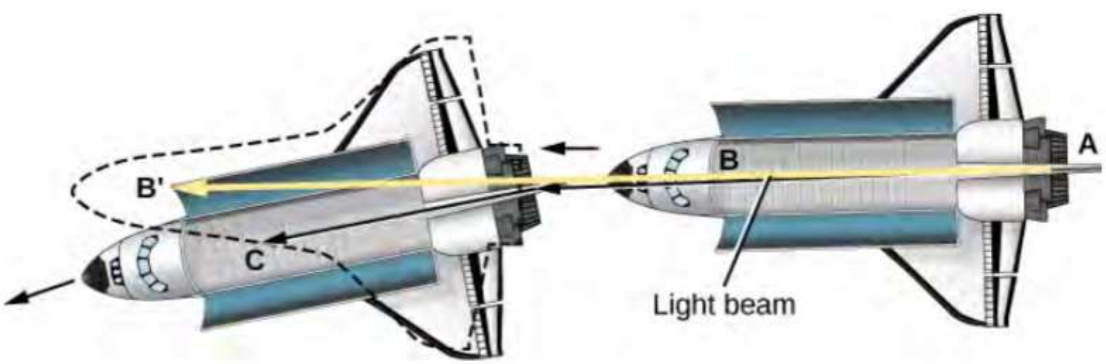
- **Time slows down as you go faster**

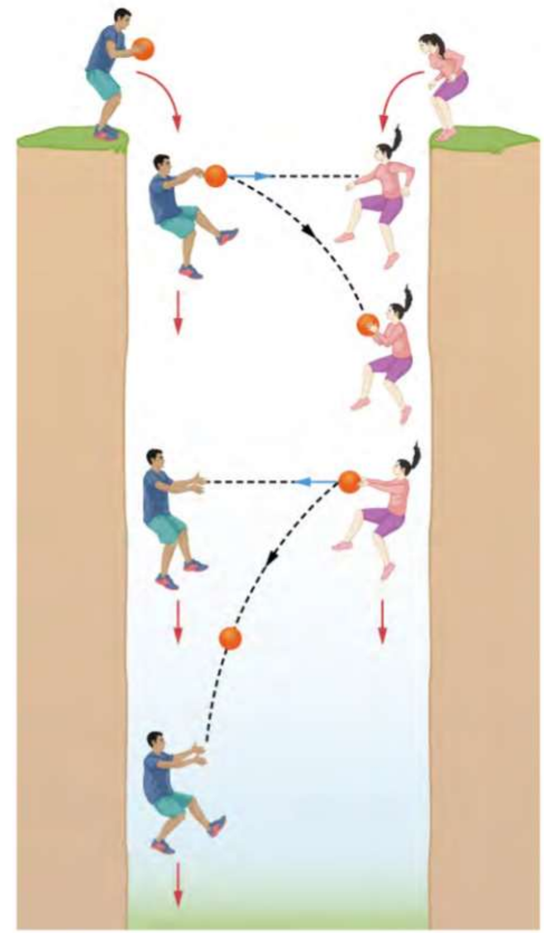
Aside: What is the Equivalence Principle?

It is impossible for us to determine our relative motion:

Example: Being in an elevator, or a plane…

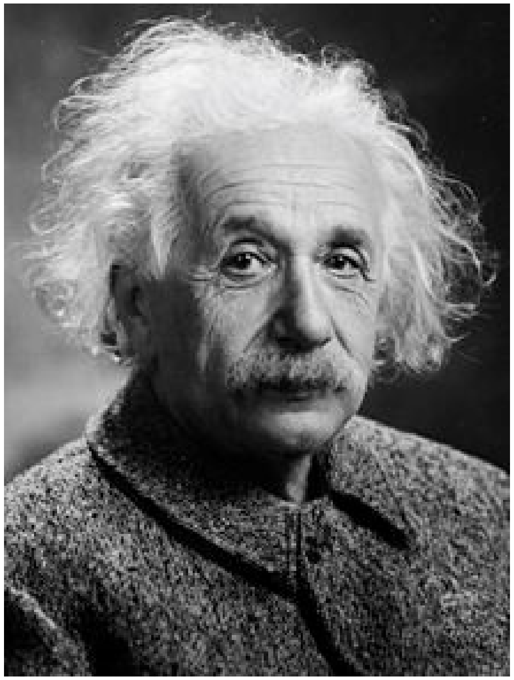
Are we in free fall, or not moving at all?





Gravity must be bending the light, but how?

Aside: What is General Relativity?



Light follows the shortest paths on spacetime (geodesic paths)

Gravity causes spacetime to slow down

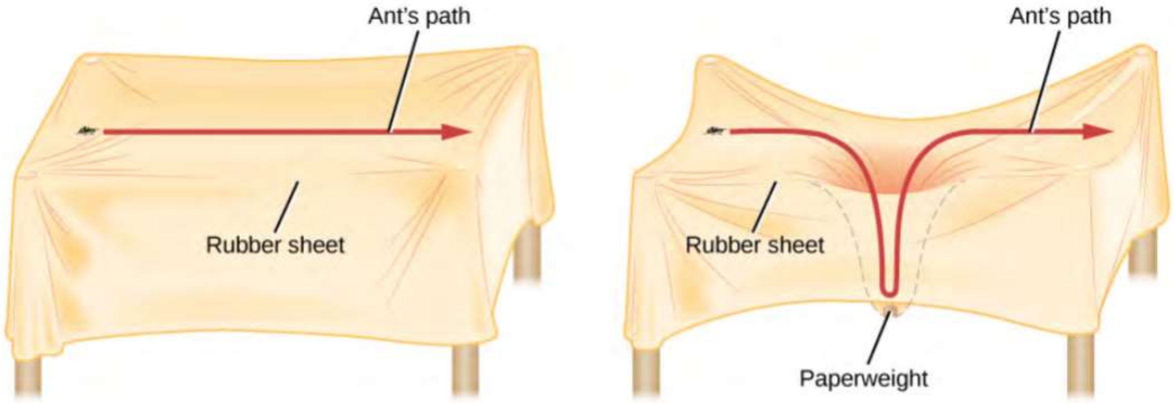


Figure 24.8 Three-Dimensional Analogy for Spacetime. On a flat rubber sheet, a trained ant has no trouble walking in a straight line. When a massive object creates a big depression in the sheet, the ant, which must walk where the sheet takes it, finds its path changed (warped) dramatically.

Example: GPS Satellites

GPS relies on ~ 24 satellites orbiting Earth, where at any time 4 of them are in line of sight of any position on Earth, allowing accuracy to better than 50 feet.

To judge distance, the satellites have very accurate atomic clocks, but they must be corrected for:

Special Relativity: The satellites are traveling at ~14,000 kilometers per hour… as they approach the speed of light, time slows down. They need to be corrected by ~ 7 millionths of a second per day.

General Relativity: BUT, the satellites are 20,000 kilometers above Earth, where gravity is about four times weaker. According to general relativity, these satellites would tick about 45 millionths of a second faster than they would on Earth.

Overall correction is that they tick ~ 38 microseconds faster than on Earth.

Example: Mercury

Mercury precession should be 531 arcseconds per century but is actually 574 arcseconds per century.

→ Caused many astronomers to search for Vulcan

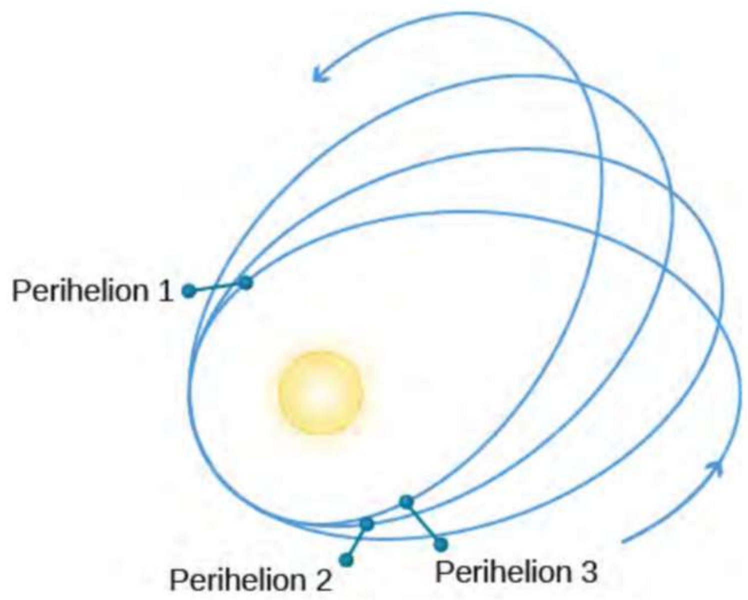
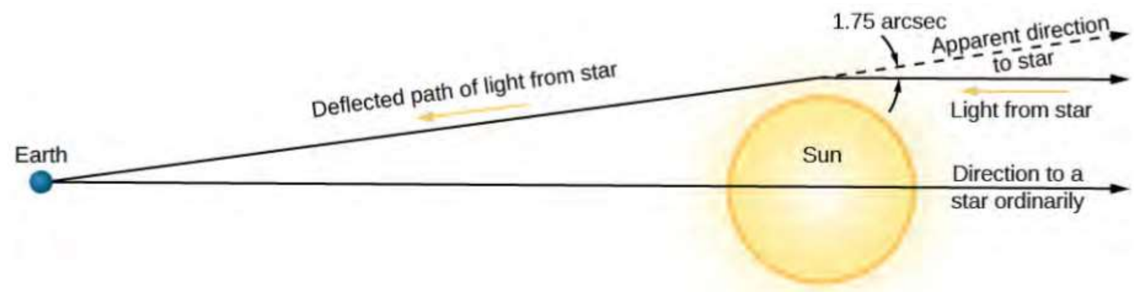


Figure 24.9 Mercury's Wobble. The major axis of the orbit of a planet, such as Mercury, rotates in space slightly because of various perturbations. In Mercury's case, the amount of rotation (or orbital precession) is a bit larger than can be accounted for by the gravitational forces exerted by other planets; this difference is precisely explained by the general theory of relativity. Mercury, being the planet closest to the Sun, has its orbit most affected by the warping of spacetime near the Sun. The change from orbit to orbit has been significantly exaggerated on this diagram.

Example: Bending of Light

Can be observed by comparing night sky 6 months apart from a solar eclipse



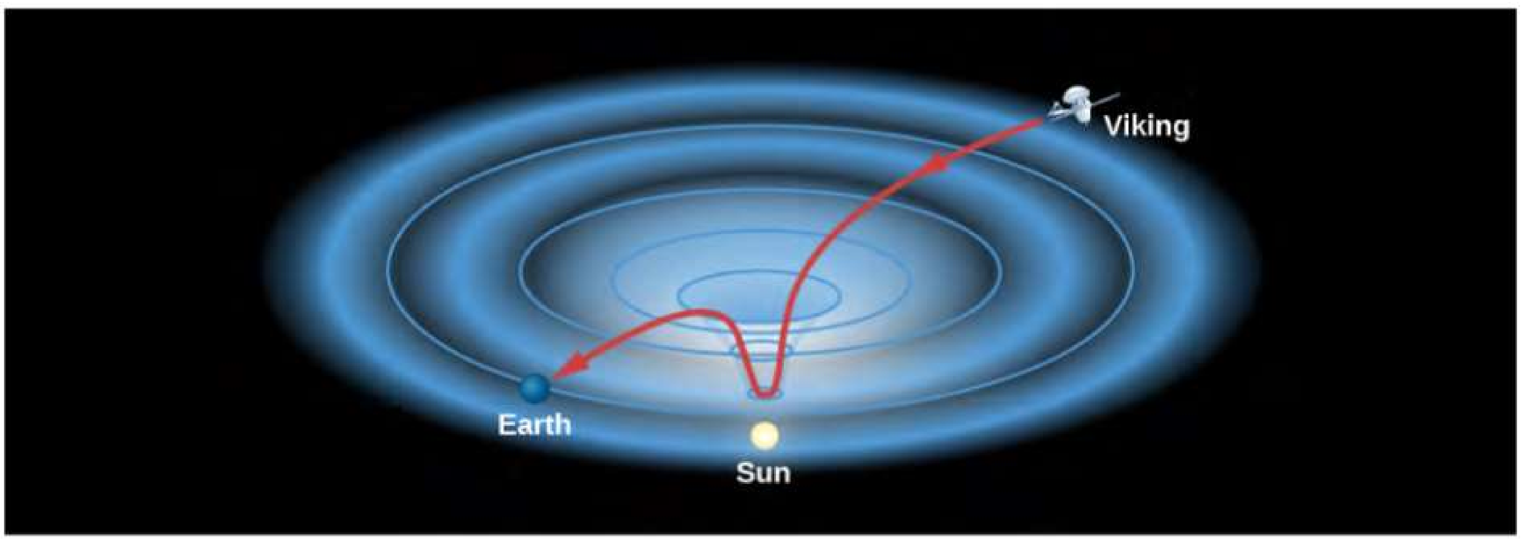
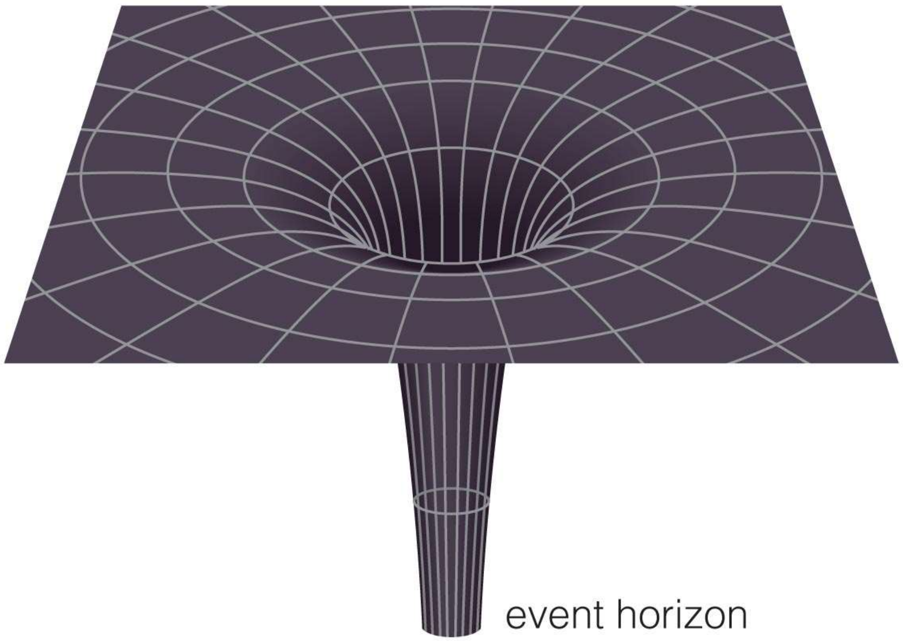


Figure 24.11 Time Delays for Radio Waves near the Sun. Radio signals from the Viking lander on Mars were delayed when they passed near the Sun, where spacetime is curved relatively strongly. In this picture, spacetime is pictured as a two-dimensional rubber sheet.

What is a black hole?



c The curvature of spacetime becomes greater and greater as we approach a black hole, and a black hole itself is a bottomless pit in spacetime.

- A ***black hole*** is an object whose gravity is so powerful that not even light can escape it.
- Some massive star supernovae can make a black hole if enough mass falls onto the core.
- Nothing can stop it from collapsing anymore – it becomes an infinitely dense point… a **Singularity.**

Thought Question

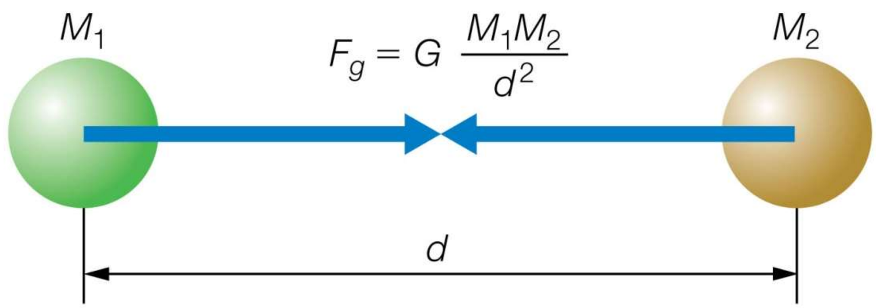
What happens to the escape velocity from an object if you shrink it?

A. It increases.

B. It decreases.

C. It stays the same.

Hint:



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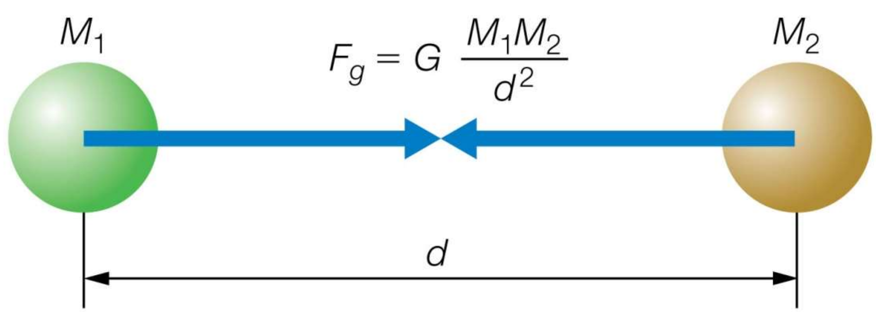
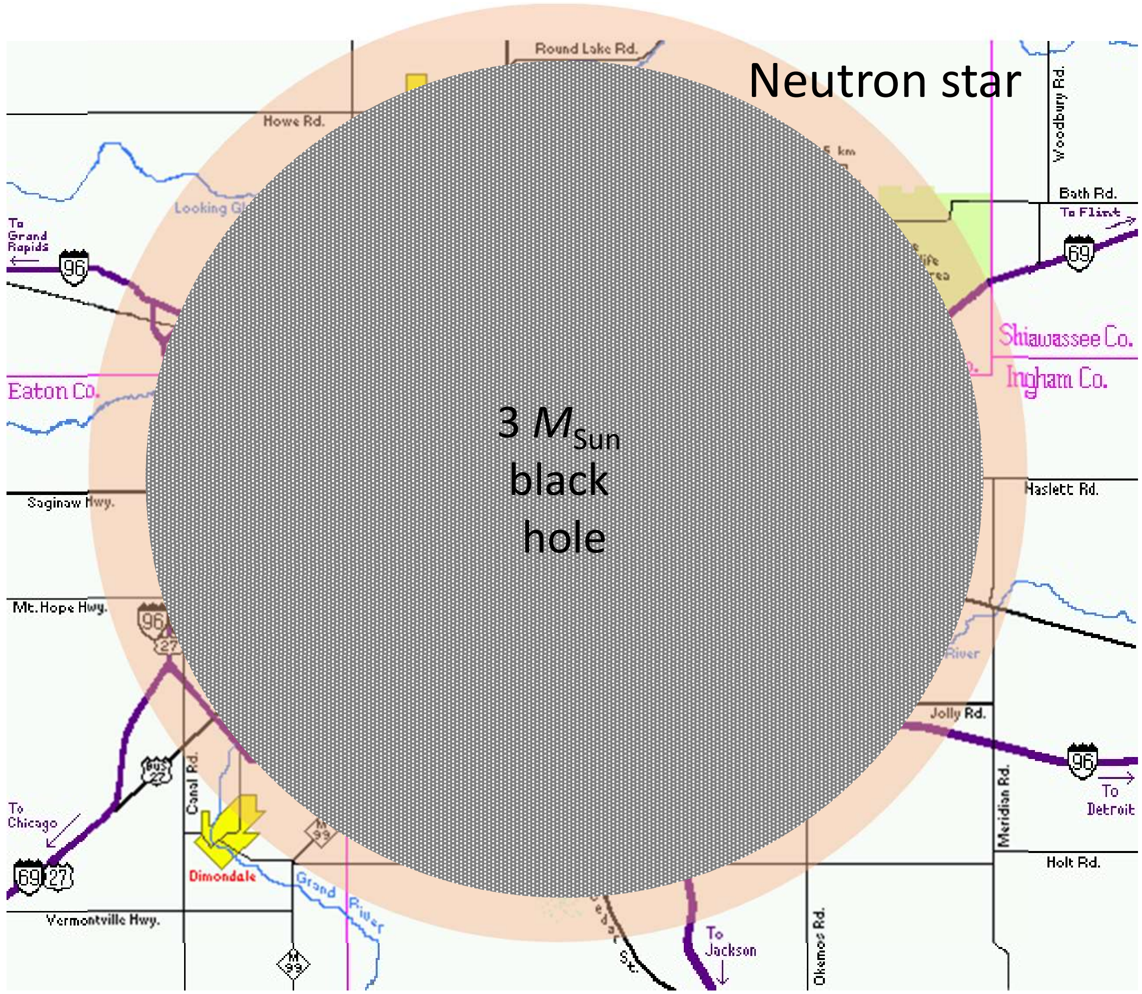


How Big is a Black Hole?



The event horizon of a $3M_{Sun}$ black hole is also about as big as a small city.

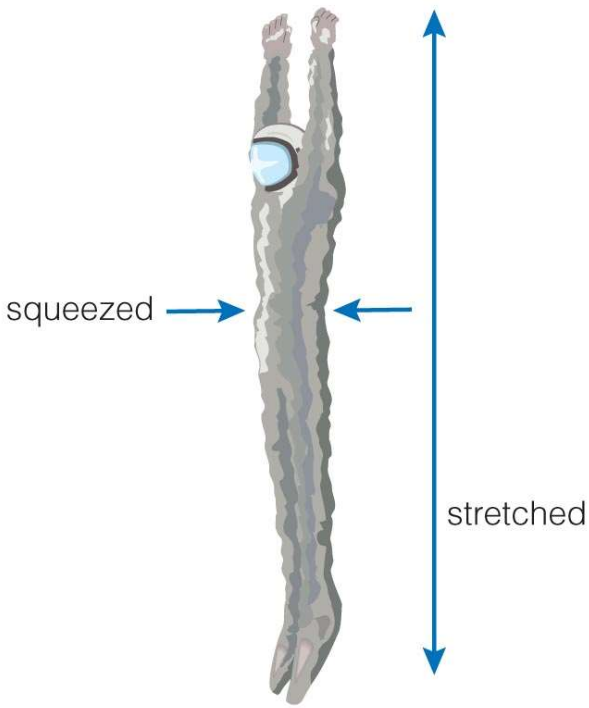
What Happens to Light Near a Black Hole?

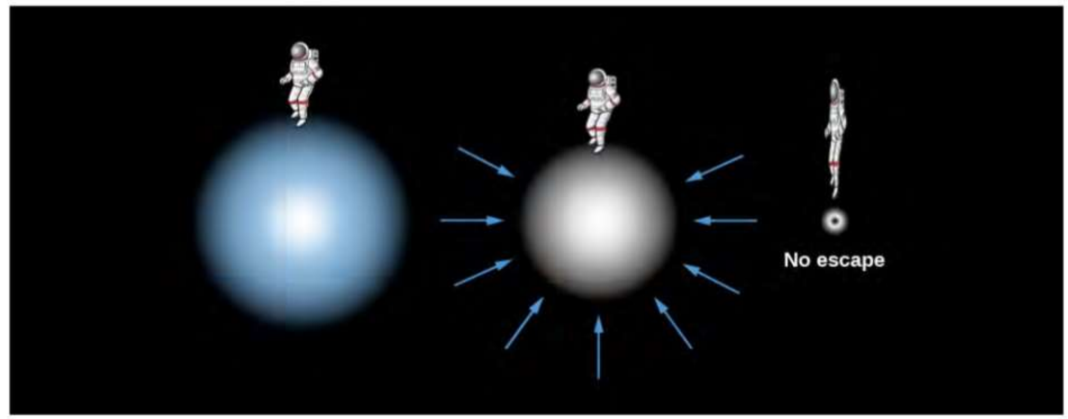
Schwarzschild radius would be about 3 kilometers for our Sun

Gravity does not change substantially unless you get within about 5 Schwarzschild radii

Blackholes don’t suck!

What Happens When you Get Near a Black Hole?





Tidal forces near the event horizon of a

$3M_{Sun}$ black hole would be lethal to humans.

Tidal forces would be gentler near a supermassive black hole because its radius is much bigger.

End of Todays Lecture