Telescope Observing Night

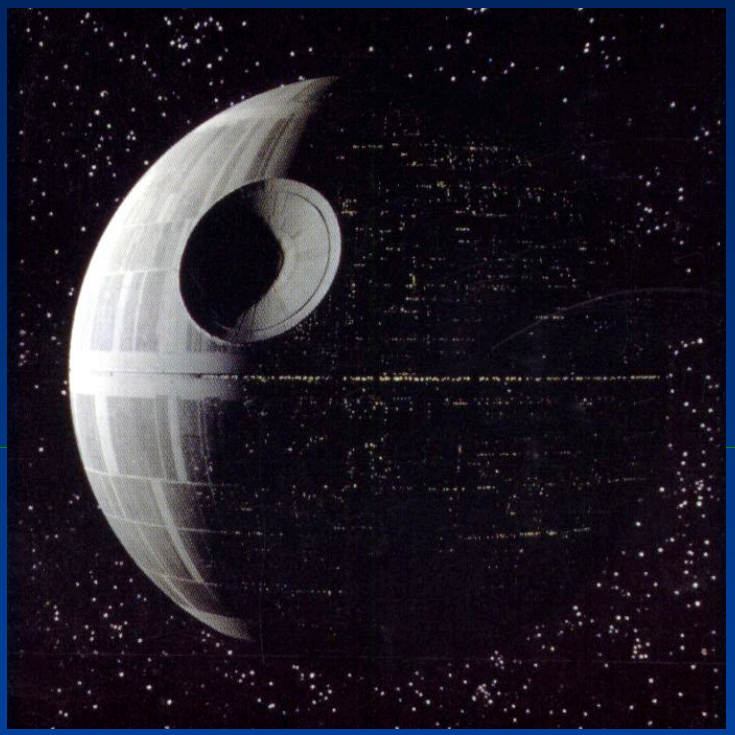
- We will be holding an optional observing night this coming Tuesday, Nov. 8th from 7-9 p.m. on the Science Center roof. We'll be looking at Mars, stellar clusters, binary stars, and more...

- Because we live in lovely cloudy Boston, we have to prepare for inclement weather. We will make an announcement on the course website by 4 p.m. on Tuesday letting you know if the observing session is on for the night or cancelled.

Q&A Monday 11/7

- I was confused by the fact that more massive white dwarfs are smaller in size than less massive ones. More specifically, why does gravity compress white dwarfs to different sizes?
- I absolutely loved the part on neutron stars and on how powerful their density was. That power is almost unimaginable to me. Other than that, I found the reading to be pretty clear. Congratulations on the new baby as well.
- Black holes are simply fascinating. The hypothetical situation about the person crossing the event horizon and what could potentially happen to them is unbelievable. For a split second, I felt a little scared that I might ever approach a black hole…

THE DEATHS OF STARS



White Dwarfs, Neutron Stars, Black Holes, Supernova Explosions, and the Origins of Humanity

Science A-47: Cosmic Connections

Monday, November 7th 2005

OUTLINE

- **WHITE DWARFS AND NEUTRON STARS**
  - Exotic States of Matter
- **SUPERNOVA EXPLOSIONS**
  - How We Are All Made of Stardust
- **BLACK HOLES**
  - Journey to the Dark Side and Beyond

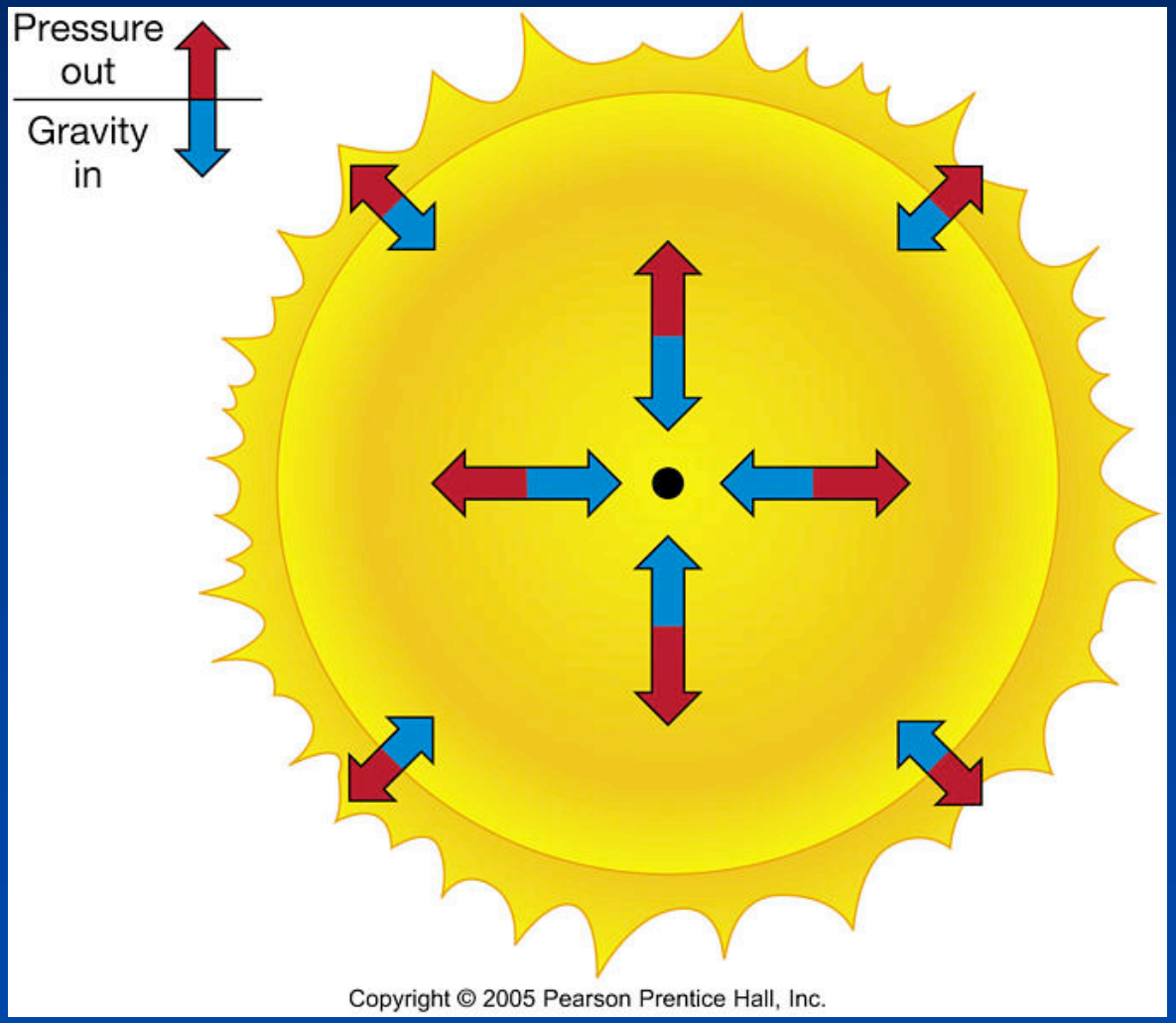
ASTRONOMICAL PROPERTIES

	Mass/ M_{sun}	Radius [km]	Density [g/cm^3]	Gravitational Acceleration / 9.8 m/s^2	Escape Velocity [km/s]
Earth	$3x10^{-6}$	$6x10^3$	5.5	1	11
Sun	1	$7x10^5$	1	27	600
White Dwarf	1	$6x10^3$	10^6	$3x10^5$	6000
Neutron Star	1	10	10^{14}	10^{11}	$1.5x10^5$
Black Hole	3	6	$6x10^{15}$	$5x10^{11}$	$3x10^5$

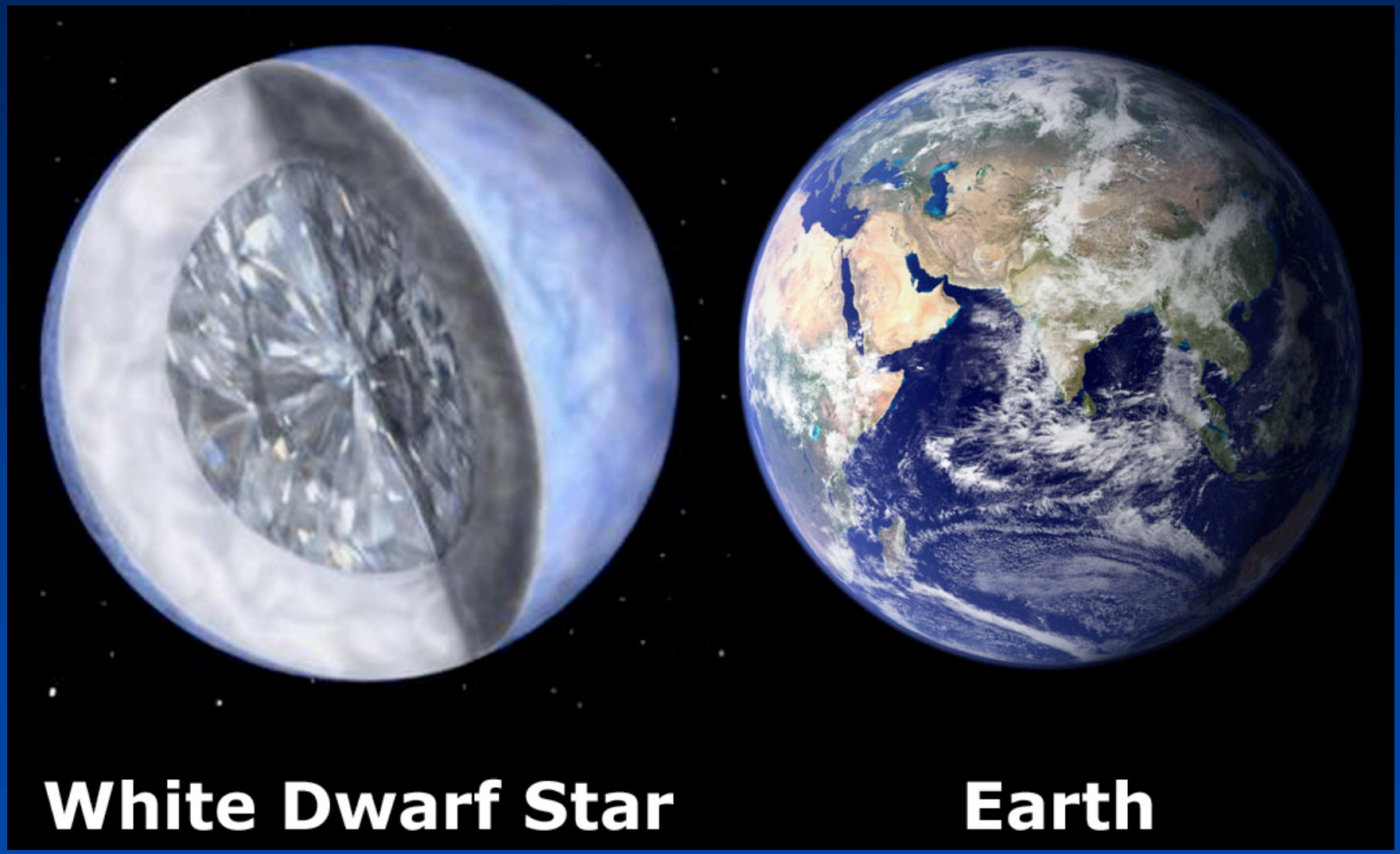
Approximate numbers for typical objects. White Dwarfs can be as massive as 1.4 M_{sun}, Neutron Stars up to ~2-3 M_{sun}, and Black Holes of up to 10^9 M_{sun} have been found and can be as large as the universe.

STAR WARS

- Gravity vs. pressure.

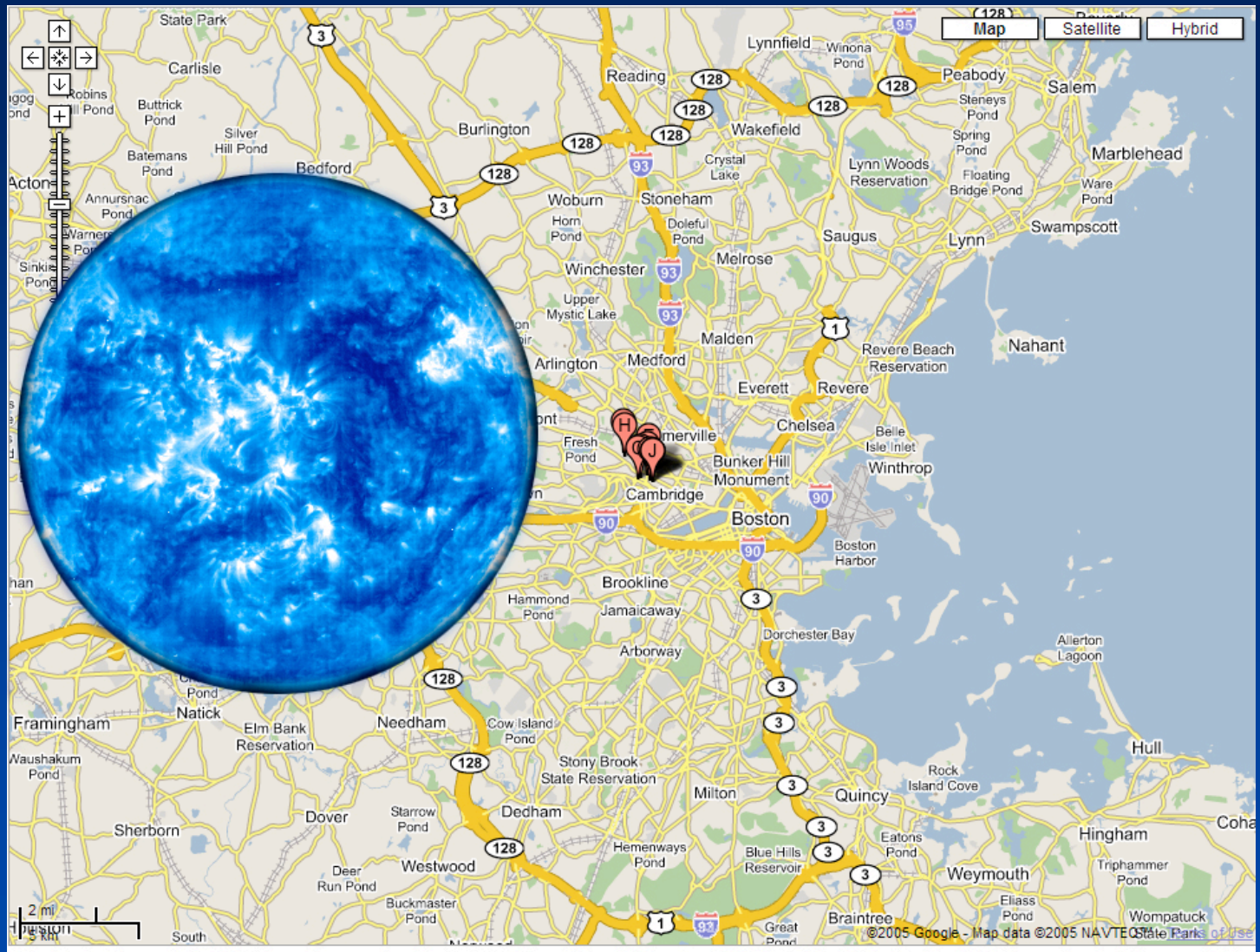


WHITE DWARFS



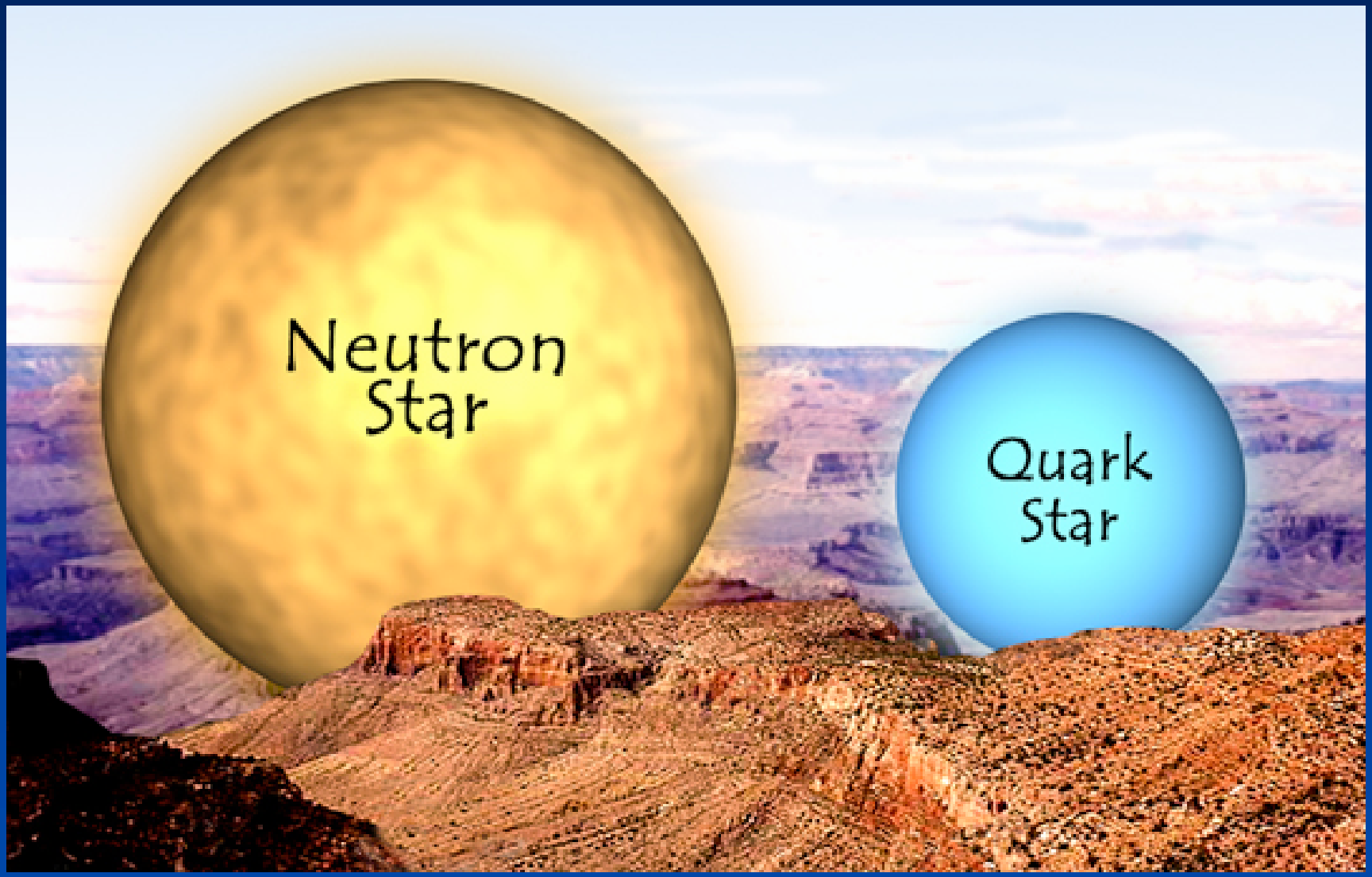
WHITE DWARFS

NEUTRON STARS



Neutron Star to Attend Harvard

QUARK STARS



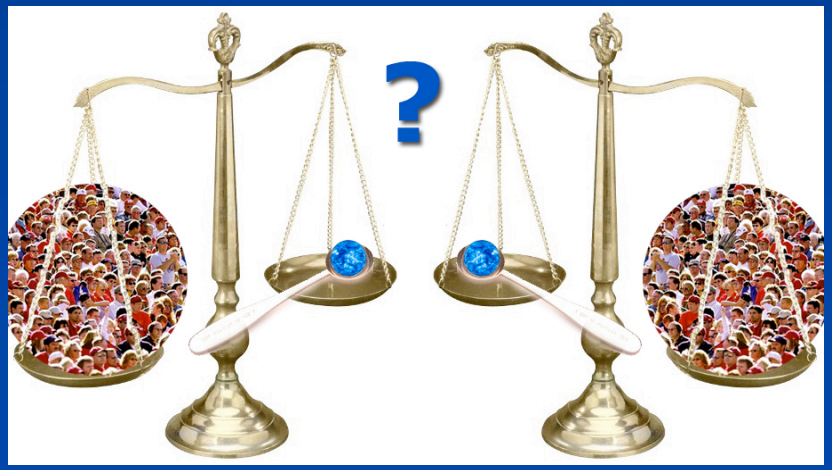
STAR WARS

Astrophysical Object	Force Fighting Gravity
People	Electromagnetism
Planets	Electromagnetism
Protostars	Thermal Pressure (gravitational contraction)
Main Sequence Stars	Thermal Pressure (nuclear fusion)
White Dwarfs	electron degeneracy pressure
Neutron Stars	neutron degeneracy pressure
Quark Stars	quark pressure?
Black Holes	NOTHING!

PRS QUESTION #1

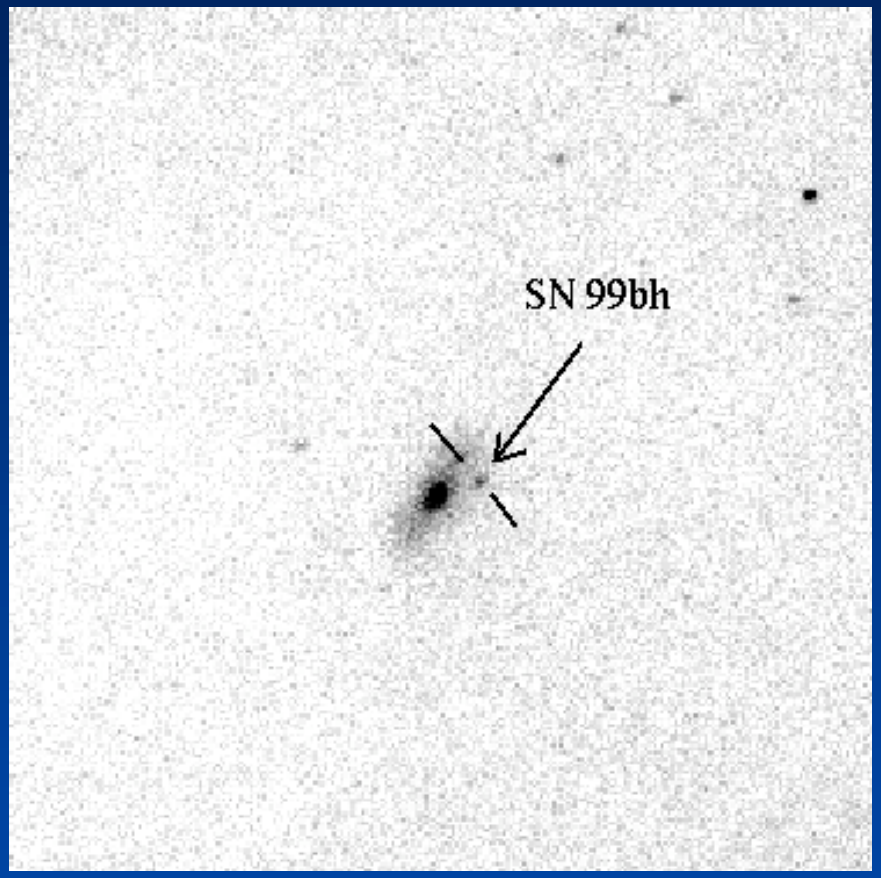
A Neutron Star has an average density of about 10^{14} g/cm^3. A teaspoon has a volume of about 5 cm^3. Assuming an average person weighs 50kg, which of the following has the most total mass?

- The guest lecturer
- A teaspoon of material from the sun's core
- A teaspoon of white dwarf material
- A teaspoon of neutron star material
- The mass of all six billion human beings on Earth



SUPERNOVAE

SN 1994d
Hubble Space Telescope



SN 1999bh – Katzmann
Automated Imaging
Telescope & Andy

HISTORICAL SUPERNOVAE

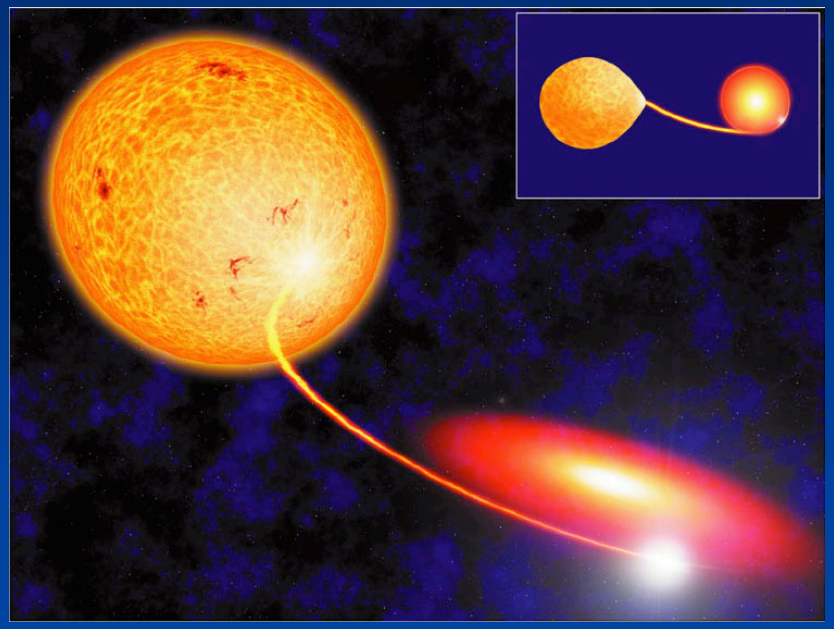
Supernovae in our galaxy (or a nearby galaxy)

Year	Report	Supernove Remnant
1006	China, Japan, Korea, Arab lands, Europe	Identified with radio SNR
1054	**China, Japan**	**Crab Nebula**
1181	China, Japan	Possible identification with radio SNR 3C58
1572	Europe (Tycho Brahe), China, Japan	Tycho's remnant
1604	Europe (Kepler), China, Japan, Korea	Kepler's remnant
1987	***SN 1987A – Large Magellanic Cloud***	***Remnant still observable***

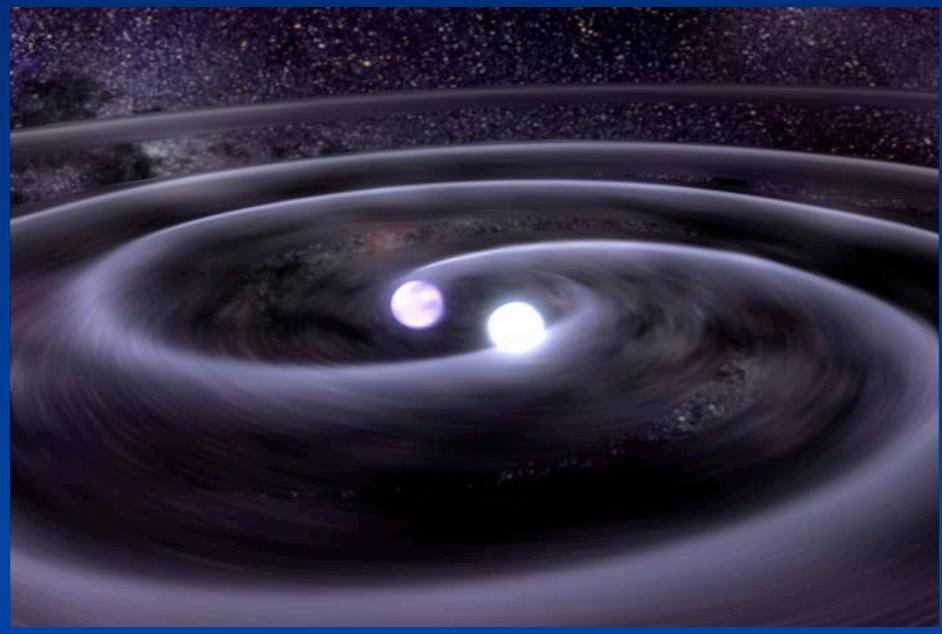
TYPE IA SUPERNOVAE

Thermonuclear Bombs in Space!

Explosions of White Dwarfs in Binary Systems



WD Accretion From Main Sequence Companion

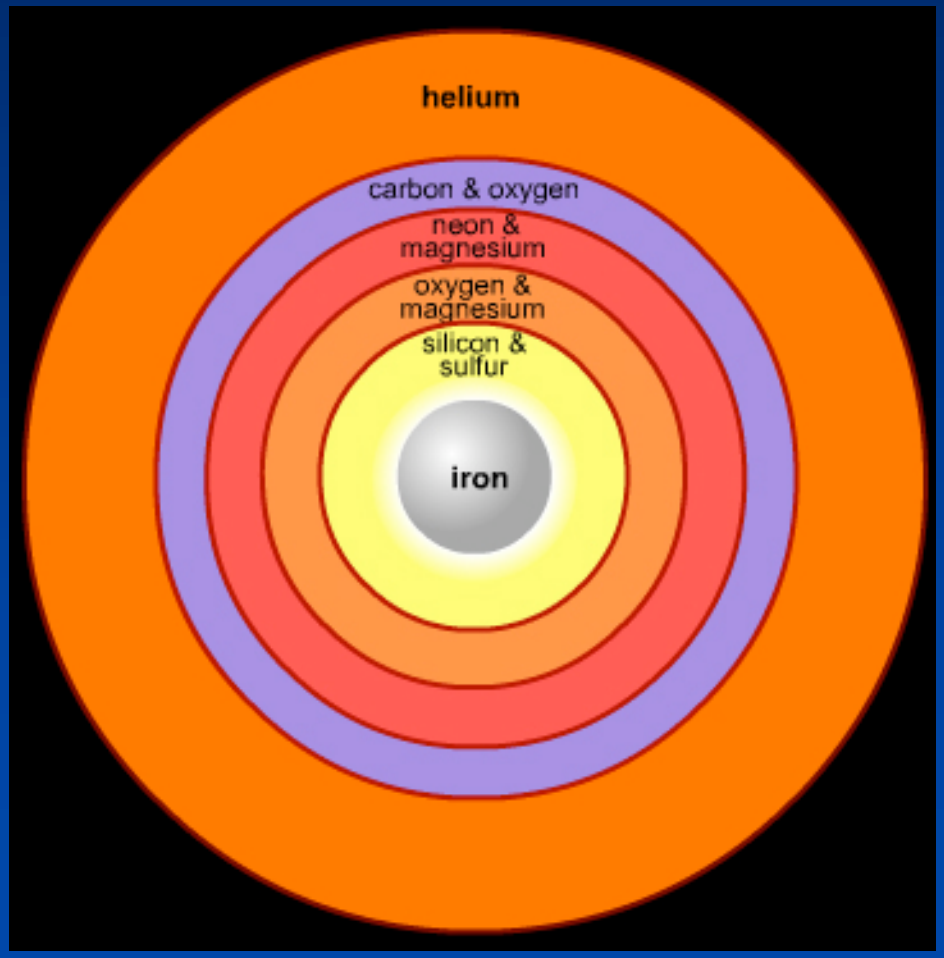


Merger of 2 White Dwarfs

TYPE II SUPERNOVAE

Gravity Bombs!

Gravitational Core Collapse of Massive Stars

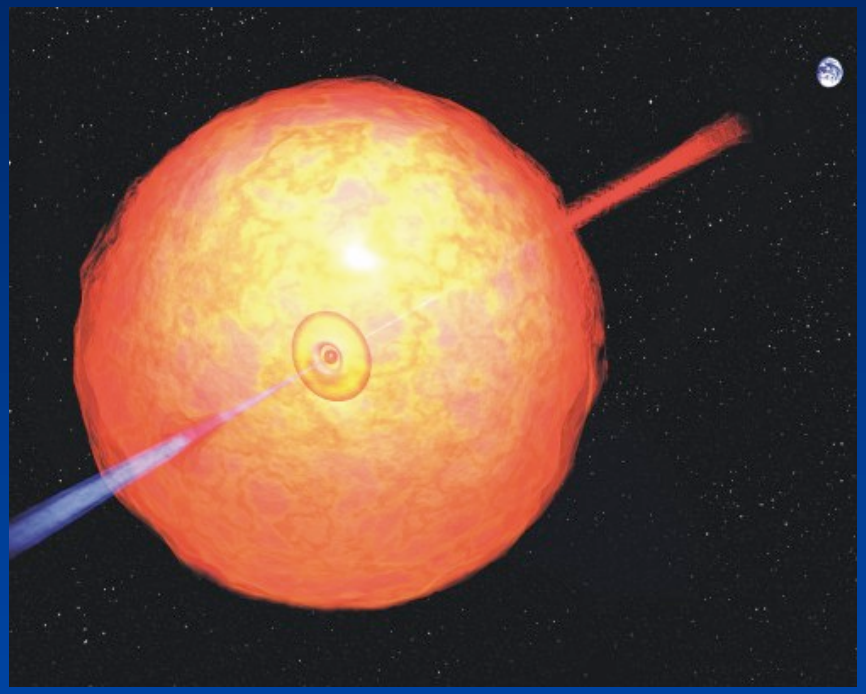


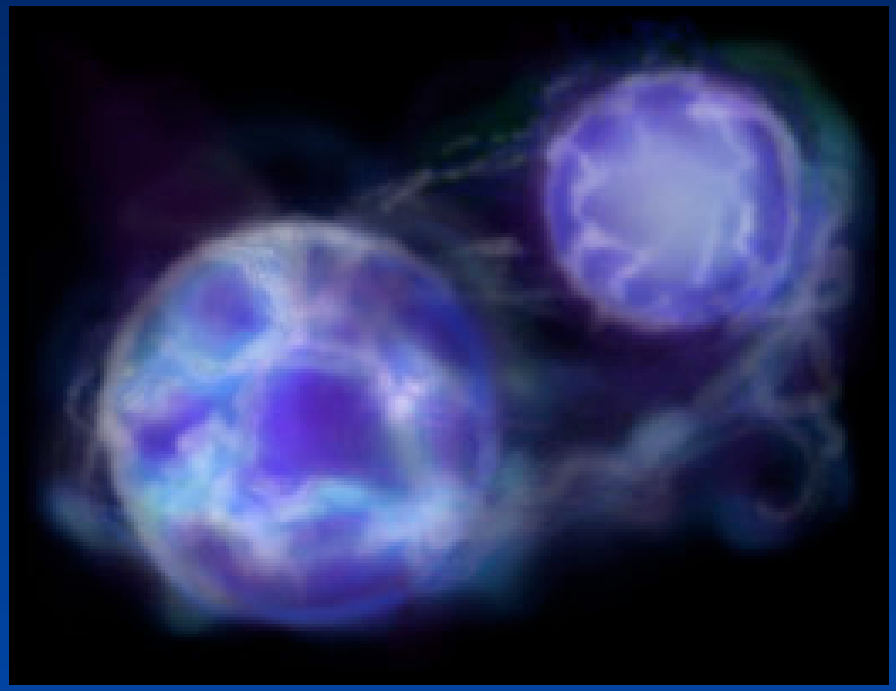
Star with M > 8 M_{sun}

The Sun

GAMMA-RAY BURSTS (GRBs)

The Brightest Explosions in the Universe!





<u>Long Duration GRBs</u>
Occur along with core collapse supernovae of some massive stars

<u>Short Duration GRBs</u>
Probably merging neutron stars

STELLAR EXPLOSION MOVIES

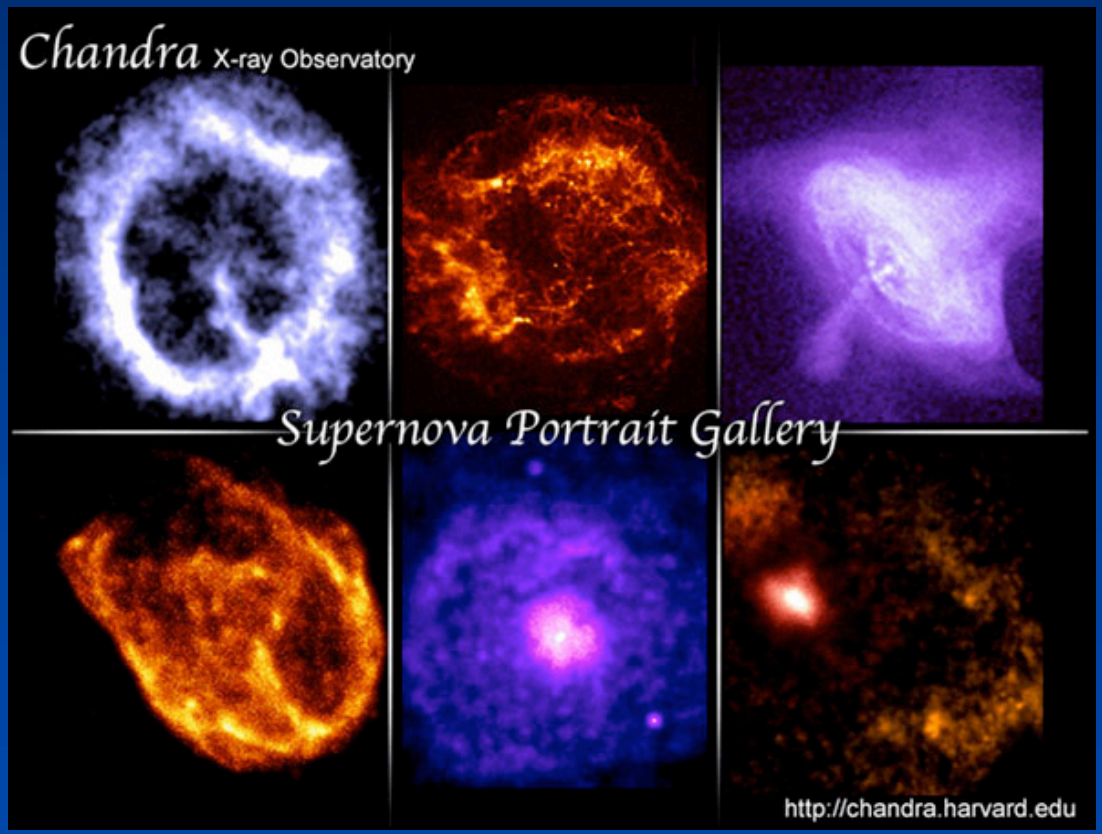
Core Collapse
Supernova Movie

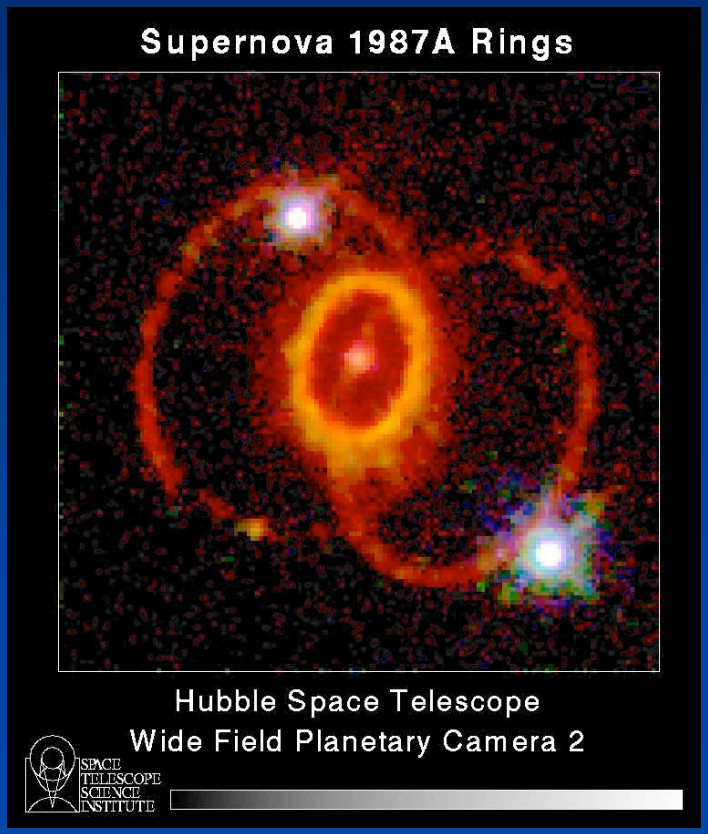
LEFTOVER COMPACT OBJECTS

Type of Stellar Explosion	Compact Remnant
Type Ia	NOTHING!
Failed Type Ia	*NEUTRON STAR?*
Type II	NEUTRON STAR
	BLACK HOLE
Gamma-Ray Burst	BLACK HOLE

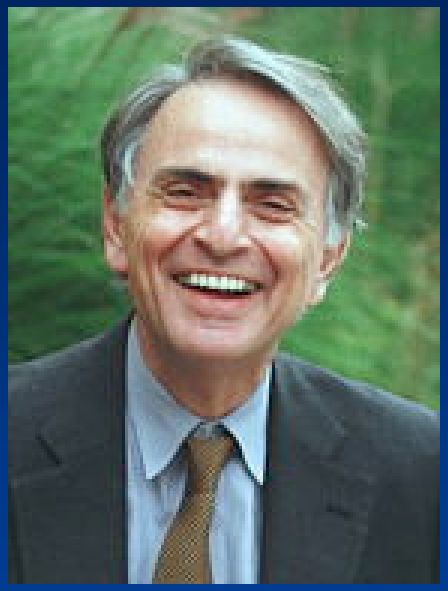
SUPERNOVA REMNANTS

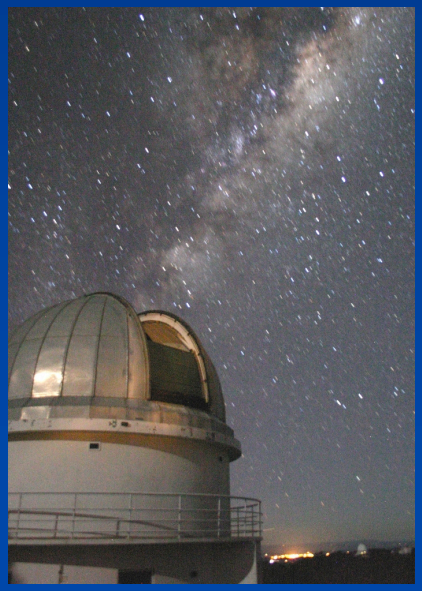
- ***Where do all the elements come from?***
- ***What about elements heavier than Iron?***



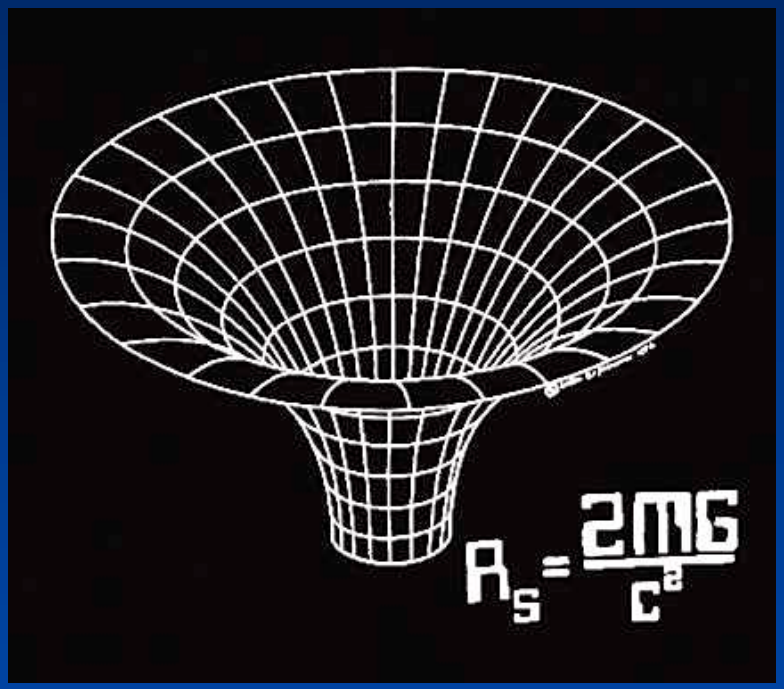


WE ARE ALL MADE OF STARS



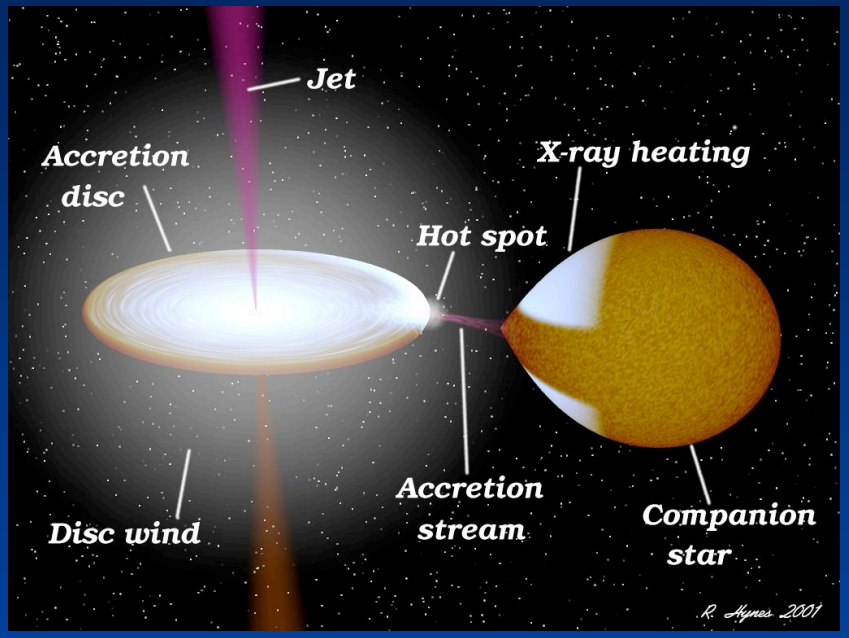


BLACK HOLES



The Schwarzchild Radius

EVIDENCE FOR BLACK HOLES



Stellar Mass Black Holes

$M \sim 3 - 20\ M_{sun}$

Supermassive Black Holes

$M \sim 10^6 - 10^9\ M_{sun}$

BLACK HOLES

Gas around a Black Hole Movie

PRS QUESTION #2

If the sun were to magically turn into a 1 solar mass black Hole right now, what would happen to the Earth?

a). The earth would be sucked into the Black Hole Sun in about 8 minutes.

b). The earth would start becoming cold & dark in ~8 minutes and then be sucked into the BH sun.

c). The earth would start becoming cold & dark in ~8 minutes but its orbit would remain unchanged.

d). Nothing of consequence would happen to the Earth.

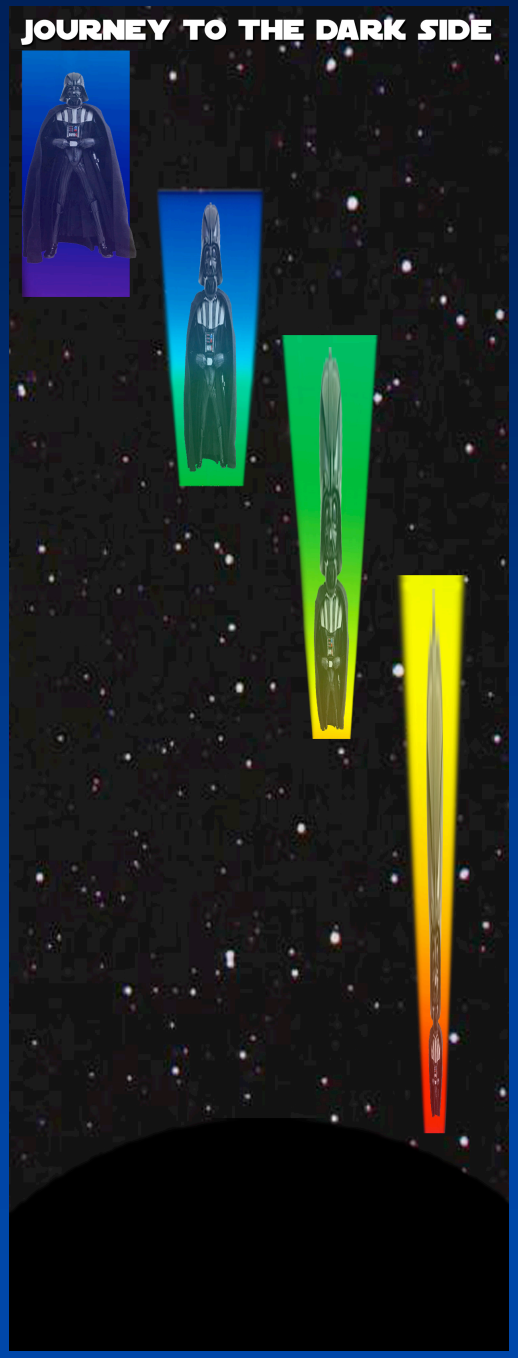
e). Not enough information.

FALLING INTO A BH

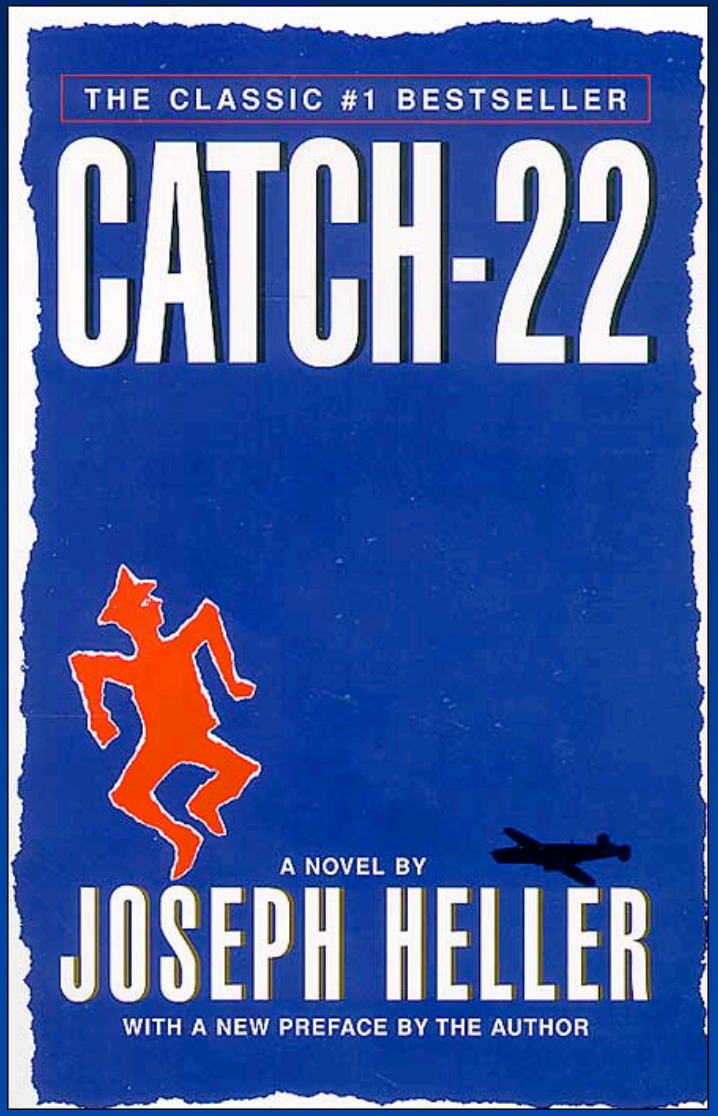
- ***Strange Gravitational Effects Near a Black Hole***
  - *Gravitational Redshift*
  - *Time Dilation*
  - *Tidal Forces*
  - *Bending of Light*

- *What would we see?*

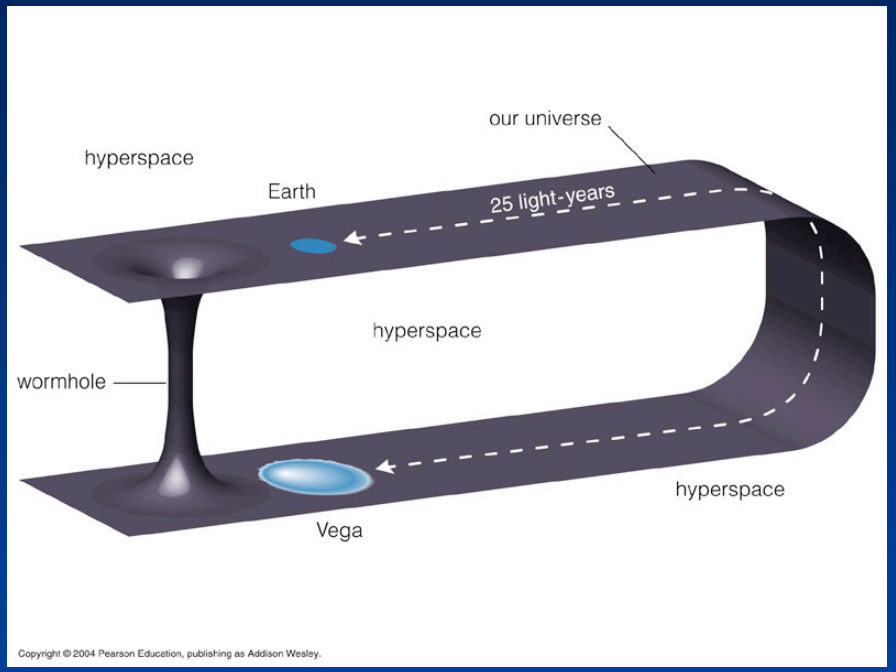
- *What would Darth Vader see?*



WHAT'S INSIDE A BLACK HOLE?

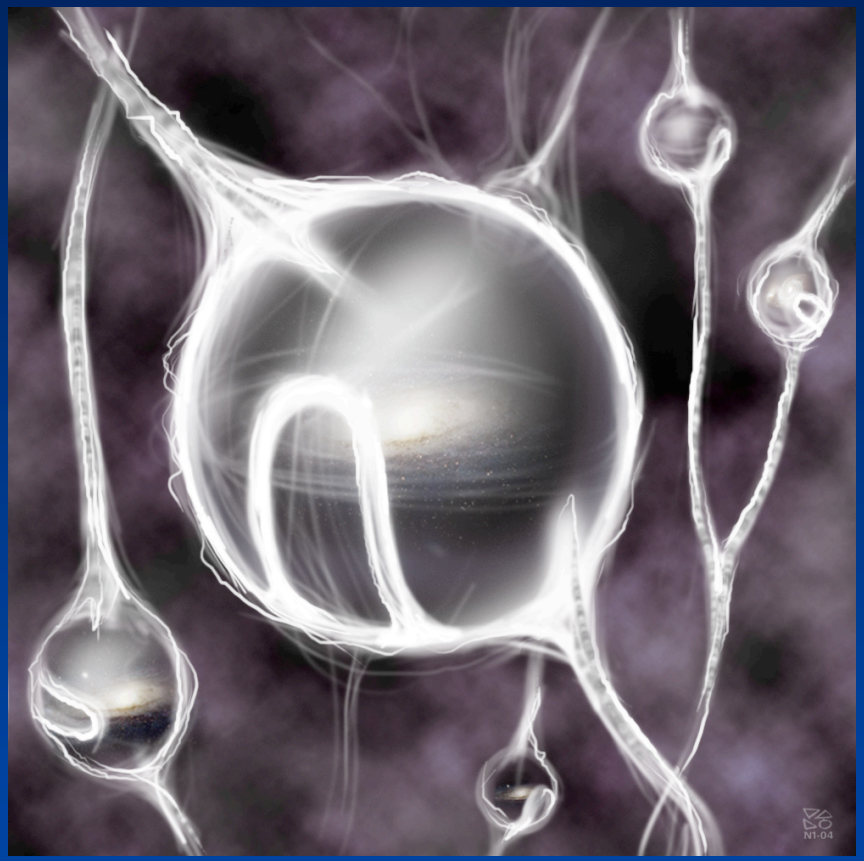


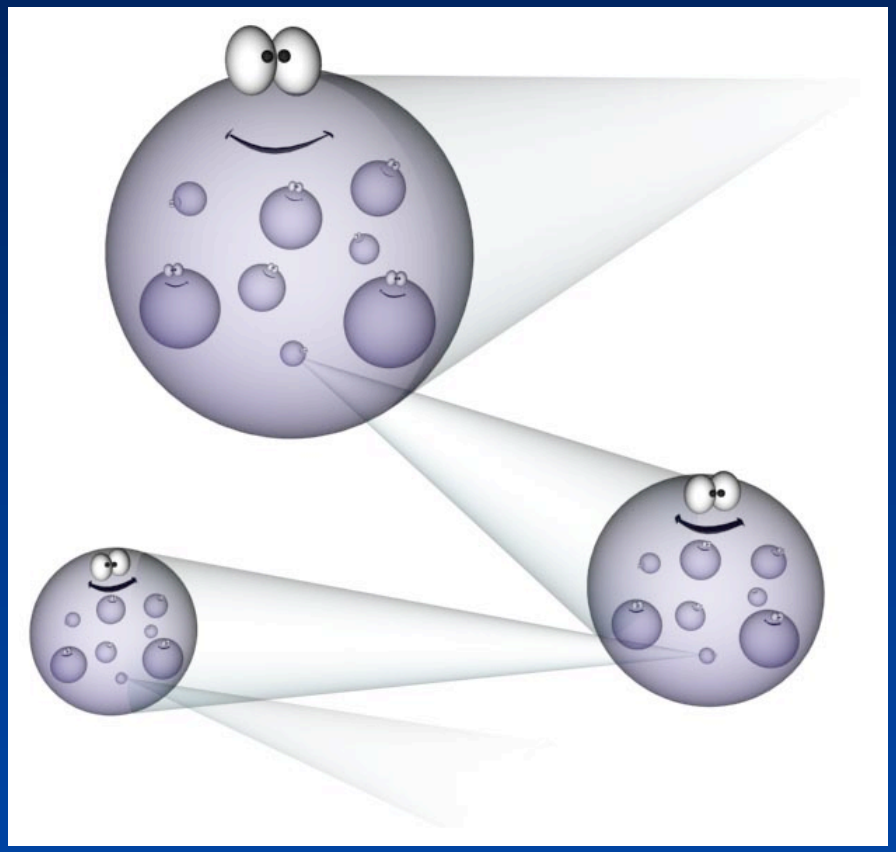
WORMHOLES



- Perhaps a collapsed star is not a Black Hole, but a "***wormhole***" or cosmic shortcut

IS OUR UNIVERSE A BH?





- Perhaps there are many universes connected via black holes or wormholes

CONCLUSIONS

- The universe is weird!
- White Dwarfs and Neutron Stars are among the most exotic states of matter.

- ***We are all made of stars.***
- Supernova explosions are prerequisites for our existence.

- Black holes of some kind probably do exist.
- No one knows what's inside a Black Hole.