

MASSIVE Stars – How They END

**What we know so far about
the Bizarre Objects and Effects that
result from Supergiant Star Death.**

by Rick Kang

Oregon Astrophysics Outreach

Who's Rick?

- Program Developer and Presenter for Oregon Astrophysics Outreach, my company, based in Eugene.
- I travel the state visiting K-12 classes.
- <http://oregonsky.org/>
- In summers I've been a tourguide at U of O's Pine Mountain Observatory, which you can VISIT during Summer evenings.
- <http://pmo.uoregon.edu/>

Visit **Pine Mountain** near Bend Fri/Sat evenings, June-Sept. Great Camping and Sky Viewing!



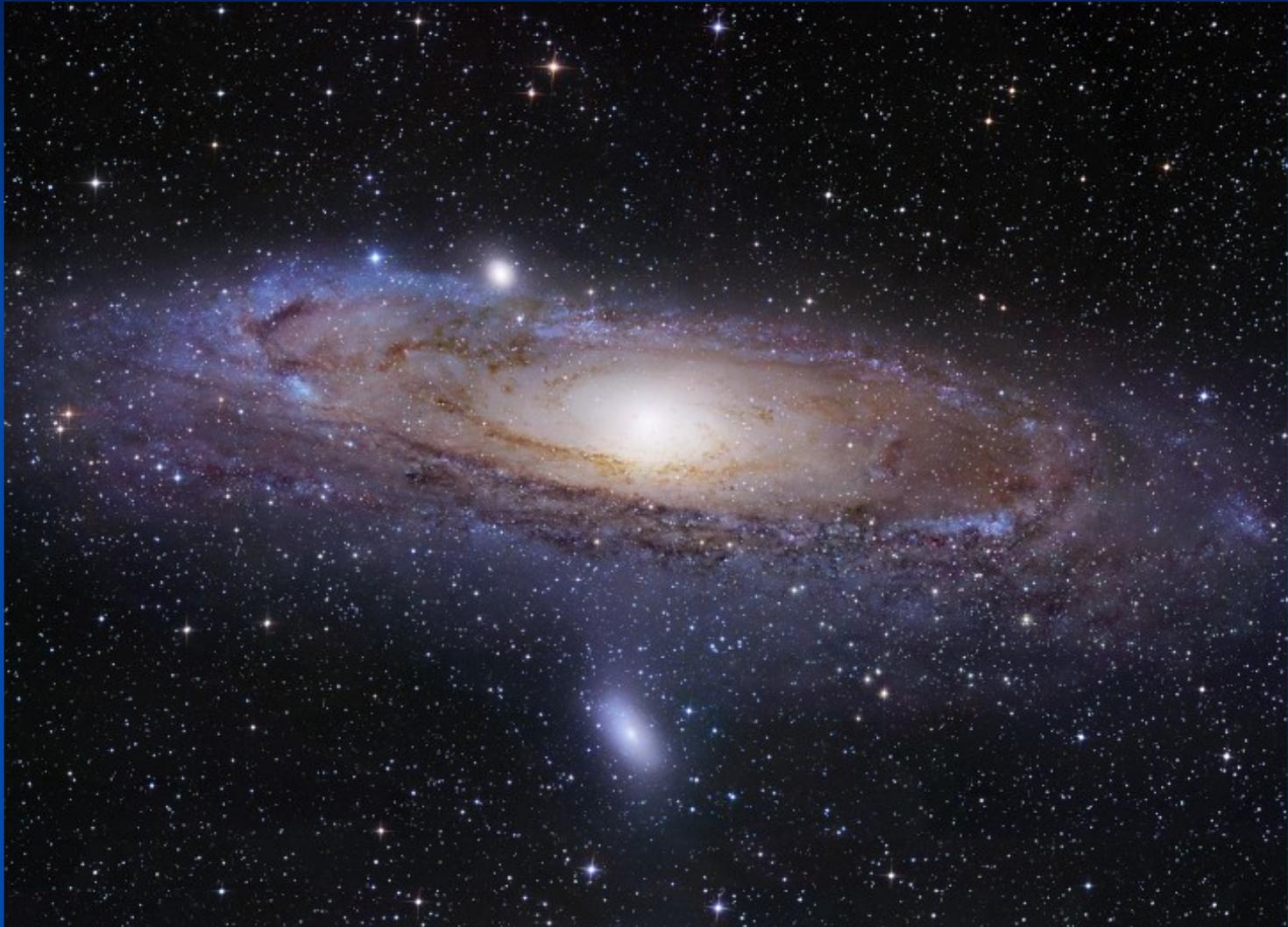
Today's Topics

- Types of Stars – Mass dependent
- Formation/Evolution/Demise of Stars
- Remainder of Giants/Supergiants
 1. Neutron Stars/Pulsars
 2. Black Holes
 3. Quark or Strange Stars???
 4. Gamma Ray Bursters
 5. Gravity Waves???

“Big Stars Make Rain” **(aka “Big Trees Make Rain”)**

- **Nucleosynthesis of many of the CHEMICAL ELEMENTS (Fusion)**
- **Pushing waves of energy across gulfs of empty space (supernova explosions)**
- **Enriching the Nebulas with the heavier elements (recycling process)**

a GALAXY is a STAR CITY



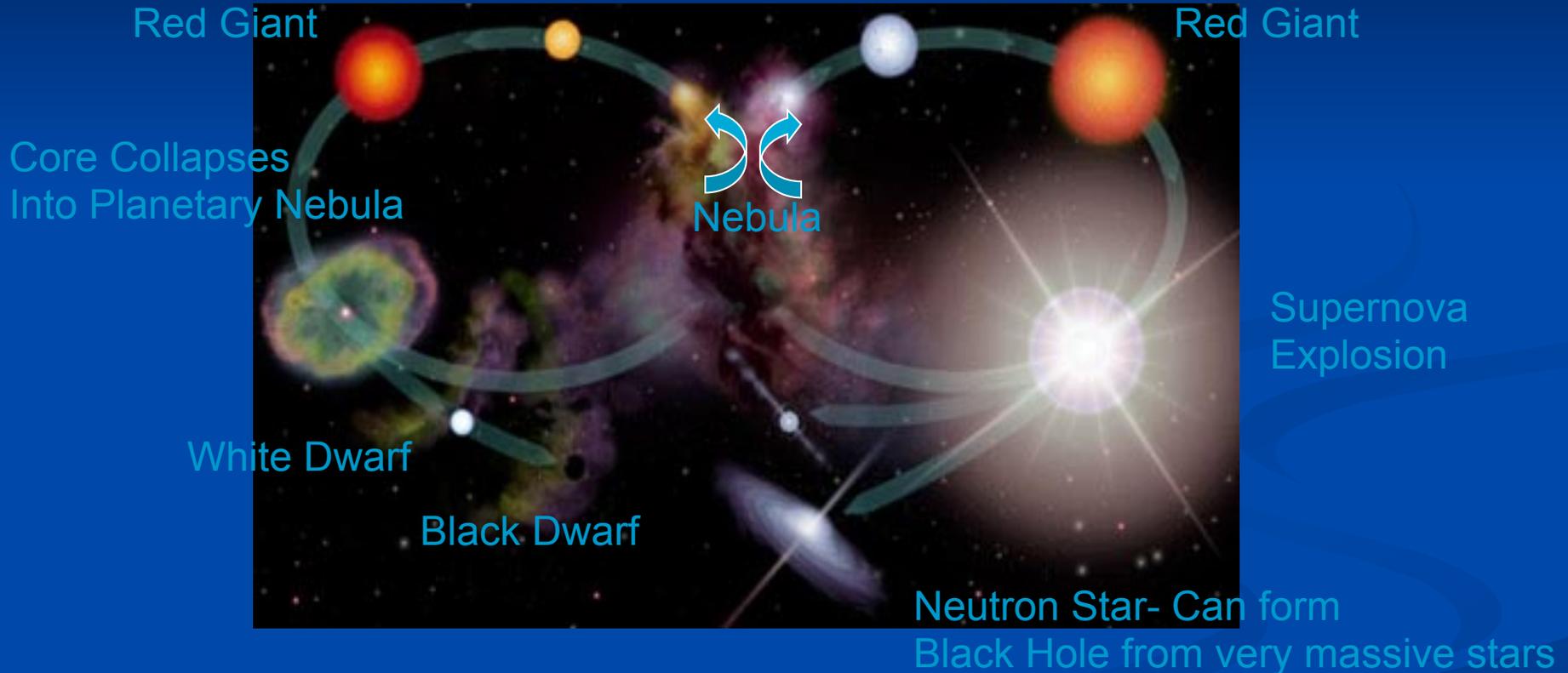
Dust and Gas are in NEBULAS within Galaxy



Life Cycle of a Star

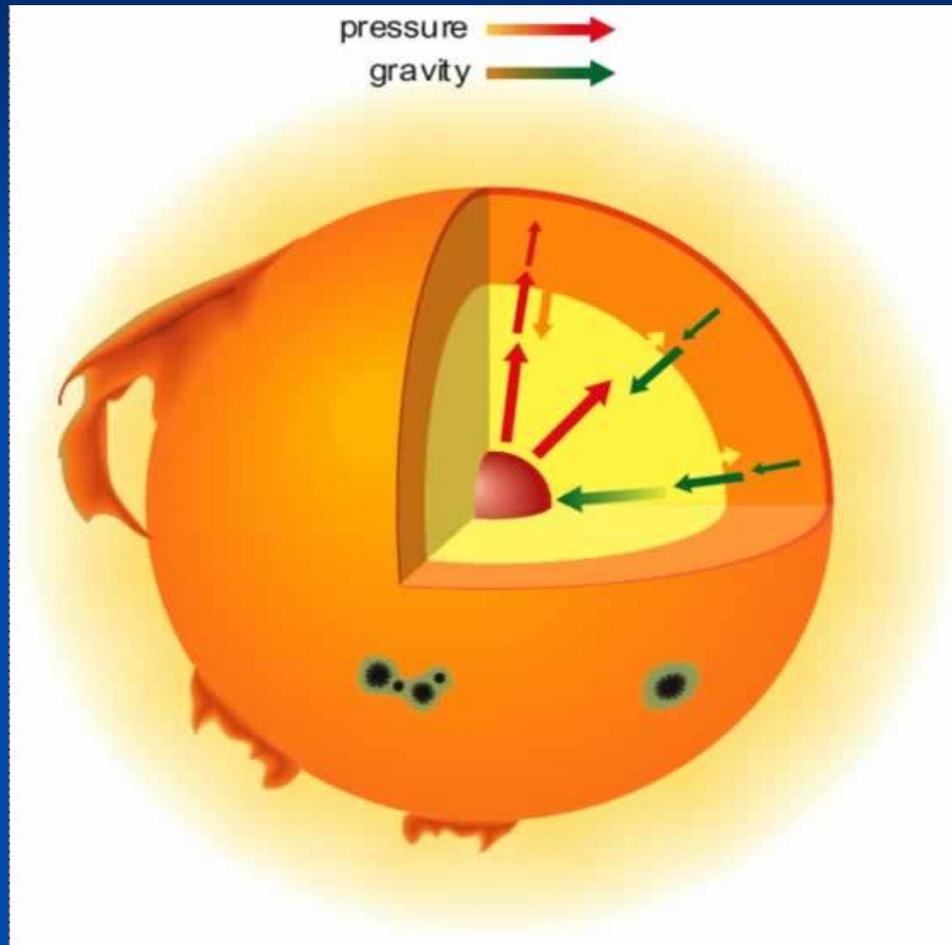
Low Mass Star

High Mass Star



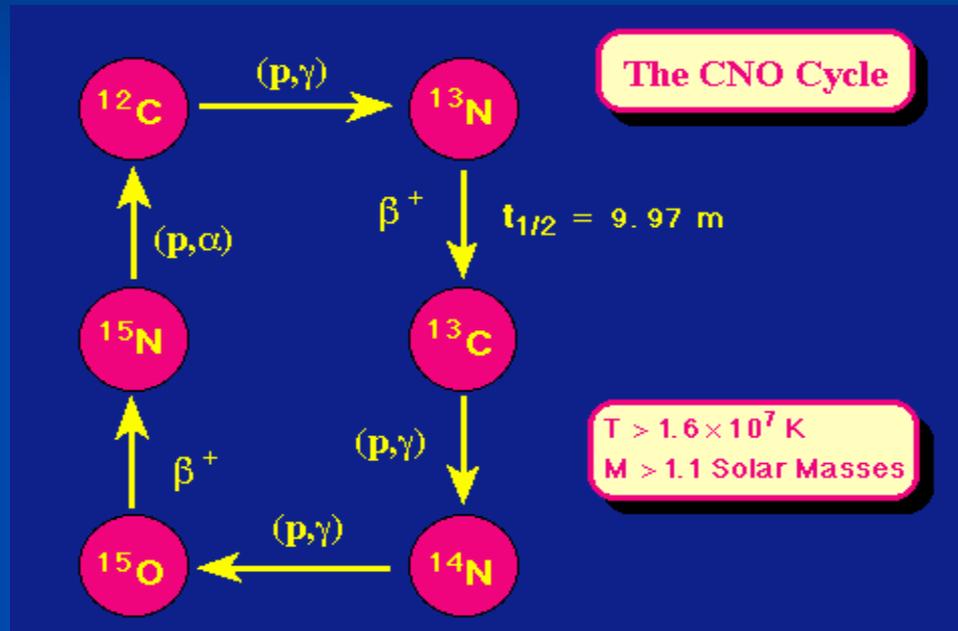
The illustration above compares the different evolutionary paths between low-mass stars (like our Sun) and high-mass stars take after the red giant phase.

Radiation Pressure balances Gravity of Star's mass

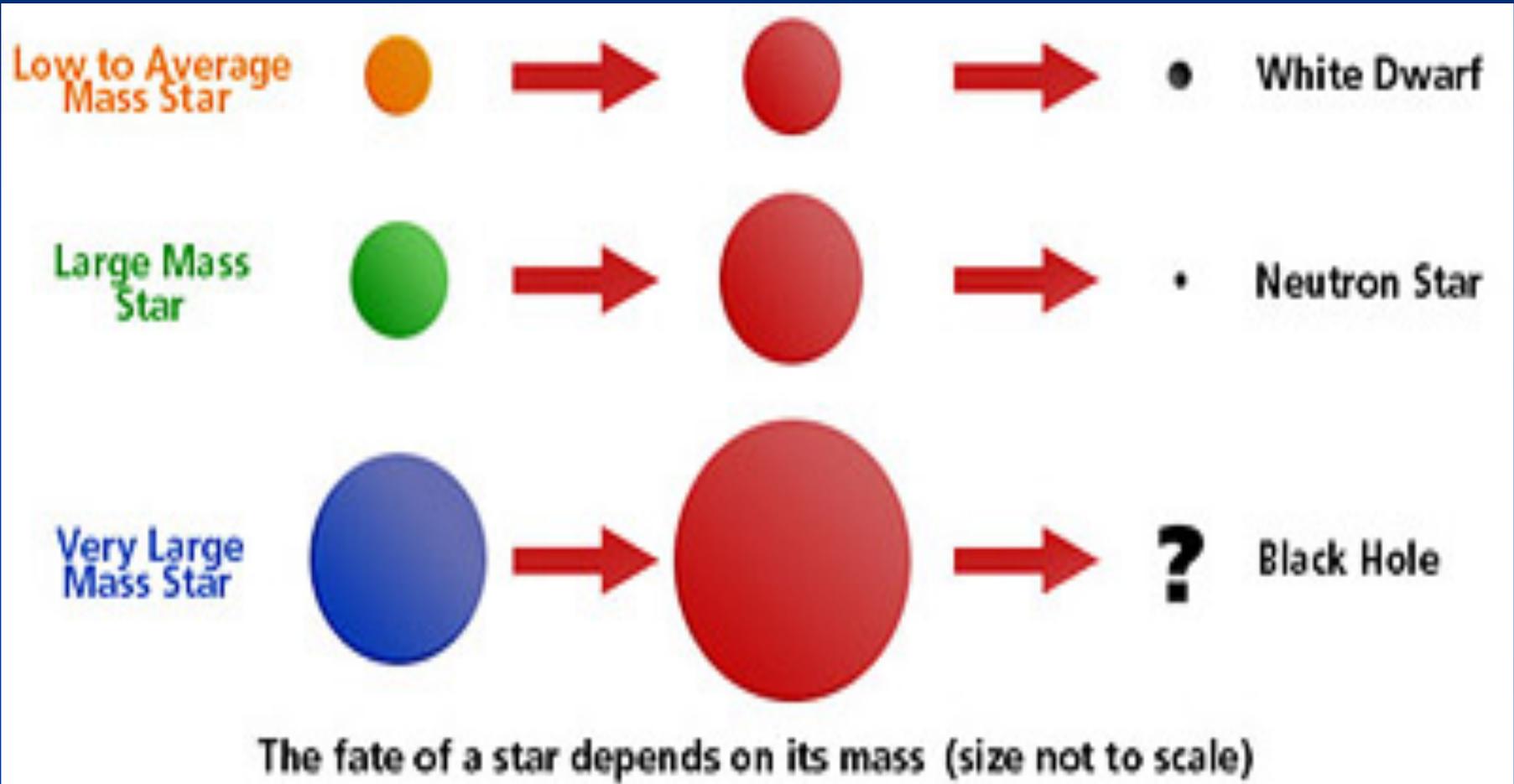


Nucleosynthesis

CNO cycle in older stars



Initial MASS determines outcome



Most Stars are Class M Red Dwarfs

- Our view of stars is very BIASED
- We see the brightest stars (largest, hottest)
- Many of the dimmest stars remain hidden
- Note the population distribution locally (Star Cards data)

- We can search for cool dim stars by using Infra Red sensitive cameras
- Keep in mind that due to distance, ALL stars appear as points of light even though many stars are LARGER than our Sun!



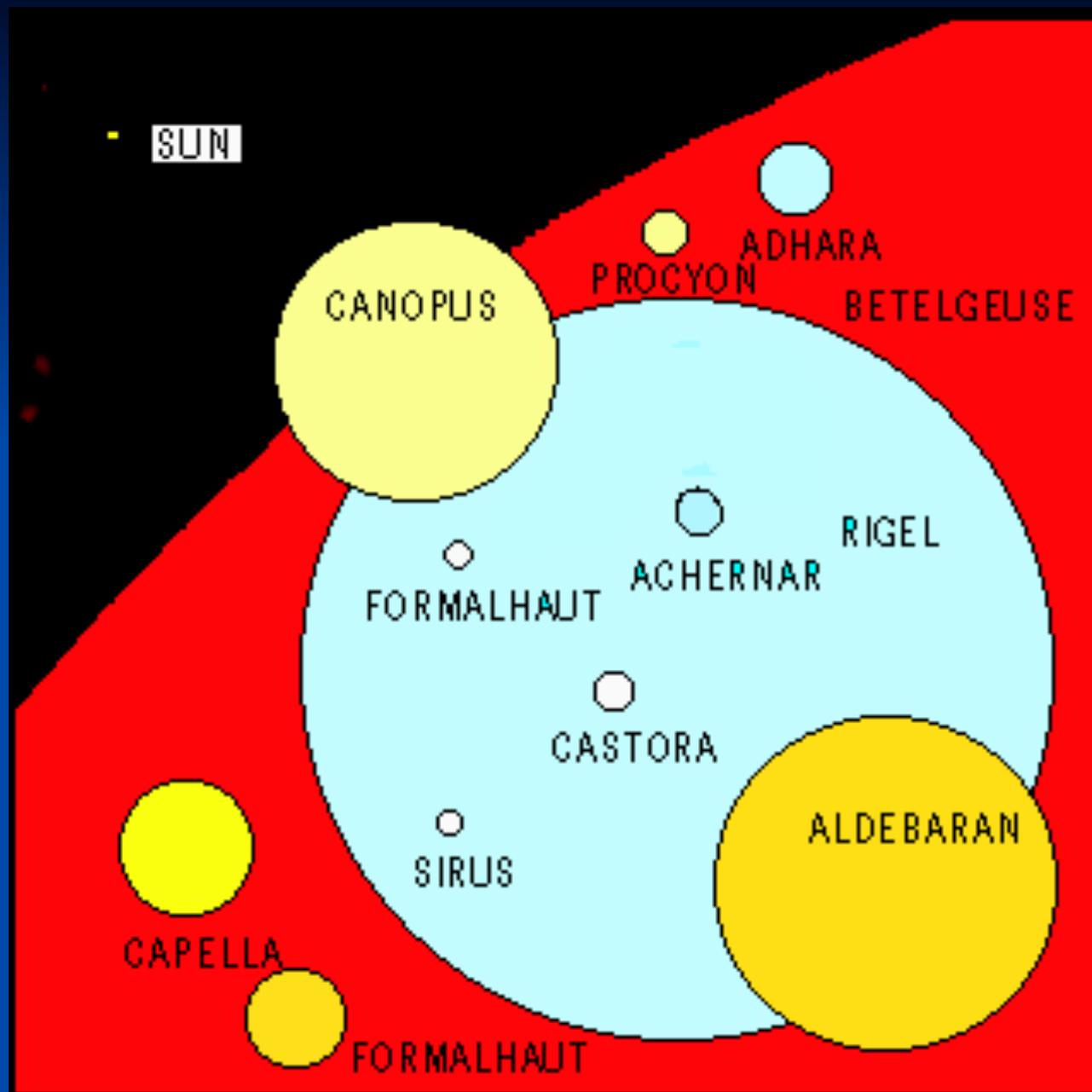
Our Sun



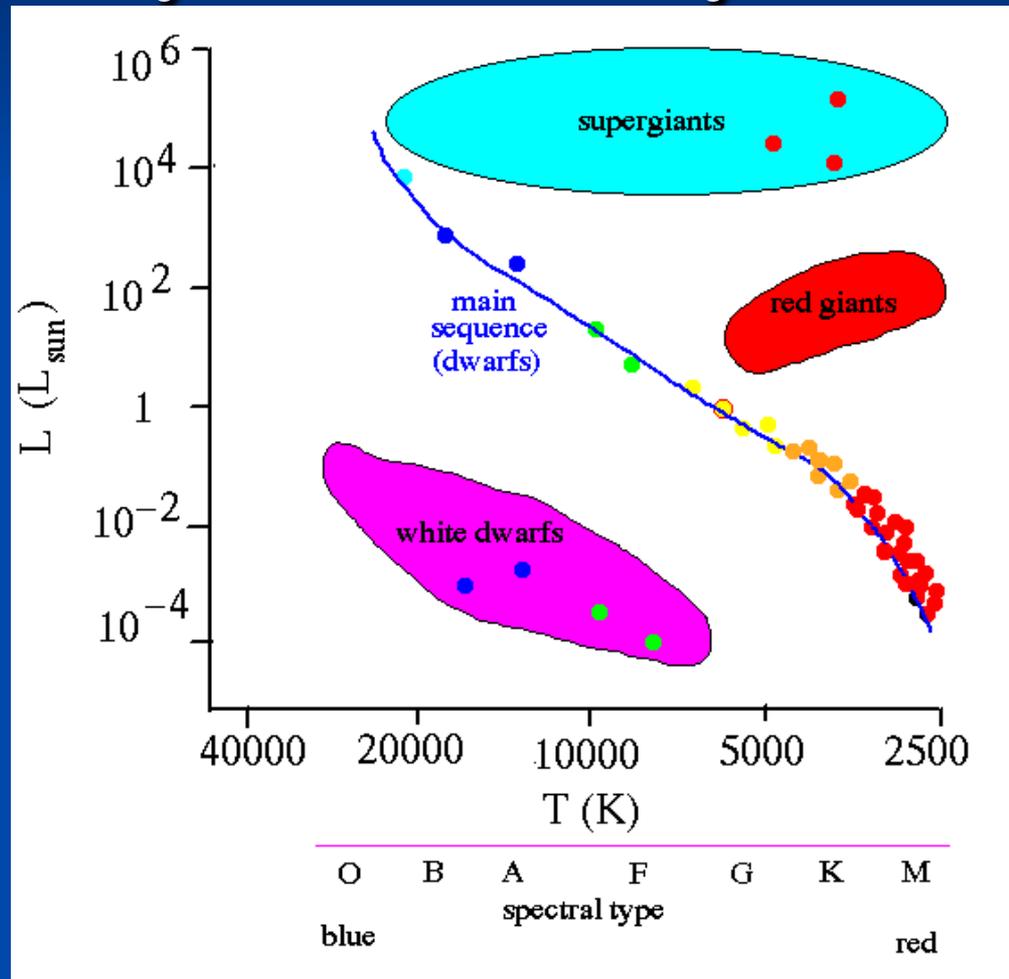
White Dwarf

Red Giant



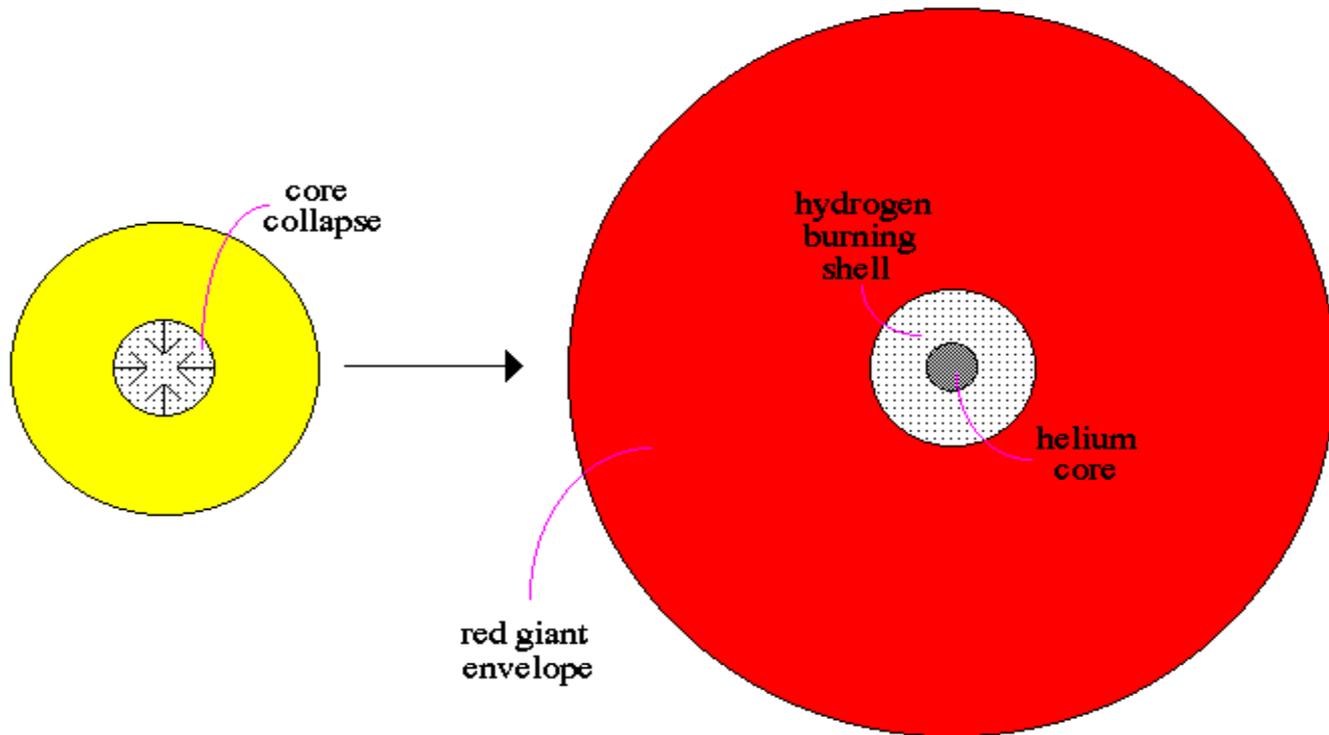


We classify and track Stars on a Hertzsprung-Russell diagram, typically Luminosity vs. Temp.



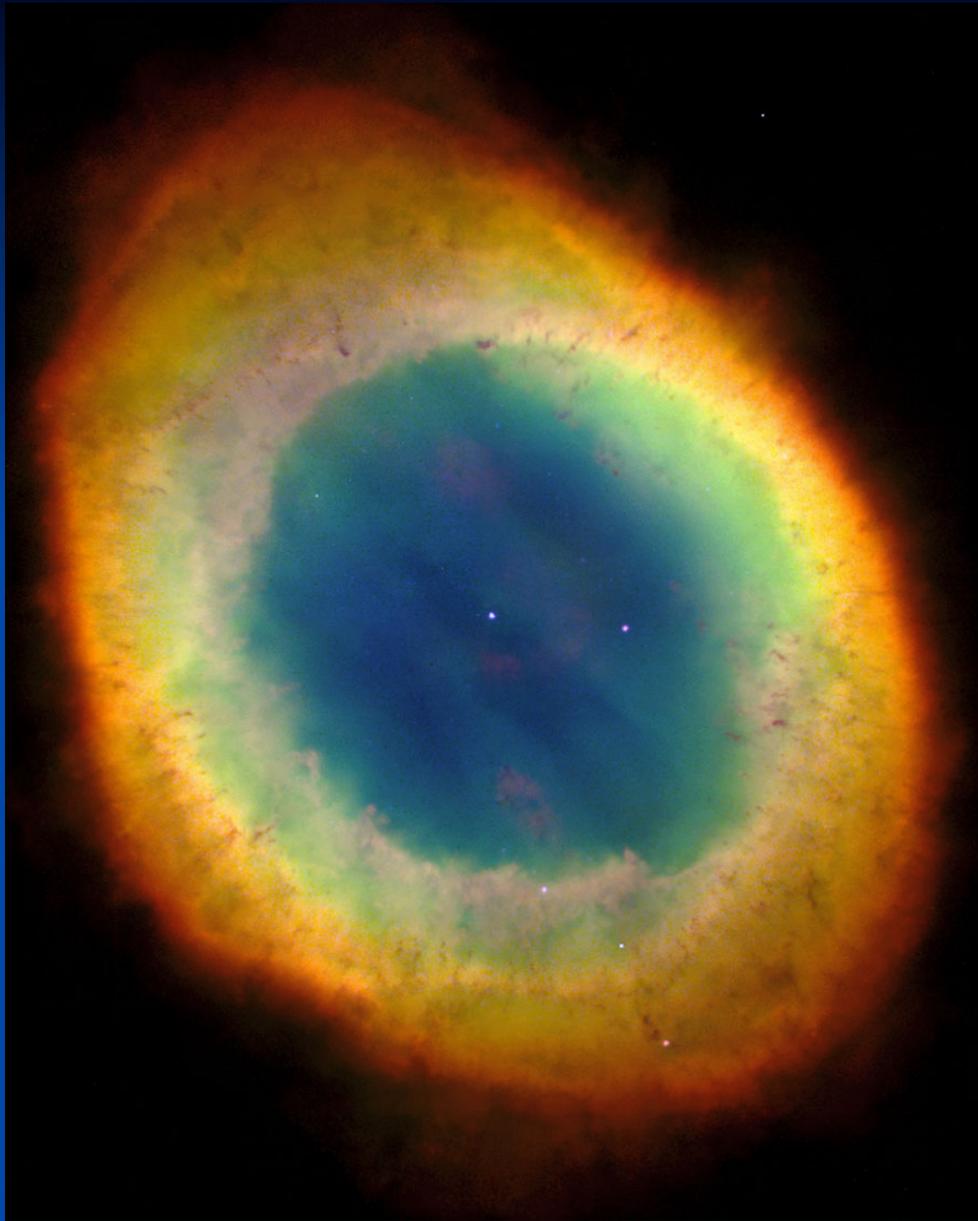
Solar Mass star evolves to Red Giant, gently sheds outer layers

Hydrogen Shell Burning

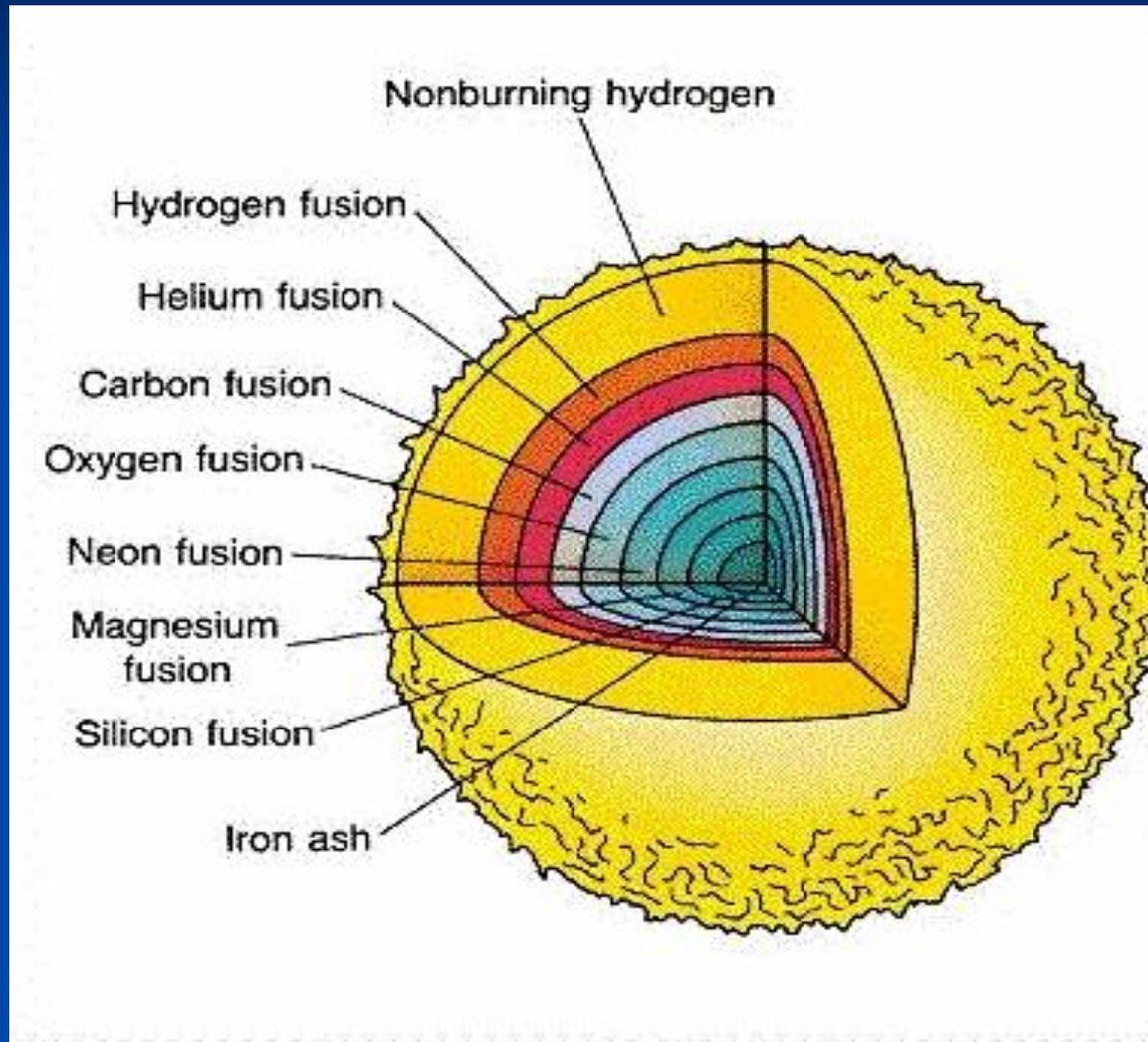


Several **BILLION** years from now

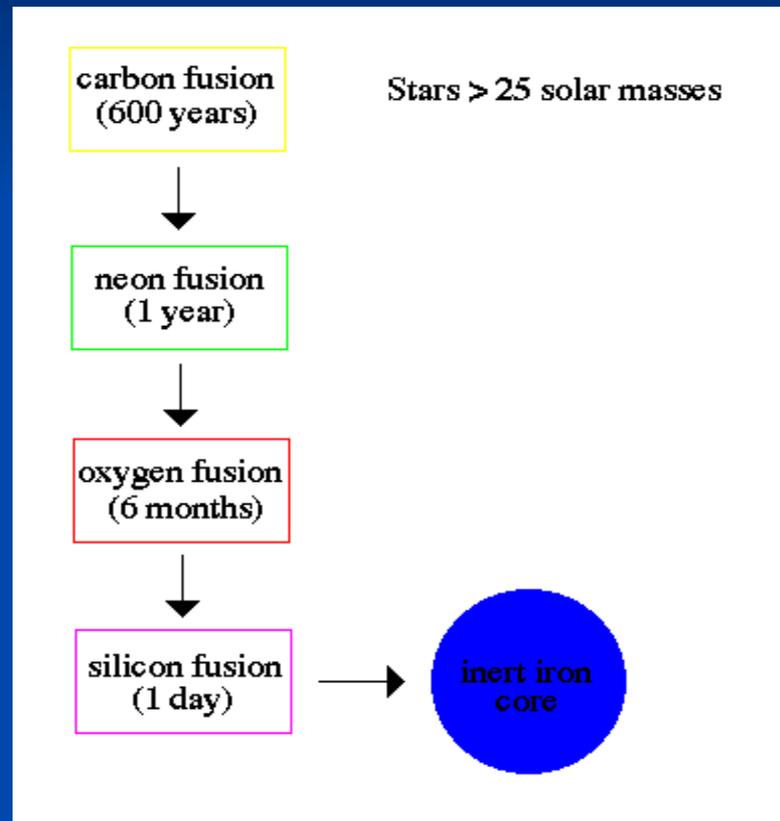
- Our **SUN** will become a gentle **RED GIANT**
- Large enough to be wider than the orbit of Mars
- **Thus, the four inner planets of our Solar System will be swallowed up by the evolving Sun.**
- The outer layers will dissipate outward
- The core will remain as a very hot **WHITE DWARF** carbon star for billions of years more. Electron exclusion resists collapse.



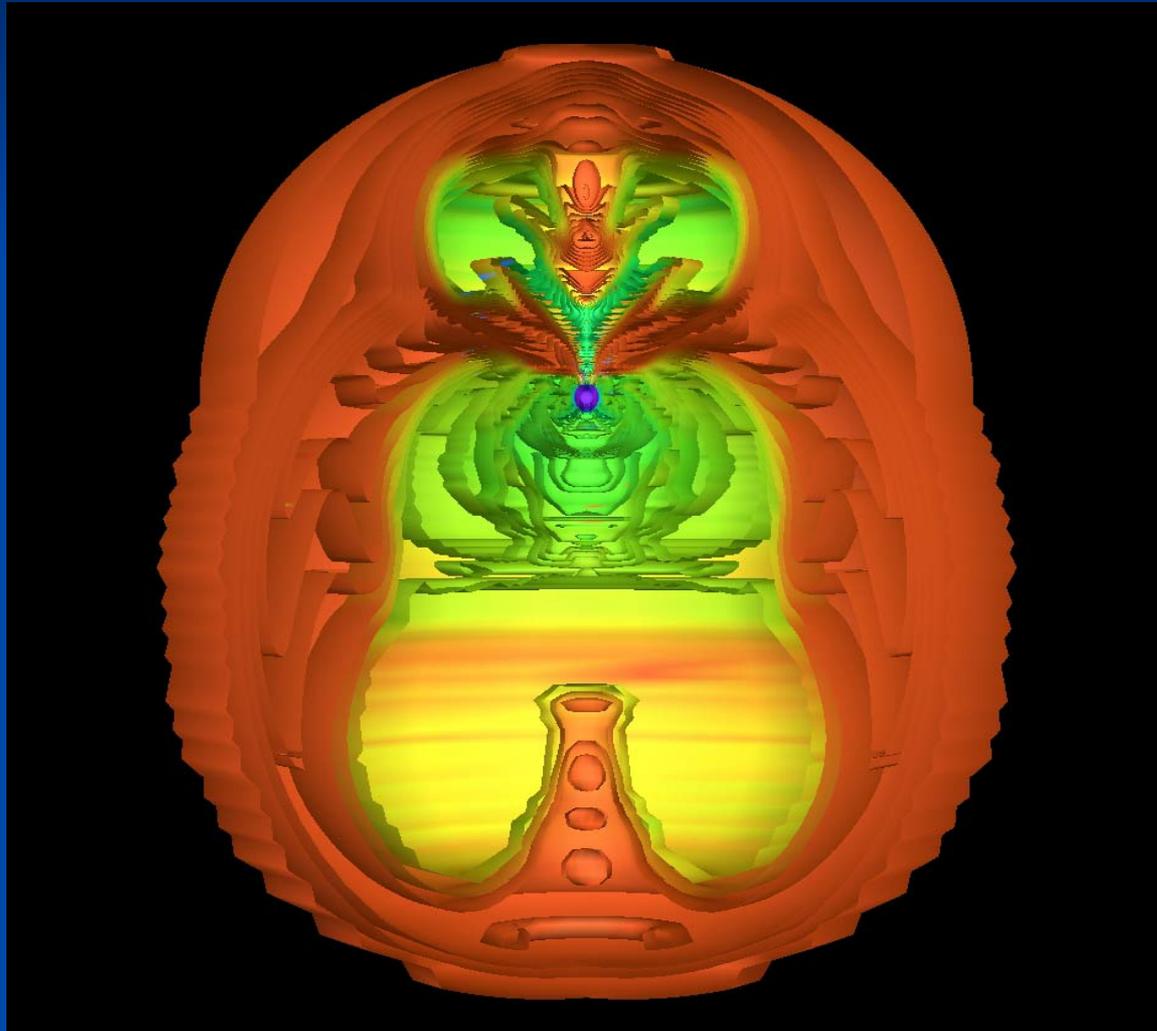
**Giant Stars live fast, die hard.
Iron is end of line for supergiant.**



GRAVITY WINS! COLLAPSE. REBOUND: Supernova!

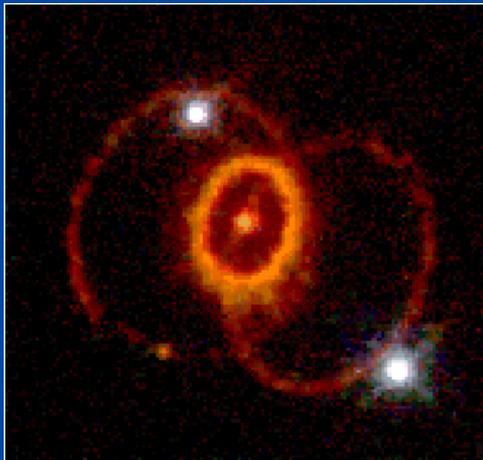


Computer modeling of shock waves inside supernova

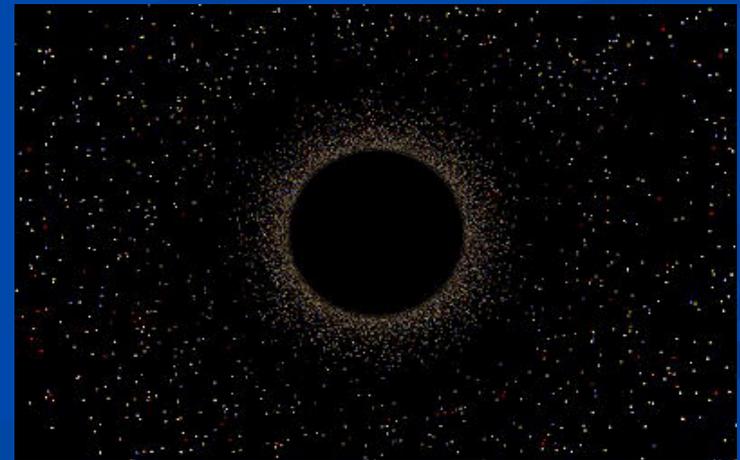
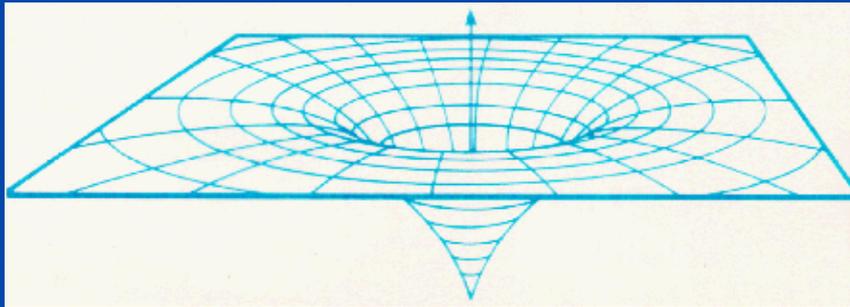
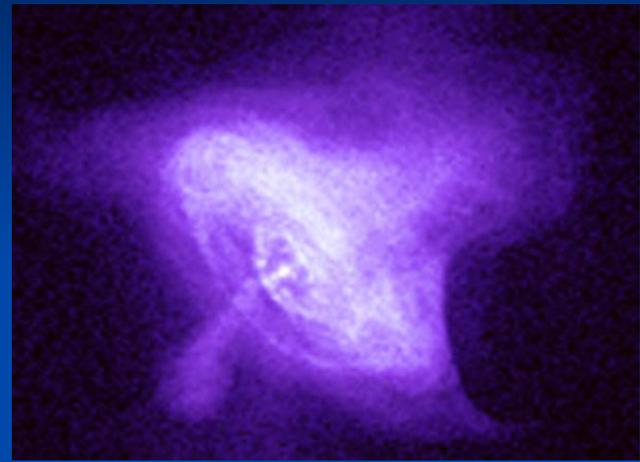
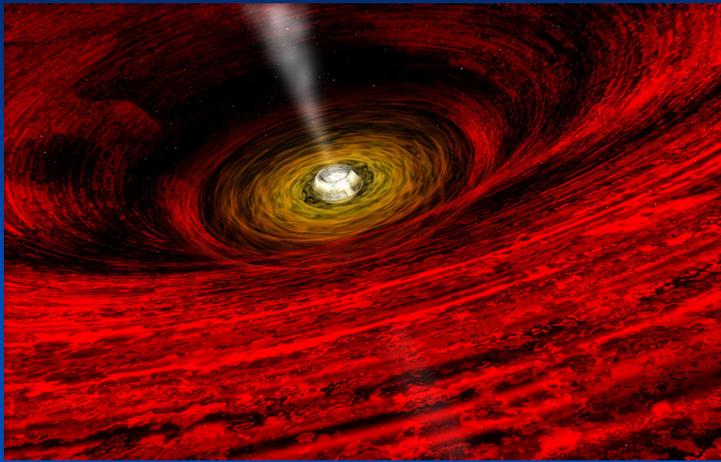




Supernova remnants and “Light Echoes”



Compact Stellar Remnants – Neutron Stars and Black Holes



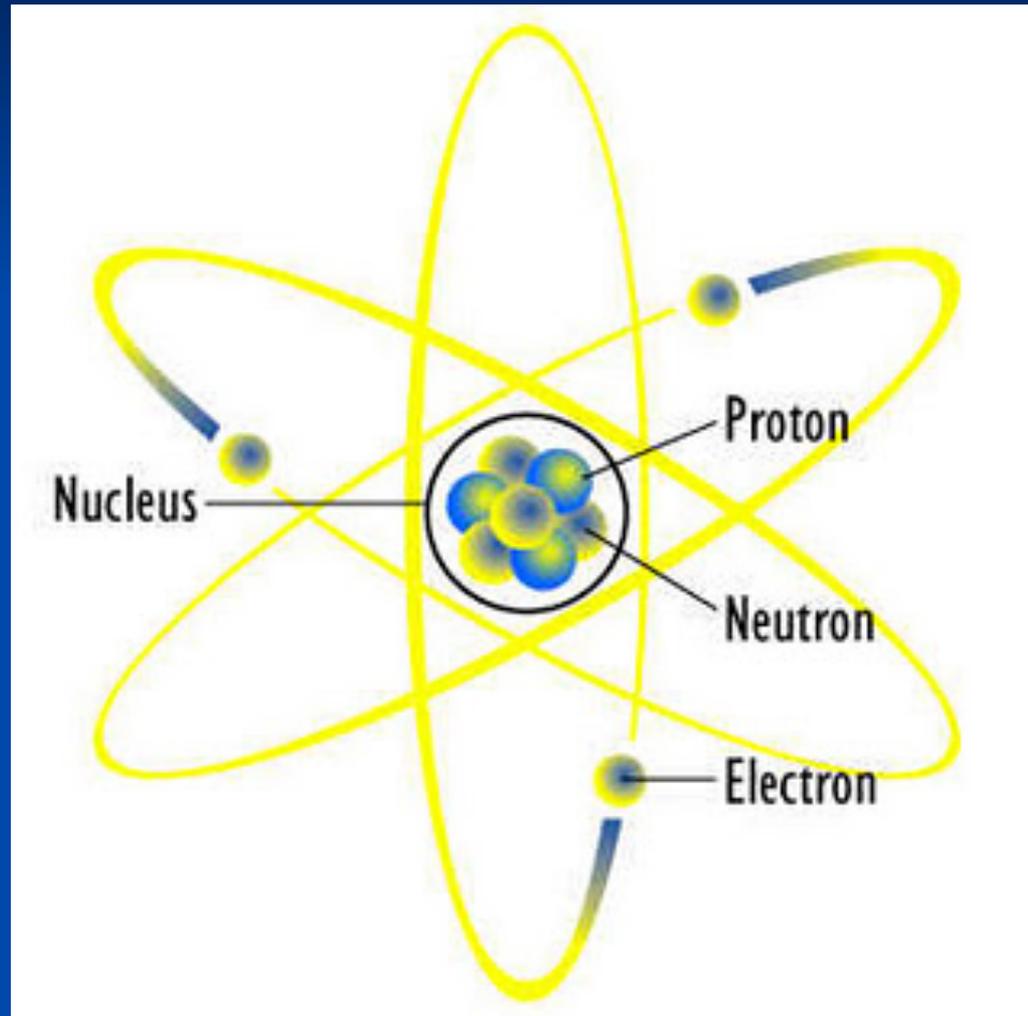
The SUPERNOVA Blast

- Unbalanced star pressure ->
 - Collapse of outer layers ->
 - Rebound onto/from core ->
 - Blowout of outer layers into space ->
 - Crushed core.
-
- What's left?

The SUPERNOVA Blast

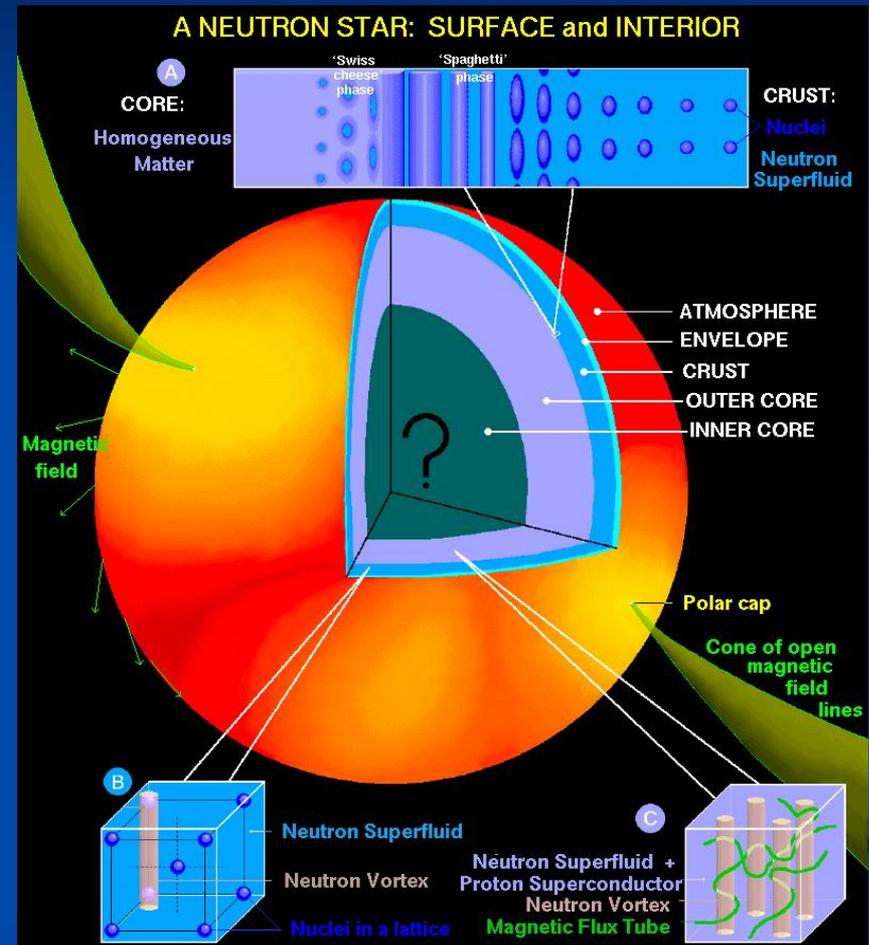
- Unbalanced star
 - Gravity WINS! Collapse
 - Rebound
 - Blowout
 - Crushed core
-
- What's left? Depends on mass of original star and mass of core...
NEUTRON STAR or...BLACK HOLE

Diagram of ATOM – very tiny!

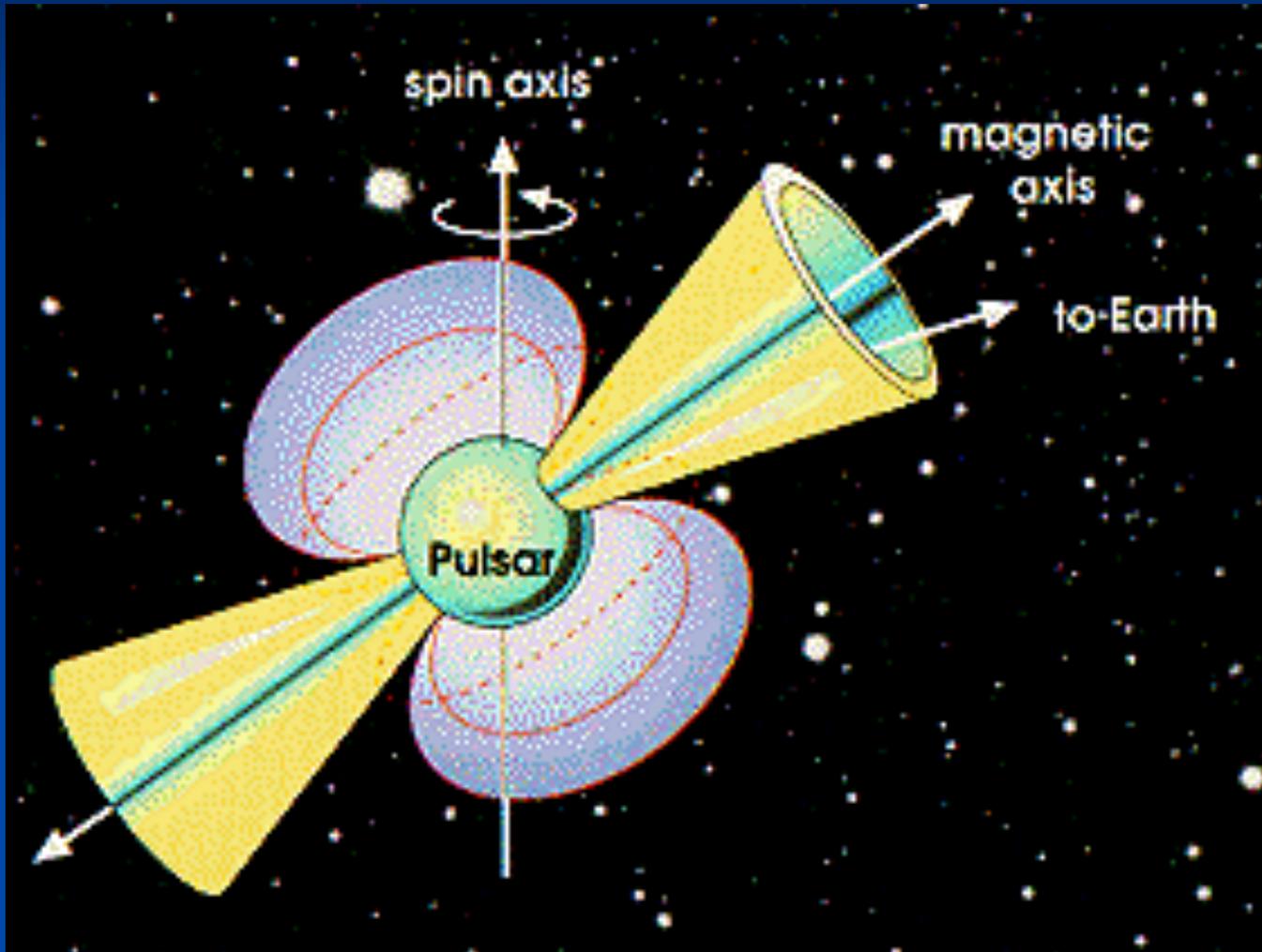


~2 Solar Mass core left usually results in Neutron Star

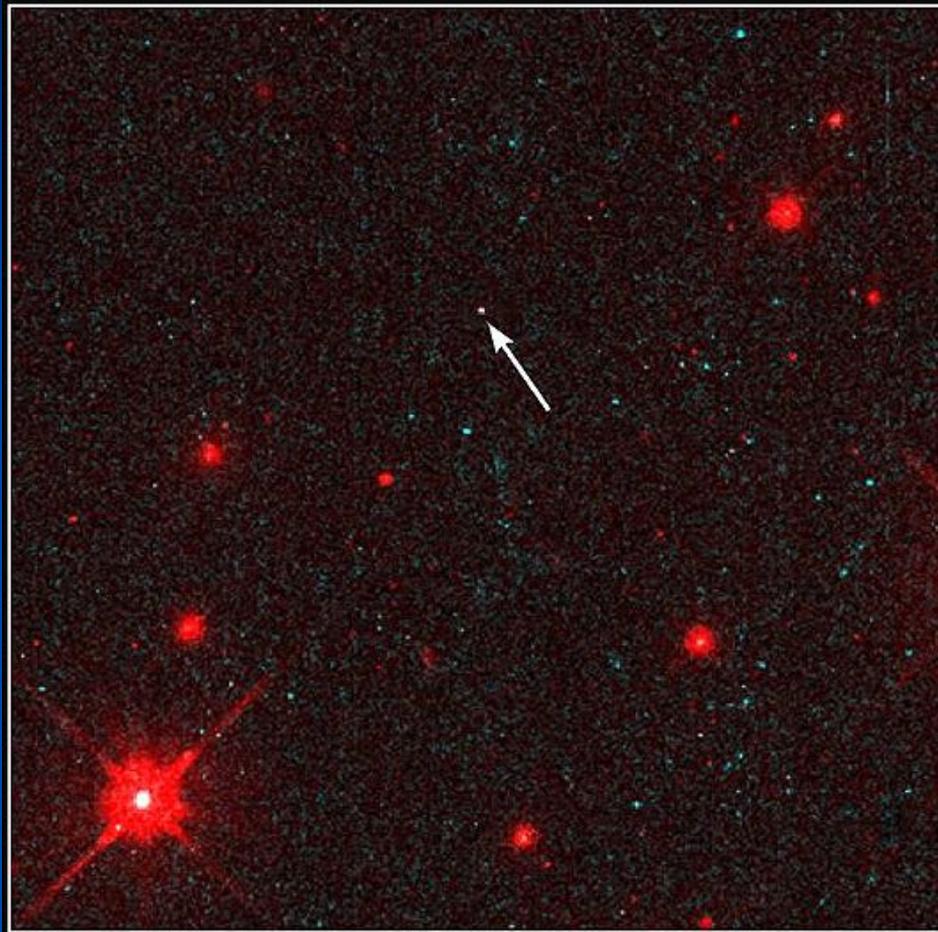
- Protons and Electrons are squashed together, they form Neutrons
- Star rotates rapidly due to shrinkage
- Rigid crust forms
- Pulsar effect may result



Pulsar Beam Effect



HST image of Neutron Star



Isolated Neutron Star RX J185635-3754 HST • WFPC2

PRC97-32 • ST ScI OPO • September 25, 1997

F. Walter (State University of New York at Stony Brook) and NASA

Several Solar Mass Core likely to form Black Hole

- What is “DENSITY”?

DENSITY plus GRAVITY forms Black Hole

- What is “DENSITY”?
- MASS PER UNIT VOLUME
- Objects are denser if they have greater
greater

DENSITY plus GRAVITY forms Black Hole

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greater MASS or
lesser VOLUME

We’ ll experiment with our flexible
“SPACETIME” MODEL plus Aluminum Foil.

Explore why Spacetime is flexible:

- What does MASS do to Spacetime?
- What happens to a second MASS?
- **How does this mimic GRAVITY?**
- What would make a DEEP, STEEP DISTORTION ? (start by placing flat piece of foil onto Spacetime, any noticeable effect?)
- NOW INCREASE DENSITY OF FOIL. PREDICT, RETEST on Spacetime.

Continue to INCREASE DENSITY

- Predict and test effect on the Spacetime

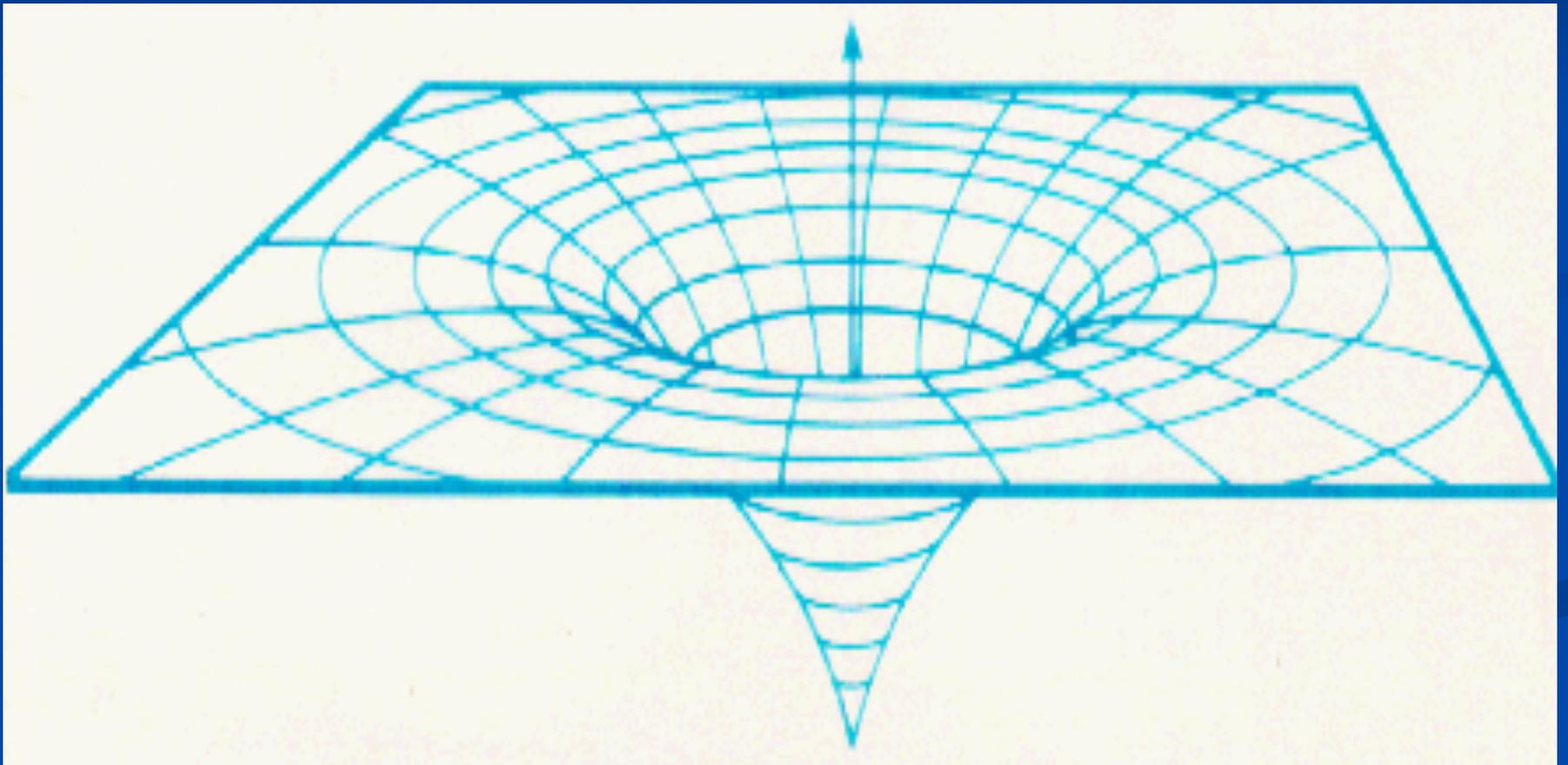
Can you convert your foil into a BLACK HOLE?

- What would you need to do?
- Do your best...see what happens

Runaway Gravitational Collapse

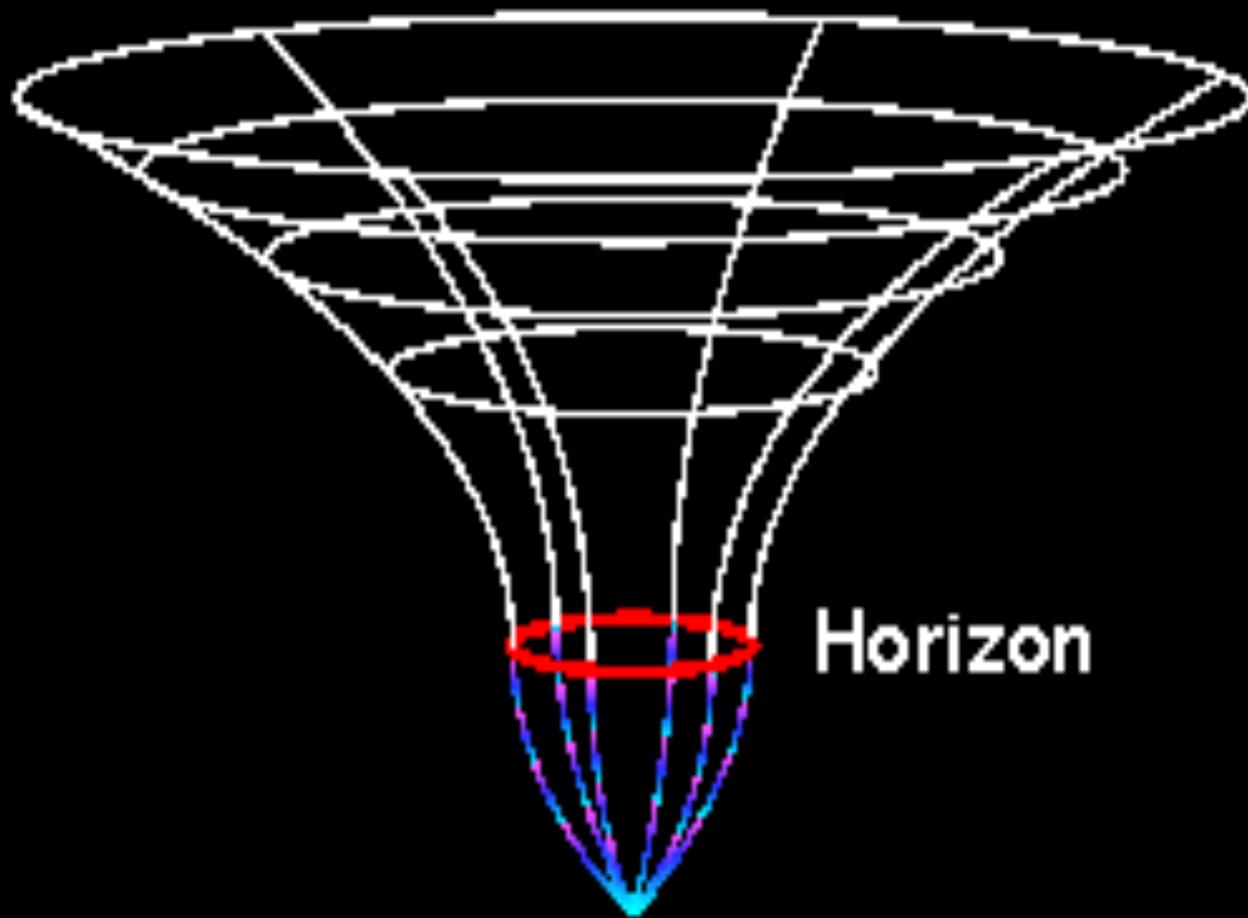
- Volume shrinks
 - Density increases
 - Gravity increases
 - Go to step 1 above
-
- Until we reach a SINGULARITY...a
Dot...Zero Volume...
 - INFINITE DENSITY!

You've created a
GRAVITY WELL,
a **BLACK HOLE!**



Conversion to SINGULARITY

- **SCHWARTZCHILD RADIUS:**
- Pick a mass, figure out how small you need to squash it to hold all light in:
- roughly, diameter (km) $\sim 3 M/M_{\text{Sun}}$
our Sun shrunk to 3 km would be a black hole. Earth to size of baseball.
- *(Formally, $R_s = 2GM/c^2$ where $G = 6.668 \times 10^{-11}$ and $c = 3 \times 10^8$ meters per second and mass is in kilograms.)*



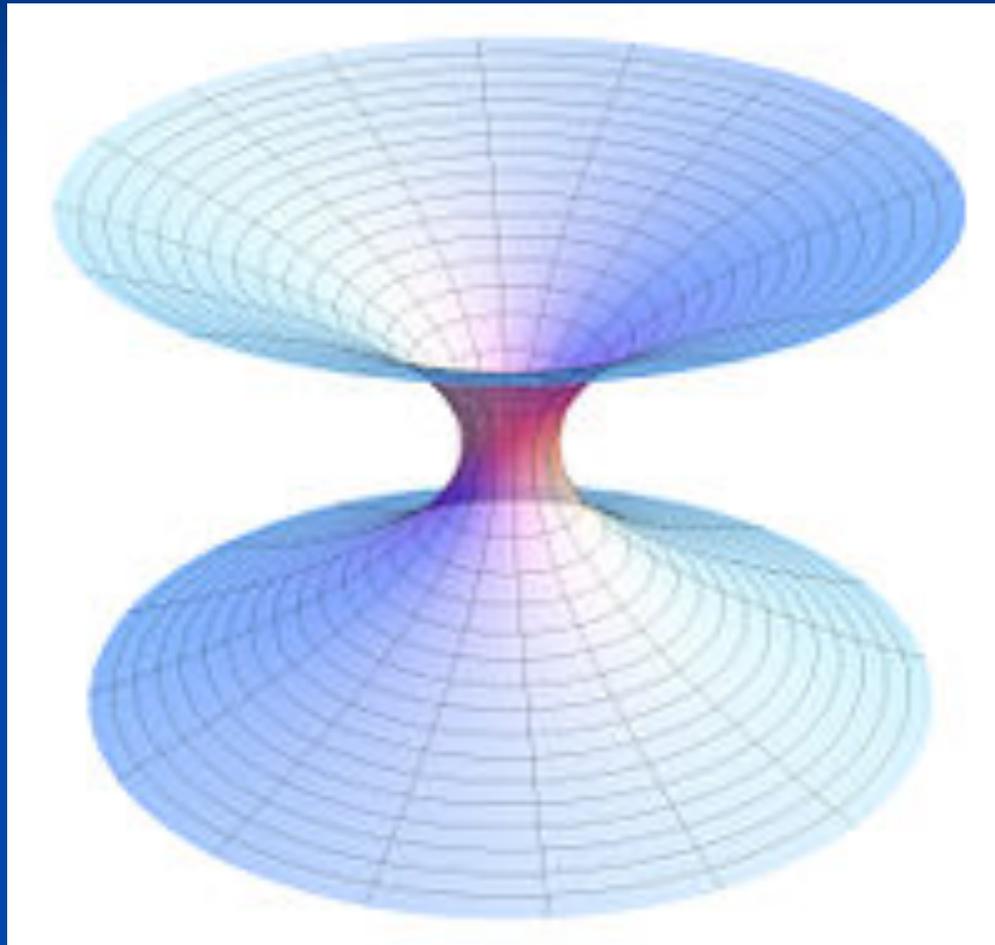
Horizon

Singularity

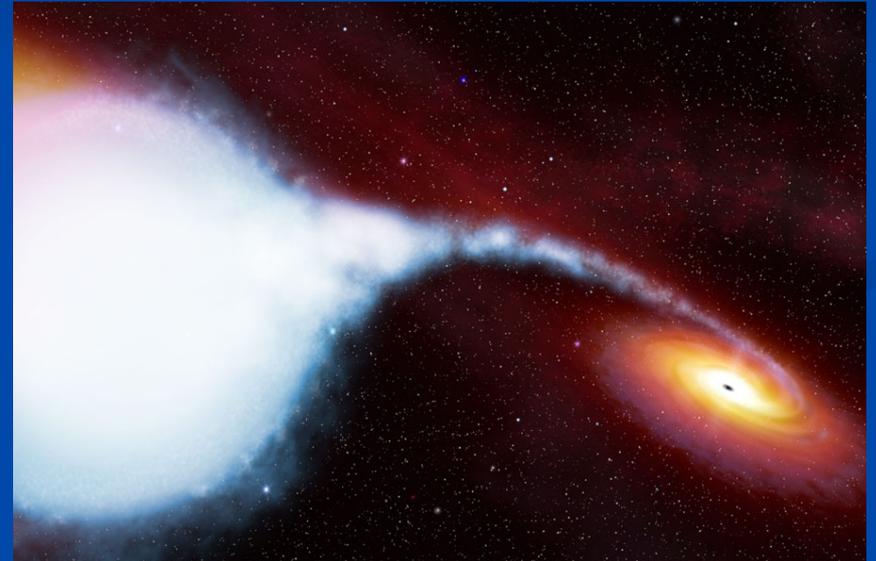
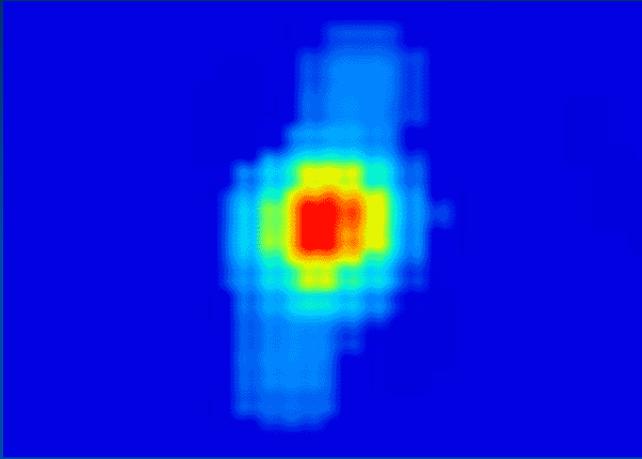
Where do objects go that fall into the Singularity?

- Good question, we don't know...
- Involves “infinities”, can't calculate.
- Gone from our Universe.
- Possible WORMHOLE connection to other Universe?????

**Science Fiction idea:
through the “wormhole” to a
different Universe! ????**



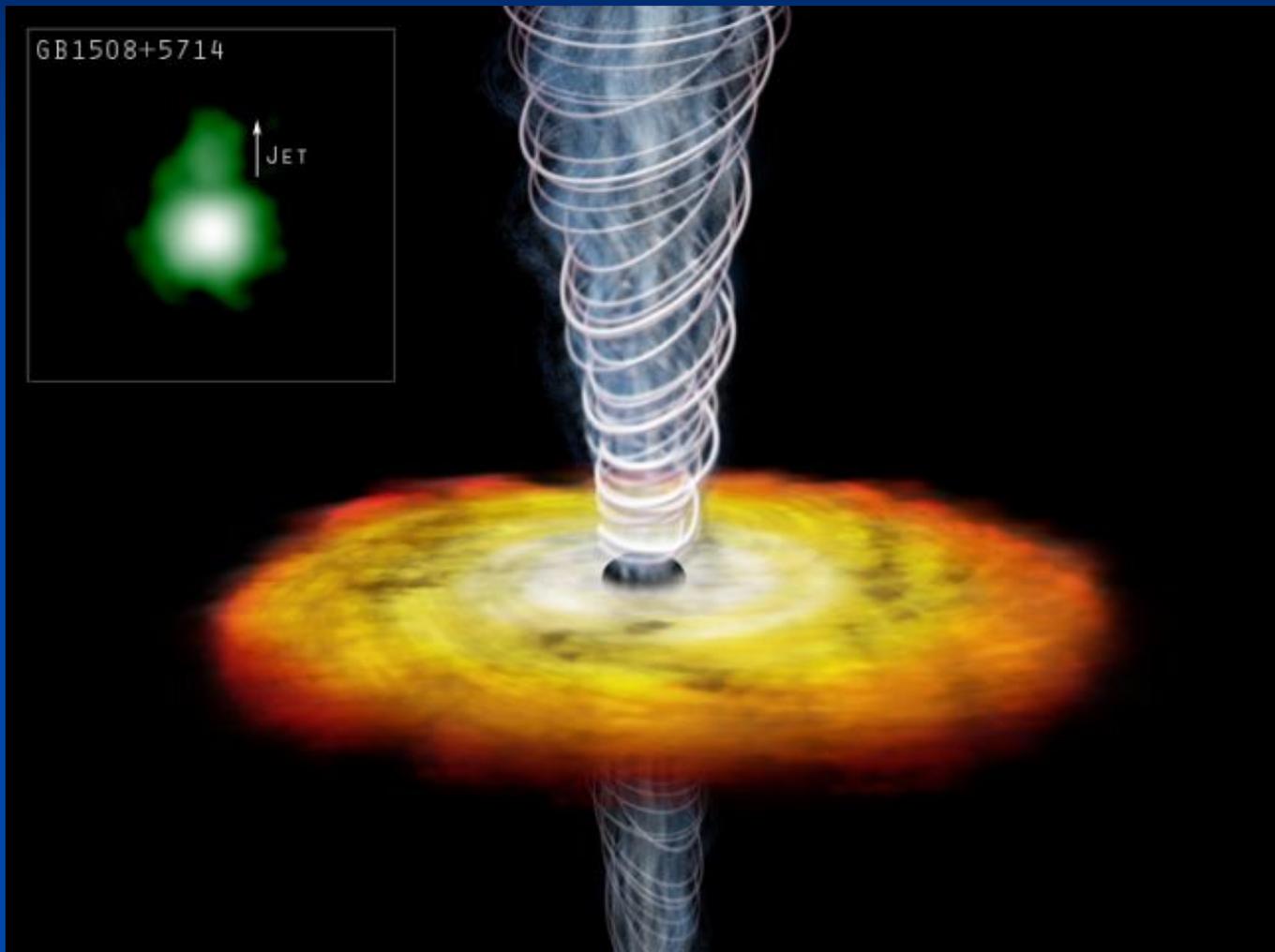
Images and drawings



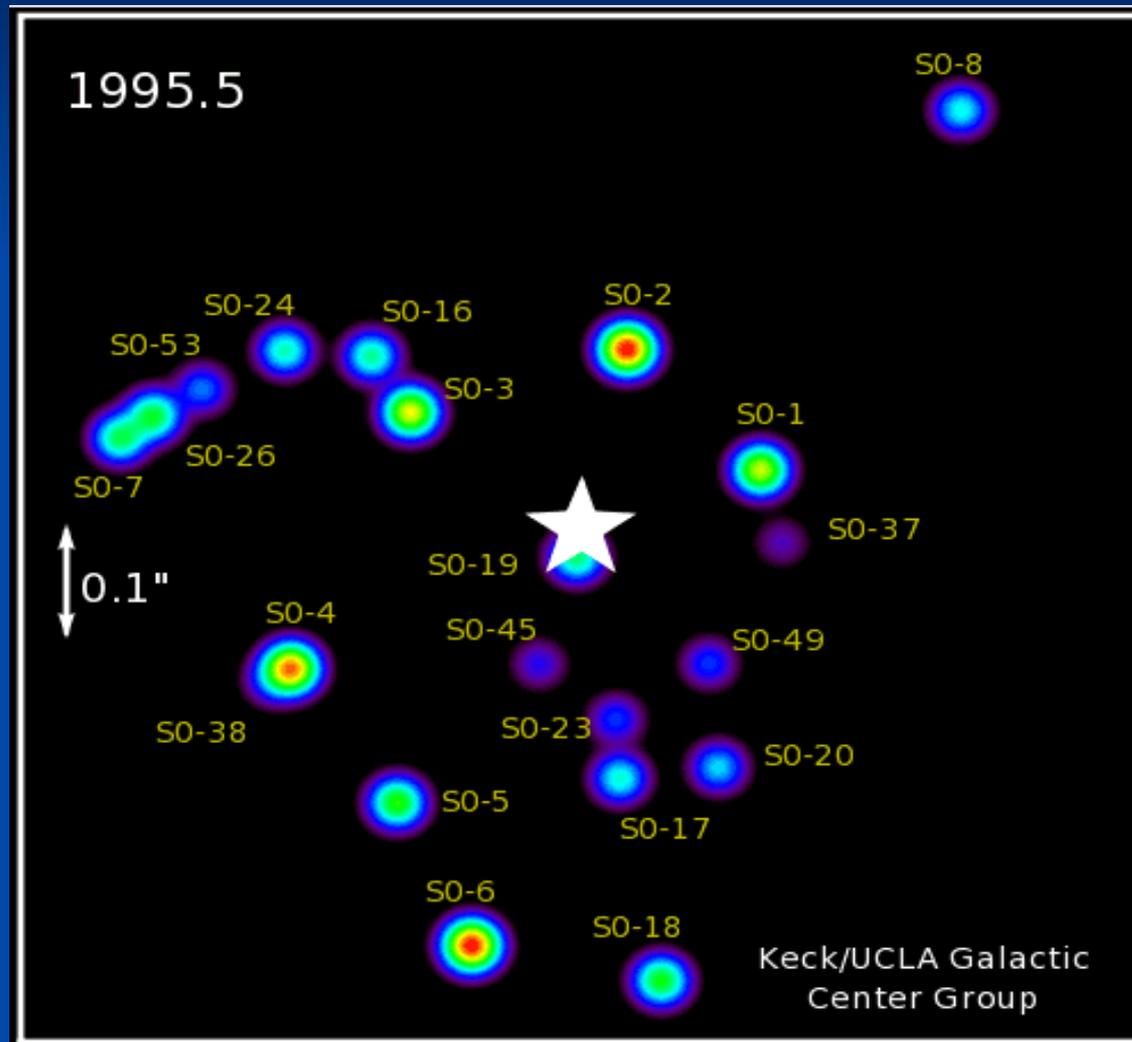
**How can we detect Black Holes if
we can't see them?**

The background of the slide is a solid blue color. In the bottom right corner, there are several overlapping, wavy, light blue lines that create a sense of motion or depth, resembling ripples or a stylized horizon.

Light from hot accretion disk and from jets



Noting objects swirling around invisible body



Gravitational Lensing



Good news/Bad news

- Closest known Black Hole is a stellar one, about 1600 LY away.
- Too distant to affect us.
- Too distant to send a rocket to
(would be over a 50 Million Year long trip!)

Will our Sun become a Black Hole?

- No, not nearly massive enough...
- Probably will swell to Red Giant and burn up Earth, but not for several million years yet.

(then will gently puff off outer layers, leaving a white dwarf)

- If our Sun somehow instantly became a black hole, we'd freeze but not be pulled in...why not?

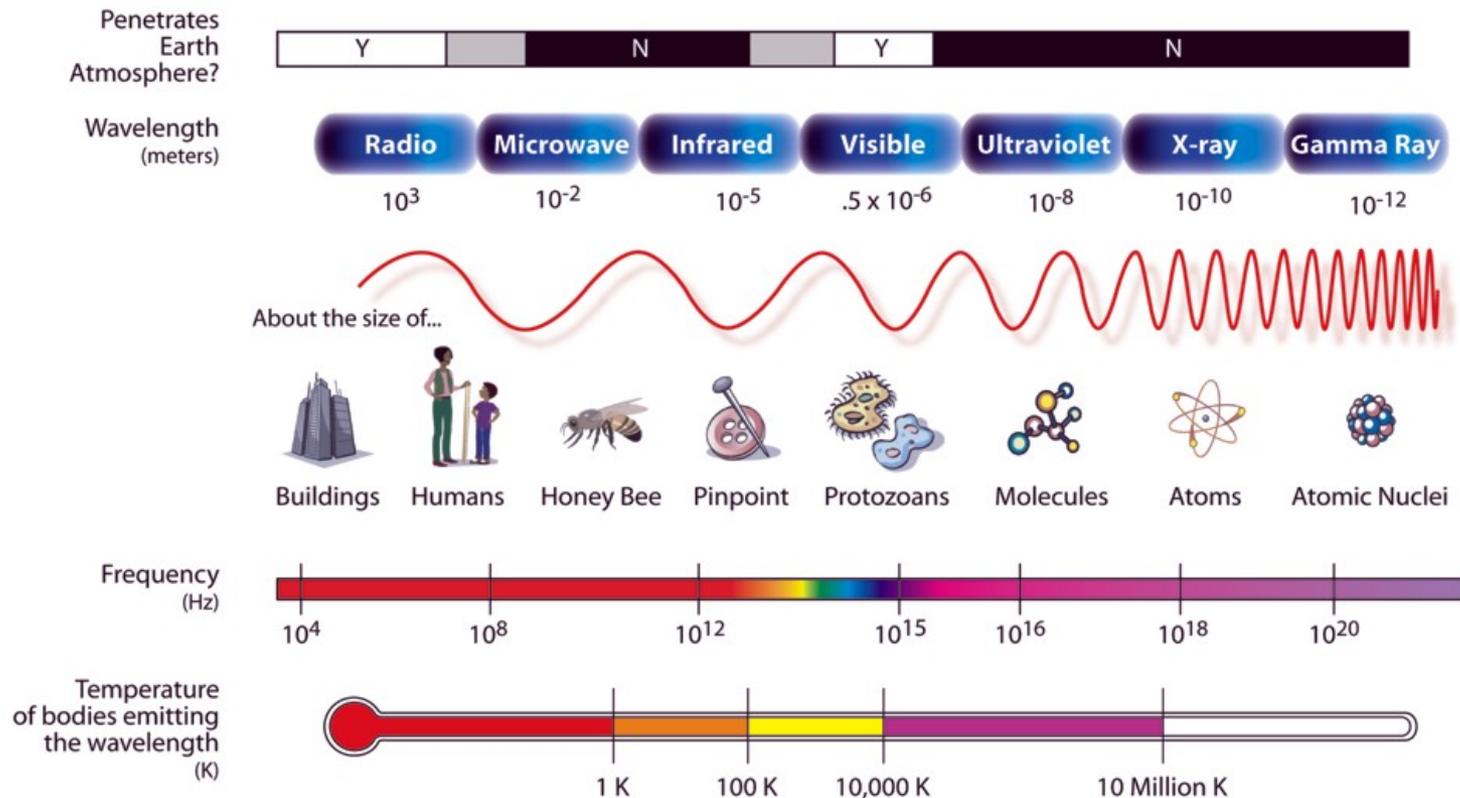
**A couple of other twists:
if stellar core collapses short of
singularity, maybe could form**

1. **QUARK STAR:** atoms crushed into their sub-components (quarks), or
2. **STRANGE STAR:** atoms crushed into “strange” form of quarks (“strange” is a particle physics technical term in this usage!)

We haven't observed any of these types of objects YET, but theory does predict them.

Gamma Ray Bursters: What are Gamma Rays? Very High Energy E/M Radiation!

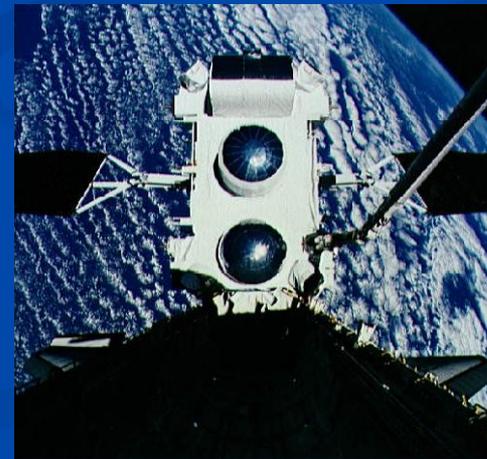
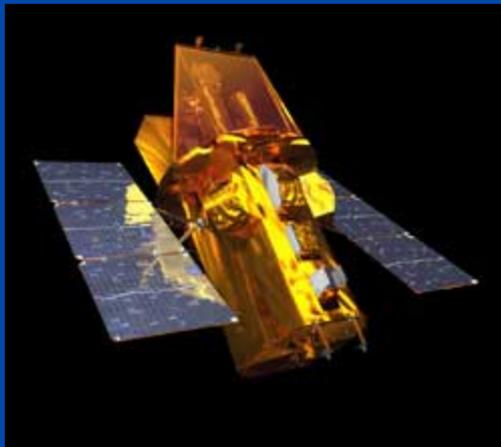
THE ELECTROMAGNETIC SPECTRUM



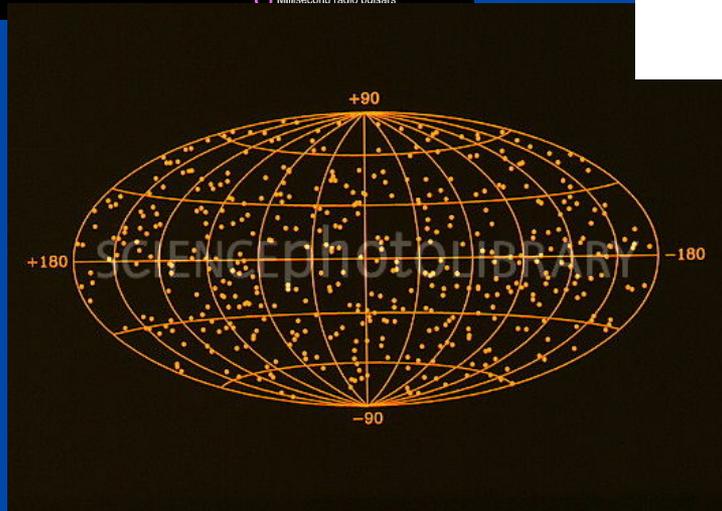
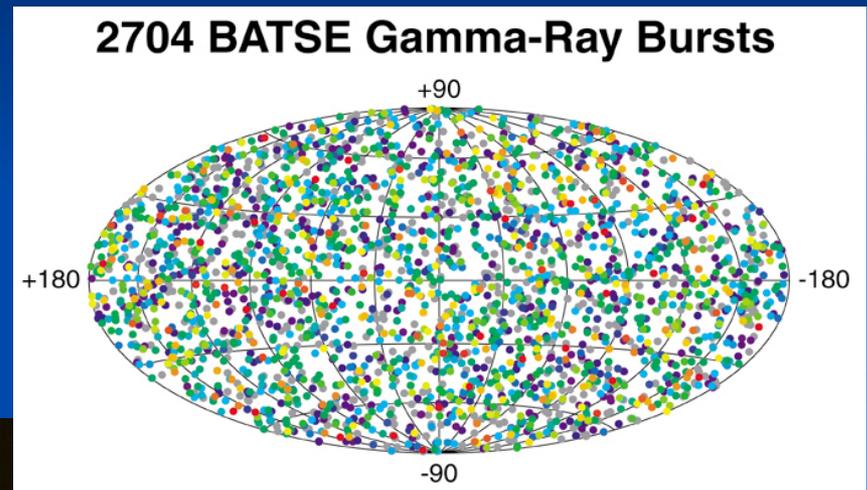
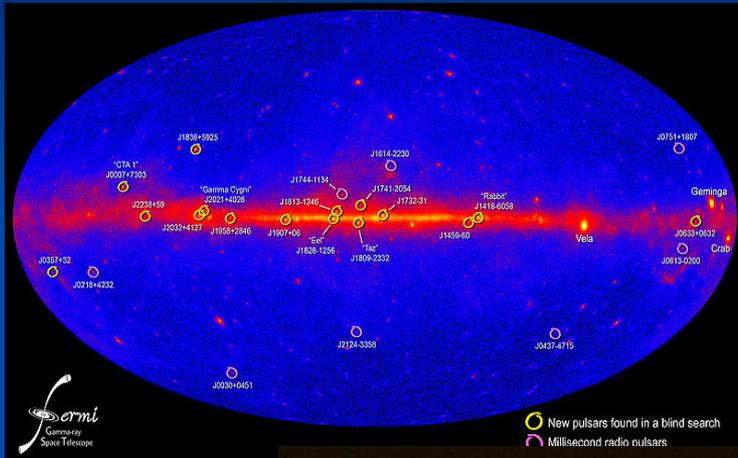
Sporadic (random) sources – very baffling for long time!

- Numerous space based instruments used:
 1. Vela satellites early on-nuclear tests
 2. Italian/Dutch BeppoSax
 3. Compton Gamma Ray Observatory with BATSE sensor
 4. SWIFT scanner
 5. Fermi-GLAST sensor

Fermi, Beppo, Swift, Compton



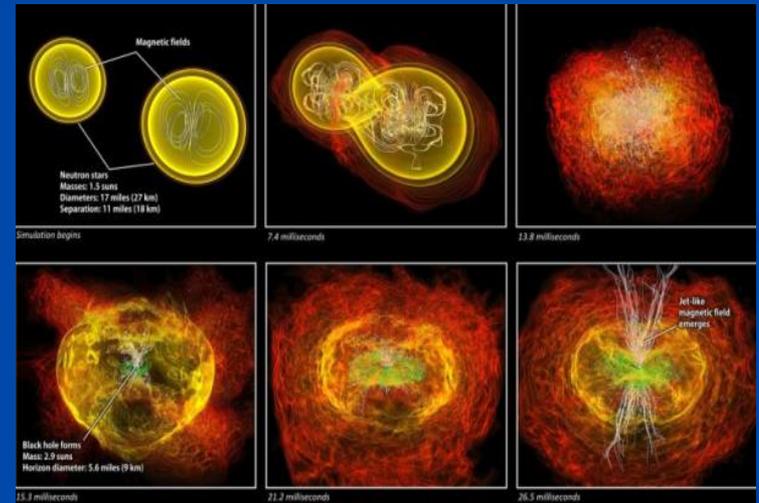
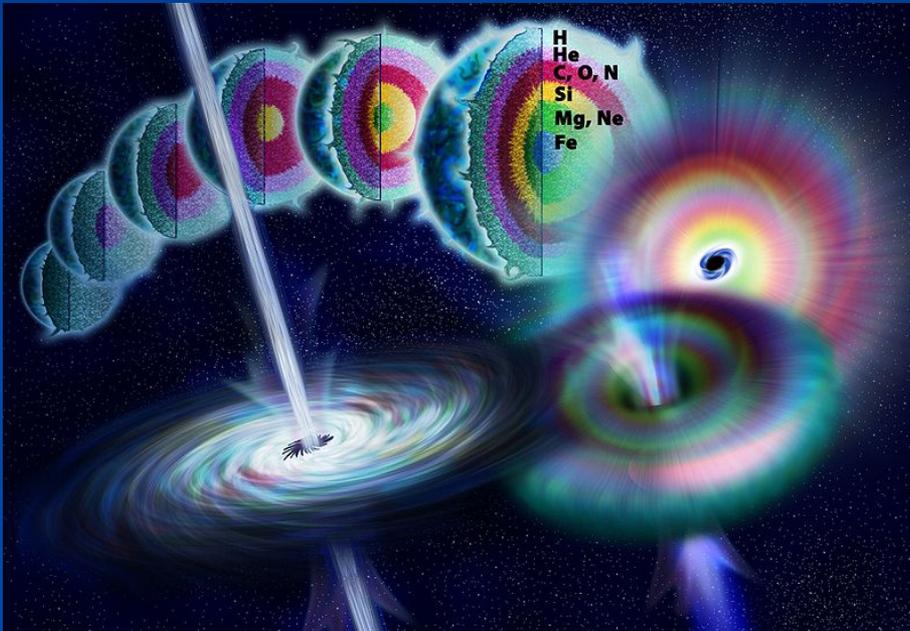
Galactic or beyond? Far beyond! Super powerful! “All-sky” maps show uniformity.



Long and Short Bursts

Long (minutes) : New supernovas???

Short (sec) : Mergers of BHs, Neut.Strs?



Gamma Ray Light Curves

Gamma-Ray Bursts (GRBs): The Long and Short of It

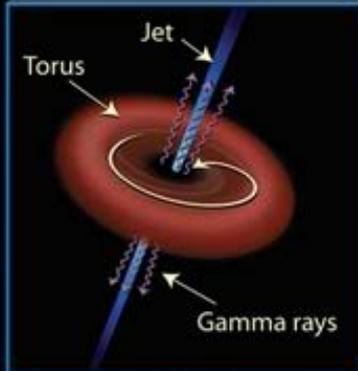
Long gamma-ray burst
(>2 seconds' duration)



A red-giant star collapses onto its core...



...becoming so dense that it expels its outer layers in a supernova explosion.



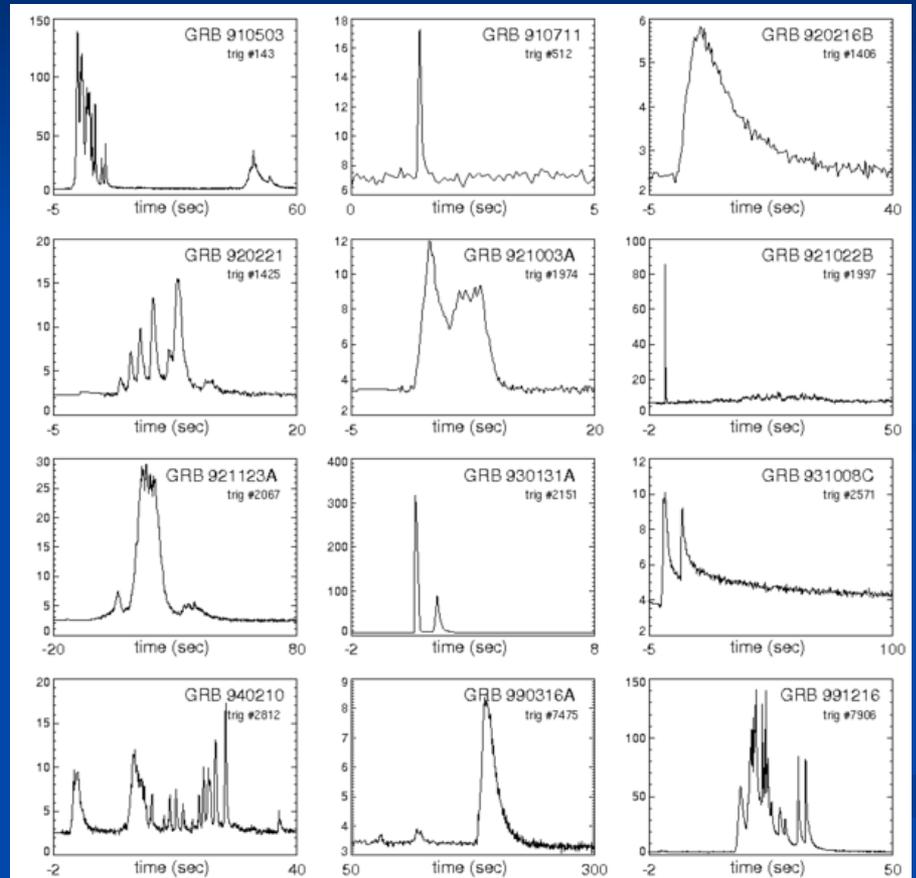
Short gamma-ray burst
(<2 seconds' duration)



...eventually colliding.



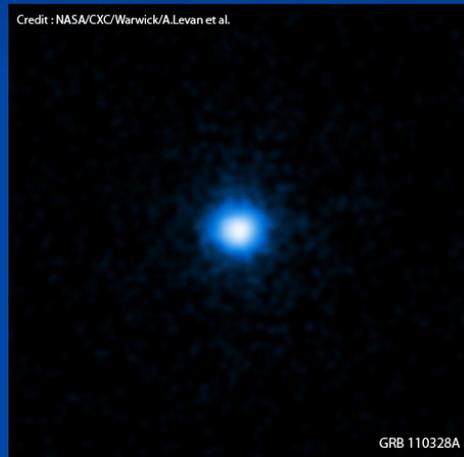
*Possibly neutron stars.



To appear so intense (mag 5 from 6 million LY away!), we must be looking down jet beam! Generation still not understood.



GRB image, jet diagram, Vela GRB image coded for Gamma Rays



GRBs spotted daily, most extreme energy in our Universe!

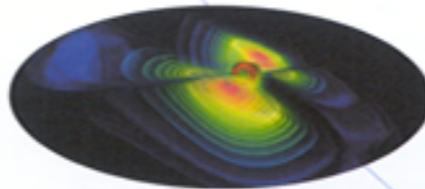
- Still poorly understood.
- Likely related to interaction of powerful objects like Black Holes at cores of Galaxies, or individual Supernovas.
- Extragalactic GRBs too dim to harm us, but...
- If Wolf-Rayet star in our Galaxy gets us in its sights, woe be Earth! Trilobites show evidence of extinction from ancient blast!

What else happens when mighty objects shake?

- **GRAVITY WAVES...**
- **RIPPLES IN THE FABRIC of SPACETIME!**
- **LIGO OBSERVATORY TRYING TO DETECT, NO LUCK SO FAR.**
- **(Two observatories, one in Hanford, Wa., sister observatory in Louisiana.)**
- **LIGO = Laser Interferometer Gravitational Wave Observatory. Perpendicular arms containing laser beams.**



Two neutron stars
orbit each other



and collide, merging into one,

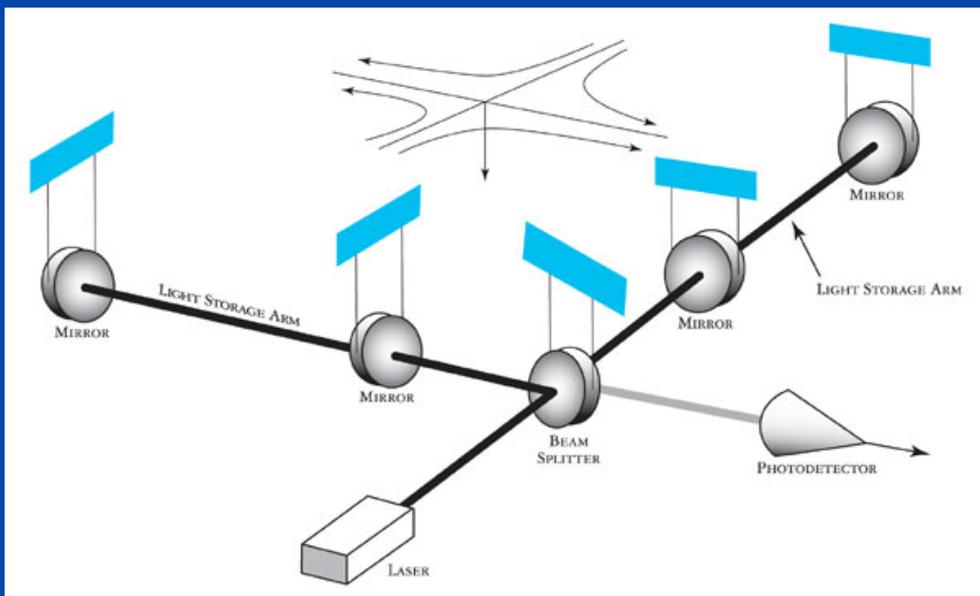


the force of which is so great,
it creates ripples



which reach Earth and will be
detected simultaneously
at two observatories.

LIGO at HANFORD



**Something's not right...
expected daily events, not a
peep so far.**

- **Working on increasing SENSITIVITY of Detector. (finds dump trucks very well!)**
- **Space based version (LISA) almost ready to launch.**
- **Stay tuned, scientists at work!**

You can visit LIGO-Hanford by pre-appointment.

See you at Pine Mountain this Summer!