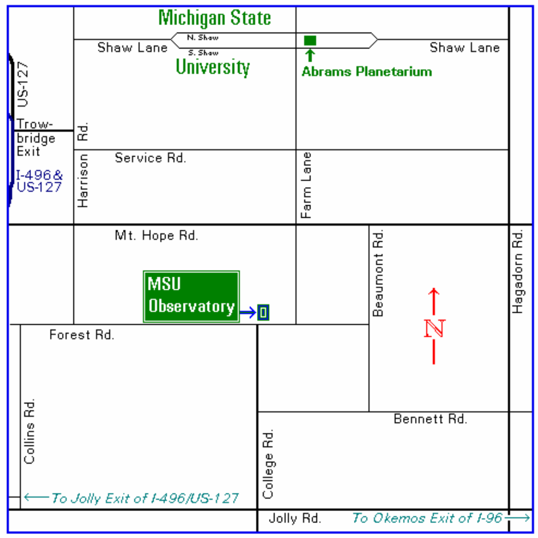
Open Houses at the Campus Observatory

- Friday and Saturday, 9-11pm, weather permitting

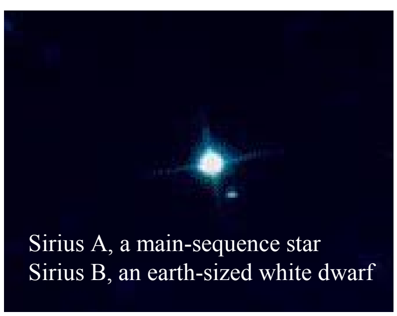


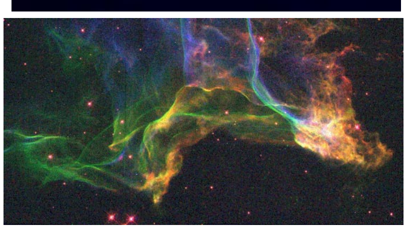
Astronomical Horizons Lecture

- Speaker: Professor Ed Loh
- Time: 7:30pm
- Place: Abrams Planetarium
- Subject: Infrared Astronomy with the SOAR Telescope

- Professor Horace Smith
- Office: room 3272 BPS
- Email: smith@pa.msu.edu
- Office hours: TTh 1:50-2:40 or by appointment
- Reminder: Homework Number 6 is ready and due at 6:30pm, Friday, March 30

White Dwarfs & Other Ends–March 22





Cygnus Loop
Supernova 20,000 yr ago

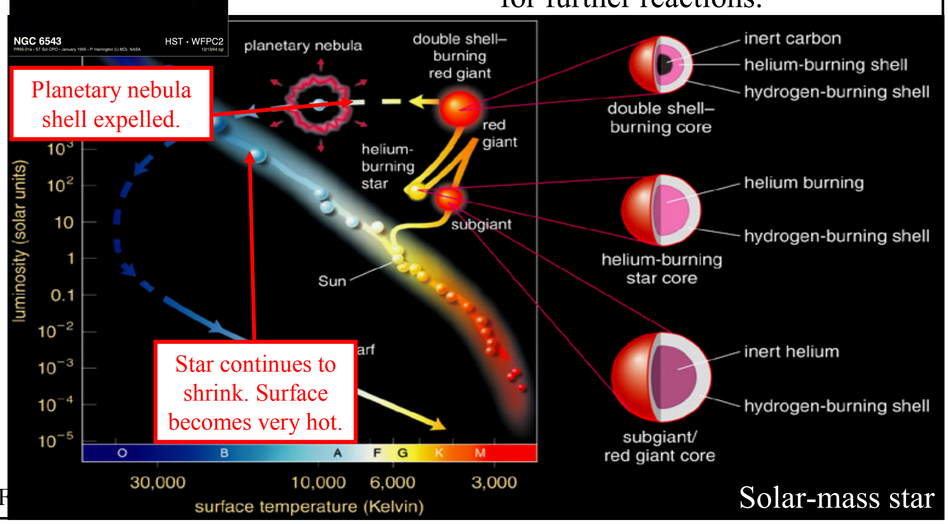
- When the sun dies, it becomes a white dwarf. Why is a white dwarf different from a main-sequence star?
- What causes pressure?
  - In a main-sequence star, gas particles moves because they are hot. (Normal gas)
  - In a WD, electrons move because they are close to each other. (Degenerate gas)
- Other ends
  - Neutron star
  - Black hole
  - Supernova

Nuclear Reactions in Stars

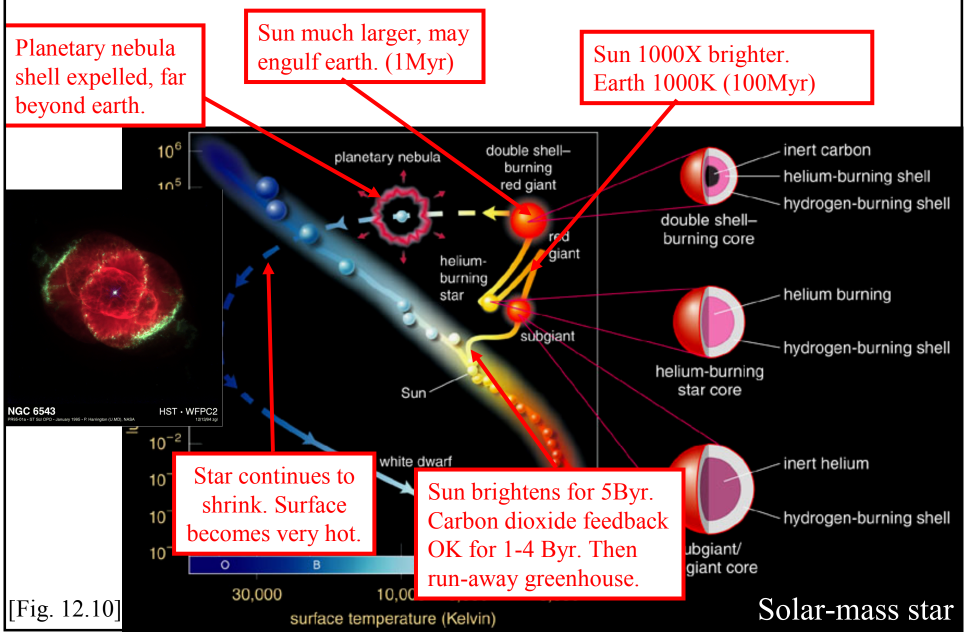
Reaction	Min. Temp.
$4\ {}^{1}H \rightarrow {}^{4}He$	$10^{7}\ {}^{o}K$
$3\ {}^{4}He \rightarrow {}^{12}C$	$2x10^{8}$
${}^{12}C + {}^{4}He \rightarrow {}^{16}O$, Ne, Na, Mg	$8x10^{8}$
Ne $\rightarrow$ O, Mg	$1.5x10^{9}$
O $\rightarrow$ Mg, S	$2x10^{9}$
Si $\rightarrow$ Fe peak	$3x10^{9}$

Stars with < 2 $M_{\odot}$

- End is He $\rightarrow$ C, O burning.
- Core never gets hot enough for further reactions.



What happens to the earth?



[Fig. 12.10]

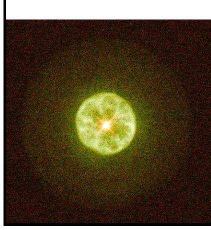
Solar-mass star

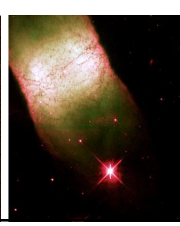
Planetary Nebulae

Planetary nebulae, former red giants, blow away outer 25% of their mass.

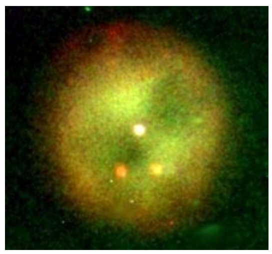
The remnant in the center becomes a white dwarf.

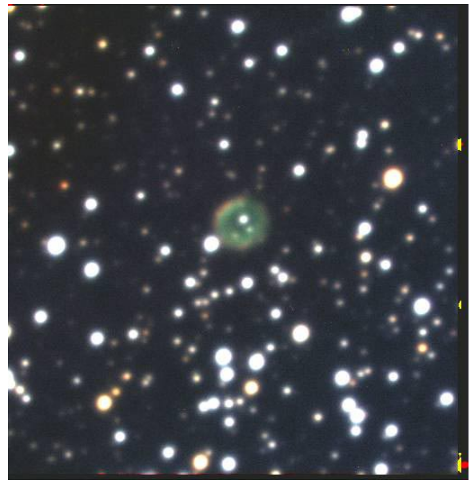
Pictures from Hubble Space Telescope





Pictures taken by AST 208 students





Gravity vs Pressure

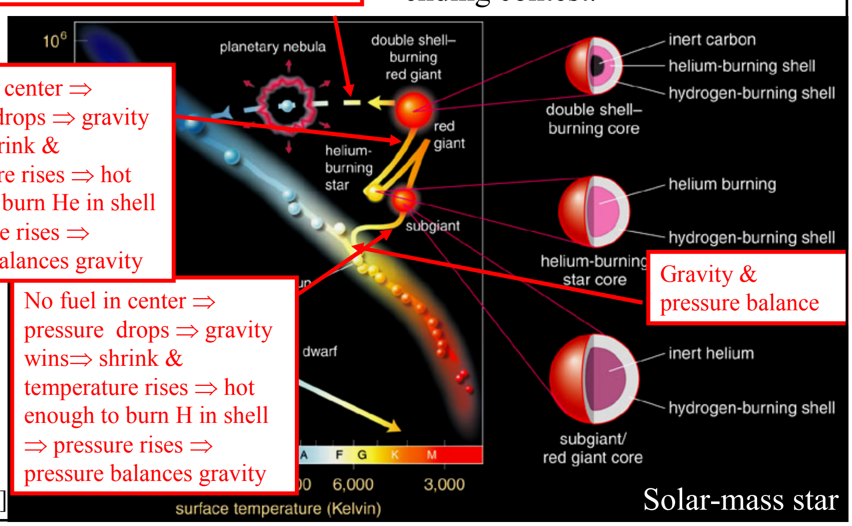
• Gravity pulls in, and pressure pushes out. A never ending contest.

No fuel in center ⇒ pressure drops ⇒ gravity wins⇒ shrink & temperature rises ⇒ not hot enough to burn Ne ⇒ new kind of pressure ⇒ pressure balances gravity

No fuel in center ⇒ pressure drops ⇒ gravity wins⇒ shrink & temperature rises ⇒ hot enough to burn He in shell ⇒ pressure rises ⇒ pressure balances gravity

No fuel in center ⇒ pressure drops ⇒ gravity wins⇒ shrink & temperature rises ⇒ hot enough to burn H in shell ⇒ pressure rises ⇒ pressure balances gravity

Gravity & pressure balance



[Fig. 12.10]

Solar-mass star

Pressure in a normal gas

- What is pressure?
  - Think of gas particles in a balloon as baseballs in the balloon.
  - Baseballs move and hit walls of balloon
  - Baseballs push on the balloon
- Normal gas
  - Pressure is greater at hotter temperature
    - Baseballs move faster at hotter temperature
    - Baseballs hit walls faster & more often
    - Pressure is higher

Pressure in a degenerate gas

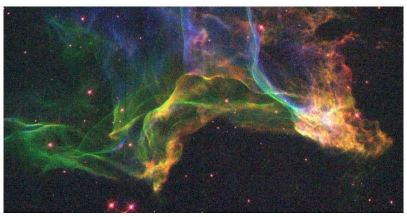
- What is pressure?
  - Think of gas particles in a balloon as baseballs in the balloon.
  - Baseballs move and hit walls of balloon
  - Baseballs push on the balloon
- Degenerate gas
  - Pressure is not greater at hotter temperature
  - Baseballs move because they are close together
  - Quantum mechanics: uncertainty relation
    - Speed $\times$ confinement = Planck's constant
  - Pressure is greater if gas is confined to smaller region
    - In a smaller star, baseballs move faster
    - Baseballs hit walls faster & more often
    - Pressure is higher

White dwarf

- Degenerate gas
  - Pressure is not greater at hotter temperature
  - Baseballs move because they are close together
  - Quantum mechanics: uncertainty relation
    - Speed × confinement = Planck's constant
  - Pressure is greater if gas is confined to smaller region
    - In a smaller star, baseballs move faster
    - Baseballs hit walls faster & more often
    - Pressure is higher
- A teaspoon of white dwarf weighs several tons
- To get the largest amount of WD matter, choose the smallest one.

- Q Why does the sun end up as a carbon white dwarf?
  a. It does not have enough mass to burn neon.
  b. The sun becomes degenerate
  c. The sun loses too much mass as a planetary nebula
  d. It takes too long to burn neon.

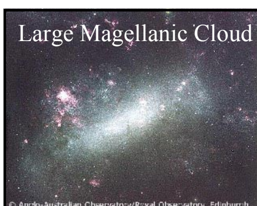
Supernovae

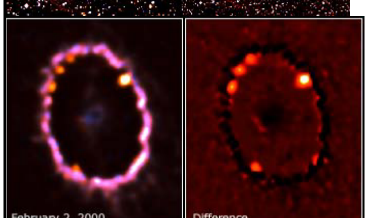


Cygnus Loop
Supernova 20,000 yr ago

- Where were the elements in the baby made?
  - Carbon was made and expelled by giants
  - Iron was made in massive stars and expelled by supernovae
- Supernova
  - Neutron star
  - Black hole

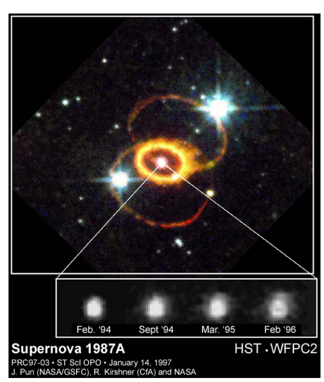
Supernova 1987A





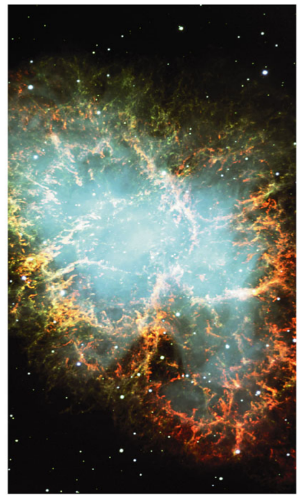
- Exploded in Large Magellanic Cloud
  - LMC is small galaxy that orbits our own Milky Way Galaxy.

Pre-existing circumstellar ring lit up first by photons from SN, now by blast wave from SN.



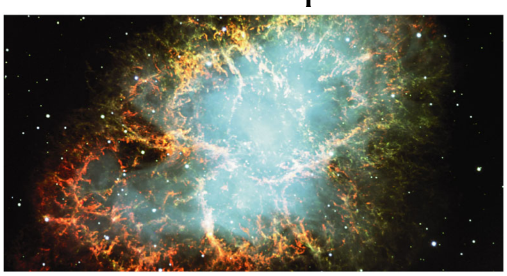
Guest star of 1054

- Records of Sung Dynasty
  - In the first year of the period Chih-ho, …, a guest star appeared several degrees SE of Thien-kuan. After more than a year it gradually became invisible.–p564.
- Gas expelled in 1054AD, still glowing
- Other SN
  - 1572 Tycho
  - 1604 Kepler

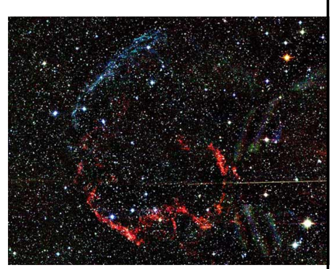


Supernova remnants

We expect one supernova in Milky Way every 25-100 yrs.



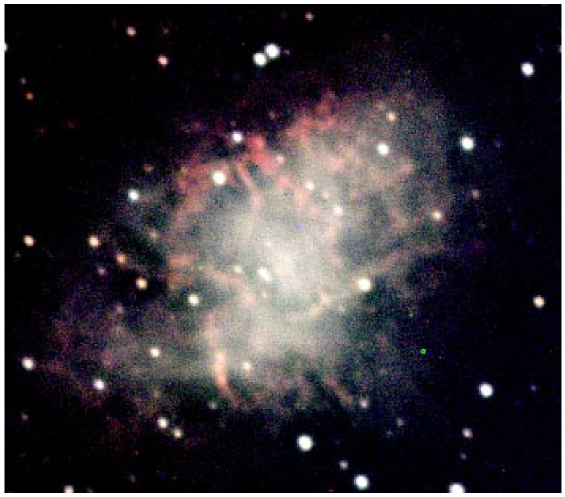
Crab
1,000 yrs old



IC 443
8000 yrs old

Cygnus Loop
20,000 yrs old.
2500 LY away.

AST 208 Students



Supernovae

- Explosion releases enormous energy
- Luminosity in photons temporarily exceeds that of whole galaxy full (100 billion) of stars.

What is a supernova? Why sun becomes a white dwarf, not a supernova

- In future double-shell burning sun, hot enough to burn
  $3\,^4He \rightarrow \,^{12}C$
- When He exhausted, gravity wins, and core contracts.
- Temperature rises.
- Electrons are so tight that they become degenerate.
- New source of pressure to resist gravity.
- Temperature not hot enough to burn carbon.

Reaction	Min. Temp.
$4\,^1H \rightarrow \,^4He$	10^7 ° K
$3\,^4He \rightarrow \,^{12}C$	$2x10^8$
$^{12}C + \,^4He \rightarrow \,^{16}O$, Ne, Na, Mg	$8x10^8$
Ne → O, Mg	$1.5x10^9$
O → Mg, S	$2x10^9$
Si → Fe peak	$3x10^9$

What is a supernova? Why massive star becomes a supernova

- In future double-shell burning <u>massive star</u>, hot enough to burn
  $3\,^4He \rightarrow \,^{12}C$
- When He exhausted, gravity wins, and core contracts.
- Temperature rises by larger amount b/c gravity is stronger.
- Temperature hot enough to burn carbon.
  $^4He + \,^{12}C \rightarrow \,^{16}O$, etc

Reaction	Min. Temp.
$4\,^1H \rightarrow \,^4He$	10^7 ° K
$3\,^4He \rightarrow \,^{12}C$	$2x10^8$
$^{12}C + \,^4He \rightarrow \,^{16}O$, Ne, Na, Mg	$8x10^8$
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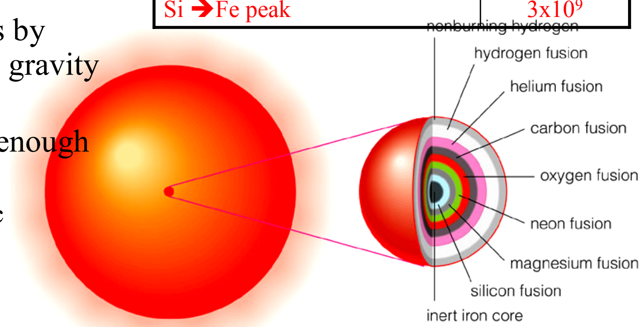

What is a supernova? Why massive star becomes a supernova

- Hot enough to burn
  $^4He + ^{12}C \rightarrow ^{16}O$, etc
- When C exhausted, gravity wins, and core contracts.
- Temperature rises.
- Temperature hot enough to burn neon.
  $^{20}Ne + ^4He \rightarrow ^{24}Mg$
- Disaster with iron
  - Burning releases energy
  - Fusing iron takes up energy
- Gravity finally wins.

Reaction	Min. Temp.
$4\ ^1H \rightarrow ^4He$	10^7 °K
$3\ ^4He \rightarrow ^{12}C$	2×10^8
$^{12}C + ^4He \rightarrow ^{16}O$, Ne, Na, Mg	8×10^8
Ne $\rightarrow$ O, Mg	1.5×10^9
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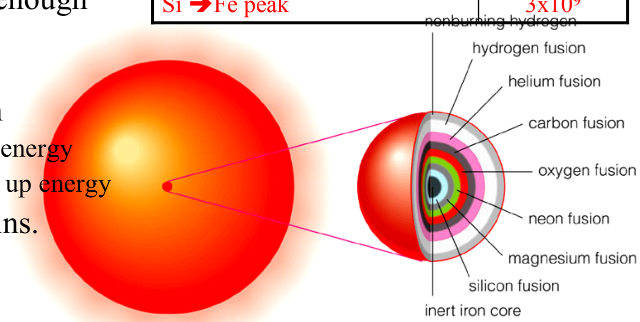

What is a supernova? Why massive star becomes a supernova

- Disaster with iron
  - Burning releases energy
  - Fusing iron takes up energy
- Gravity finally wins.
- Star collapses in few seconds
- Rebounds as supernova
  - Reason for rebounding is topic of current research
- Expel outer layers

Reaction	Min. Temp.
$4\ ^1H \rightarrow ^4He$	10^7 °K
$3\ ^4He \rightarrow ^{12}C$	2×10^8
$^{12}C + ^4He \rightarrow ^{16}O$, Ne, Na, Mg	8×10^8
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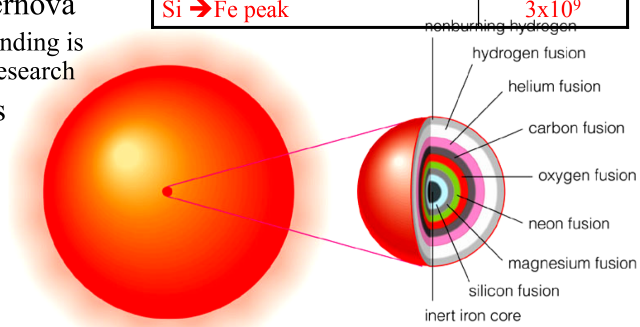
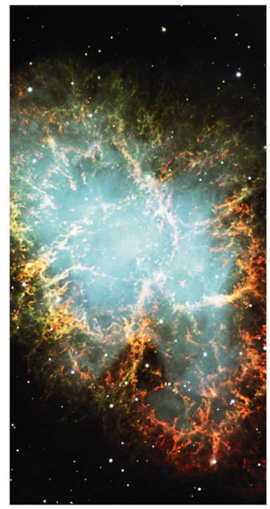


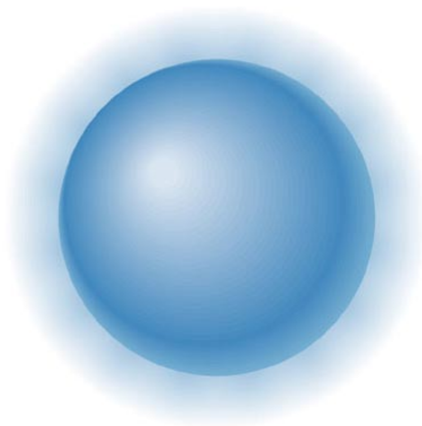
What is left?

- Outer layers expelled into space. New stars may form.
- Core becomes
  - Neutron star. One in Crab. Pulses every 1/30 s.
  - Black hole
- Neutron star
  - Normally neutron→proton+electron+neutrino+energy
  - Pressure is so high that proton+electron+energy→neutron+neutrino
  - Whole star is like a big nucleus of neutrons.
  - Neutrons are degenerate
  - Star is size of Lansing



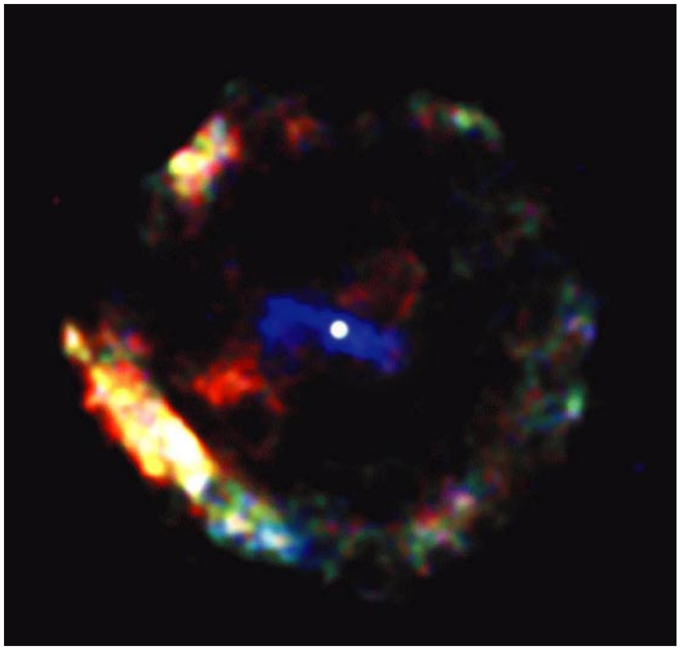
Neutron Stars

$1.0M_{Sun}$ white dwarf



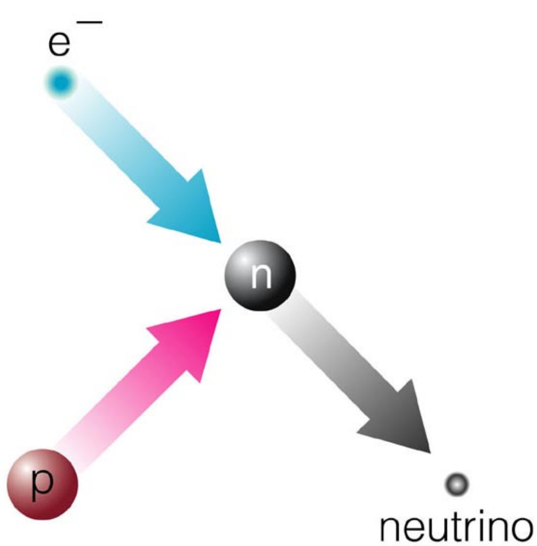
A white dwarf is about the same size as Earth

What is a neutron star?



A neutron star is the ball of neutrons left behind by a massive-star supernova

Degeneracy pressure of neutrons supports a neutron star against gravity



Electron degeneracy pressure goes away because electrons combine with protons, making neutrons and neutrinos

Neutrons collapse to the center, forming a ***neutron star***

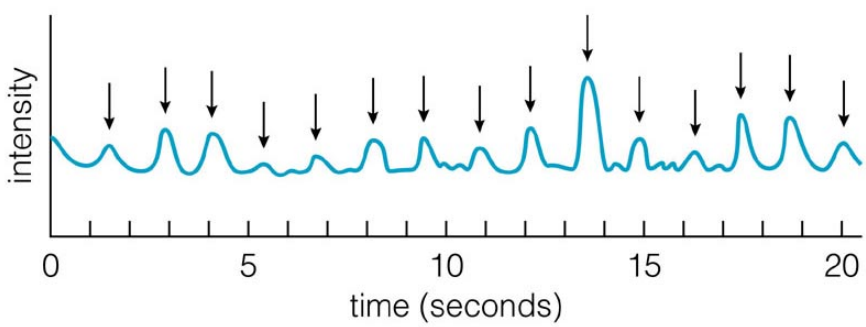
A neutron star is the size of a city

- Diameter: about 10 km
- Mass: about 1.4 solar masses
- Much denser even than a white dwarf!

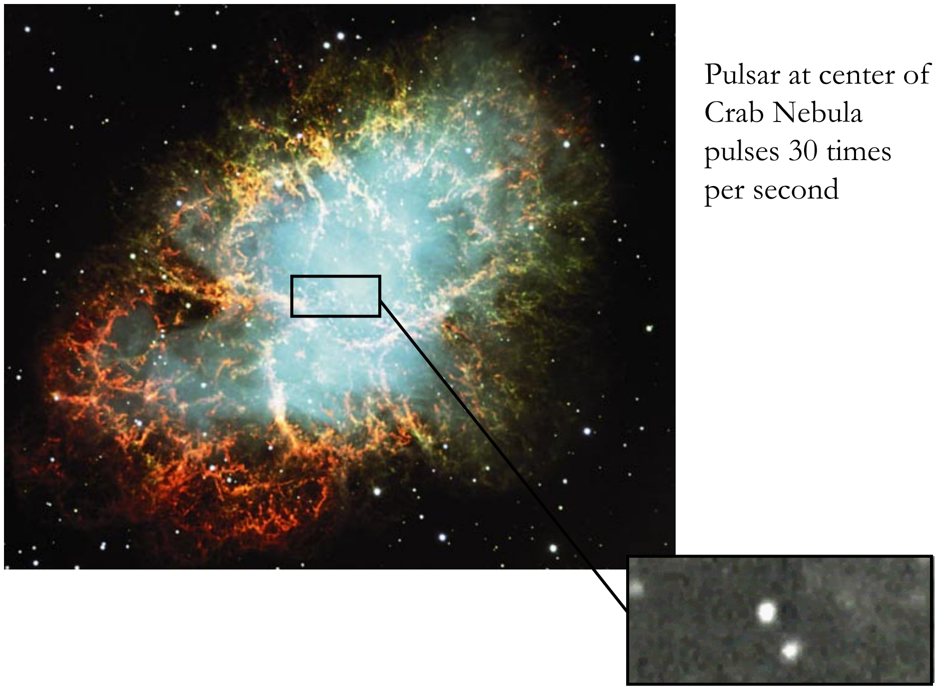
How were neutron stars discovered?

Pulsars

- In the late 1960s, strange repeating pulses of radio emission from space were detected
- But what were they?



Pulsars are neutron stars that give off very regular pulses of radiation



Pulsar at center of Crab Nebula pulses 30 times per second

Pulsars are rotating neutron stars that act like lighthouses

Beams of radiation coming from poles look like pulses as they sweep by Earth

2. What prevents the sun from becoming a supernova?

a. Iron core is stable.
b. Degeneracy pressure prevents temperature from rising.
c. Carbon burning.
d. That is wrong; the sun will become a supernova.

3. If neon were the most stable element, massive stars would live

A) longer
B) shorter