ASTR 1120 – February 27

Exam #1 Graded
Average: 66.1
Standard Deviation: 13.6

Next exam will be soon. Tuesday, March 18

Website
http://casa.colorado.edu/~wcash/APS1120/APS1120.html

Problem Sets 4 and 5 on the website. Due next week.

Next Tuesday (March 4)
Class will be at Fiske Planetarium
Geodesic Dome near events center

DO NOT COME HERE. GO DIRECTLY THERE.
Supernovae
Nature’s Biggest Explosion

- 10,000BC
- 185AD m
- 396 -3
- 1006 -10 1300pc
- 1054 -6 1800 Crab II
- 1572 -4.1 5000 Tycho’s I
- 1604 -2.2 7000 Kepler’s I
- 1667 >5 3400 Cas-A II
- 1987 4.0 55,000 SN1987A II

We now see a dozen or so every year in distant galaxies.
Supernovae

Occur about once every hundred years per galaxy.

Briefly outshines the other 100 Billion stars in the galaxy.
Type I Supernovae

White dwarf is gaining mass.

Over time, the mass will approach the Chandrasekhar Limit. Remember, at 1.4M\(_\odot\), electron degeneracy fails.

What happens?
White Dwarf Collapse

As WD starts to collapse, the material falls through the gravitational field of the star.

It heats very rapidly.

In just a few seconds it reaches $>100,000,000$K.

Carbon and Oxygen ignite and burn by fusion to even heavier elements.

The whole star explodes in a frenzy of nuclear burning.

Blows completely apart.

All that remains is an expanding shell of gas that used to be a white dwarf and the companion star slingshot into space.
Explosion Starts at Center where pressure is highest
Energy Released

Nuclear Energy Generates 2MeV per atom in forming molecule (burning)
2MeV = 3\times 10^{-13} \text{ Joules}

Number of Atoms in Star:
\[
N = \frac{M}{m_p} = \frac{2 \times 10^{30} \text{ kg}}{1.6 \times 10^{-27} \text{ kg}} = 10^{57}
\]

Available Energy
\[
E = 3 \times 10^{-13} \times 10^{57} = 3 \times 10^{44} J
\]

About $10^{44}$J release in just a few seconds.

That’s as much energy as the Sun emits during its entire lifetime.
In a few seconds!!!!

This is so titanic we can see it across the universe

A billion trillion trillion atomic bombs

Gas returning to interstellar space has more CNO etc.
SN1987A – Before and After
The Crab Nebula

Supernova Dominated Sky in 1054 AD
Observed by Chinese (not in Europe)
Recovered in 18th Century by Messier

Called a “Supernova Remnant”
1pc in diameter
Expanding Rapidly
Tycho’s Supernova

Seen in X-ray
Gas at 10,000,000K
Expanding at 5000km/s
Type II Supernovae

High Mass Star --- $M > 5M_\odot$

In low mass star, envelope is blown off into space, creating planetary nebula, before Carbon in core can flash.

High mass star has enough gravity to hold onto the gas. Get a Carbon flash just like the Helium Flash

Carbon burns to Neon
Then Neon flash

Gets very complicated
Onion Skin Model
Nuclear Reactions

\[ ^{12}\text{C} + ^{12}\text{C} \rightarrow ^{20}\text{Ne} + ^4\text{He} \]

\[ ^{20}\text{Ne} + \gamma \rightarrow ^{16}\text{O} + ^4\text{He} \]

\[ ^{16}\text{O} + ^{16}\text{O} \rightarrow ^{28}\text{Si} + ^4\text{He} \]

\[ ^{28}\text{Si} + ^{28}\text{Si} \rightarrow ^{56}\text{Fe} \]

- neon shell
- oxygen shell
- silicon shell
- iron core

Iron cannot nuclear burn at any temperature
(On border between fusion and fission)

Develops degenerate iron core than cannot flash
Just gets hotter and heavier down in the middle of the star
Collapse

When the degenerate iron core exceeds the Chandrasekhar limit, electron degeneracy can no longer support it.

It will start to collapse.

Electrons do not have individual quantum states left.

They hide by merging with protons to form neutrons:

\[ P + e^- \rightarrow n + \nu \]

Every time this happens, a neutrino is also created.

Neutrinos are free to escape to infinity and carry energy with them.
Reversal of the Nuclear Reactions

Every iron nucleus in the core was formed in nuclear burning.
There is one electron for each proton.
After electrons are absorbed, the nucleus consists of 56 neutrons.
That’s unstable and the nucleus dissolves into free electrons.
Millions of years of fierce nuclear burning is reversed in a few seconds!

The star keeps shrinking.
By the time it has shrunk from 6000 to 600km, this process is complete.
So it’s a ball of neutrons.
Still nothing to stop its collapse.

Keeps shrinking.
Finally, when radius is about 7km, it stops.

Has at least 1.4M☉, but is a speck the size of Boulder
Neutron Degeneracy

Neutrons, like electrons, must have individual quantum states.

What stops the descent is “neutron degeneracy”
    Conceptually identical to electron degeneracy.

Because a neutron is 1838 times more massive than an electron,
the radius of the degenerate star is 1838 times smaller.

This is called a Neutron Star.
It is roughly 14km in diameter and has 1.4 times the mass of the Sun.

They are formed in the middle of Type II Supernovae.
Energy of Collapse

As neutron ball collapses it releases gravitational energy.

\[ E = \frac{GM^2}{R} = \frac{6.7 \times 10^{-11} \times (3 \times 10^{30})^2}{7000} = 10^{47} \text{ J} \]

Sun will only emit $10^{44}$ J in its entire life.

This is about a thousand times greater than the energy released in at Type I supernova.
Where did the energy go?

• Neutron Stars were found in supernova remnants in the 1960’s.
• Type I and Type II Supernovae have comparable brightness.
• Type II’s are NOT 1000x brighter.

• Where did 99.9% of the energy go??
Neutrinos

Ball of neutrons radiates thermal neutrinos the same way that a ball of electrons will radiate photons.

These elusive particles carry away 99.9% of the energy.

So poorly coupled to regular matter that they travel unimpeded through the Universe at close to the speed of light.

In fact, at this moment, each and every one of us has about 10 neutrinos per second passing through our bodies. They were generated in distant supernova in galaxies far, far away – long, long ago.
Neutrinos

So what if we view this as a personal violation?

Let’s go to the Department of Homeland Security and ask them to put up a shield that will protect us from these nasty neutrinos.

We’ll make it out of one of the best materials for stopping them – lead.

How thick will the shield have to be?

Answer: About a parsec!!

Looks like neutrinos have a mass about a million times lower than electrons.
Core Bounce

When star reaches neutrons star size it is collapsing so fast that it overcompresses. It reverses direction and grows some.

This outward shock wave couples into the rest of the star and drives the stellar envelope into space.

That’s the $10^{44}$J we see.
Explosive Nucleosynthesis

Expanding shell starts out very hot.

Nuclear reactions are taking place rapidly.

As it expands it cools rapidly.

Some very heavy elements can’t survive long at high temperature. A few get frozen in during cooling.

That’s where all the elements heavier than iron come from.

That’s why heavy elements are expensive.

They’re made in supernovae! And they’re trace resultants at that.
SN1987A

- First naked eye supernova since 1604.
- Discovered by Ian Shelton. Feb 23, 1987 UT 23.316
- Showed hydrogen escaping at 30,000km/s

- In Large Magellanic Cloud
- Tiny galaxy orbiting the Milky Way.

- Huge international response of the astronomy community.
Progenitor

Star that exploded was tracked down. Not terribly prominent.

SK-69 202
B3 Supergiant  \( m=12.4 \)  \( M=-7.8 \)
\( T=16,000K, \ R=40R_\odot \)

Distance 55,000pc – actually outside Milky Way.
## Stellar History

- Burned H 10,000,000 years
- He 1,000,000
- C 300
- Ne 5 months
- O 6
- Si 2 days

POW!!!!