Assignments:

- HW8 due Friday

Last time: Death by Subatomic Particles!?

Today: **Gamma-Ray Bursts**

http://apod.nasa.gov/apod/ap081227.html

http://www.spacetelescope.org/images/opo9730b/
Massive Star Threat

Massive star death leads to several cosmic dangers

So far:

- focussed on threat from the supernova explosion and it’s signature in ejected matter

But more dangers lurk!

- center of explosion is dead star “cinder”
- large mass crushed to small size: huge gravity
Review: The Life and Death of a Massive Star

1. Main Sequence
2. Red Supergiant
3. Blue Supergiant
4. Red Supergiant II
5. Supernova!
6. Neutron star or black hole
Massive Star Death: Recap

The life of a star is a struggle against gravity

- Massive star death begins when core of star stops generating heat
- Gravity overcomes pressure
- Core of star collapses under its own weight

Fate of core?

- During collapse: nuclei and electrons compressed to enormous density
- First: electrons squeezed into protons, making neutrons (and neutrinos)
- Neutrons compressed until touching
  - Neutron core forms a solid supported by “degeneracy pressure”
  - Touching neutrons ordinarily only exist in atomic nuclei
- Core becomes a giant nucleus made of $10^{57}$ neutrons

And then?

- If star mass $< 30 \, M_{\odot}$ or so (highly uncertain), this newborn “neutron star” remains stable, cools off, remains as “corpse” of massive star
- If star mass larger than this: neutron star driven to become unstable—leads to black hole
What is a neutron star?

The collapsed core of a massive star
Consists almost entirely of neutrons
As dense as an atomic nucleus
  » large mass around $1.5 \, M_{\text{sun}}$
  » in tiny radius around 30 km
Think of it as matter with all the empty space squeezed out of it
Originally thought to be too small to ever see
A neutron star is about the same size as a small city, with 500,000 times the mass of the Earth!
A sugarcube of neutron star has more mass than a mountain!
In 1967, Jocelyn Bell discovered radio pulses from the constellation Vulpecula that repeated regularly. Every 1.337... seconds. What could it be? Perfect timing, but no real encoding of signal. Jokingly called LGMs.

› beacons from space aliens--“little green men”

Then pulsars (pulsing star)

The signal from a pulsar is a series of regular pulses.
Pulsars: Hear the Fear!

http://www.jb.man.ac.uk/~pulsar/Education/Sounds/sounds.html

Pulsar signals first seen in radio waves

› recall: radio is just another form of electromagnetic radiation, but with wavelength much longer than visible light
› by now: pulsars have been seen in many wavelengths

Radio signal is periodic (repeating)

› to get a feel, can convert radio to sound, like when listening to ordinary non-astronomical radio stations
A pulsar lies at the center of Supernova 1054

Youngest known pulsar
Period: 30 millisec = 30 pulses per second!

Lesson: pulsars are created by supernova explosions and thus arise in massive star death

NASA video clip:
http://chandra.harvard.edu/photo/2008/crab/animations.html

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What’s going on?

What could it be?

‣ Pulses were too fast to be surface pulsations of a star
‣ Very precise repetition, better than atomic clocks.
‣ Periods from 8.51s down to 0.00156 s!

Could they be spinning objects?

‣ Imagine Earth spun once per second (1 day is now 1 sec!)
  surface would move at huge speeds: 10% c!
  outward centrifugal forces overwhelm gravity
  Earth would fling itself apart!
  Q: which tells us?
‣ Lesson: to be spinning so fast requires very large mass in very small sizes
  so that gravity acceleration $GM/R^2$ strong enough to keep object from flinging itself apart
‣ Spinning neutron stars?!?
A pulsar is a spinning neutron star

Neutron star’s intense magnetic field creates **back-to-back beams of radiation**

- **but beams not quite along spin axis:** misaligned

Rapid rotation carries beams around the sky

- **sweep out cone-shaped pattern in each hemisphere**

What do we see? Depends on whether Earth happens to be “in the beam”

- **If Earth lies in path of beam:** as beam sweeps over Earth, **see a flash of light once per rotation**
  - Like a lighthouse!
- **But if Earth not in path (cone) of beam sweep:** **see nothing!**

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Why does a neutron star spin so fast?

When the stellar core collapsed, the rotation rate and magnetic field strength both increased.

Extreme version of angular momentum conservation we saw in protosolar nebula.
Neutron star limit

If star leading to supernova has $M \gtrapprox 30 \, M_{\text{Sun}}$

- Huge mass of star = huge gravity force on core
- Neutron pressure cannot stop the crush of gravity
- Stellar core collapses

Leaves behind a black hole

- like pulsars, expected to be rapidly spinning
- much more on black holes to come, but for now: regions of extremely strong gravity
Imagine

› The beam comes without warning.
› You’re walking downtown, hanging out, suddenly, an incredibly bright light in the sky!
› It hurts to look at it at first, then it begins to dim.
› Hours later, silent subatomic particles slam into the Earth’s atmosphere.
› No matter if people are inside or not, a large fraction of the Earth is exposed to lethal radiation.
› 60% of the population of the world starts dying from the high dose.
Imagine

- The ozone layer has been dramatically damaged, and solar UV radiation will kill off the food chain.
- A thick layer of smog forms and the sky turns a dark reddish-brown. Plants begin to die, then the acid rain starts.
- A new ice age begins.
- Survivors realize that the supermassive star Eta Carinae exploded.
- As you die, you wonder how a star trillions of miles away killed you, and why didn’t Brian talk about it in class?
Top 10 Ways Astronomy Can Kill you or your Descendants

✓ Impacts! Splat.. Boom… Watch out for space rocks!
✓ Orbital Chaos - Jupiter wreaks havoc with planet orbits
✓ Solar storms - Magnetic bubble, coil, and trouble
✓ Death of the Sun - Burn the land and boil the sea
✓ Nearby Supernova - Sirius danger?
Top 10 Ways Astronomy Can Kill you or your Descendants

6. Gamma Ray Bursts - Cosmic Blowtorches
Outline

Cold War discovery of something weird
Where do gamma-ray bursts originate?
What produces a gamma-ray burst?
The Cold War Connection

In 1962, US tested a large nuclear bomb

- 1.4 Megatons
- exploded in space
  - 250 miles above the Pacific

Caused electromagnetic pulse far larger than expected

- Including gamma-rays
- Blew out streetlights in Hawaii 900 miles away
In the 1963, the US and USSR decided to ban some testing of nuclear weapons. Signed the historic Partial Nuclear Test Ban Treaty

- No nuclear explosions in atmosphere or space
- Have to monitor the other side to verify no cheating!
- Key signature: nuke explosions create gamma rays
- So needed to monitor gamma rays
To See Gamma-Rays, We Need to Go to Space?

Gamma-rays are high energy photons - billions of times more energetic than optical photons. Earth’s atmosphere is blocks gamma-rays

- none reach the ground
- same with X-rays and some UV

Gamma-ray studies require balloons, rockets, or satellites.
Vela satellites:

- secret Defense Department project
- in orbit around Earth
- monitoring for gamma rays from Soviet nukes in space or atmosphere

July 2, 1967, they detected their first hit!

- Didn’t look like a nuclear blast and no solar flares reported
- Couldn’t determine location

Moon bombs?
First Detected Gamma-Ray Burst (GRB)

Gamma-ray pulse spread over about 8 seconds
Vela found 10-20 such gamma-ray bursts (GRBs) per year!

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Where do they come from?

With more than one Vela satellite, can compare signal arrival times

- gamma rays are EM radiation, travel at speed $c$
- so arrival times at each satellite give distances to source
- compare distances: “triangulate” on source location

Results:

- GRBs not from Earth! must be from somewhere beyond!
- no GRBs ever seen to repeat each one from new place in sky definitely not periodic
Where do gamma-ray bursts orginate?

In our solar system?
In our galaxy, the Milky Way?
Incredibly far away near the edge of the observable Universe?
April 5, 1991 – June 3, 2000
Four gamma-ray instruments: EGRET, COMPTEL, OSSE, and BATSE
BATSE (Burst And Transient Source Experiment) proved to be the most useful instrument for GRB detection
iClicker Poll:
Guess the GRB sky pattern!

The disk of our galaxy (the combined light of billions of distant stars) appears as a band around the sky. If gamma ray bursts are in the Milky Way, what would the map look like?

A. Evenly scattered around the sky
B. Concentrated along the disk of the galaxy
C. Centered on our Sun

Map of entire sky
Showing positions of stars in our Galaxy
Gamma ray burst locations - Evenly distributed around the sky

Gamma ray bursts observed by the BATSE instrument

Update: NASA Swift satellite
http://www.youtube.com/watch?v=qomRweB6moc
Gamma-Ray Bursts: The Situation after Compton

BATSE monitored all sky for about 9 years taught much about GRBs found:

‣ directions are randomly distributed on sky
  not connected to position of Sun
  not connected to stars in our Galaxy
  suggests GRB origins beyond our Galaxy!
‣ event rate: 2704 BATSE bursts seen
  about 1 GRB/day!
‣ no repeat events from same direction
‣ burst duration from 0.1 sec to 100 sec
‣ time history (lightcurves): highly nonuniform
  some highly variable: huge changes over 0.1 sec timescales!
  but others fairly smoothly varying

But mysteries remained:
sky locations of burst only known to within 1 degree = 2 full moons across
  like looking through “coke-bottle glasses”
‣ too big a region to quickly search with telescopes
‣ no counterparts seen at any other wavelengths!
‣ Needed to get more precise locations on sky

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Breakthrough: BeppoSax

February 28, 1997

March 3, 1997

GRB 970228 X-ray afterglow at 8 hours (left) and 3 days (right) after the Gamma-ray burst.
GRB afterglow detected in visible light!

Using X-rays to pinpoint GRB location, possible to search using ordinary telescopes detections made at all wavelengths!

non-gamma signals dim over time, but last much longer: “afterglows”
Gamma-ray Burst Afterglows

The afterglow of a GRB looks like a supernova
GRB Host Galaxies

GRBs are often observed in galaxies with active star formation

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GRB Afterglows: Lessons

GRB afterglows always found at locations of other galaxies beyond our own

- confirms that GRBs are from very distant sources
- the farthest GRBs are almost as far as it is possible to see across the Universe!

GRB afterglows mostly (but not always) found in star-forming regions of galaxies

- lesson: most GRBs connected with birth of stars
- but recall: massive stars have short lifespans so they die where they are born
- thus most GRBs likely from deaths of massive stars

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Gamma-ray bursts are really far away

- Detected as far as 13 billion light years away!
- Near the edge of the observable universe!
- yet we still can see the bursts!? 

Means huge energy

- $\sim 1 \ M_{\text{Sun}}$ converted into gamma-rays in a second!
- But, that’s crazy talk!
What if the energy were beamed?

In an isotropic explosion, energy goes out in all directions.

If the energy were beamed to 0.1% of the sky, then the total energy could be 1000 times less - comparable to supernova energies.

Nothing seen down here.
Many objects in the universe, on many scales, exhibit polar jets.

Jets of gas from the center of a distant galaxy.

Jets from a young protostar.