Astronomy 150:

Killer Skies

<u>This Class (Lecture 23):</u>
Killer Gamma-Rays Bursts

<u>Next Class:</u>
GRBs and Mass Extinctions

HW8 due on Monday!

Night Obs due next Friday.
Exam 2 on Nov 5th!
Computer lab due on Nov 12th!

Music: *Blackhole Sun*– Soundgarden

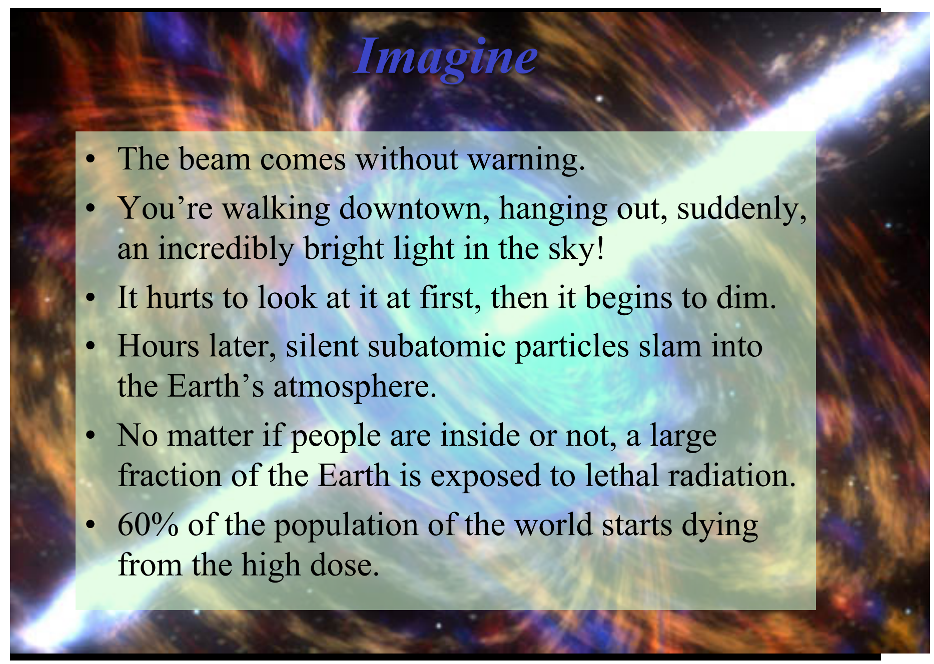
Question

Exam 2 is in two weeks. How many questions should be on the exam?

a) 25
b) 30
c) 35
d) 40
e) 45

Outline

- Cold War discovery of something weird
- The biggest bangs since the Big Bang!
- Long time GRBs– hypernova
- Short time GRBs– merging neutron/neutron or neutron/black hole



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 Leslie talk about it in class?

Top 10 Ways Astronomy Can Kill you or your Descendents

1. Impacts!
   Splat.. Boom… Watch out for space rocks!
2. Solar Evolution.
   MS to Red Giant to White Dwarf.
3. Coronal Mass Ejections
   Cold winter days..
4. Supernova in your face!
   Super sunburn.
5. Gamma Ray Burst.
   From anywhere…

Top 10 Ways Astronomy Can Kill you or your Descendents

5. Gamma Ray Bursts!

Supernova are dangerous if you get too close, otherwise they are sort of pretty. On the other hand, GRBs, which are massive supernovae, are beamed, sort of like a pulsar. If you are in the beam, these can kill from further away. Are we in danger?

Top 10 Ways Astronomy Can Kill you or your Descendents

5. Gamma Ray Bursts!

http://www.youtube.com/watch?v=ogg0SuF0sdE

GRB 080319B was 2.5 million times brighter than the brightest supernova! Visible by eye, and 7.5 billion light years away!

Top 10 Ways Astronomy Can Kill you or your Descendents

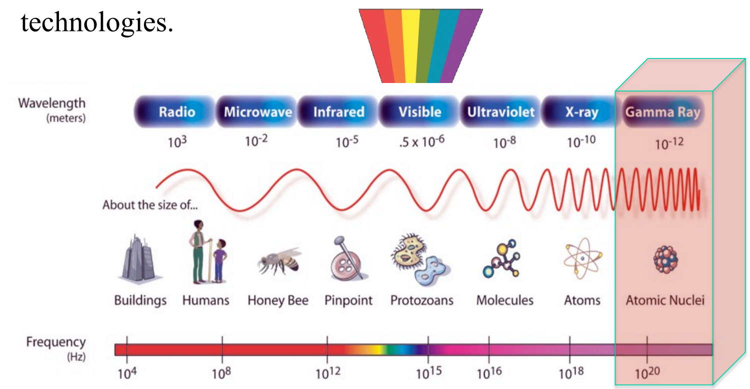
5. Gamma Ray Bursts!

http://www.youtube.com/watch?v=gDg1gRuAcJE

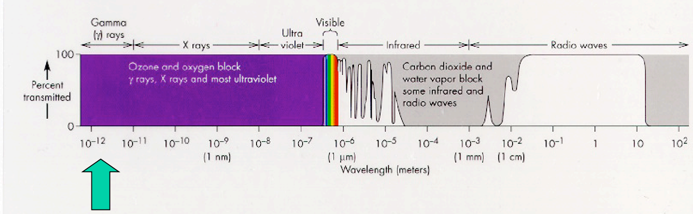
GRB 090423 is also the oldest known object in the Universe. It is 13 billion light years away! The Universe is only 13.7 billion years old, so this thing happened 30 million years after the Big Bang!

What is Light?

- Visible light only a tiny portion of the full light spectrum
- Light comes in many colors that you can not see! The color x-ray or color radio or color microwave.
- Divisions between regions are really only from biology or technologies.

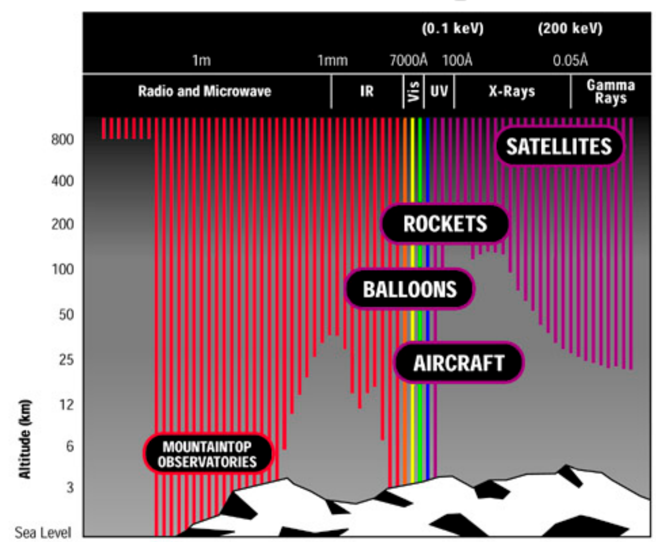


To See Gamma-Rays, We Need to Go to Space?



- Gamma-rays are high energy photons, corresponding to blackbody temperatures above 10^9 K.
- Billions of times more energy than optical photons.
- Earth's atmosphere is optically thick to gamma-rays.
- Gamma-ray studies require balloons, rockets, or satellites.

To See Gamma-Rays, We Need to Go to Space?



Question

Gamma Rays are

a) Going to kill us all.
b) Just light.
c) Freaky and rare radiation
d) We don't know.

The Cold War Connection

- In the 1950s, the US and USSR nuclear arms race was getting out of control.
- The USSR tested a 50 Megaton thermonuclear bomb. Still the largest tested in history!
- The US tested a 1.4 Megaton bomb 250 miles above the Pacific, blew out streetlights in Hawaii. Detected a huge pulse of gamma-rays.

Mr. Khrushchev said "We will bury you."

The Cold War Connection

In the 1960s, the US and USSR decided to ban the testing of nuclear weapons. The historic Nuclear Test Ban Treaty

The Cold War Connection

But, US assumed that they can't trust the USSR, so how to check?

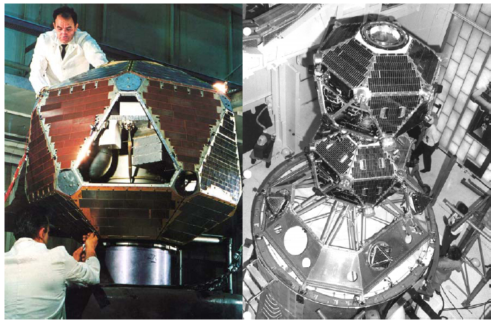
- Seismic Waves
- Low Frequency Sound Waves

Mogul Project

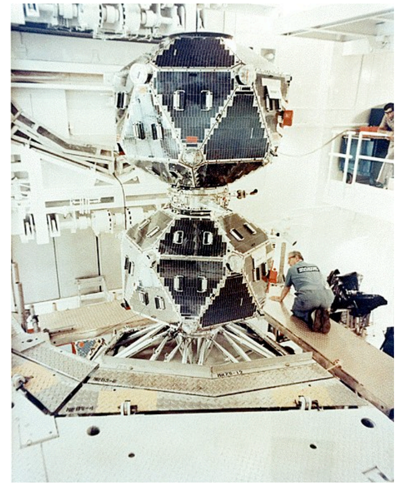
Crashed Balloon became Roswell Alien!

Gamma Rays: Vela Satellites

- US was worried about USSR testing nuclear weapons on the far side of the Moon.
- How to detect?
- Gamma-rays, but atmosphere blocks them.
- Launch a satellite!
- But, the Sun was thought to also emit gamma-rays.

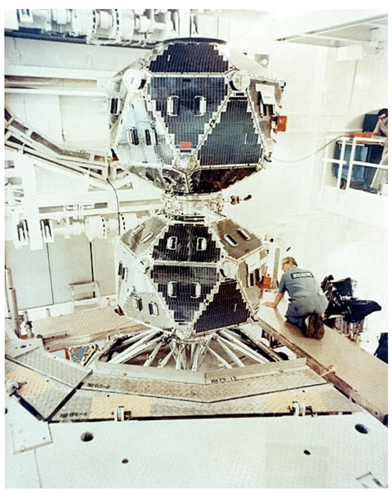


Gamma Rays: Vela Satellites



- But, nuclear weapons have a distinct double-peaked signature.
- Vela satellites were launched in pairs to watch for cheating of the partial test and help eliminate contamination.

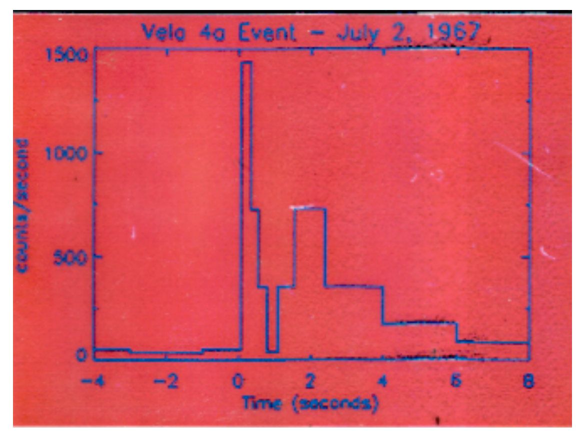
Gamma Rays: Vela Satellites



- However, they spotted something weird.
- July 2, 1967, they detected their first hit.
- But, it didn't look like a nuclear blast, and no solar flares reported.
- Couldn't determine location.
- Moon bombs?

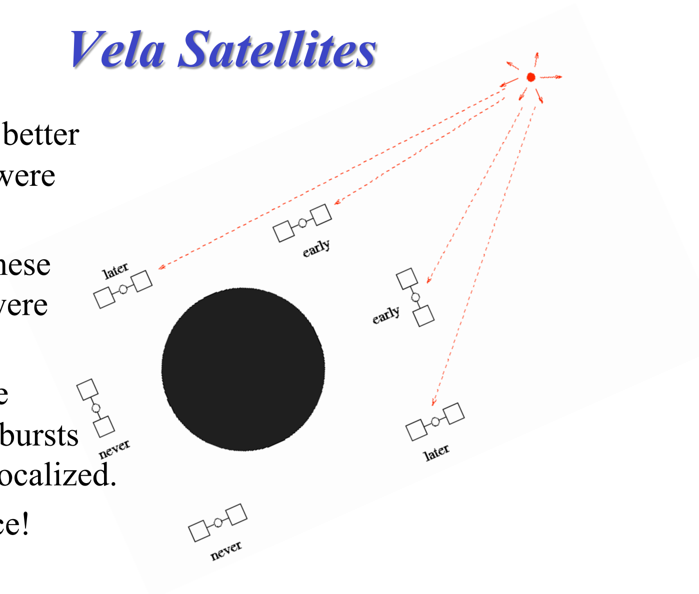
First Detected Gamma-Ray Burst

- A strong, sharp peak for less than a second
- Followed by a longer, weaker pulse lasting several seconds.



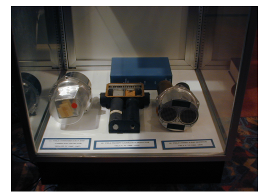
Vela Satellites

- More and better satellites were launched.
- More of these "bursts" were detected.
- With more satellites, bursts could be localized.
- From space!



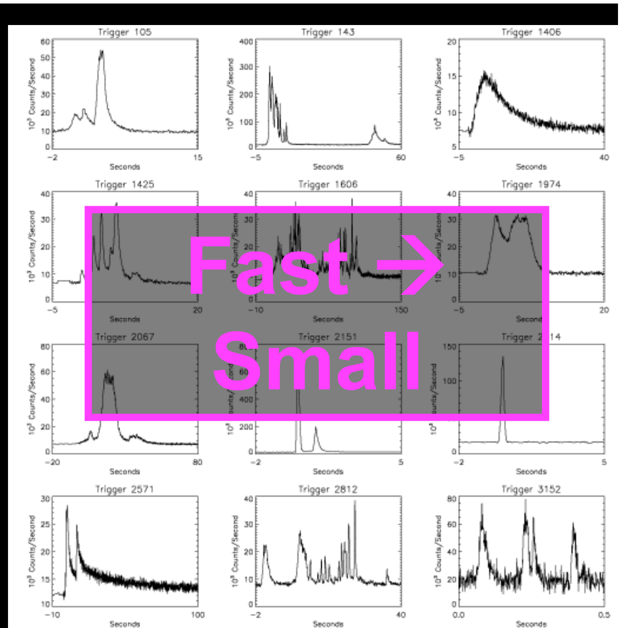
Vela Satellites - Results

- 73 Bursts in Gamma-Rays over 10 years
- They did spot many nuclear tests (non-USSR).



What do gamma ray bursts actually look like?

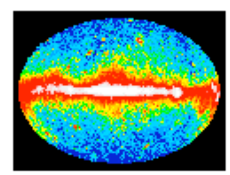
(light curves)

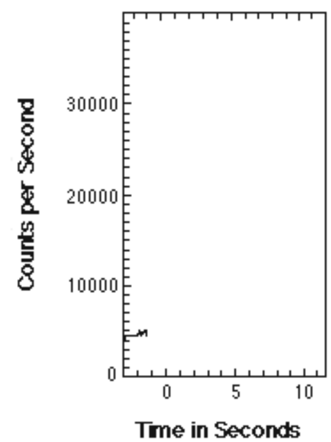


J.T. Bonnell (NASA/GSFC)

Gamma Ray Bursts

- Completely unknown group of sources!
- What are they?
- Needed to wait for real-time info and better directional info.



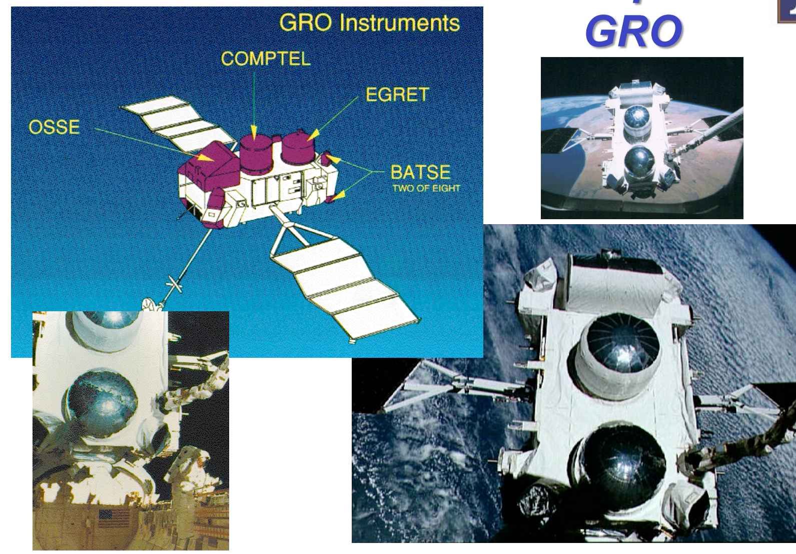


Question

GRBs are

a) Nuclear weapon tests
b) Great Research Blackholes
c) Short gamma ray light sources in space.
d) Grand Rotating Bodies

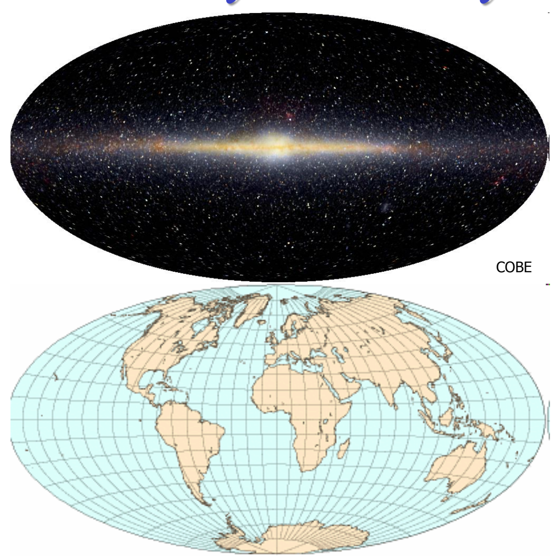
Compton GRO



Compton Gamma Ray Observatory

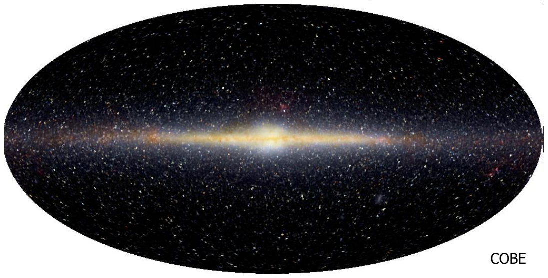
- April 5, 1991 – June 3, 2000
- Four separate gamma-ray detection devices: EGRET, COMPTEL, OSSE, and BATSE
- BATSE (Burst And Transient Source Experiment) proved to be the most useful instrument for GRB detection

Are they in the Milky Way Galaxy?



If gamma ray bursts are in the Milky Way, what would the map look like?

Gamma ray burst locations



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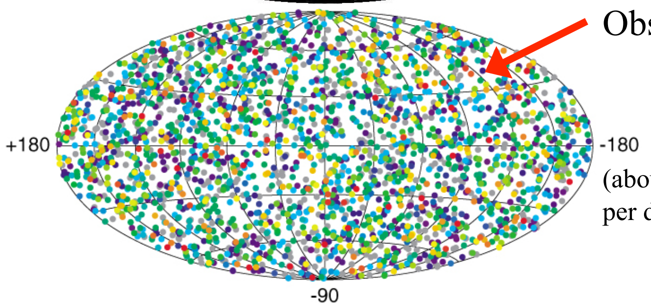
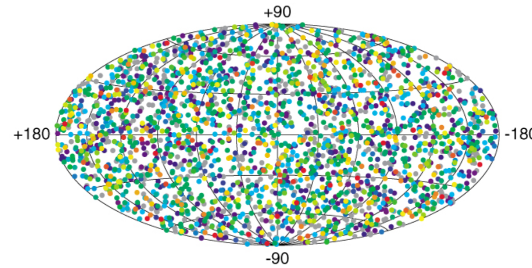
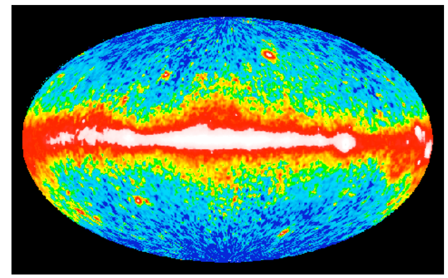


Gamma ray bursts observed by the BATSE instrument on the Compton Gamma Ray Observatory

(about one gamma ray burst per day was observed)



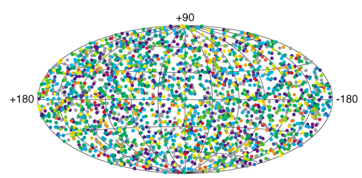
GRB distribution



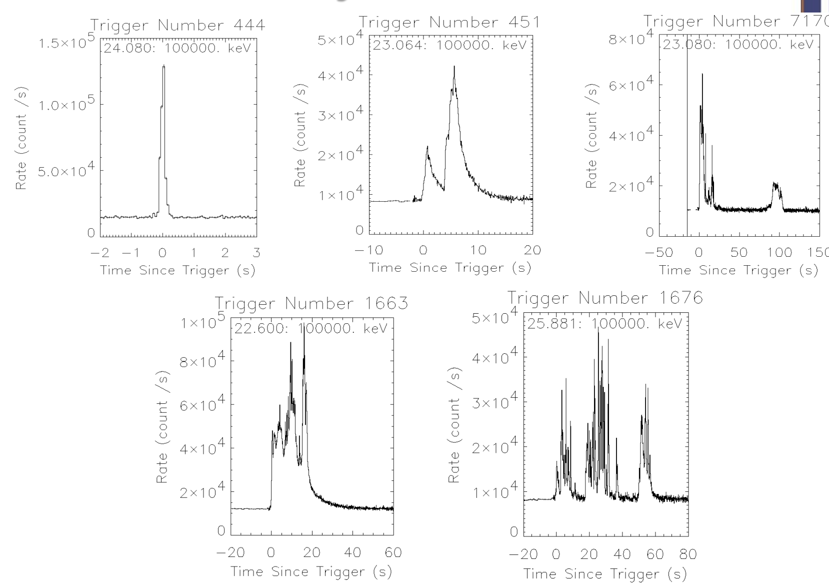
Gamma-ray sky

GRB Distribution

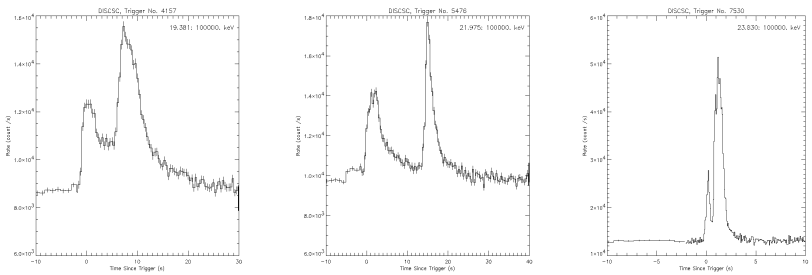
- Evenly distributed around the sky.
- If in the Solar System, would see more in one direction than the other (we aren't in the center).
- Could be uniformly distributed within a few hundred light years
  - How? Stars can't make gamma-ray bursts!
- Could be very, very, very far away.
  - How? If that far away, the energy is ridiculously high!



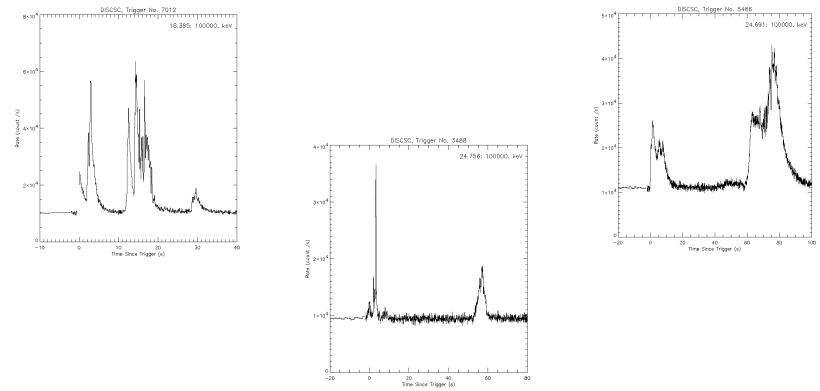
Diversity of GRB Profiles



Examples of Double-Peaked GRBs

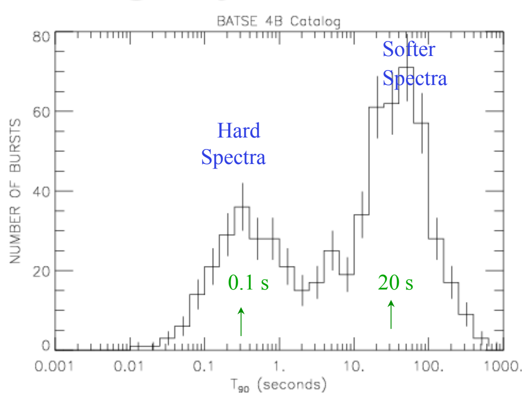


Multiple-Episode Bursts



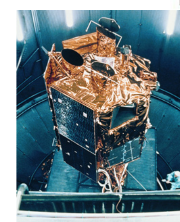
Distinct subclasses of Gamma–Ray Bursts: Short/Hard & Long/Soft

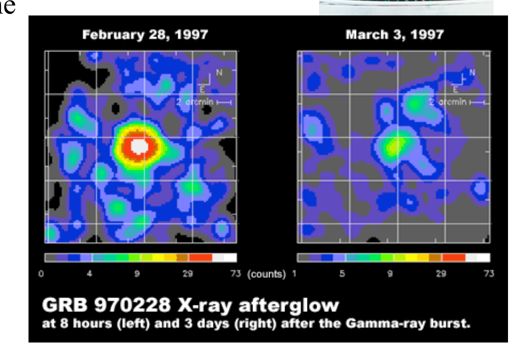
Hard/Soft means higher/ lower energy photons.



Breakthrough: BeppoSax

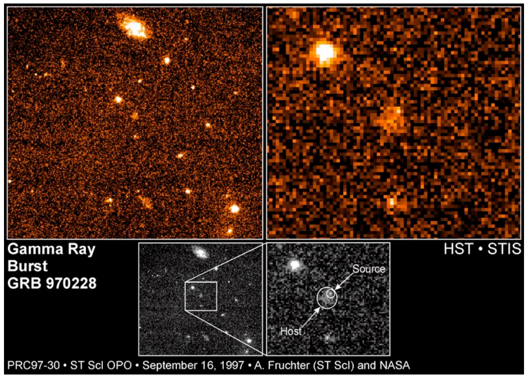
- Dutch/Italian satellite launched in 1996
- Had gamma-ray and x-ray detectors (x-ray telescopes have higher resolution)
- Was able to detect x-ray afterglow position of GRB in Feb 1997 (GRB 970228)
- Then, this enabled the Hubble Space Telescope to catch a glimpse.



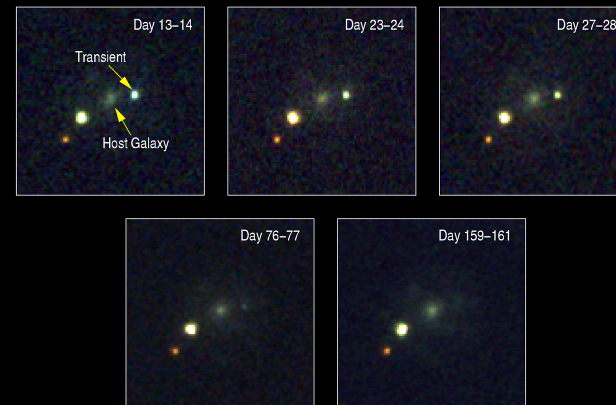


Breakthrough: BeppoSax

- GRB afterglow detected in optical light!
- And it was right next to a distant galaxy
- Afterwards, the Keck telescope obtained a spectrum of a host galaxy
- These things are far away (billions of light years)!

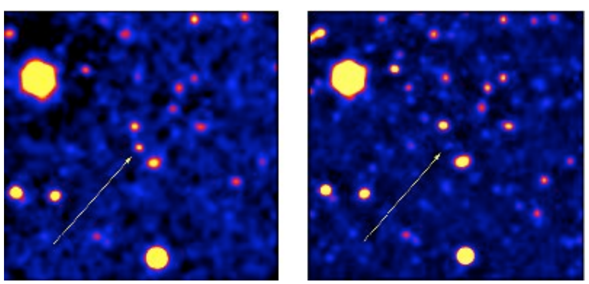


Gamma-ray Burst Afterglows



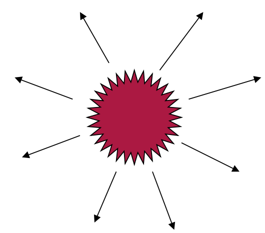
A Supernova in GRB 011121
Hubble Space Telescope/Wide Field Planetary Camera (WFPC2)
Shri Kulkarni, Joshua Bloom, Paul Price, and the Caltech–NRAO GRB Collaboration

Gamma-ray Bursts are Really, Really Far Away

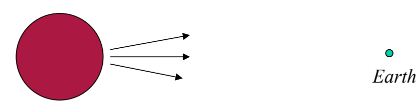


- GRBs are at the edge of the observable universe
- They must be the most powerful explosions in the universe: ~ 1 solar mass is converted into gamma-rays in a second! **(But, that's crazy talk!)**

What if not Isotropic?

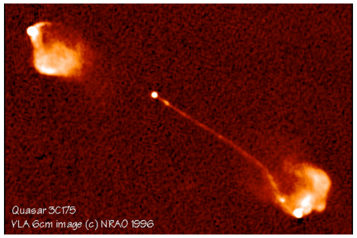


If the energy were beamed to 0.1% of the sky, then the total energy could be 1000 times less, closer to supernova energies.

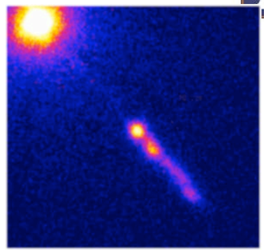


Nothing seen down here

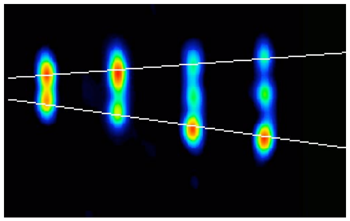
We know that jets are common



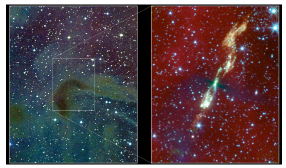
Quasar 3C 175 as seen in the radio



Quasar 3C273 as seen by the Chandra x-ray Observatory

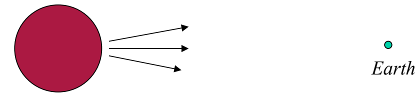


Microquasar GPS 1915
in our own Galaxy – time sequence



L1157 protostar

What if beamed?



Nothing seen down here

- There is evidence of beaming in the observational data.
- We see signs of asymmetry in supernova 1987A.
- The long duration GRBs are always seen in star forming galaxies.
- The afterglow light curve does looks like a supernova

Question

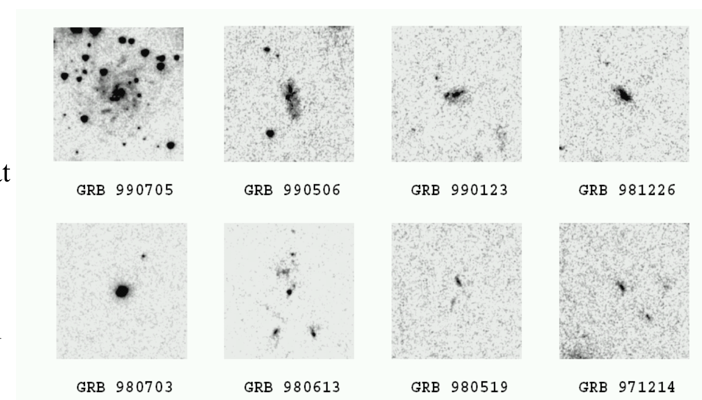
What evidence is there that GRBs are beamed and are not isotropic?

a) Based on their color
b) Based on the energy required
c) Based on their emission profile
d) Based on a theory of GRBs that places them in the Solar System

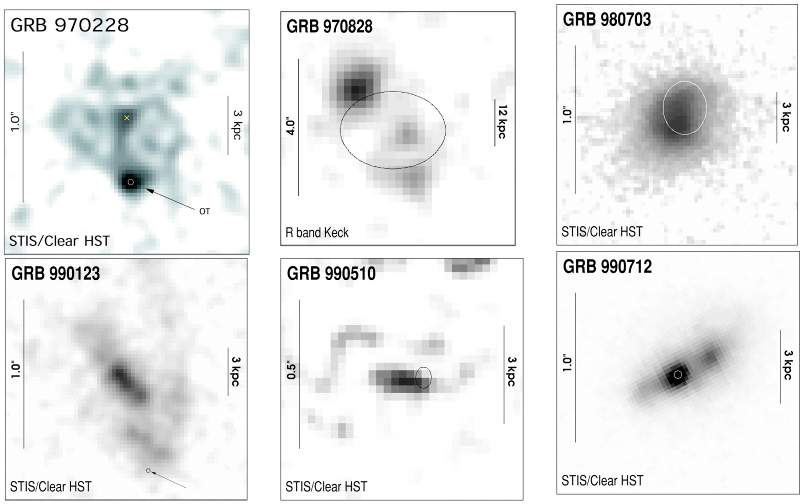
Host Galaxies

Hosts are similar to star-forming galaxies at similar distances.

High star formation rates.



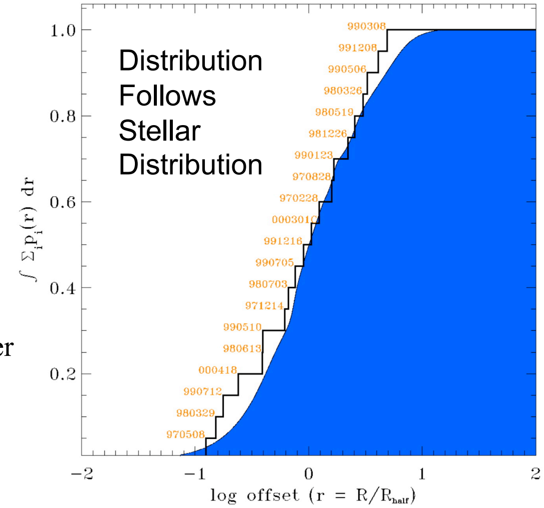
Location of GRB within Host



Location of GRB within Host

The environments of GRBs show higher gas densities, higher metallicities, and higher dust content than random locations in host galaxies.

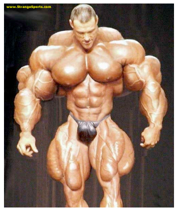
Suggests that GRBs occur in star forming regions.



GRB Locations

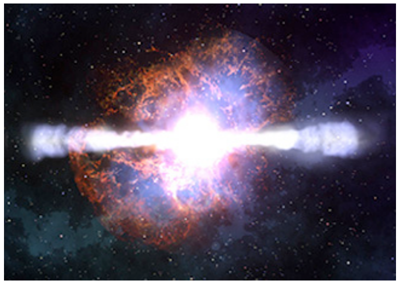
- GRB hosts are star-forming galaxies
- GRBs trace the stellar distribution (in distance from galaxy center)
- GRBs occur in dense environments (probably star forming regions)

- Suggests collapsar or hypernova model or a supernova on steroids!



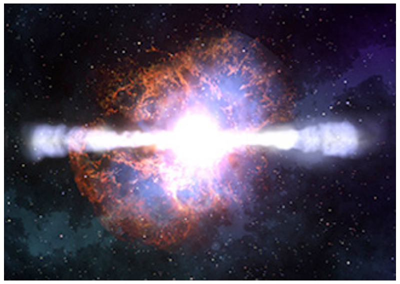
Hypernova or Collapsor

- The death of an exceptionally massive star, greater than ~50 solar masses!
- The core quickly collapses down to a black hole.
- The star must be rapidly rotating.



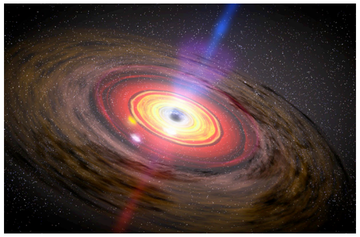
Hypernova or Collapsor

- For the jet to make it out of the star, most of the hydrogen envelope should have been lost during the earlier evolutionary stages.
- Combination of magnetic field and temperature create a strong gamma-ray beam.



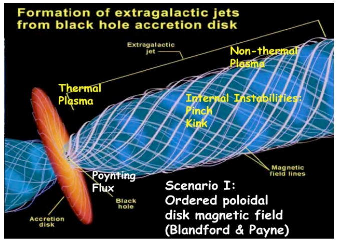
Blackhole Traffic

- Material falls into the revolving black hole is revolving around it, like water in a sink.
- This causes a traffic jam, material is all trying to fall in, but it meets resistance.
- This creates the formation of an accretion disk around the black hole. (Everyone loves disks!)
- Freaky high friction, heats up disk.



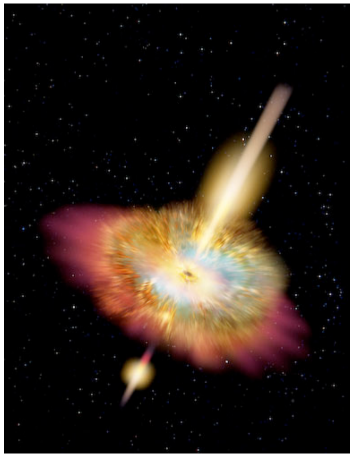
The Jet: So it Starts

- As in the case of neutrons stars, during the collapse the magnetic field strength increases.
- This combined with the hot temperatures tend to drive material away from the blackhole (outside of Schwarzschild radius)
- It can't move in disk plane, but above and below is open!
- Particles get accelerated, causing a pair of tight beams coming out of the magnetic poles.



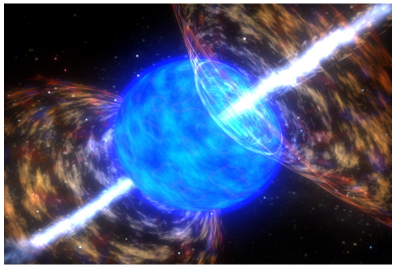
The Jet: So it Starts

- In the hypernova, all of this is happening fast!
- Moments after the black hole forms, an accretion disk forms and all that energy, a billion billion times the Sun's output, is focuses into twin beams of destruction.
- The beams chew their way through the star to the surface, where they are free!



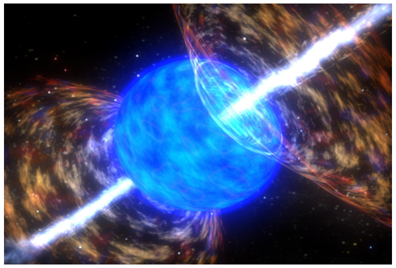
The Jet Goes Universal

- Ironically, the beam does not have too much stuff in it- only a few Earth masses.
- Matter can be accelerated to crazy speeds, almost the speed of light!
- The material thrown off as it evolves still surrounds the star, so this beam rams into it, creating shock waves, on a huge scale!



The Jet Goes Universal

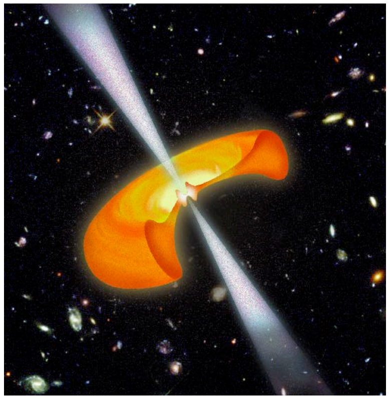
- These shocks and shocks in the jet itself emit copious amounts of gamma-rays; a GRB is born!



http://www.youtube.com/watch?v=npzgasXkHtk

The End

- Beams continue on to the edge of the Universe.
- Since the explosion is beamed, we only see a small fraction of them.
- So much rarer than normal core collapse supernova, or we'd see more.
- After the beam is gone, the supernova is still going on, which is where the optical afterglows come from.



http://www.youtube.com/watch?v=X6PLcM2dXmw&feature=fvw

2:25+

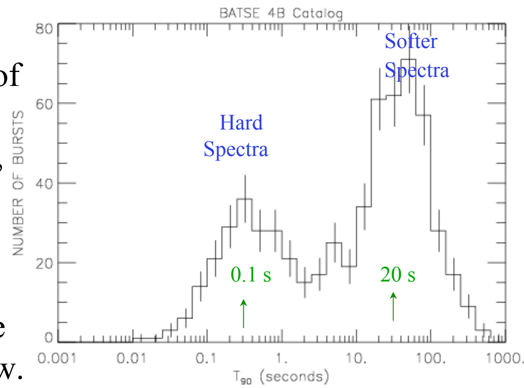
Question

What causes the beamed output of a hypernova?

a) Crazy spin
b) The entire mass of the stars is squirted up along the spin axis.
c) We don't know, but it is very rare. Only occurring once every 1000 years.
d) It is a combination of magnetic fields and starspots that cool the core during the supernova explosion.
e) The accretion of material into the blackhole also squirts material up along the axis due to temperature and magnetic fields.

More Than One Way

- Hypernovas or collapsors explain the long gamma-ray bursts, but what about the short ones?
- These are not seen in star forming galaxies.
- Seen in outskirts of galaxies or in old elliptical galaxies, which are no longer making stars.
- No supernova like emission afterglow.

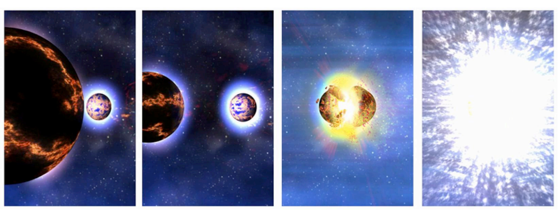


More Than One Way

- Although, astronomers are not actually sure, the most popular idea is an neutron star-neutron star merger or neutron star-black hole merger.
- Multiple systems are common, so we need a binary system with two 10-30 solar mass stars,
- The most massive star goes supernova, then the next.
- We're left with two compact objects in orbit.

Double Neutrons

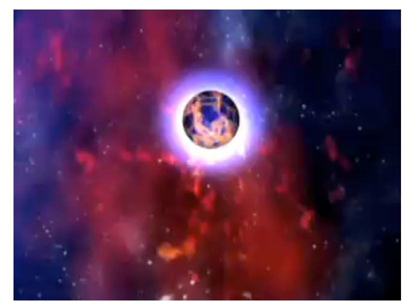
- Over billions of years, the orbits decrease.
- The neutron stars get closer and closer together
- They quickly rip apart and merge with enough mass to turn into a blackhole.
- If enough material left over, it can form a black hole with accretion disk too.



- Fast and no supernova light expected.

Double Neutrons

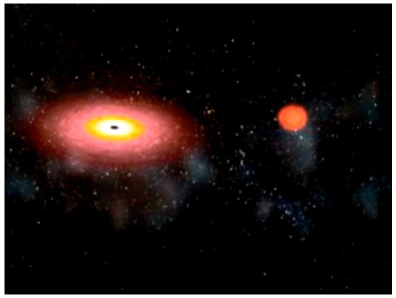
- Very similar to the hypernova
- Accretion disk, magnetic fields, powerful gravity creates twin beams of death.
- Expected to be shorter and higher-energy gamma-rays, and that is seen.



- Although hard to detect and rare, we do know of existing examples of close pairs in our Galaxy.

Neutron/Black Hole Merger

- Or, similarly, a neutron star mergers with a black hole.
- Again, accretion disk with possibility of GRB.
- We don't know of any, but rare and very hard to detect.
- Good news is that the total energy in all of these objects is smaller as they are so short in time.



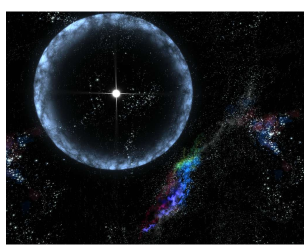
Question

Why does colliding/merging two 2 solar mass neutron stars create a black hole?

a) The total mass is greater than what can be supported by neutron degeneracy.
b) It doesn't.
c) The temperature at impact is so hot that only a black hole can be created.

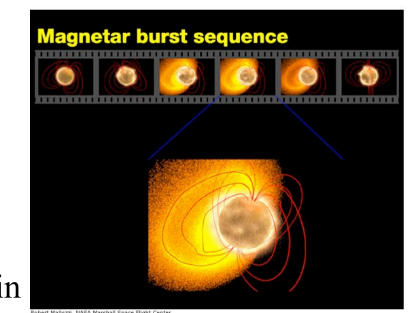
Magnetars

- Magnetars (high magnetic field neutron stars) also can produce GRB-like bursts, called magnetar flares.
- Stellar quakes from the twisting magnetic fields similar to solar flares.
- In Dec 2004, one was so bright (equal to 100,000 yrs of Sun output) that it blinded all gamma-ray satellites.
- It impacted the Earth's atmosphere, puffing up the Earth's ionosphere.



Magnetars

- The Dec 2004 magnetar was 50,000 light years away!
- If it was within 10 light years, it would have destroyed our ozone layer.
- No known magnetars within 13,000 light years.



Robert Mallozzi, NASA Marshall Space Flight Center

http://www.youtube.com/watch?v=L73hXWxdKM8
6:00-8:30