

Killer Skies

- ▶ **Homework 7** due Monday
- ▶ Night Observing--**done (Report due Nov 15th)**
- ▶ Last time: Death of High Mass Stars
- ▶ Today: Gamma Ray Bursts



Music: *Sun King* – Beatles

Top 10 Ways Astronomy Can Kill you or your Descendants

- 1. Impacts! Splat.. Boom... Watch out for space rocks!**
- 2. Solar storms - Magnetic bubble, coil, and trouble**
- 3. Death of the Sun - Burn the land and boil the sea**
- 4. Nearby Supernova - Sirius danger?**
- 1. Gamma Ray Bursts - Cosmic Blowtorches**

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



Nuclear Test Ban Treaty

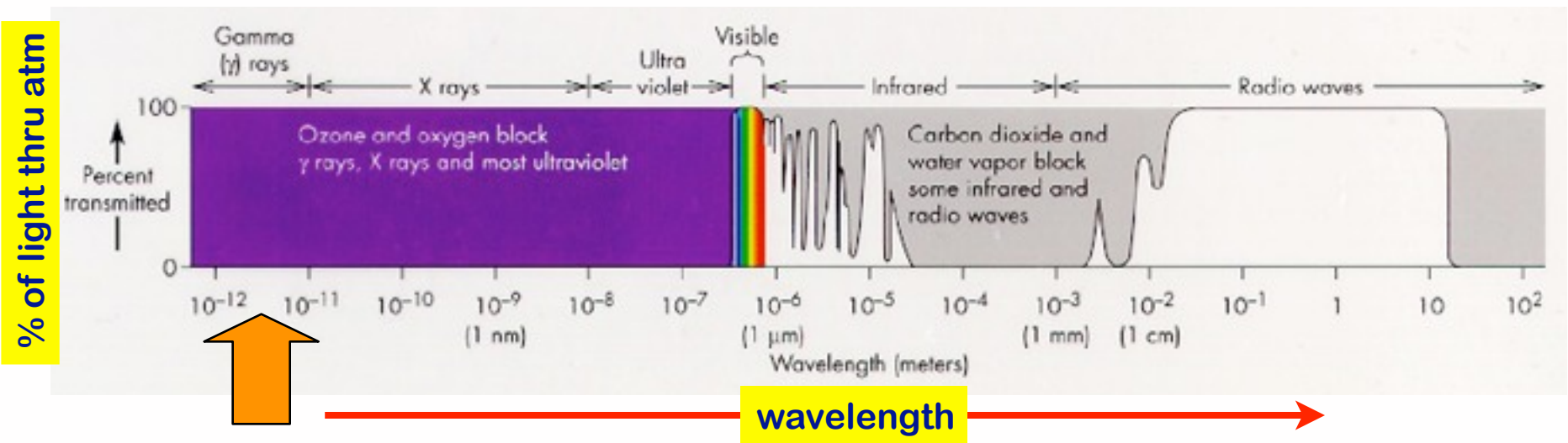


In the 1963, the US and USSR decided to ban some testing of nuclear weapons.

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 blocks gamma-rays

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

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

How to detect?

Launch a satellite!

Vela program commissioned to monitor for nuclear bomb tests in space and upper atmosphere

Vela Satellites Spot Something Weird

Vela satellites:

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

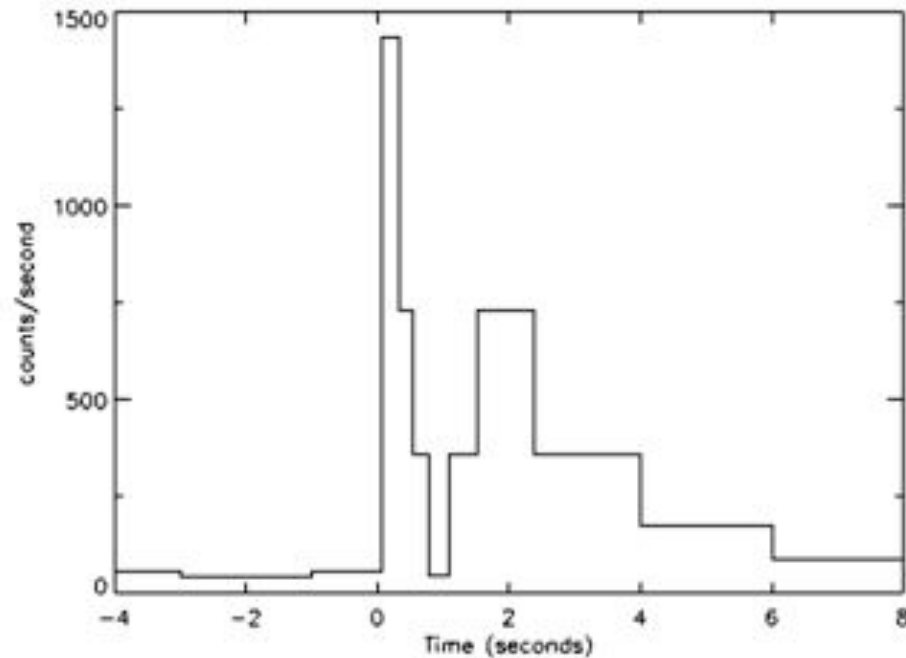
**July 2, 1967, they detected
their first hit!**

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!**

7

A strong, sharp peak for less than a second

Followed by a longer, weaker pulse lasting several seconds.

On July 2, 1967, at 14:19 UTC, the Vela 4 and Vela 3 satellites detected a flash of gamma radiation unlike any known nuclear weapons signature.[8] Uncertain what had happened but not considering the matter particularly urgent, the team at the Los Alamos Scientific Laboratory, led by Ray Klebesadel, filed the data away for investigation.

73 Bursts in Gamma-Rays over 10 years

Completely unknown group of sources!

What are they?

Needed to wait for real-time info and better directional info.

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**

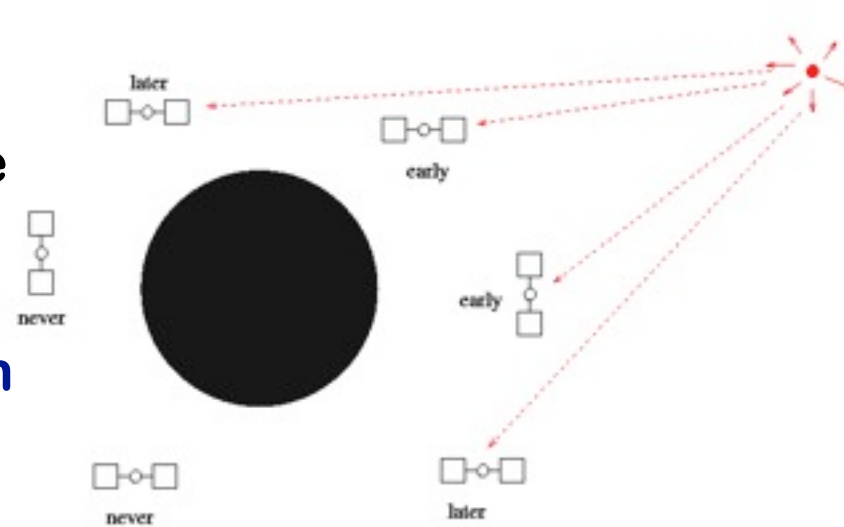
Results:

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

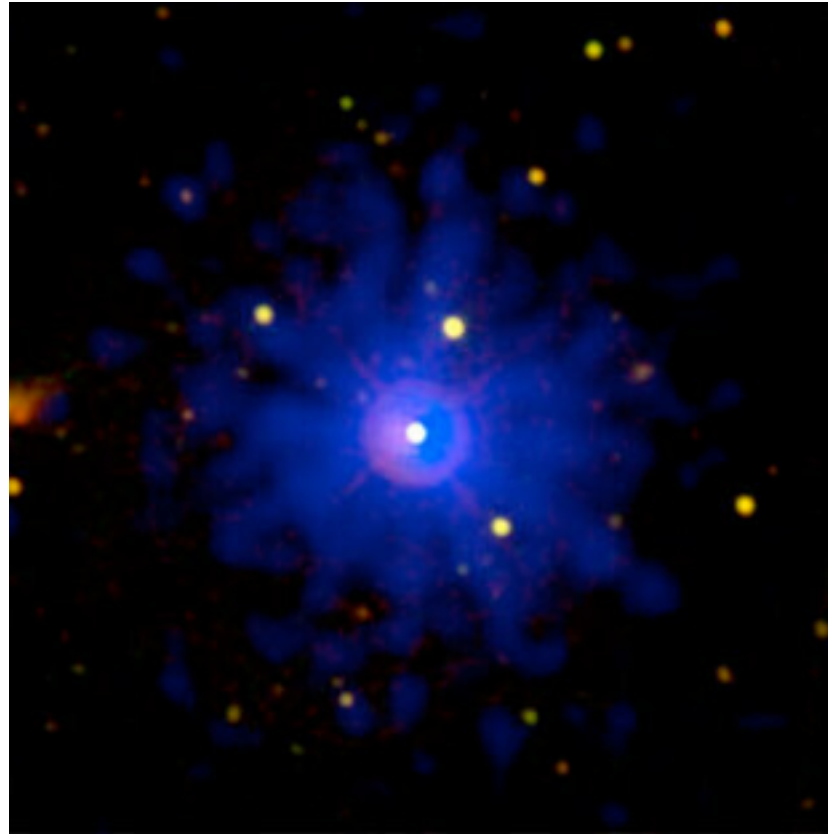


Where do gamma-ray bursts originate?

In our solar system?

In our galaxy, the Milky Way?

**Incredibly far away near the
edge of the observable
Universe?**



Compton Gamma Ray Observatory

The GRB Hunter



April 5, 1991 – June 3, 2000

Four gamma-ray instruments: EGRET, COMPTTEL, OSSE, and BATSE

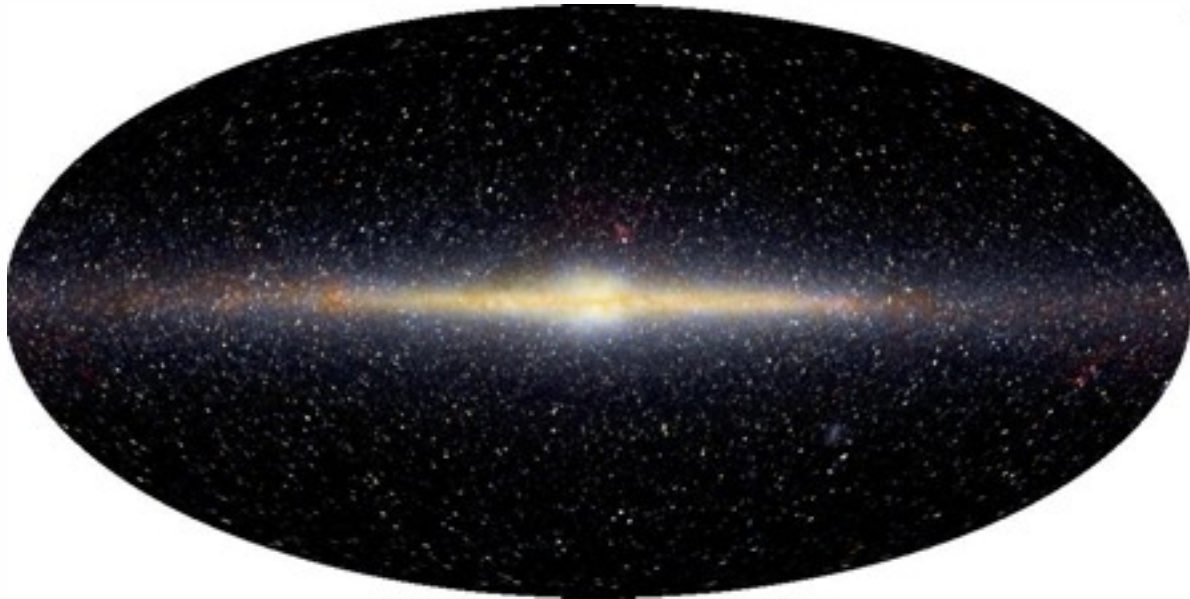
BATSE (Burst And Transient Source Experiment) proved to be the most useful instrument for GRB detection

iClicker Poll:

Guess the GRB sky pattern!

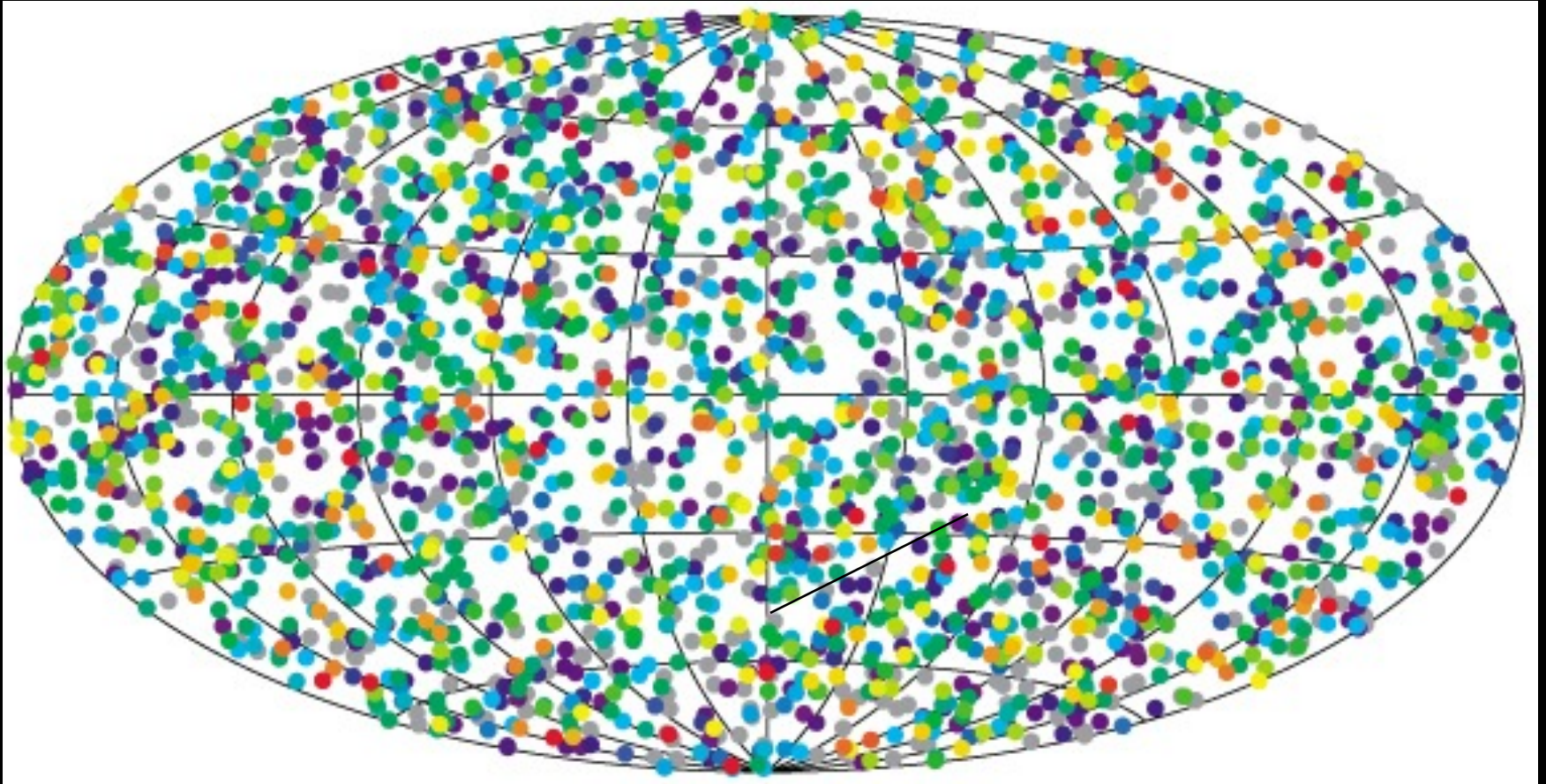
The disk of our galaxy (the combined light of billions of distant stars) appears as a band around the sky. If gamma ray bursts are in the Milky Way, what would the map look like?

- 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

Evenly distributed around the sky. No galactic origin.
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!

Gamma ray burst locations - Evenly distributed around the sky



<http://www.youtube.com/watch?v=qomRweB6moc>

Gamma-Ray Bursts: The Situation after Compton

BATSE monitored all sky for 9 years
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: 1 GRB/day!

no repeat events from same direction

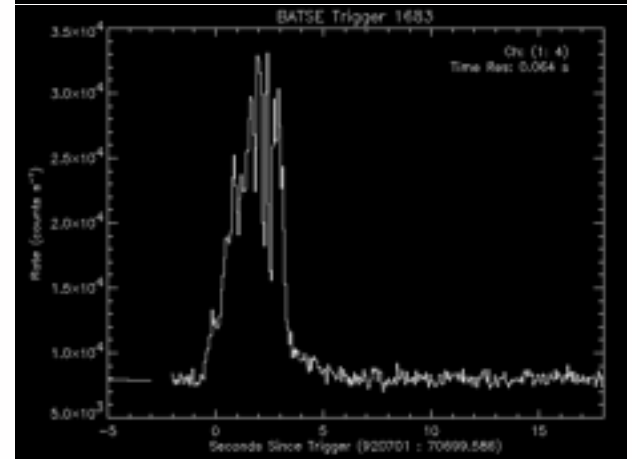
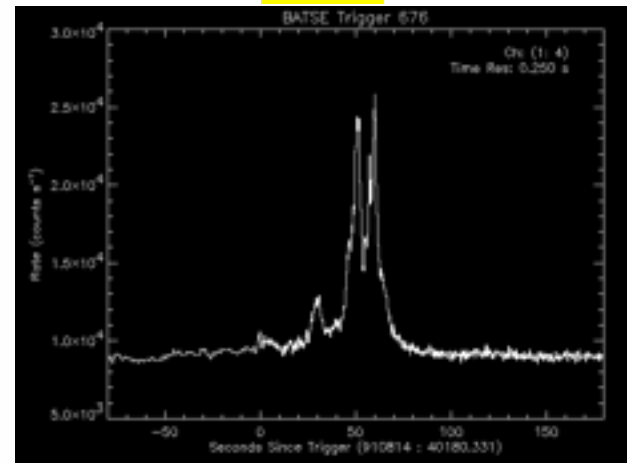
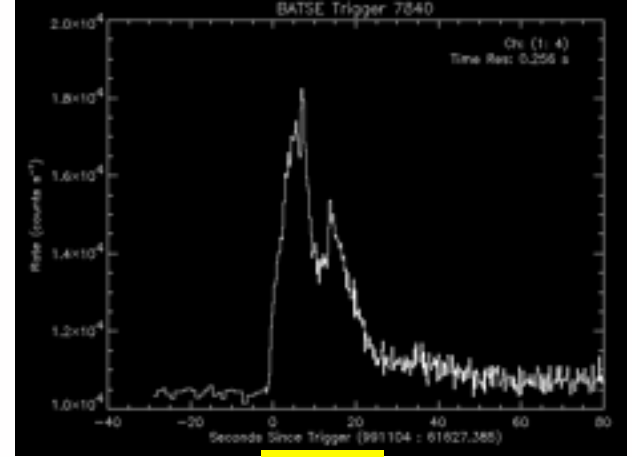
burst duration from 0.1 sec to 100 sec

time history (lightcurves): highly nonuniform

- ▶ some highly variable: huge changes over 0.1 sec timescales!
- ▶ but others fairly smoothly varying

gamma signal

time



Gamma-Ray Bursts: The Situation after Compton

But mysteries remained:
sky locations of burst only
known to within
1 degree = 2 full moons across

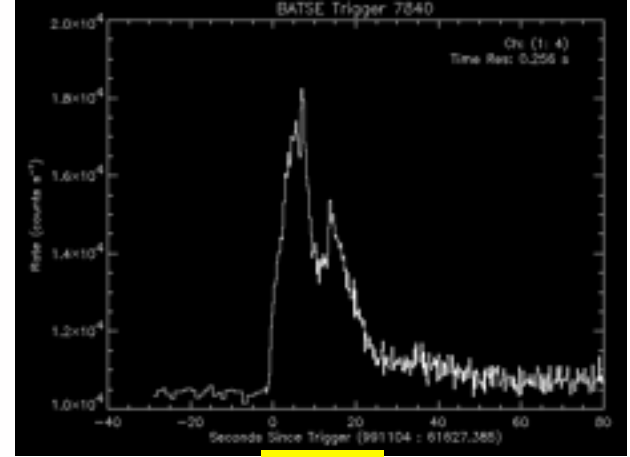
like looking through “coke-bottle
glasses”

too big a region to quickly search
with telescopes

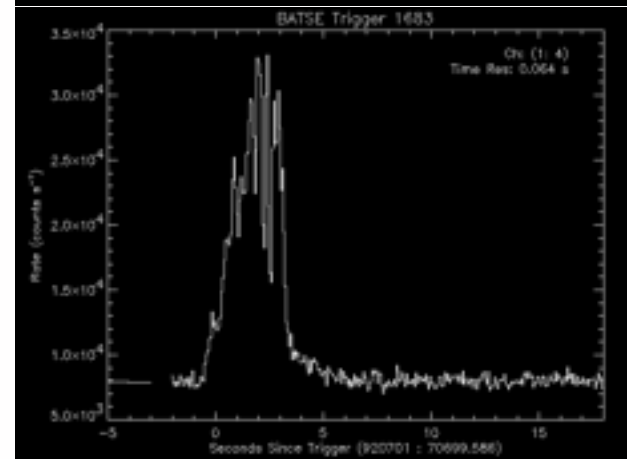
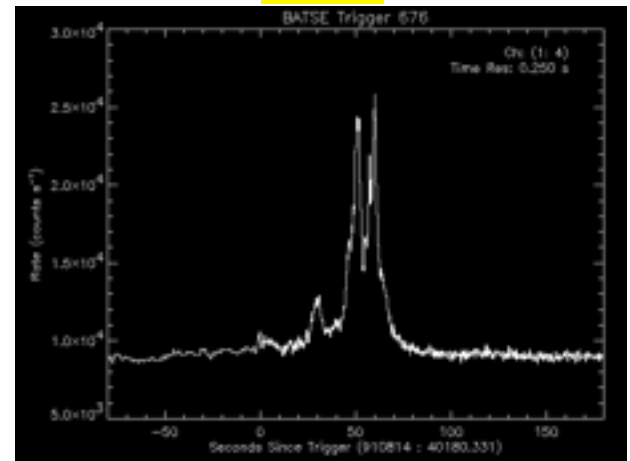
no counterparts seen at any other
wavelengths!

Needed to get more precise locations
on sky

gamma signal

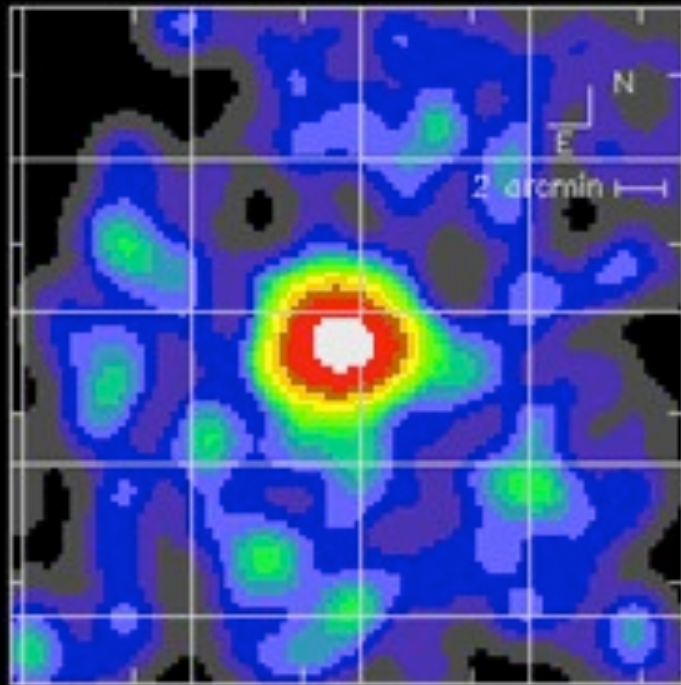


time



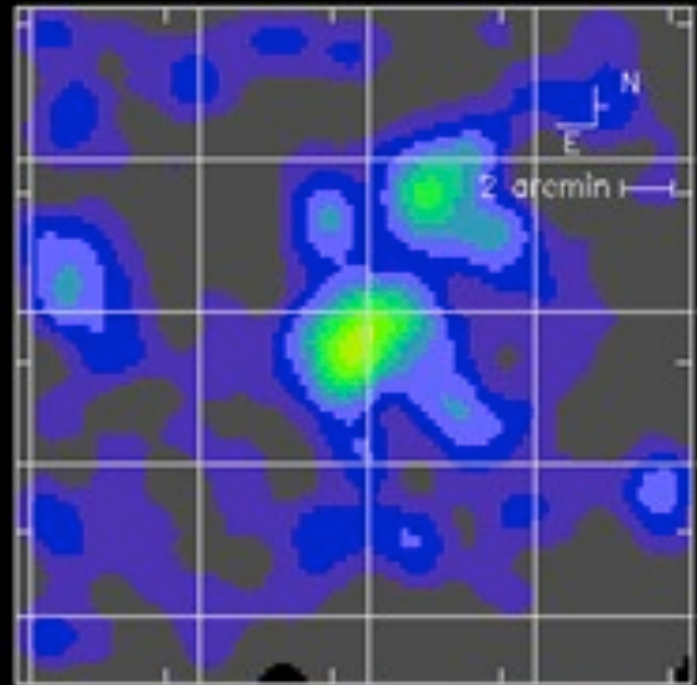
Breakthrough: BeppoSax

February 28, 1997



0 4 9 29 73 (counts) 1

March 3, 1997



1 5 9 29 73

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

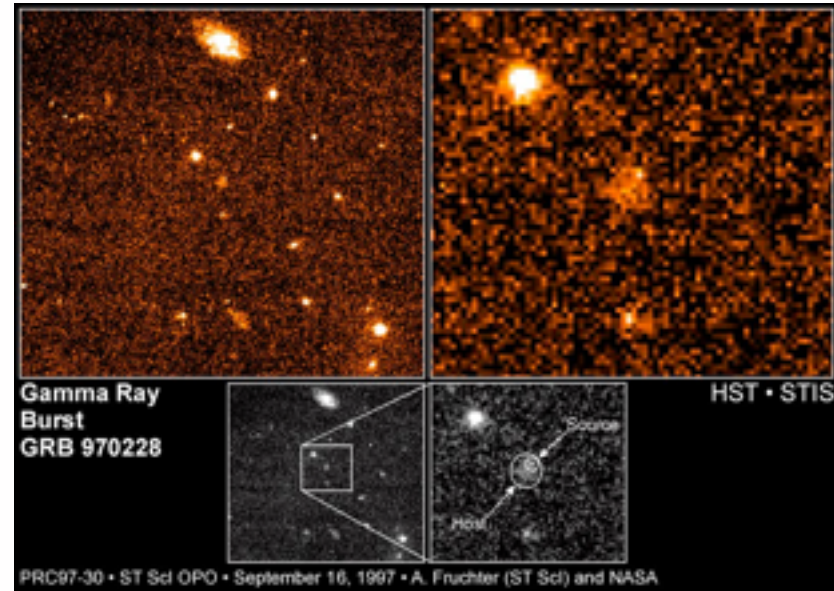
Dutch/Italian satellite launched in 1996
Had gamma-ray and x-ray detectors (x-ray telescopes have higher resolution)
Was able to detect x-ray afterglow position of GRB in Feb 1997 (GRB 970228)
Then, this enabled the Hubble Space Telescope to catch a glimpse.

GRB afterglow detected in visible light!

Using X-rays to pinpoint
GRB location, possible to
search using ordinary
telescopes

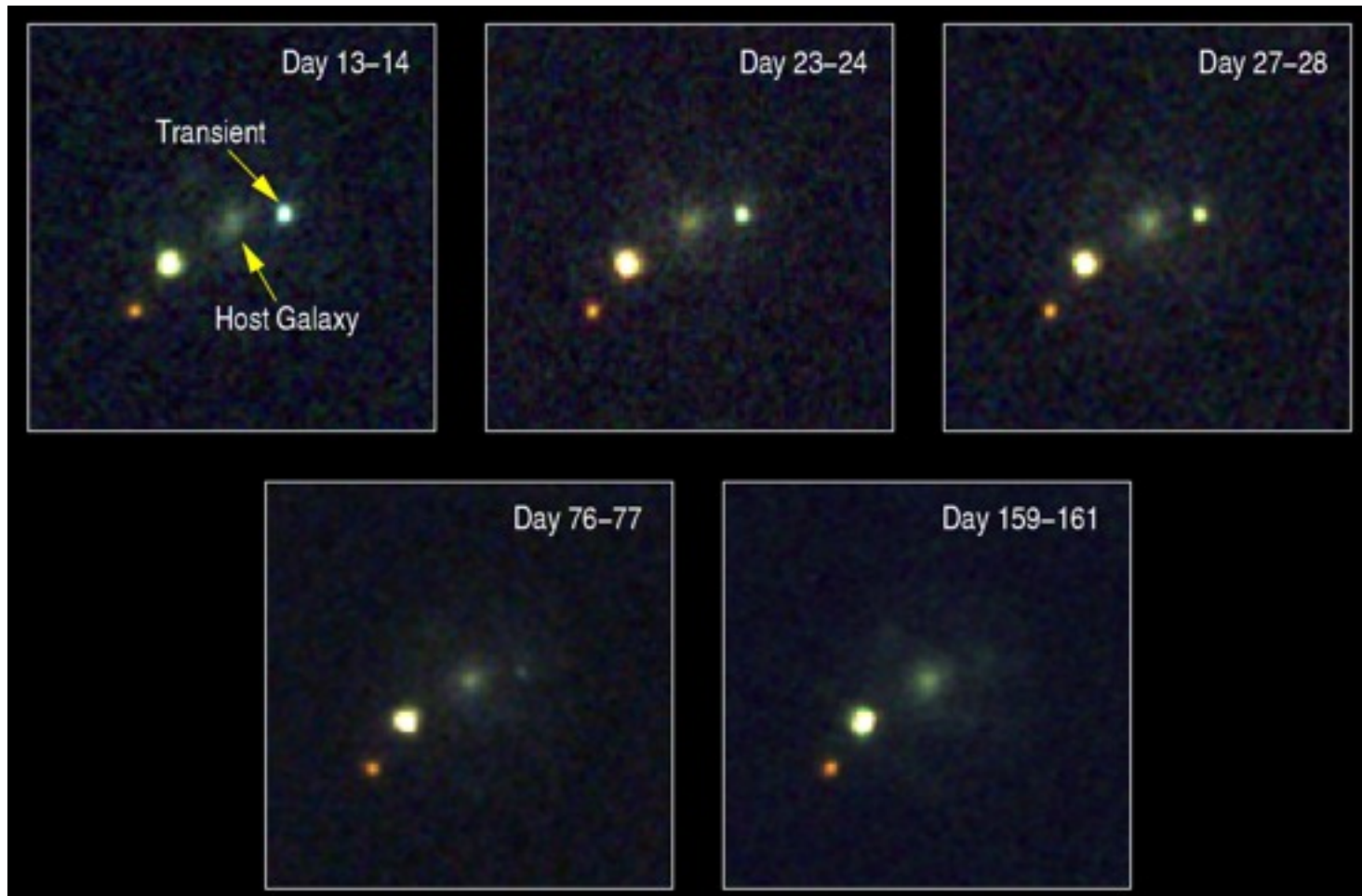
detections made at all
wavelengths!

non-gamma signals dim
over time, but last much
longer: “**afterglows**”



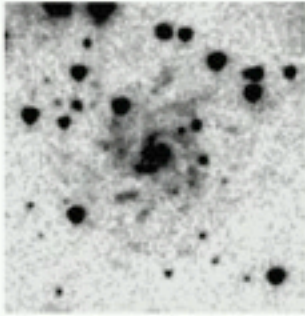
GRB afterglow detected in optical light!
And it was right next to a distant galaxy
Afterwards, the Keck telescope obtained a spectrum of a host galaxy
These things are far away (billions of light years)!

Gamma-ray Burst Afterglows

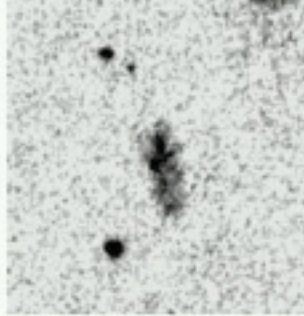


The afterglow of a GRB looks like a **supernova**

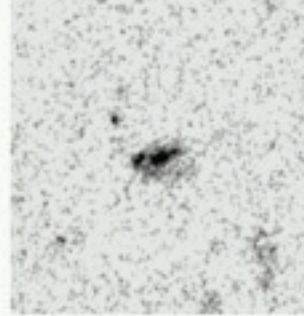
GRB Host Galaxies



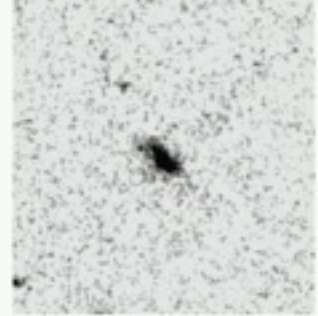
GRB 990705



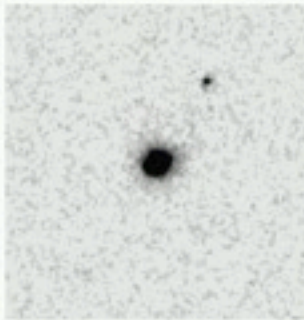
GRB 990506



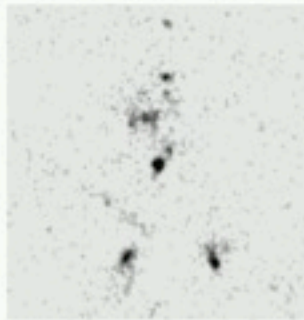
GRB 990123



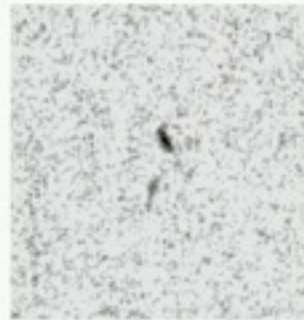
GRB 981226



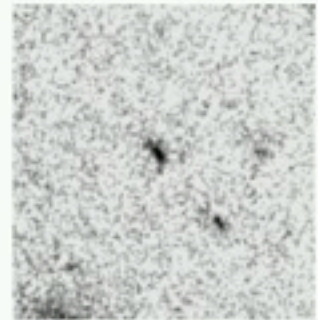
GRB 980703



GRB 980613



GRB 980519



GRB 971214

**GRBs are often observed in galaxies
with active star formation**

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

Visible to the Naked Eye

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



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

GRBs must have very high energies

Gamma-ray bursts are really far away

Detected as far as
13 billion light years away!

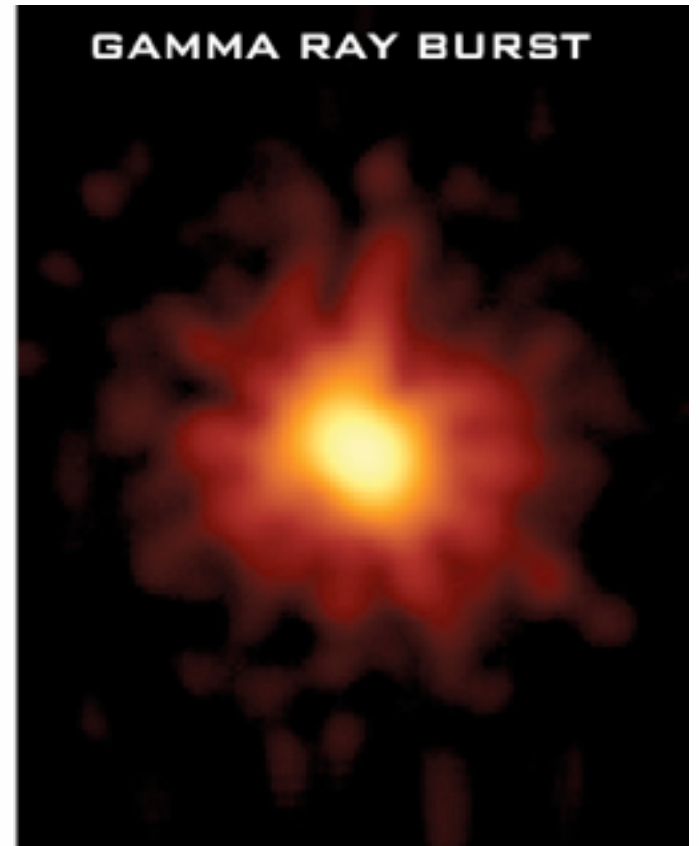
Near the edge of the observable
universe!

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!

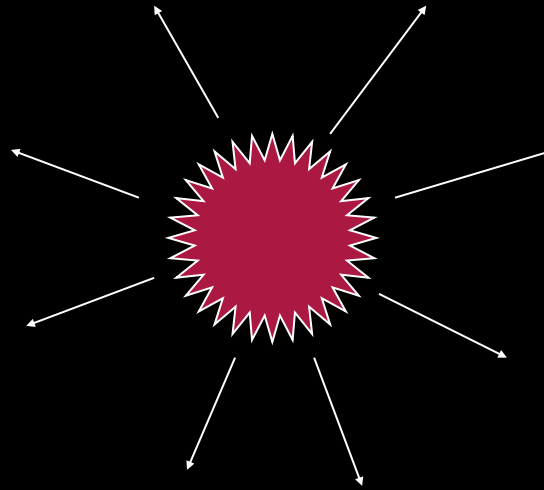


GRB detected at 12.8
billion light years
away!

No known process in the Universe can produce this much energy in such a short time.

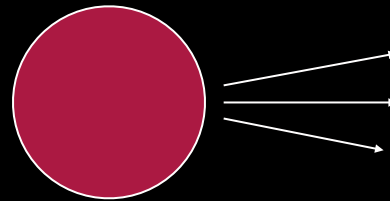
What if the energy were *beamed*?

In an isotropic explosion, energy goes out in all directions



Earth

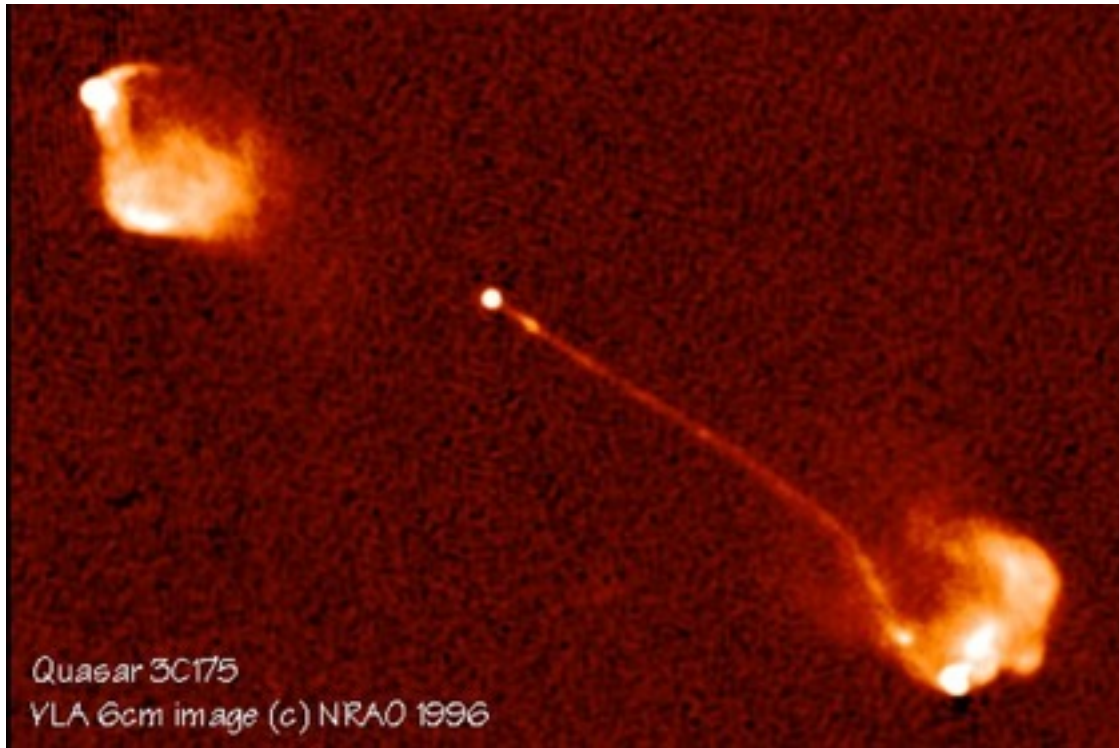
If the energy were beamed to 0.1% of the sky, then the total energy could be 1000 times less - comparable to supernova energies



Earth

*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**

Hypernova or Collapsar

- The death of an exceptionally massive star $>50M_{\text{sun}}$!
- The core quickly collapses down to a **black hole**.
- The star must be rapidly rotating.



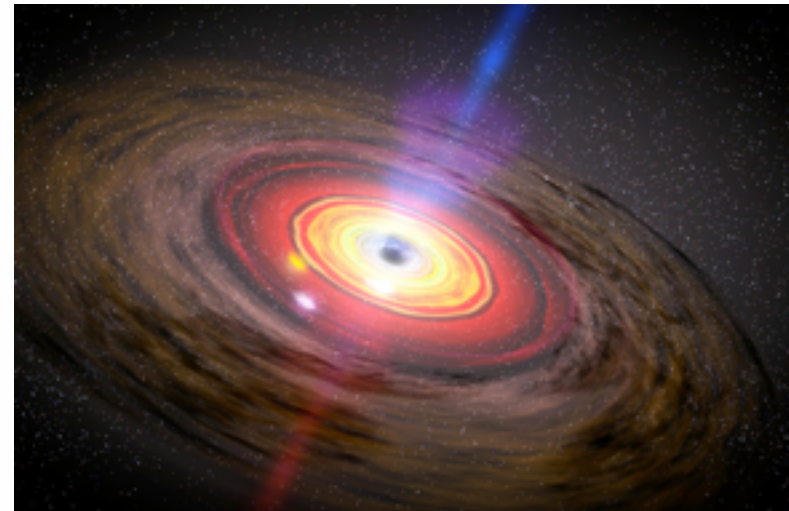
Hypernova or Collapsar

- But GRB is addition to normal supernova blast, and must be highly beamed
- need to create high energy, tightly focussed “jet”
- 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.



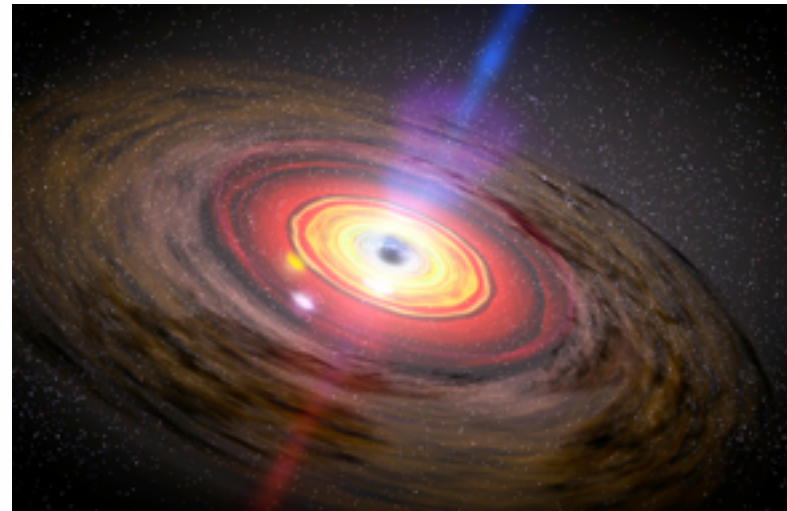
Blackhole Traffic

- This creates a “traffic jam” and leads to the formation of an **accretion disk** around the black hole. (Everyone loves disks!)
- Freaky high friction, heats up disk.
- Friction causes orbiting material to slowly spiral into the black hole



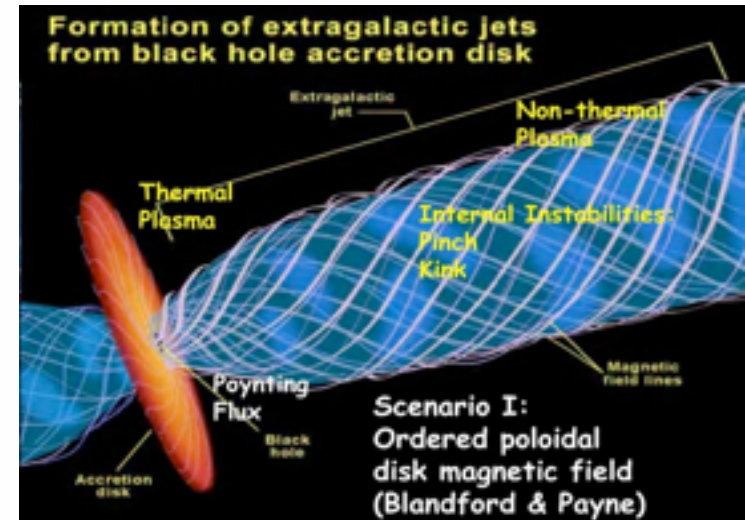
Blackhole Traffic

- Material falls into the revolving black hole is revolving around it, like water in a sink.
- Material is pulled toward the star by gravity (“**accretion**”)
- but accreted material is also orbiting--closer orbits are faster (Kepler’s laws!)



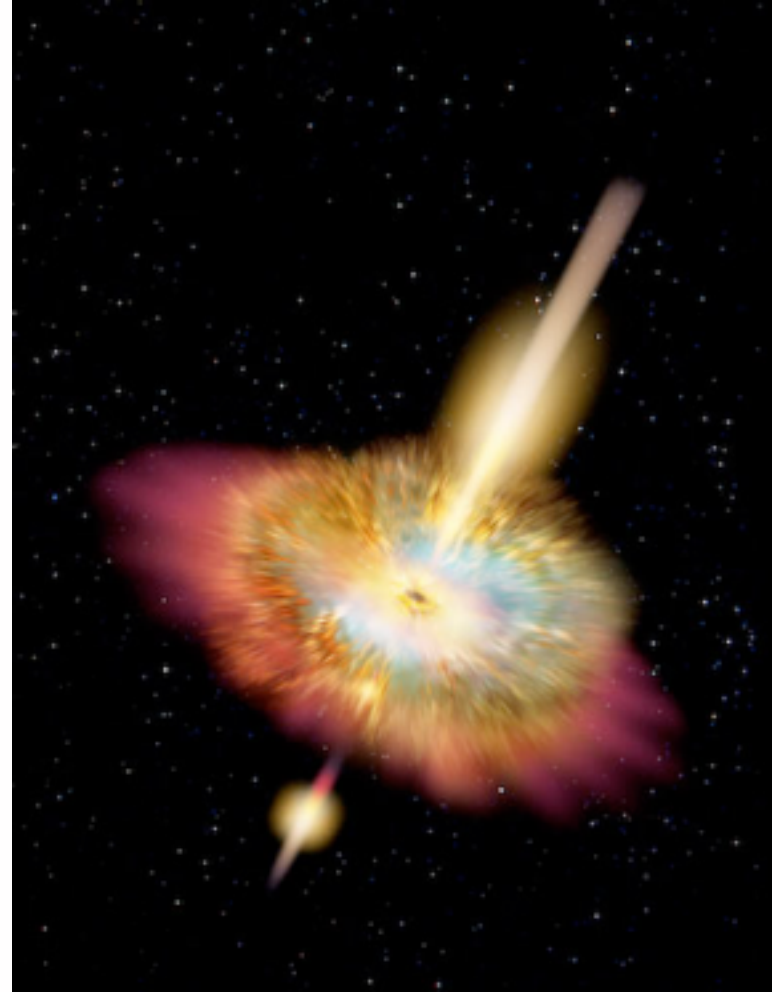
The Jet: So it Starts

- As in the case of neutron stars, during the collapse the magnetic field strength increases.
- This combined with the hot temperatures tend to drive material away from the black hole
- 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.



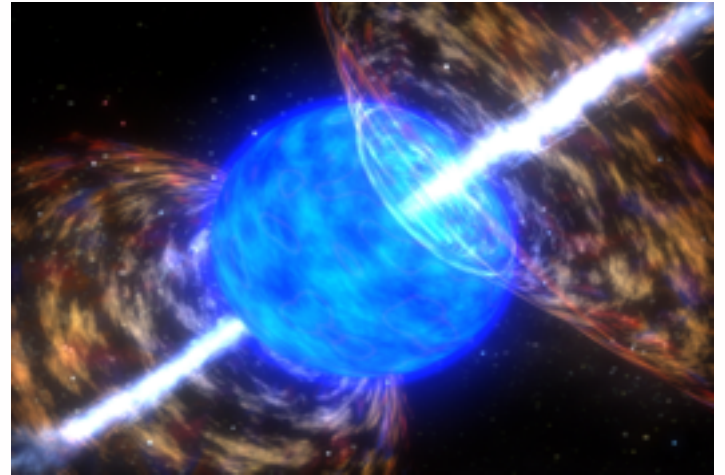
The Jet: So it Starts

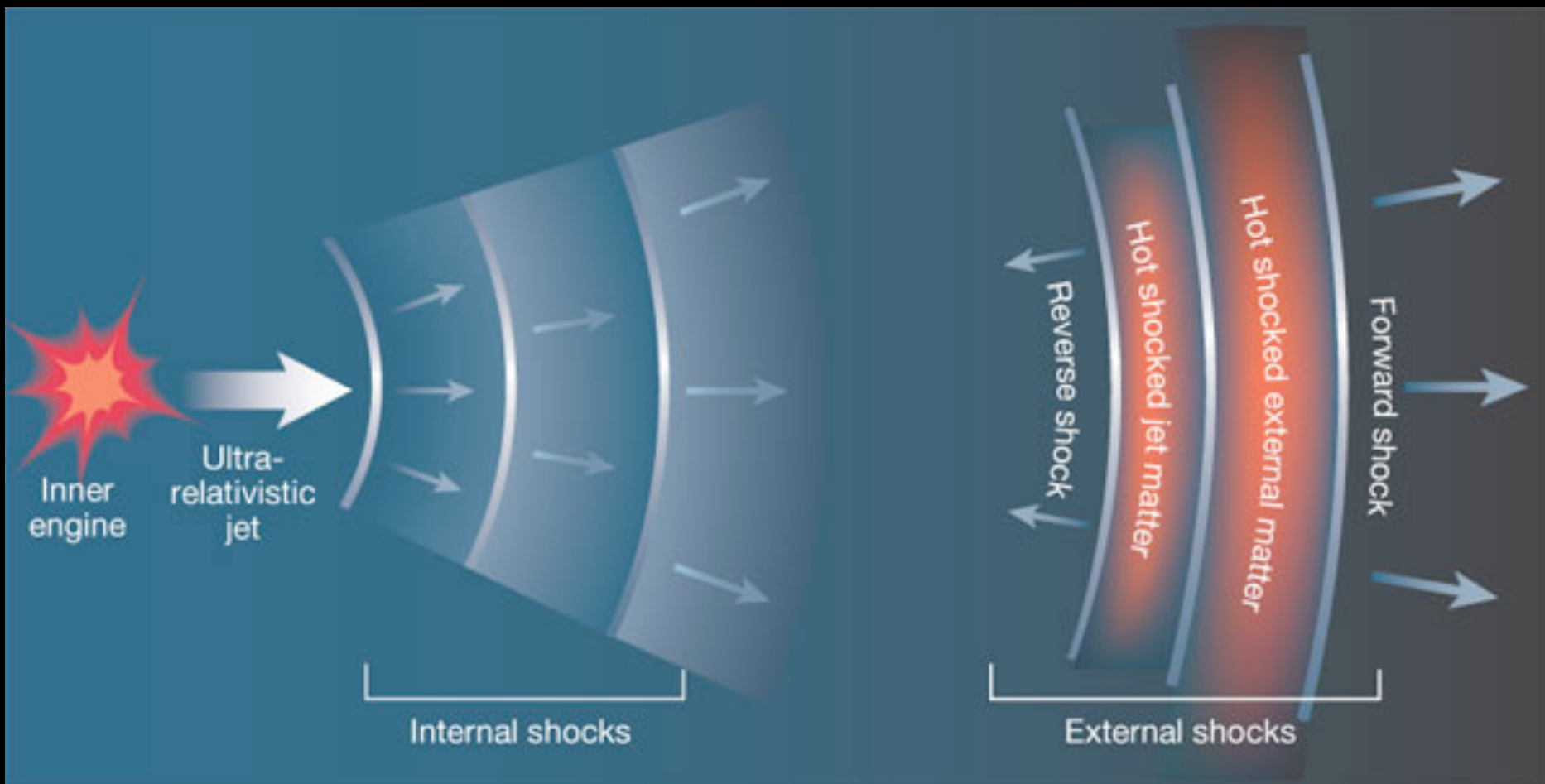
- In the hypernova, all of this is happening fast!
- Moments after the black hole forms, an accretion disk forms
- and all that energy, a billion billion times the Sun's output, is focuses into twin back-to-back beams of destruction.
- The beams chew their way through the star to the surface, then erupt
- blast into space 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!
- But region surrounding the exploding star is filled with debris blown off by powerful winds during the stars life
- the high-energy beam rams into the surrounding matter



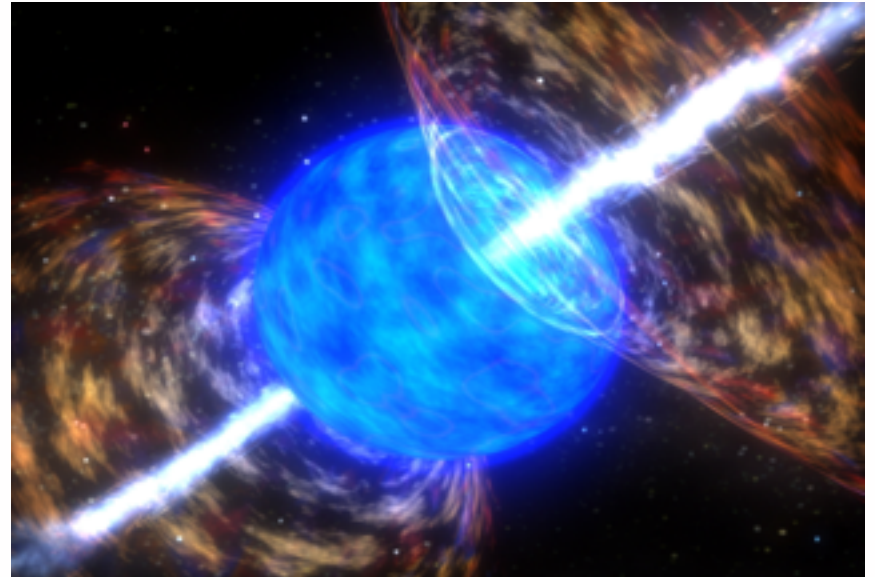


Colliding material within the jets create colossal shock waves that trigger the gamma-ray burst

A gamma-ray burst (GRB) is thought to be driven by an 'inner engine', a cataclysmic event such as the collapse of a massive star. Inside an ultra-relativistic jet of particles thrown out from the explosion, internal shocks release a vast amount of energy in a burst of γ -rays. When the jet is slowed down by surrounding matter, external shocks are created: the forward shock that propagates further into space, and the reverse shock that is reflected back against the relativistic flow. Both types of shock waves heat the surrounding matter, producing an afterglow to the GRB.

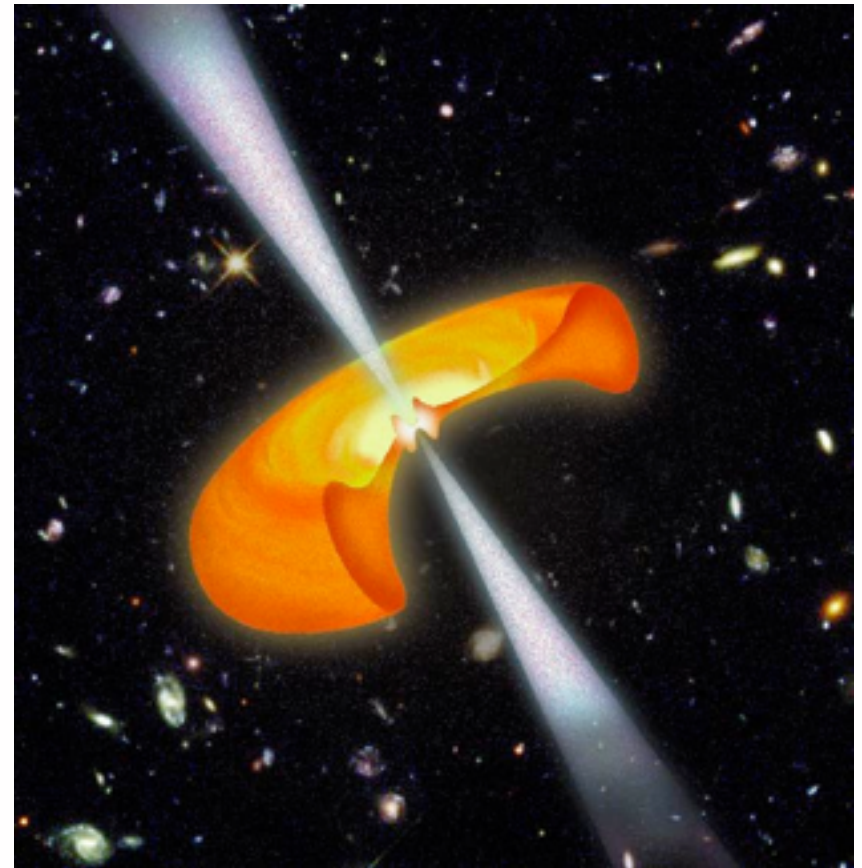
The Jet Goes Universal

- These collisions of gas at high speed produce shocks that heat the gas up to huge temperatures
- and shocks in the jet itself emit copious amounts of gamma-rays; a GRB is born!



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.



GRBs



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

Question



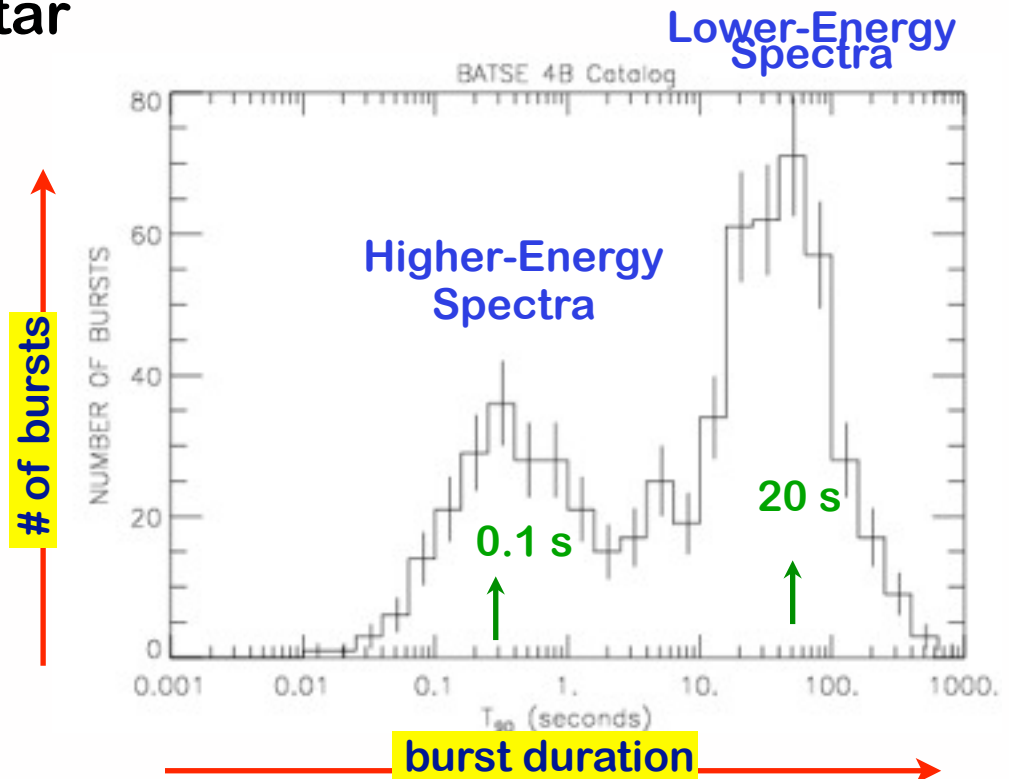
What causes the beamed output of a hypernova?

- A. Slow spin**
- B. The entire mass of the star 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.**

Answer E

More Than One Way

- Gamma-ray bursts seem to come in **two varieties**:
 - shorter-lasting and higher-energy
 - longer-lasting and lower-energy
- Hypernovas or collapsars 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.



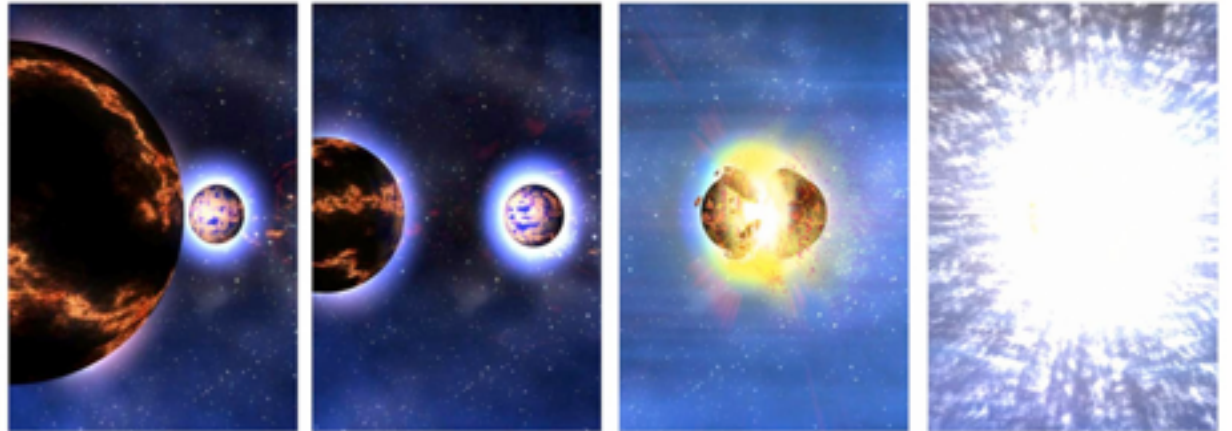
More Than One Way

- 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.



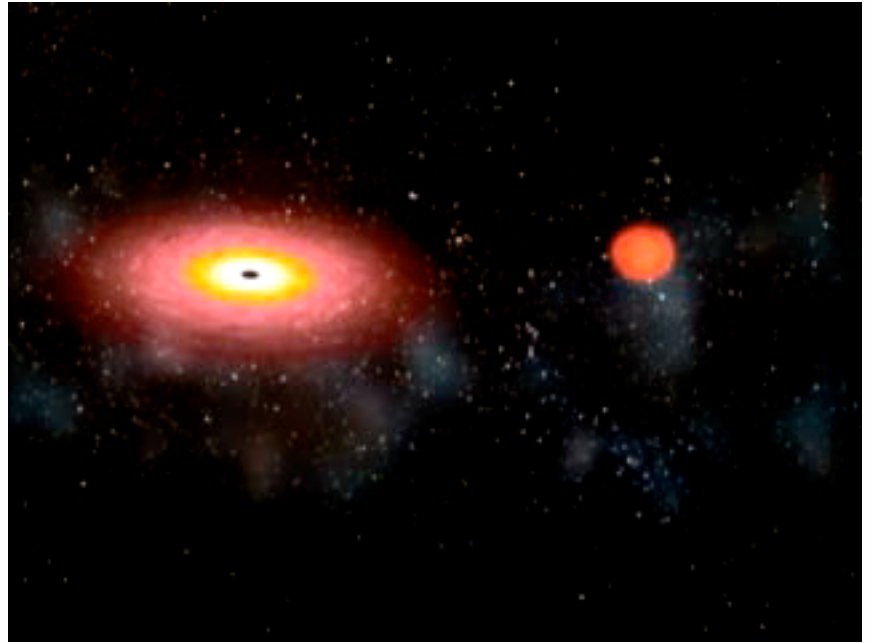
Double Neutron Stars

- 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.



iClicker Poll:

Merging neutron stars

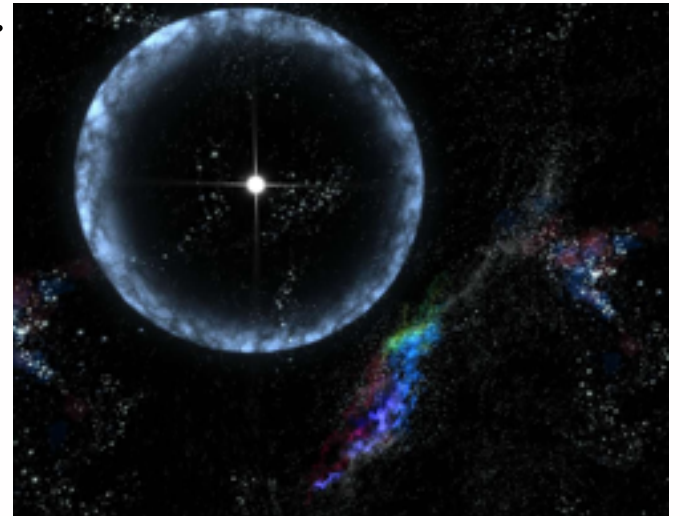
Why does colliding/merging two 2 solar mass neutron stars create a black hole?

- A. The total mass leads to gravity that is stronger than what can be supported against gravity.
- B. It doesn't.
- C. The temperature at impact is so hot that only a black hole can be created.

Answer A. We'll come back to this, but just like there is a maximum mass to a white dwarf, there is a maximum mass to a neutron star. Once you go over that mass, the object is going to be a black hole— gravity wins!

Magnetars

- Magnetars (neutron stars with ultrahigh magnetism) 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.
- **Good news:** No known magnetars within 13,000 light years.

