## *Astronomy 150:*
# *Killer Skies*

This Class (Lecture 21):
Gamma-Ray Bursts

Next Class:
Gamma Ray Killers

**HW7 due on Sunday!**

**Night Obs/Computer labs due in class on Nov 9th.**
**HW 2 due on the 7th.**
**Exam 2 on the 30th!**

**Music: *3rd Planet*– Modest Mouse**

# *Did You See Them Tuesday Morning?*

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

Not this one:
http://www.youtube.com/watch?v=A9V5Ba0_9Xs&NR=1

# *Night Obs*

- Dates:
  - Monday, Sept. 21st ✔
  - Tuesday, Sept. 22nd ✗
  - Wednesday, Sept. 23rd ✗
  - Thursday, Sept. 24th ✗
  - Monday, Sept. 28th ✗
  - Tuesday, Sept. 29th ✔
  - Wednesday, Sept. 30th ✔
  - Thursday, Oct. 1st ✗
  - Monday, Oct 5th ✔
  - Tuesday, Oct 6th ✗
  - Wednesday, Oct 7th ✔
  - Thursday, Oct 8th ✗
  - Monday-Thursday, Oct 12th –15th ✗
  - Monday, Oct 19th ✔

Night Obs is finished.

Turn in assignment in-class before or no Nov 9th.

# *Outline*

- Cold War discovery
- The biggest bangs since the Big Bang!

# Supernova on Steroids?

Is there any nova bigger than a super?

## 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 were 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*

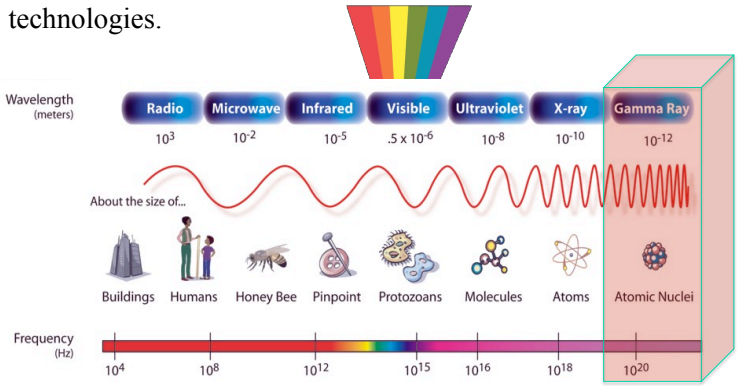
5. Gamma Ray Bursts!

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

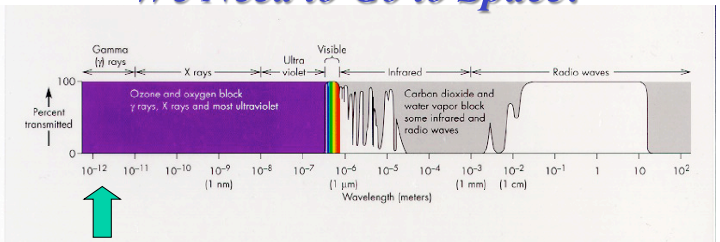
GRB 090423 is also the oldest known object in the Universe. It is 13 billion light years away! The Universe is only 13.7 billion years old, so this thing happened 30 million years after the Big Bang!

## 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.

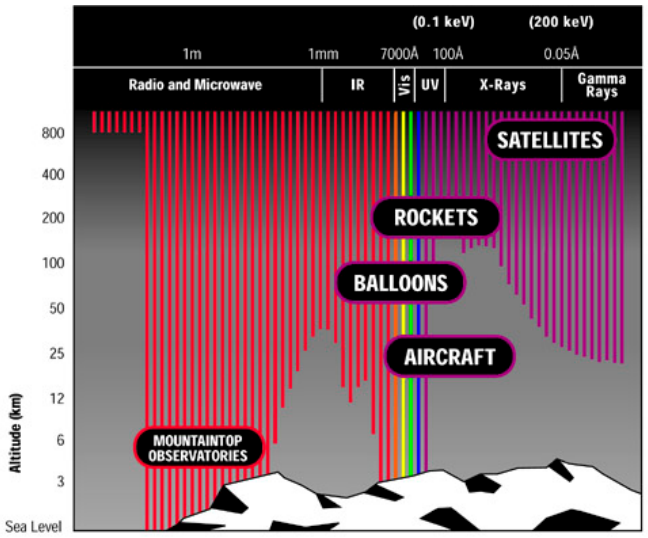


## To See Gamma-Rays, We Need to Go to Space?




- 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 we can't trust the USSR, so how do to check?

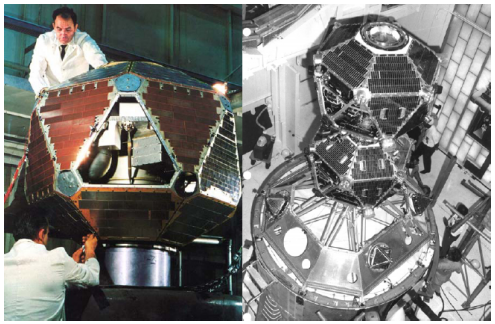
- Seismic Waves
- Low Frequency Sound Waves

Mogul Project

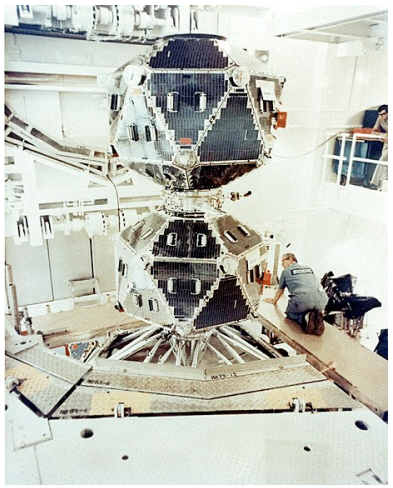
Crashed Balloon became Roswell Alien!

# 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.

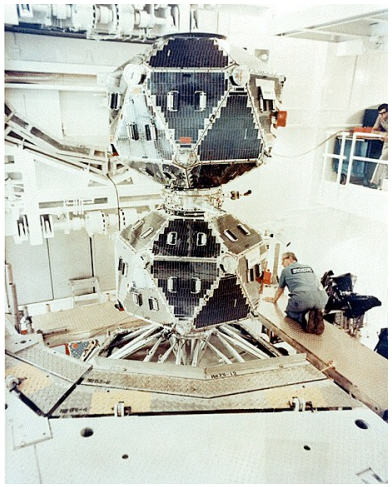


# Gamma Rays: Vela Satellites



- 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.

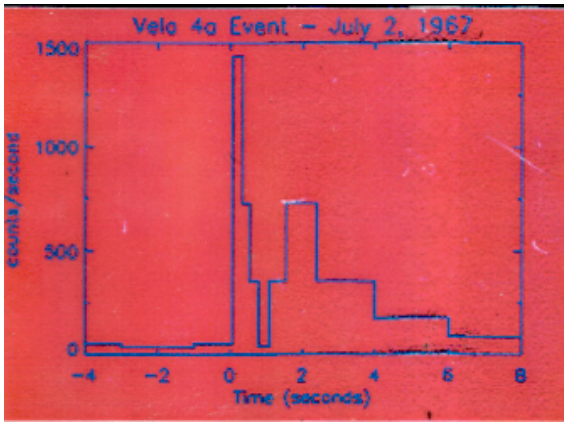
## Gamma Rays: Vela Satellites



- 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?

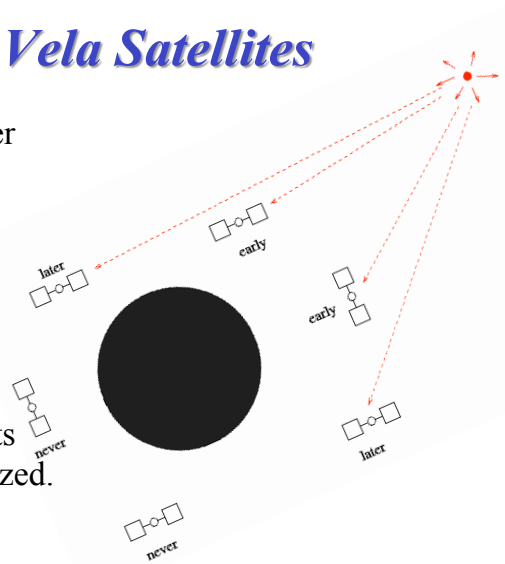
## First Detected Gamma-Ray Burst

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



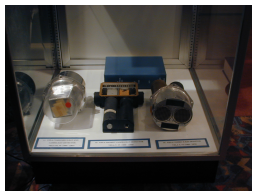

## Vela Satellites

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



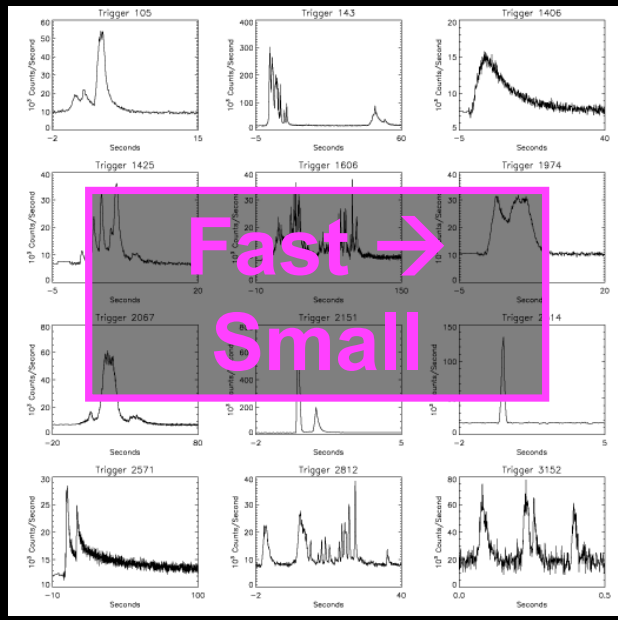

## Vela Satellites - Results

- 73 Bursts in Gamma-Rays over 10 years
- Really random, not in the plane of solar system
- They did spot many nuclear tests (non-USSR).



## *What do gamma ray bursts actually look like?*

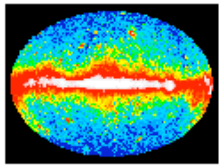
*(light curves)*

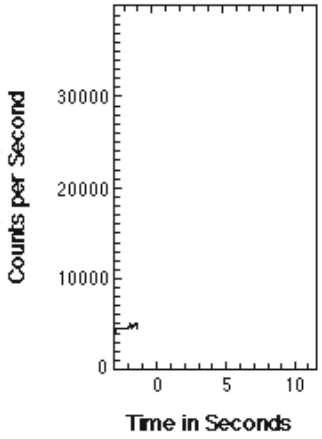



J.T. Bonnell (NASA/GSFC)

## *Gamma Ray Bursts*

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



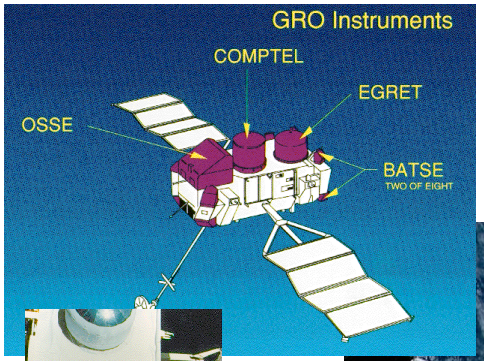


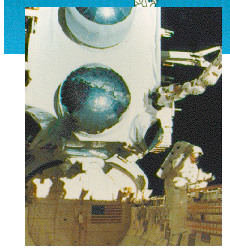

## *Question*

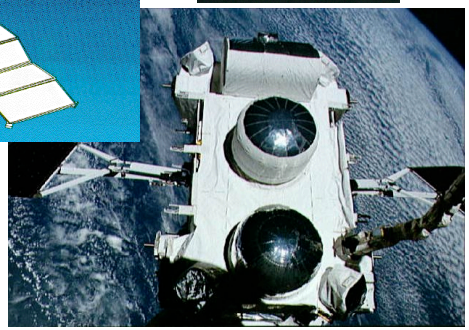
GRBs are

a) Nuclear weapon tests
b) Short gamma ray light sources in space.

## *Compton GRO*



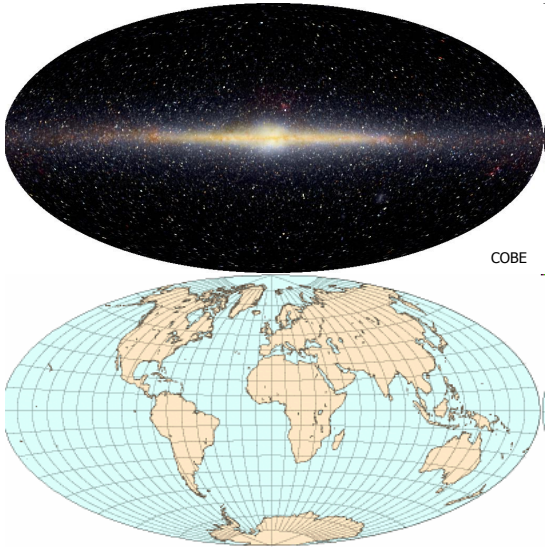





## *Compton Gamma Ray Observatory*

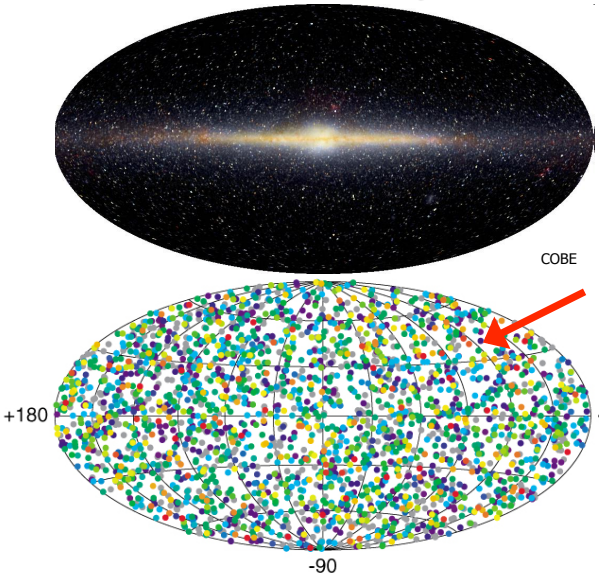
- April 5, 1991 – June 3, 2000
- Four separate gamma-ray detection devices: EGRET, COMPTEL, OSSE, and BATSE
- BATSE (Burst And Transient Source Experiment) proved to be the most useful instrument for GRB detection

## *Are they in the Milky Way Galaxy?*



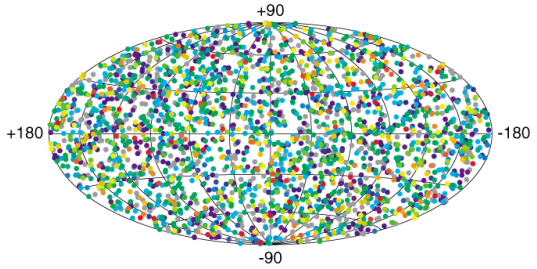

If gamma ray bursts are in the Milky Way, what would the map look like?

## *Gamma ray burst locations*

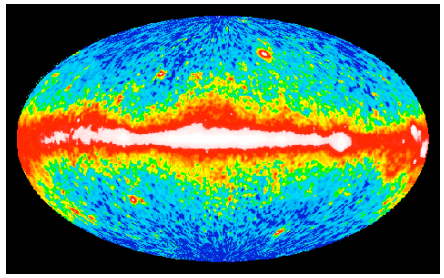



Gamma ray bursts observed by the BATSE instrument on the Compton Gamma Ray Observatory

(about one gamma ray burst per day was observed)

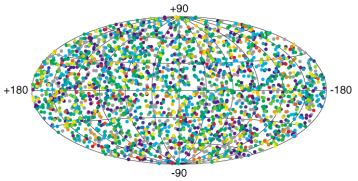



GRB distribution



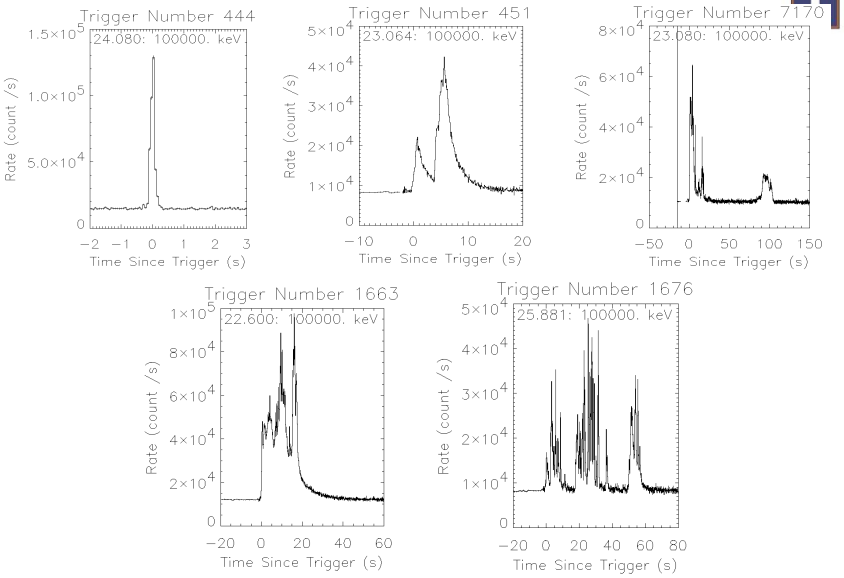
Gamma-ray sky

# GRB Distribution

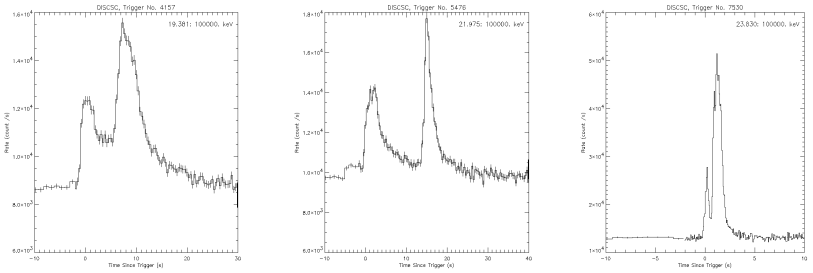



- Evenly distributed around the sky.
- If in the Solar System, would see more in one direction than the other (we aren't in the center).
- Could be uniformly distributed within a few hundred light years
  - How? Stars can't make gamma-ray bursts!
- Could be very, very, very far away.
  - How? If that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

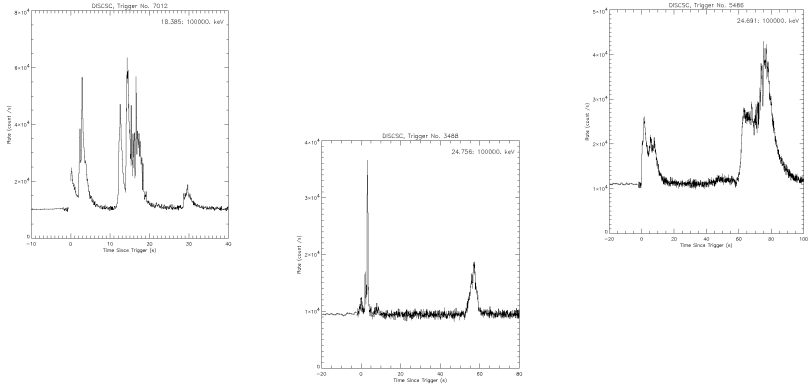
# Diversity of GRB Profiles




# Examples of Double-Peaked GRBs

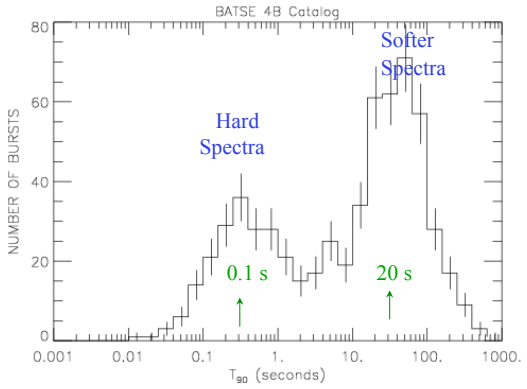


# Multiple-Episode Bursts



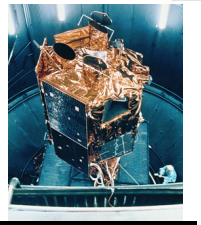
# Distinct subclasses of Gamma–Ray Bursts: Short/Hard & Long/Soft

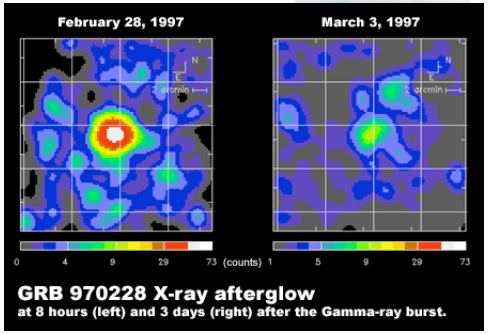
Hard/Soft means higher/ lower energy photons.




# Breakthrough: BeppoSax

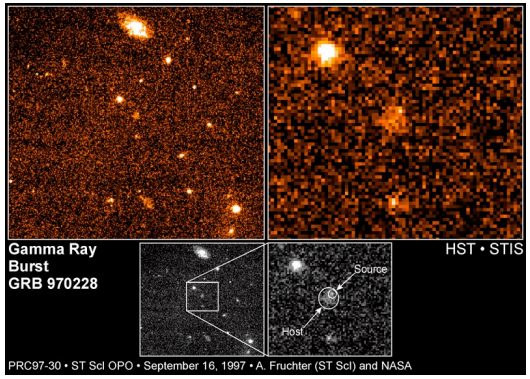
- Dutch/Italian satellite launched in 1996
- Had gamma-ray and x-ray detectors (x-ray telescopes have higher resolution)
- Was able to detect x-ray afterglow position of GRB in Feb 1997 (GRB 970228)
- Then, this enabled the Hubble Space Telescope to catch a glimpse.



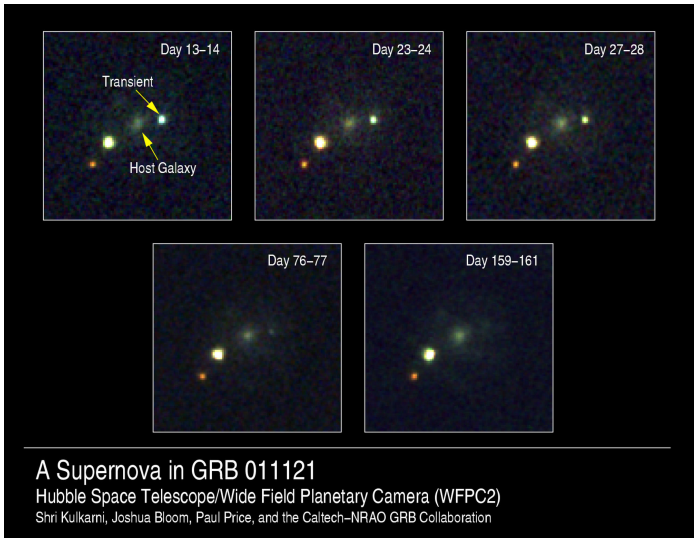



# Breakthrough: BeppoSax

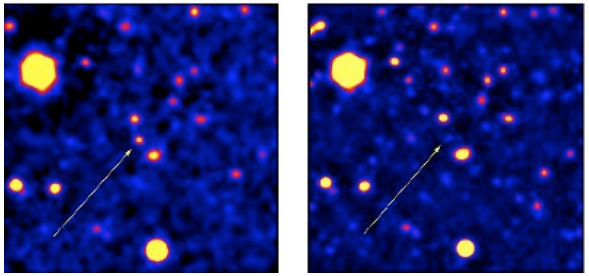
- GRB afterglow detected in optical light!
- And it was right next to a distant galaxy
- Afterwards, the Keck telescope was able a spectrum of a host galaxy
- These things are far away (billions of light years)!




# Gamma-ray Burst Afterglows

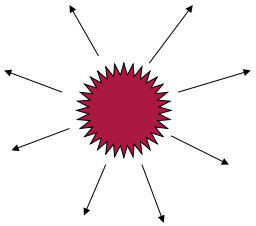


# Gamma-ray Bursts are Really, Really Far Away

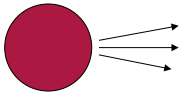


- GRBs are at the edge of the observable universe
- They must be the most powerful explosions in the universe: ~ 1 solar mass is converted into gamma-rays in a second! **(But, that's crazy talk!)**

# What if not Isotropic?

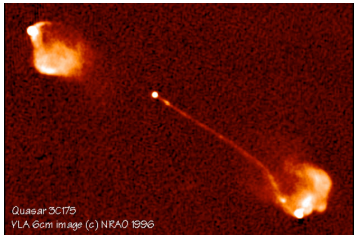


*If the energy were beamed to 0.1% of the sky, then the total energy could be 1000 times less, closer to supernova energies.*

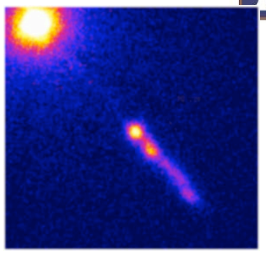



*Nothing seen down here*

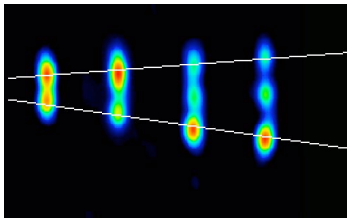
# We know that jets are common



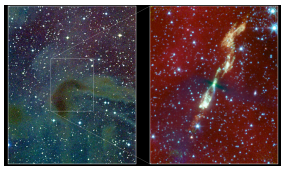

Quasar 3C 175 as seen in the radio



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

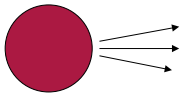


Microquasar GPS 1915
in our own Galaxy – time sequence



L1157 protostar

# What if not Isotropic?



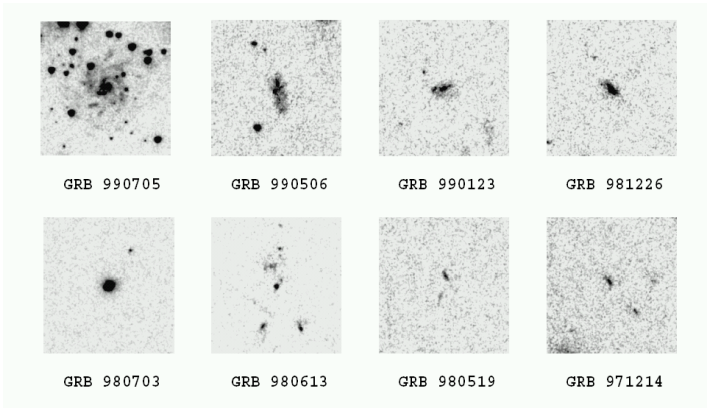

*Nothing seen down here*

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

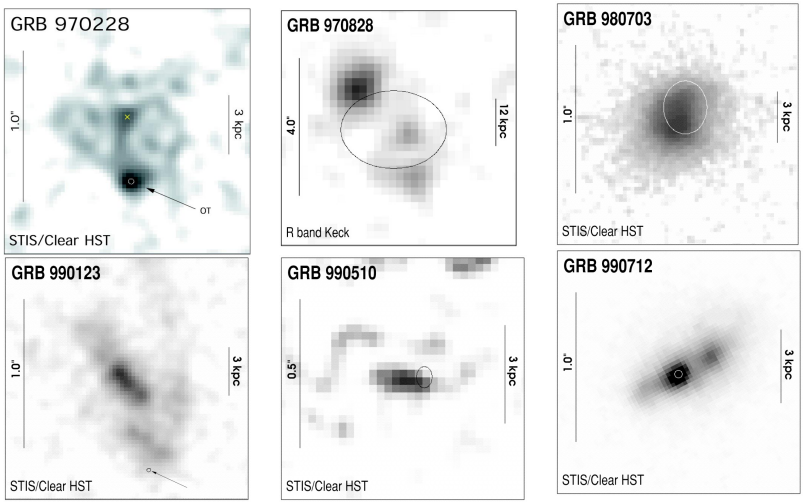
# Host Galaxies

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

High star formation rates.



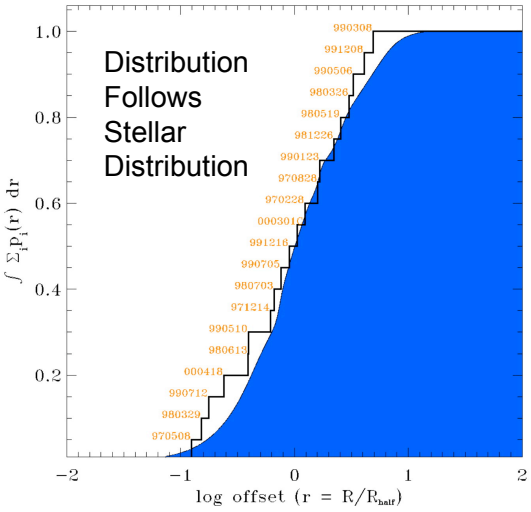

# Location of GRB within Host




# 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.



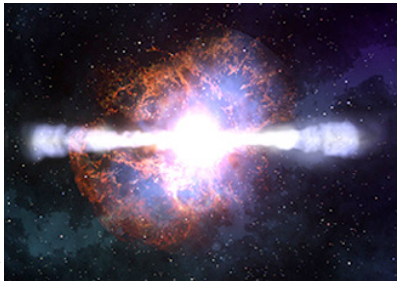

# GRB Locations

- 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

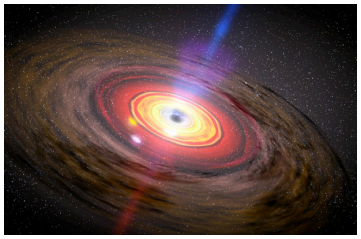
## Hypernova or Collapsor

- 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.
- For the jet to make it out of the star, most of the hydrogen envelope should have been lost during the earlier evolutionary stages.



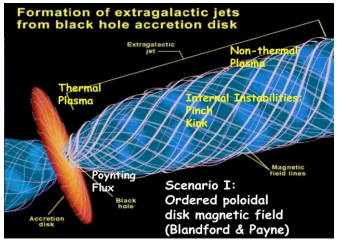
## Blackhole Traffic

- 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.



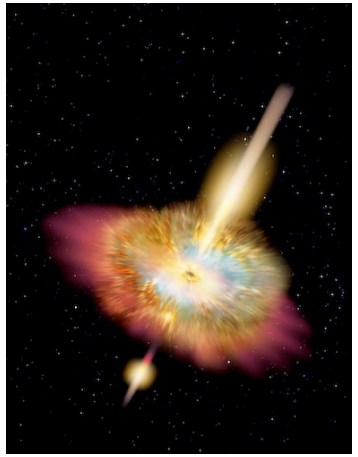
## The Jet: So it Starts

- 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.



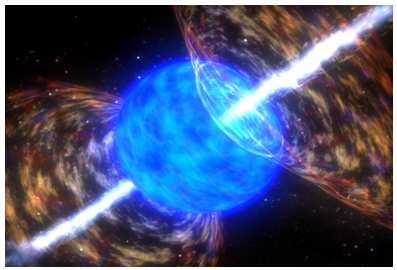

## The Jet: So it Starts

- 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!



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