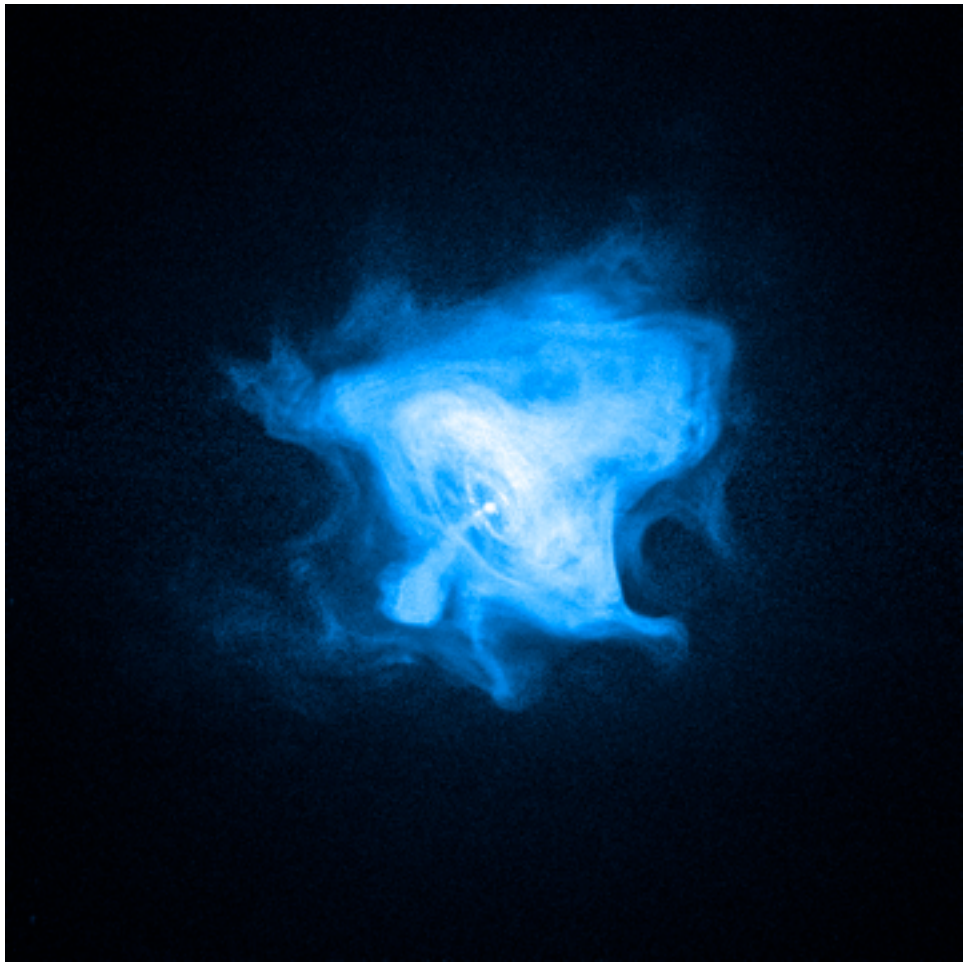
Astronomy 150: Killer Skies
Lecture 25, March 26

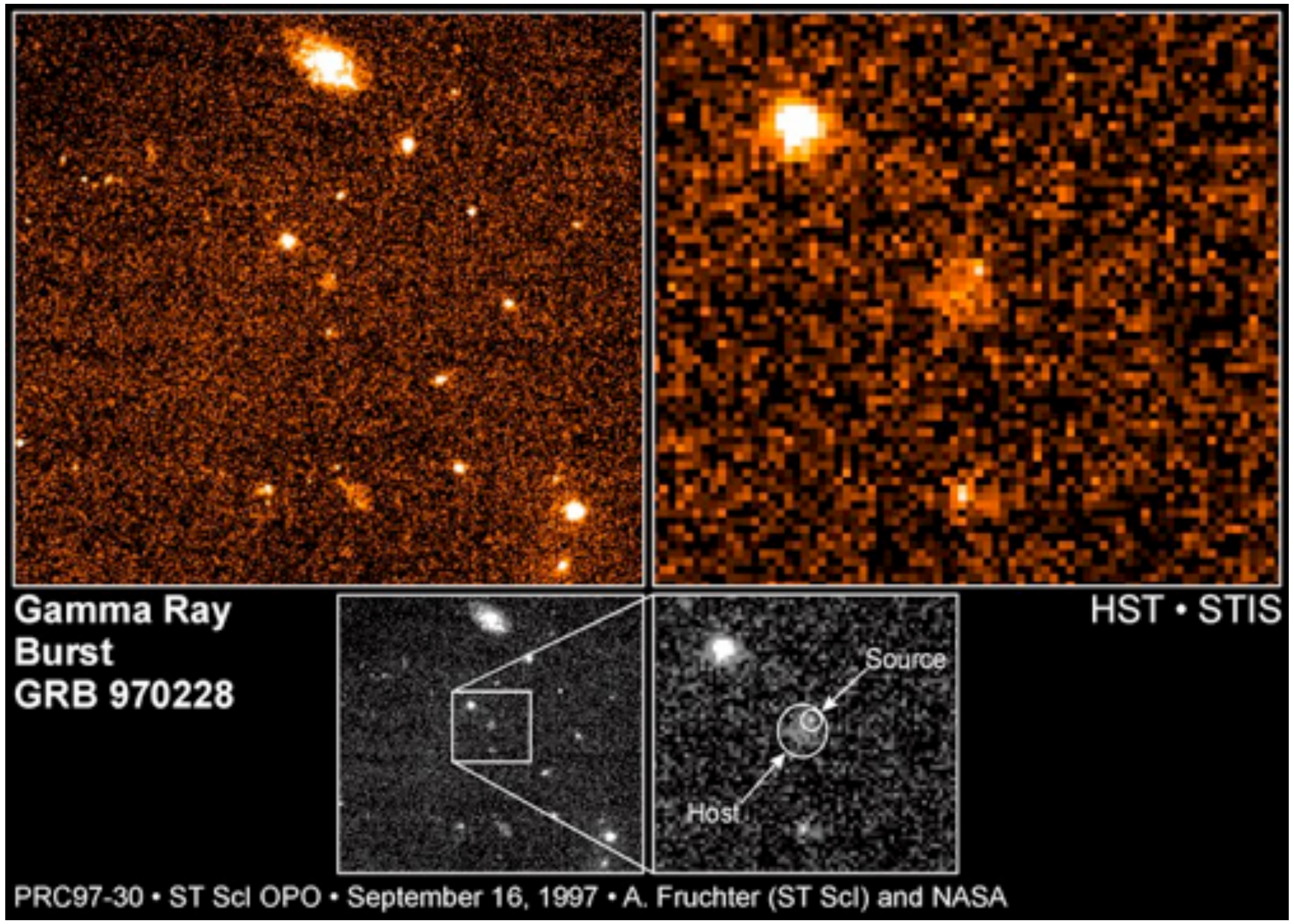
Assignments:

- 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

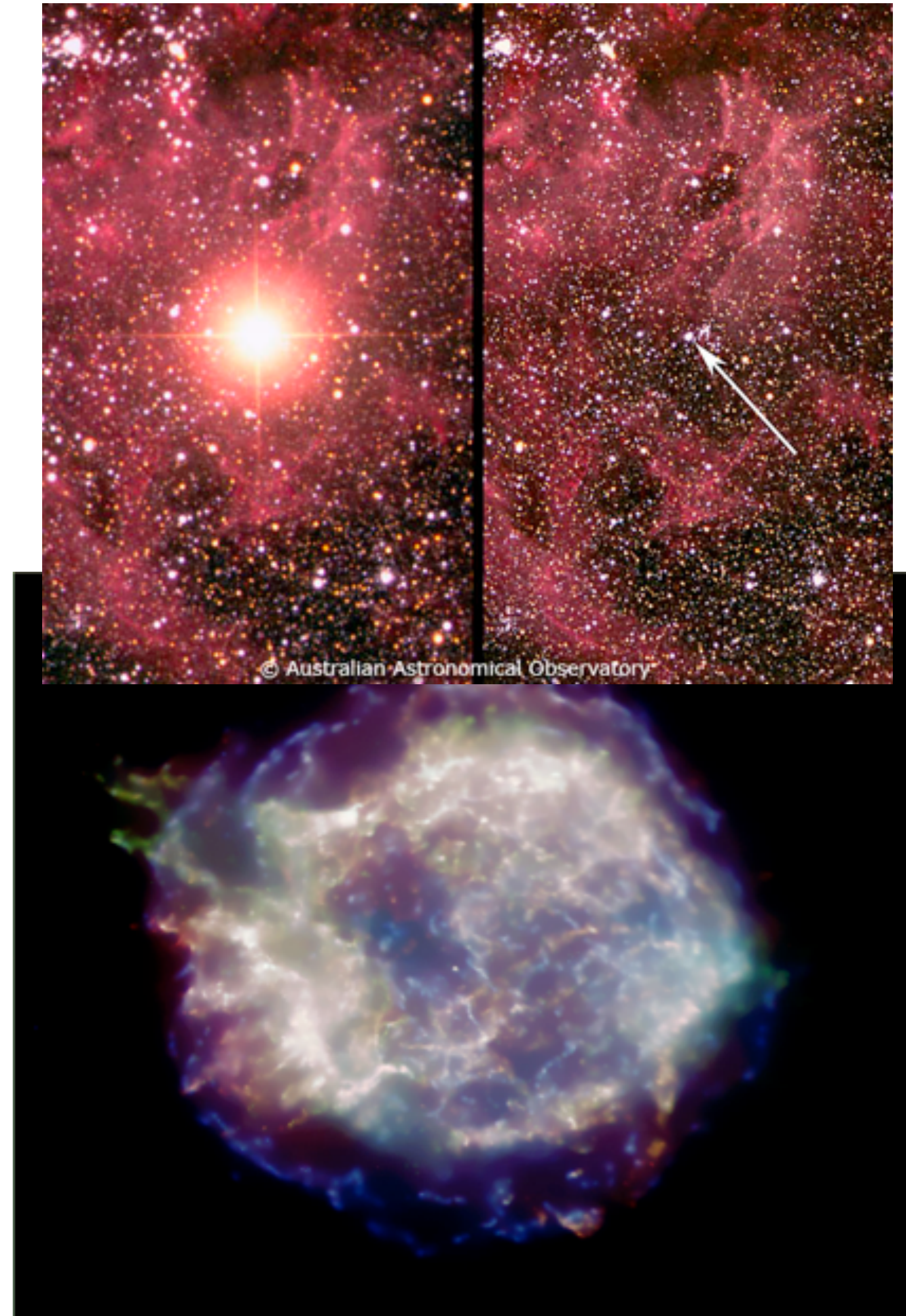
Massive star death leads to several cosmic dangers

So far:

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

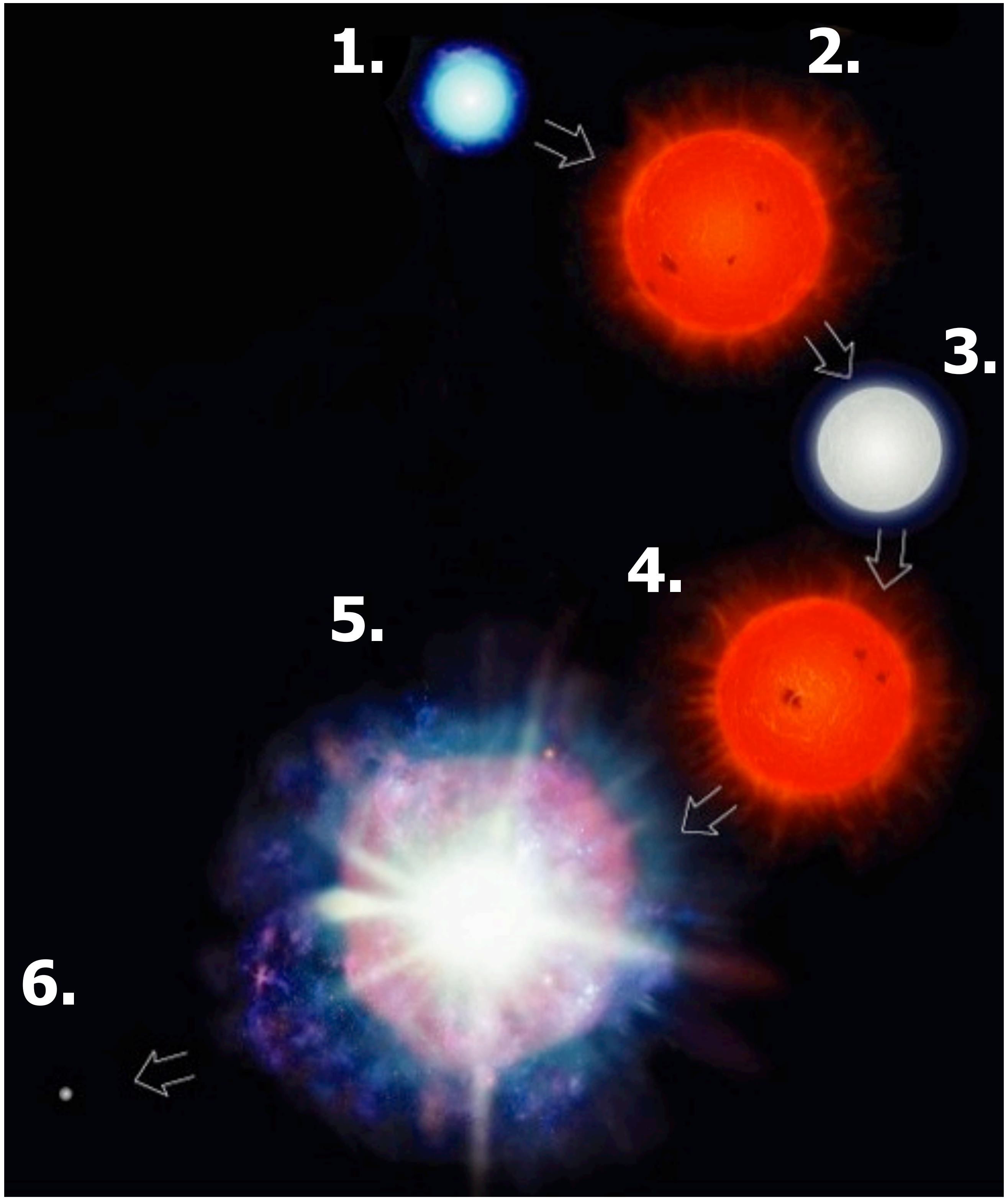
But more dangers lurk!

- center of explosion is dead star "cinder"
- large mass crushed to small size: huge gravity



Review: The Life and Death of a Massive Star

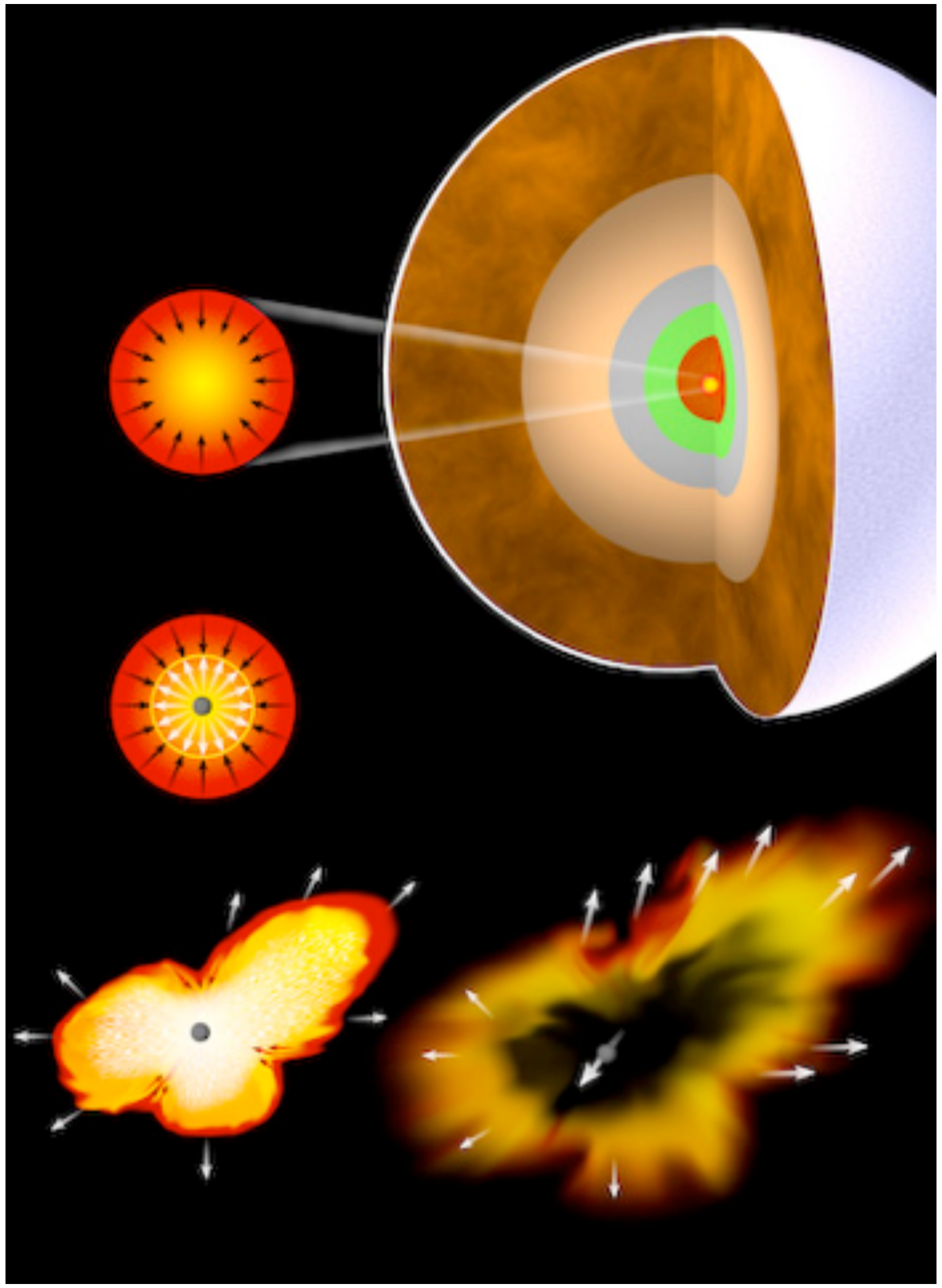
1. Main Sequence
2. Red Supergiant
3. Blue Supergiant
4. Red Supergiant II
5. Supernova!
6. Neutron star or black hole



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?

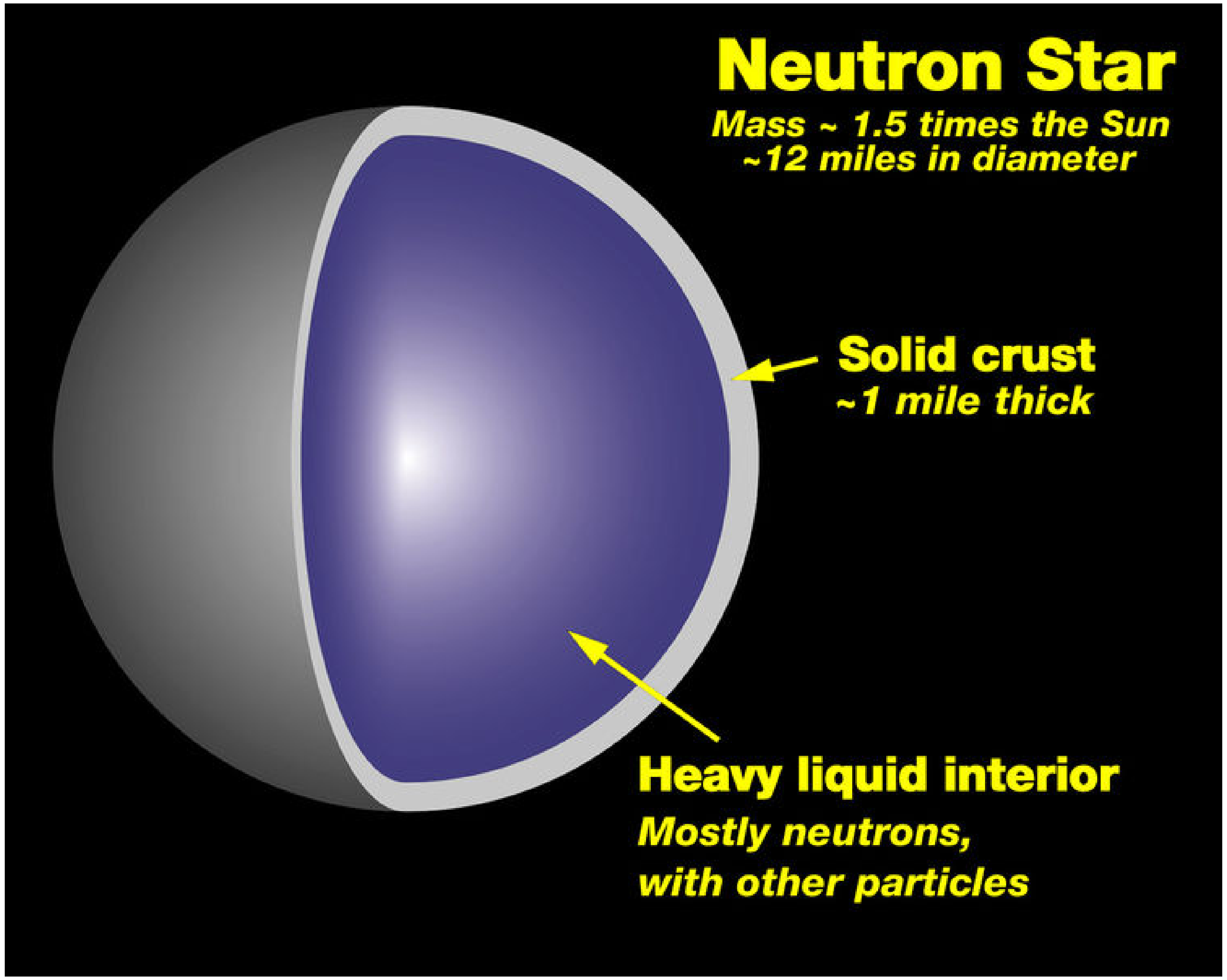
- during collapse: nuclei and electrons compressed to enormous density
- first: electrons squeezed into protons, making neutrons
  - (and neutrinos)
- neutrons compressed until touching
  - neutron core forms a solid supported by “degeneracy pressure”
  - touching neutrons ordinarily only exist in atomic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

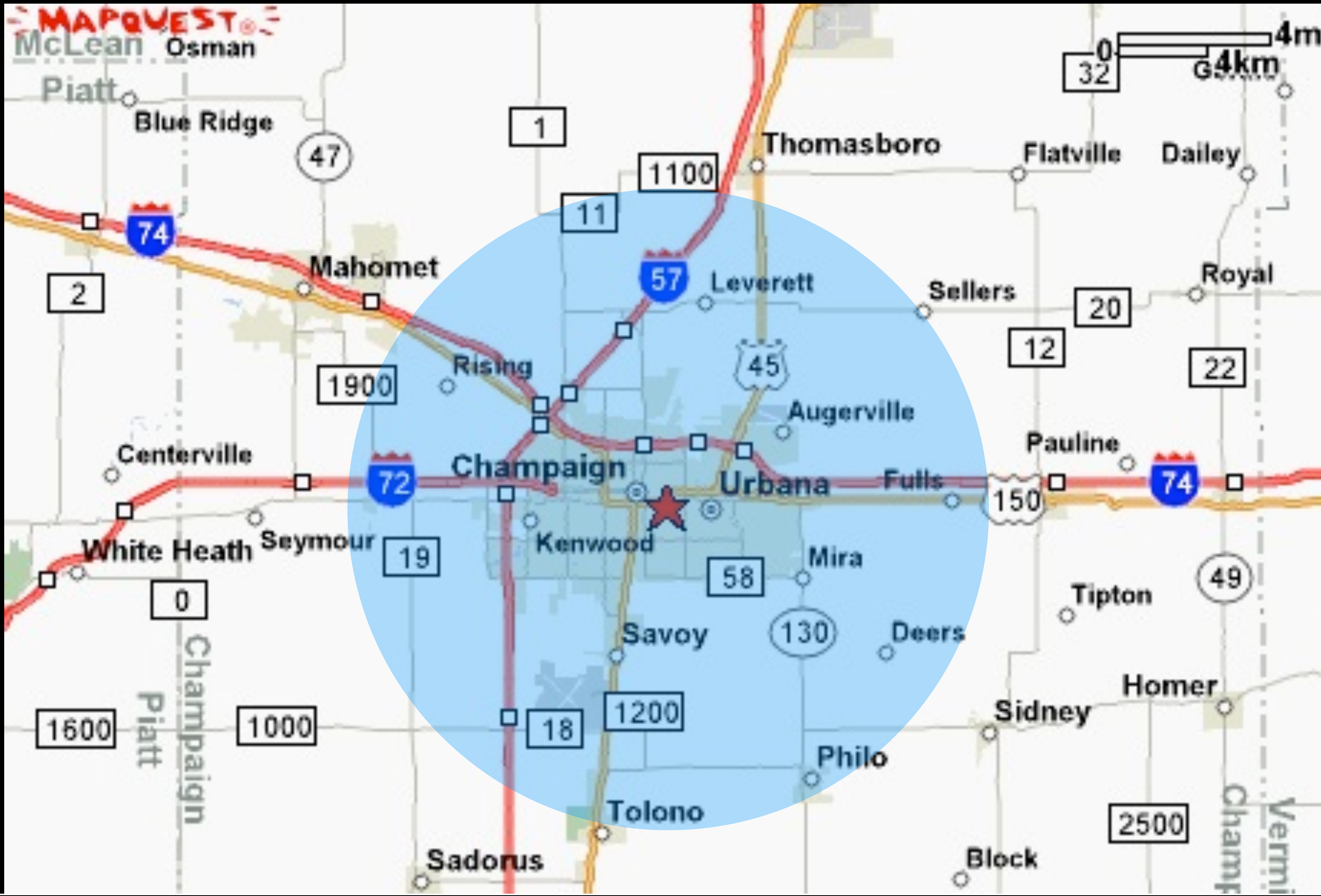
And then?

- if star mass < 30 M_{sun} 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_{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!

Pulsars

Joyceln Bell

In 1967, Jocelyn Bell discovered radio pulses from the constellation Vulpecula that repeated regularly

Every 1.337... seconds

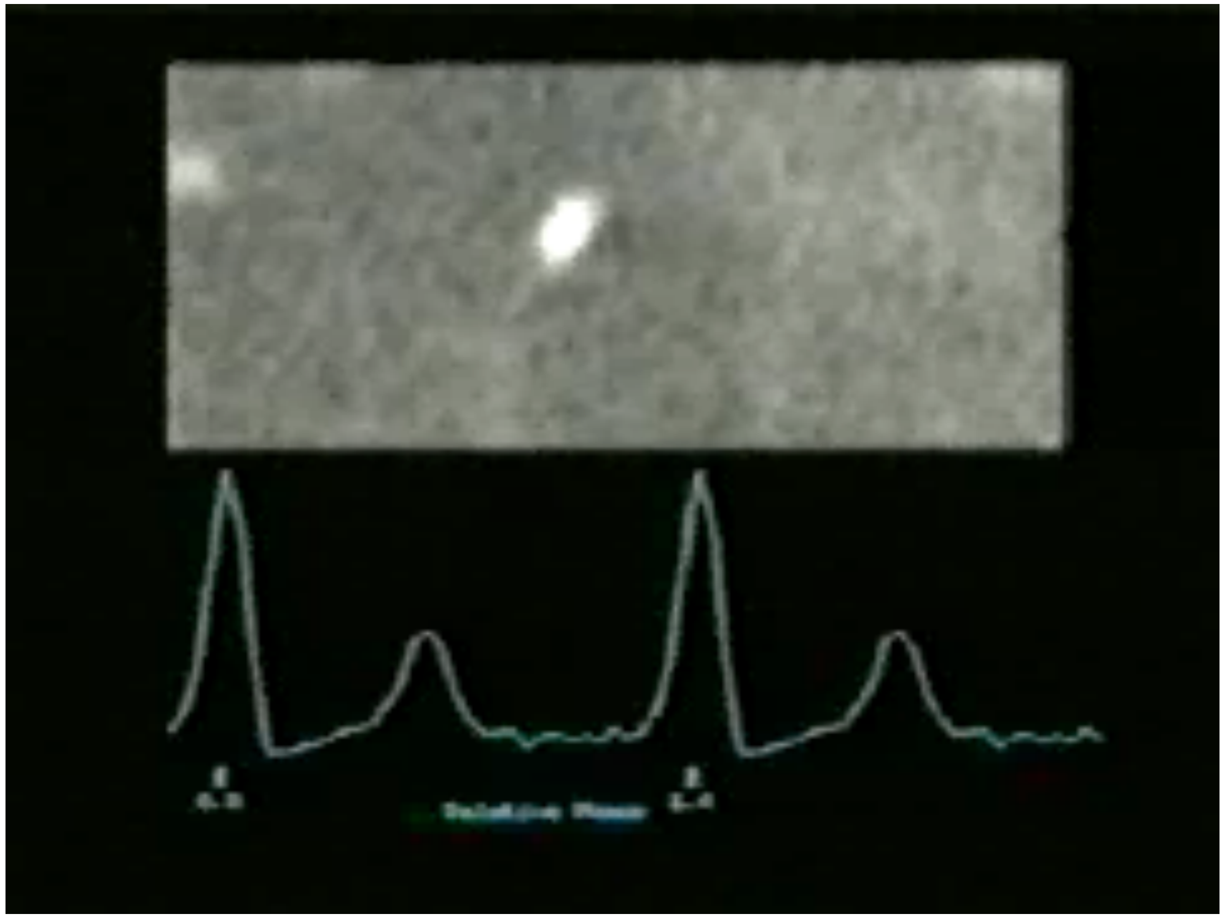
What could it be?

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!

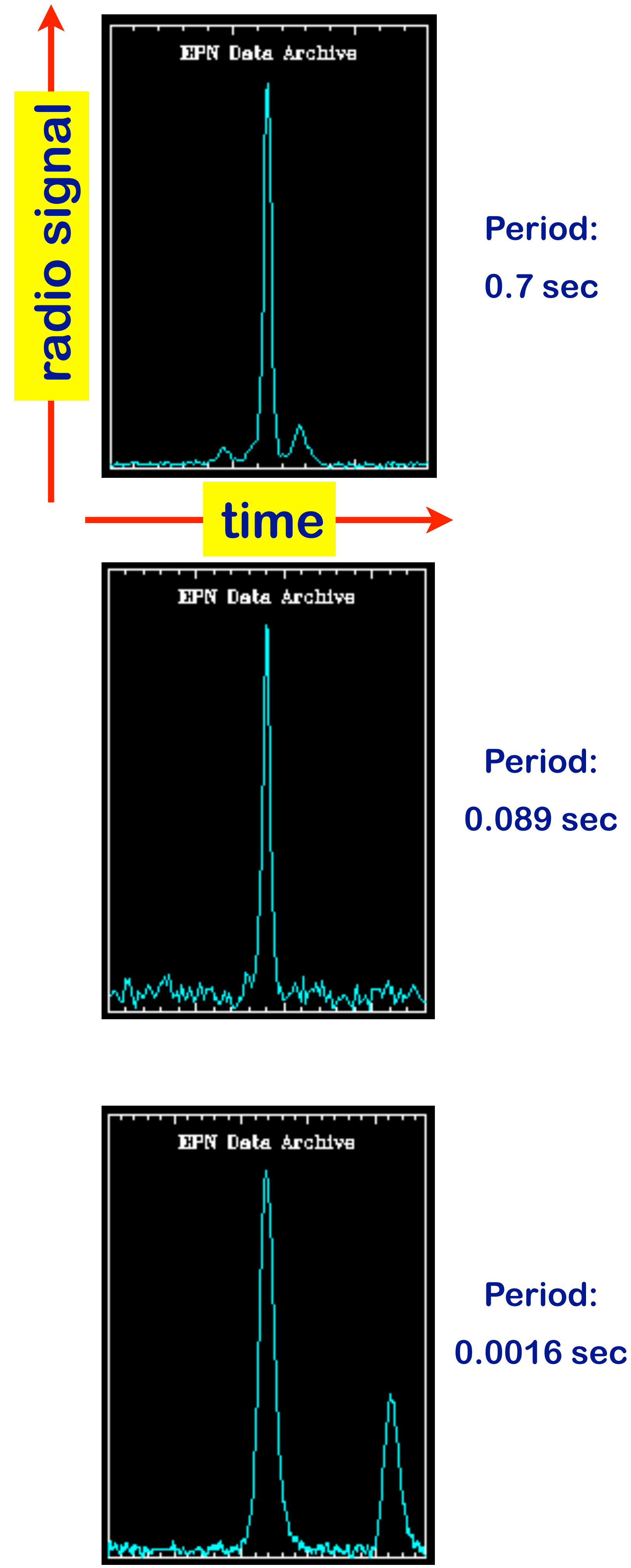
http://www.jb.man.ac.uk/~pulsar/Education/Sounds/sounds.html

Pulsar signals first seen in radio waves

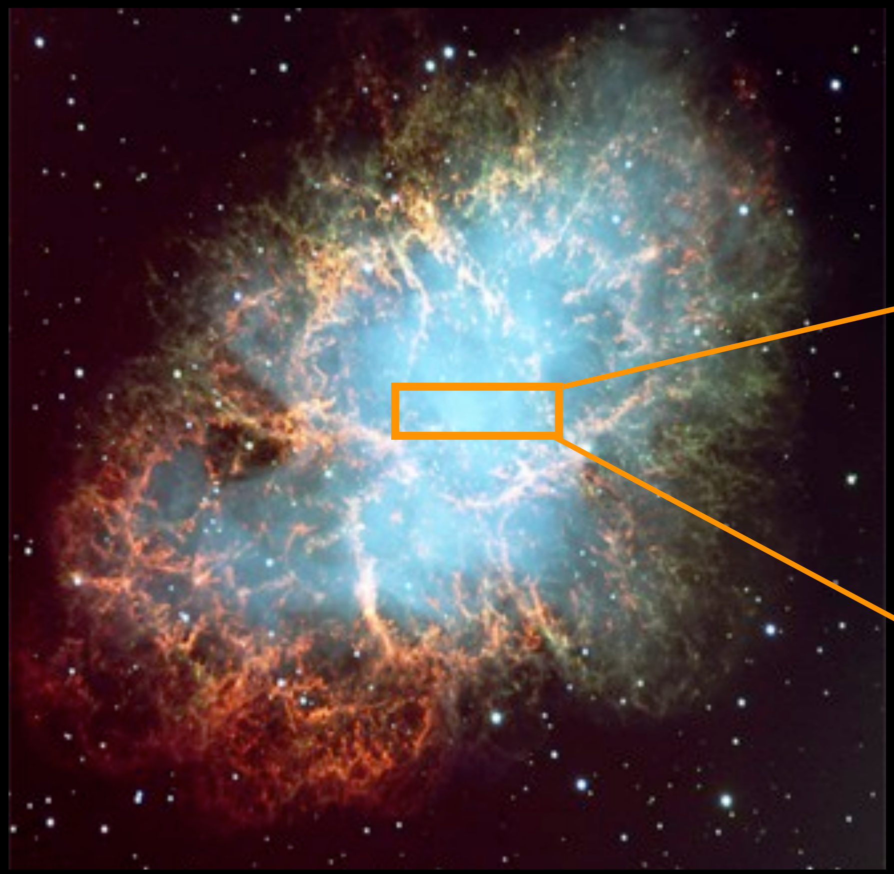
- recall: radio is just another form of electromagnetic radiation, but with wavelength much longer than visible light
- by now: pulsars have been seen in many wavelengths

Radio signal is periodic (repeating)

- to get a feel, can convert radio to sound, like when listening to ordinary non-astronomical radio stations

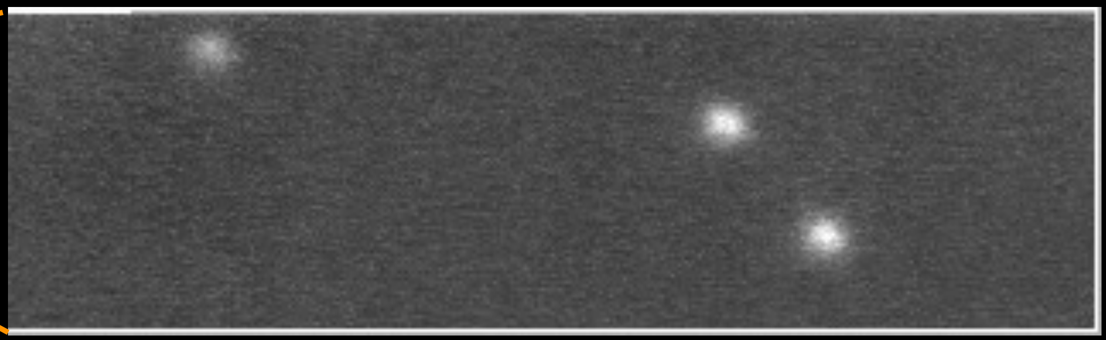


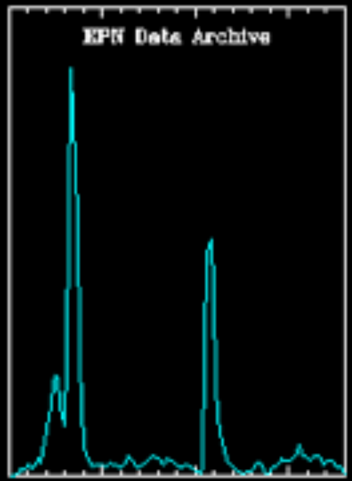
A pulsar lies at the center of Supernova 1054

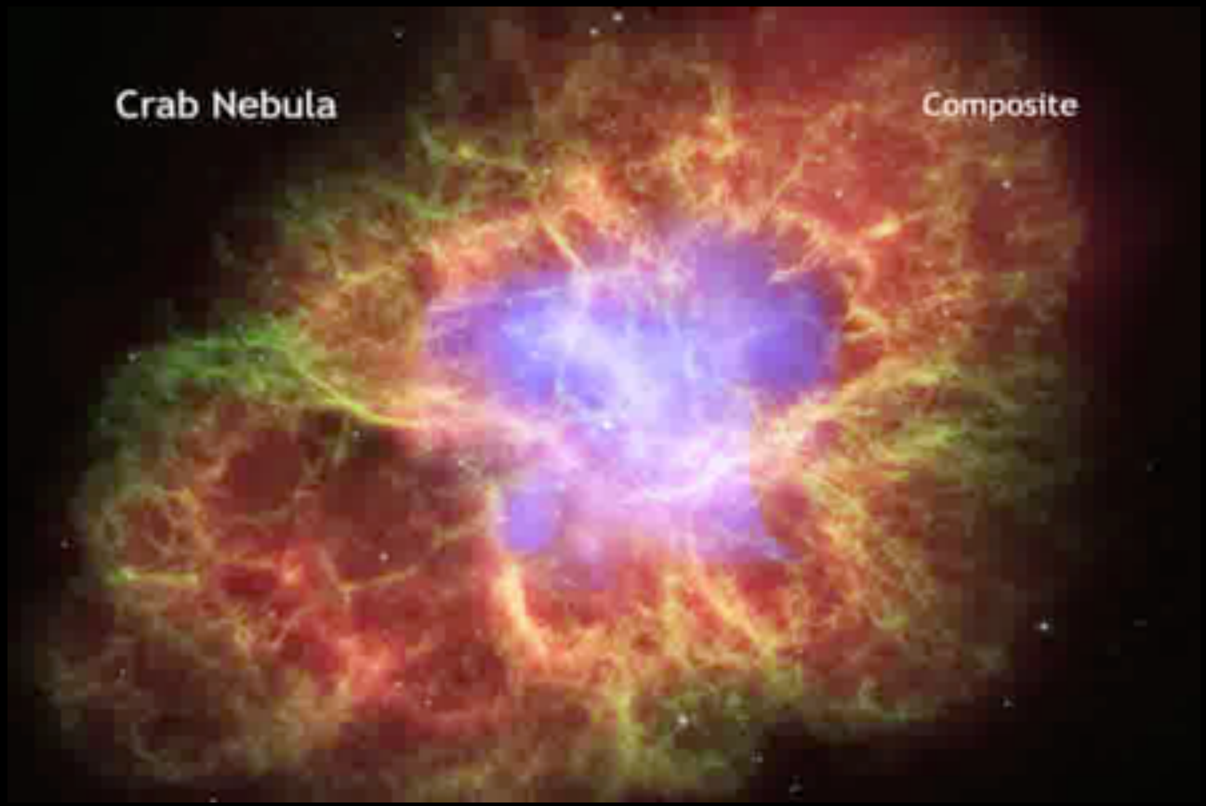


Youngest known pulsar

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

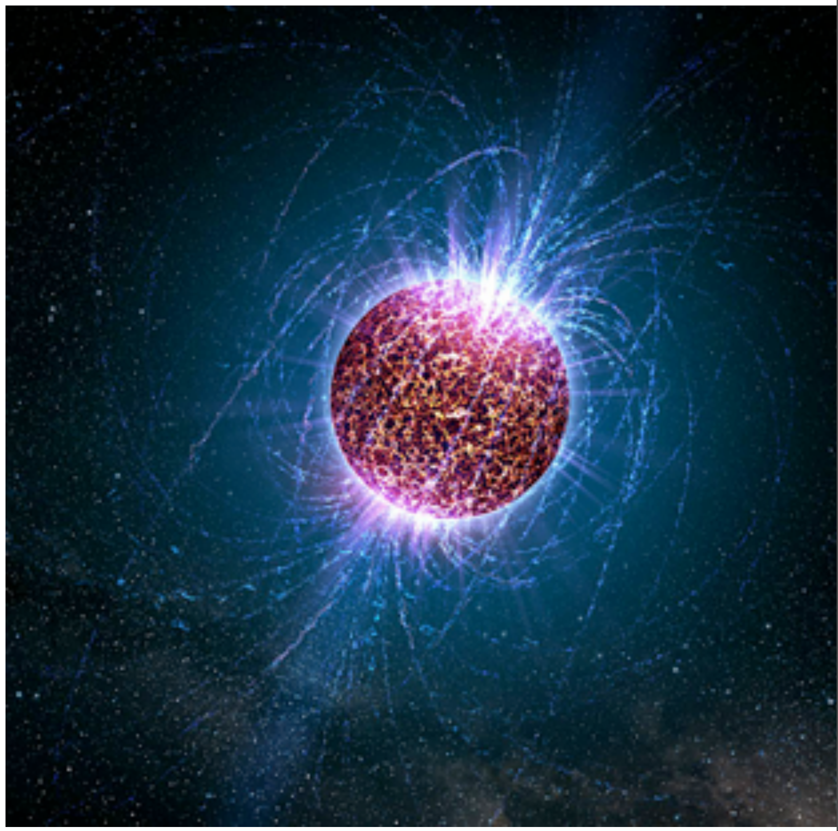
What's going on?

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?!?



An artist's impression of a neutron star

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

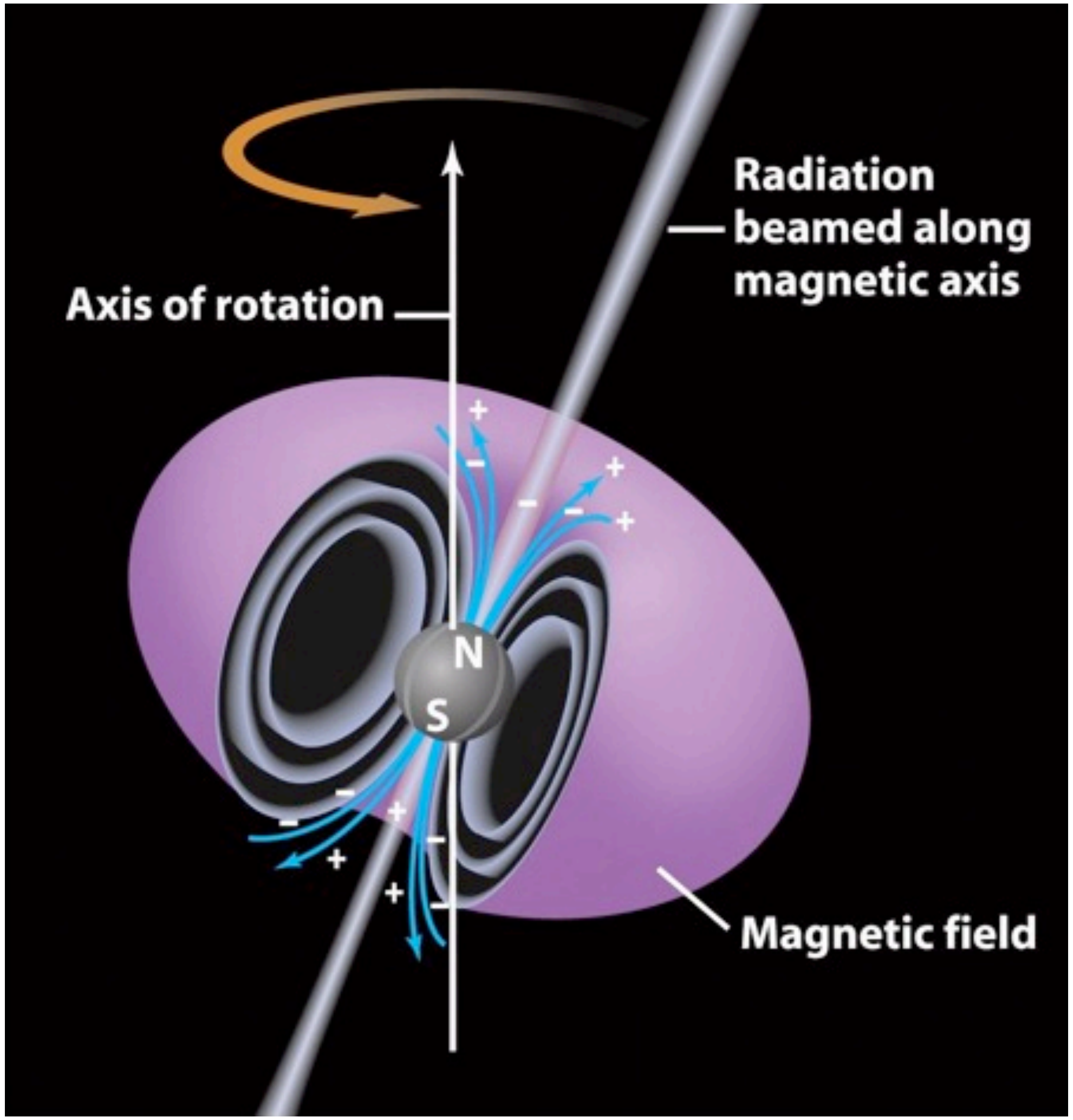
- sweep out cone-shaped pattern in each hemisphere

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

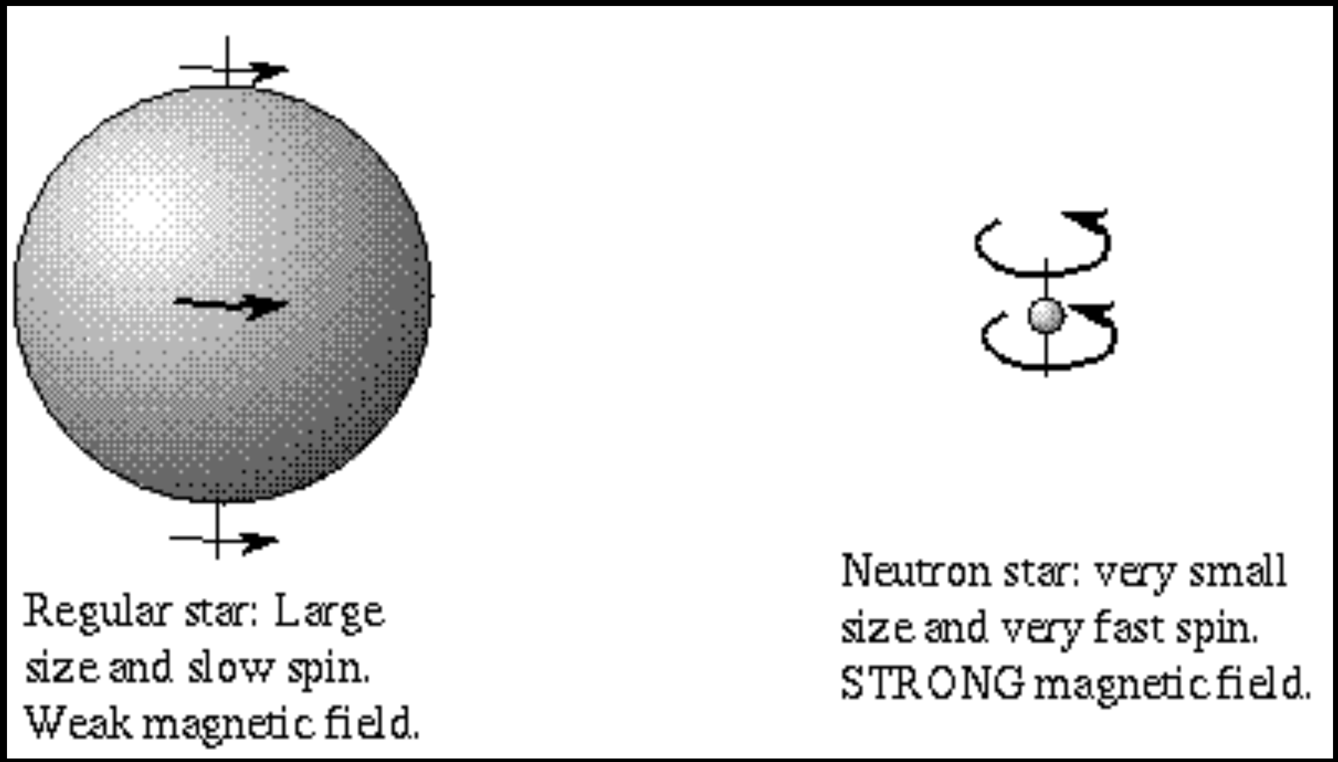
- If Earth lies in path of beam: as beam sweeps over Earth, see a flash of light once per rotation

  Like a lighthouse!

- But if Earth not in path (cone) of beam sweep: see nothing!



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

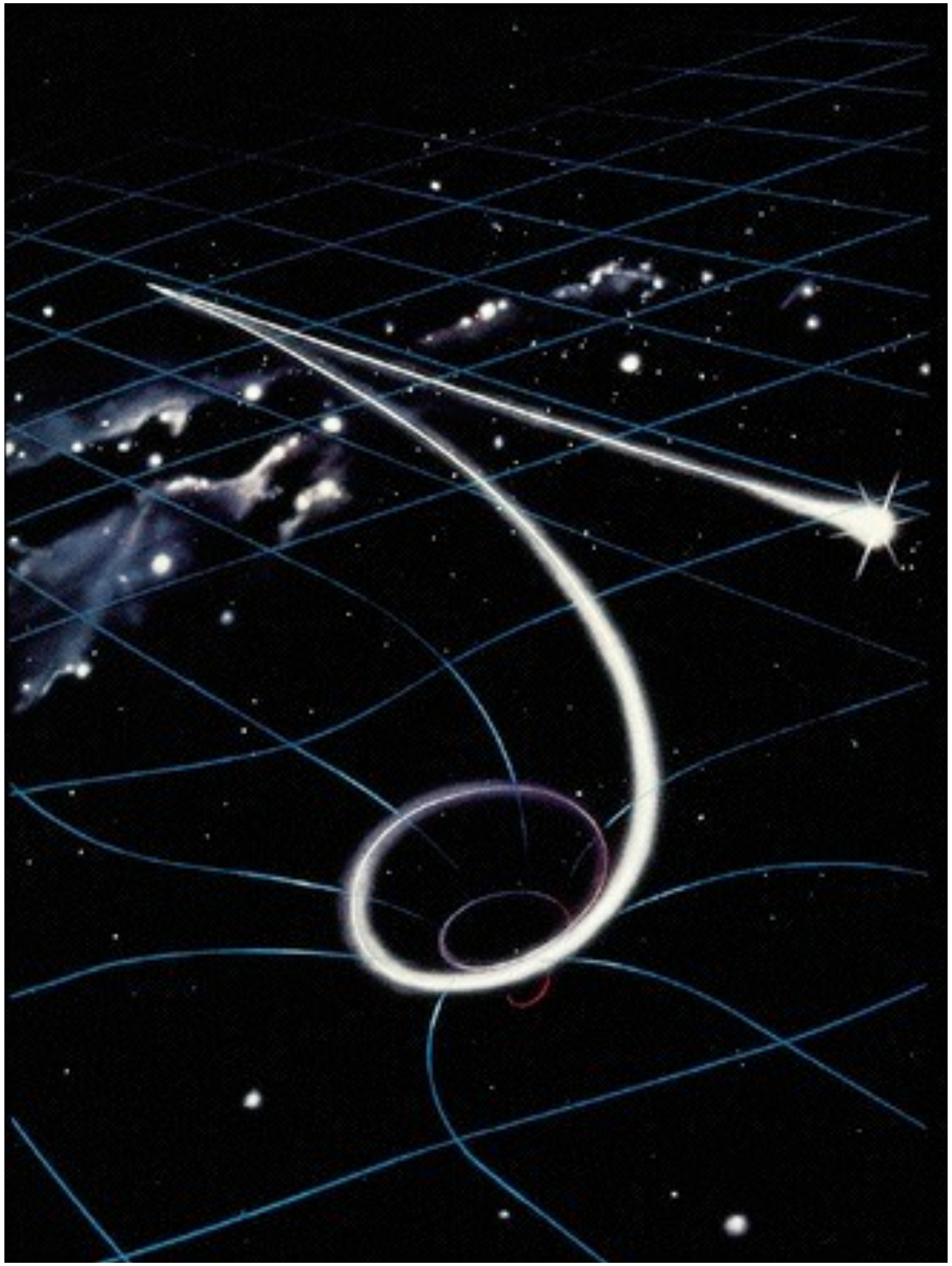
Neutron star limit

If star leading to supernova has $M \gtrsim 30\ M_{Sun}$

- 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

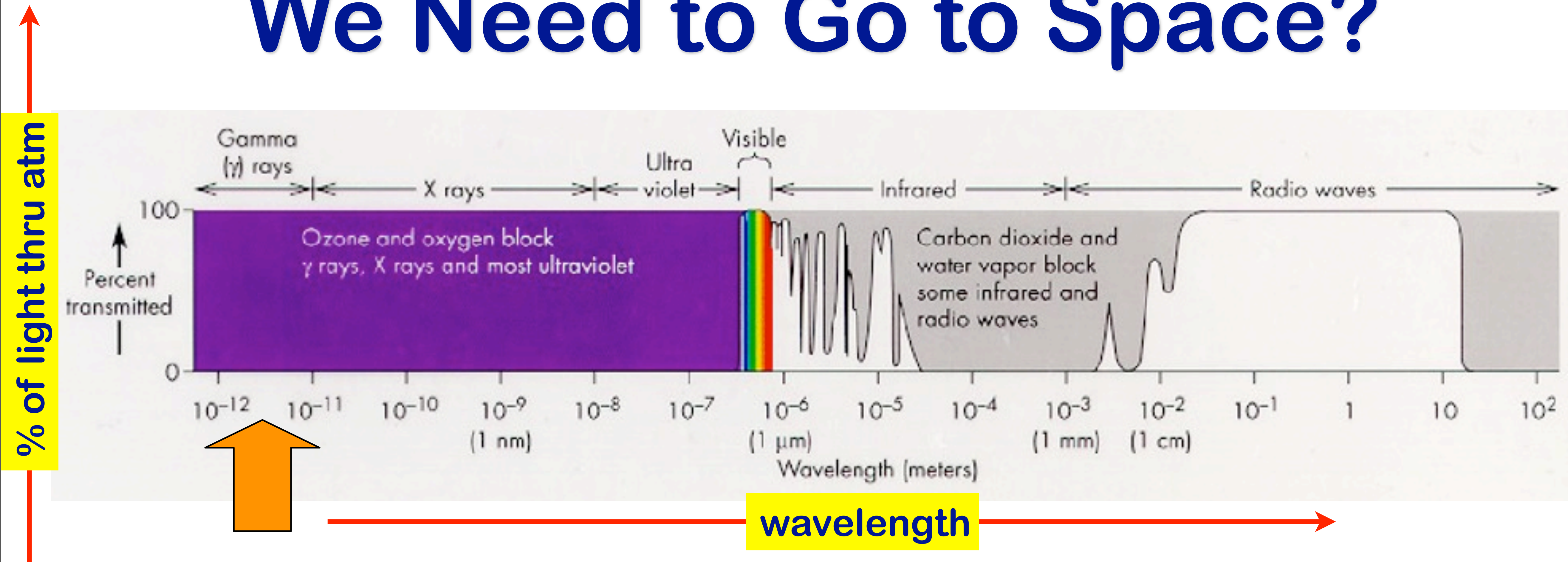
- Including gamma-rays
- Blew out streetlights in Hawaii 900 miles away

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 is blocks gamma-rays

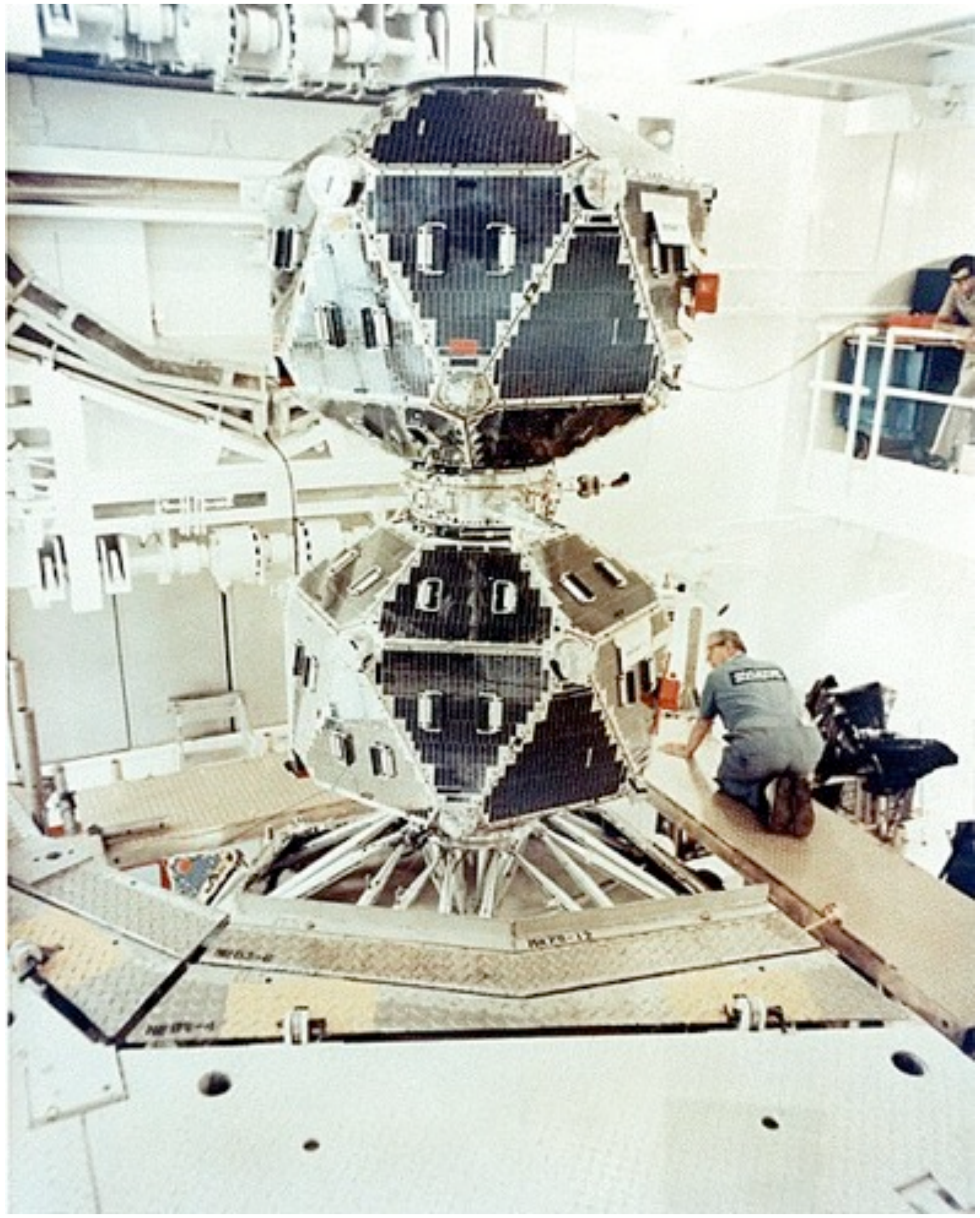
- none reach the ground
- same with X-rays and some UV

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

Vela Satellites Spot Something Weird

Vela satellites:

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

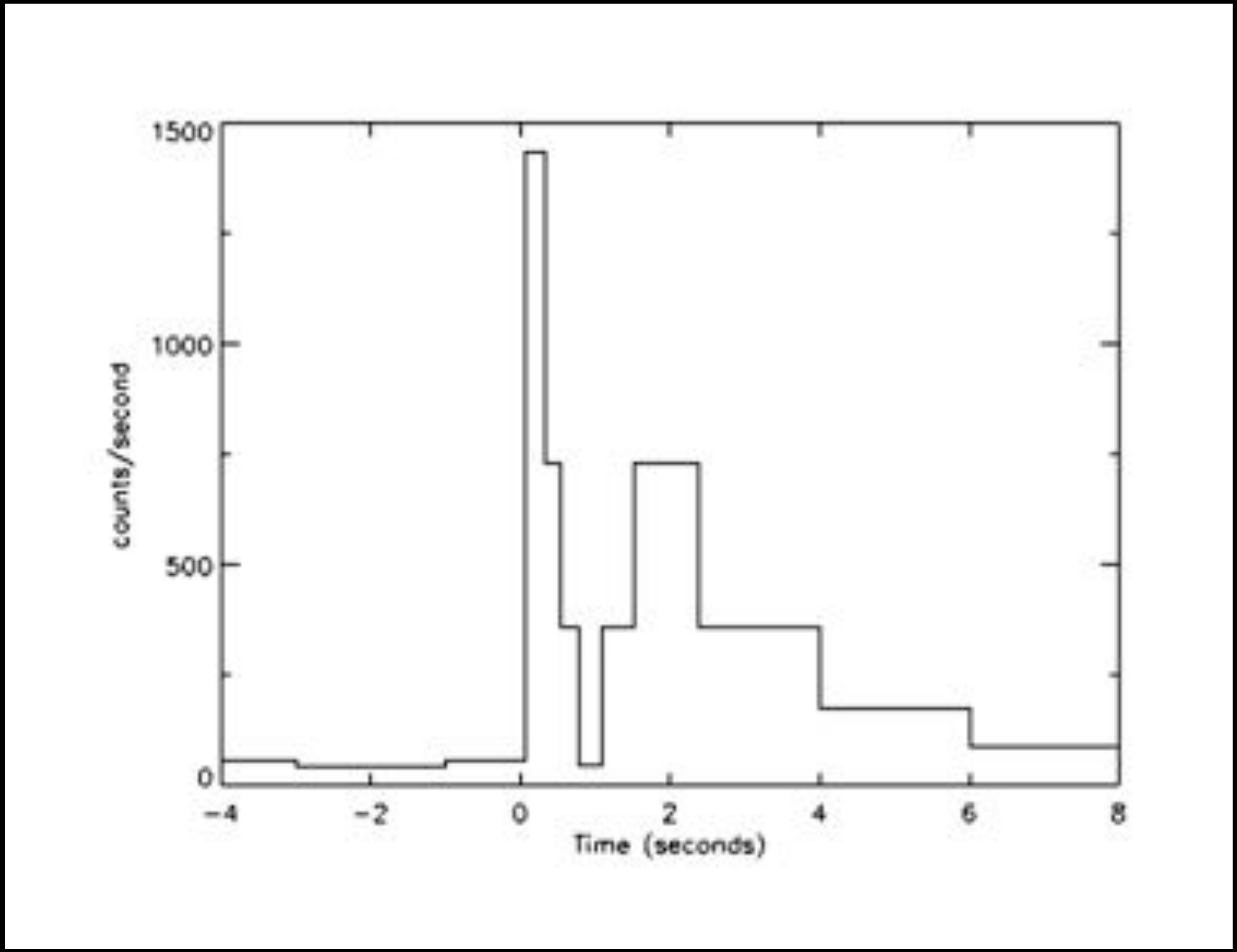


July 2, 1967, they detected their first hit!

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

Moon bombs?

First Detected Gamma-Ray Burst (GRB)



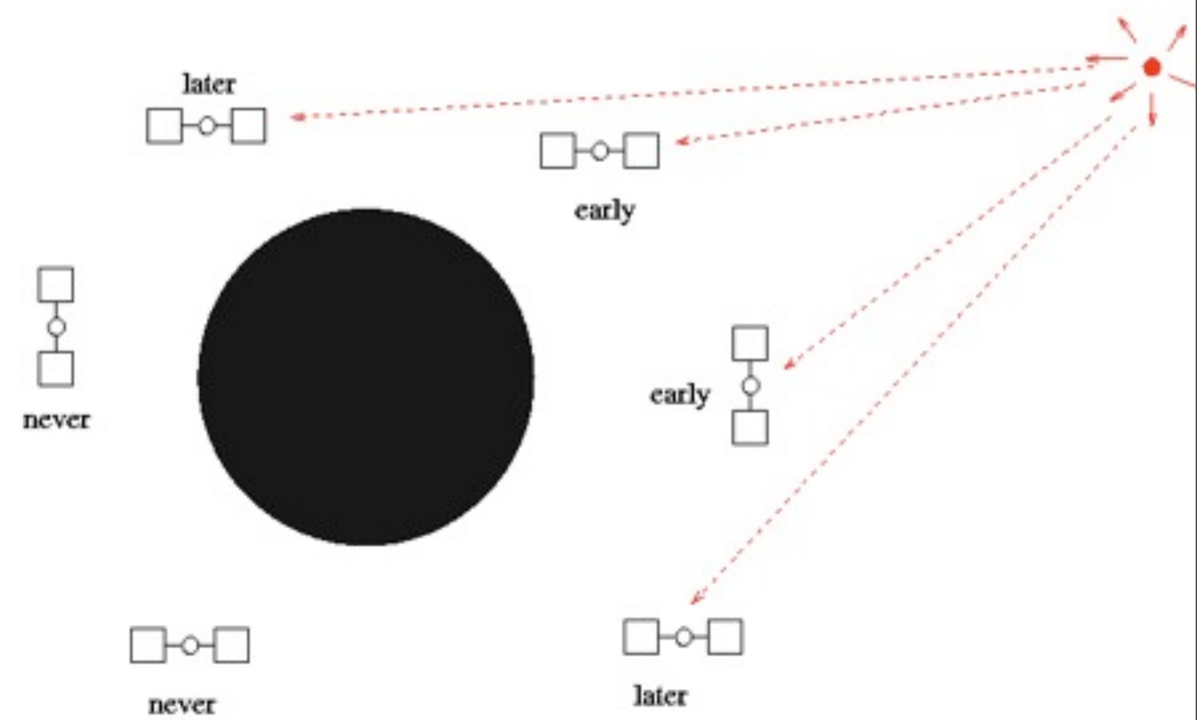
Gamma-ray pulse spread over about 8 seconds

Vela found 10-20 such gamma-ray bursts (GRBs) per year!

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

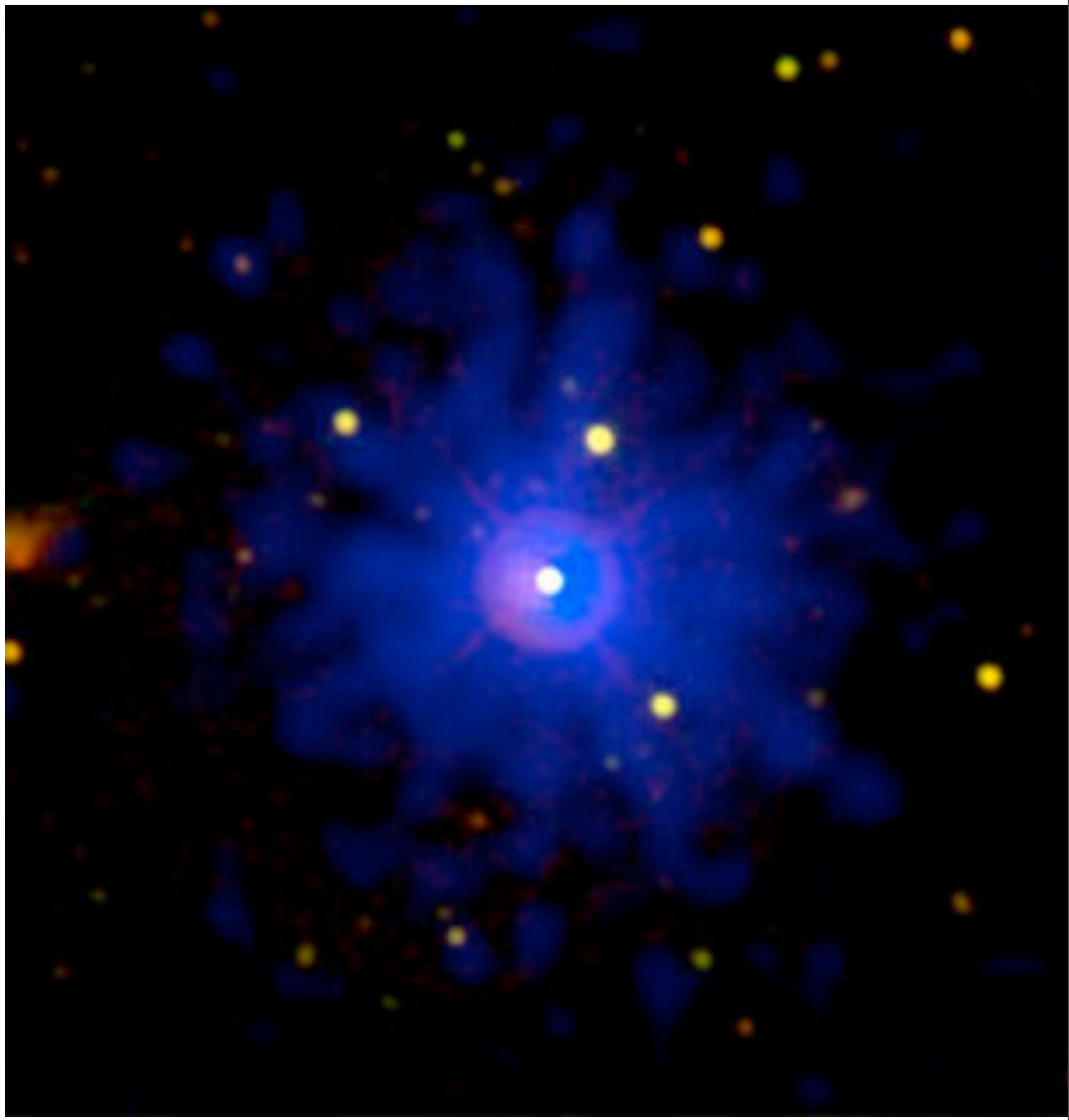
  definitely not periodic

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?



Compton Gamma Ray Observatory
The GRB Hunter

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:

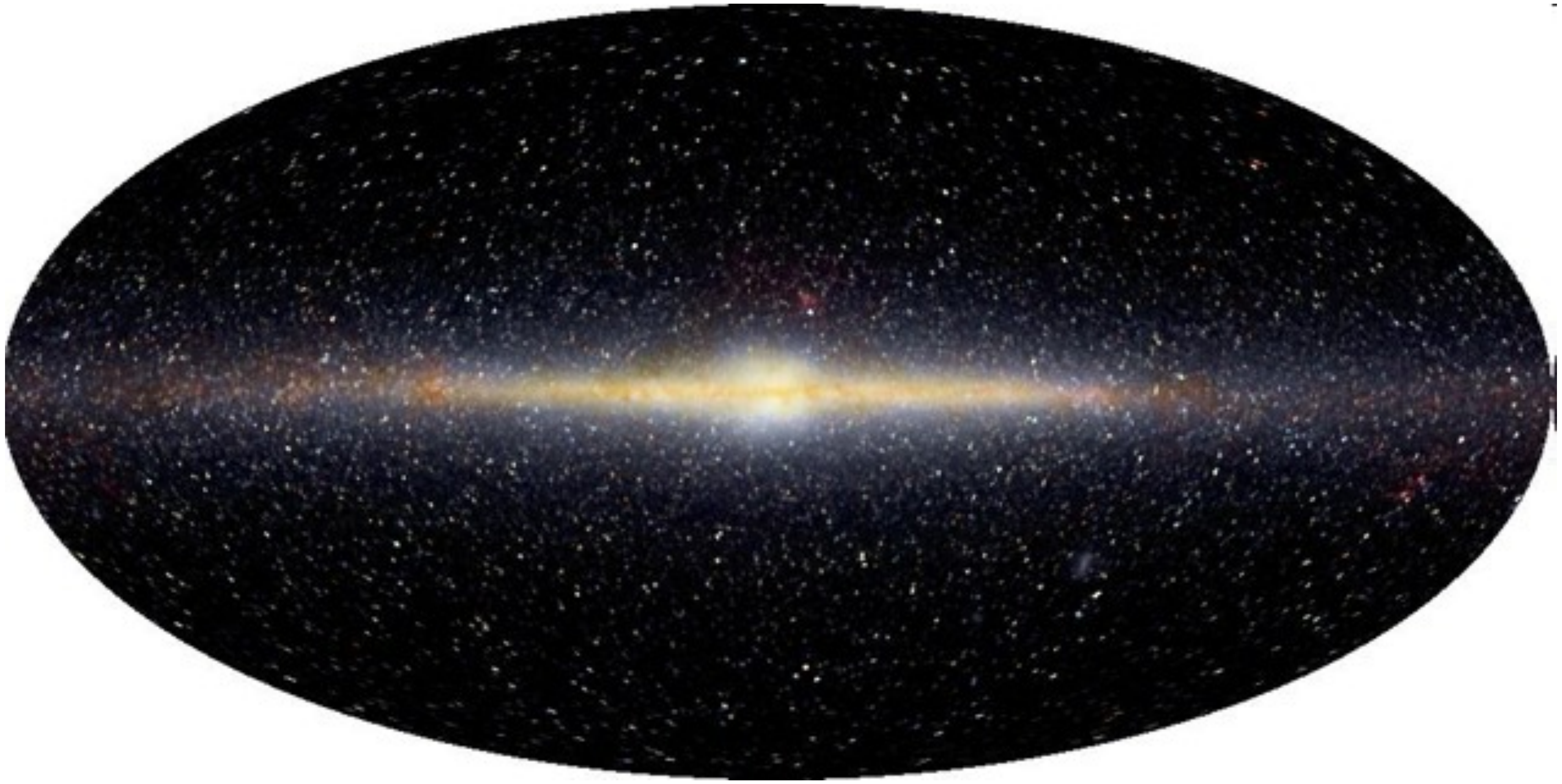
Guess the GRB sky pattern!

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

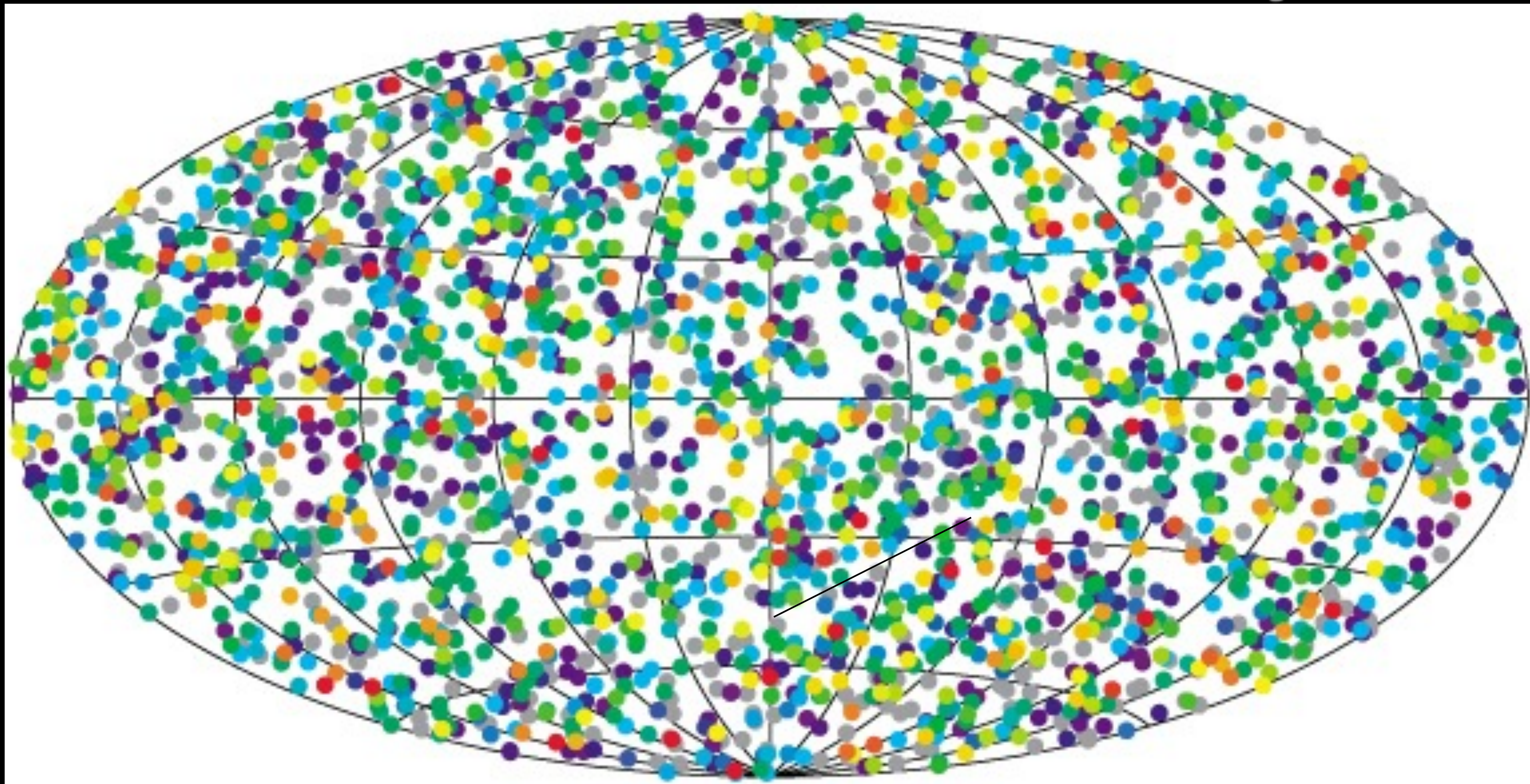
B. Concentrated along the disk of the galaxy

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

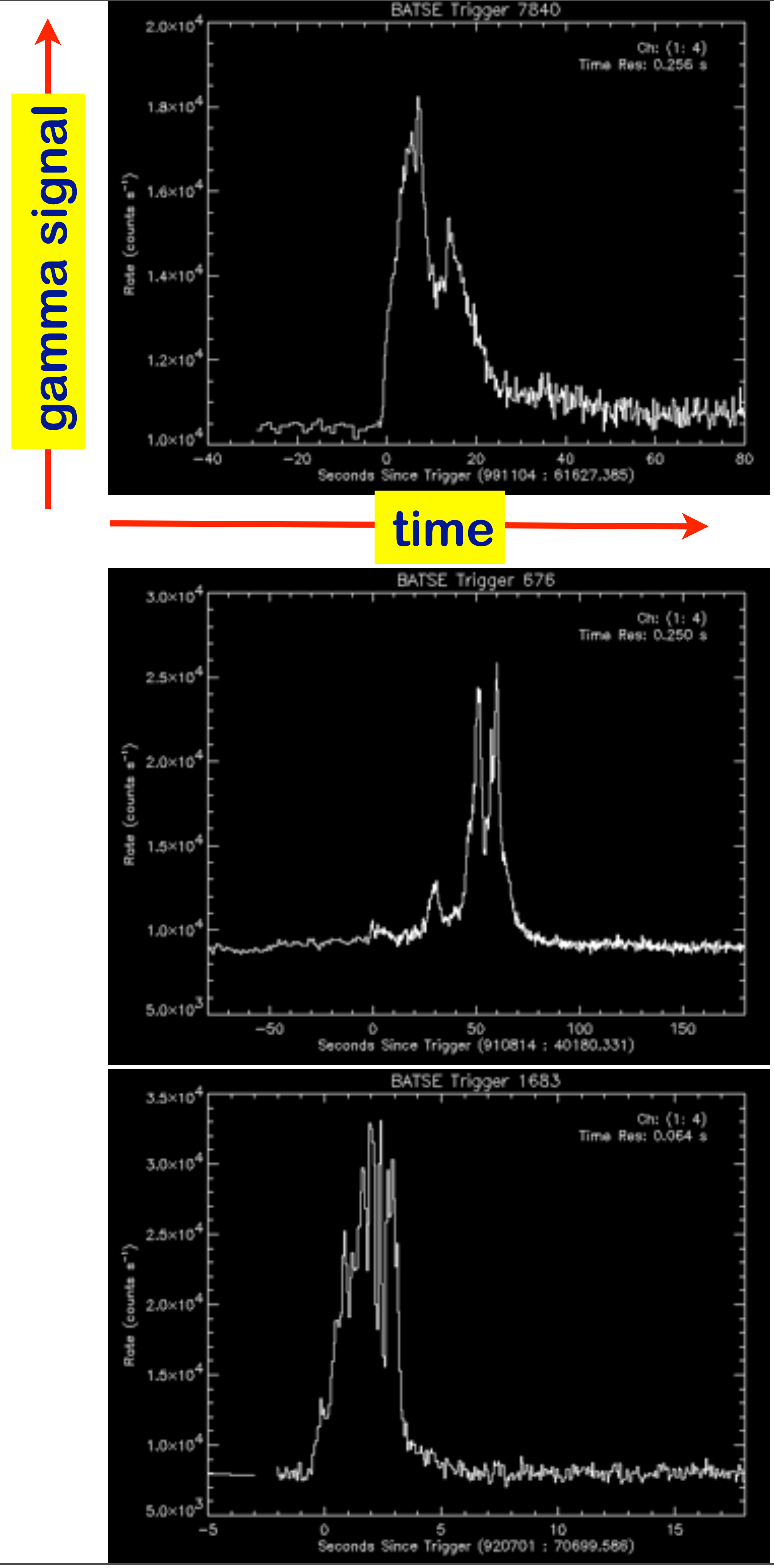
Update: NASA Swift satellite

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

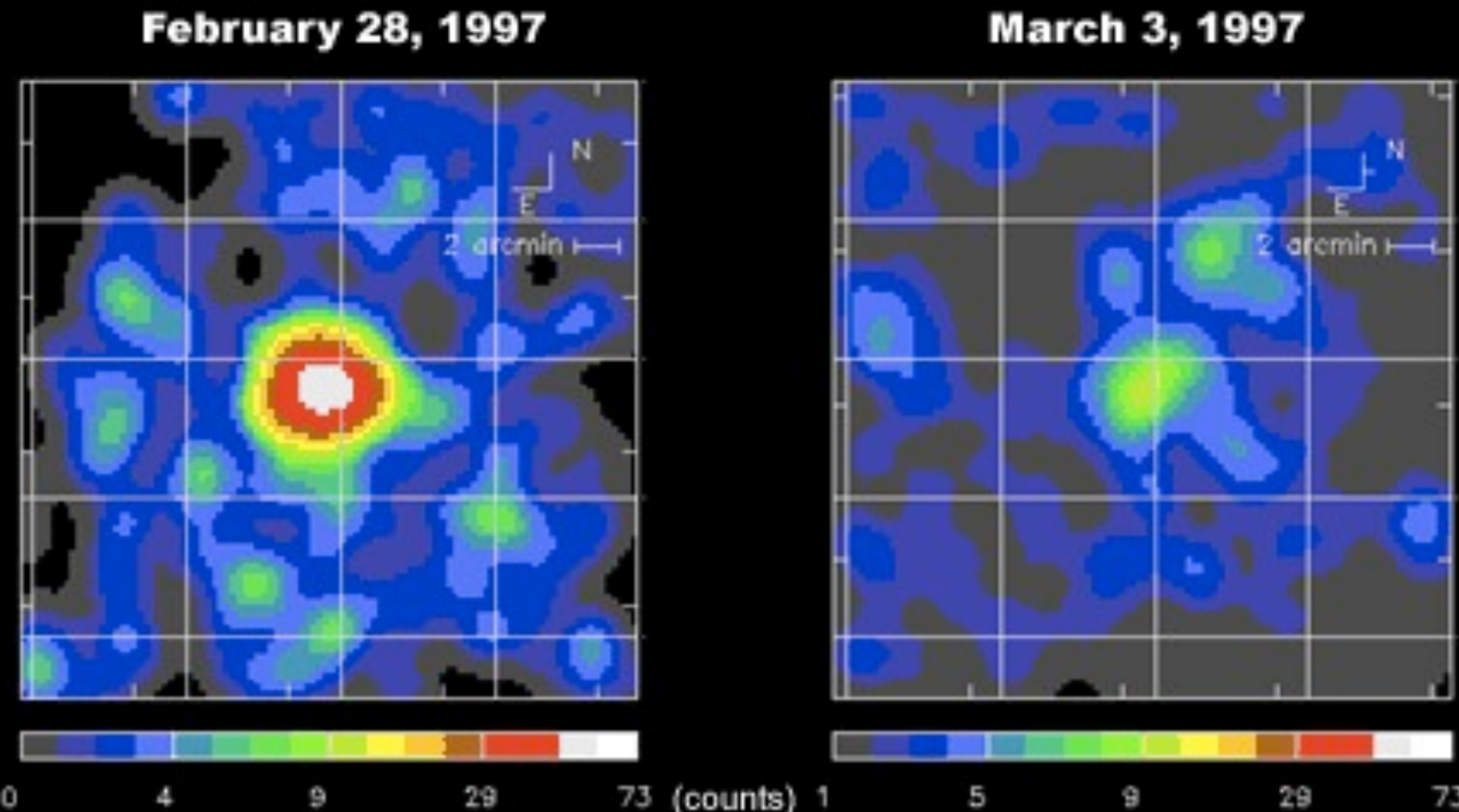


But mysteries remained:

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

Breakthrough: BeppoSax



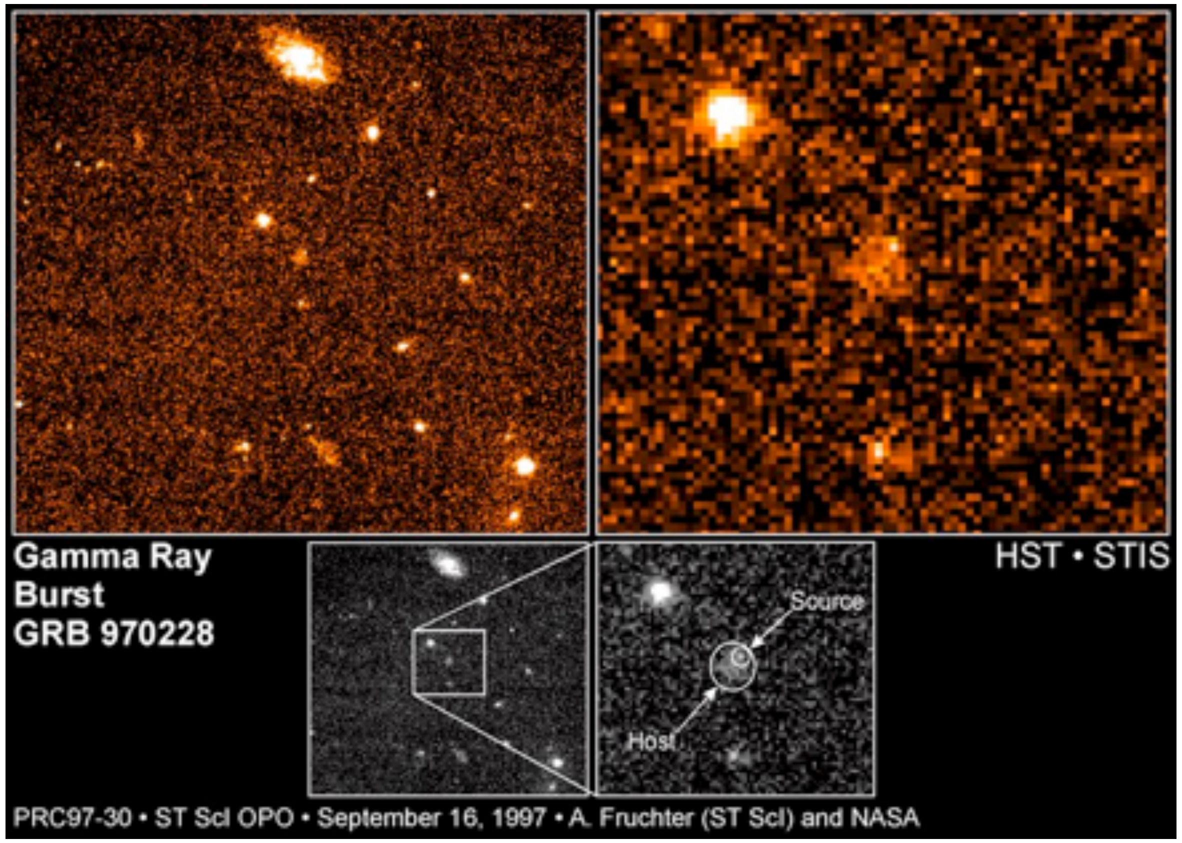
GRB 970228 X-ray afterglow
at 8 hours (left) and 3 days (right) after the Gamma-ray burst.

GRB afterglow detected in visible light!

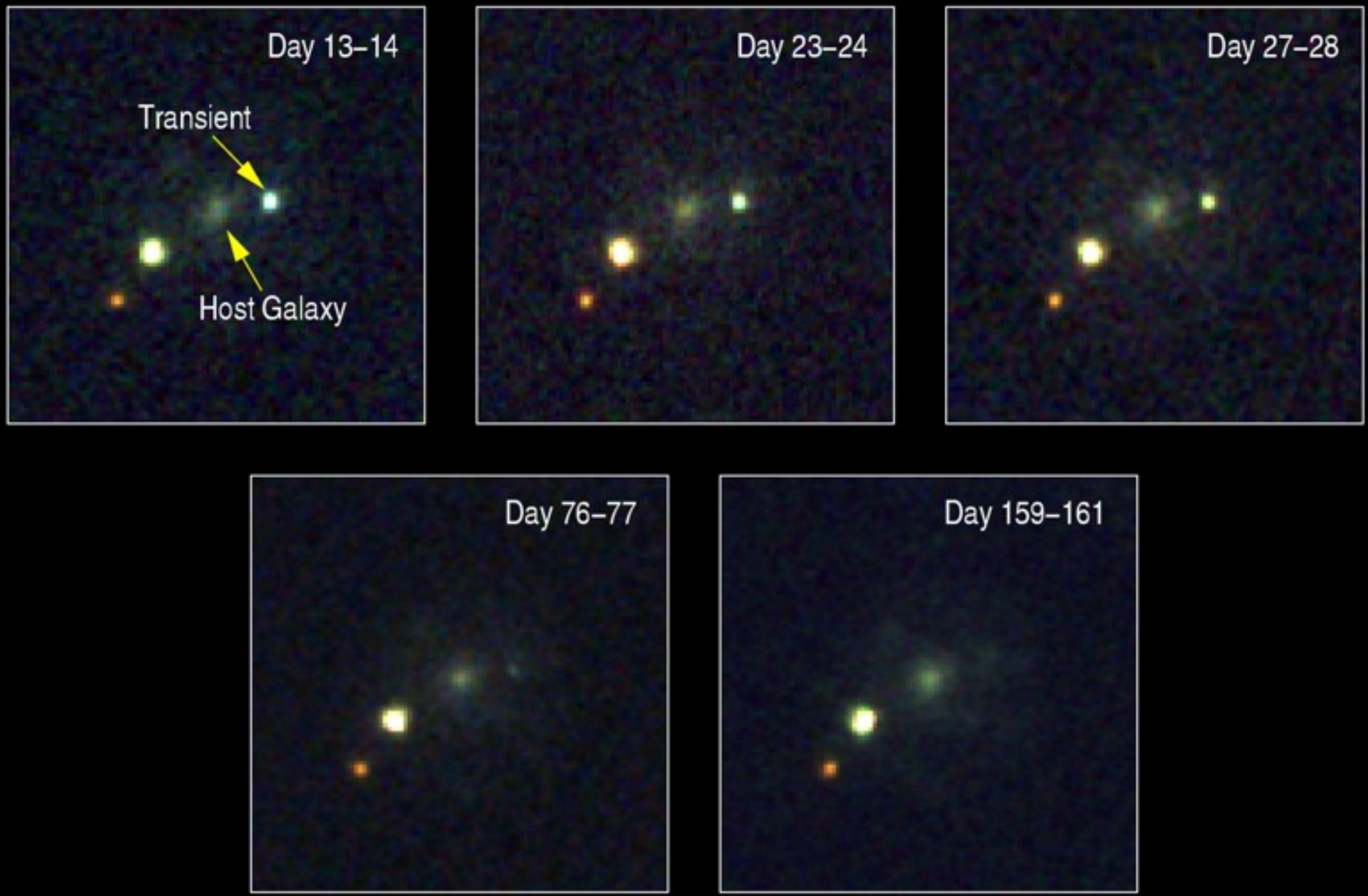
Using X-rays to pinpoint GRB location, possible to search using ordinary telescopes

detections made at all wavelengths!

non-gamma signals dim over time, but last much longer: "afterglows"

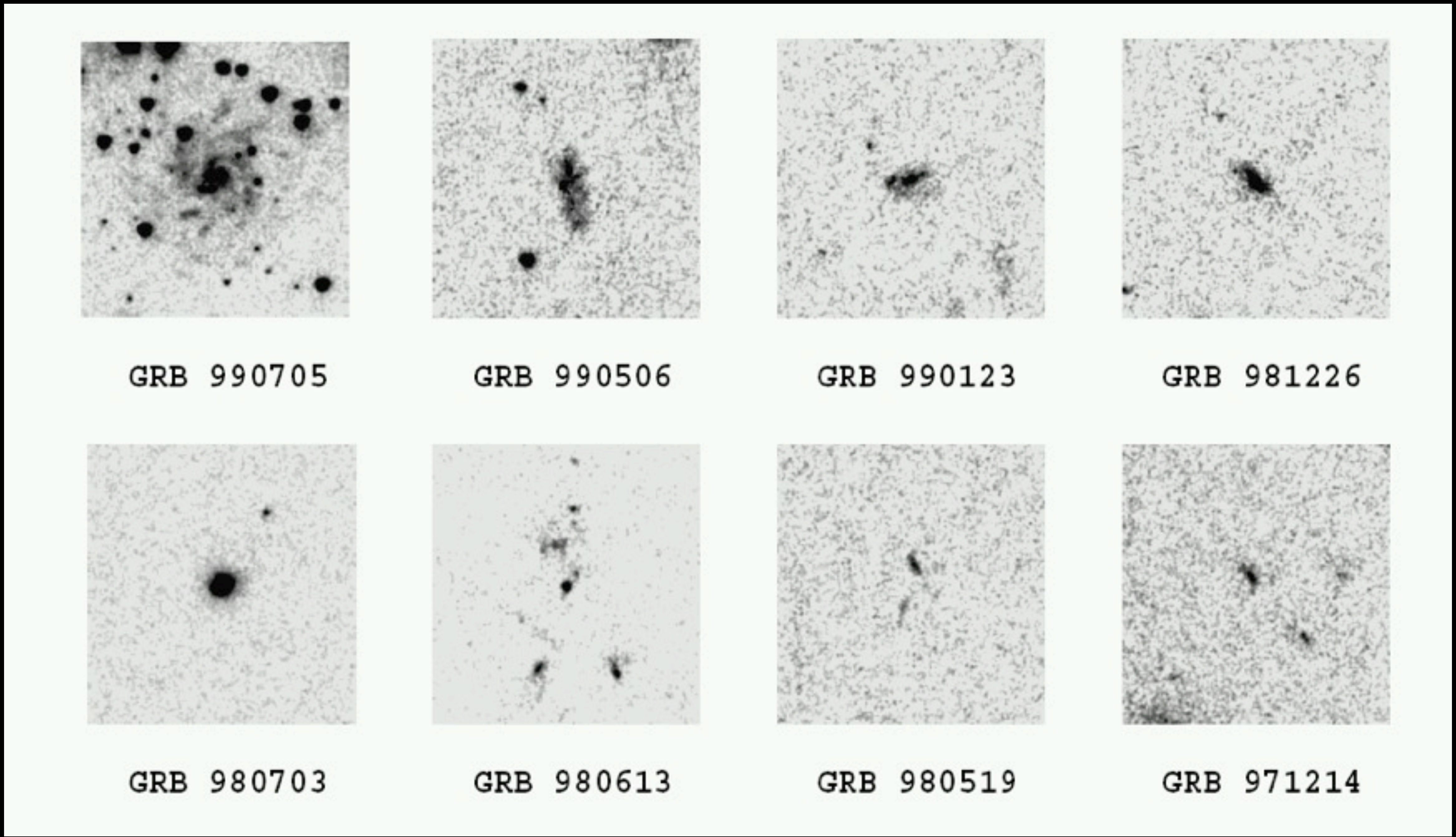


Gamma-ray Burst Afterglows



The afterglow of a GRB looks like a supernova

GRB Host Galaxies



GRBs are often observed in galaxies with active star formation

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!

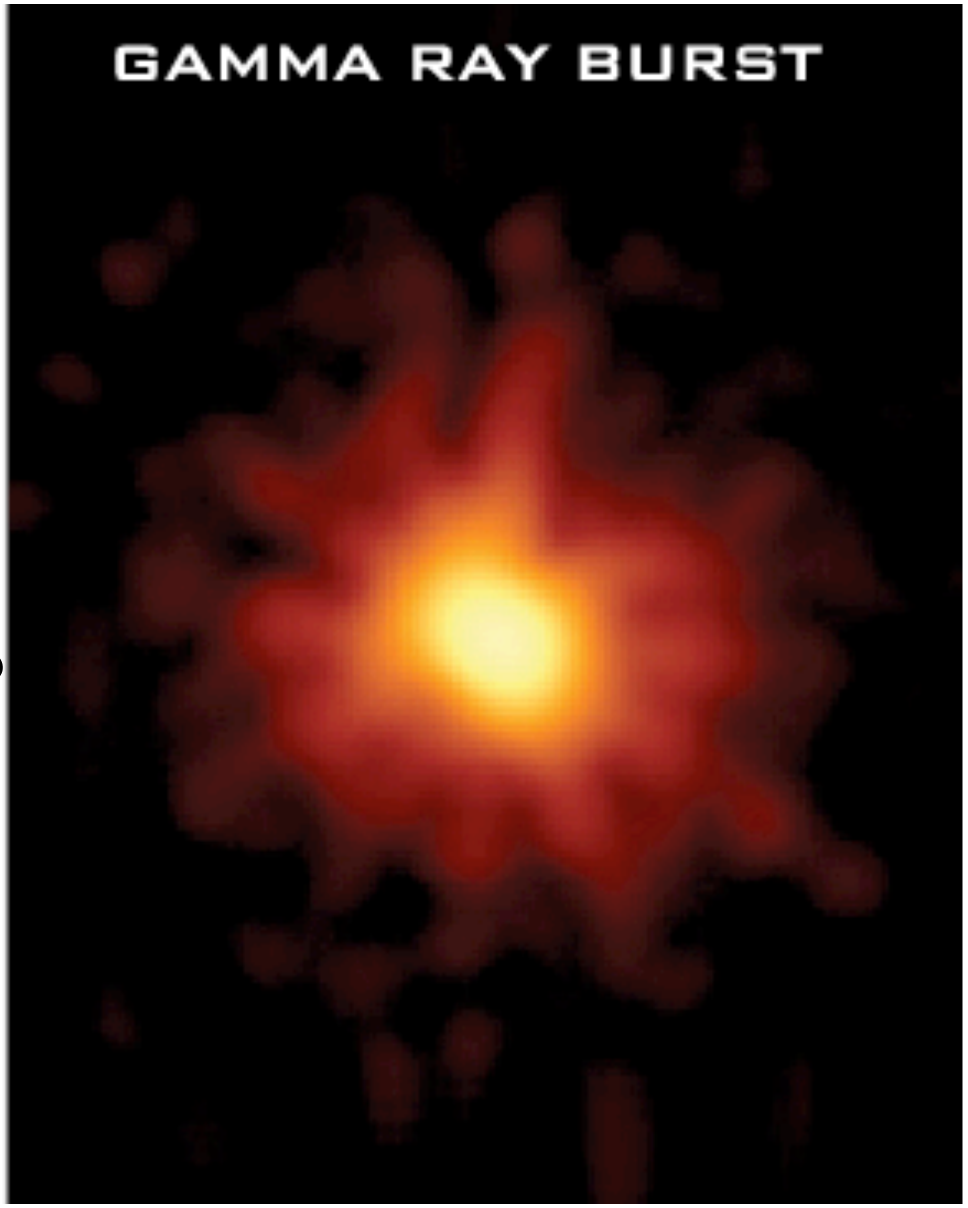
GRB afterglows mostly (but not always) found in star-forming regions of galaxies

- 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

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!?

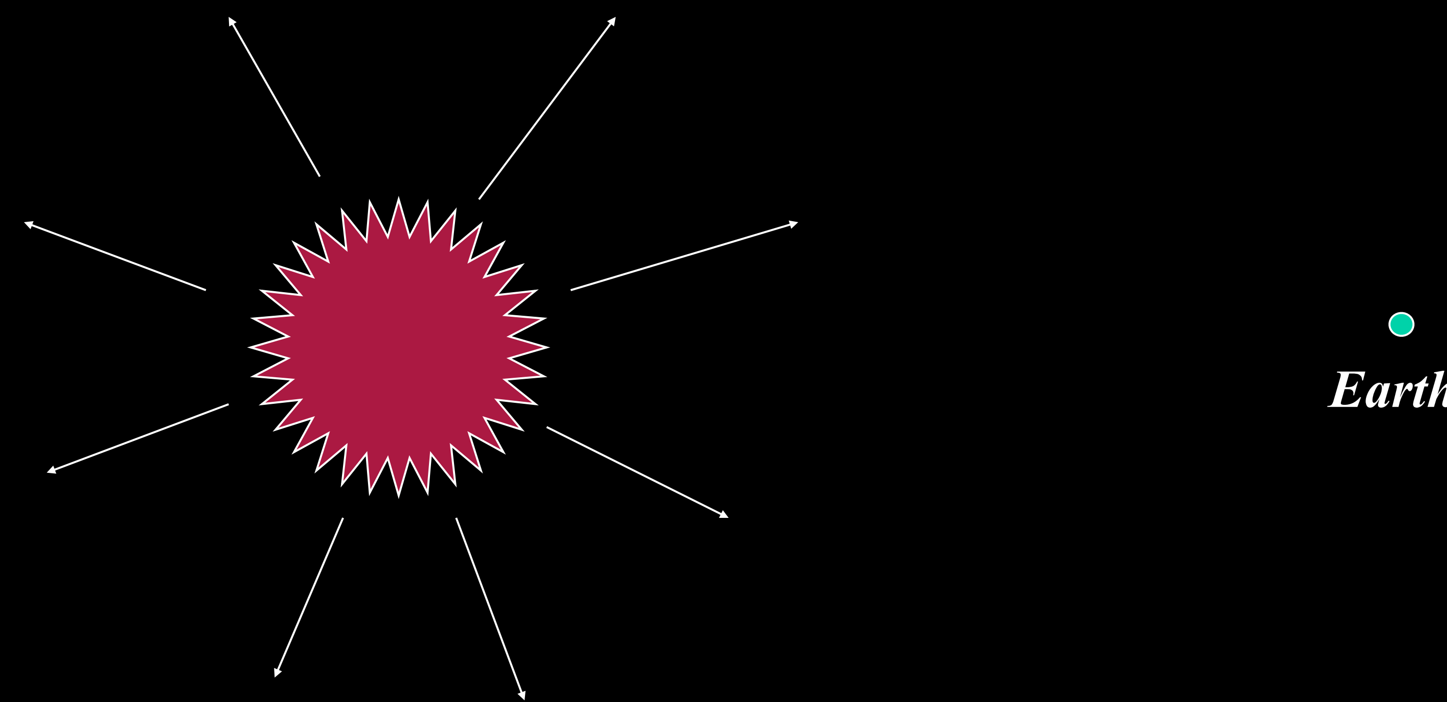


Means huge energy

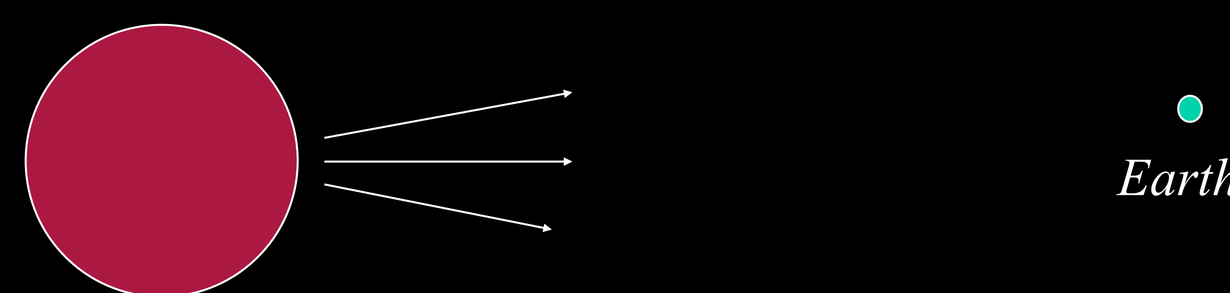
- ~ 1 M_{Sun} converted into gamma-rays in a second!
- But, that's crazy talk!

What if the energy were *beamed*?

In an isotropic explosion, energy goes out in all directions

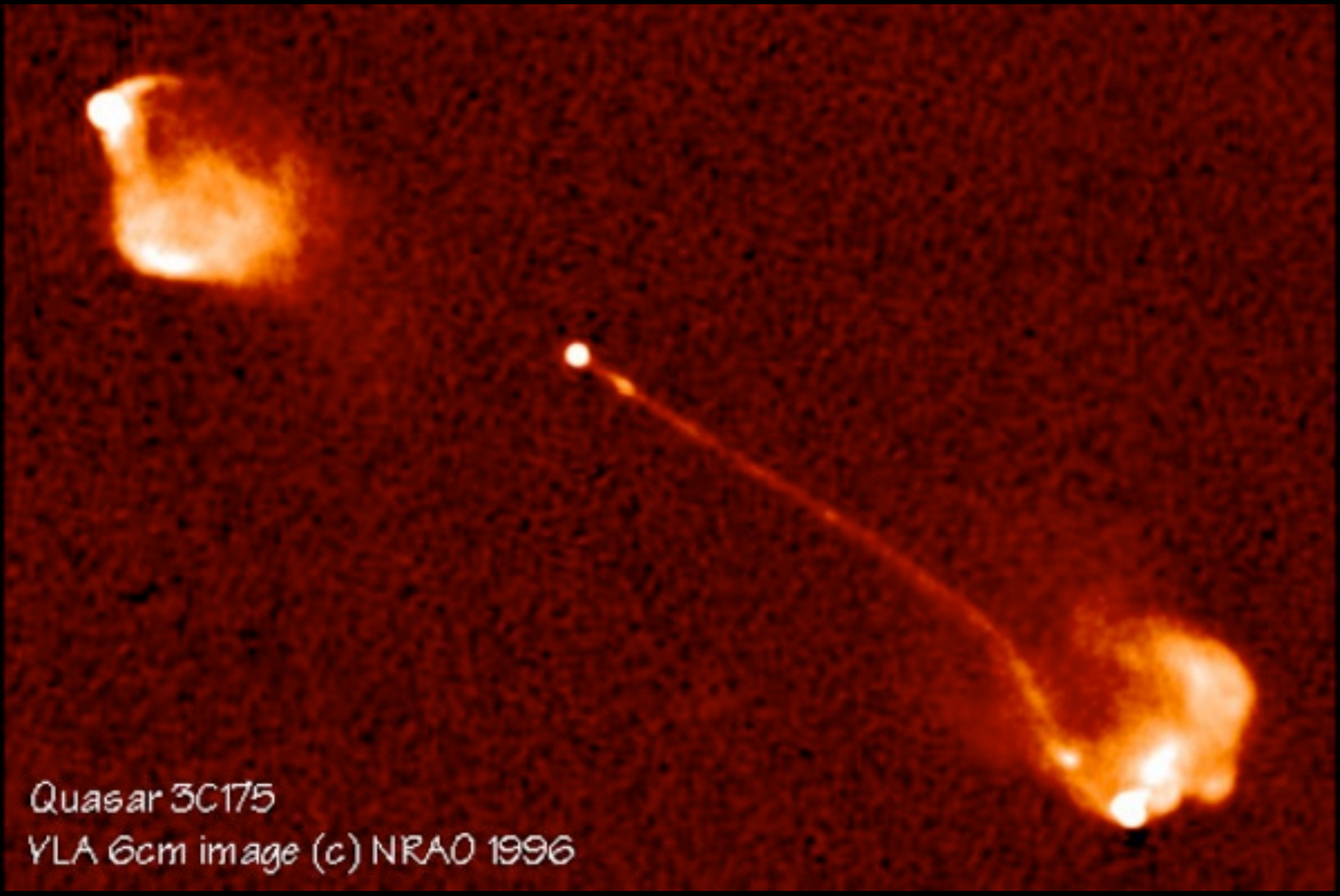


If the energy were beamed to 0.1% of the sky, then the total energy could be 1000 times less - comparable to supernova energies



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