THE UNIVERSITY OF CHICAGO
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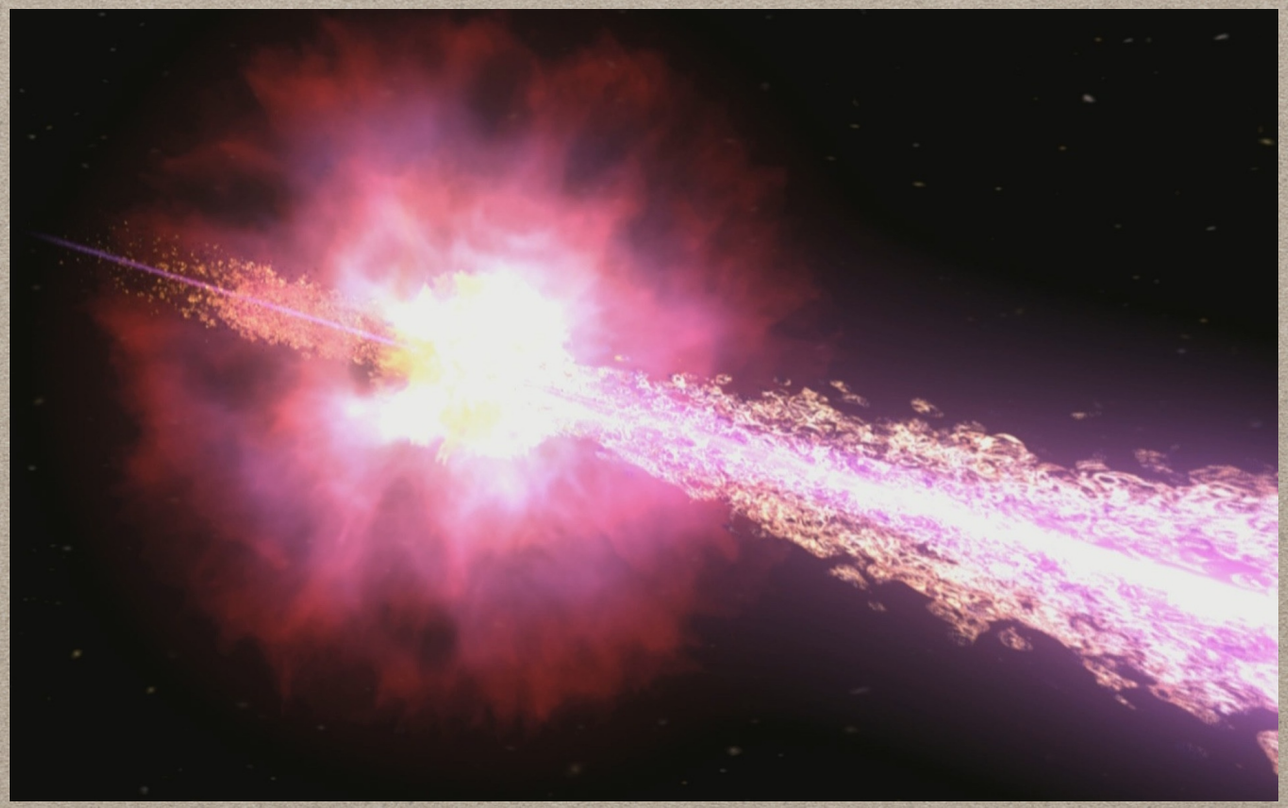
THE 82ND ARTHUR H. COMPTON LECTURE SERIES

by Dr. Manos Chatzopoulos
Enrico Fermi Postdoctoral Fellow
FLASH Center for Computational Science
Department of Astronomy & Astrophysics
University of Chicago



LECTURE 5

"BEAMED" STELLAR EXPLOSIONS: GAMMA-RAY BURSTS

10/31/2015

JETTED ENERGETIC STELLAR EXPLOSIONS

Gamma-Ray Bursts (GRBs)

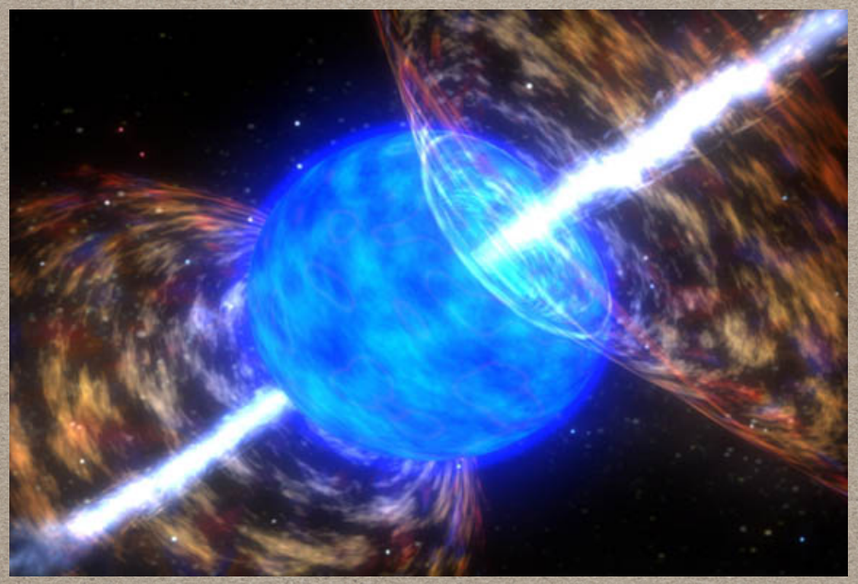
Cosmic explosions, flashes of gamma-rays lasting about 30 seconds, detected by satellites.

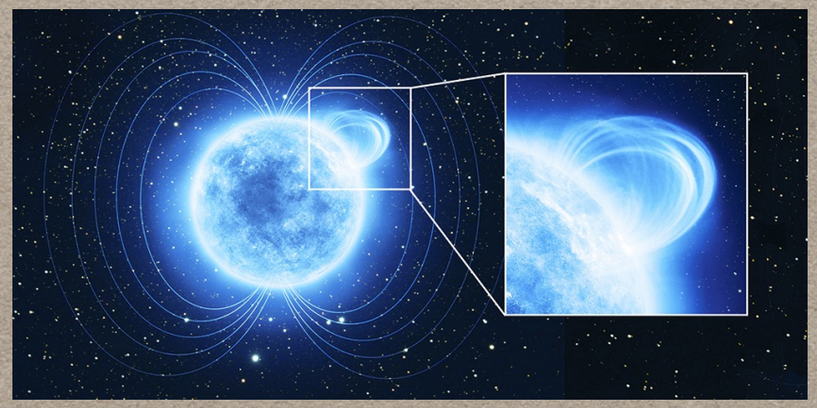
Seen across the Universe.

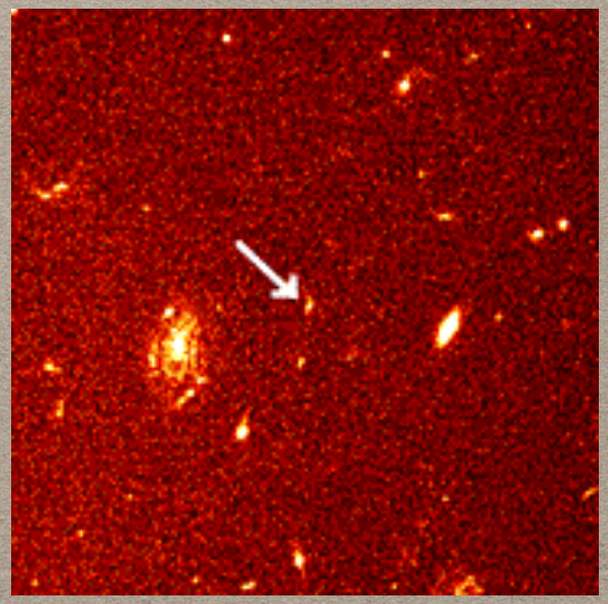
Energy is expelled in narrow jets.
Energy comparable to that of supernovae, but all in gamma-rays, with later ***afterglow*** in X-ray, radio and optical radiation.

Birth of a black hole or magnetar?

Fermi gamma-ray observatory







A GRB seen in gamma-rays!

GAMMA-RAY FLARES: UNITING STARS AND COSMOLOGY

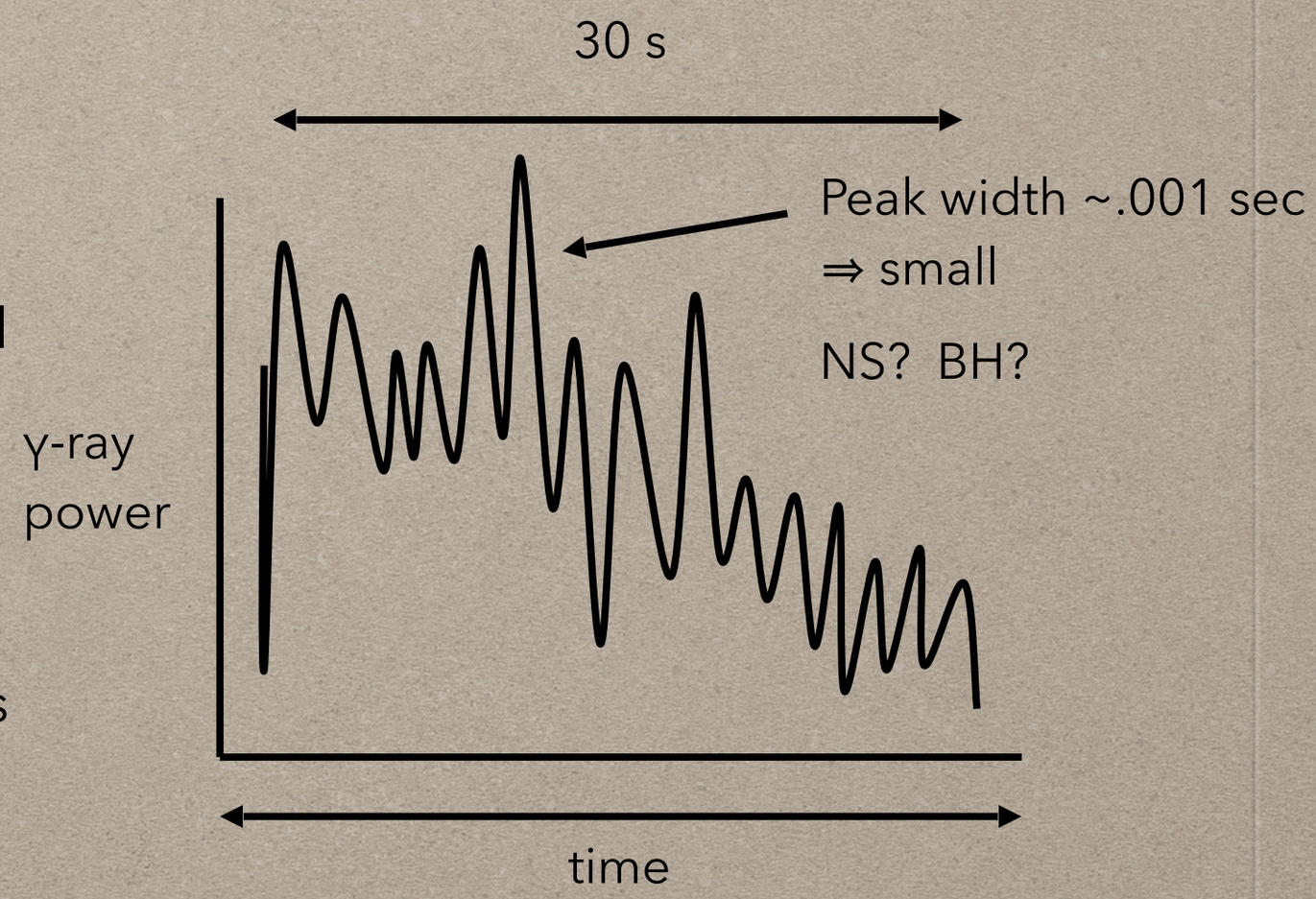
Mystery since late 60's - satellites to monitor space nuclear test ban treaty, avoid confusion between astronomical effects, and bombs

Flare of γ -rays lasts ~ **30 sec**

Never Repeat - for 30 years, no optical counterpart.

Can't focus gamma-rays.

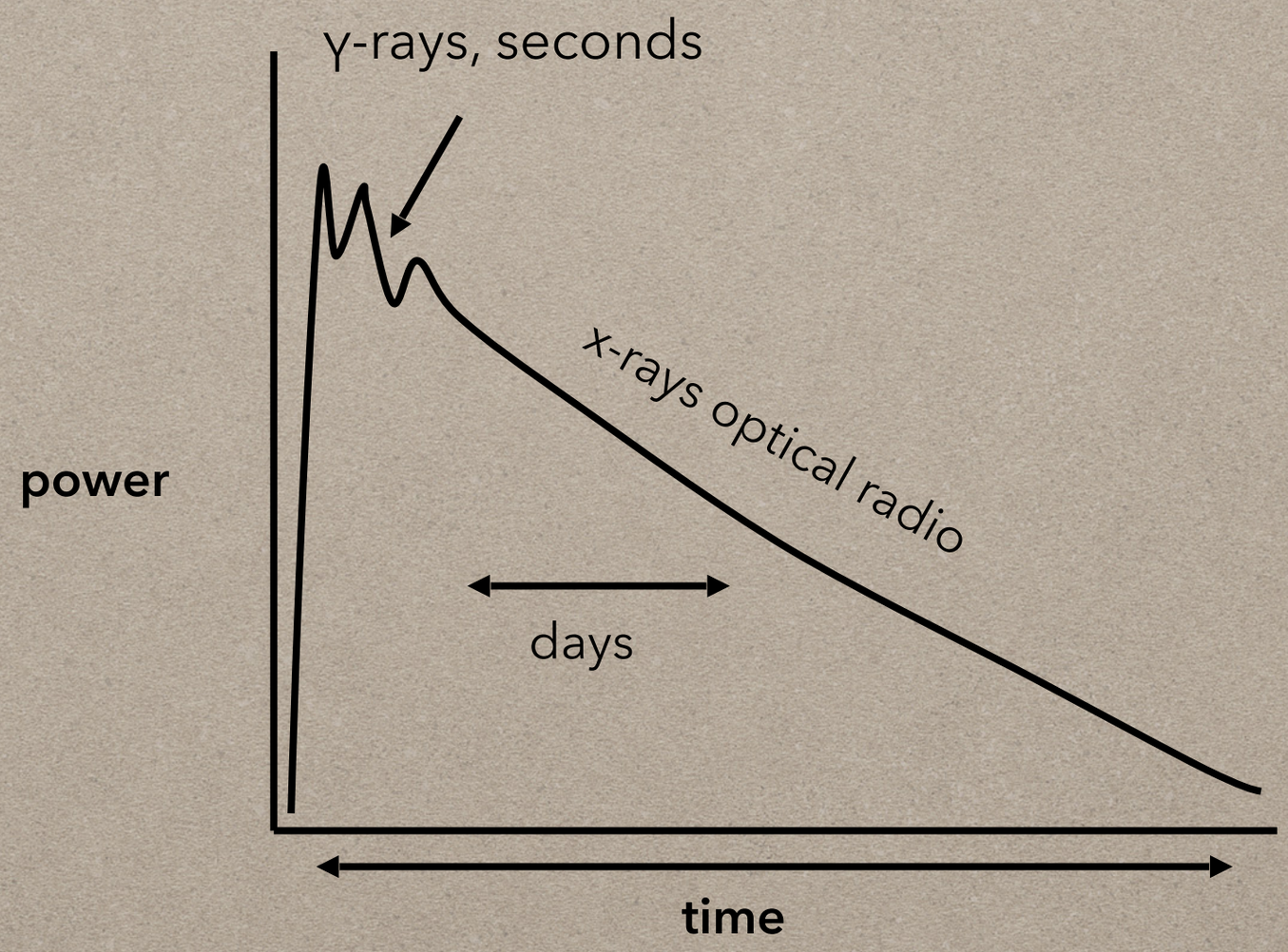
Did not know which of millions of stars to look at.



Did not know the distance: guesses ranged from within the Solar system to cosmologically distant

THE GRB "AFTERGLOW"

Revolution in 1997: 1st detection of "afterglow" - optical, radio, X-ray, fading light



Position localized! - could bring full armament of modern astronomy to bear on the fading radiation.

GRB ENERGETICS

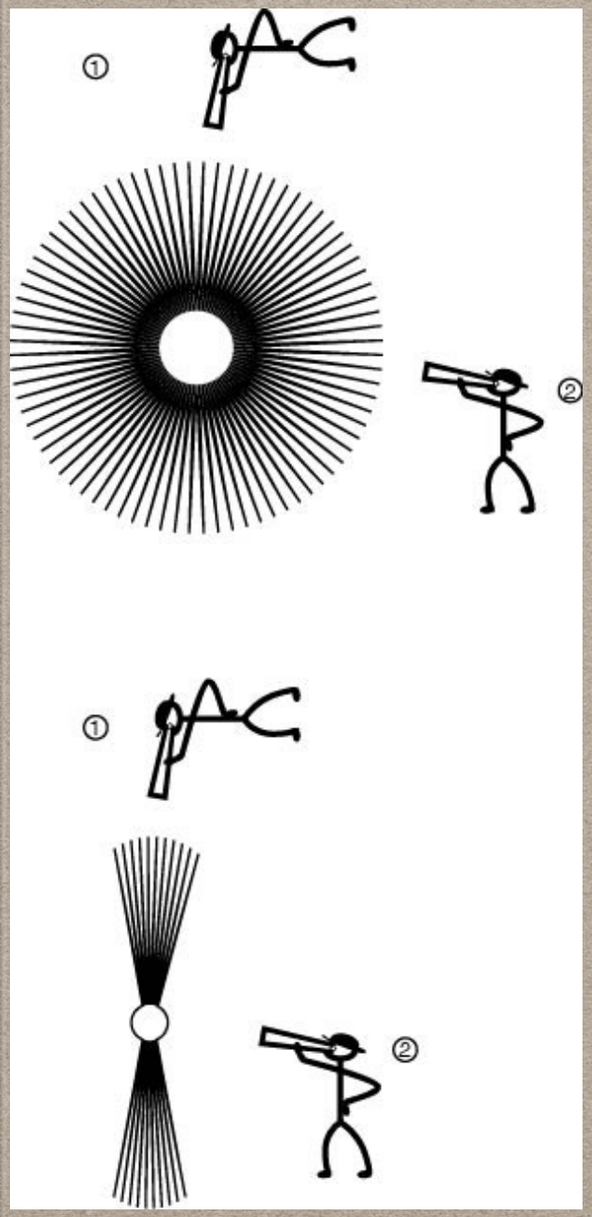
⇒ Found bursts were in **distant galaxies** - all at huge, **cosmological distances**, billions of light years away.

⇒ Very bright to shine that far

If gamma-ray bursts shine equally in all directions, the energy released in gamma rays would be **1000-10,000 × SN** or **10-100 × core collapse neutrinos!**

Comparable to **total annihilation** of entire star into pure energy (E = M c^2) !

BEAMED VS SYMMETRIC EXPLOSIONS



Bursts do not radiate in all directions!

They are strongly focused into jets!

Bursts are focused into only about 1/100 of the total area of the sky.

Typical gamma-ray burst energy ~ 1/3 supernova kinetic energy.

But send matter at 99.997% of the speed of light.

Supernova energy into a mass equivalent to Jupiter, not the mass of the Sun, as for supernovae.

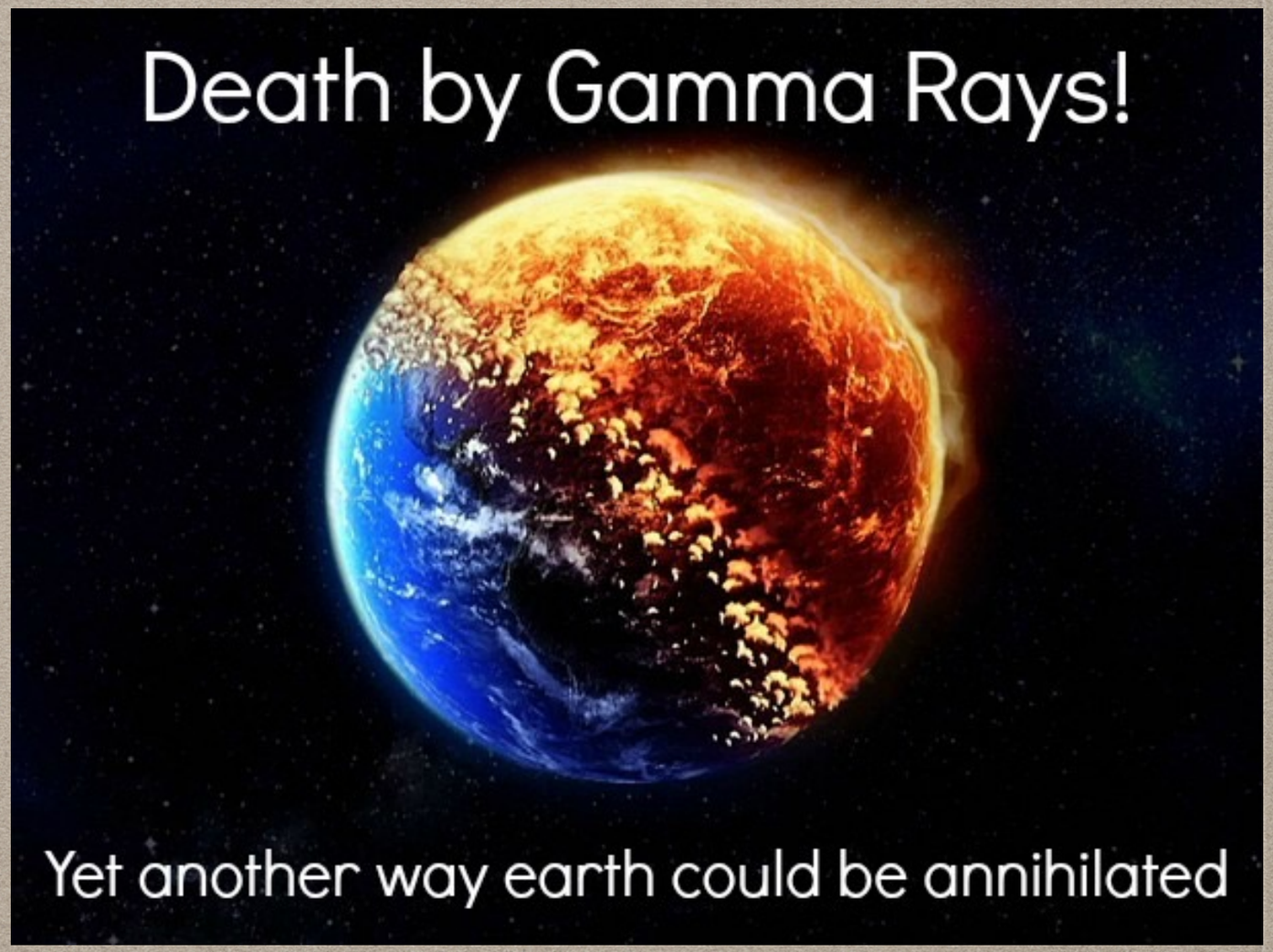
Light bulb vs laser pointer

GRBs explode ~100 times more often than observed (could observe about 2 per day if looked in all directions, all the time) because most have the jet aimed away from us.

CHANCE A GRB WILL END OUR WORLD?

What if a galactic GRB beams towards the Earth?

Very unlikely event due to:
A) **rarity** of GRBs (1 burst every 100,000-1,000,000 years!) and
B) **chance to be at beam's direction.** (probability 1 in 100 million to 1 billion years!).



But what if?

-> Cause reactions of atmosphere's oxygen and nitrogen molecules: ***photochemical smog***!

-> Enough gas production to ***cover and darken the sky***.

-> Depletion of the **ozone layer**.

THE GRB POPULATIONS - I

"Short" GRBs

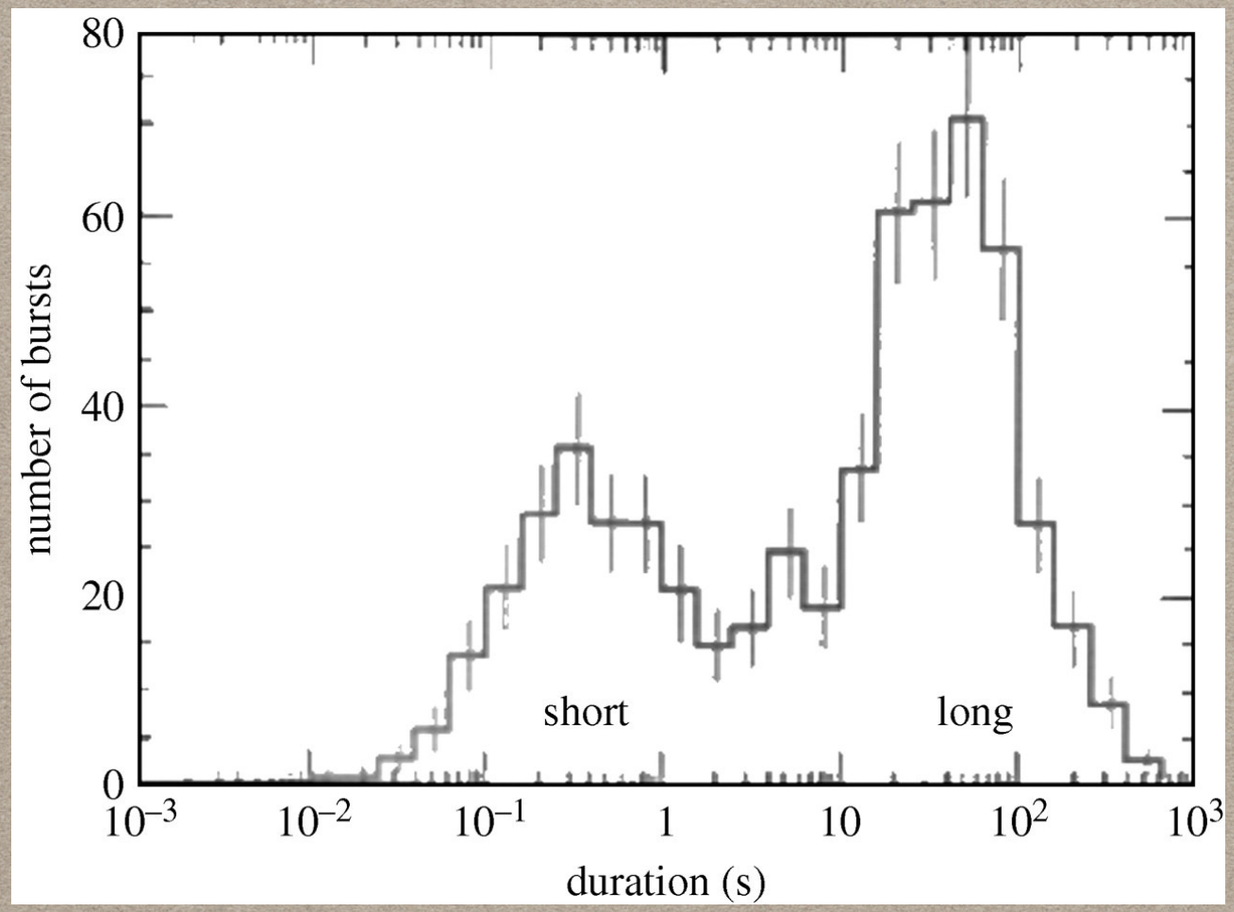
- Gamma-ray flash lasts < 2 sec
- 30% of GRBs
- No afterglow detected!
- No association with SNe!
- NS-NS / NS-BH merger?
- Example: GRB 130603B

"Long" GRBs

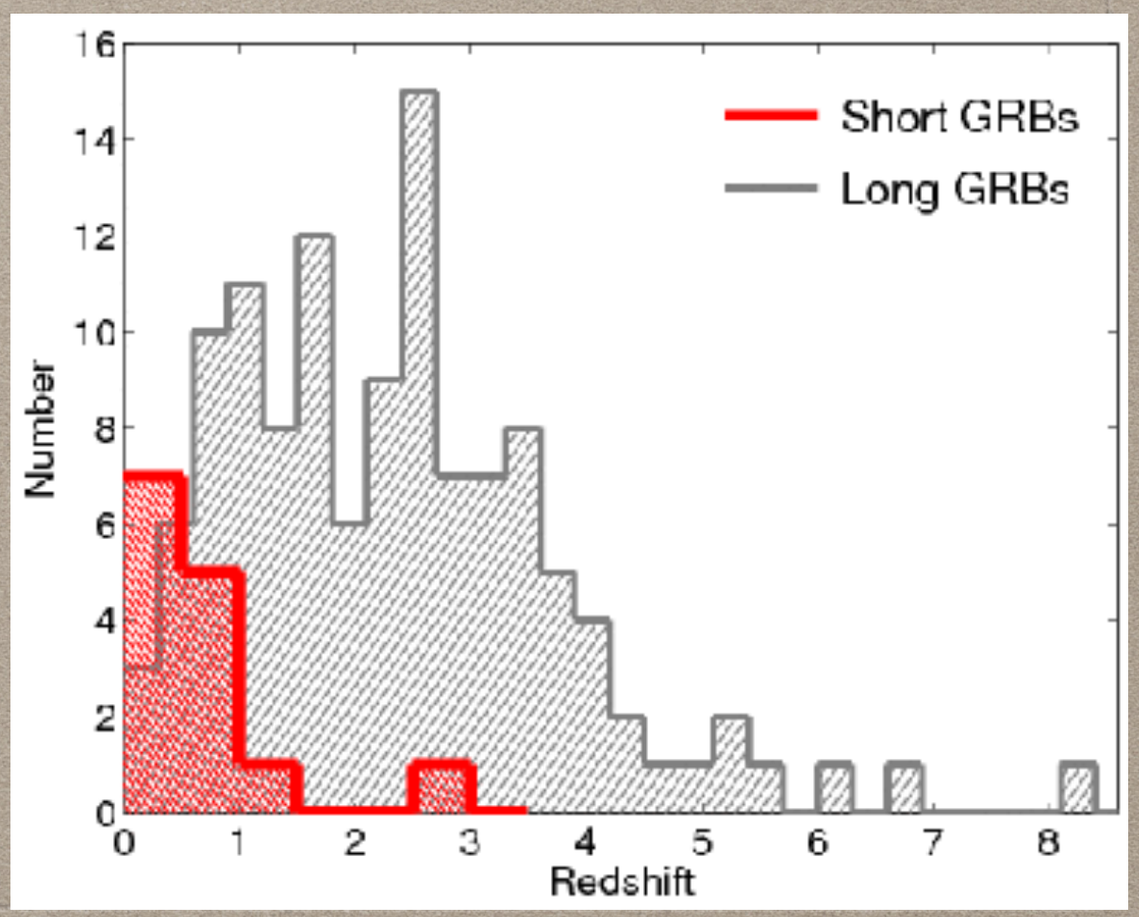
- Gamma-ray flash lasts > 2 sec
- 70% of GRBs
- X-ray/UV/Optical afterglow
- Association with broad-line SN Ic
- Jet-induced death of massive, rotating star and BH formation ("***collapsar***" model)?
- Example: GRB 980425

THE GRB POPULATIONS - II

Distribution of GRB durations (Swift/BAT orbital UV telescope)



GRB redshift (distance) distribution



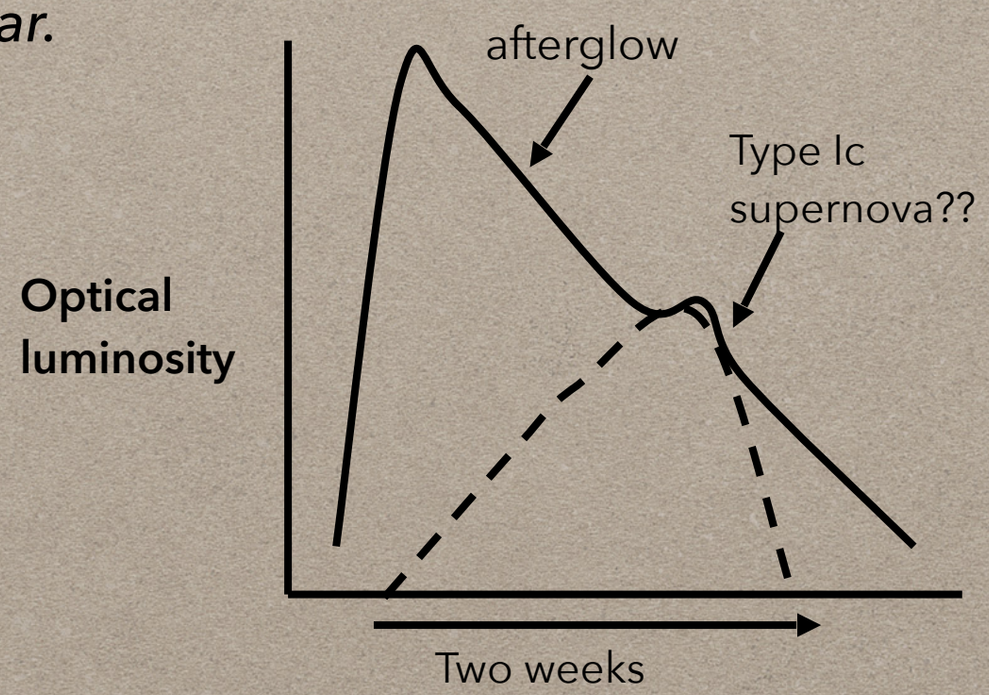
GRB-SUPERNOVA CONNECTION?

Find all gamma-ray bursts in regions of massive young stars (spiral arms of spiral galaxies, irregular star-forming galaxies like the LMC) =>

Something to do with death of massive stars

Explode once every 10^4-10^5 years in a given galaxy versus about once per 10^2 years for ordinary supernovae, so relatively rare.

Most popular guess is that gamma-ray bursts represent the birth of a ***black hole*** in the collapse of a massive star. Alternative suggestion -might be a highly magnetized neutron star or *magnetar*.



Early circumstantial evidence for several bursts associated with supernovae.

THE TYPE-IC SN - GRB LINK

Are gamma-ray bursts produced in some form of core-collapse supernova?

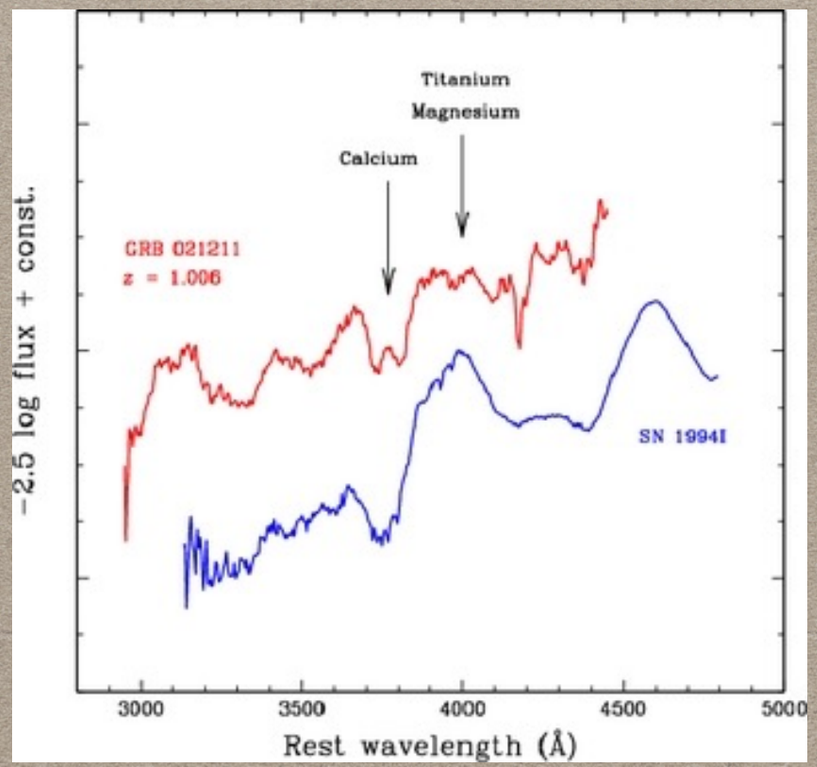
Circumstantial evidence was followed by proof:

GRB 030329 was nearby, only 3 BILLION light years away!
Relatively bright, an ideal target.

SN2003dh was discovered a week later! Spectrum of a **Type Ic supernova**

By now many associated supernovae have been found: **all are Type Ic supernovae**

But all Type Ic supernovae are **not** gamma-ray bursts



Broad-line Type Ic SN associated with GRBs

A PROBLEM STILL DEBATED...

The current picture: Gamma-ray bursts result from the collapse of a massive star from which the hydrogen and most of the helium have been stripped, probably to produce a black hole (but maybe a magnetar), that emits a tightly focused, highly relativistic jet.

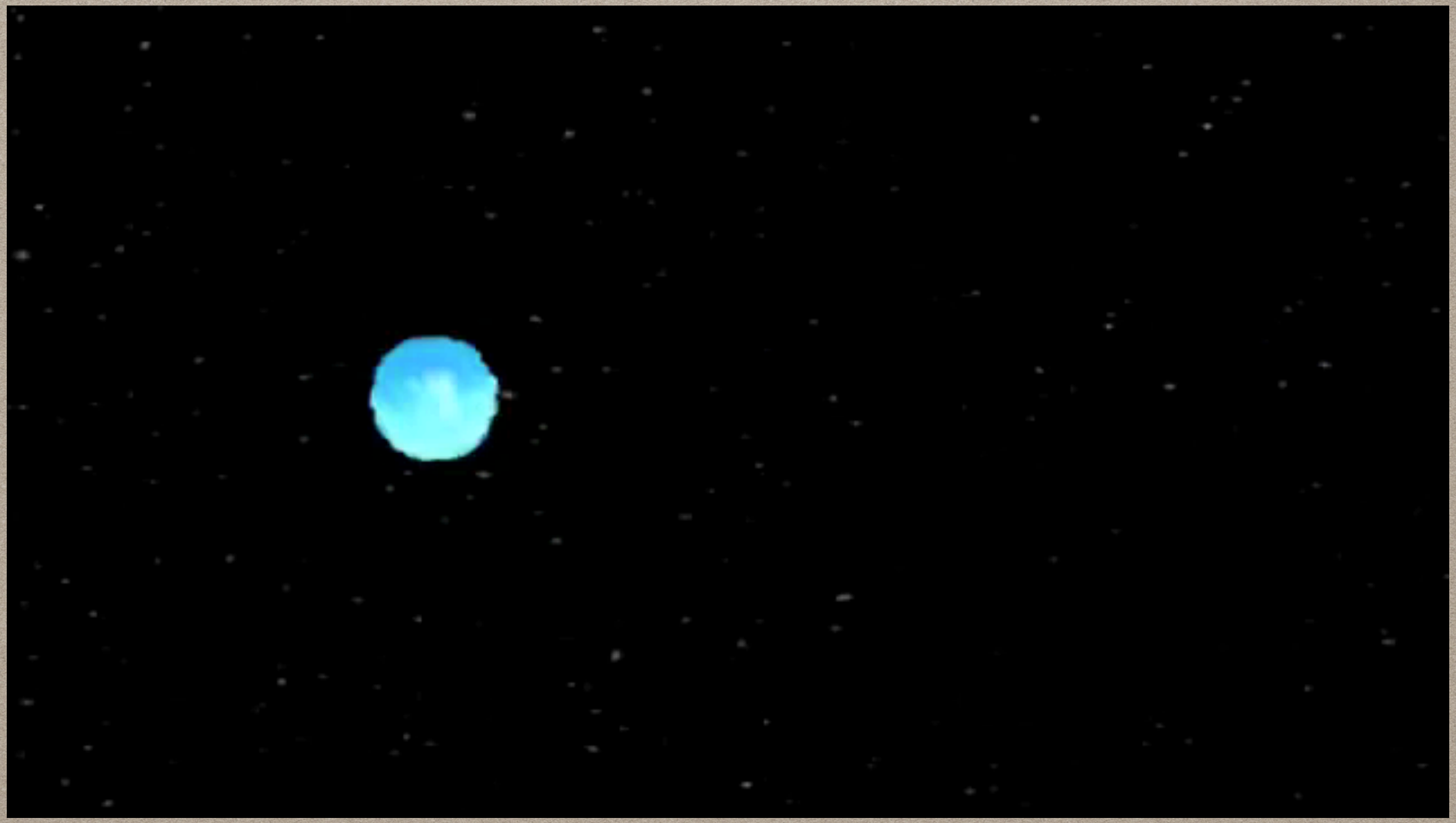
Perhaps only in **Type Ic**, missing envelope, so that jet can escape from the star.

Every burst, twice a day somewhere in the Universe -
the **birth of a black hole** aiming its jet at us?

~100 aimed elsewhere for every one aimed at us.

Have **not yet proven** that black holes are involved. Tough problem!

A "COLLAPSAR" ANIMATION BY NASA



IMPORTANCE FOR COSMOLOGY

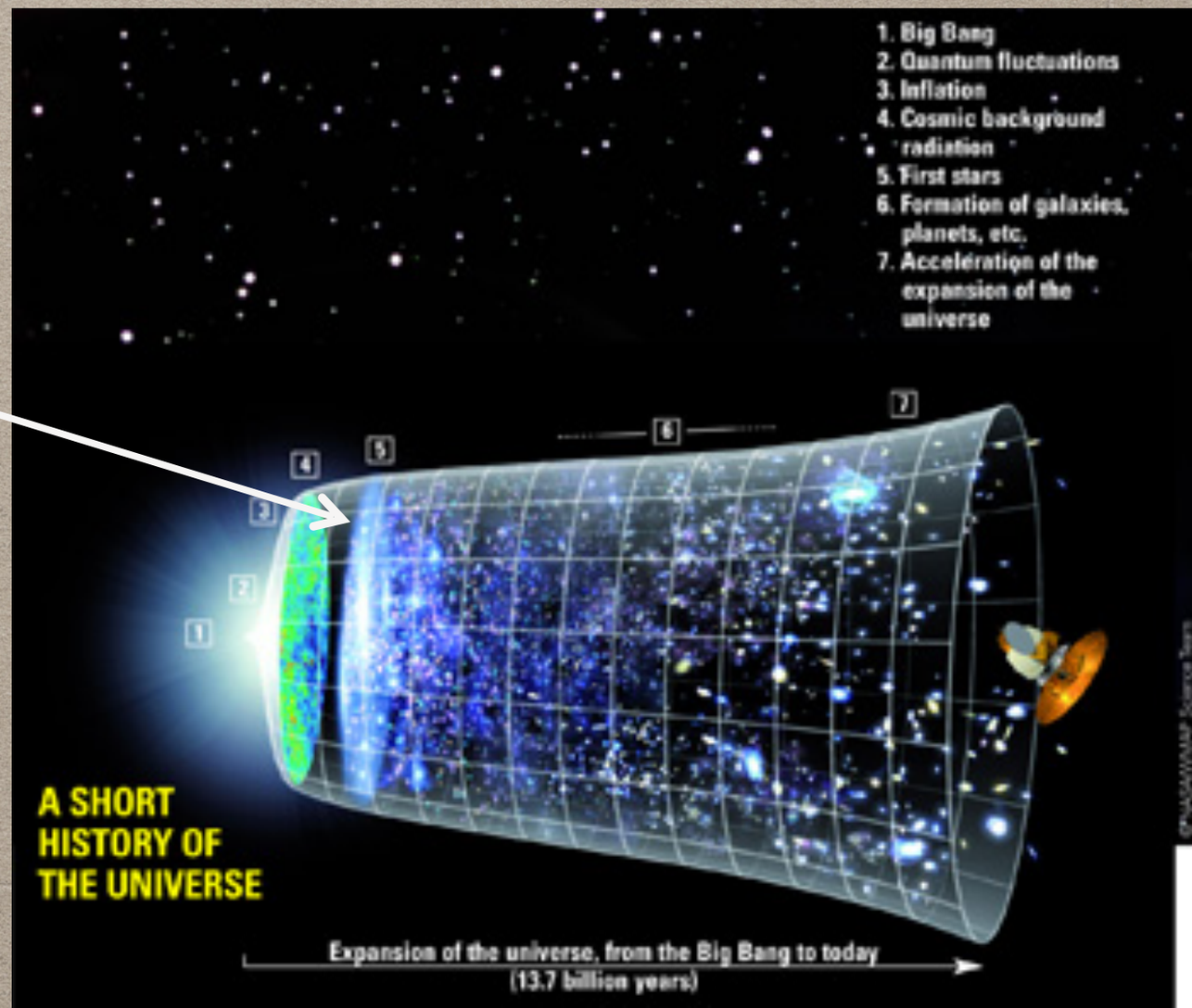
Gamma-ray bursts are intensely bright lights

Can be seen at great distance

Probe cosmology, the early Universe

Dark Ages, after the Universe cooled off a million years after the Big Bang, before stars and Galaxies first formed half a billion years later

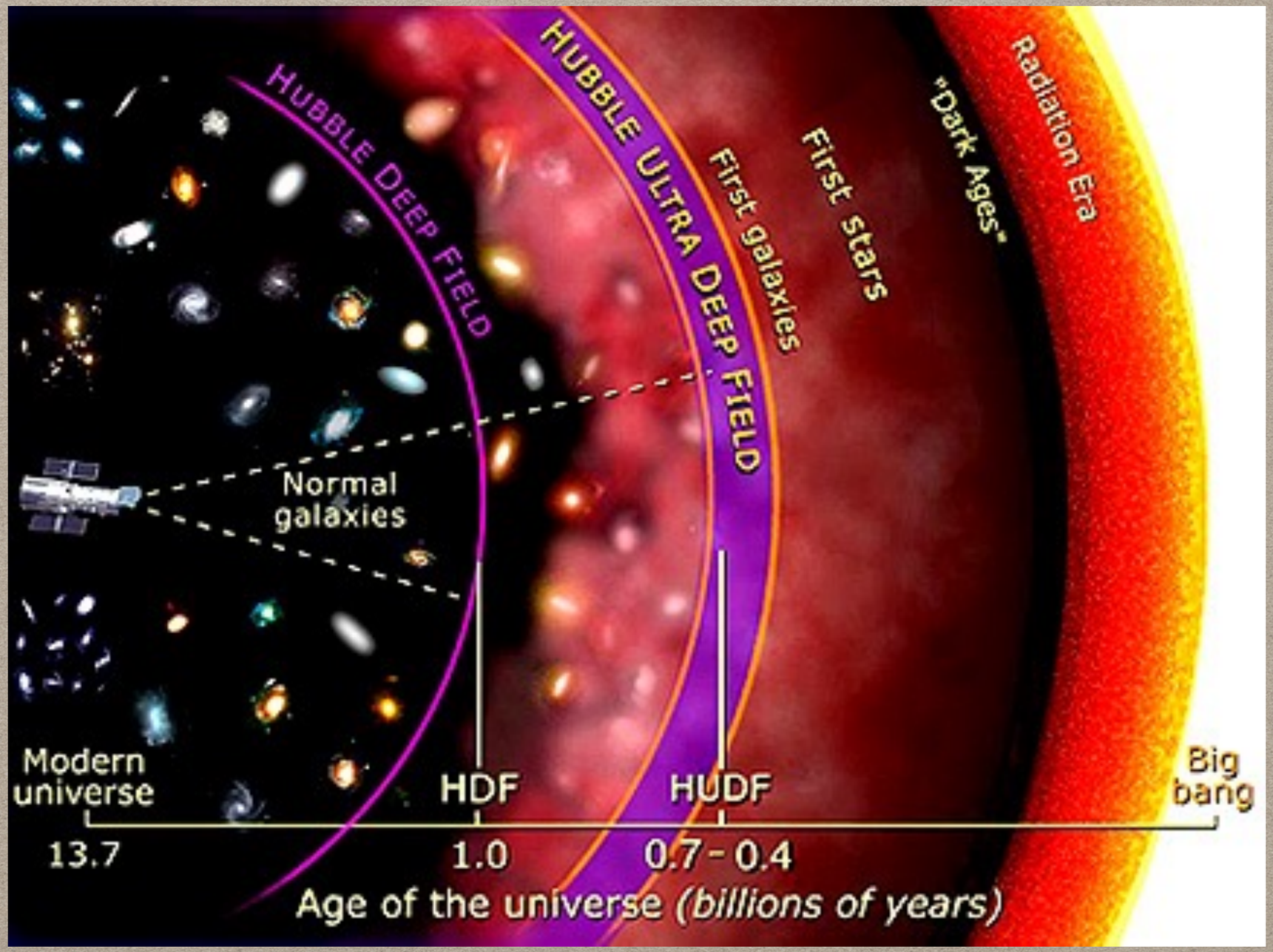
Dark Ages



Point toward the Big Bang.

PROBING THE TEENAGE UNIVERSE

The past is all around us, in every direction, out in space, back in time.



Gamma-ray bursts could be among the first objects seen at the end of the Dark Ages as the first stars are born and die, over 13 billion years ago. GRB 090423 (distance ~ 13 billion light years!) is the first example.

SUMMARY

- Gamma-ray bursts are very energetic beamed cosmic explosions that yield a very brief (few seconds) burst in the gamma-ray part of the spectrum.

- Due to the difficulty to localizing gamma-rays, the source of GRBs remained unknown for a long time. Only in the late 90's the first GRB "afterglow" was detected in the UV and optical allowing for the localization of the event and distance determination.

- The energy emitted by GRBs is equivalent to ~10,000 times the energy of a typical SN! A star would have to be converted to pure energy to shine that bright!

- Large energy and rarity of GRBs led to conclusion that they are beamed explosions and we discover them only when we happen to look directly through the jet moving toward us.

- Two categories of GRBs are seen: the short-duration (< 2 sec) and the long-duration (> 2 sec) ones.

- Short - duration GRBs probably associated with NS-NS/NS-BH mergers. Long-duration associated with massive stellar death (the "collapsar" model) and broad-line SN Ic!

- Cosmological importance: due to their brightness GRBs can be detected at large, cosmological distances when the Universe was very young.