Software error doomed Japanese Hitomi spacecraft

Space agency declares the astronomy satellite a loss.

Japan's flagship Hitomi astronomical satellite, which launched successfully on 17 February but tumbled out of control five weeks later, may have been doomed by a basic engineering error. Confused about how it was oriented in space and trying to stop itself from spinning, Hitomi's software apparently fired a thruster jet in the wrong direction — accelerating rather than slowing the craft's rotation.

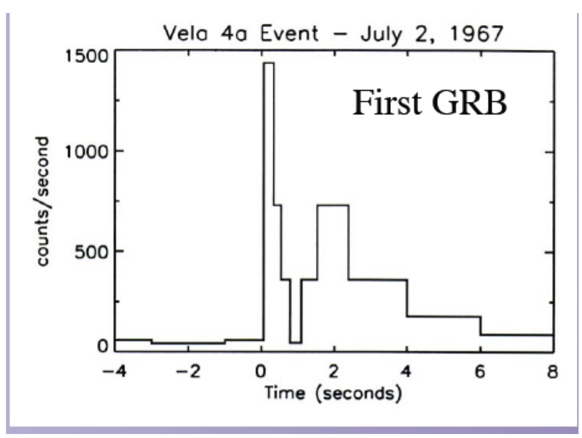
http://www.nature.com/news/software-error-doomed-japanese-hitomi-spacecraft-1.19835

Gamma-Ray Bursts- Longair 22.7

- Are bright flashes of γ-rays- for a short period of time (<100 sec)
- fluxes of ~0.1-100 photon/cm^2/sec/keV emitted primarily in the 20-500 keV band.
  - Distribution is isotropic on the sky
- Because of these properties it took ~30 years from their discovery (1967) to their identification
  - **They are at very large distances (z up to 8 (!)) with apparent luminosities of 3x10^{54} erg/sec**
  - Rate is ~10^{-7}/yr/galaxy
- What are they??- short timescales imply compact object ; what could the energy reservoir be- Mc^2 implies M~10^{33} gms~ M_{sun} if total conversion of mass into energy How does all this energy end up as γ-rays ?
  - Location of long γRBs is in and near star forming regions in smallish galaxies- associated with star formation
  - a few γRBs have been associated with a type Ic supernova

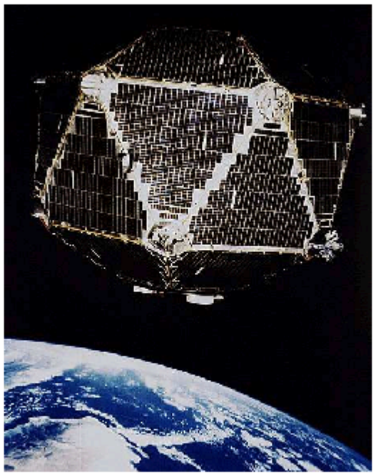
Gamma-Ray Bursts

- Cosmic γ-ray bursts (GRBs) were first reported in 1973 by Klebesadel et al (l973) but were first seen on July 2, 1967, based on data from US satellites designed to monitor Russian nuclear weapons tests in space
- They are the sign of the birth of a stellar mass black hole (not all BHs start as a γ-ray burst)
  - Gehrels, Ramirez-Ruiz & Fox, ARAA 2009
- GRBs/GRB afterglows: brightest radiation from most distant sources in the universe

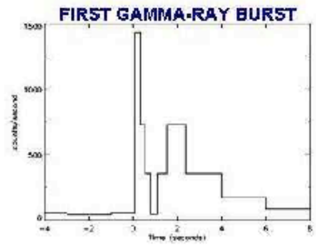


While they are on, they can outshine the sum of all other sources in the γ-ray sky, including the Sun

Discovery



Sketch of one of the Vela satellites to search for violations of the nuclear test ban treaty.



1967: Vela satellites find extremely bright flares from the sky, with durations of a few seconds: Gamma-Ray Bursts (GRBs; total of 73 GRBs found between).

Reported in 1973 only (Klebesadel et al., 1973).

During the burst, GRBs are the *brightest* gamma-ray objects in the sky, brighter than the Sun!

Gamma-Ray Bursts (GRBs)

- discovered by U.S. spy satellites (1967; secret till 1973)
- have remained one of the biggest mysteries in astronomy until 1998 (isotropic sky distribution; location: solar system, Galactic halo, distant Universe?)
- discovery of afterglows in 1998 (X-ray, optical, etc.) with redshifted absorption lines has resolved the puzzle of the location of GRBs $\rightarrow$ GRBs are the some of the most energetic events in the Universe
- duration: 10^{-3} to $10^{3}\,$s (large variety of burst shapes)
- bimodal distribution of durations: $0.3\,$s (short-hard), $20\,$s (long-soft) (different classes/viewing angles?)
- GRBs are no standard candles! (isotropic) energies range from 5×10^{44} to $2 \times 10^{47}\,$J
- highly relativistic outflows (fireballs): ($\gamma \gtrsim 100$), possibly highly collimated/beamed
- GRBs are produced far from the source ($10^{11} - 10^{12}\,$m): interaction of outflow with surrounding medium (external or internal shocks) $\rightarrow$ fireball model
- relativistic energy $\sim 10^{46} - 10^{47}\,\mathrm{J}\,\epsilon^{-1}\,f_{\Omega}$ (ϵ: efficiency, f_{Ω}: beaming factor; typical energy $10^{45}\,$J?)
- event rate/Galaxy: $\sim 10^{-7}\,\mathrm{yr}^{-1}\,(3 \times 10^{45}\,\mathrm{J}/\epsilon\,\mathrm{E})$

GRBs are powerful explosions

- visible across the universe
- most luminous sources across the electromagnetic spectrum
- afterglow lasts for days

Long GRBs

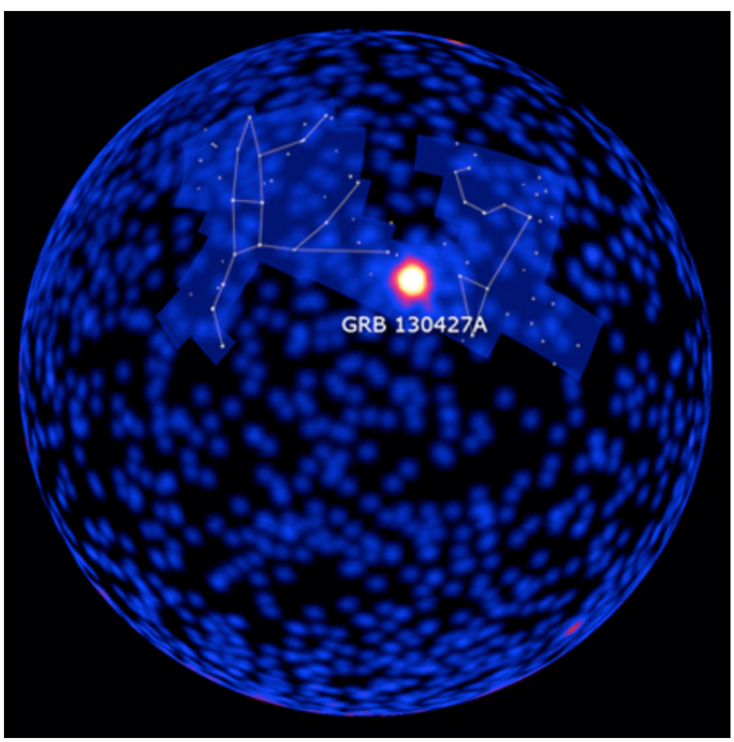
- due to core collapse to black hole of massive star
- new probe of reionization era
- produce energetic, high-velocity hypernovae (Ib/c)

possibility to use GRBs to trace star formation at high redshifts

Short GRBs

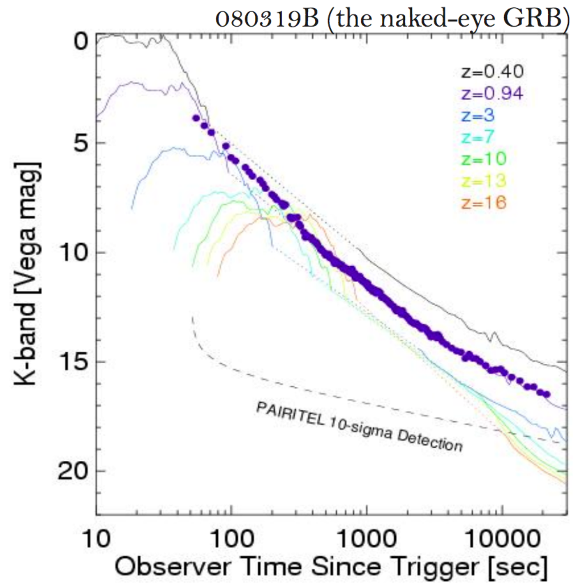
- associated with old stellar populations
- likely caused by NS-NS mergers
- less energetic than long bursts
- exciting sources for gravitational wave joint observations

Image of γ-ray Sky During Burst



How Bright Are They

- The most luminous GRBs can be detected by a 1m telescope at z>16



ghtest events are observable with 1m-class telescopes up to z>16

What Use are They?

- ISM metals and dust
- reionization of the universe and the nature of the galaxies responsible for it
- direct detection of the first stars in the universe- Pop III stars
- measuring the star formation rate at very high-z
- etc

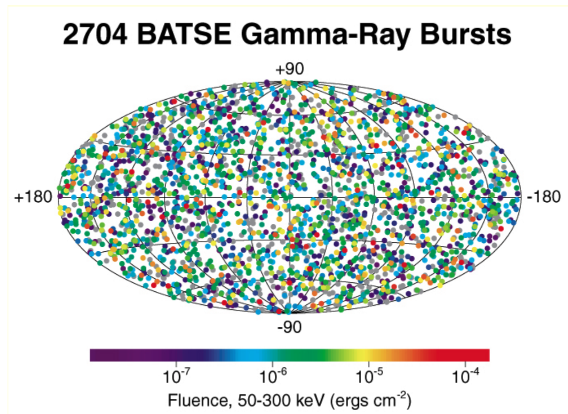
Isotropic on Sky

For 25 years their nature was unknown

while they are the brightest γ-ray sources in the sky –they occur randomly in time and last ~10's of secs

In the 1990's the BATSE experiment on GRO detected ~3000 bursts; 2-3 per day and showed that they occur isotropically over the entire sky suggesting a distribution with no dipole or quadrupole components-e.g. a spherical dist (cosmological?!)

Because they occur randomly and are isotropically distributed identification of counterparts in other wavelengths was very difficult



Breakthrough

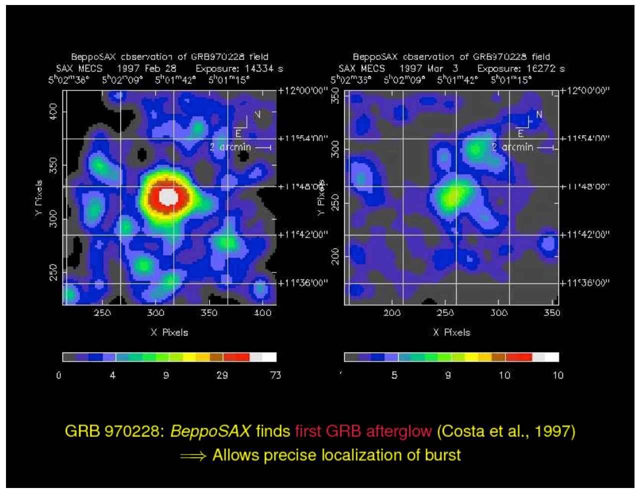
- Breakthrough in 1997 with BeppoSax- an x-ray mission was slewed rapidly to a localized region containing the burst
- Found x-ray afterglows- source flux decayed rapidly but if got to it soon enough an 'new' x-ray source was always found.
- The x-ray position was accurate enough to identify an optical counterpart.

- See chap 7 of R+B for lots more material on GRBs + Melia sec 11.2

•Breakthru discovery of 'afterglows' in the x-ray by the BeppoSax satellite (1998GRB 970228 Piro et al – ARA&A 2000. 38:379 van Paradijs et al)

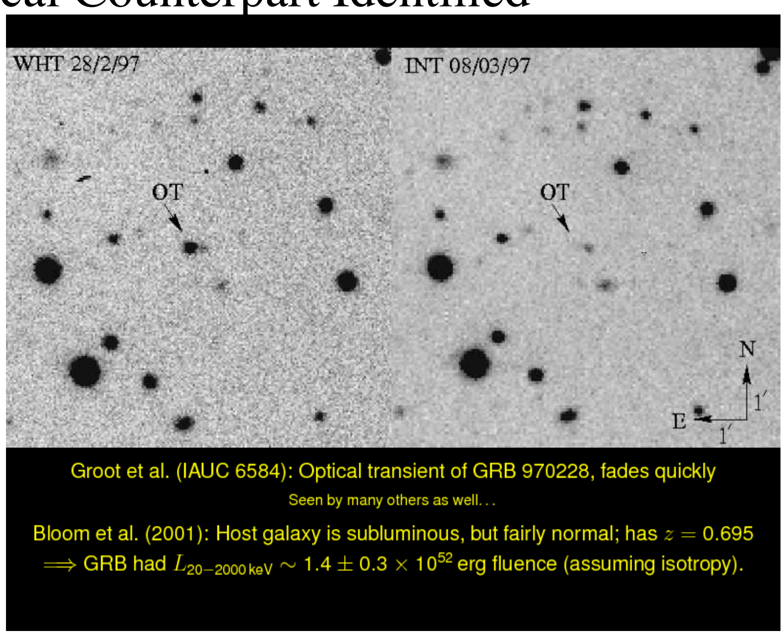
- a 'new' x-ray source appeared and faded with time

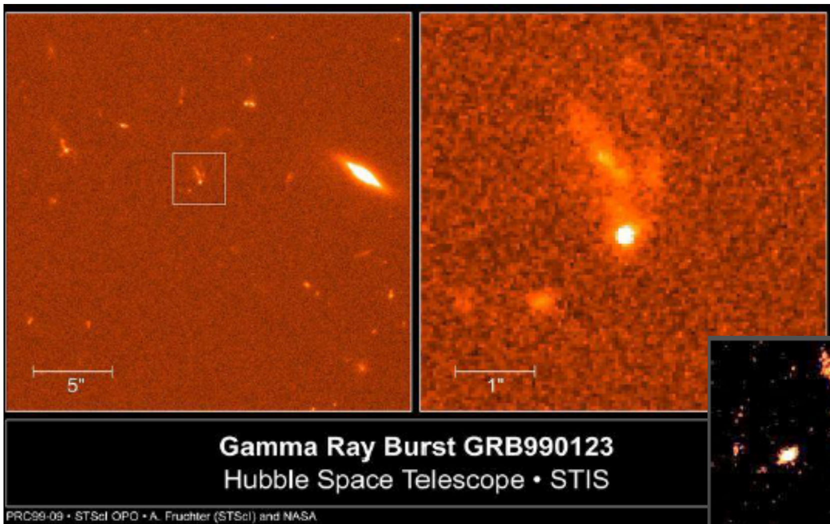
–this allowed accurate positions and the identification of the γ-ray afterglow with 'normal' galaxies at high redshifts

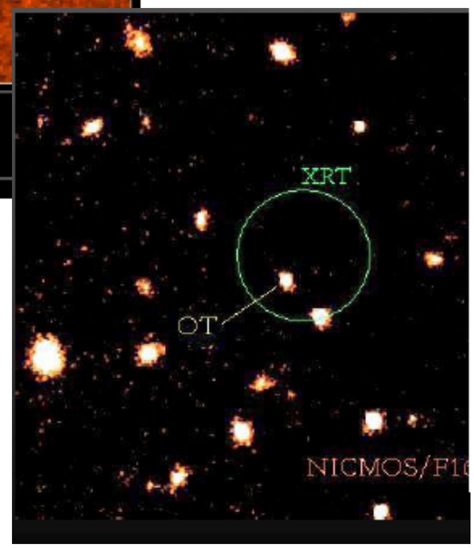


Optical Counterpart Identified

- Fades rapidly... but redshift of 0.695 measured.
- GRBs are very distant! and thus extremely luminous!







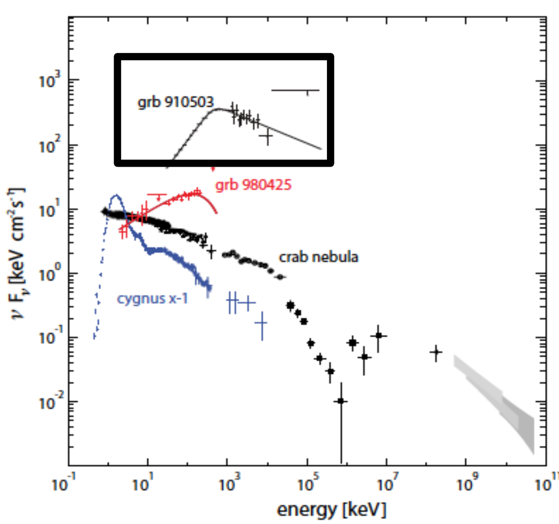
- Identification based on positional agreement with x-ray afterglow and fading of optical point source

Gamma-Ray Bursts

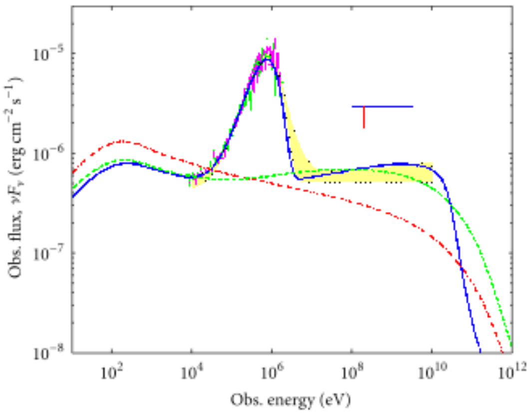
- Bright flashes of γ-rays- for a short period of time (<100 sec) fluxes of ~0.1-100 ph/cm^2/sec/keV

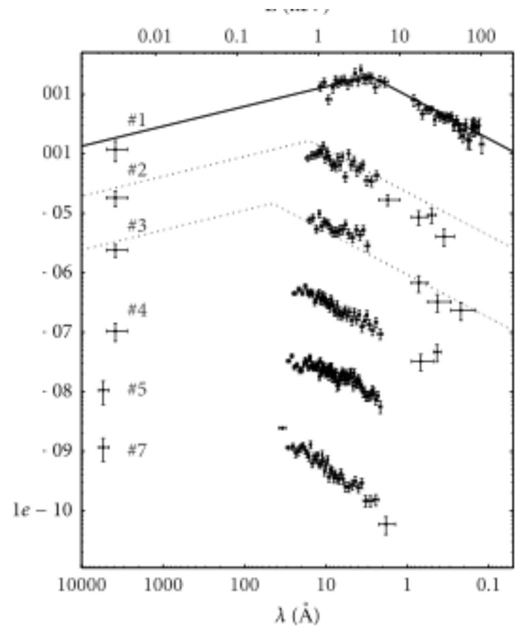
energy emitted primarily in the 20-500 keV band. (100x brighter than the brightest non-burst γ-ray sources)

  – Distribution is isotropic on the sky
  – They are at very large distances (z up to 8 (!)) with apparent luminosities of 3x 10^{54} erg/sec
  – Rate is ~10^{-7}/yr/galaxy/yr



Broad Spectral Shape





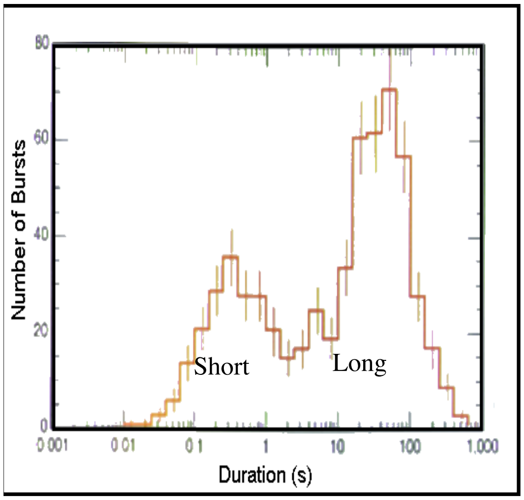
γ-ray bursts are heterogeneous in temporal properties

- the emission is primarily in gamma rays (νF(ν) peaks in the hundreds of keV
- the events have a limited duration milliseconds to about a thousand seconds,

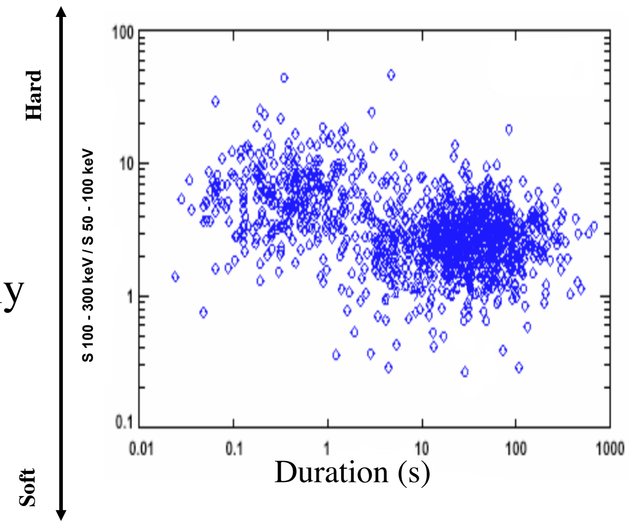
  with a broad bimodal distribution of durations, one peak being less than a second and the other being at 10-20 seconds.
- profile of the flux with time is very variable.
- distribution of locations of bursts is isotropic
- extremely broad range of flux 10^{-3} erg cm^2/s to the flux limits of detectors, down to 10^{-8} erg cm^2/s
- 'All' bursts that have been localized sufficiently for pointed follow-up have X-ray afterglows lasting days -weeks and about half have detectable optical afterglows
- Broad band (x-ray to γ-ray) spectra are simple (broken power law)

at z = 1, a10^{-5} erg cm^2/s burst has isotropic luminosity of 10^{51} erg/s (remember AGN have luminosities of 10^{42}-10^{49} ergs/sec)

Two classes (Kouveliotou et al. 1993) short and long

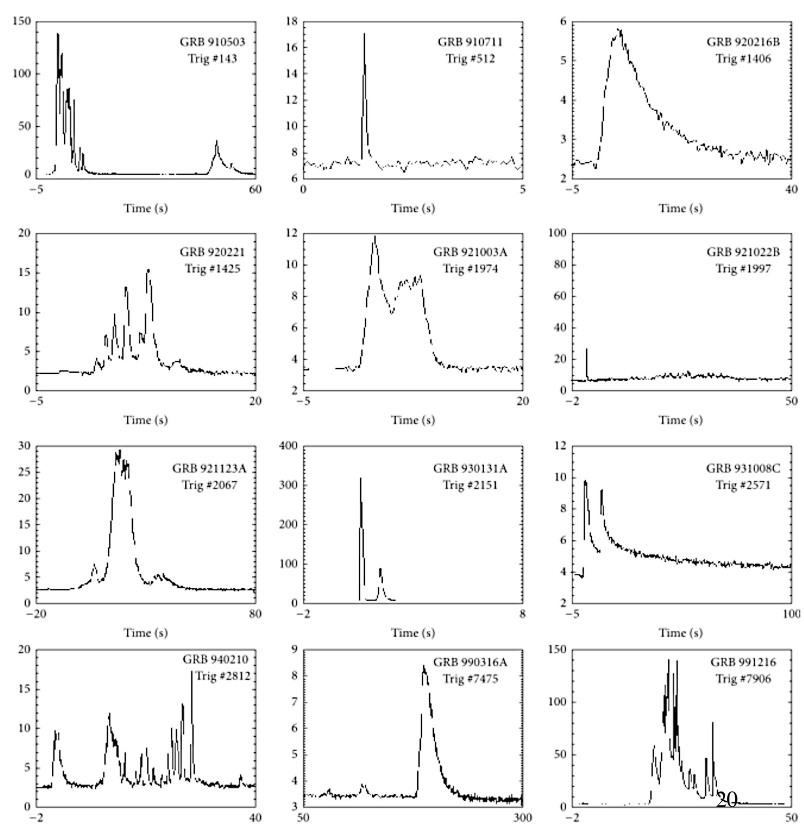


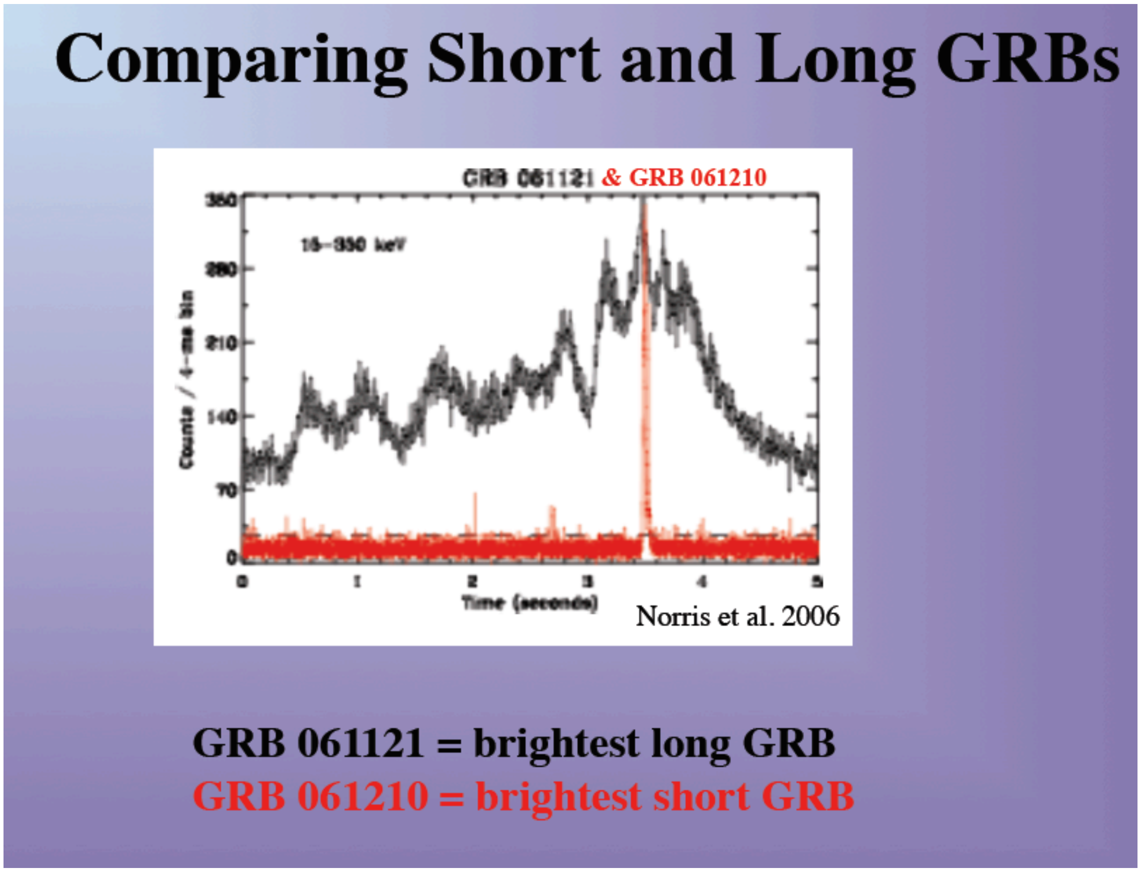
- short bursts have relatively more high-energy γ-rays than long bursts



Burst Shapes

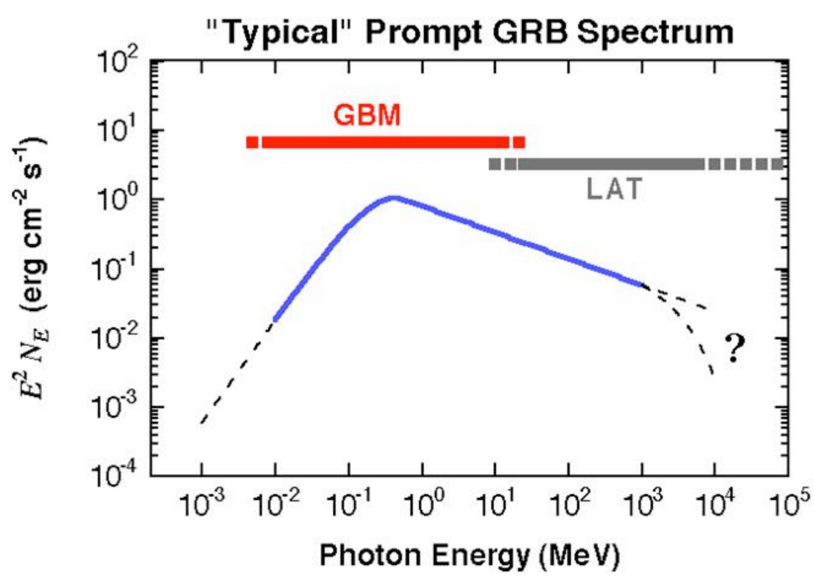
- wide range of light curves- e.g. intensity vs time





~1 Burst/day
Very wide variety of burst profiles

Spectra are 'hard' fit by a power law with an exponential cutoff, cutoff energy ~20-1000keV
2 classes- short/long



Gamma-Ray Bursts

What are they??- short timescales imply compact object ; -apparent luminosities of ~10^{53} -3x 10^{54} erg/sec

- energy reservoir - Mc^2 implies M~10^{33} gms~ M_{sun} if total conversion of mass into energy How does all this energy end up as γ-rays ?
- the very small sizes (implied by ashort variability time, Δt) and high luminosities imply a high photon density at the source.
- Compactness parameter $C=L\sigma_T/m_pc^3R \sim 10^{12} F_{-4}\, d^2_{Gpc}/\Delta t_{ms}$

F_{-4} the γ-ray flux in units of 10^{-4} erg/cm²/sec

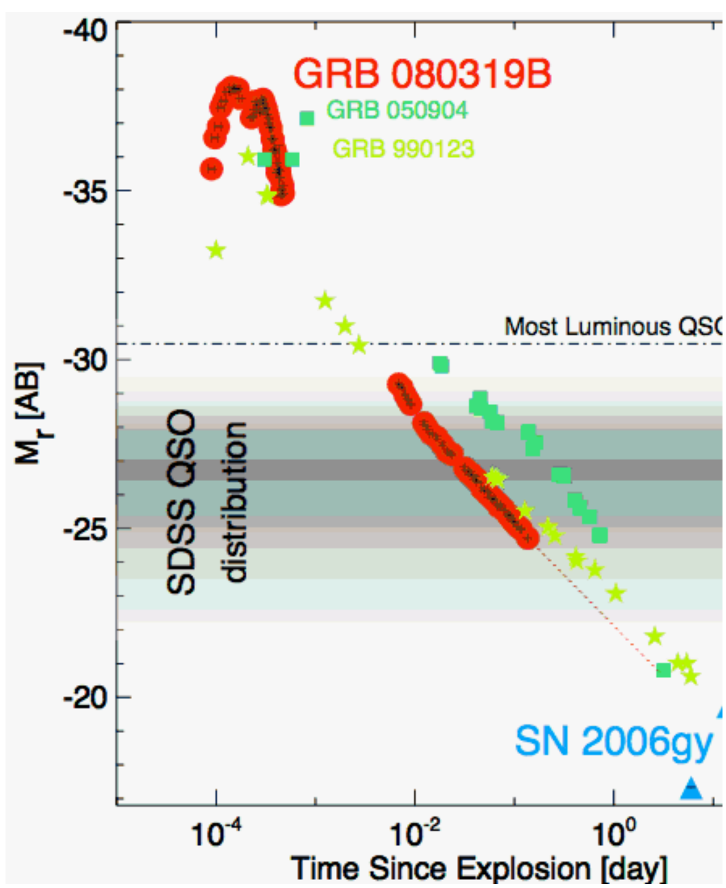
- For C>1 the source is optically thick to pair creation via γ−γ interaction;
- to create pairs from 2 photons of energy E_a,E_b colliding at an angle θ one needs $E_aE_b = 2(m_ec^2)^2/(1-\cos\theta)$; since one sees both MeV and 10Gev photons one needs θ~180; for beamed radiation opening angle of beam θ~1/γ
- Suggests that $\gamma_{bulk}^2 > E_aE_b/4(m_ec^2)^2$ or $\gamma_{bulk} > 100(E_a/10\text{Gev})^{1/2}(E_b/\text{Mev})^{1/2}$
- Relativistic motion is the solution to the quandry (see R+B pg 261-263) the optical depth to pair production is proportional to the relativistic beaming factor γ^{-6}. Need γ>100

GRBS compared to Quasars

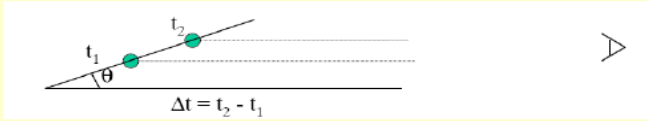
GRBs are so bright that they can be used to study galaxies at the earliest epochs to probe galaxies at the epoch of re-ionization.

GRBs allow observations of objects further back in time than what is currently possible with QSOs- 'can be 'easily' detected at z>10

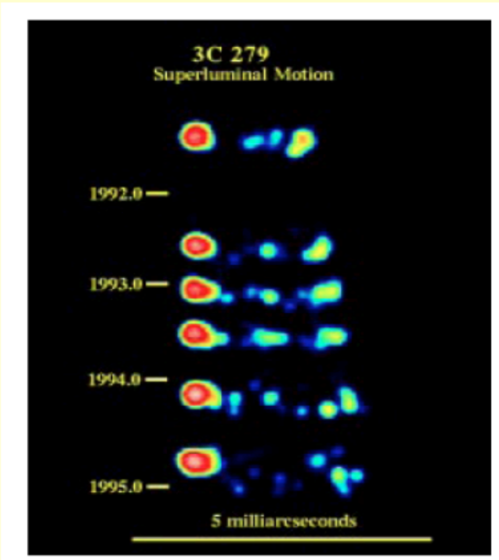
•In what type of galaxies did most of the star formation happened at z > 8, and what was the nature of the sources responsible for the re-ionization of the universe .



SUPERLUMINAL MOTION



Assume a spherical source moving with velocity u making an angle θ with our line of sight



Apparent velocity $\beta_{\perp,app} = \dfrac{\beta\cos\theta}{1-\beta\sin\theta}$

For $\beta_{\perp,app} > 1 \Rightarrow$ both $\beta \simeq 1$ and $\cos\theta \simeq 1$ required

$$\beta_{\perp,app} \approx \frac{2\theta}{\Gamma^{-2}+\theta^2}$$

e.g. if $\Gamma^{-1} < \theta \ll 1 \Rightarrow \beta_{\perp,app} \approx 2\theta^{-1} \gg 1$

$$\beta^{max}_{\perp,app} = \frac{\beta}{\sqrt{1-\beta^2}}$$ for $\cos\theta \simeq \beta$

β	$\beta_{\perp,app}$
.99	7
.999	22

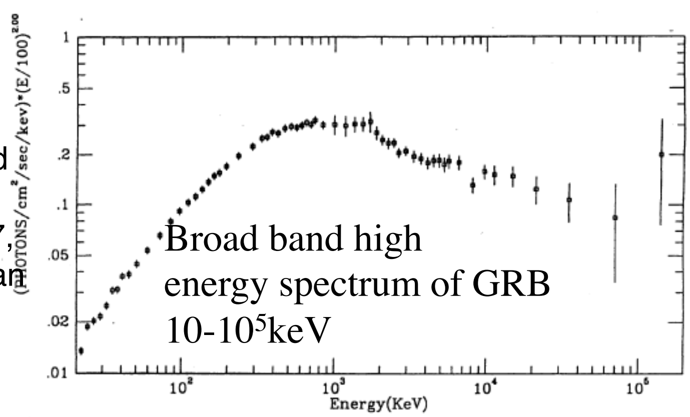
→ Long GRBs
- Probes of distant universe
- New window on supernovae
- Black hole birth

→ Enigmatic short GRBs
- Host galaxy discoveries
- Stellar mergers & collisions
- Black hole birth

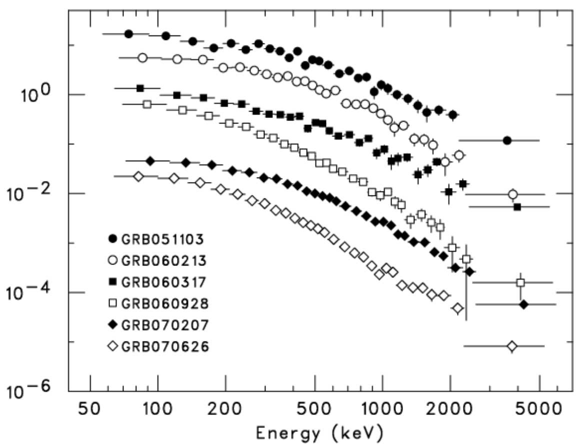
–Location of long γRBs is in and near star forming regions in smallish galaxies- associated with star formation

– a few γRBs have been associated with a type IIc supernova

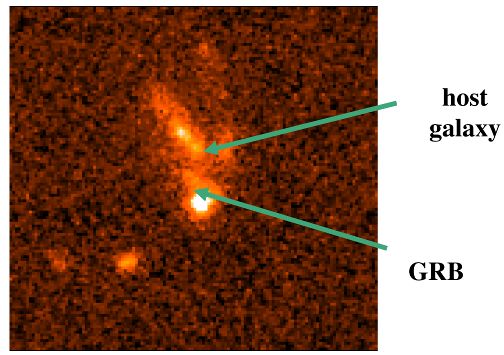
recent reviews
SN connection (Woosley and Bloom 2006), short GRBs (Lee and Ramirez-Ruiz 2007, Nakar 2007a), afterglows (van Paradijs et al. 2000, Zhang 2007) and theory (Meszaros 2002)



Broad band high energy spectrum of GRB $10\text{-}10^5$keV γ-ray **spectra** of aset of bursts, well fit by a 'Band' model (e.g. a broken power law flat at low E steep at high E)



HST image of host galaxy and the GRB itself

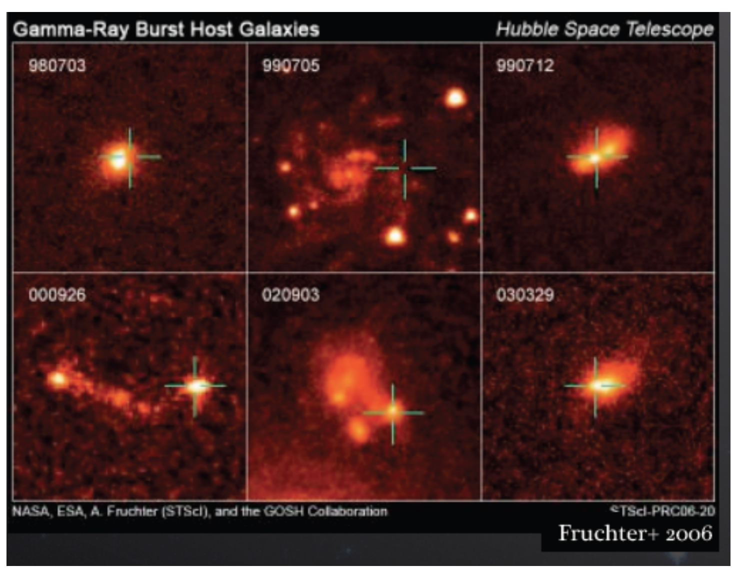


Long GRBs: The Death of Massive Stars and the Birth of Black Holes

- Galactic scale:

  Occur in star forming galaxies w/ young stellar pop.
- Individual progenitor scale:

  Associated with Type Ic core collapse supernovae
- Sub-galactic scale:
  - Offsets trace star formation in an exponential disk
- Locations coincide with unusually bright UV regions



Formation of GRBs-2 Scenarios