TUM Astrophysics Seminar WS 2003/2004

Observations and Physics of Gamma-Ray Bursts

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GRB Characteristics

- Gamma-Ray Emission Bursts, Brighter than Galaxies & QSO's
- Duration 0.1 sec ... 1000 sec, Bi-Modal (3rd in-between?)
- Diversity of Time Profiles
- Diversity of Energy Spectra
- No Apparent Correlation Among GRB Observables
- No Known / Identified Counterpart Objects
- Sometimes Afterglows in X-Rays...Optical
- Host Galaxies ~Normal, but blue (star-forming)
- Isotropic Appearence in Sky
- Paucity of Low-Intensity GRB's

GRB Observations

- **Isotropy and Confinement**
  - No Direction Preferred
  - Paucity of Low-Intensity GRBs

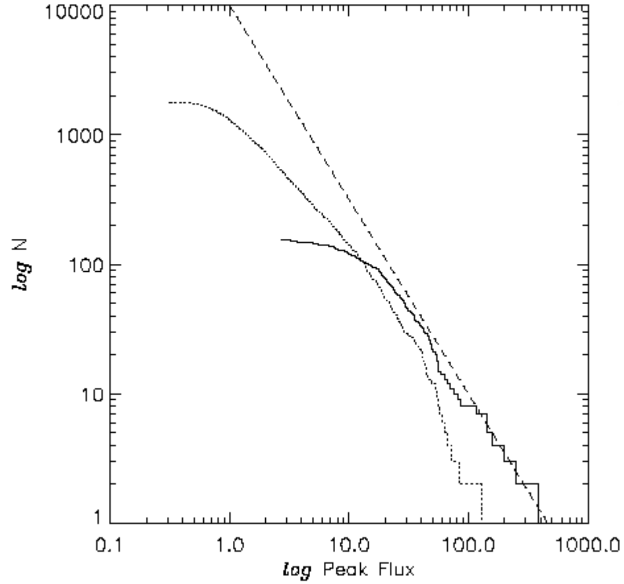
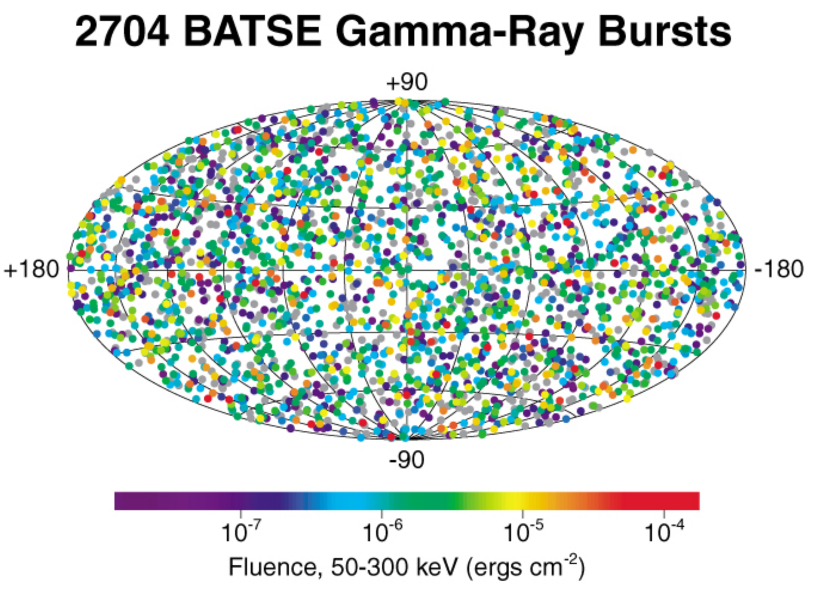
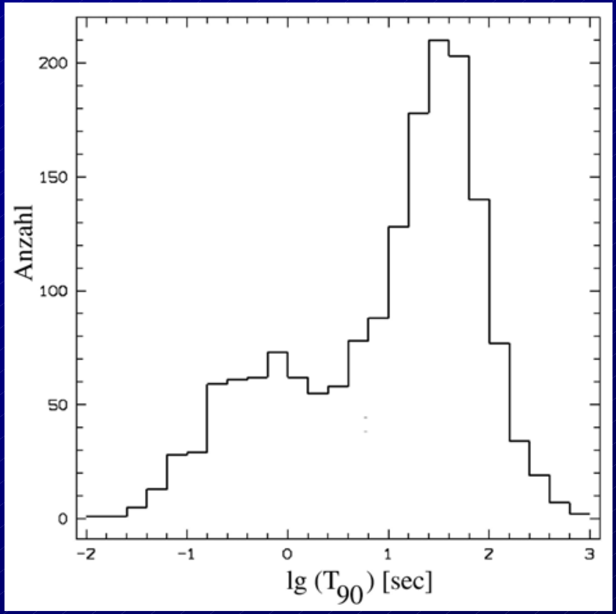


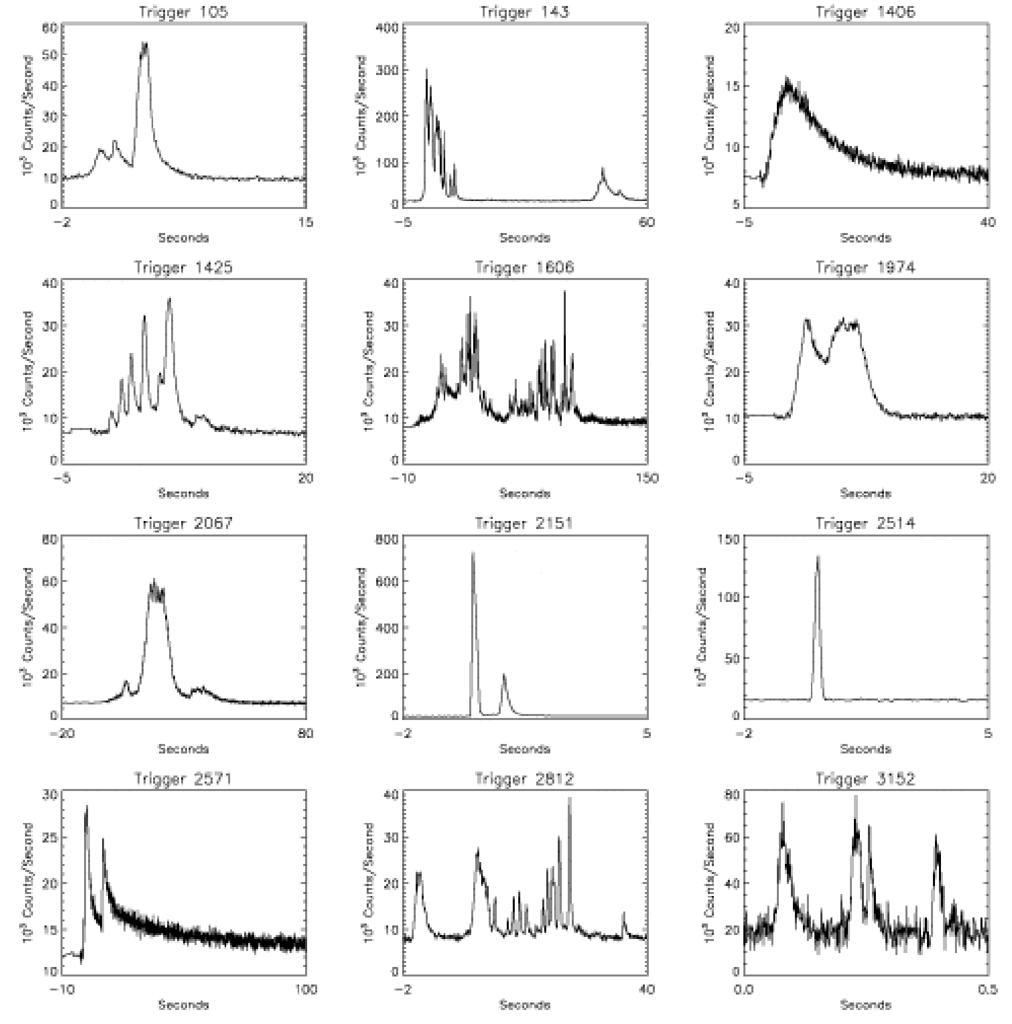
FIG. 3.—Peak flux distribution for the catalog bursts, compared with a −3/2 power law (*dashed*) as well as the 1772 BATSE 64 ms peak flux catalog values for the same period of time (*dotted line* ; the " Current " catalog). It is important to note that this set of bright bursts has an obvious selection bias, since they were selected on the basis of their total fluence or peak flux. In addition, there are peak fluxes based upon a 16 ms timescale included in our sample, so some values are brighter than they would be in the BATSE 64 ms peak flux data set.



GRB Time Profiles

- ☞Variety of Profiles
- ☞Two Classes





GRB Spectra

- Empirical Findings:
    - ☞Photon Emission up to MeV...2 GeV Energies
    - ☞~Power-Law Type Spectra in Gamma-Ray Region, No Lines/Features
    - ☞Temporal Evolution of Spectrum During GRB (hard->soft)
  - ☆ Parametrizations:
    - ☞Range of Power Law Exponents (low, high end; ~-0.5...-1.5, -2...-3)
    - ☞Range of Characteristic Energies (Epeak, Ebreak; ~100 - 1000 keV)
  - ☆ Temporal Evolutions: E_{peak} (t) ~exp(-E(t)/-E_o)
  - ☆ Harder Emission from Short GRB Class (<2 s)
  - ☆ Observed Gamma-Ray Emission:
    - ☞Synchrotron Emission from a Relativistically-Ejected Plasma
    - ☞Spectral Evolution: Flow Deceleration (Beam Widening, Jet Geometry)
- Physical Processes: ??!??
- Underlying Object/Event:
    - ☞Relativistically-Expanding Fireball as Inner Source

GRB Spectra

- ☆ Power Law Spectra
- ☆ Characteristic 'break'
- ☆ Temporal Evolution

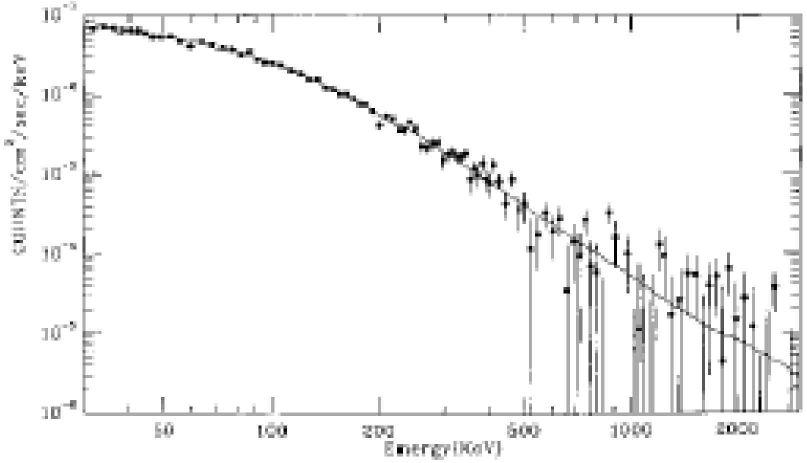


FIG. 1.—Example of a spectral fit. The GRB model (eq. [1]) was fitted to the average spectrum of 1B 911127. The low-energy spectral index is $\alpha = -0.968 \pm 0.022$, the high-energy spectral index $\beta = -2.427 \pm 0.07$, and the break energy $E_0 = 149.5 \pm 2.1$. With 100 degrees of freedom, $\chi^2 = 121.58$.

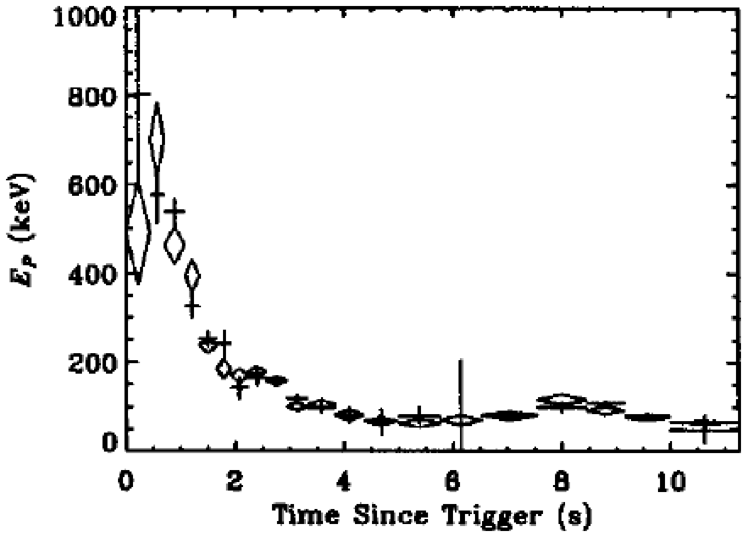


FIG. 4.—E_p as determined from two detectors viewing the burst 2B 921207. The high-gain detector (*crosses*) covered the energy range from 20.2 to 1283 keV and the low-gain detector (*diamonds*) ranged from 43.1 to 3300 keV.

GRB Polarization?

- ☞RHESSI, 2003

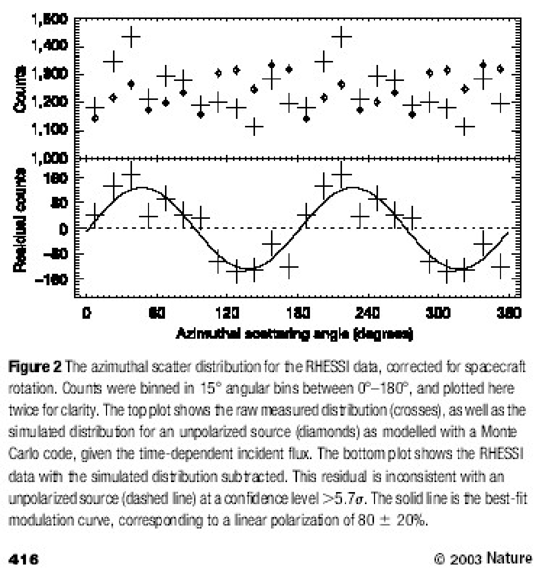


Figure 2 The azimuthal scatter distribution for the RHESSI data, corrected for spacecraft rotation. Counts were binned in 15° angular bins between 0°–180°, and plotted here twice for clarity. The top plot shows the raw measured distribution (crosses), as well as the simulated distribution for an unpolarized source (diamonds) as modelled with a Monte Carlo code, given the time-dependent incident flux. The bottom plot shows the RHESSI data with the simulated distribution subtracted. This residual is inconsistent with an unpolarized source (dashed line) at a confidence level $>5.7\sigma$. The solid line is the best-fit modulation curve, corresponding to a linear polarization of 80 ± 20%.

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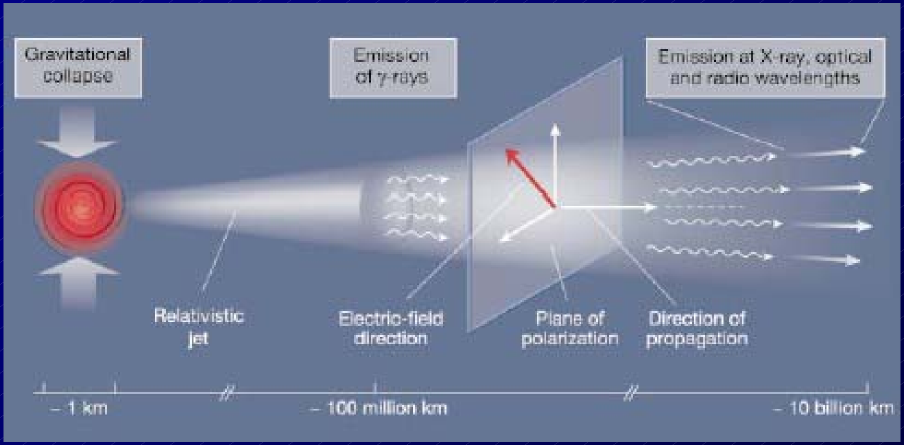

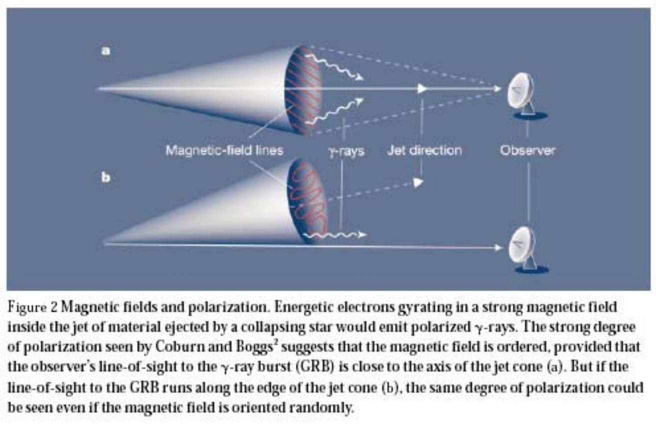

Figure 2 Magnetic fields and polarization. Energetic electrons gyrating in a strong magnetic field inside the jet of material ejected by a collapsing star would emit polarized γ-rays. The strong degree of polarization seen by Coburn and Boggs[2] suggests that the magnetic field is ordered, provided that the observer's line-of-sight to the γ-ray burst (GRB) is close to the axis of the jet cone (a). But if the line-of-sight to the GRB runs along the edge of the jet cone (b), the same degree of polarization could be seen even if the magnetic field is oriented randomly.

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Empirical Models

- ☆ Relativistically Expanding Fireball
- ☆ Canonball Scenario

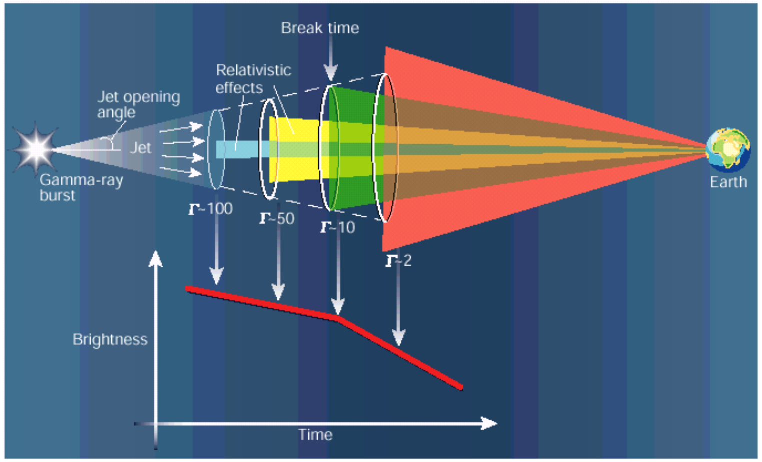
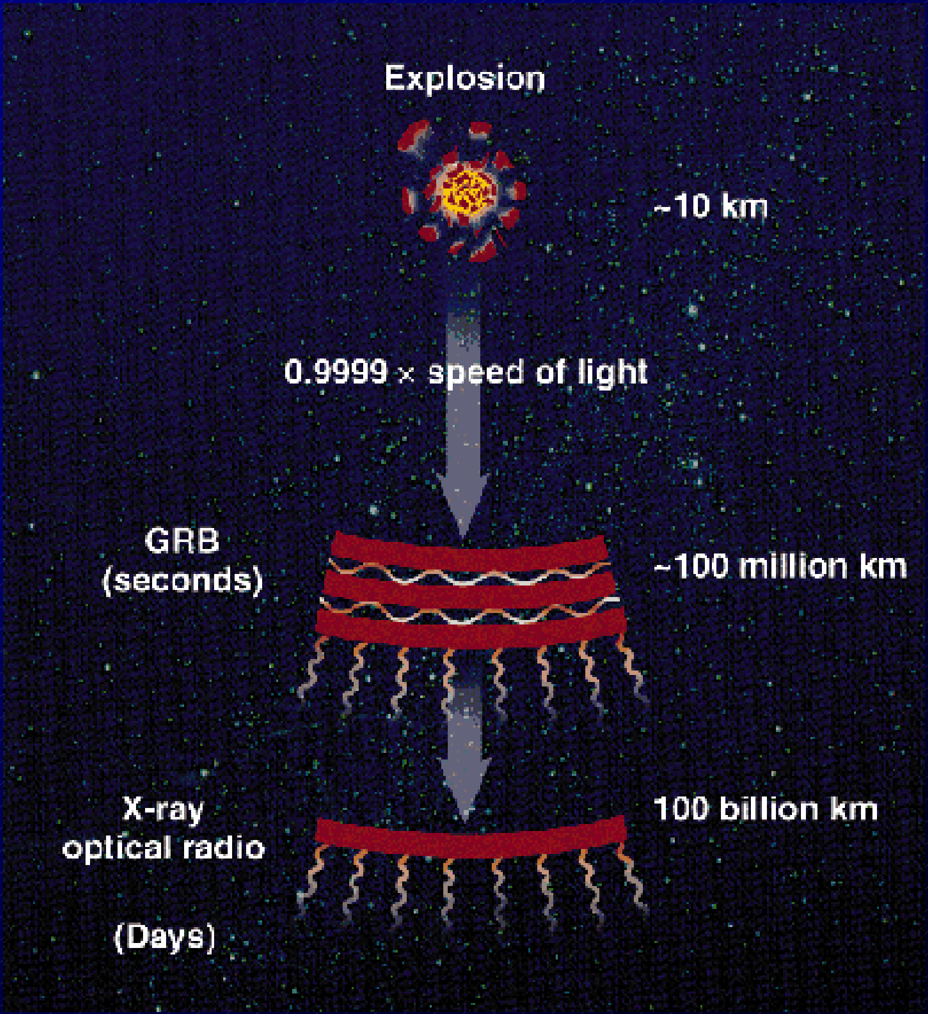


Figure 1 Size and shape of a gamma-ray burst. The burst launches a jet of material that moves at nearly the speed of light, corresponding to a Lorentz factor, Γ, of 200. Because of the effects of special relativity, an observer on Earth can initially only see a tiny fraction of that jet (light blue). Is it a jet or a sphere? It's too early to tell. As time passes and the jet runs into the surrounding material it slows down, and an observer on Earth can see more of the jet (yellow). Eventually, at the so-called break time, the entire jet becomes visible (here, when Γ~10; green). Beyond this point, no new matter becomes visible and the brightness of the afterglow declines more quickly. When Γ~2 the jet has slowed enough for all the matter within a much larger area (orange) to become visible. Frail *et al.*[2] have now analysed the afterglow break times of 17 bursts and calculated the size of their jets. From this they find a typical energy for gamma-ray bursts, which is similar to that of an ordinary supernova.



Collapsars

- **Model:**
  - Massive Star Core Collapse to Black Hole
  - Accretion Disk Formation -> Preferred Jet Axis -> GRB

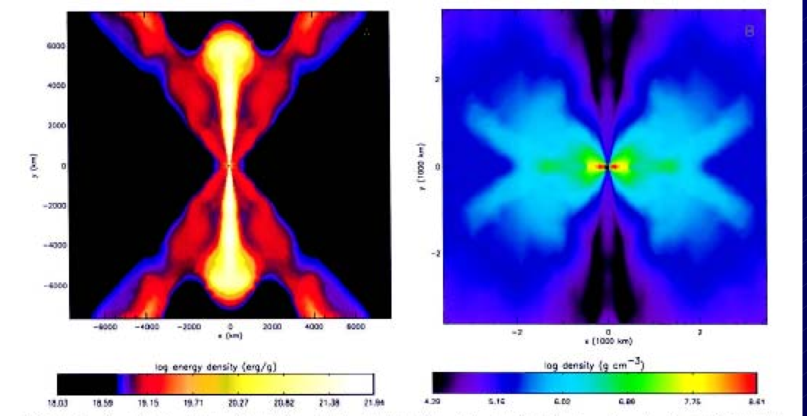
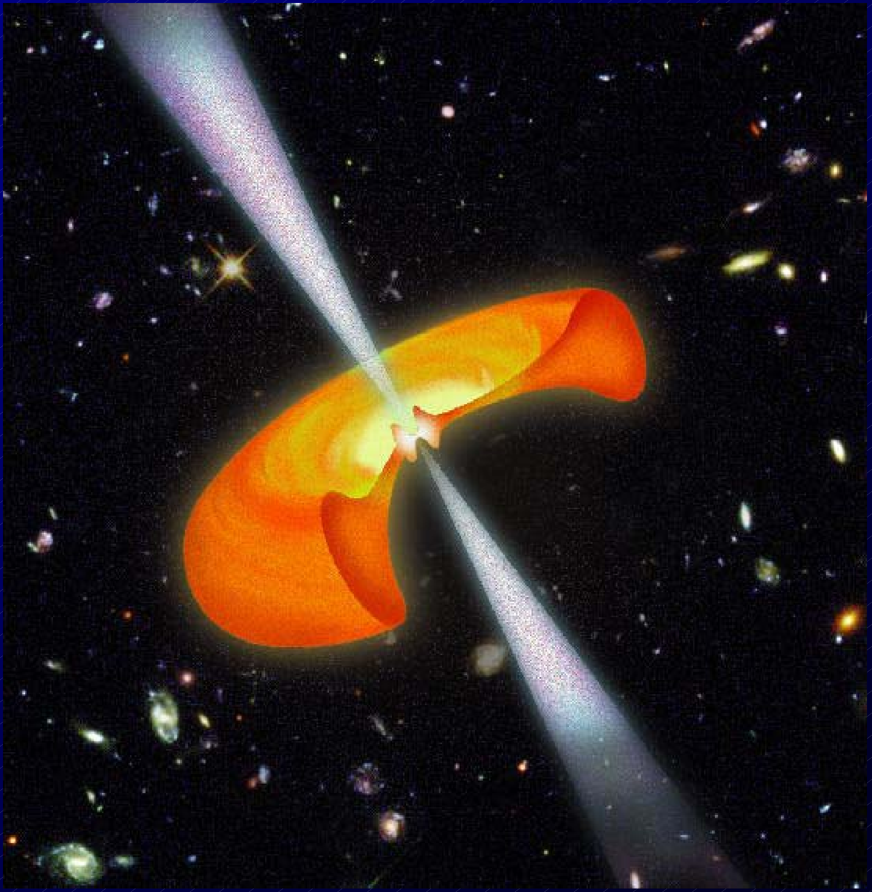


FIG. 3. Two-dimensional hydrodynamic simulations (18) show the formation of a low-density region above the poles of a rotating black hole formed in the collapsar model. (*A*) The energy density in the jets and surrounding area ~1 sec after its initiation. The jet has moved to a distance of ~10,000 km, and its opening angle is of order 10 degrees. (*B*) The density contours ~16 sec after the onset of collapse. The yellow/red region shows the dense accretion disk around the black hole.



Merging of Neutron Stars

- -> Formation of Black Hole
- Angular Momentum -> Disk Accretion, Jet Formation

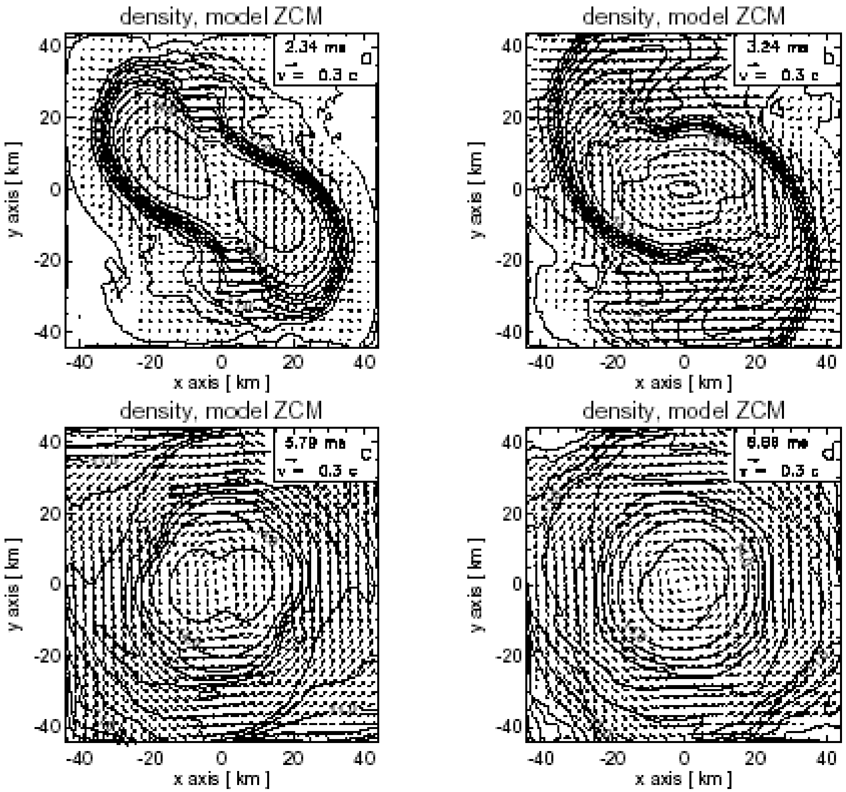
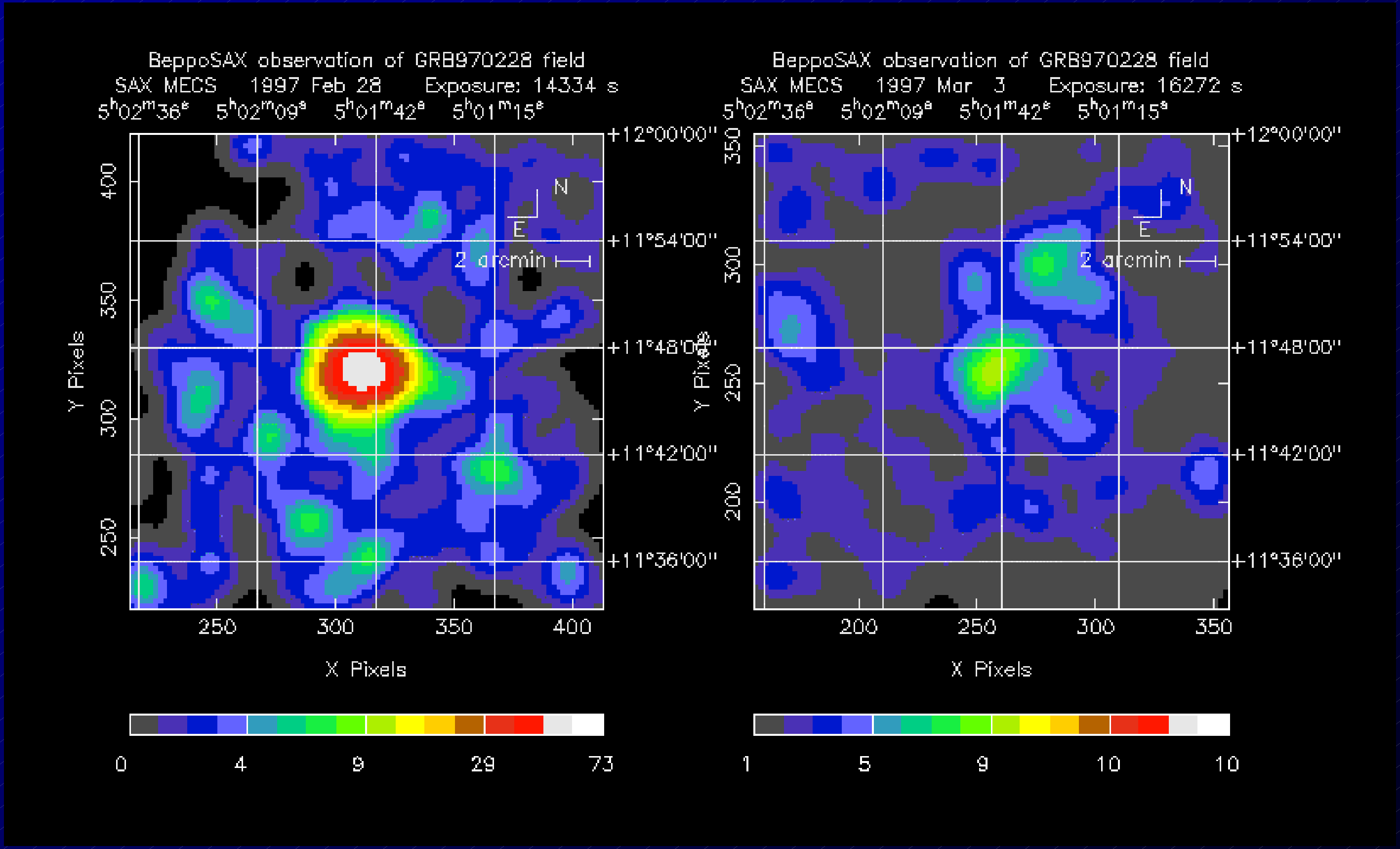


Fig. 1. Cuts in the orbital plane of Model ZCM at four instants in time showing the density contours together with the velocity field. The density contours are logarithmically spaced with intervals of 0.5 dex. The density is measured in units of g/cm^3. The bold contours are labeled with their respective values. The legend at the top right corner of each panel gives the scale of the velocity vectors and the time elapsed since the beginning of the simulation

GRB Afterglows (1)

Afterglows in X and Radio Regimes

- Allow Precise Location of GRB
- Identification of Host Galaxy -> Distance



GRB Afterglows (2)

Spectral Evolution of GRB

- ☞ Expansion Dynamics
- ☞ Jet Constraints
- ☞ CSM Constraints

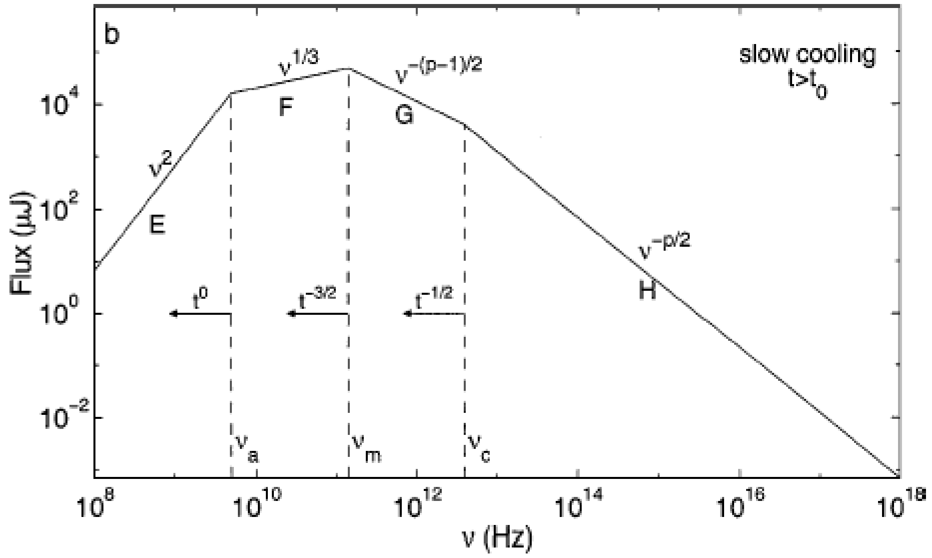


Figure 3 The piecewise power-law schematic shape of blast wave synchrotron spectra for later afterglow evolution (Sari et al 1998). The characteristic break frequencies and their time evolution are indicated, as is the spectral slope in each regime. This can be directly compared with the observed spectrum of GRB 970508 (Figure 12).

GRB Afterglows (3)

Afterglows in Optical and IR

- Identifying the Host Galaxy
- Power-Law Decay (1st Order)
- Complex Decay in Detail
    - ISM/CSM?
    - "Cannonballs"?

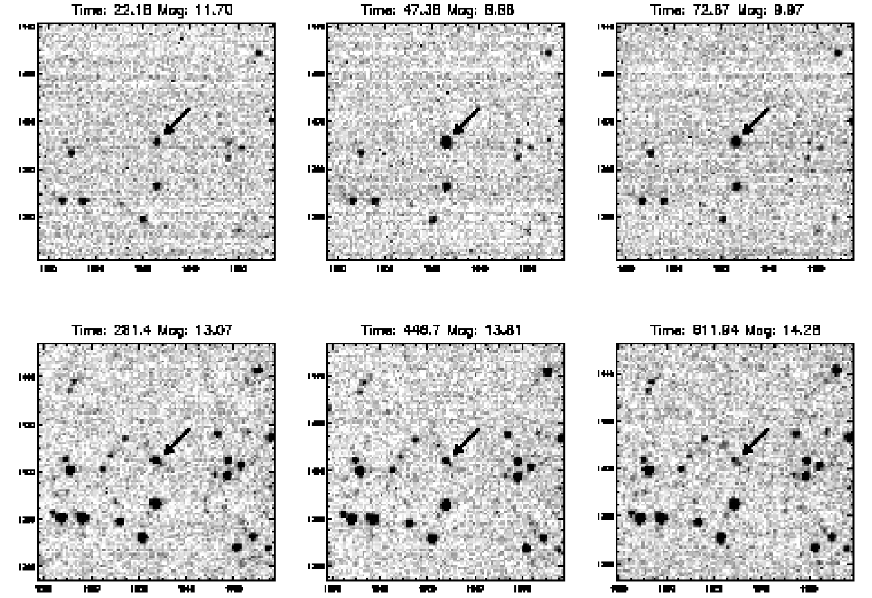


Figure 17 The ROTSE discovery images of the prompt optical emission from GRB 990123, from 22 to 800 s after trigger (Akerlof et al 1999).

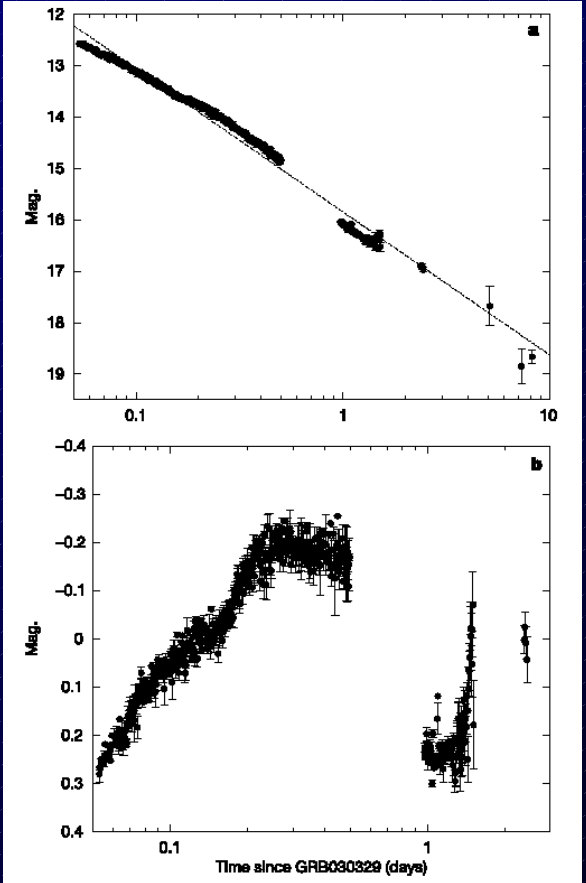


Figure 1 Light curves of the optical afterglow of GRB030329. The abscissa denotes the time from the burst (29 March 2003, 11:37:1467 UT) in days, shown in logarithmic scale. The ordinate denotes the R_c-magnitude in **a** and the residual magnitude from a power-law decay in **b**. The dotted line in **a** is the best-fitted power-law model, which was used to calculate the residual magnitude in **b**. Our observations are indicated with filled

GRBs and cc-Supernovae

- ☆ … Confirming the collapsar model…

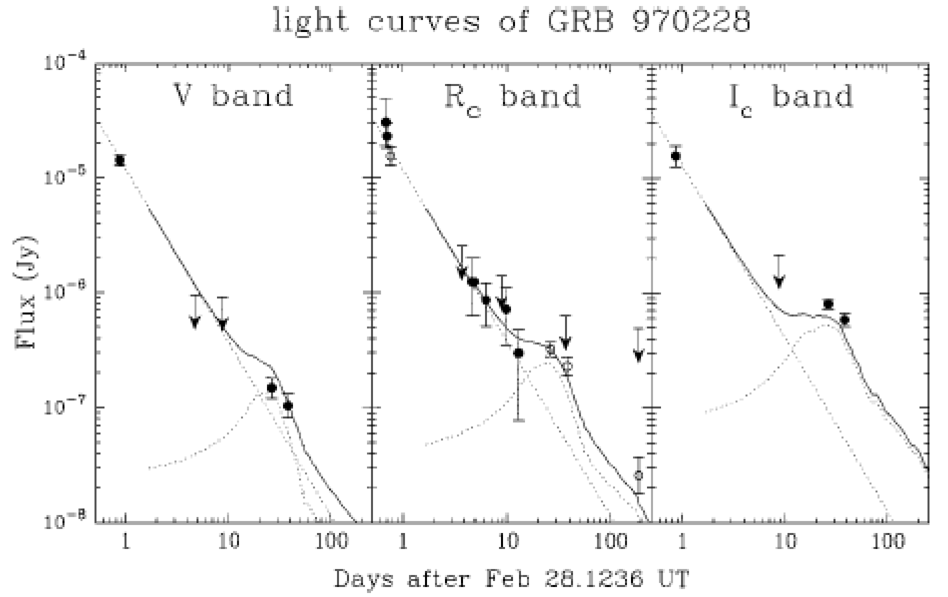


Figure 7 The *VRI* light curves of the afterglow of GRB 970228, showing the evidence of a supernova component superposed on the power-law decline at late times (Galama et al 2000).

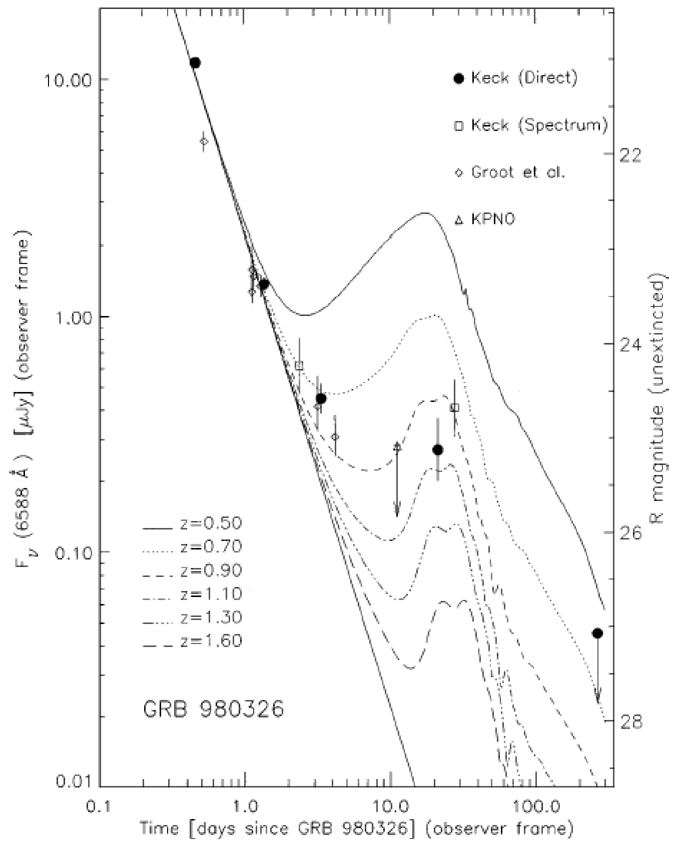


Figure 16 The *R* light curve of GRB 980326, with model curves representing the power-law decay of a relativistic afterglow superposed with the light curve of SN 1998bw, shifted to various redshifts (Bloom et al 1999a).

Seminar Plan

Date	Theme
24.10.2003	Introduction: GRB Overview, and Talk Assignments
31.10.2003	GRB Time Profiles and Spatial Distribution
07.11.2003	GRB Spectra and their Evolution
14.11.2003	Empirical Models (Fireball Scenario, Cannonballs, etc.)
21.11.2003	The Collapsar Model
28.11.2003	The Merger Model
05.12.2003	GRB Afterglows: X-rays, Radio
12.12.2003	GRB Afterglows: Opt/IR
19.12.2003	GRB Afterglows: Theories
16.01.2004	GRB Energetics
23.01.2004	GRB Host Galaxies and Progenitors
30.01.2004	GRBs and Core-Collapse Supernovae
06.02.2004	Cosmology with GRBs
13.02.2004	GRB Observations: Instrumental Challenges