Rapid-Response Optical Observations of Gamma-Ray Bursts

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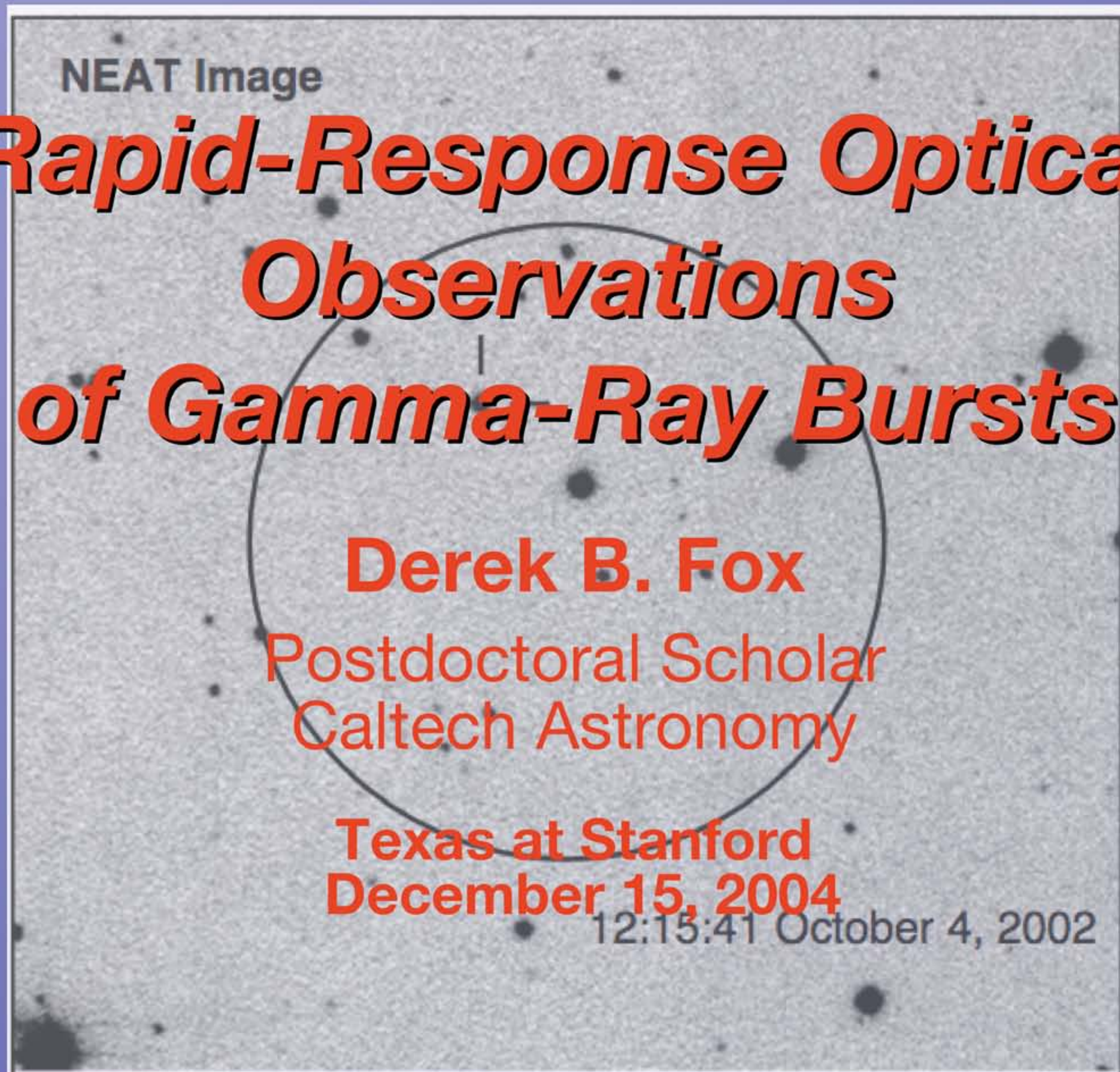
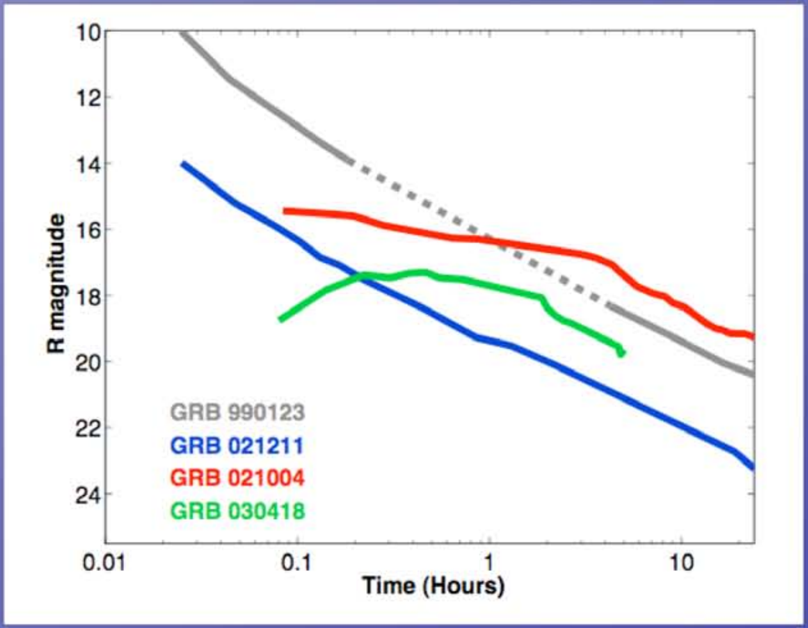


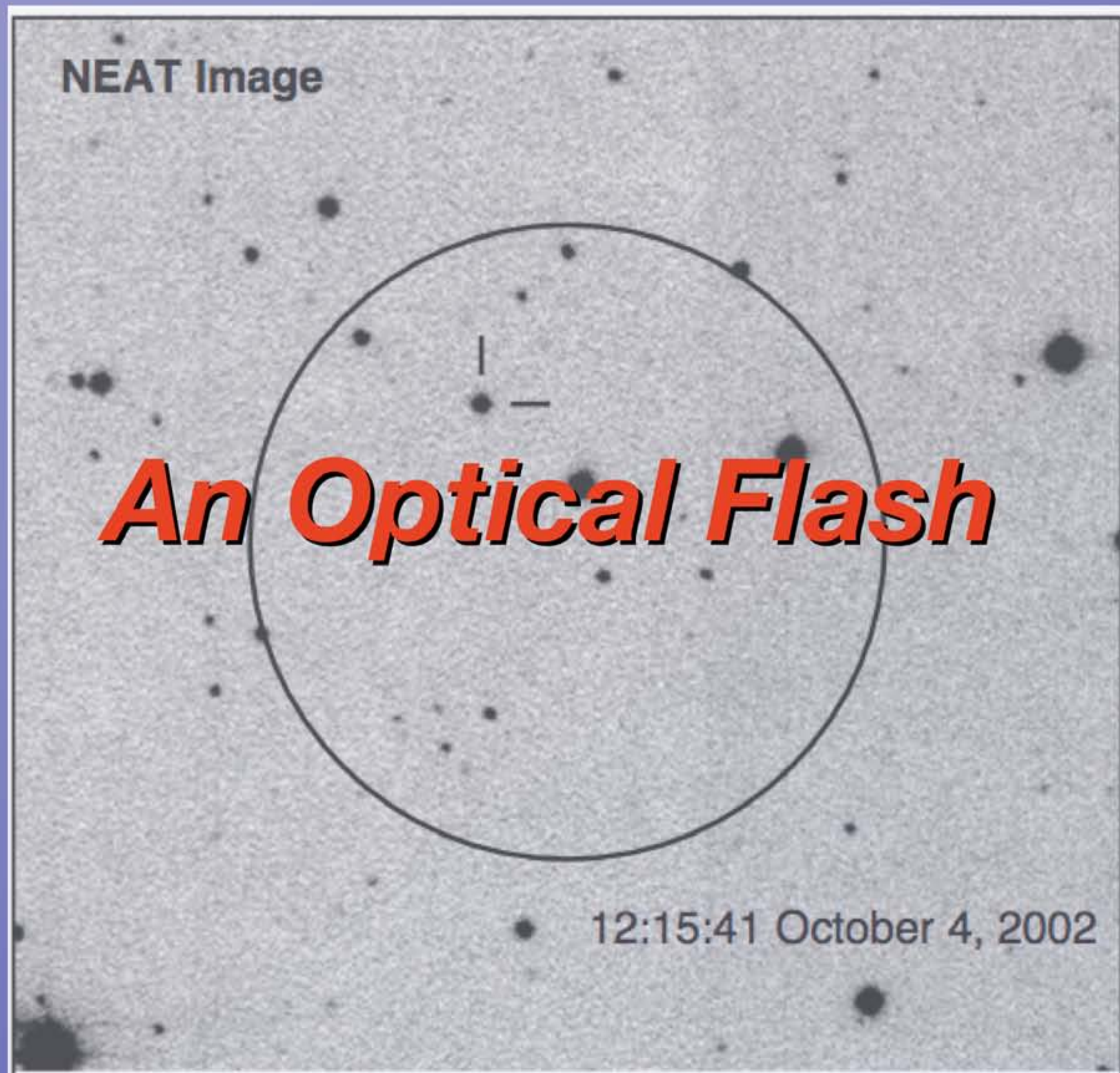
The GRB Relativistic-Astrophysical Lab

Rapid-response optical observations of GRBs address:

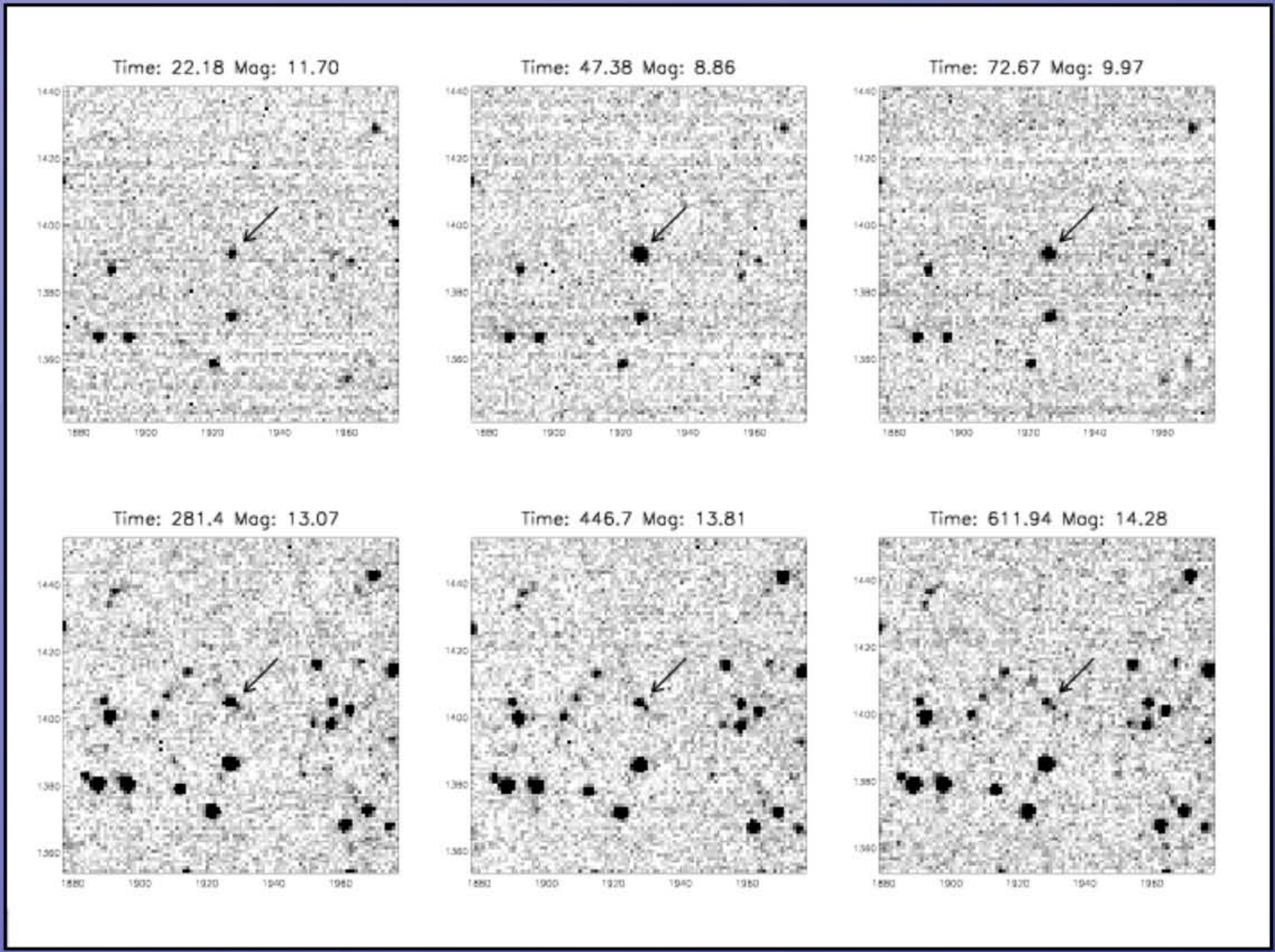
- GRB Lorentz factor (Γ)
- Jet energy structure as E(t), E(Γ), or E(Ω)
- Hydrodynamic vs. Electromagnetic nature
- Magnetic fields: Global vs. shock-generated
- Reverse shock vs. Preflash ionization (or other)



An Optical Flash



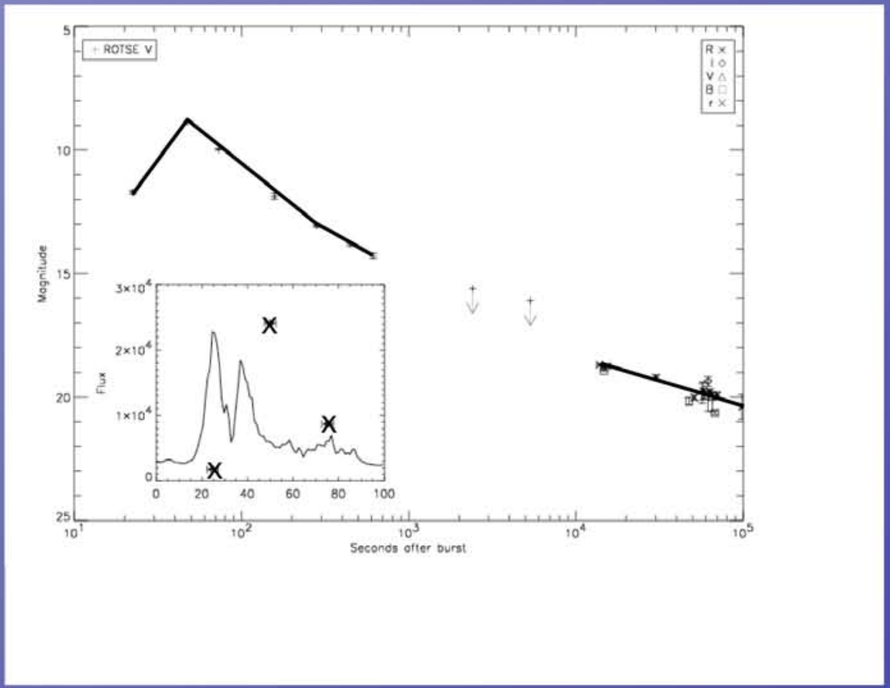
GRB 990123



Akerlof et al. 1999

GRB 990123

- Discovery of GRB prompt optical emission
- First observation 25-s after burst trigger (near GRB peak)
- Gamma-ray and optical light curves differ
- Peak optical magnitude $V \sim 9$, or $M_B = -37.5$ at $z = 1.6$
- Fast early decay as t^{-2}
- Slower late decay as $t^{-1.1}$, typical of previous afterglows (Galama et al. 1999)

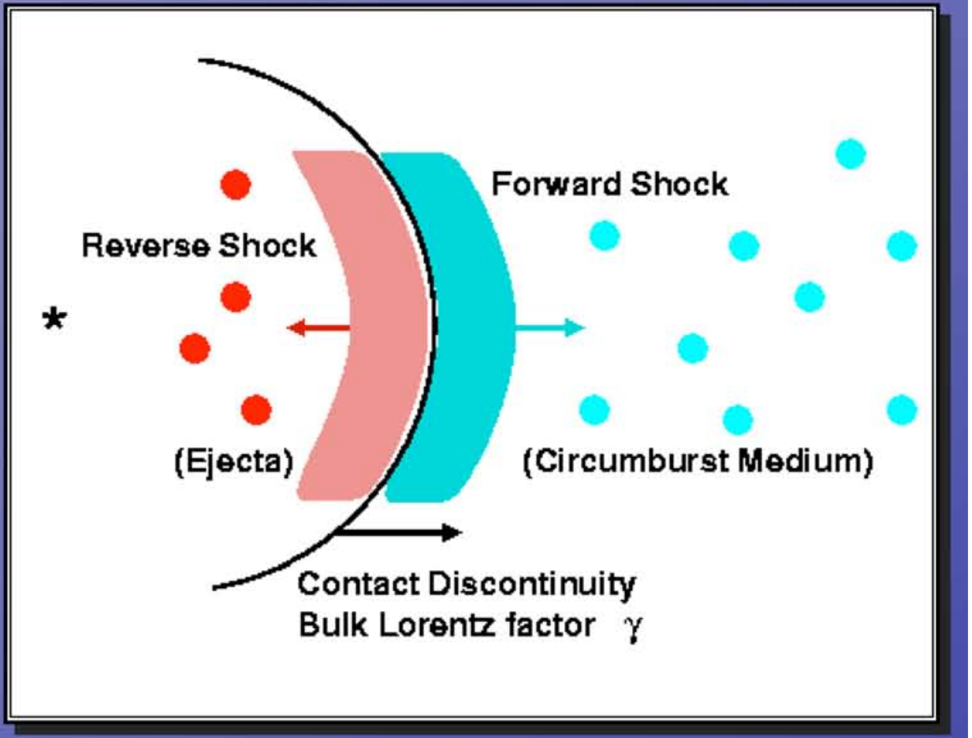


Akerlof et al. 1999

Two Shocks

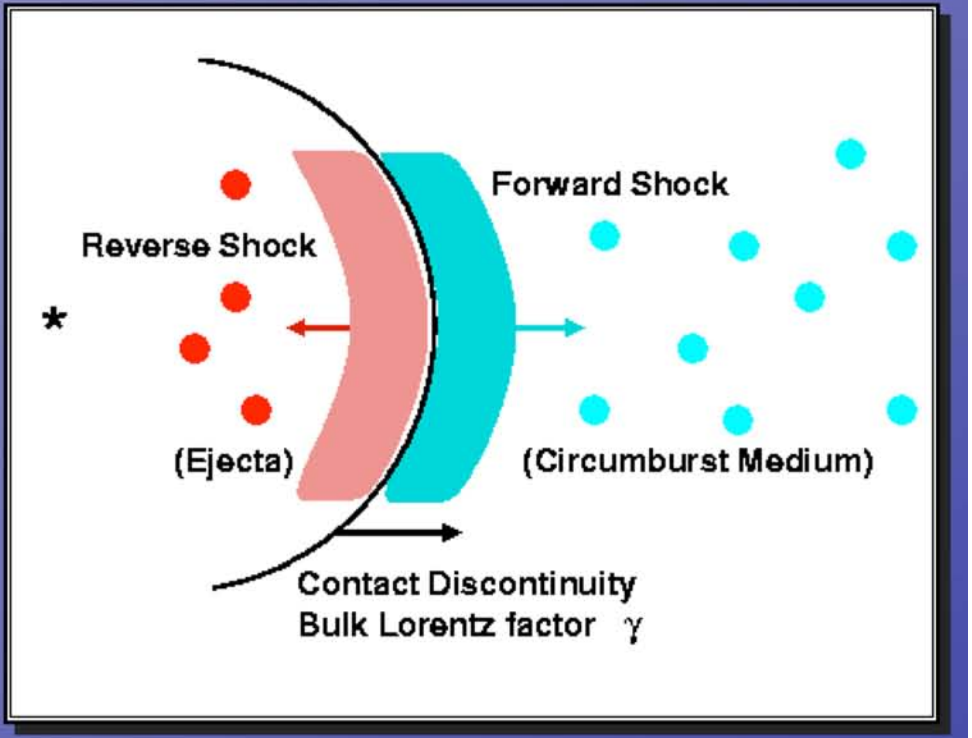
Consistent with theoretical predictions of Mészáros & Rees (1997) and Sari & Piran (1999a,b):

- Ratio of peak frequencies: $\nu_{m,f} / \nu_{m,r} \sim \Gamma^2$
- Ratio of peak fluxes: $F_{\nu,m,r} / F_{\nu,m,f} \sim \Gamma$
- Single-pulse emission
- Deceleration or intrinsic timescale (longer of these)

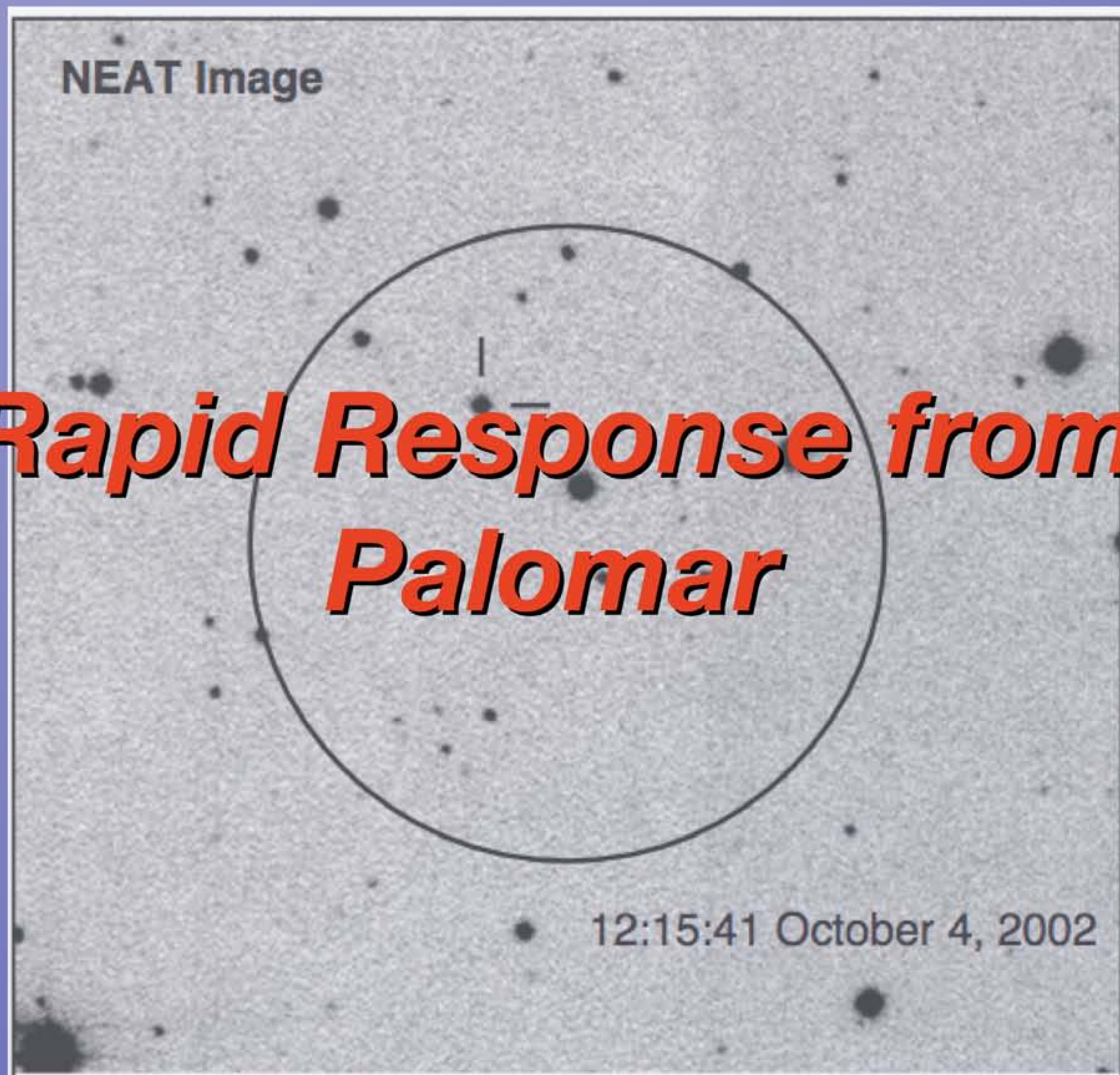


Two Shocks

- Peak time ⇔ Lorentz factor:
  $\Gamma \sim 125\, E_{52}^{1/8}\, n^{-1/8}\, T_2^{-3/8}$
- Flux decays as t^{-2} (adiabatic evolution)
- Or *faster* if the cooling frequency is below the optical band

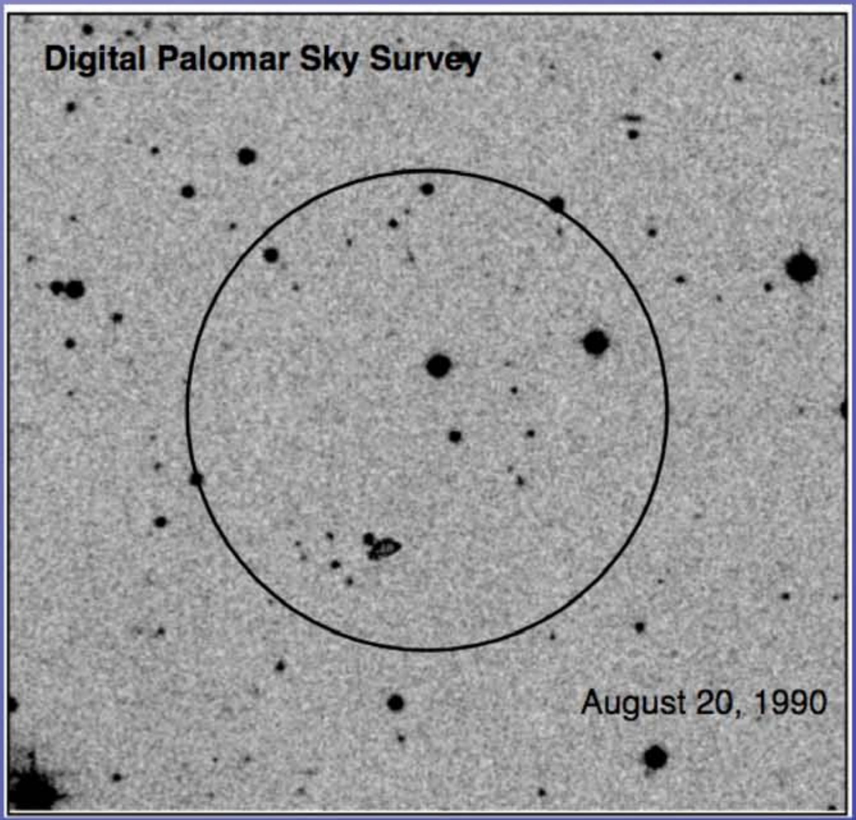


Rapid Response from Palomar



GRB 021004

- Prompt *HETE* alert with a 30’ radius
- Just before dawn in Pasadena and Palomar
- Email (pajama) triggering
- First observation at t+9 min
- Final *HETE* position (shown): 2’ radius
- Our discovery announcement at t+3 hours



Fox et al. 2003a

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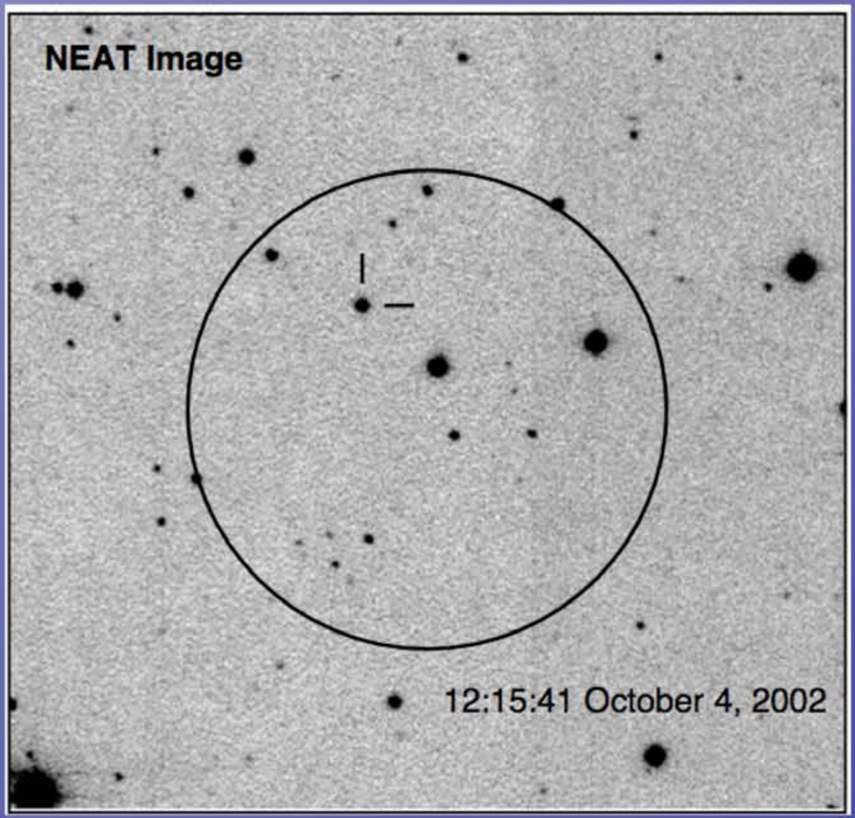
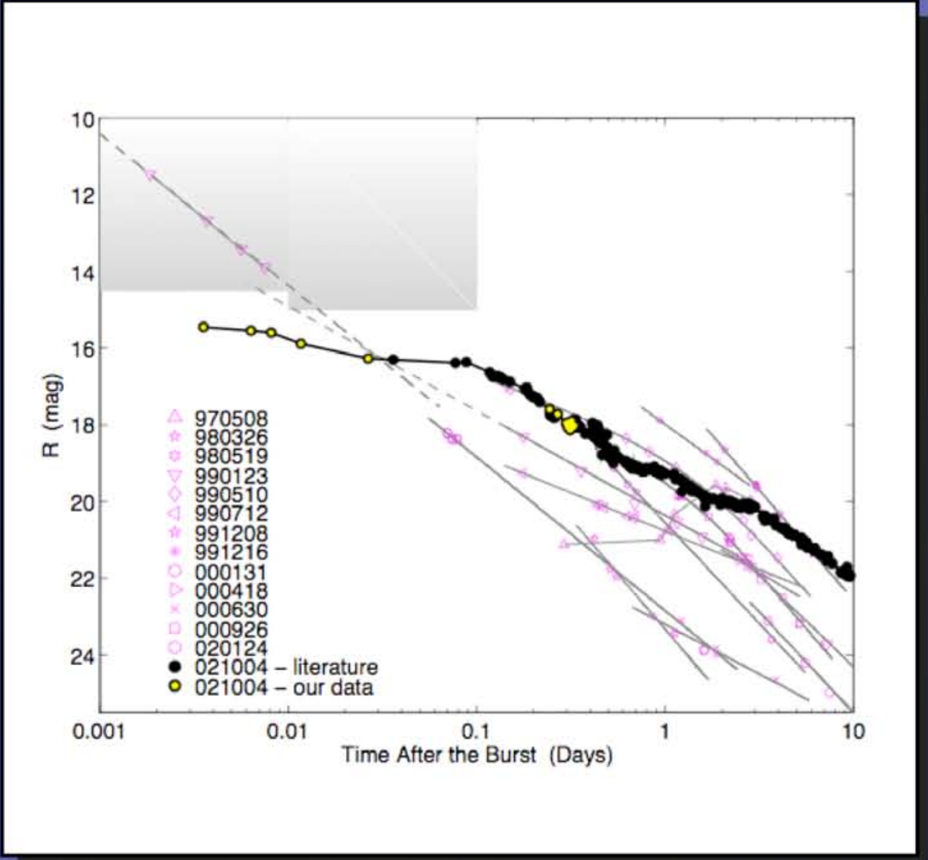


Fox et al. 2003a

GRB 021004

Early-time afterglow #2:

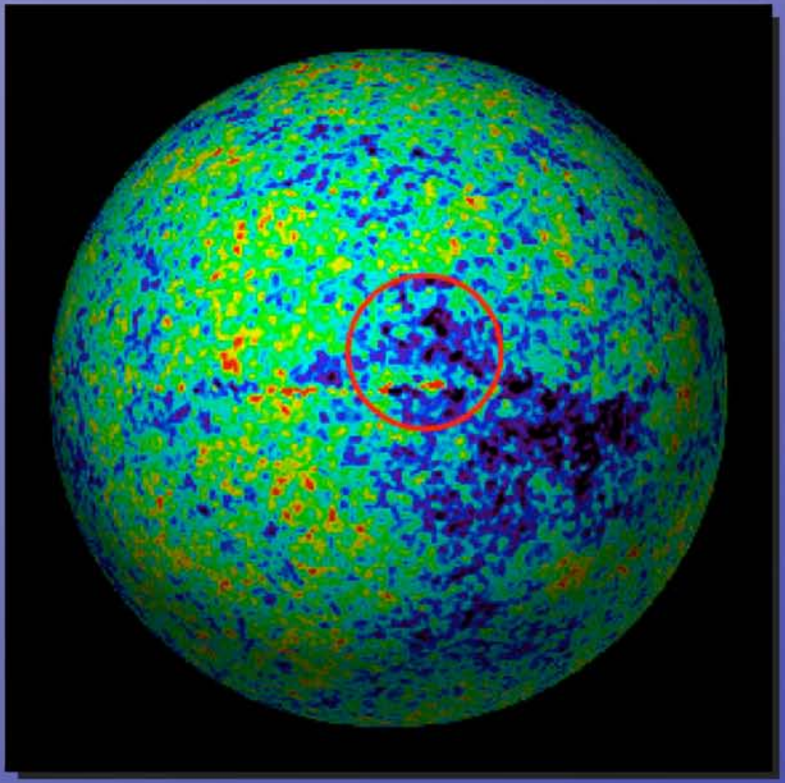
- Observations as early as t+150 sec (RIKEN)
- Slow early-time decay:
  $f \sim t^{-0.4}$ for $t < 3$ hours
- "Bumps and wiggles"
- "Patchy jet" (Nakar, Piran & Granot 2003)
- Or energy injection (Fox et al. 2003a)
- Energy variations in solid angle or in time –



Fox et al. 2003a

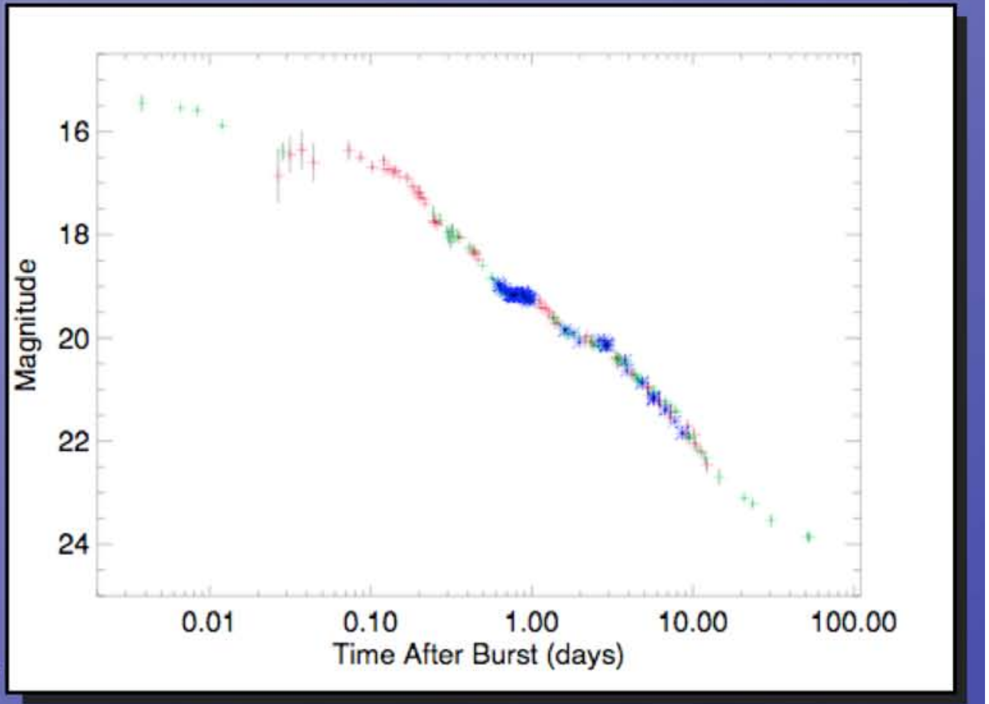
Patchy Jets

- Jet "surface" has local hot & cold spots
- As the jet decelerates, new patches come into view
- Light curve "bumps" = hot spots
- Steep light curve decays = cold spots
- Produces variations with timescale $\Delta t \sim t$
- Amplitude of variations decreases with time



Energy Input

- Produces "bumps" only (no fast decays)
- Optical and X-ray variations should be correlated
- Increases kinetic energy budget for the GRB (x3)
- Could reflect ongoing activity of the GRB's central engine (hours to days)
- Could indicate a "dirty fireball" – E(Γ)



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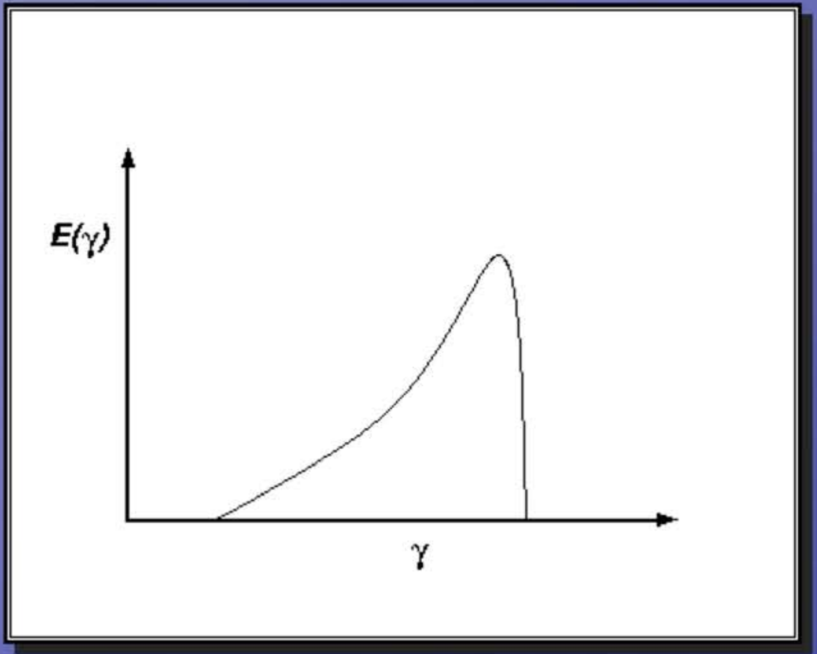
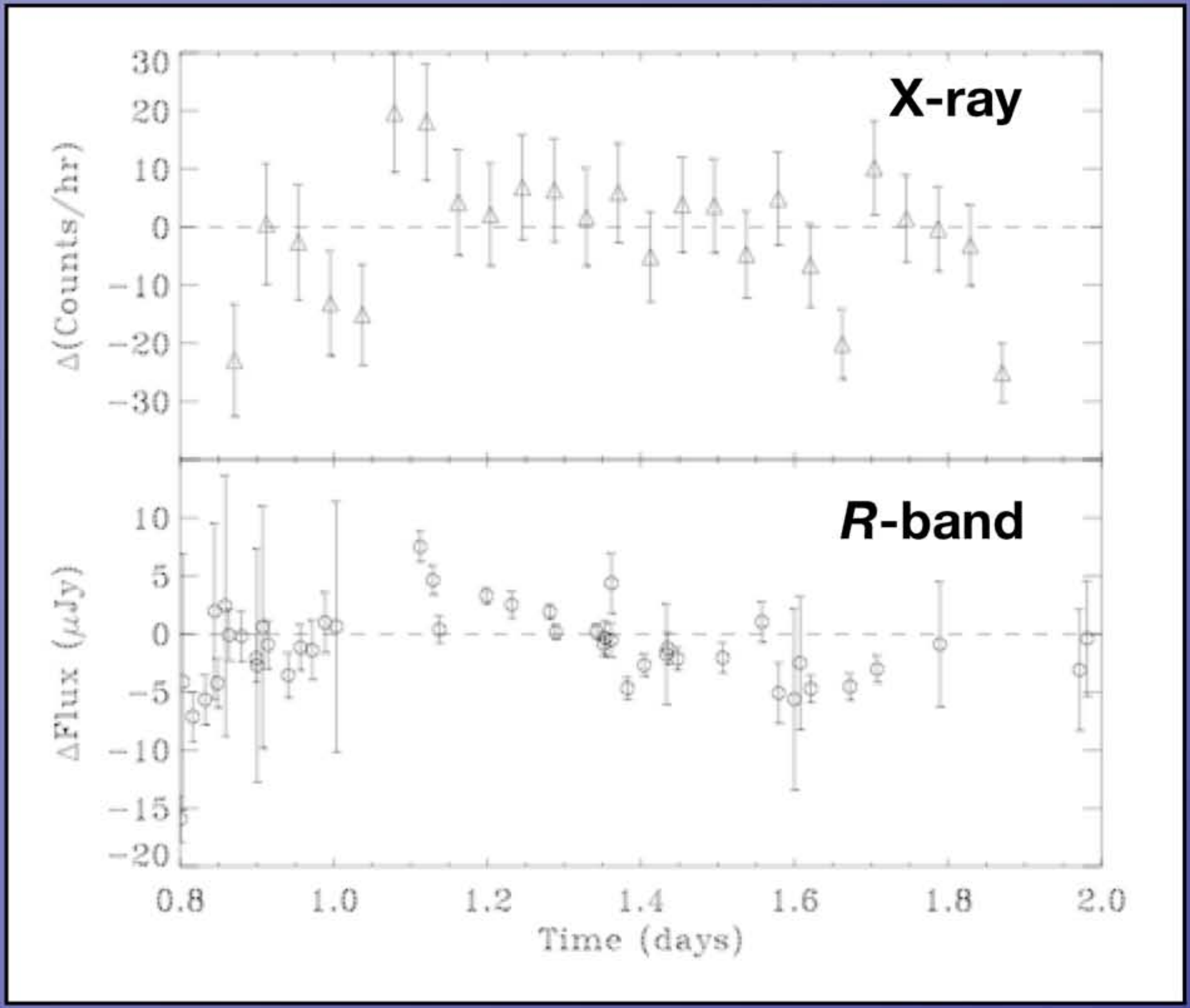


Energy distribution by Lorentz Factor

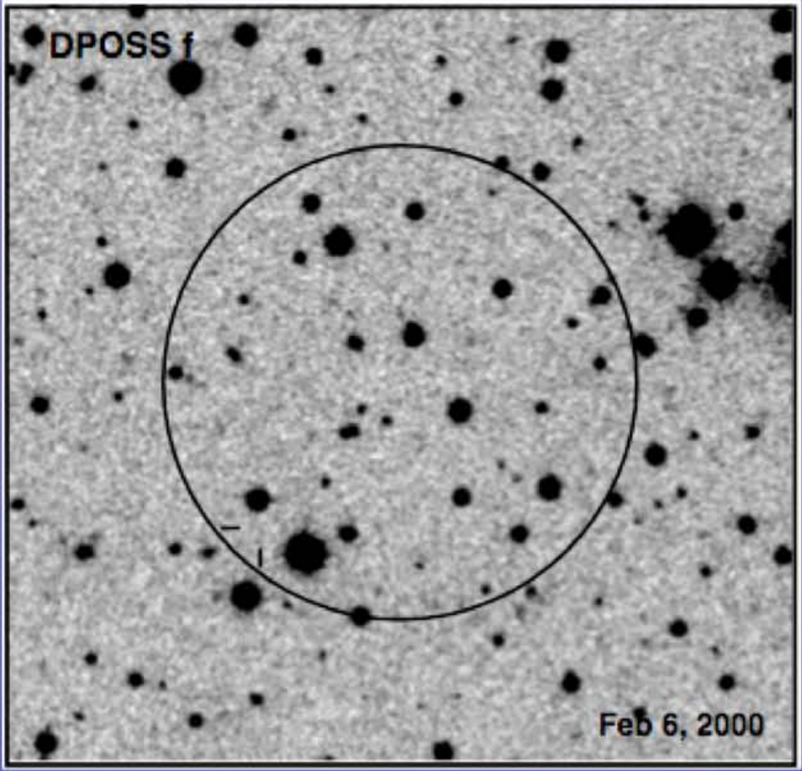
Energy Input for GRB021004



Fox et al. 2003a

GRB 021211

- Prompt *HETE* alert with a 14' radius
- Night-time email triggering
- First observation at t+20 min
- Discovery announcement at t<1 hour
- Final *HETE* position (shown): 2' radius
- Other early observations by RAPTOR, KAIT, Super-LOTIS



Fox et al. 2003b

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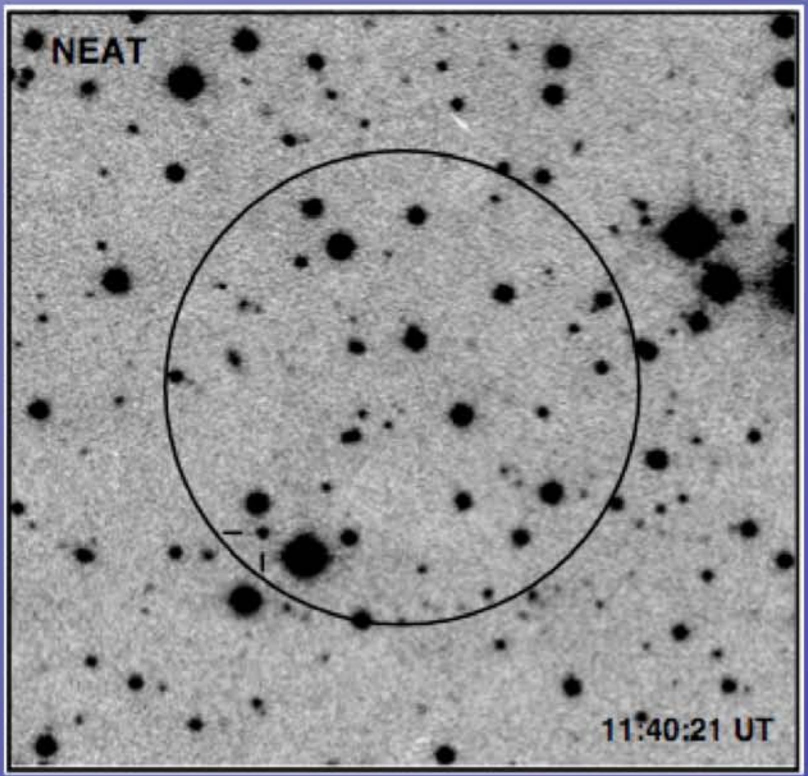
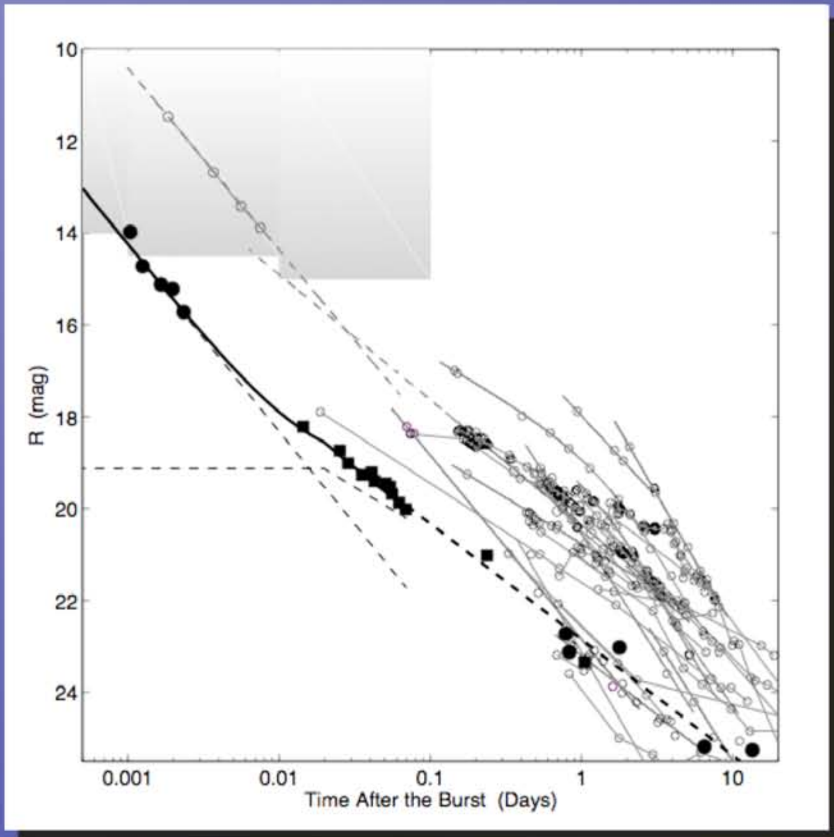


Fox et al. 2003b

GRB 021211

Early-time afterglow #3:

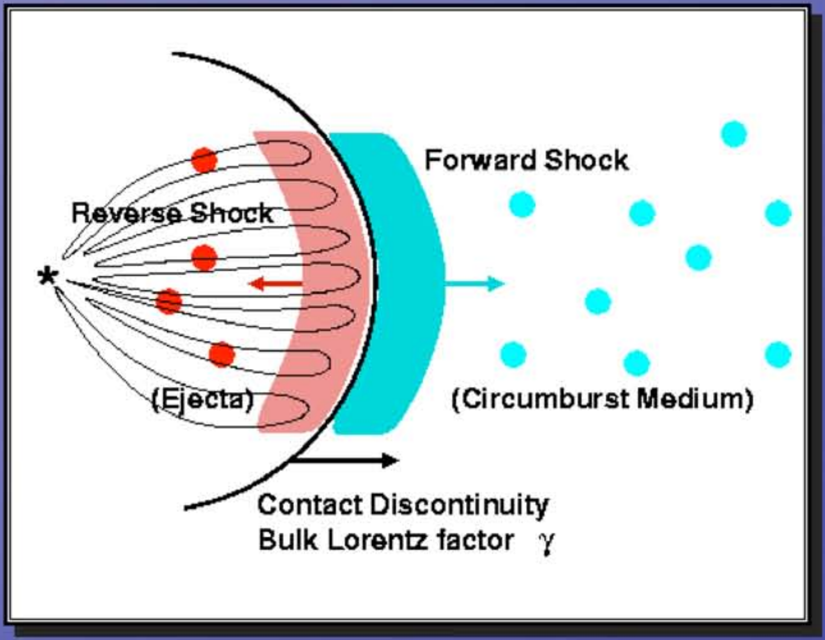
- Decaying from first observation (RAPTOR, *t*+60 s): $\Gamma > 100$
- Characterization of the flash-to-afterglow transition (KAIT; Li et al. 2003)
- A faint (not extinguished!) and fast-fading afterglow
- Possible evidence for "magnetized ejecta" –



Fox et al. 2003b

Magnetized Ejecta

- Stronger magnetic field (energy density) in the reverse shock
- Globally-ordered magnetic field not necessary
- Parameterize by:
  $R_B = B_r \,/\, B_f = \sqrt{(\varepsilon_{B,r}/\varepsilon_{B,f})}$
- Hydrodynamic jets or electromagnetic jets?
- Implications for the central engine of the GRB
- Note: Pure EM jet has no reverse shock (Lyutikov & Blandford 2004) but may make a flash by other means



Magnetized Ejecta

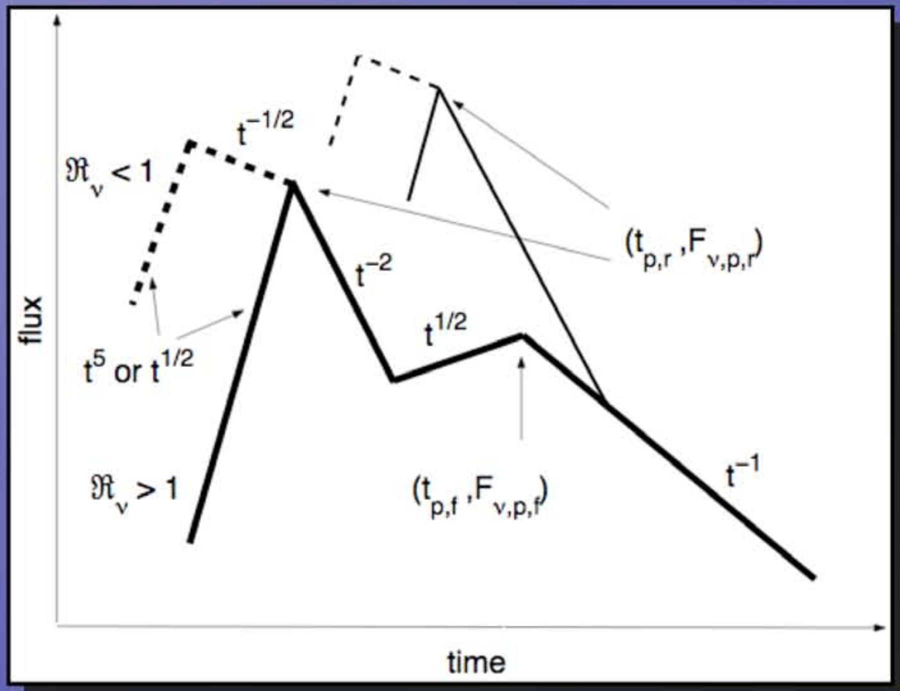
Looking at the flash-to-afterglow transition for GRB021211:

- "Flattening" light curves have:

  $\Gamma < R_B^{7/5}\, R_\nu^{2/5}$,

  where $R_\nu = \nu_{opt} / \nu_{m,r}$

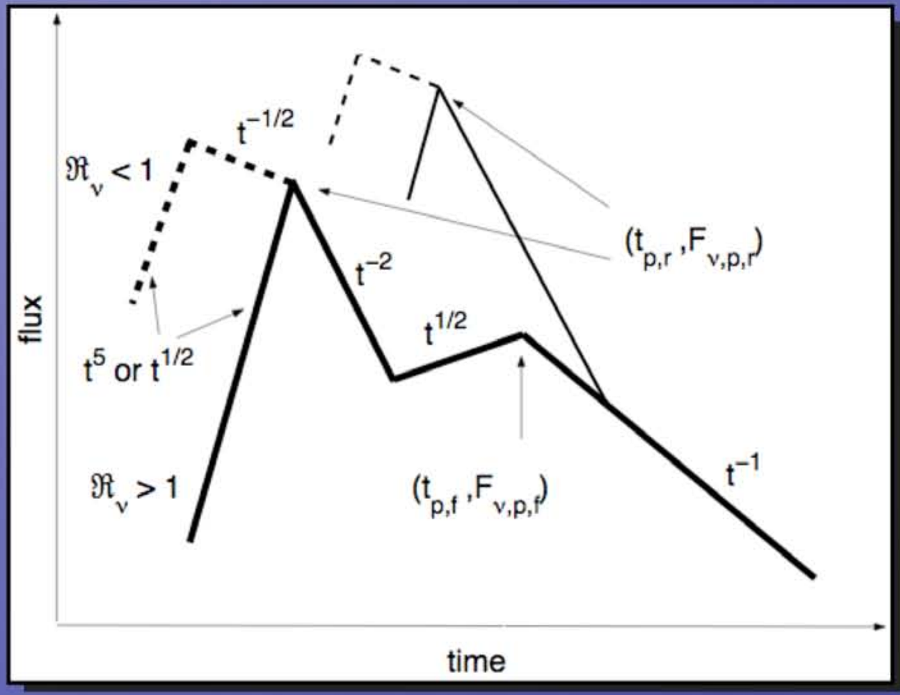
- $\Gamma > 100$ so R_B or R_ν is large
- Large R_ν strongly suppresses the optical flux
- Suggests $R_B > 10$ for this burst
- Distinct support from Kumar & Panaitescu (2003)
- Observing the peak of the flash would help!



Zhang, Kobayashi & Mészáros 2003

Tests of Magnetization

- Optical observations:
  R_B and R_ν
- Multiple colors: Synchrotron break frequencies
- Polarization: Globally-ordered magnetic fields?

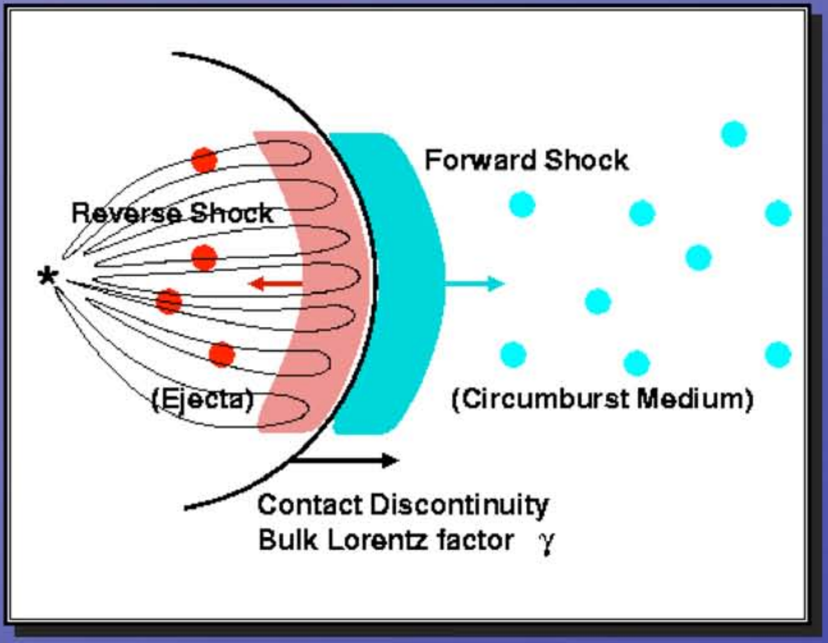


Zhang, Kobayashi & Mészáros 2003

Tests of Magnetization

Two classes of polarization measurement:

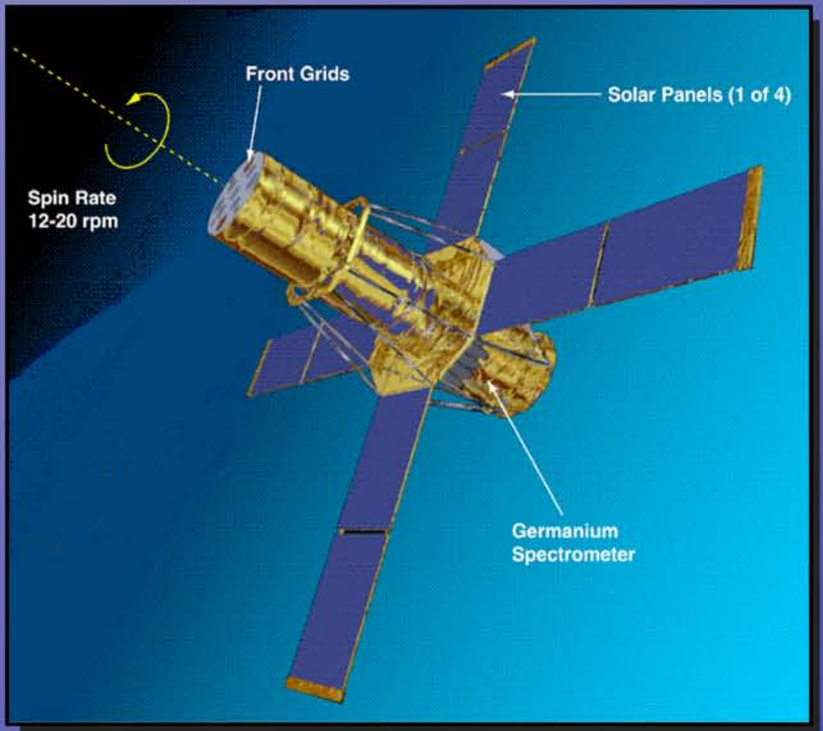
- Polarization of the prompt gamma-ray emission
- Polarization of the reverse-shock optical flash



A Polarization Non-Measurement

GRB021206 gamma-ray polarization with *RHESSI* (Coburn & Boggs 2003):

- Many Compton-scattered gamma-rays (~10%)
- Angular structure of Compton scatters demonstrates
  80 ± 20% linear polarization

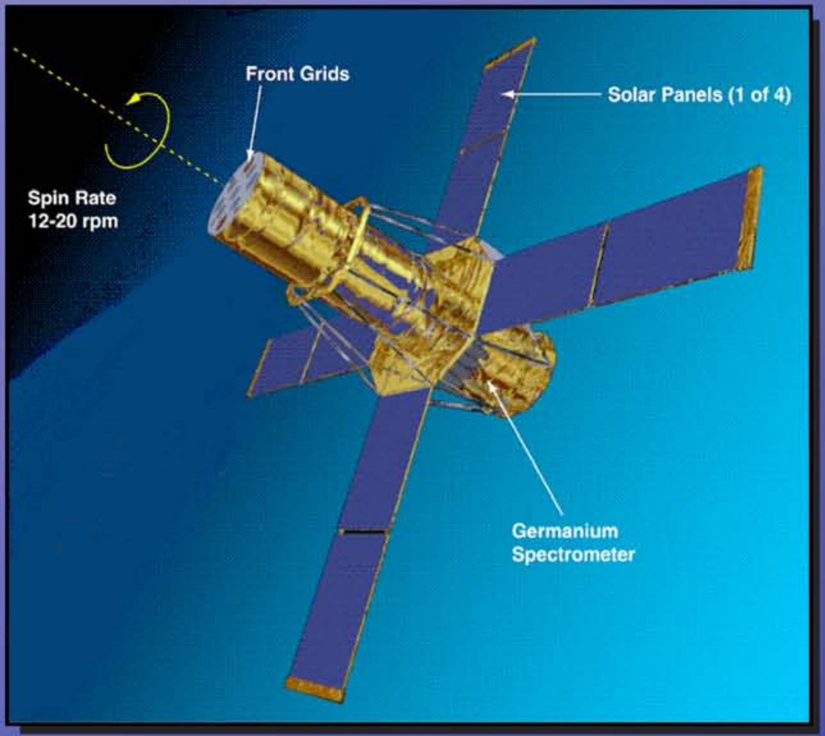


The *RHESSI* Spacecraft

A Polarization Non-Measurement

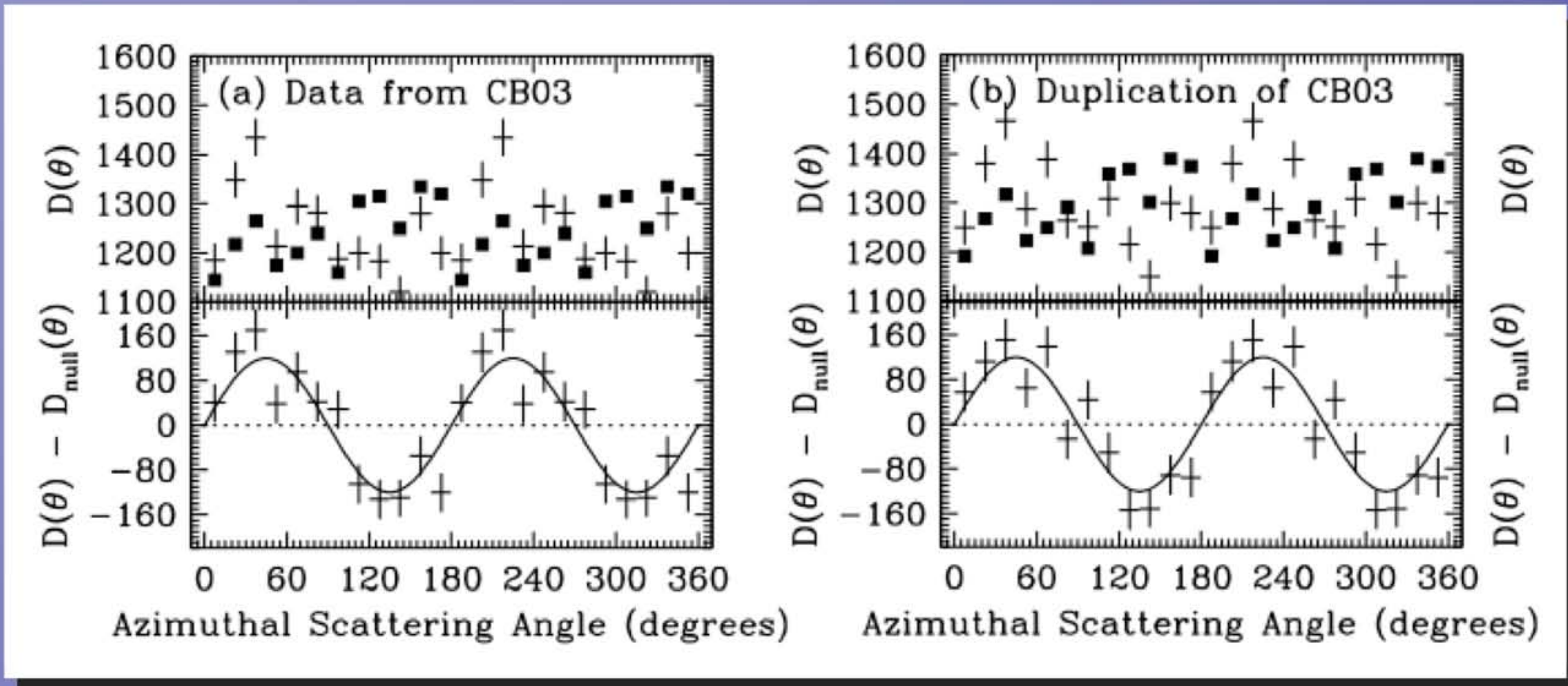
In fact (Rutledge & Fox 2004):

- Relatively few Compton scatters (~1%)
- 2-detector coincidences show angular structure
- *RHESSI* is not a sensitive GRB polarimeter
- Confirmed by subsequent analysis of Wigger et al. (2004)



The *RHESSI* Spacecraft

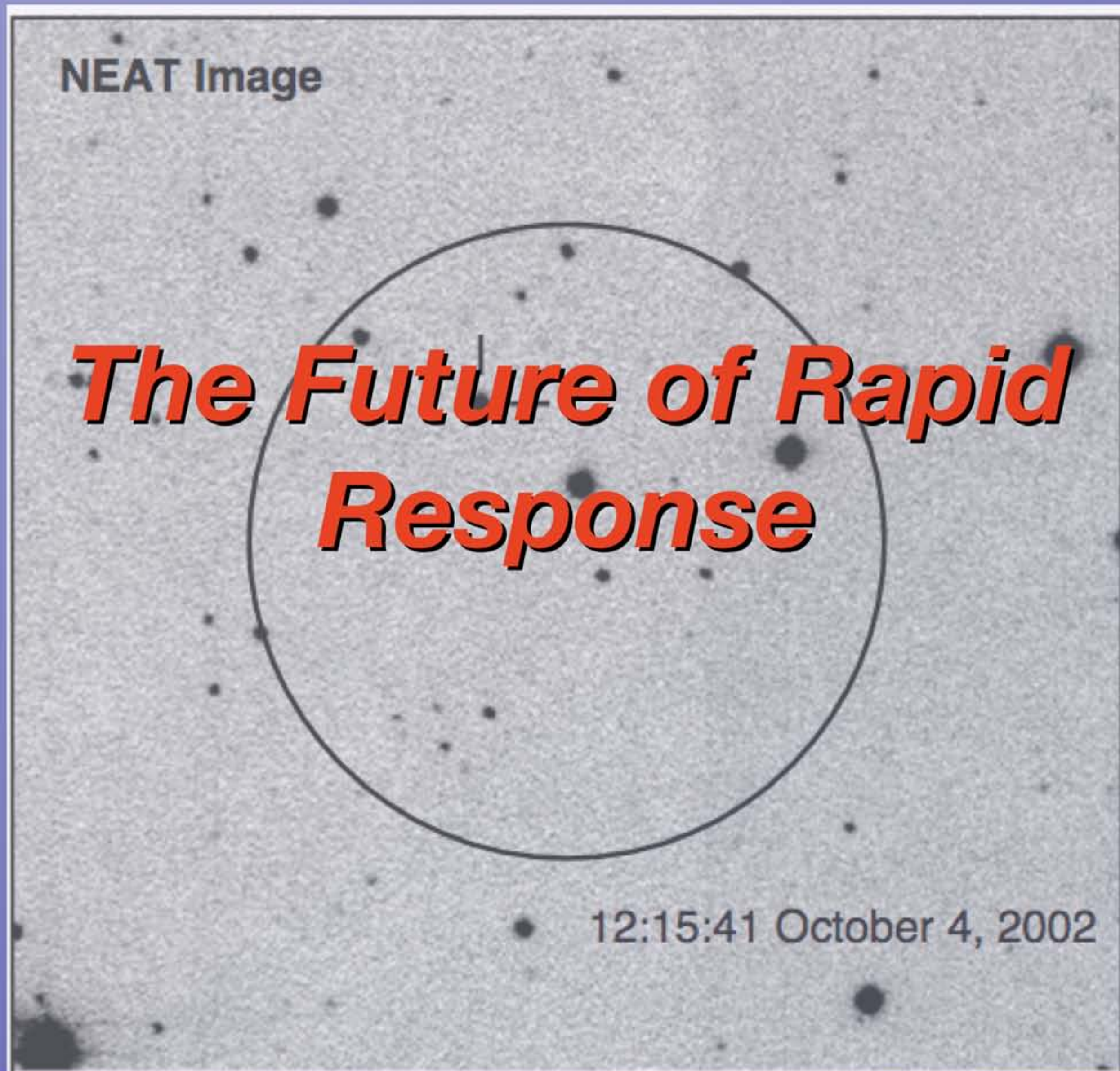
Reproducing the modulation



CB03 data compared to pure coincidence model

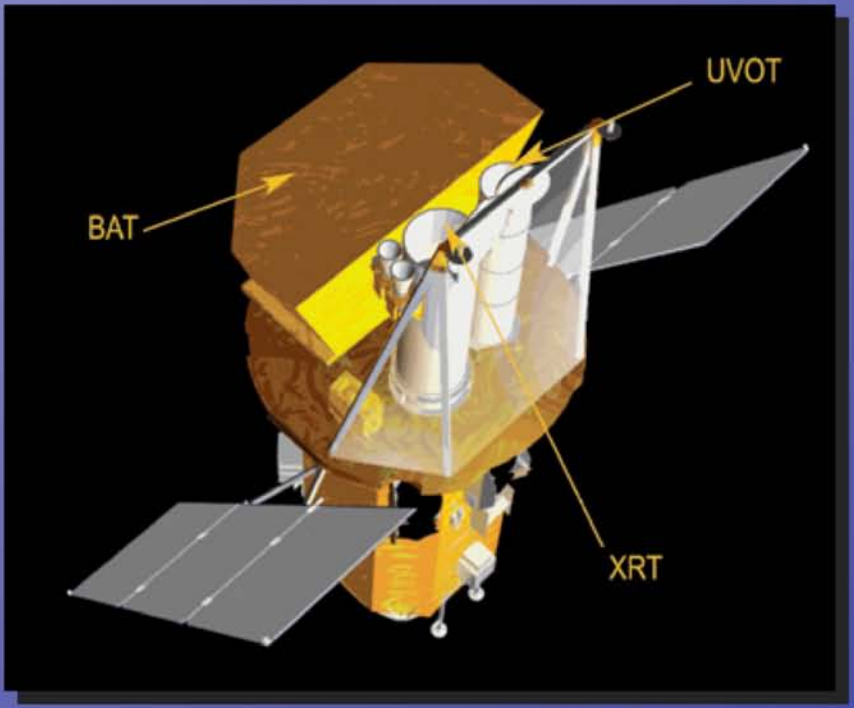
Rutledge & Fox 2004

The Future of Rapid Response

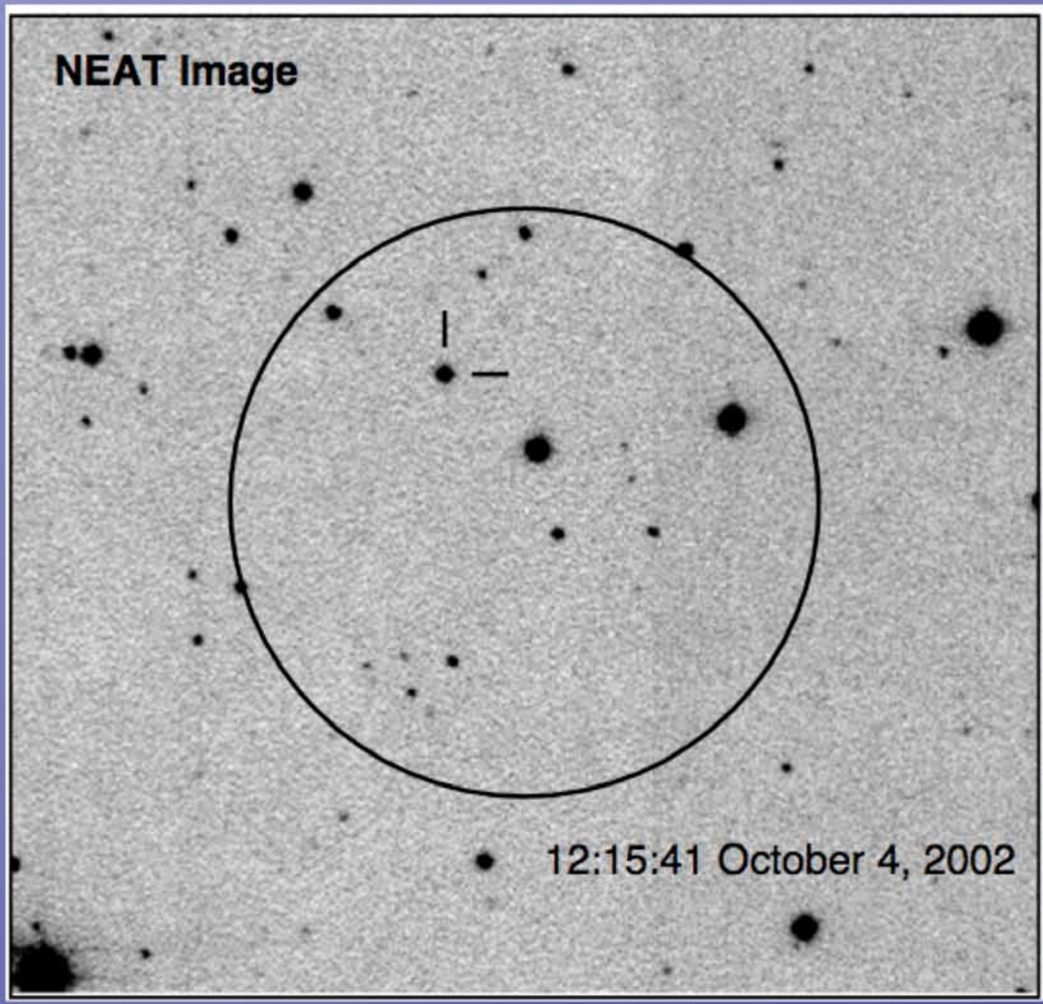


The Swift Mission

- BAT (1.5 sr fov) localizes to 2' radius in real time
- Robotic slew to point at the GRB position (100 sec)
- X-ray telescope (135 cm^2) derives 2"-radius position
- UV/Optical telescope observes in UV to *V*-band
- Grism spectroscopy
- X-ray and UV/optical follow-up for days to weeks
- ***In orbit!*** *(activating…)*

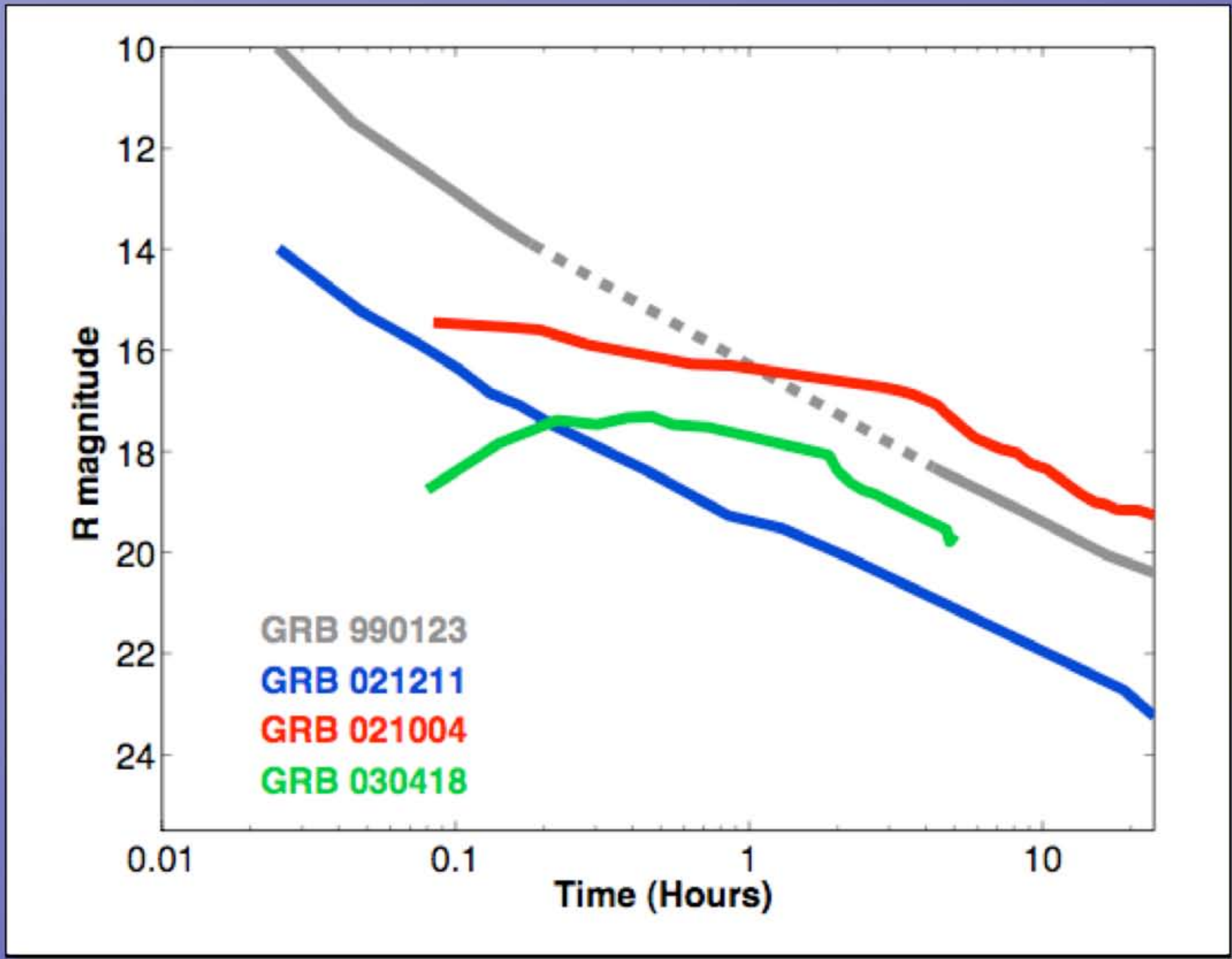


100 BAT Positions per year



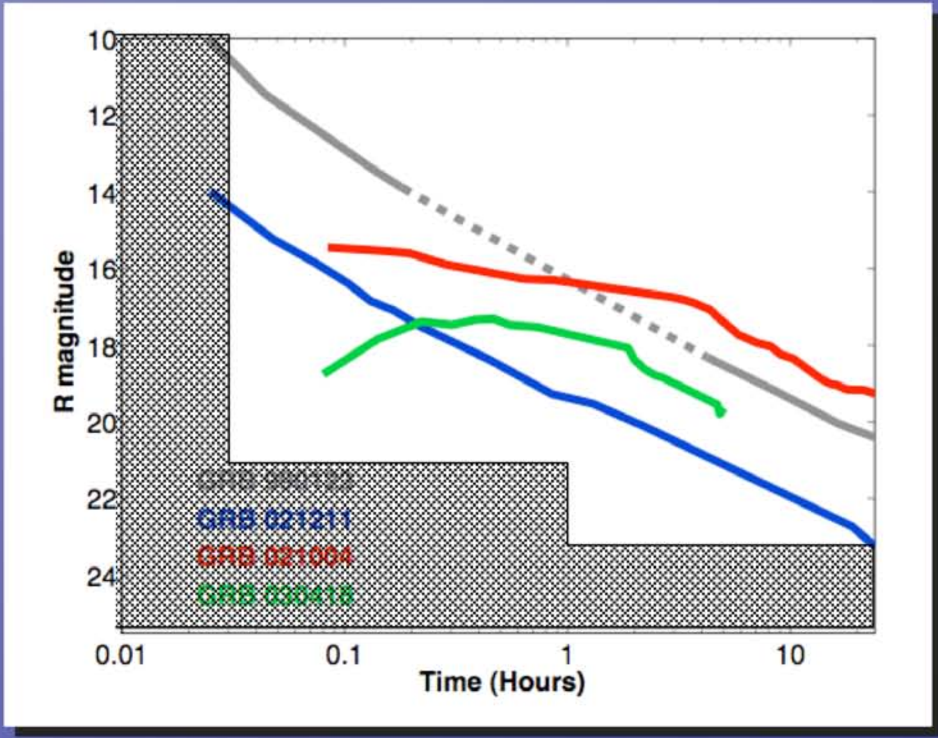
Fox et al. 2003a

Many more young afterglows

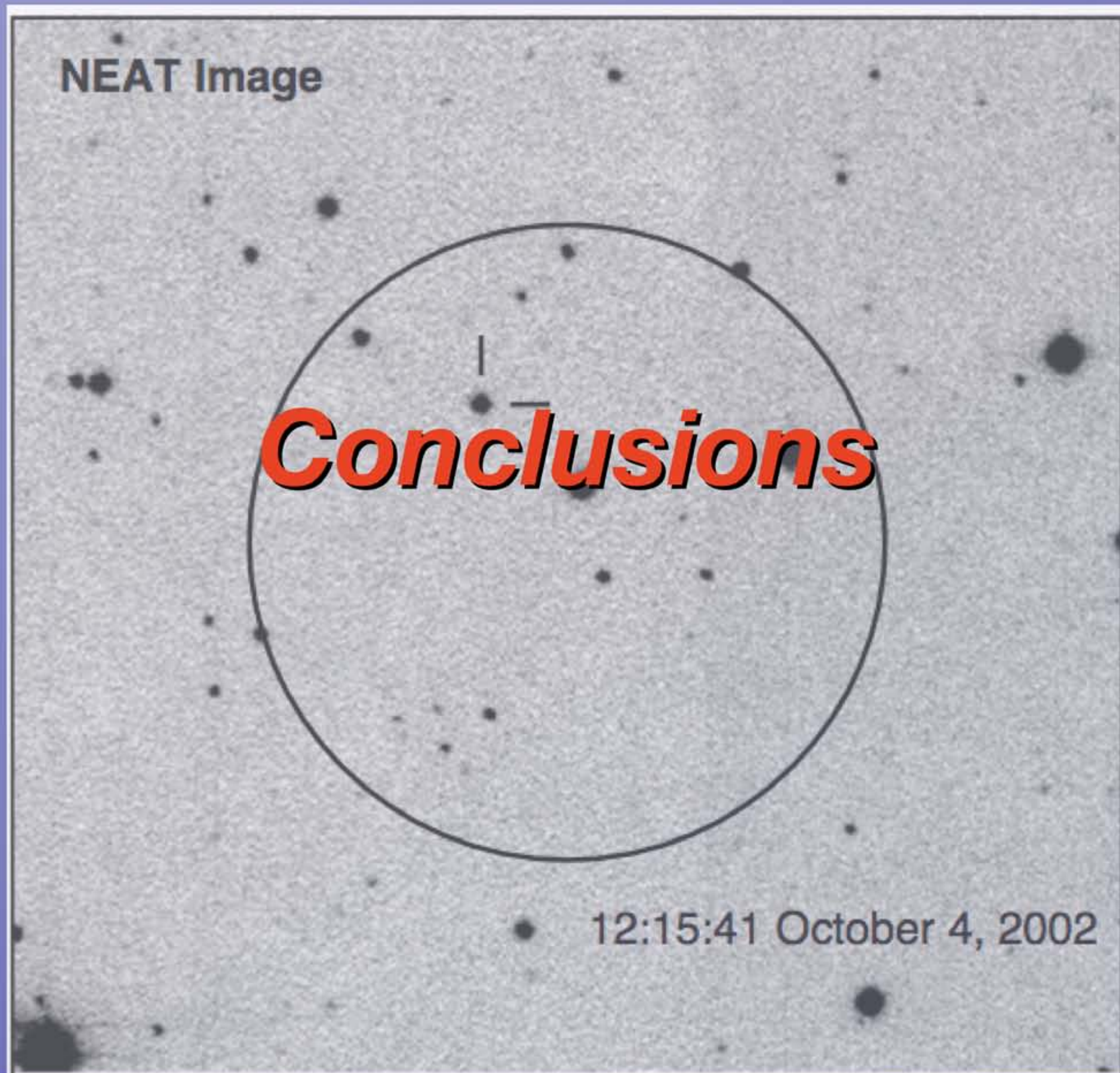


P60 for Rapid Response

- 2-minute response to *Swift* BAT alerts
- *R* > 20 in seconds
- Follow burst decay for hours
- Pipeline processing for transient discovery
- Multi-filter photometry (*BVRIz*)

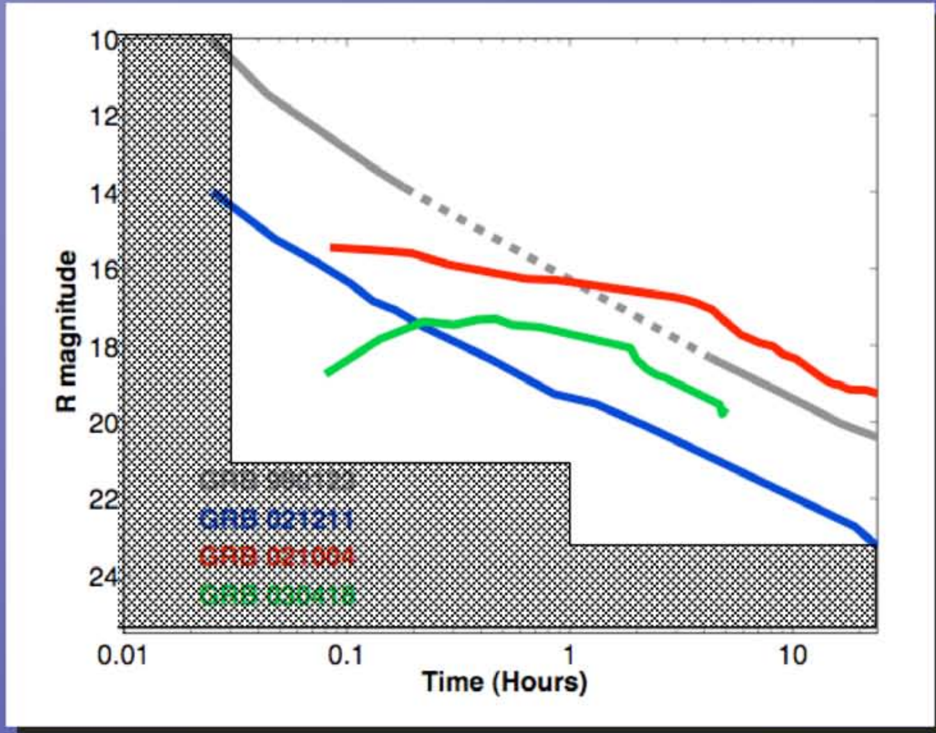


Conclusions



Rapid Response To-Date

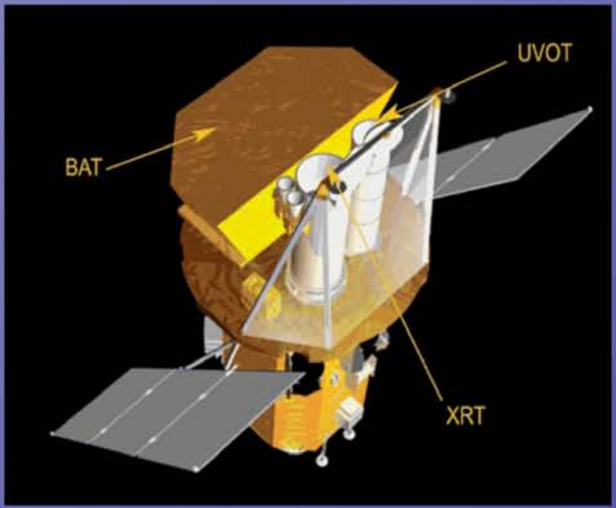
- ROTSE found the original "optical flash"
- We characterized two young afterglows
- GRB021004: Patchy jet or energy injection?
- GRB021211: Magnetized ejecta?
- *ROTSE-III*: GRB030418 peak at t=40 min



Rapid Response with Swift

Patchy Jets vs. Energy Injection

- Bump sizes, timescales
- Bump decay properties
- Optical vs. X-ray correlations



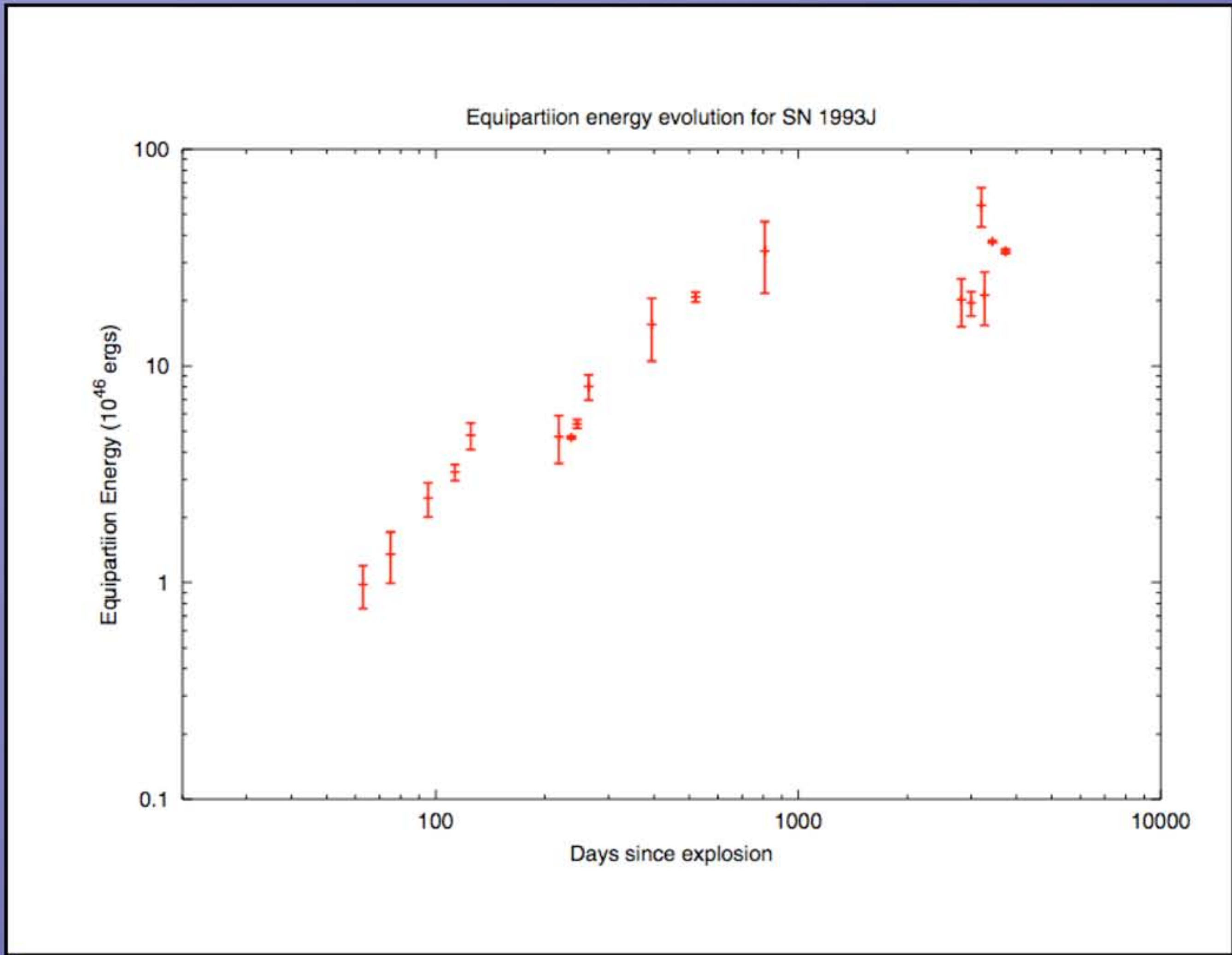
Hydro vs. EM Jets

- Optical flash/afterglow transition
- Optical polarization

Reverse shocks vs. Other

- Optical/radio comparisons
  (Nakar & Piran 2004)
- Colors of early emission (Lyutikov & Blandford 2004)

SN1993J at Meter Wavelengths



Poonam Chandra (private comm.)