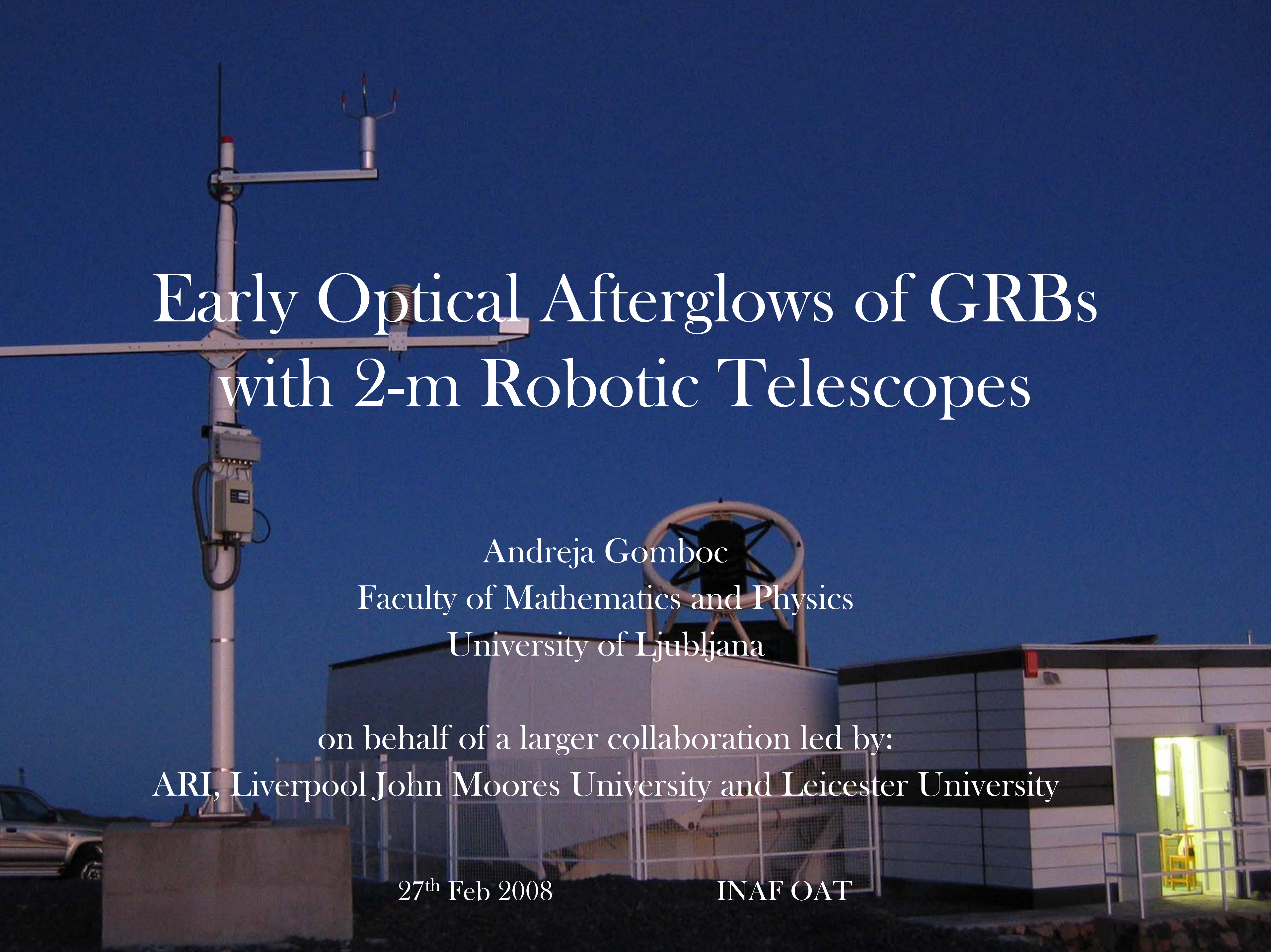

Early Optical Afterglows of GRBs with 2-m Robotic Telescopes

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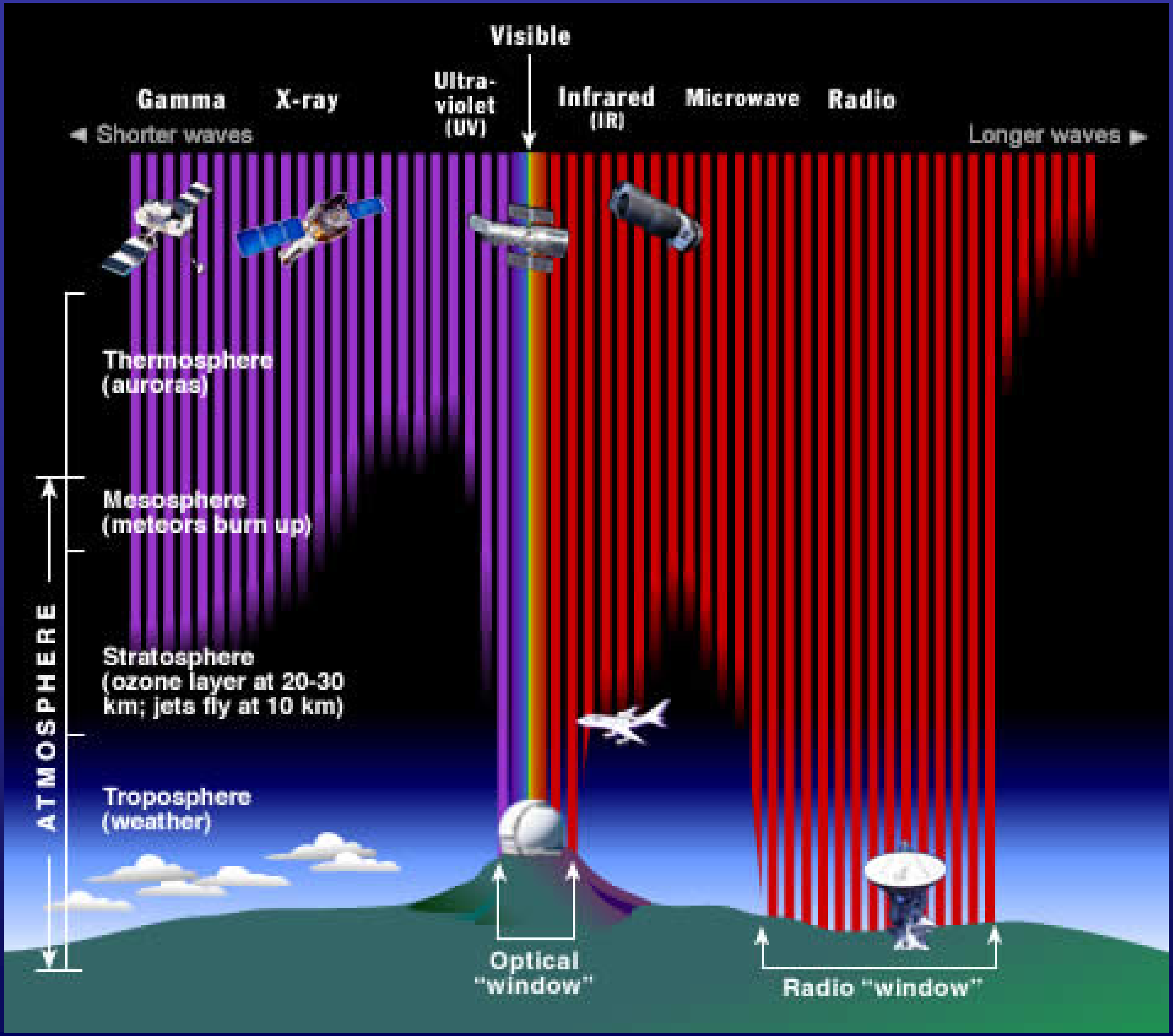
Faculty of Mathematics and Physics
University of Ljubljana

on behalf of a larger collaboration led by:
ARI, Liverpool John Moores University and Leicester University

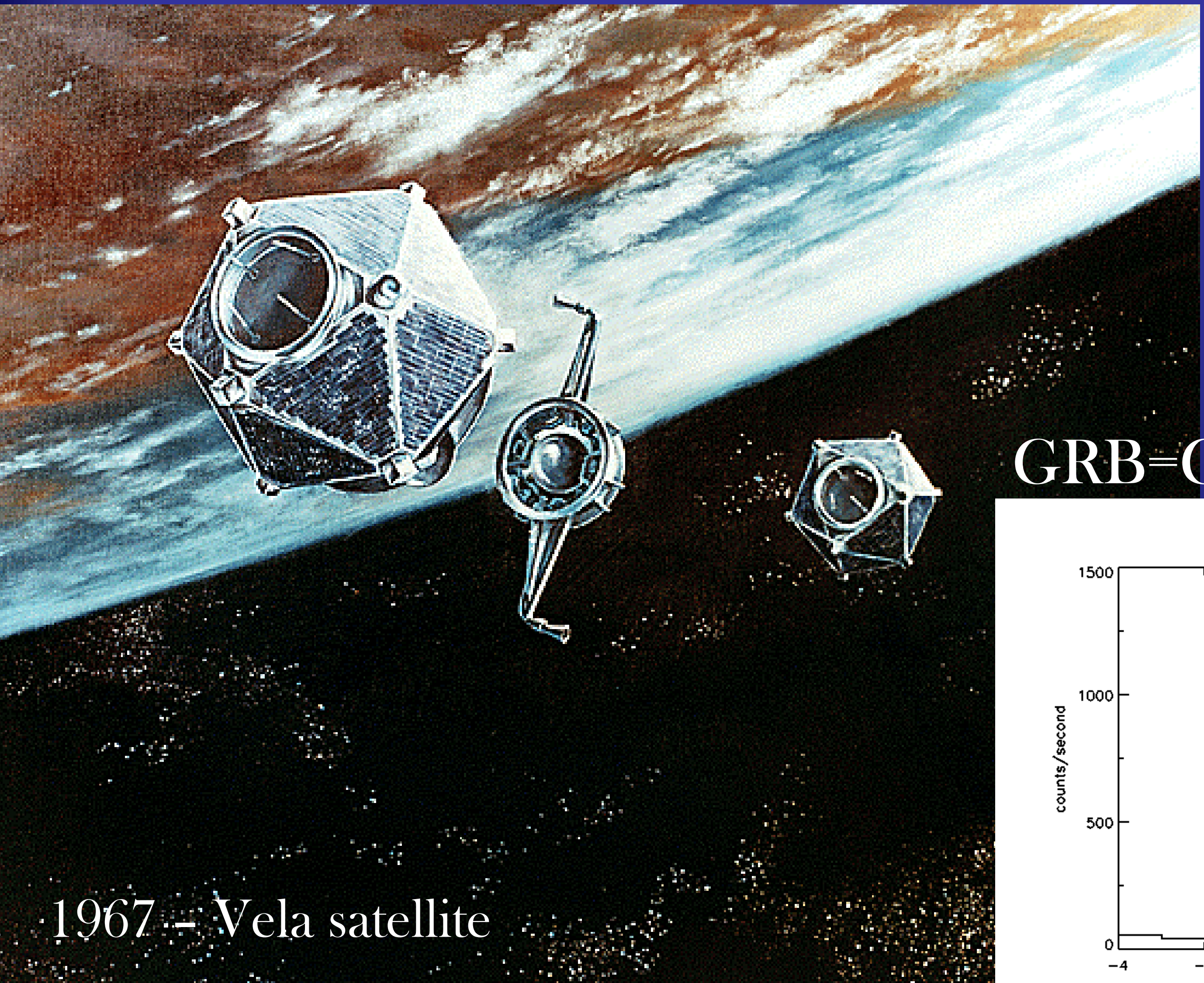
27th Feb 2008 INAF OAT

Outline

- short history of GRBs
- present knowledge on GRBs in the Swift era
- optical follow-up observations with 2-m robotic telescopes:
  - observational strategy,
  - results and
  - hot topics: dark bursts, jet-breaks, polarization,...

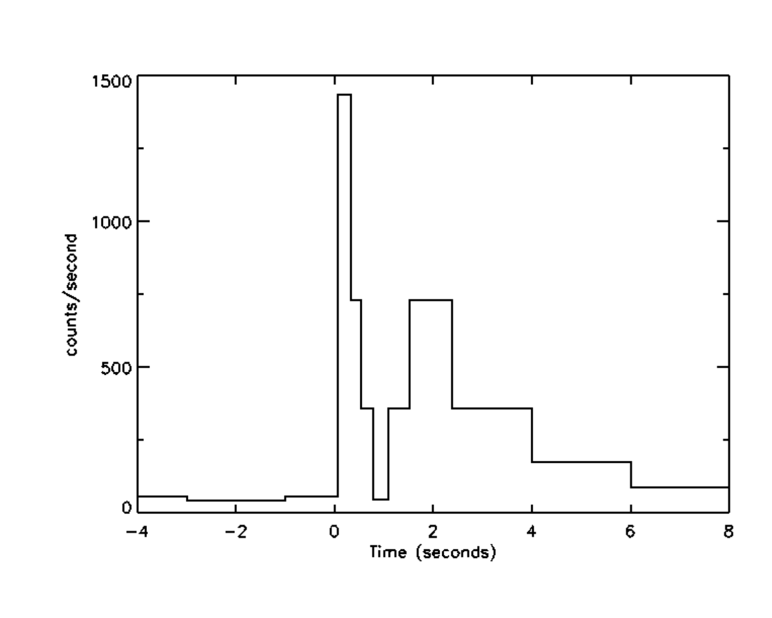

Visible
Gamma
X-ray
Ultra-
violet
(UV)
Infrared
(IR)
Microwave
Radio
◄ Shorter waves
Longer waves ►
Thermosphere
(auroras)
Mesosphere
(meteors burn up)
Stratosphere
(ozone layer at 20-30
km; jets fly at 10 km)
Troposphere
(weather)
ATMOSPHERE
Optical
"window"
Radio "window"

Discovery



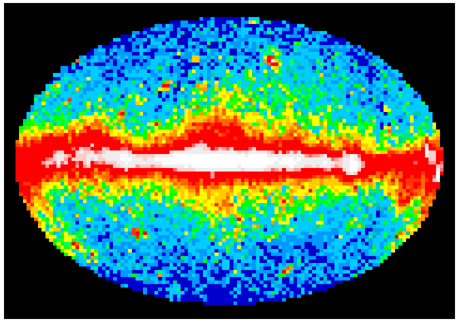
1967 – Vela satellite

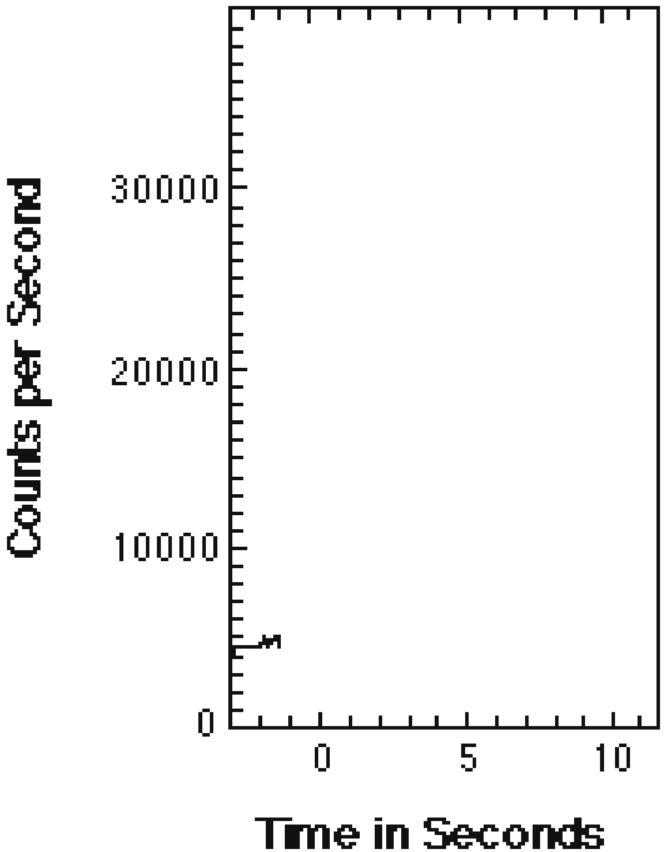
GRB=Gamma Ray Burst



next 25 years

- localization
- distance=??? ⟹ energy=???
- >100 theories

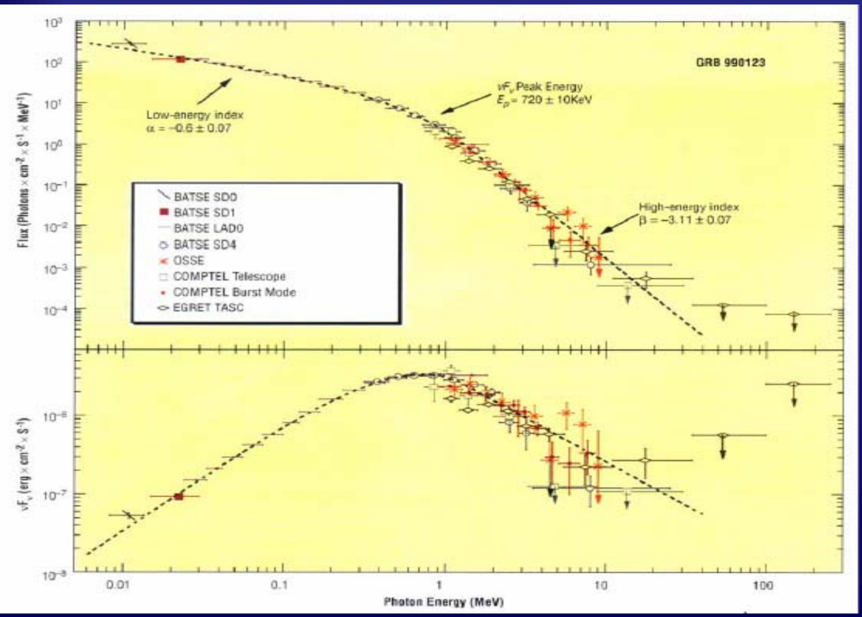


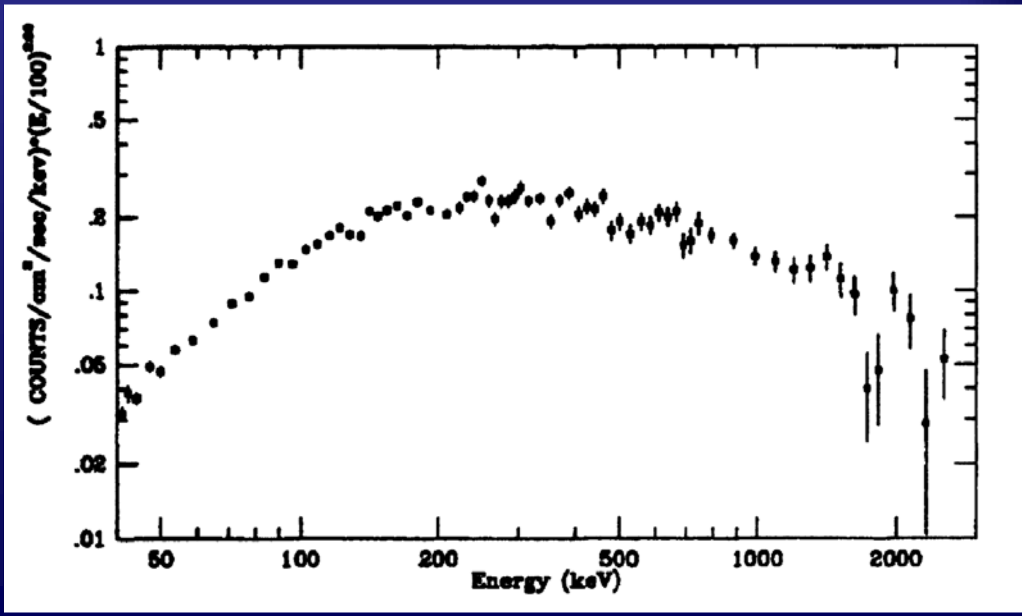


1990-ties and BATSE

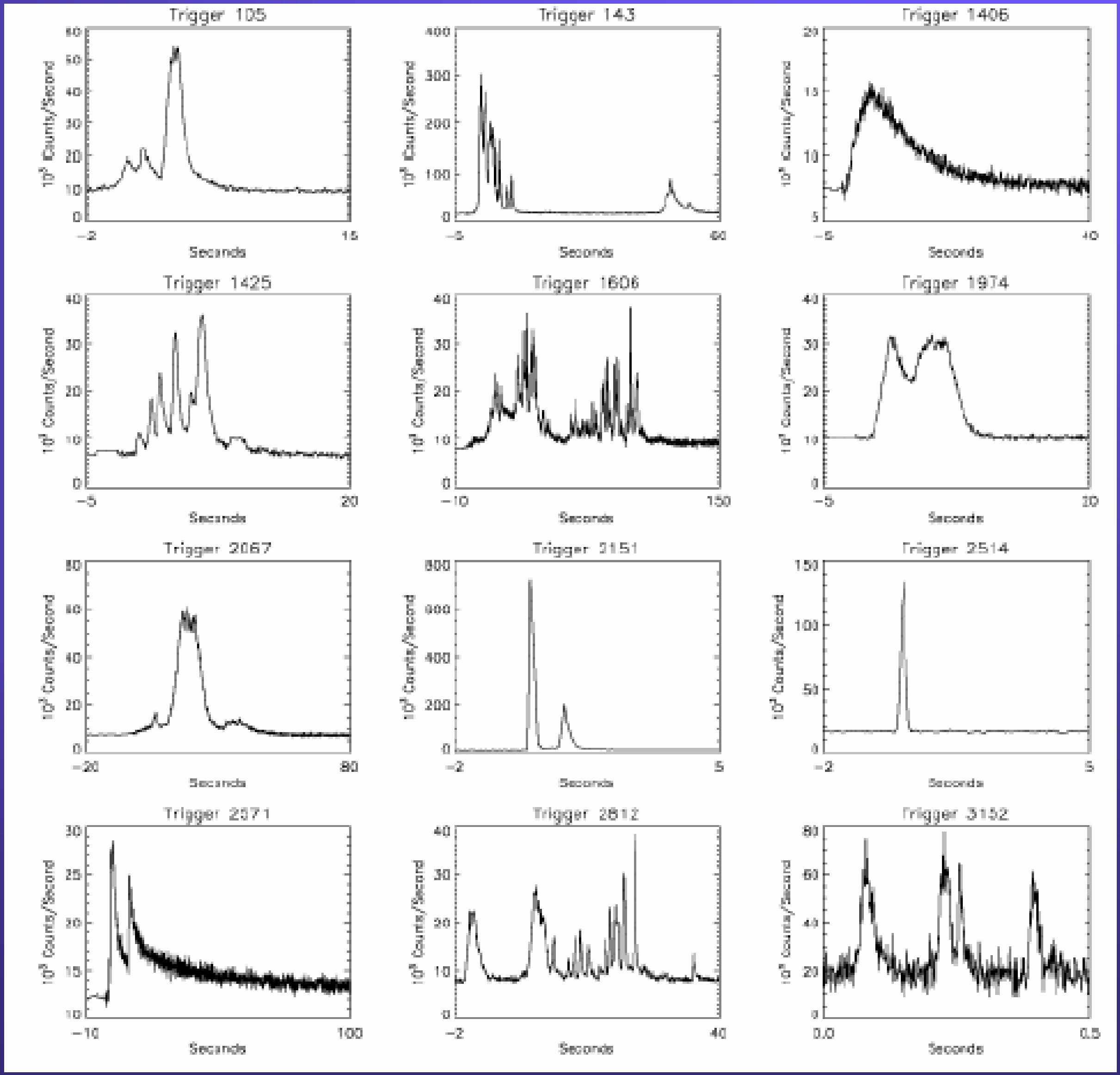
BATSE on Compton Gamma-Ray Observatory:

- ~ 1/day
- not repeating
- bulk of the energy in hν between 0.1 and 2 MeV
- spectrum: broken power law



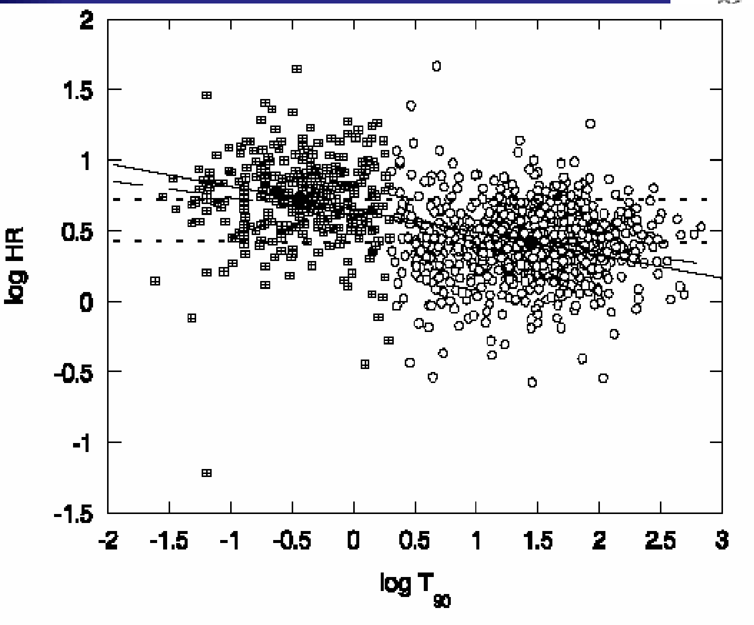


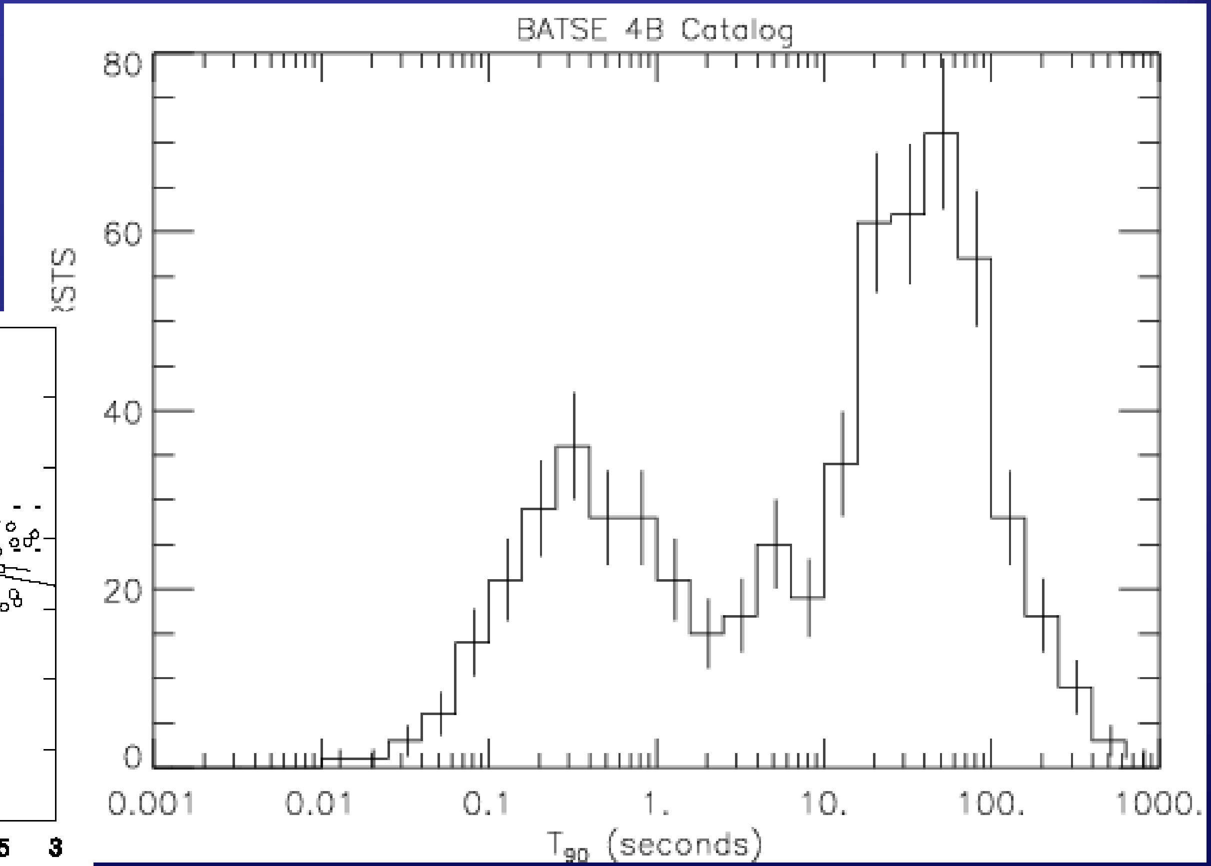
temporal profiles



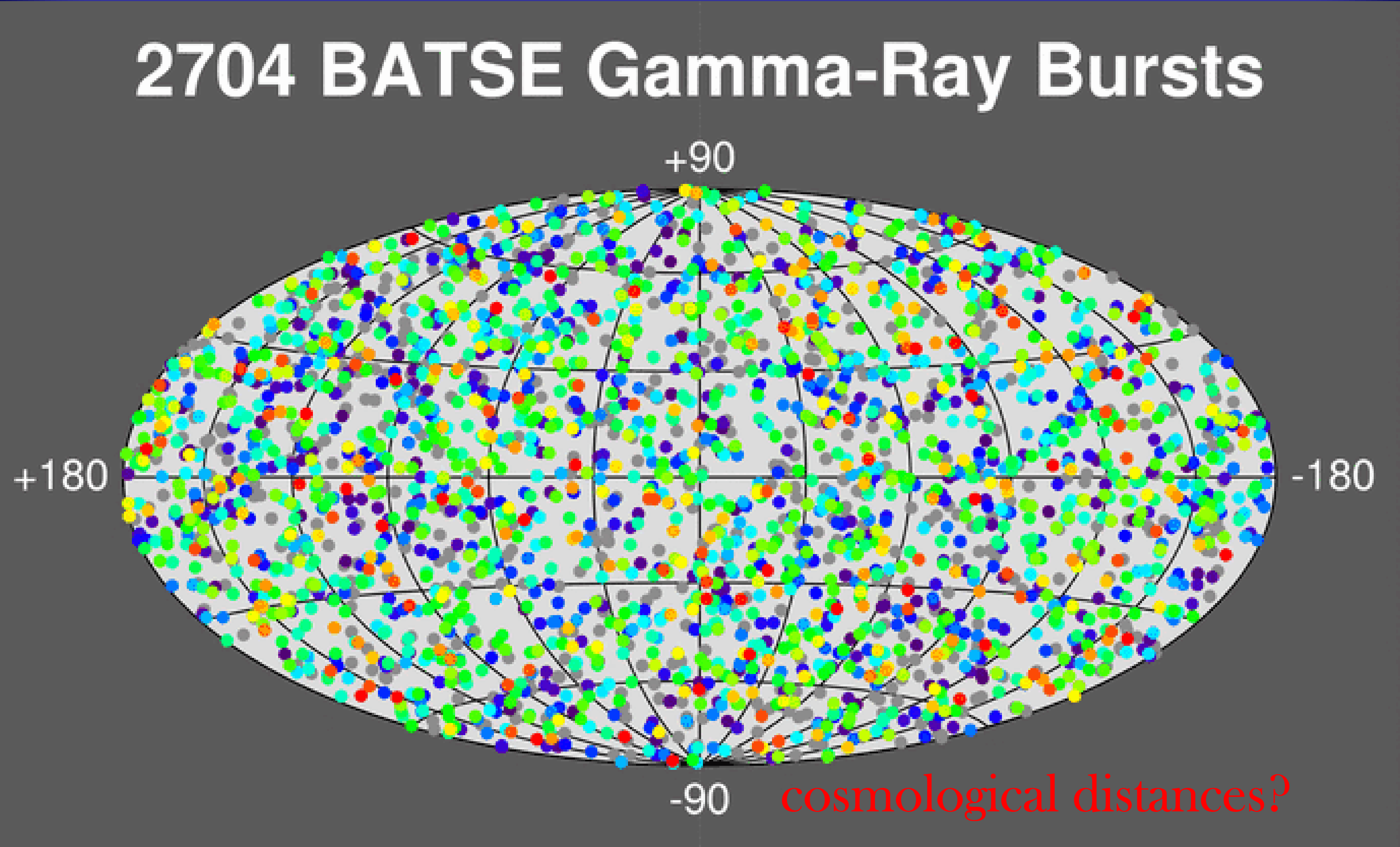
long and short GRBs

- duration distribution:
- long : t>2 s
- short: t<2s



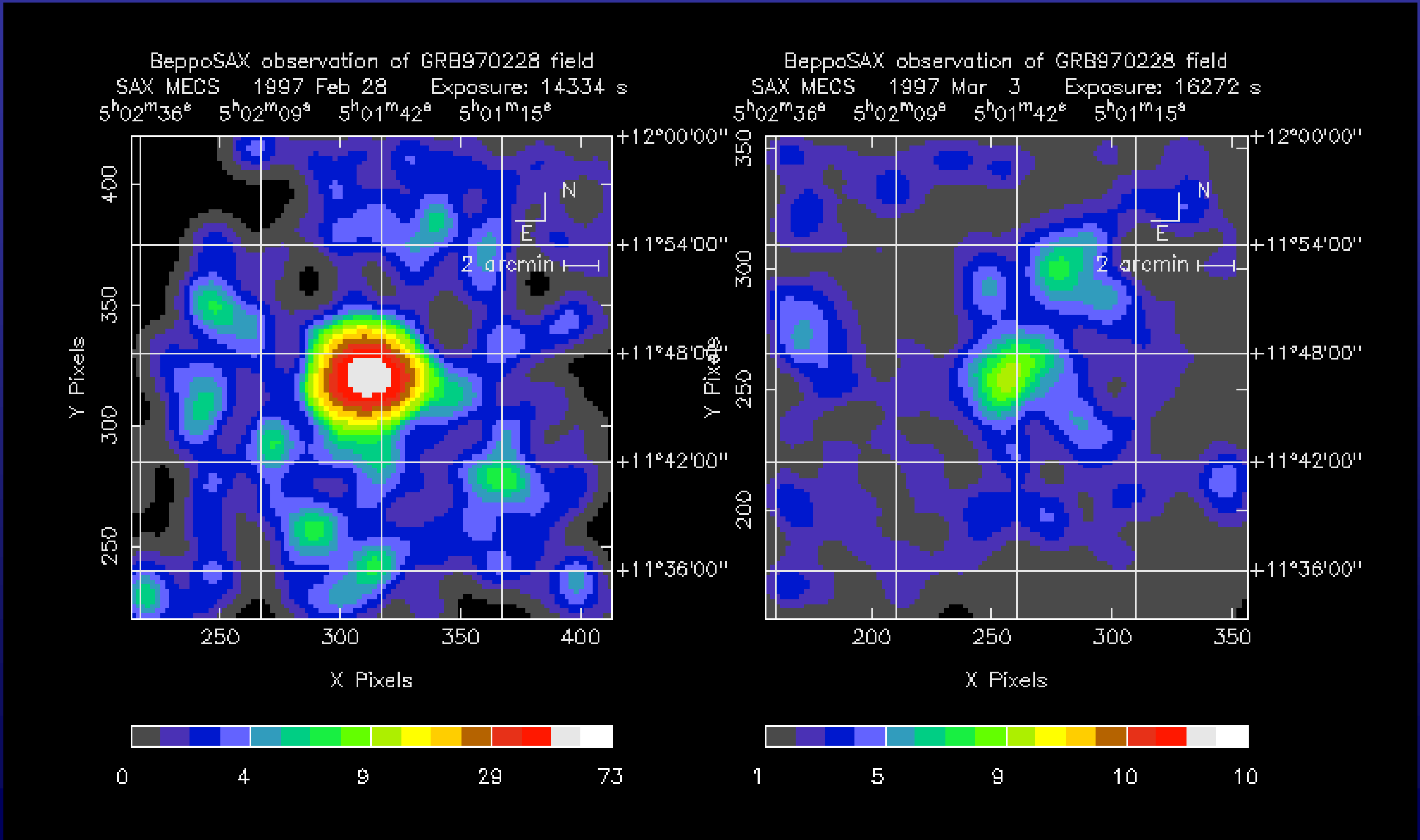


isotropic sky distribution

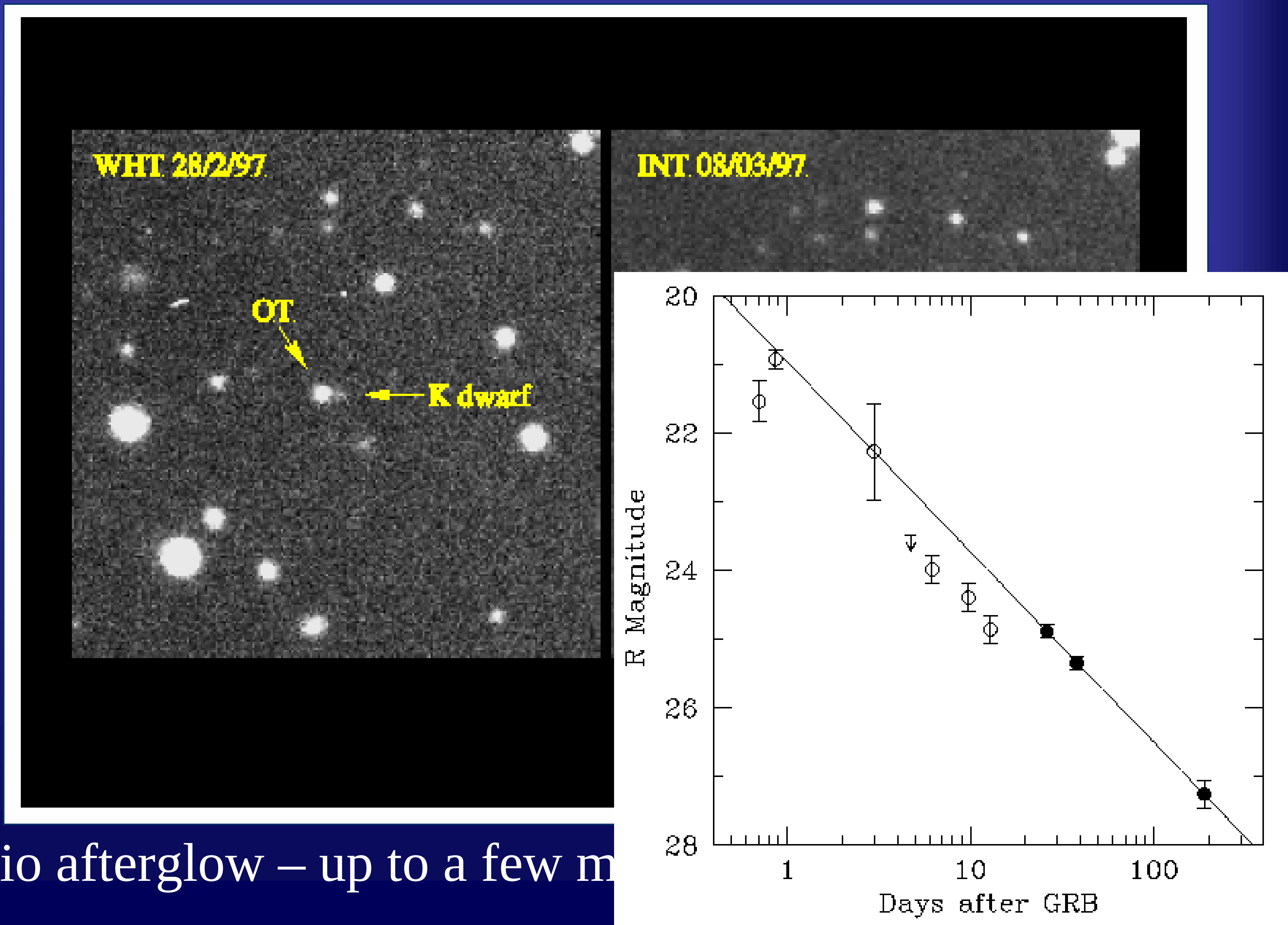


after 30 years: Beppo-SAX

- 1997 – discovery of long GRBs afterglows
- GRB 970228: in X-rays:

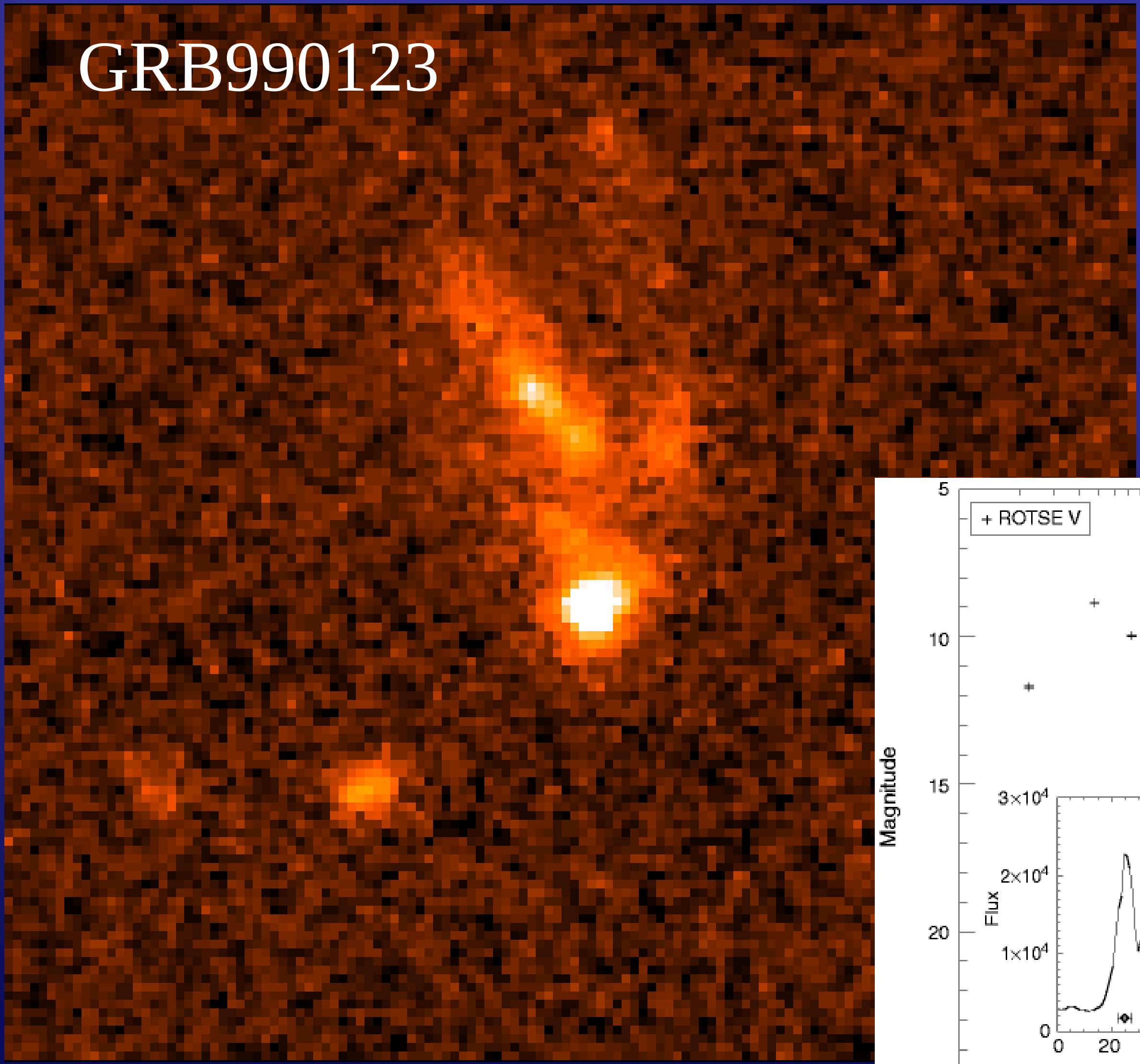


optical afterglow



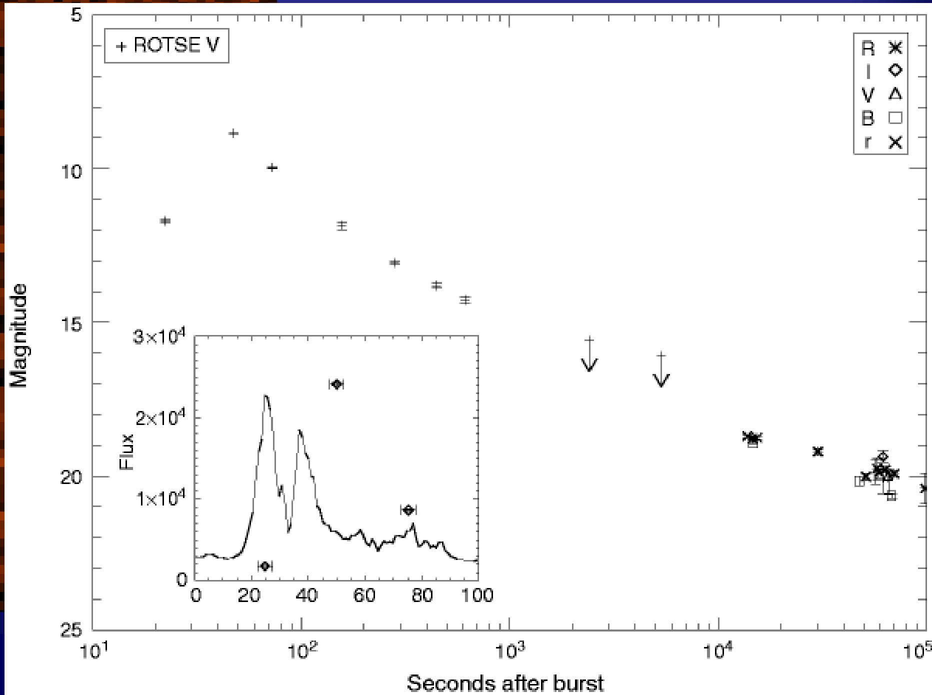
radio afterglow – up to a few m

in galaxies!



-measure galaxy's z

-distance $\Longrightarrow$ E



Energy!

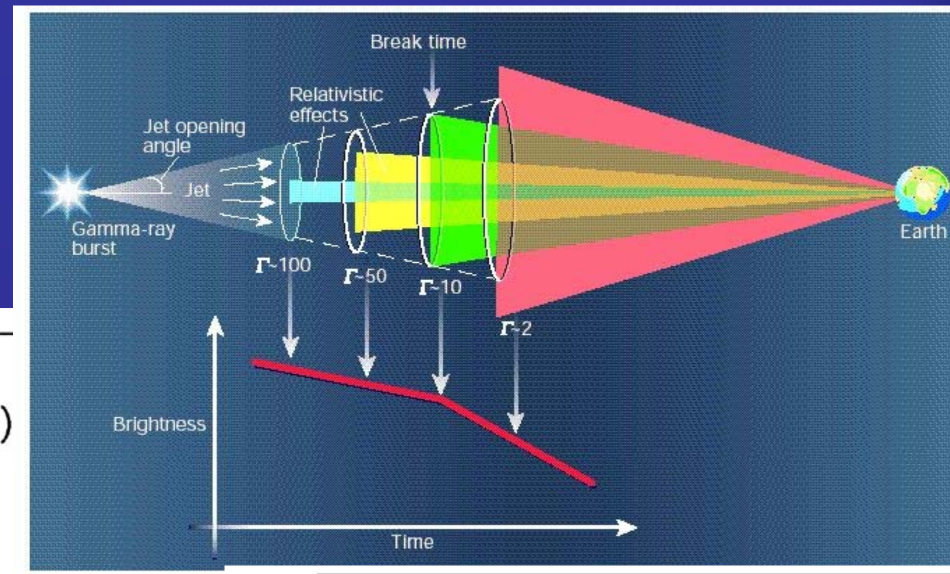
- isotropic energy release:

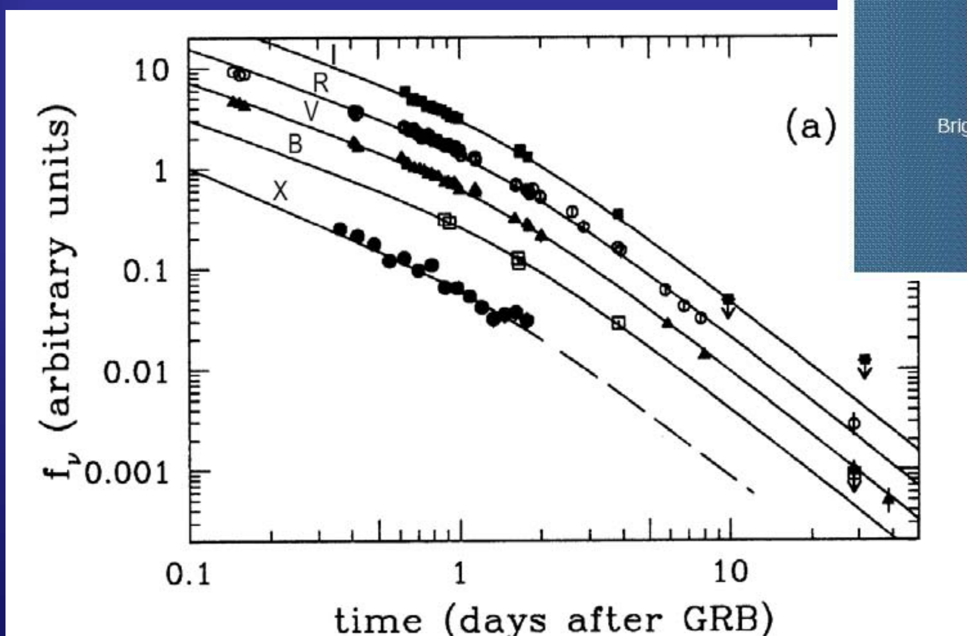
$$E \sim 10^{47}\ \mathrm{J}\ !$$

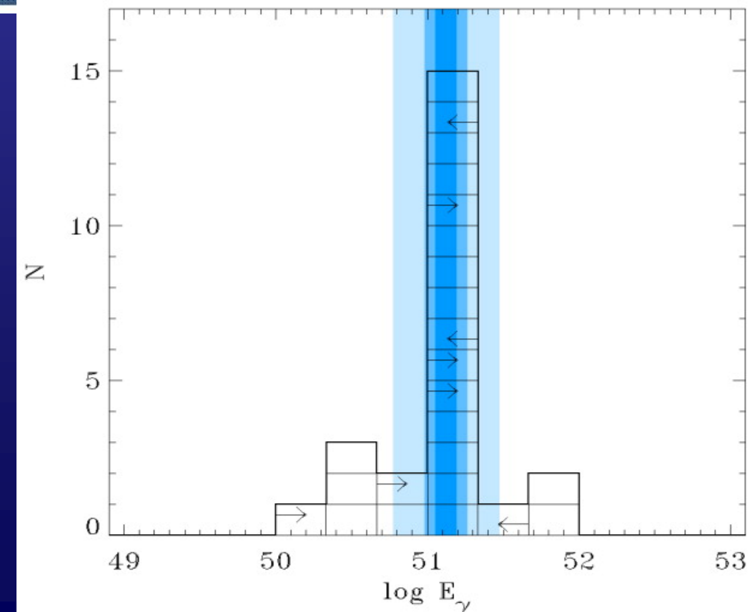
- $\sim M_{Sun} c^2$ in a time of 0.01 to 100 s

ms time variability + vast amount of energy + GeV photons -> ultra relativistic plasma with $\gamma > 100$

afterglows and jet break(?)





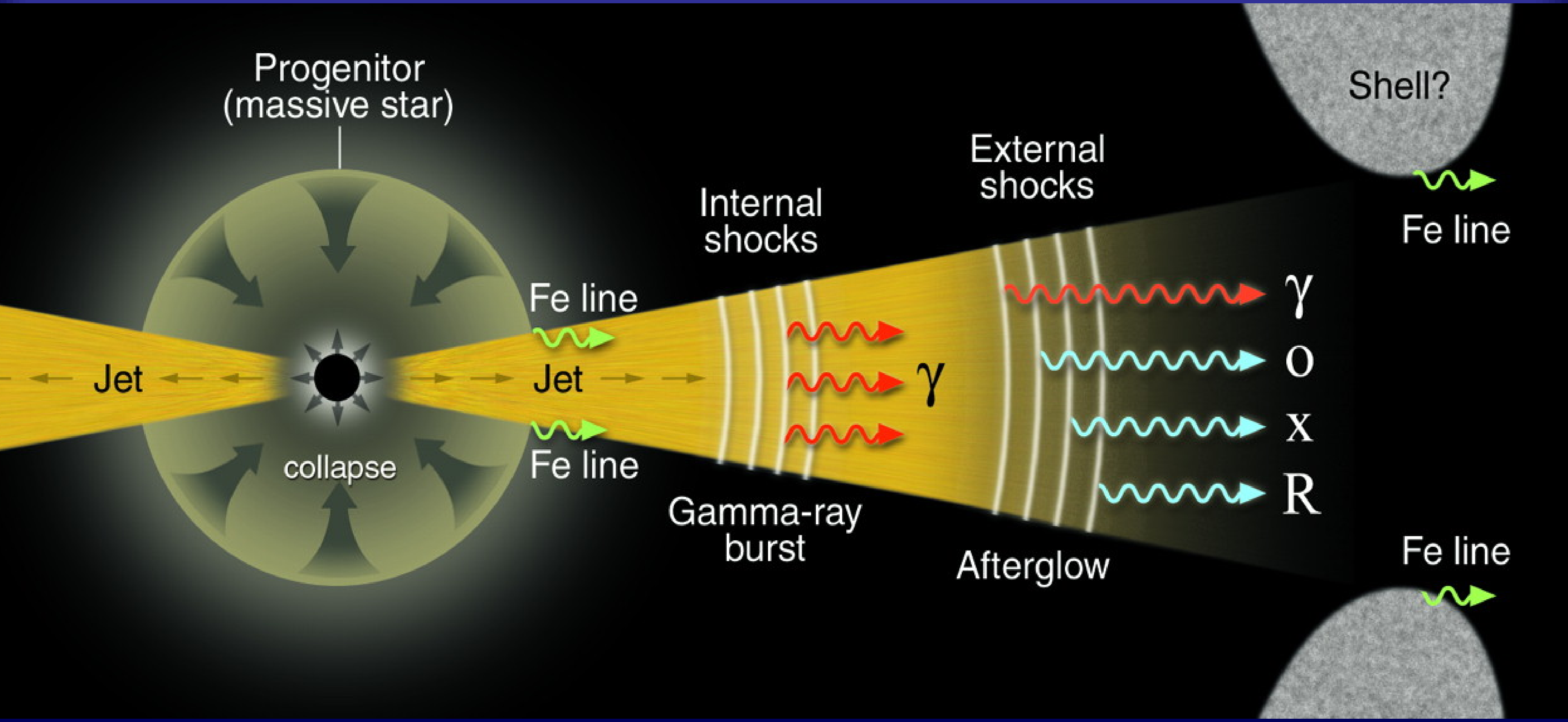


$E \sim 10^{44}$ J

N_{GRB} ↑

Fireball model

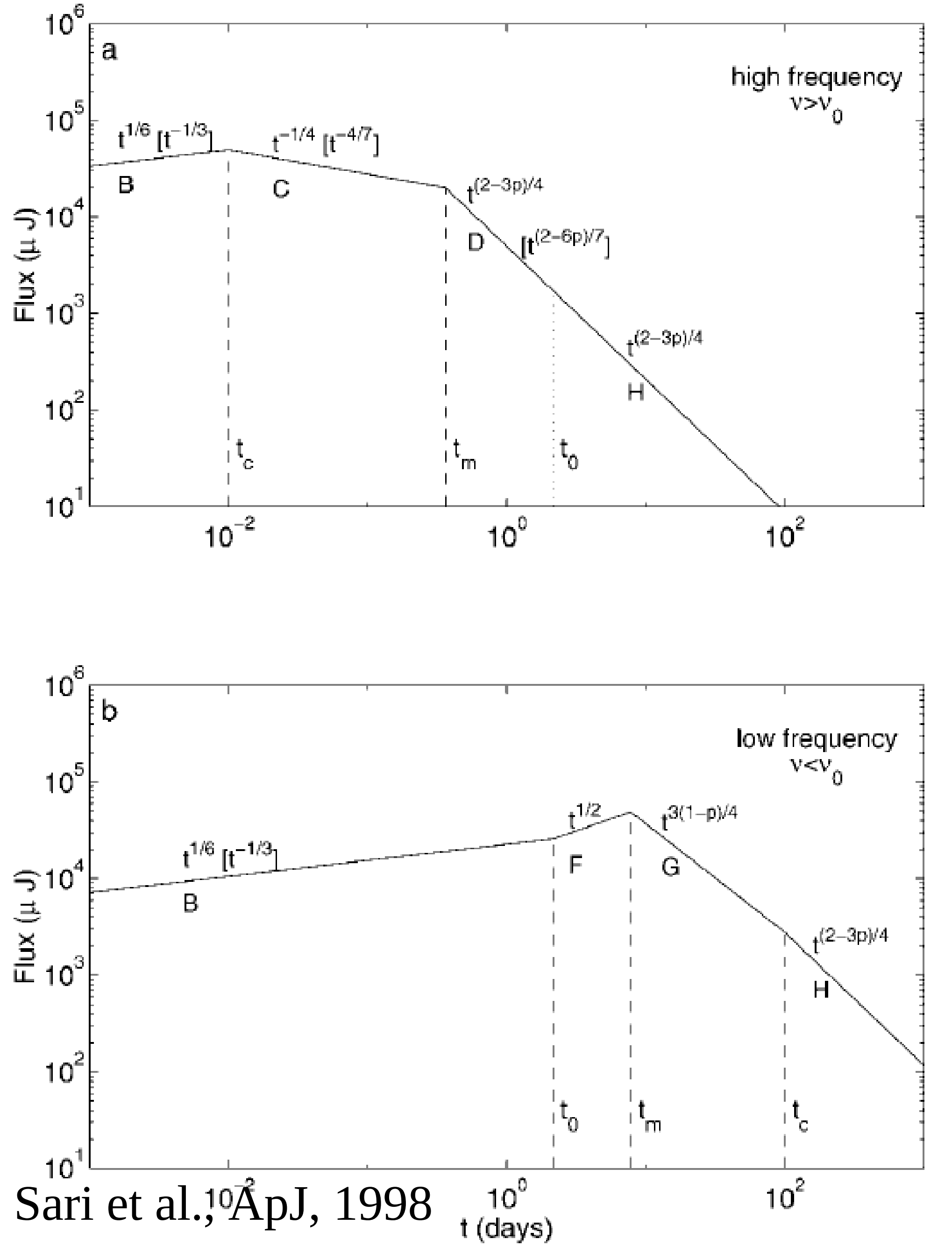
-ultra relativistic plasma with γ>100
- nonthermal spectra -> shocks, sinhrotron radiation
- internal shocks -> prompt emission (GRB)
- external shocks -> afterglow emission



Afterglow

$$N(\gamma_e)d\gamma_e \propto \gamma_e^{-p} d\gamma_e, \ \gamma_e \geq \gamma_m$$

$F \propto t^{-\alpha} \nu^{-\beta}$



Sari et al., ApJ, 1998

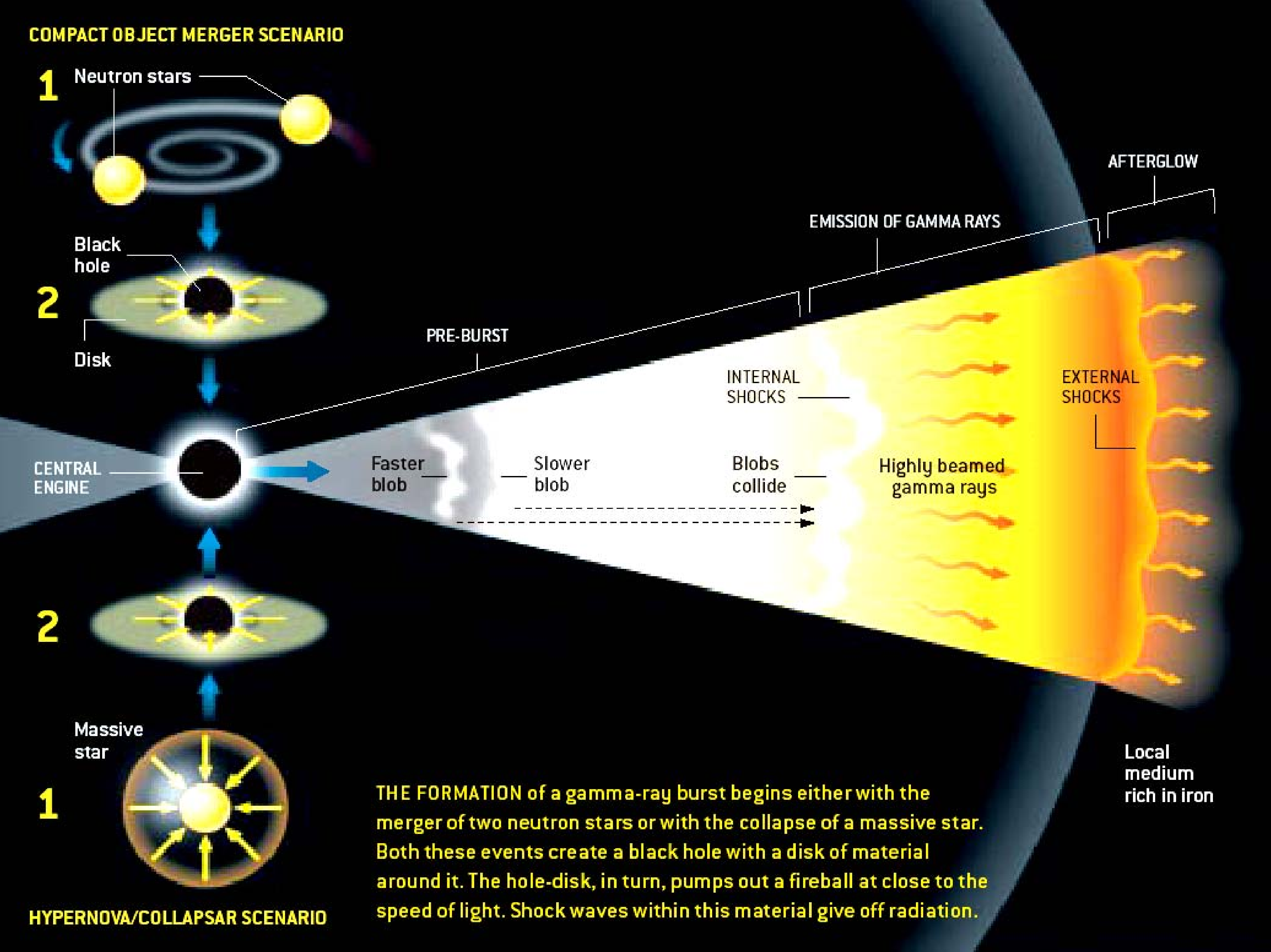
$F \propto t^{-\alpha} \nu^{-\beta}$

environment:
- Inter Stellar Medium
- wind: $\rho \propto r^{-2}$

What is the progenitor?

	β	α $(p>2,\ p\sim 2.3)$	$\alpha(\beta)$	α $(1<p<2,\ p\sim 1.5)$	$\alpha(\beta)$
ISM, slow cooling					
$\nu < \nu_a$	2	$\frac{1}{2}$		$\frac{17p-26}{16(p-1)} \sim -0.06$	
$\nu_a < \nu < \nu_m$	$\frac{1}{3}$	$\frac{1}{2}$	$\alpha = \frac{3\beta}{2}$	$\frac{p+2}{8(p-1)} \sim 0.9$	
$\nu_m < \nu < \nu_c$	$-\frac{p-1}{2}$	$\frac{3(1-p)}{4} \sim -1.0$	$\alpha = \frac{3\beta}{2}$	$-\frac{3(p+2)}{16} \sim -0.7$	$\alpha = \frac{3(2\beta-3)}{16}$
$\nu > \nu_c$	$-\frac{p}{2}$	$\frac{2-3p}{4} \sim -1.2$	$\alpha = \frac{3\beta+1}{2}$	$-\frac{3p+10}{16} \sim -0.9$	$\alpha = \frac{3\beta-5}{8}$
ISM, fast cooling					
$\nu < \nu_a$	2	1		1	
$\nu_a < \nu < \nu_c$	$\frac{1}{3}$	$\frac{1}{6}$	$\alpha = \frac{\beta}{2}$	$\frac{1}{6}$	$\alpha = \frac{\beta}{2}$
$\nu_c < \nu < \nu_m$	$-\frac{1}{2}$	$-\frac{1}{4}$	$\alpha = \frac{\beta}{2}$	$-\frac{1}{4}$	$\alpha = \frac{\beta}{2}$
$\nu > \nu_m$	$-\frac{p}{2}$	$\frac{2-3p}{4} \sim -1.2$	$\alpha = \frac{3\beta+1}{2}$	$-\frac{3p+10}{16} \sim -0.9$	$\alpha = \frac{3\beta-5}{8}$
Wind, slow cooling					
$\nu < \nu_a$	2	1		$\frac{13p-18}{8(p-1)} \sim 0.4$	
$\nu_a < \nu < \nu_m$	$\frac{1}{3}$	0	$\alpha = \frac{3\beta-1}{2}$	$\frac{5(2-p)}{12(p-1)} \sim 0.4$	
$\nu_m < \nu < \nu_c$	$-\frac{p-1}{2}$	$\frac{1-3p}{4} \sim -1.5$	$\alpha = \frac{3\beta-1}{2}$	$-\frac{p+8}{8} \sim -1.2$	$\alpha = \frac{2\beta-9}{8}$
$\nu > \nu_c$	$-\frac{p}{2}$	$\frac{2-3p}{4} \sim -1.2$	$\alpha = \frac{3\beta+1}{2}$	$-\frac{p+6}{8} \sim -0.9$	$\alpha = \frac{\beta-3}{4}$
Wind, fast cooling					
$\nu < \nu_a$	2	2		2	
$\nu_a < \nu < \nu_c$	$\frac{1}{3}$	$-\frac{2}{3}$	$\alpha = -\frac{\beta+1}{2}$	$-\frac{2}{3}$	$\alpha = -\frac{\beta+1}{2}$
$\nu_c < \nu < \nu_m$	$-\frac{1}{2}$	$-\frac{1}{4}$	$\alpha = -\frac{\beta+1}{2}$	$-\frac{1}{4}$	$\alpha = -\frac{\beta+1}{2}$
$\nu > \nu_m$	$-\frac{p}{2}$	$\frac{2-3p}{4} \sim -1.2$	$\alpha = \frac{3\beta+1}{2}$	$-\frac{p+6}{8} \sim -0.9$	$\alpha = \frac{\beta-3}{4}$
Jet, slow cooling					
$\nu < \nu_a$	2	0		$\frac{3(p-2)}{4(p-1)} \sim -0.8$	
$\nu_a < \nu < \nu_m$	$\frac{1}{3}$	$-\frac{1}{3}$	$\alpha = 2\beta - 1$	$\frac{8-5p}{6(p-1)} \sim 0.2$	
$\nu_m < \nu < \nu_c$	$-\frac{p-1}{2}$	$-p \sim -2.3$	$\alpha = 2\beta - 1$	$-\frac{p+6}{4} \sim -1.9$	$\alpha = \frac{2\beta-7}{4}$
$\nu > \nu_c$	$-\frac{p}{2}$	$-p \sim -2.3$	$\alpha = 2\beta$	$-\frac{p+6}{4} \sim -1.9$	$\alpha = \frac{\beta-3}{2}$

Zhang & Meszaros, IJMPA A19, 2385 (2004)

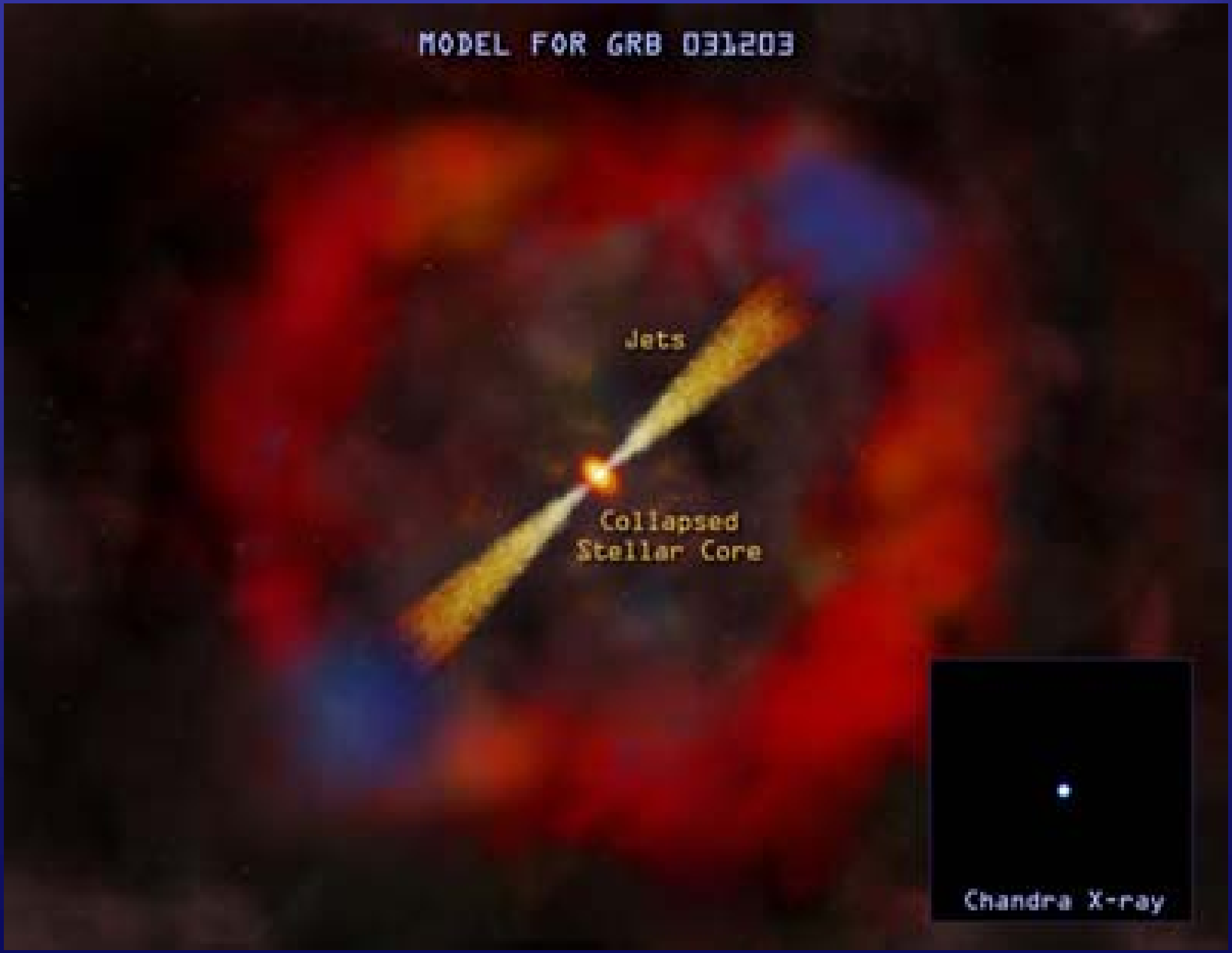


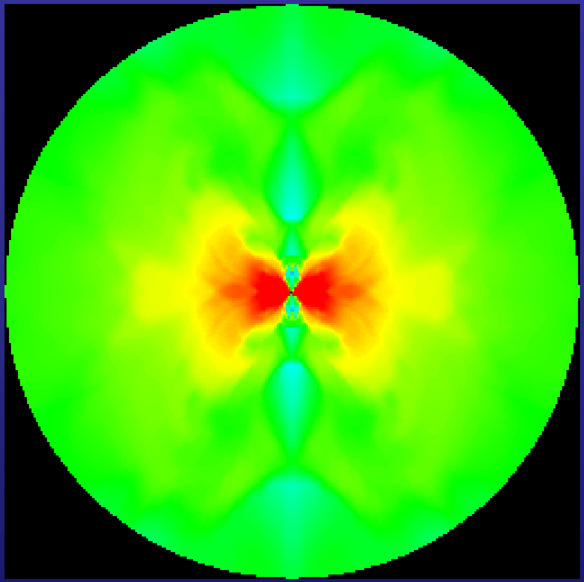
THE FORMATION of a gamma-ray burst begins either with the merger of two neutron stars or with the collapse of a massive star. Both these events create a black hole with a disk of material around it. The hole-disk, in turn, pumps out a fireball at close to the speed of light. Shock waves within this material give off radiation.

long GRBs - collapsars

hipernove

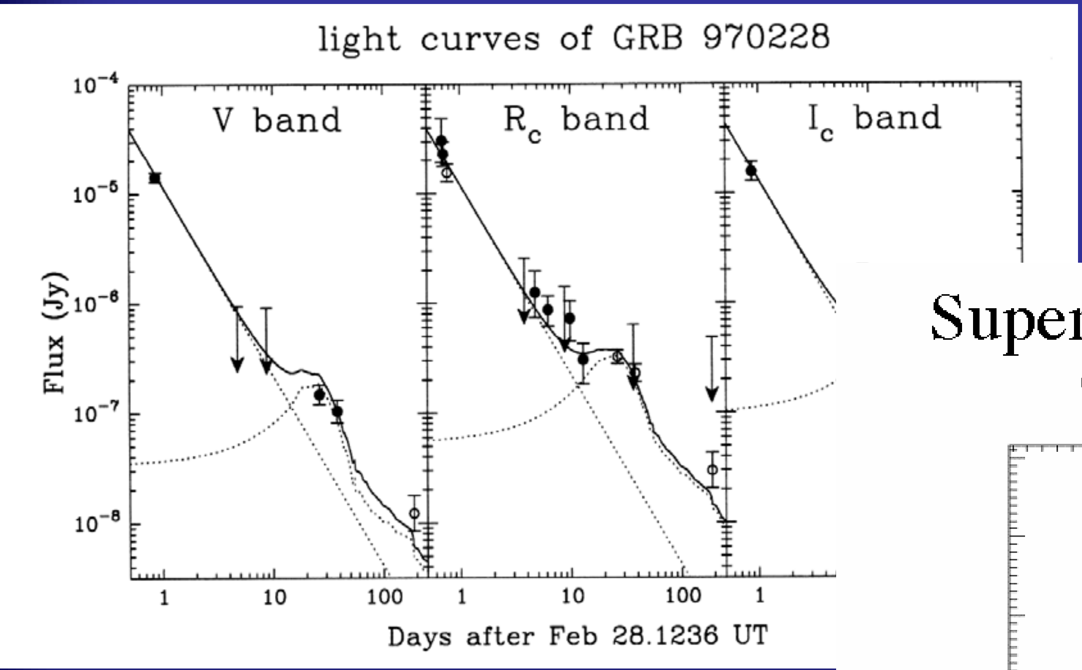
blue

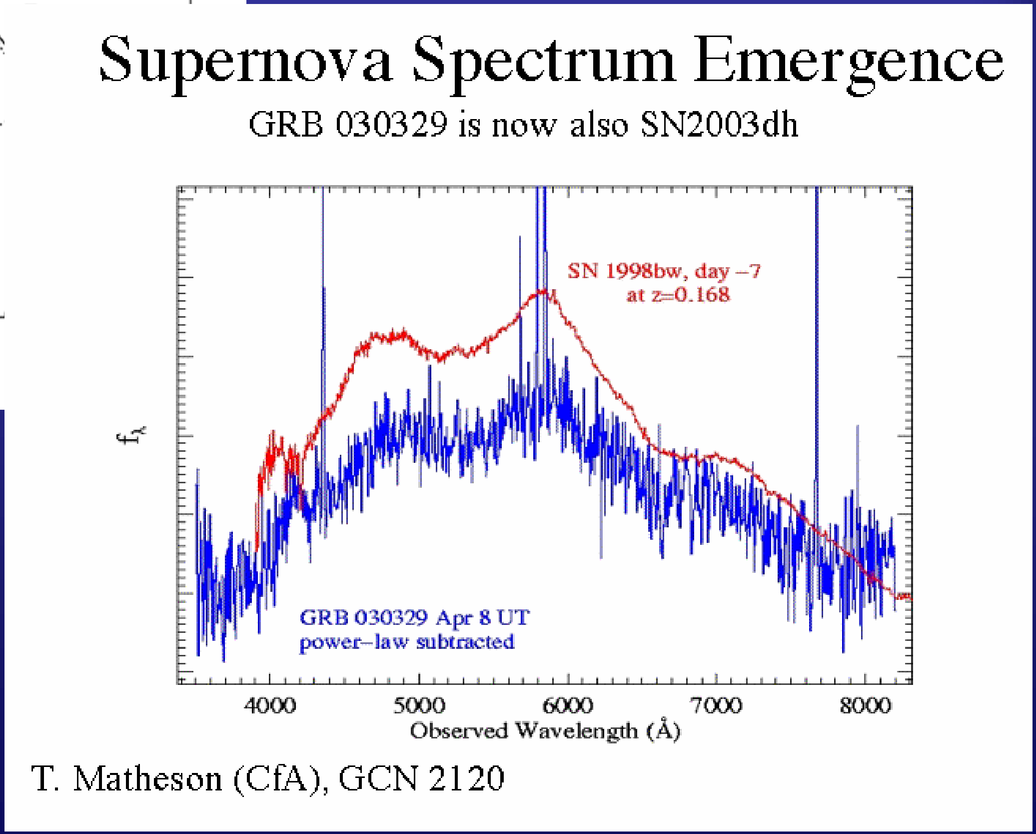




MacFadyen et al.

connection with supernovae type Ib/c



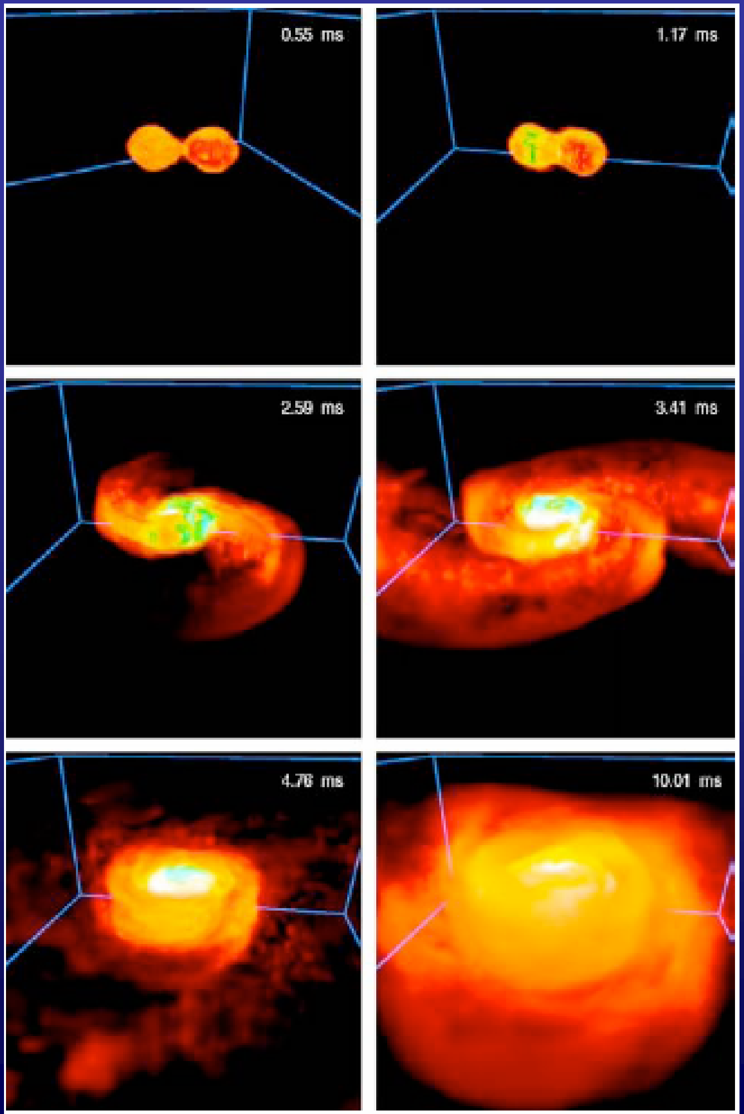


but not all!
missing supernovae ....

short GRBs - mergers?

[mergers- bh]

[mergers- ns]

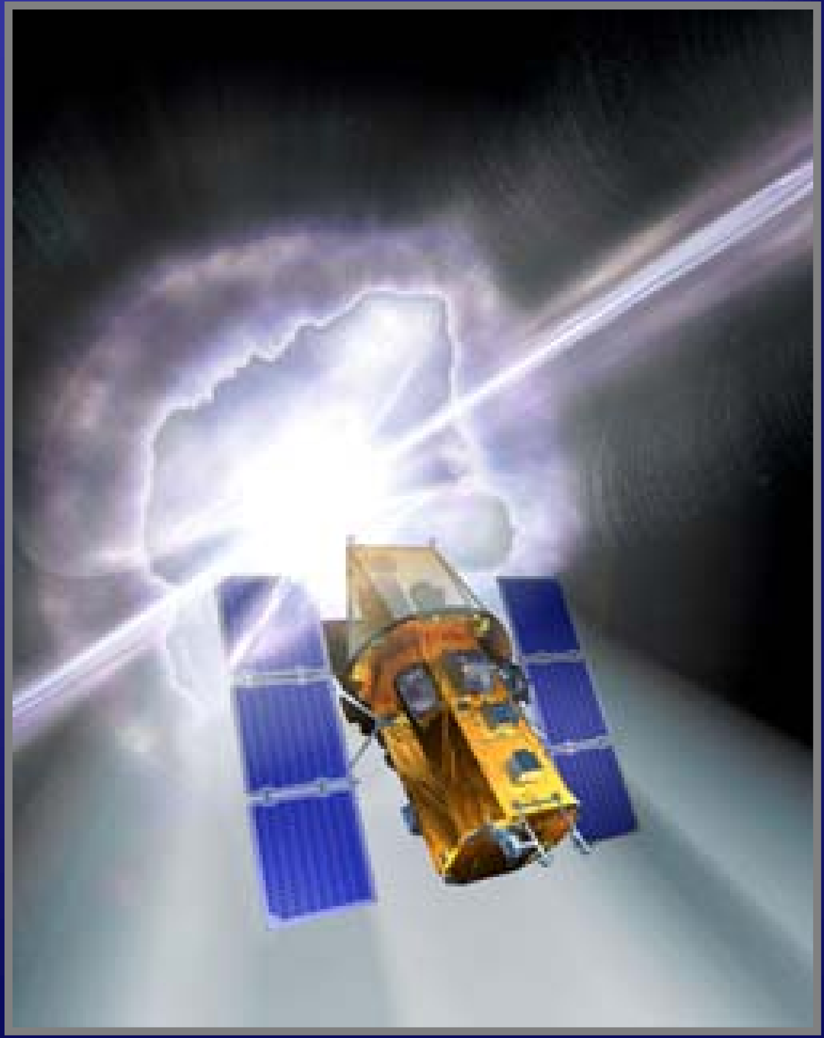


Swift !

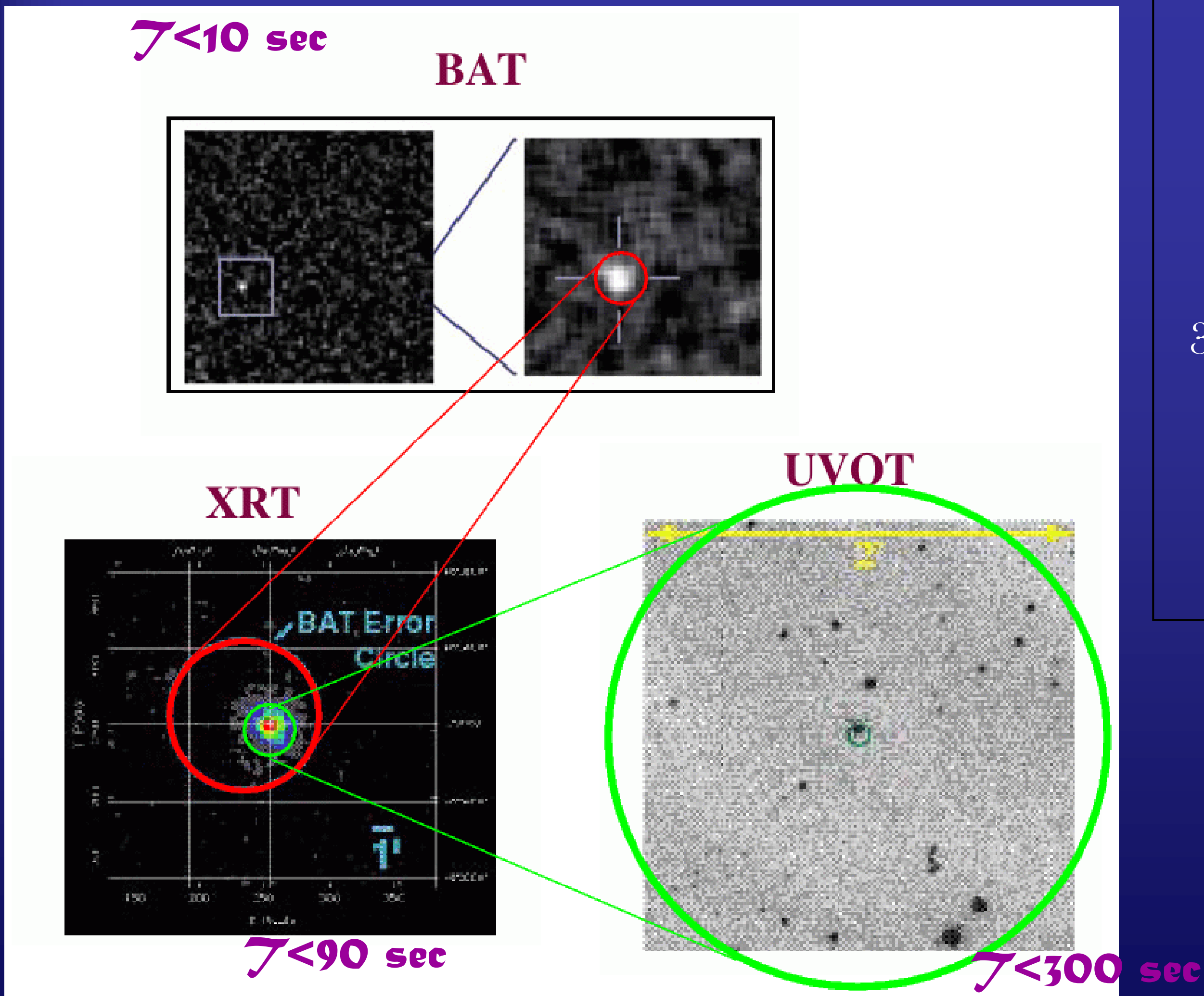
NASA
launch end of 2004,
start of science operation in 2005

detectors:
-BAT - γ
-XRT – X-rays
-UVOT – UV and optical

quick and good localizations!



Swift procedures



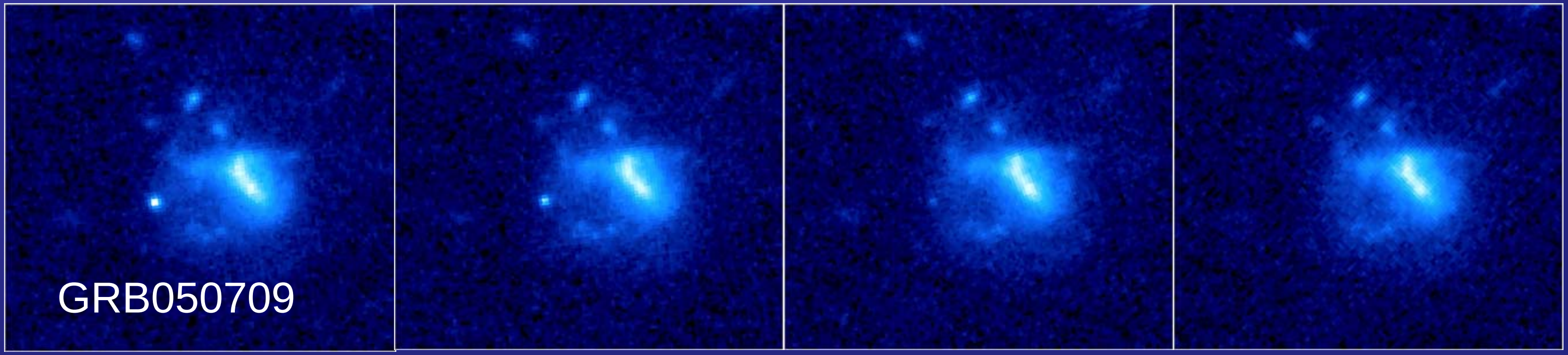
1. BAT triggers on GRB and calculates position to within 4 arcmin
2. Spacecraft autonomously slews to GRB position in 20-70 sec.
3. XRT determines position to within ~5 arcsec.
4. UVOT images field and transmit finding chart to ground

95% of triggers yield XRT detection

50% of triggers yield UVOT detection

News

- short GRBs afterglows

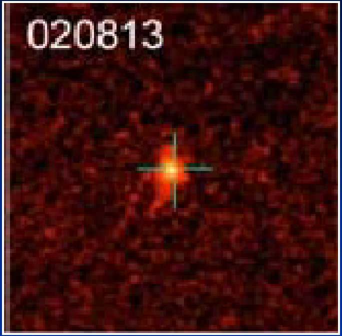


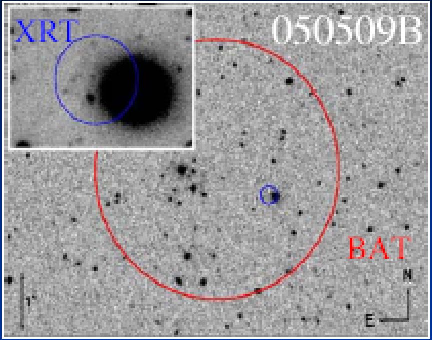
HST, 2 billion light years

also in galaxies,
lower z (<2) - selection effect?

Long GRBs | Short GRBs

SF irregulars

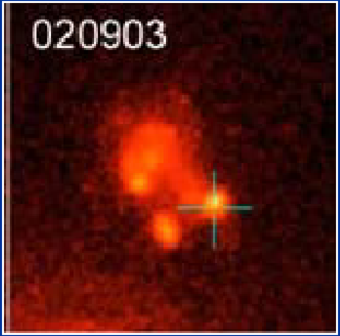


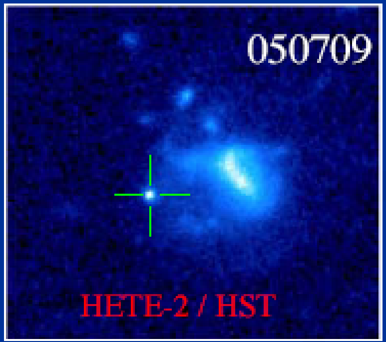


cD elliptical

SFR $< 0.2\ M_O\ yr^{-1}$

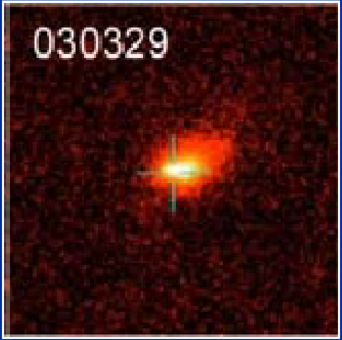
$z = 0.225$

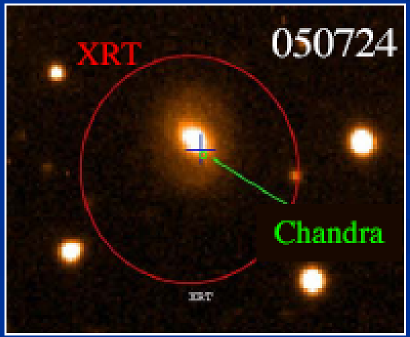




SF galaxy with offset

$z = 0.161$





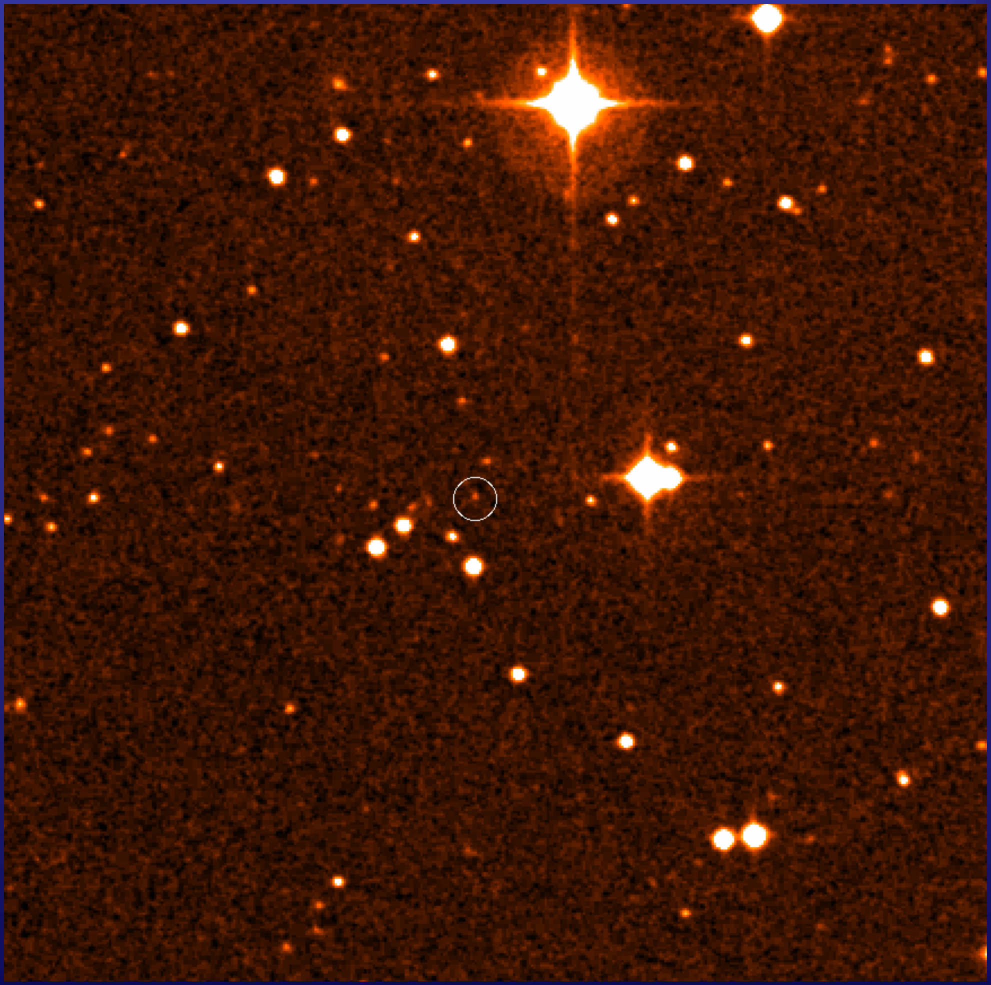
elliptical

SFR $< 0.02\ M_O\ yr^{-1}$

$z = 0.258$

Supernovae connection:

GRB 060218 and SN 2006aj (z=0.033)



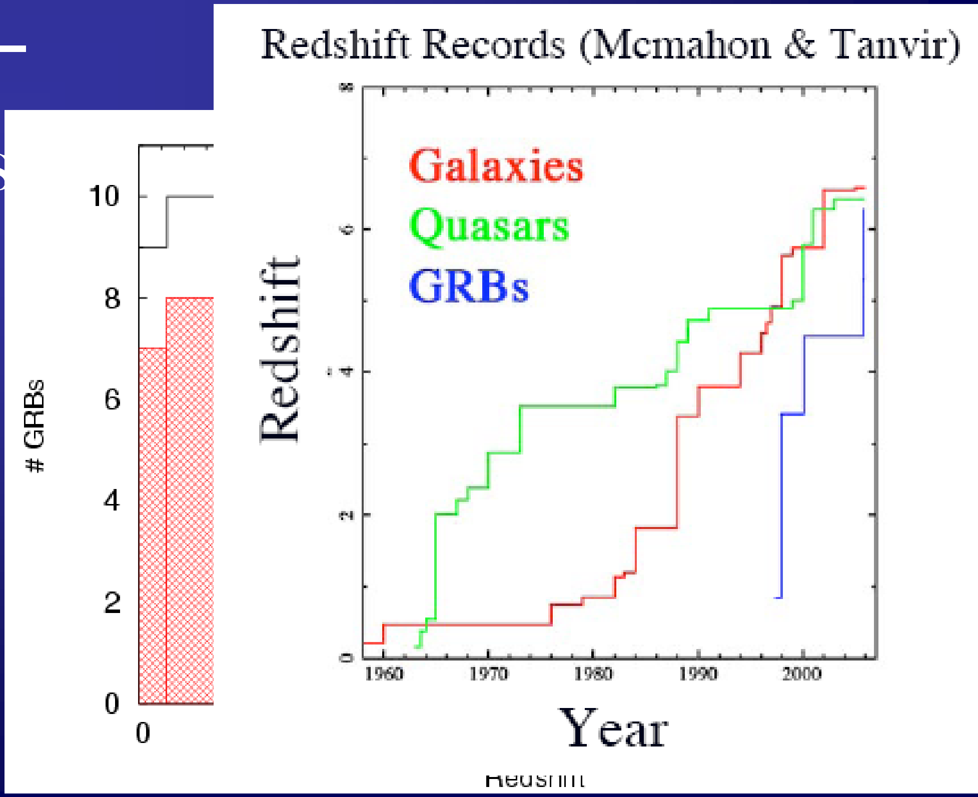
GRB 060614 and GRB 060605 – "missing" supernovae

cosmological redshift - z

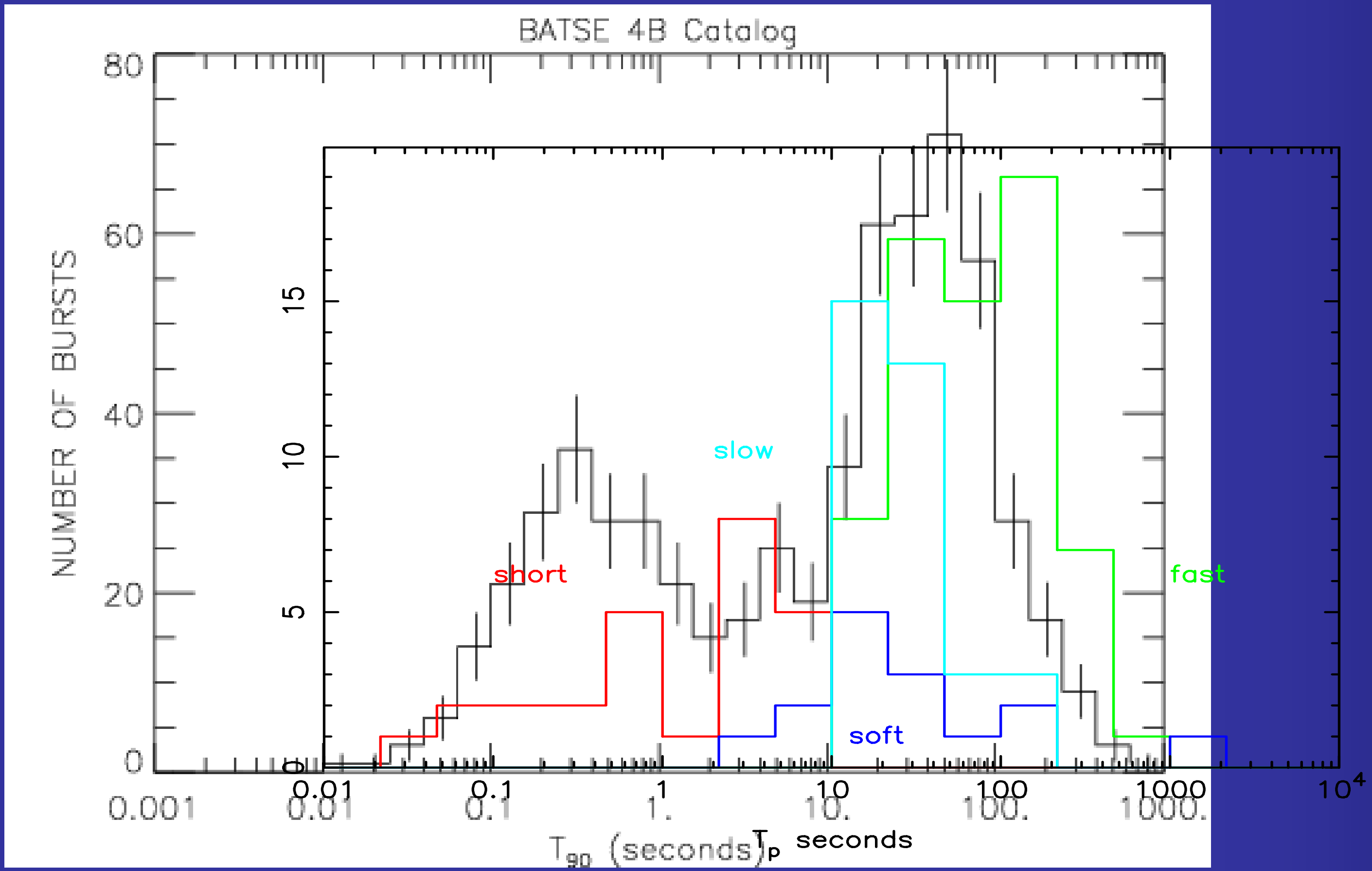
max z=6.29! GRB 050904

- cosmological probes –

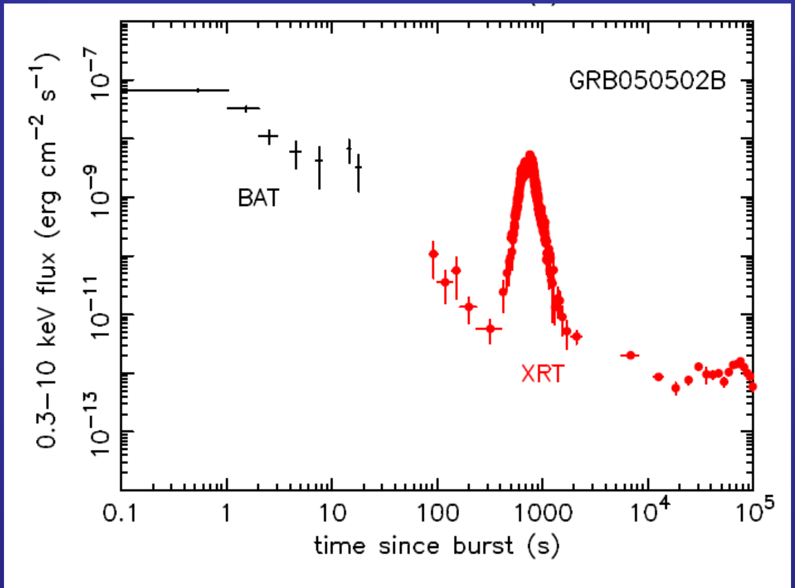
  study of early univers



at least 3 types of GRBs?

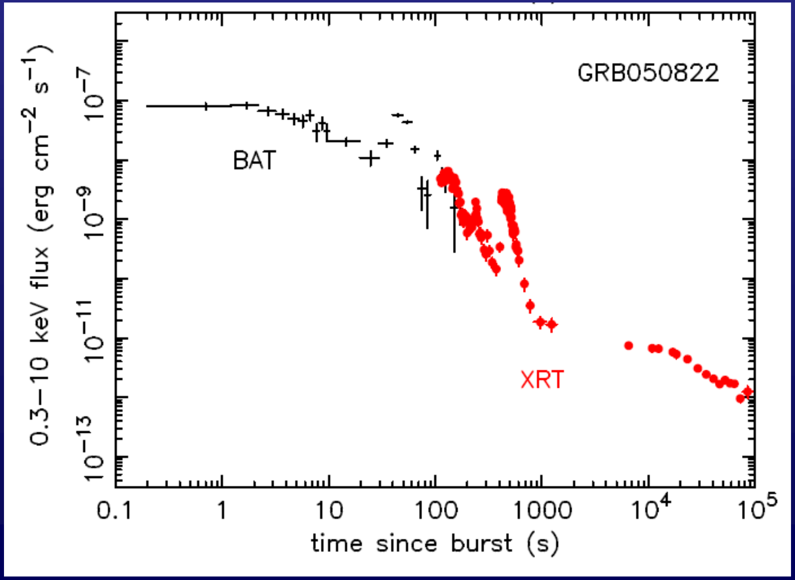


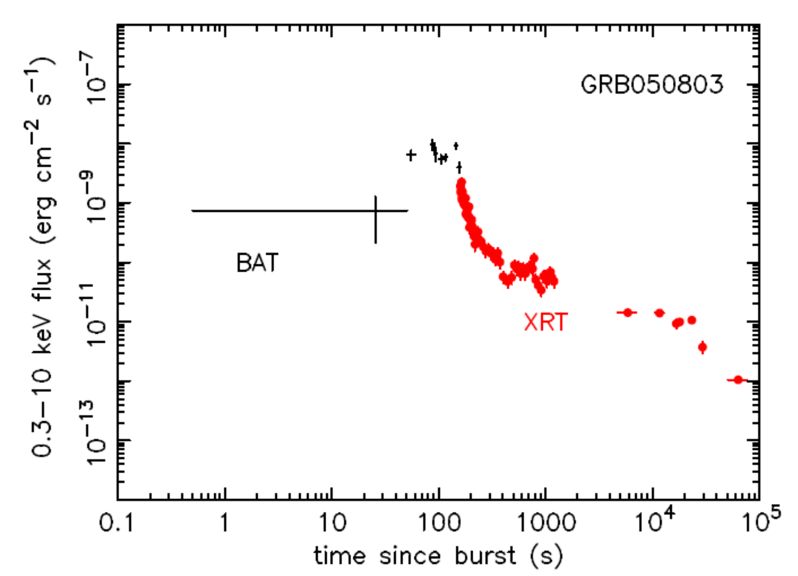
surprises in X-rays



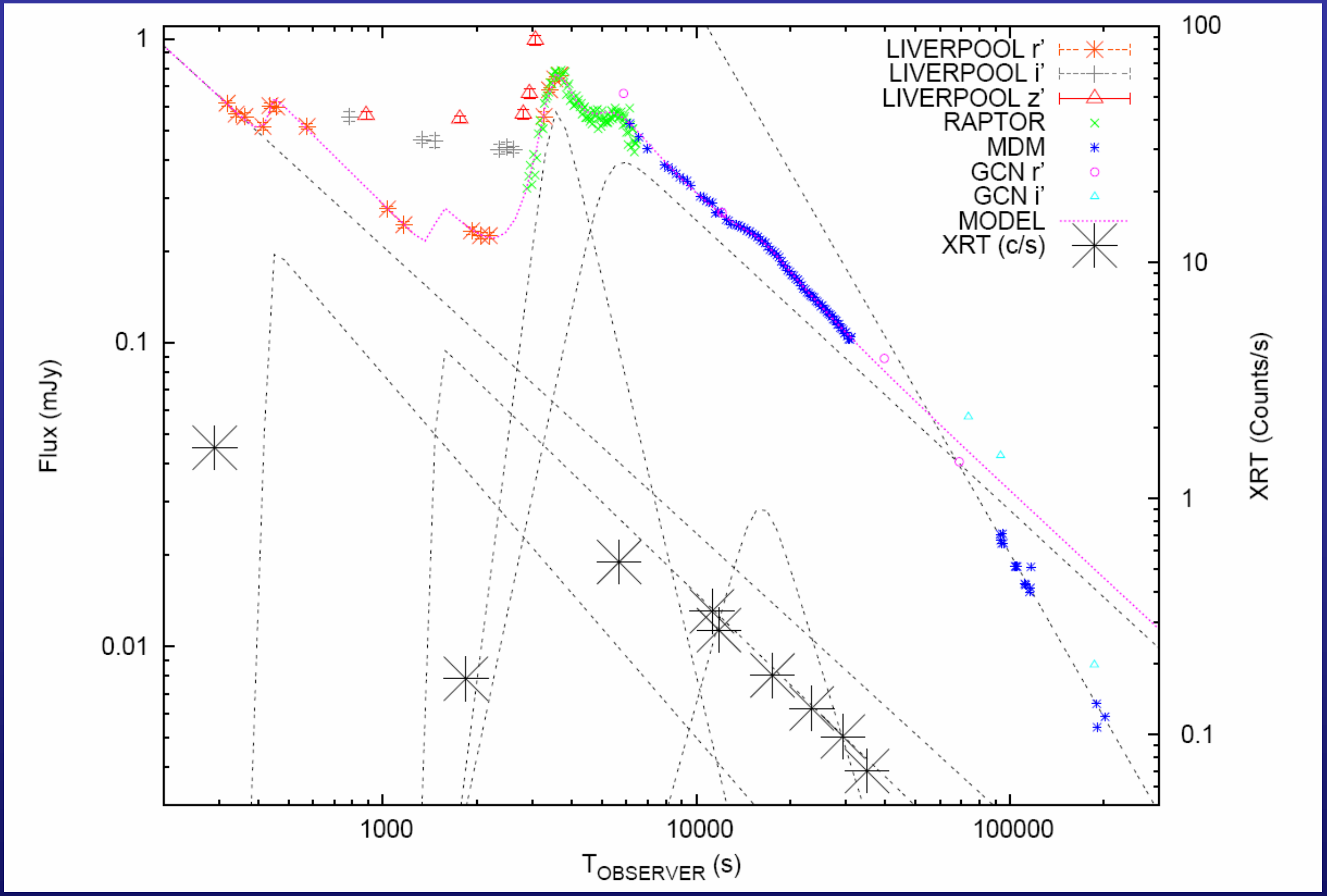
X-ray flares

steep-shallow-normal





also in optical:



- is there a connection?

Rapid optical observations!

- optical afterglows rapidly fade
- sooner, closer to progenitor
- simultaneous with γ, X-ray observations

RoboNet-1.0


Faulkes Telescope I
Liverpool Telescope
Faulkes Telescope II

RoboNet-1.0

- funded by UK PPARC
- includes members of 10 UK university teams:

  Cardiff, Exeter, Hertfordshire, Leicester, Liverpool JMU, Manchester, MSSL, QUB, St. Andrews, Southampton.

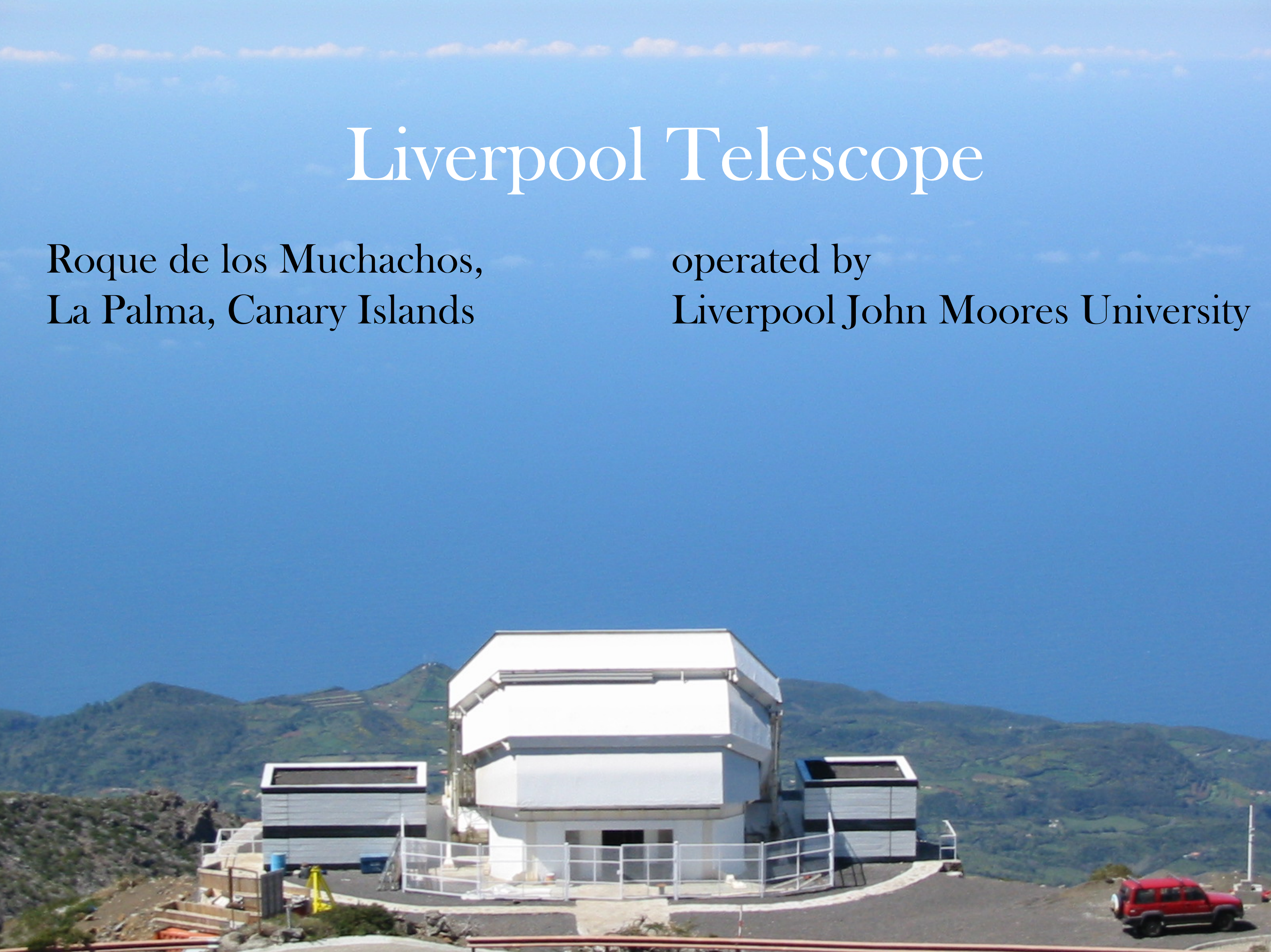
- principal technological aim:

  to integrate a global network of telescopes to act effectively as a single instrument

- scientific aims:

  - extra-solar planets
  - rapid response and optimised monitoring of GRB afterglows

  - increased sky and time coverage


Liverpool Telescope
Roque de los Muchachos,
La Palma, Canary Islands
operated by
Liverpool John Moores University

FTN & FTS

Faulkes Telescope North
Maui, Hawaii

Faulkes Telescope South
Siding Spring, Australia

primary use for UK schools - some time available to research community

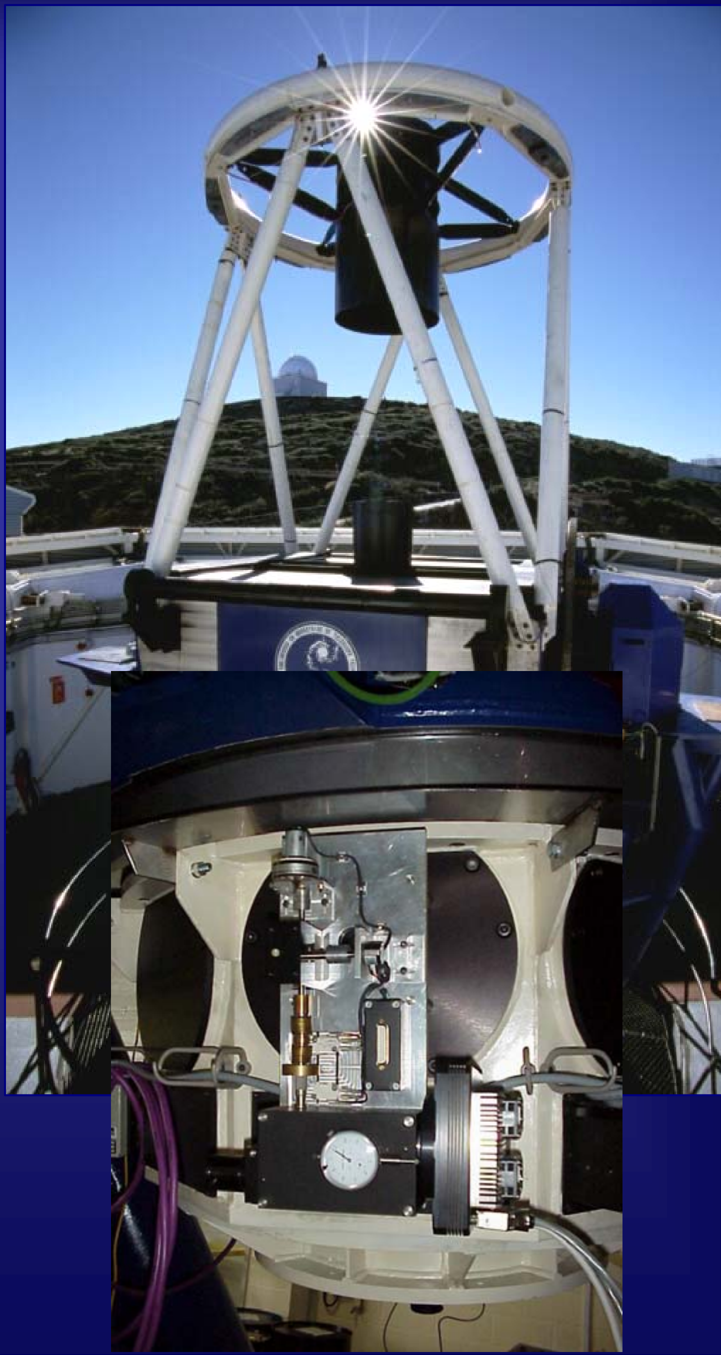
fully opening enclosure

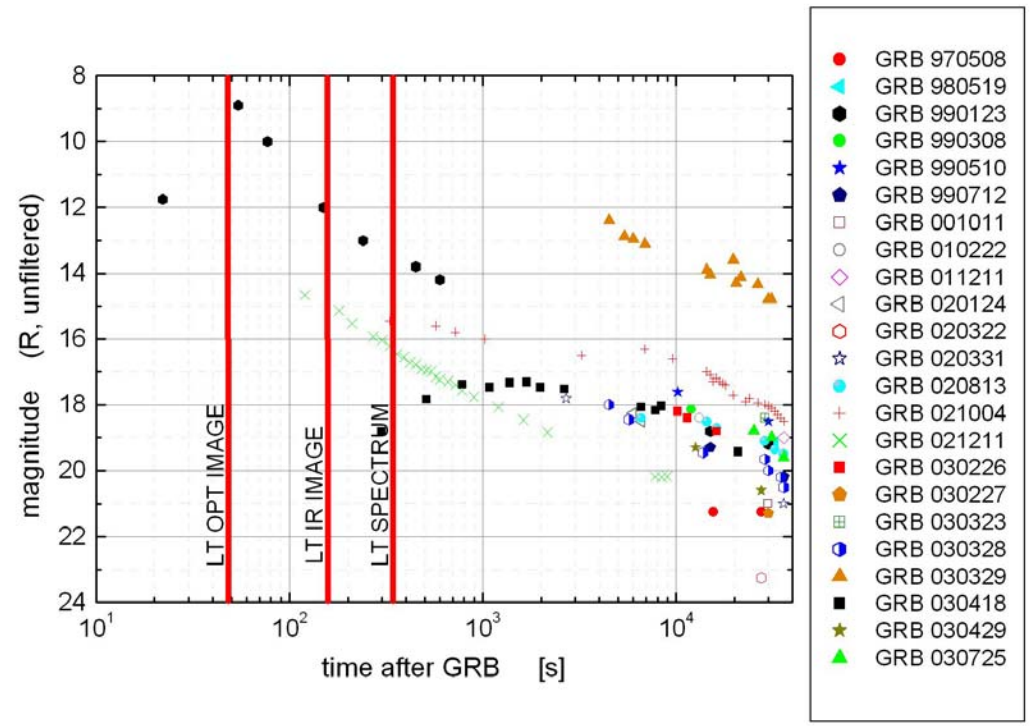
observations starting in 2-5 min after the GRB trigger time

Instrumentation

LT & FTN & FTS:
- optical CCD (with 8 filters),
- low-resolution spectrographs,

In addition LT has:
- IR camera and
- RINGO polarimeter (2006)





- robotic operation enables rapid follow-up (2-5 min)
- range of filters – multi-colour light curves
- range of instruments: early SED, IR (dust obscured, high z), early spectrometry, polarimetry
- 2-m aperture allows deep observations (faint optical afterglows)

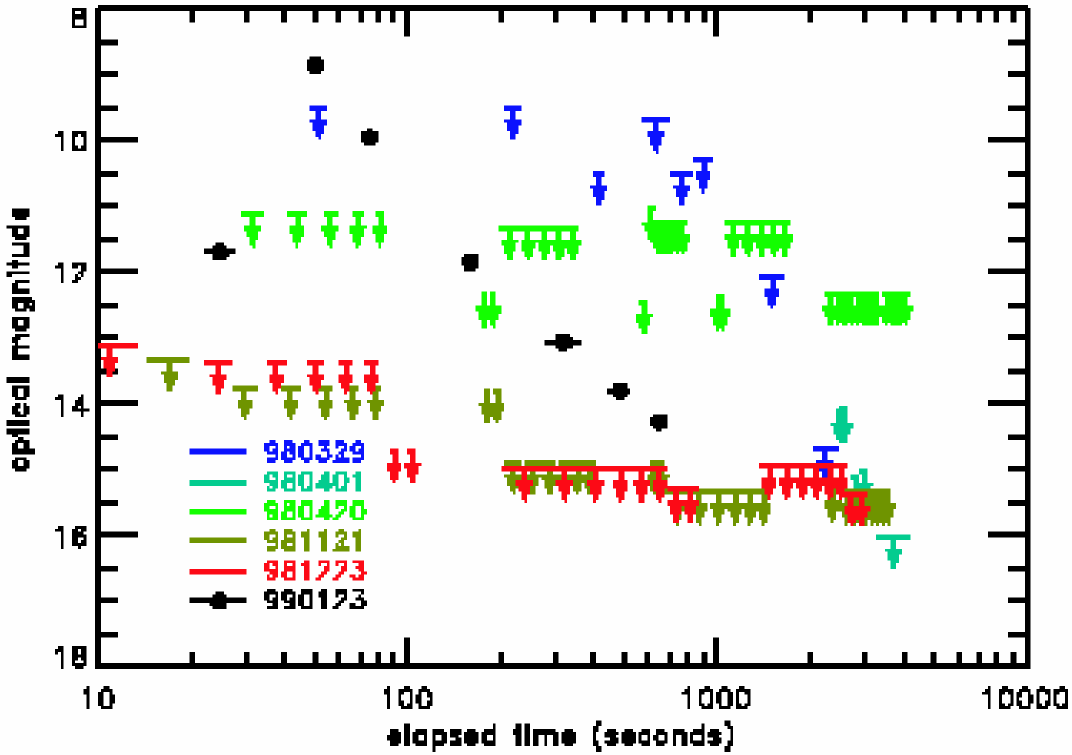


FIG. 1.—The m_{ROTSE} limiting magnitudes vs. time after gamma-ray onset. GRB 990123 optical burst detections are shown for comparison.

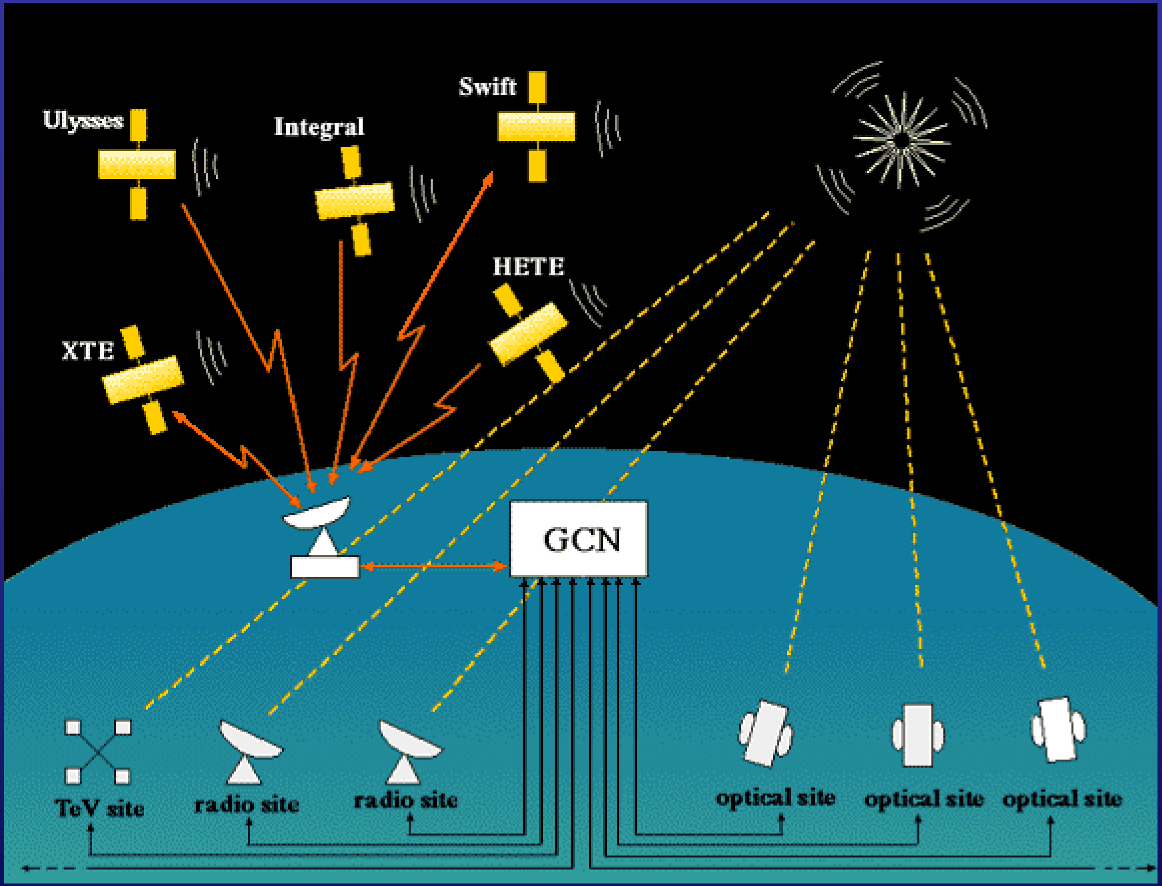
Akerlof et al. 2000

GCN

Gamma ray bursts Coordinates Network

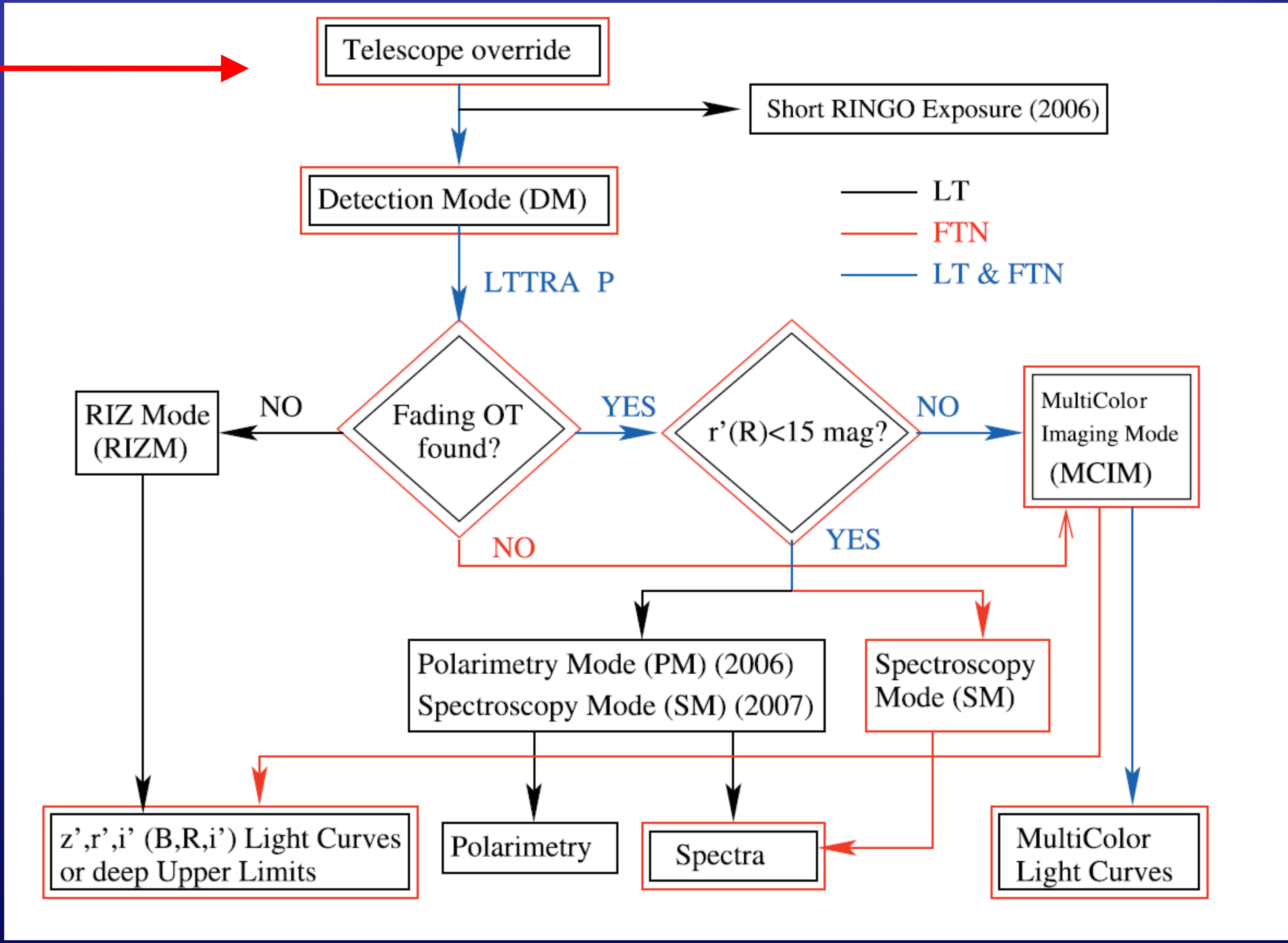
http://gcn.gsfc.nasa.gov/

alert goes to socket
and e-mail/ SMS



GRB observing strategy

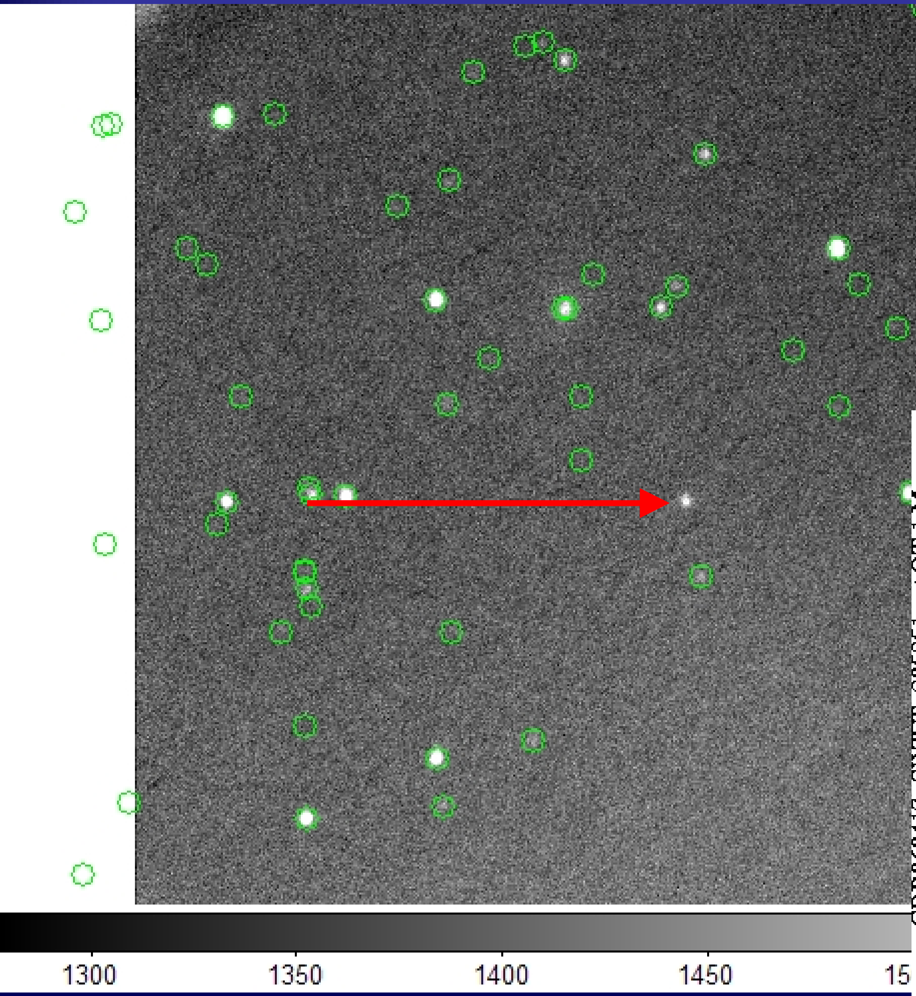
GCN



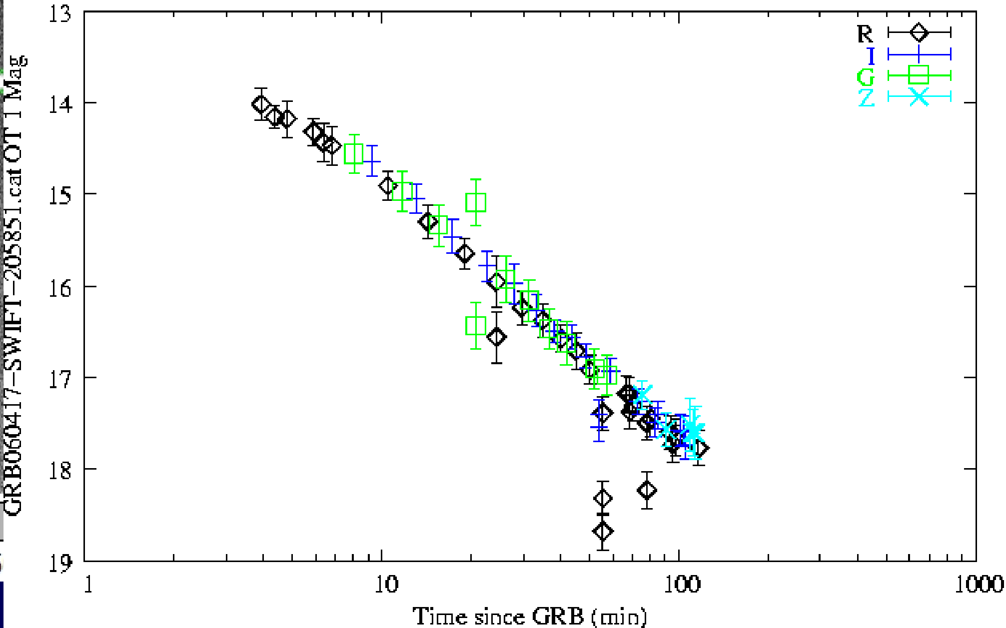
Guidorzi et al, PASP, 2006

LT TRAP

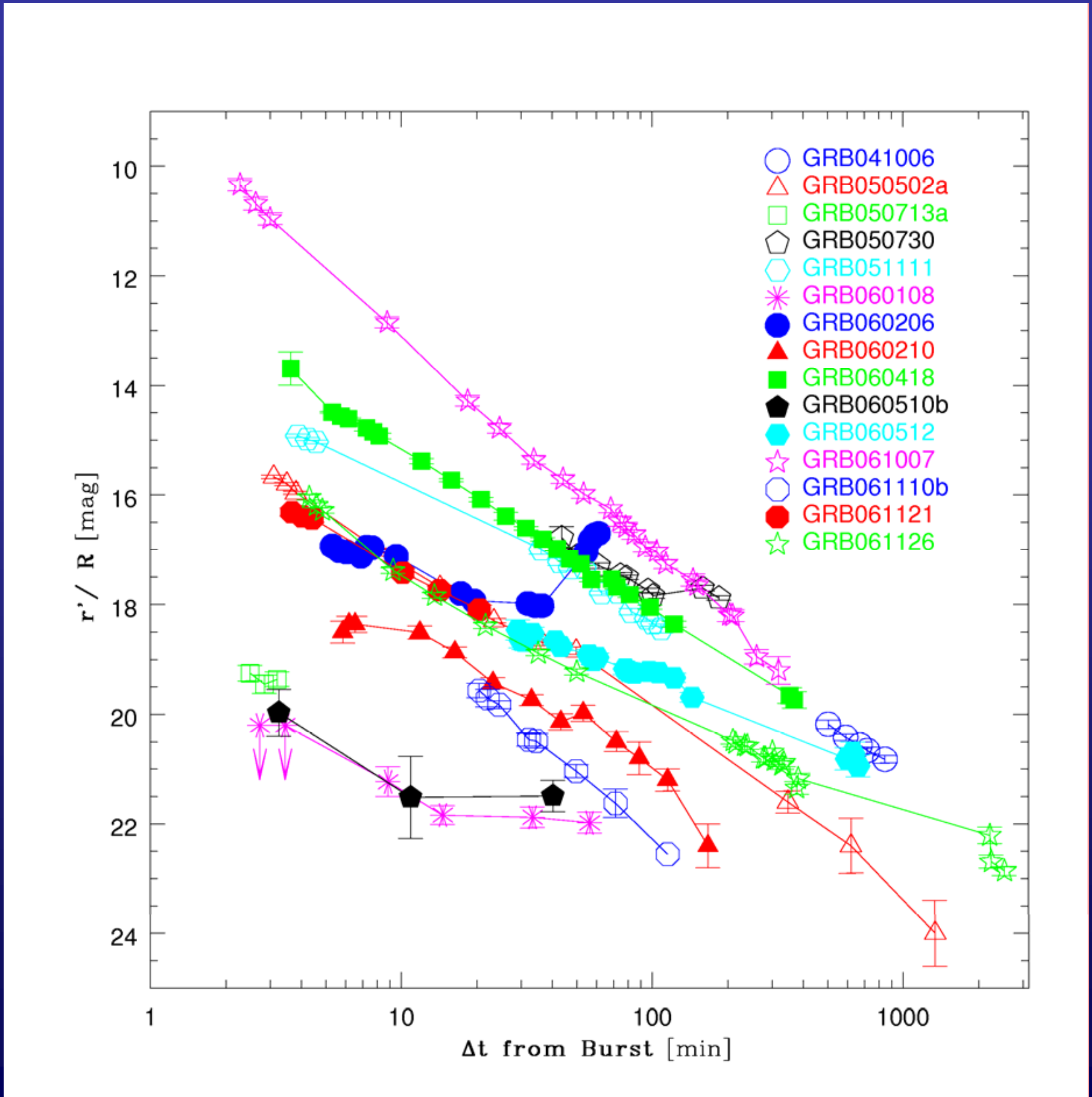
Liverpool Telescope Transient Rapid Analysis Pipeline



light curve created and updated in real-time by LT TRAP for each OT candidate



Optical afterglows by LT, FTN and FTS

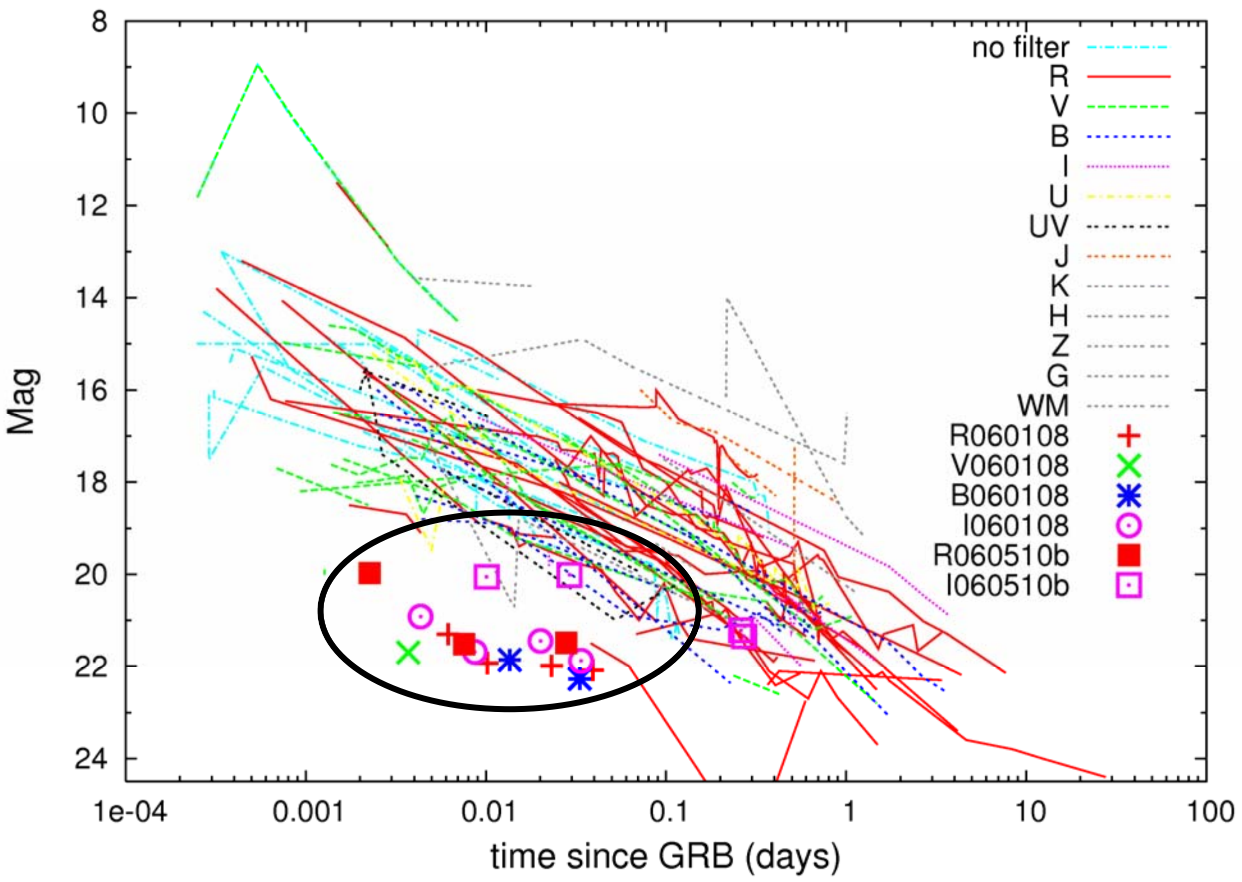


until Sep 07:

- 63 GRBs,
- 24 detections,
- 39 “deep upper limits”,
- ~65 GCN circulars
- ~20 refereed papers

Gomboc et al. 2006

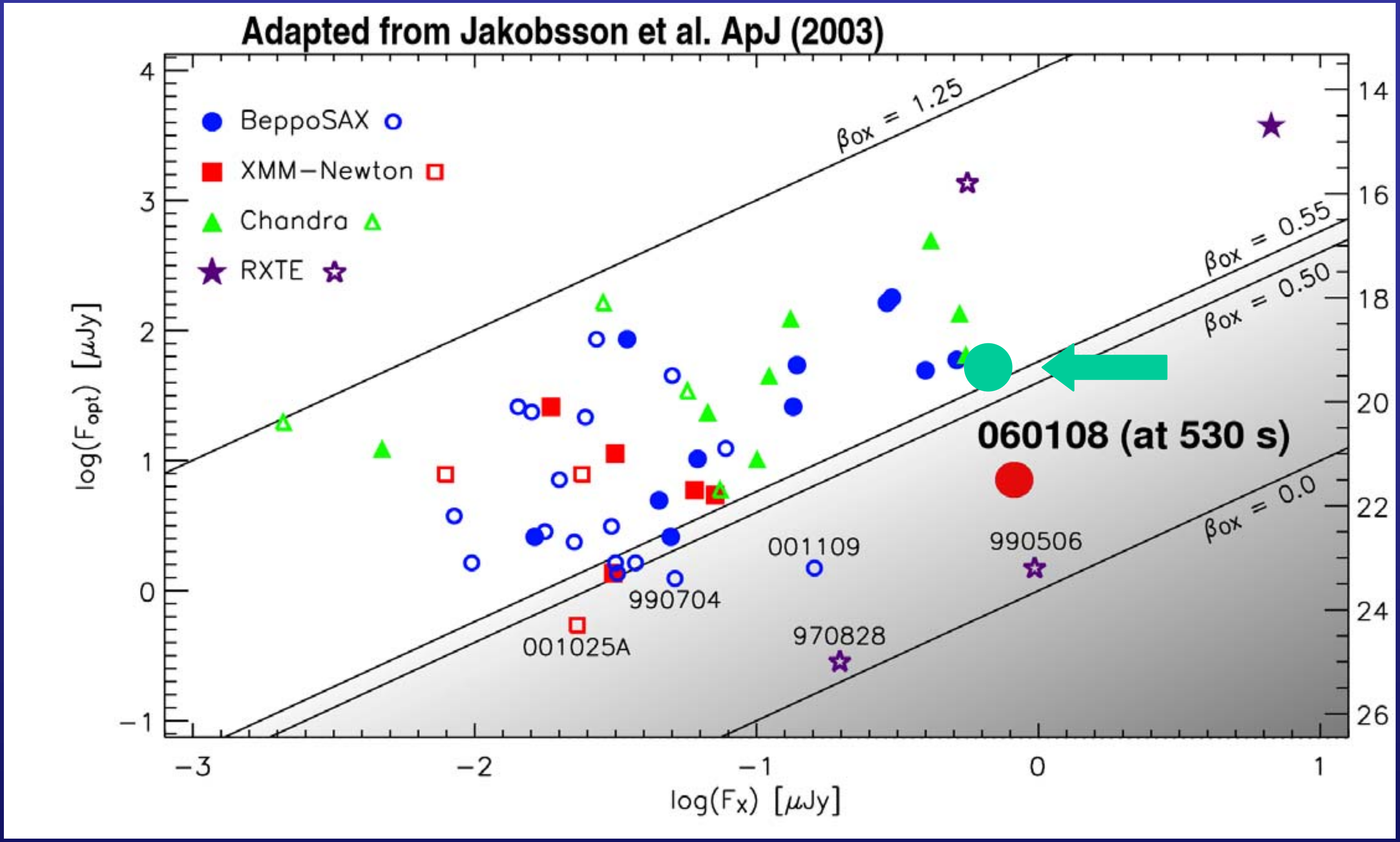
GRB 060108 & GRB 060510b



Swift No. 100:
GRB 060108:
phot. z<3.2
(Oates et al. 2006)

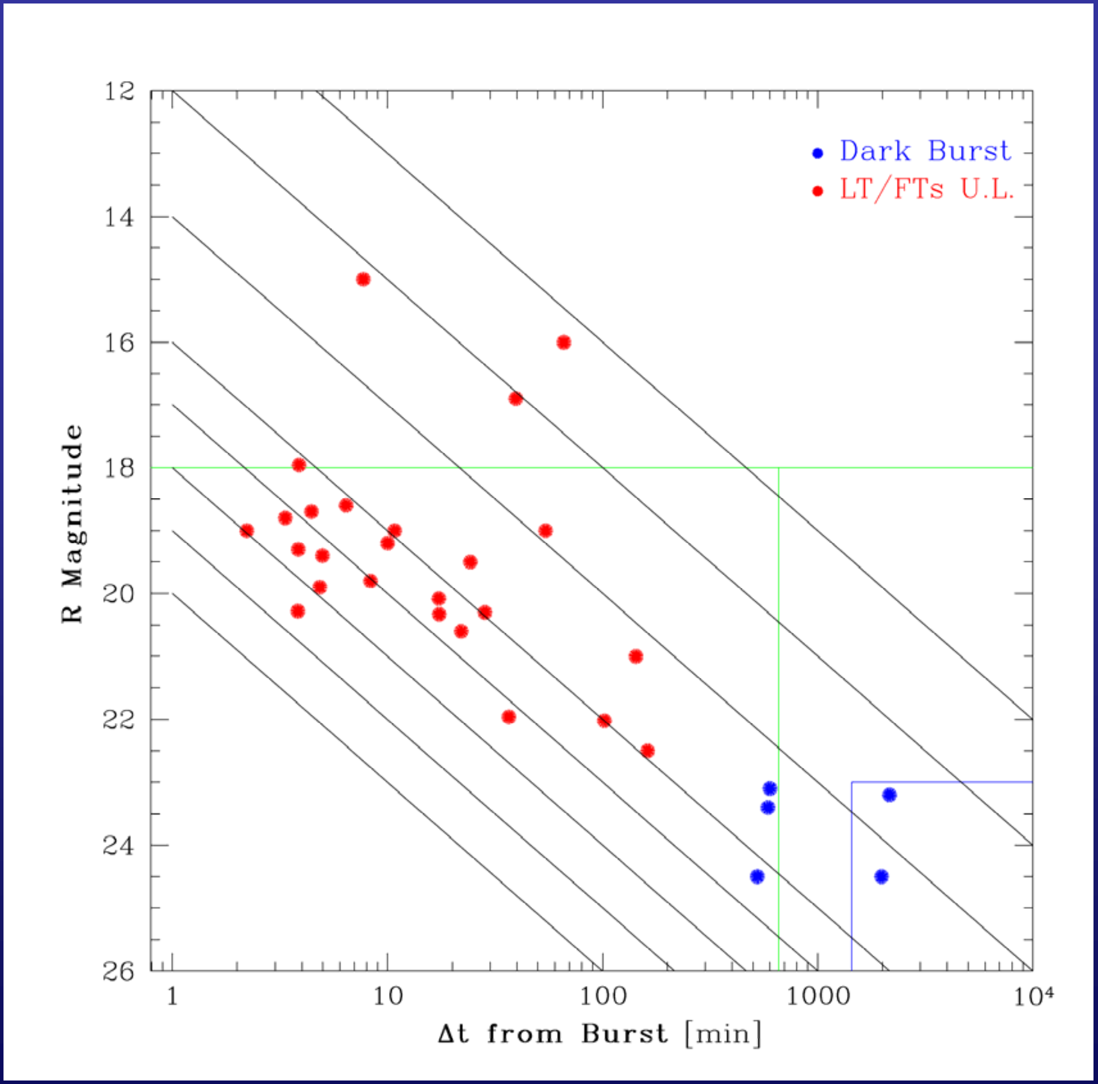
GRB 060510b:
z=4.9
(Price 2006)

Dark GRBs



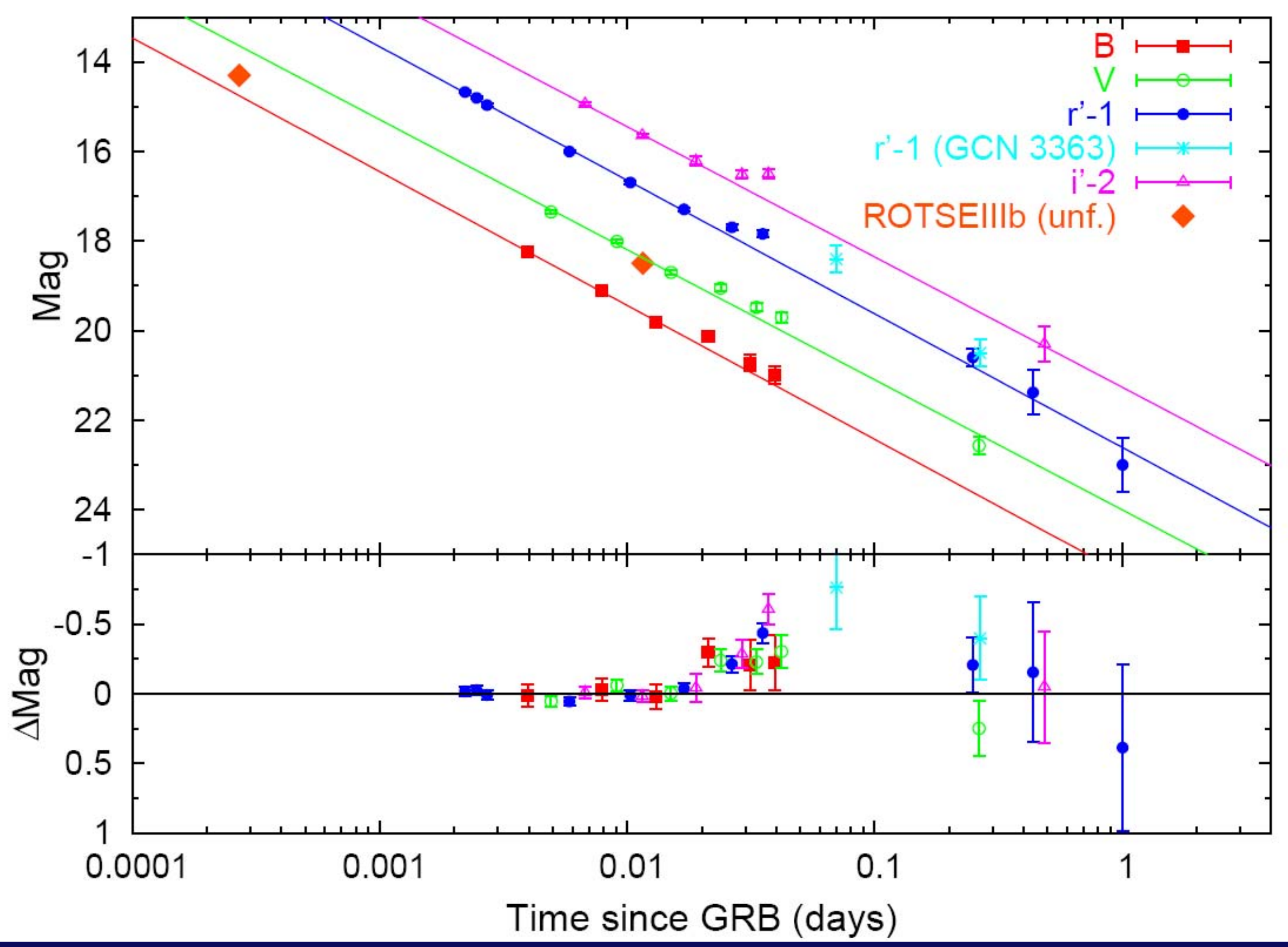
Adapted from Jakobsson et al. ApJ (2003)
BeppoSAX
XMM−Newton
Chandra
RXTE
βox = 1.25
βox = 0.55
βox = 0.50
βox = 0.0
060108 (at 530 s)
001109
990506
990704
970828
001025A
log(F_opt) [μJy]
log(F_X) [μJy]

... and upper limits



Melandri et al, in preparation

GRB 050502a



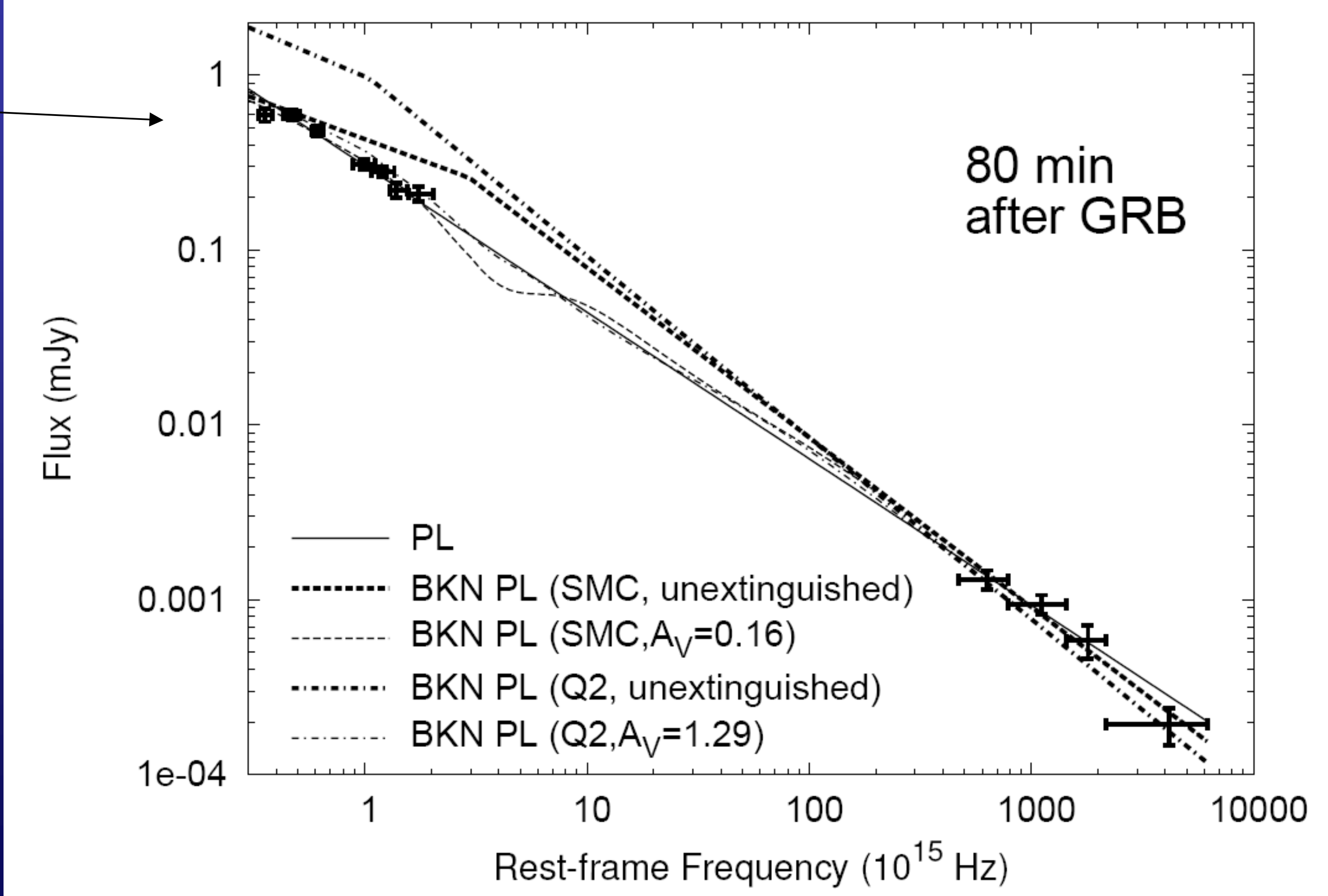
1st multi-colour light curve at t < 1hr

- bump due to density enhancement seems little more favoured than energy injection
- no strong evidence for cromatic bump

Guidorzi et al, ApJL, 2005

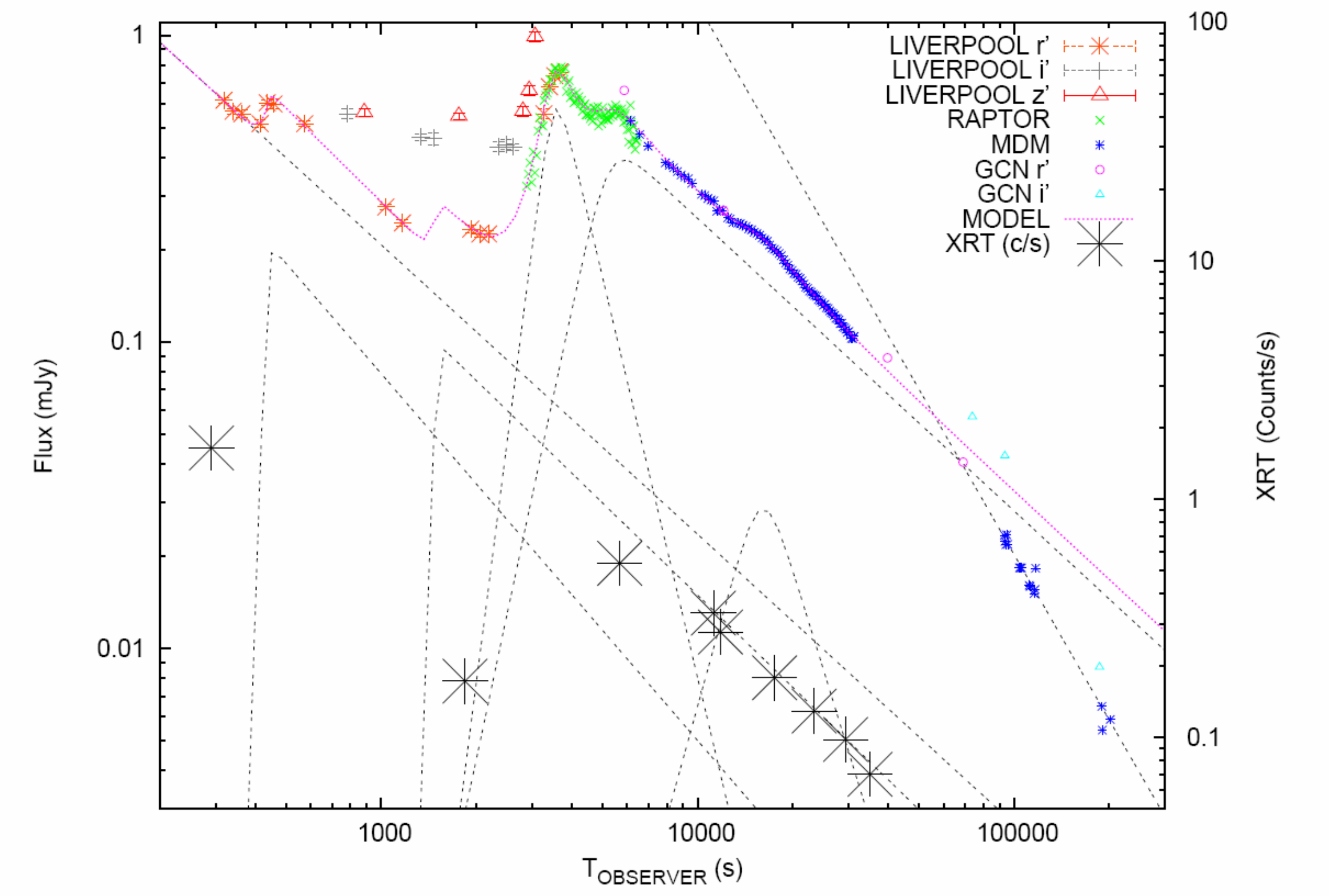
GRB 051111 – cont.

IR from Bloom et al. 2005



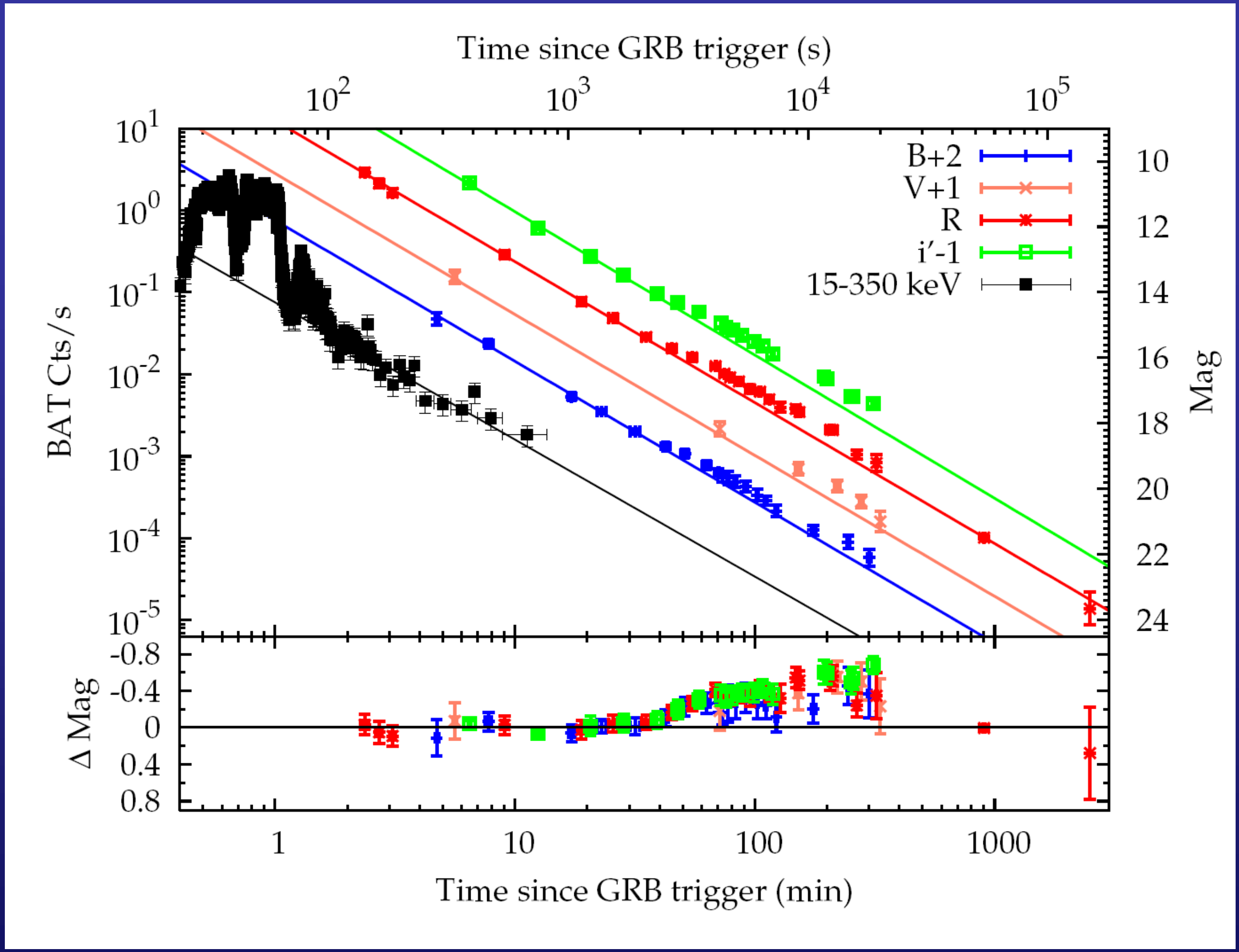
low ext., α, molecul., big grains dust, grey ext. profile

GRB 060206



Monfardini et al, ApJ, 2006 active engine, late energy injection, break not due to jet

GRB 061007



z=1.261, forward shock, no optical flash, no jet-break to 10^5 s

Mundell et al. ApJ 2007

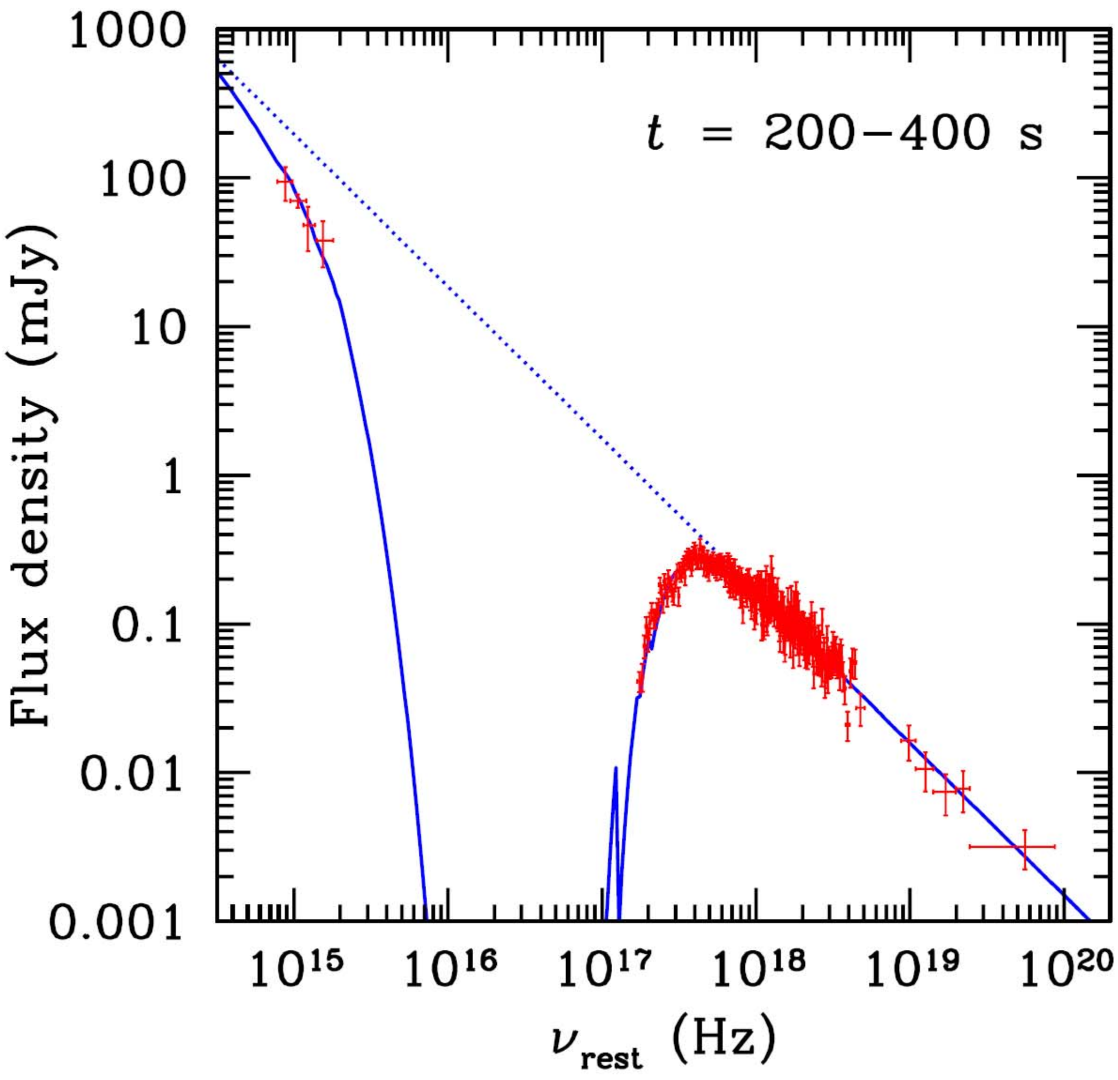
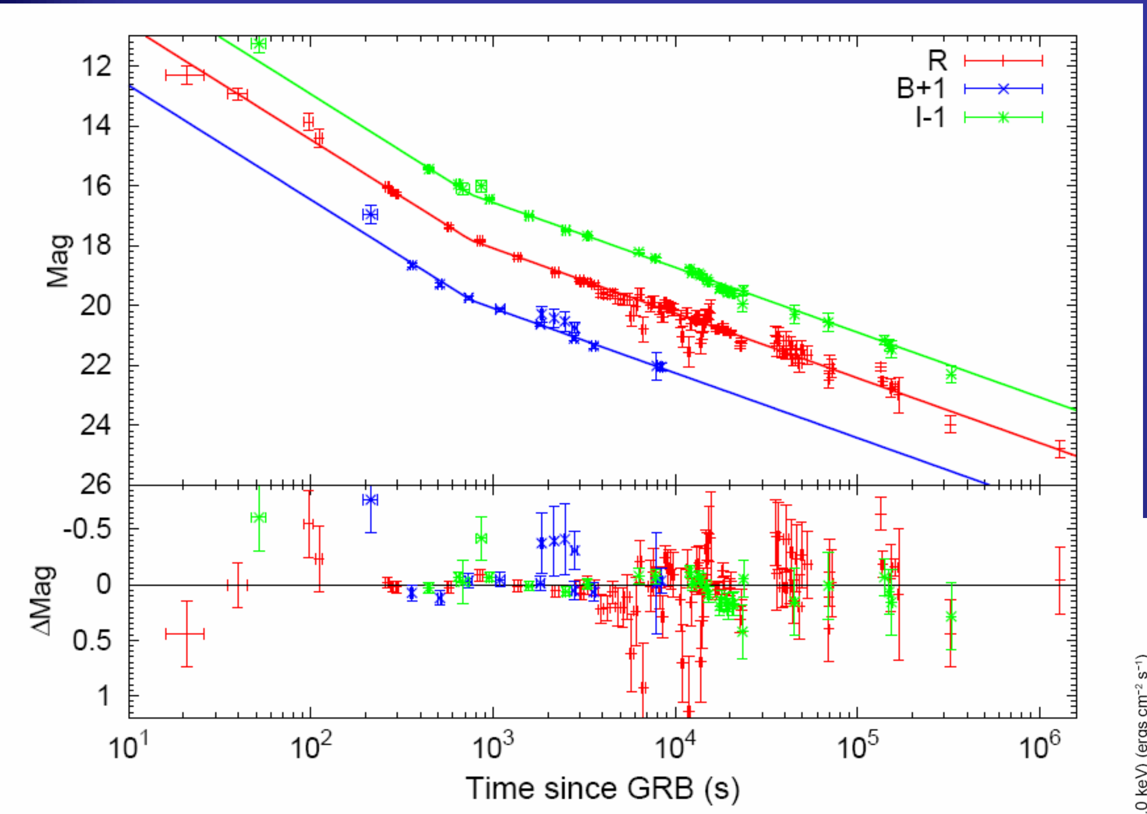


Fig. 2.— Broad-band optical to γ-ray spectral energy distribution derived for the time interval $200 < t_{obs} < 400$ s, fitted with an absorbed power law with β(opt-X-γ) $= 1.02 \pm 0.05$ and rest frame extinction A_V(SMC)$=0.48 \pm 0.19$ mag (solid line). The unabsorbed power law is also shown (dotted line).

Mundell et al., ApJ 2007

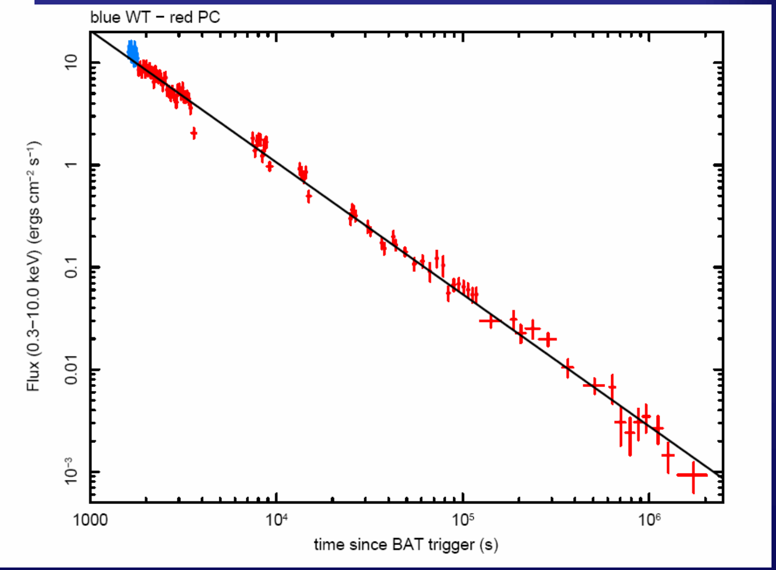
GRB 061126



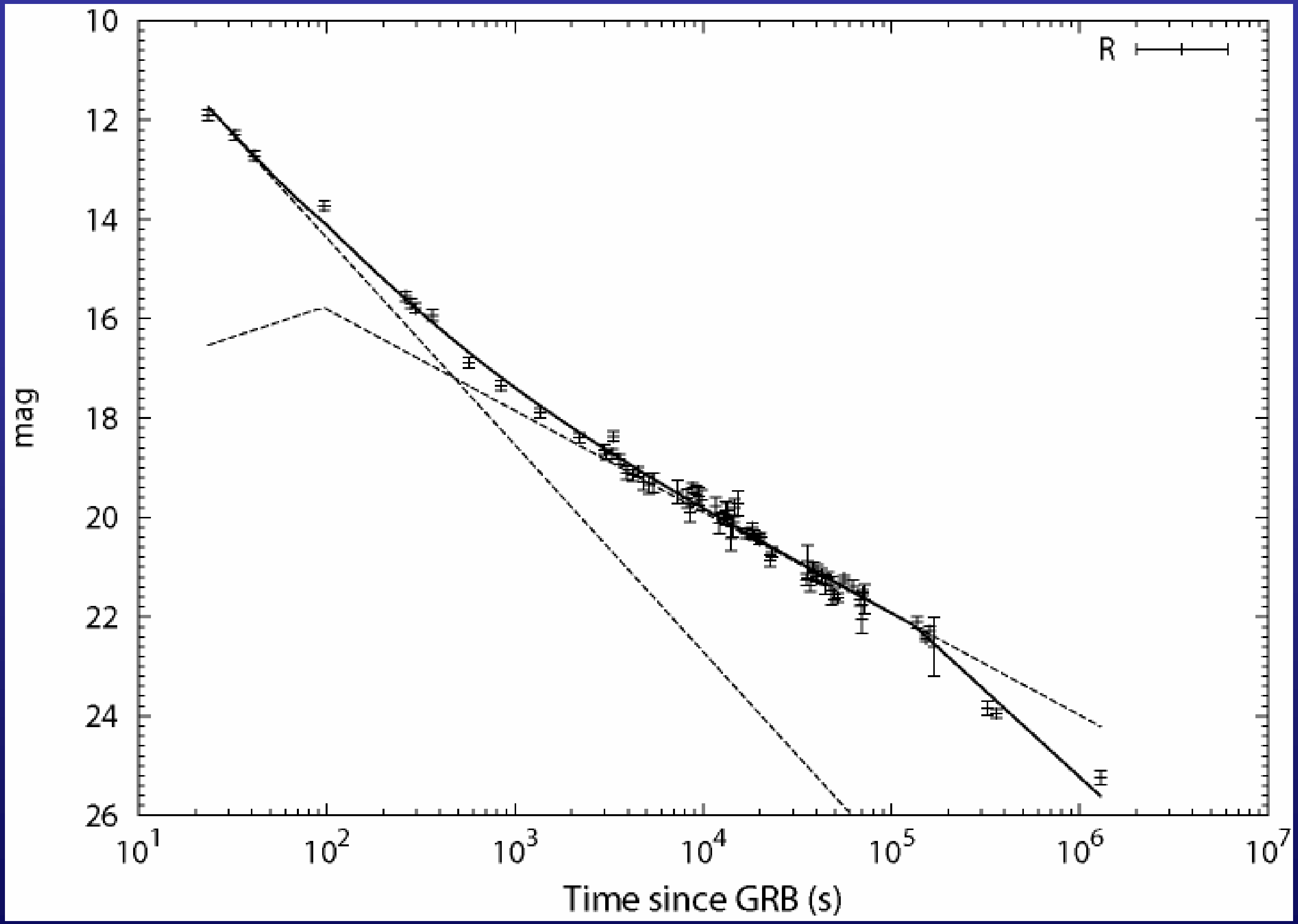
Gomboc et al, in preparation

α_1=1.5, α_2=0.8, t=700 s, jet break @ 1.3x10^5 s

α_X=1.29



GRB 061126: reverse + forward shock



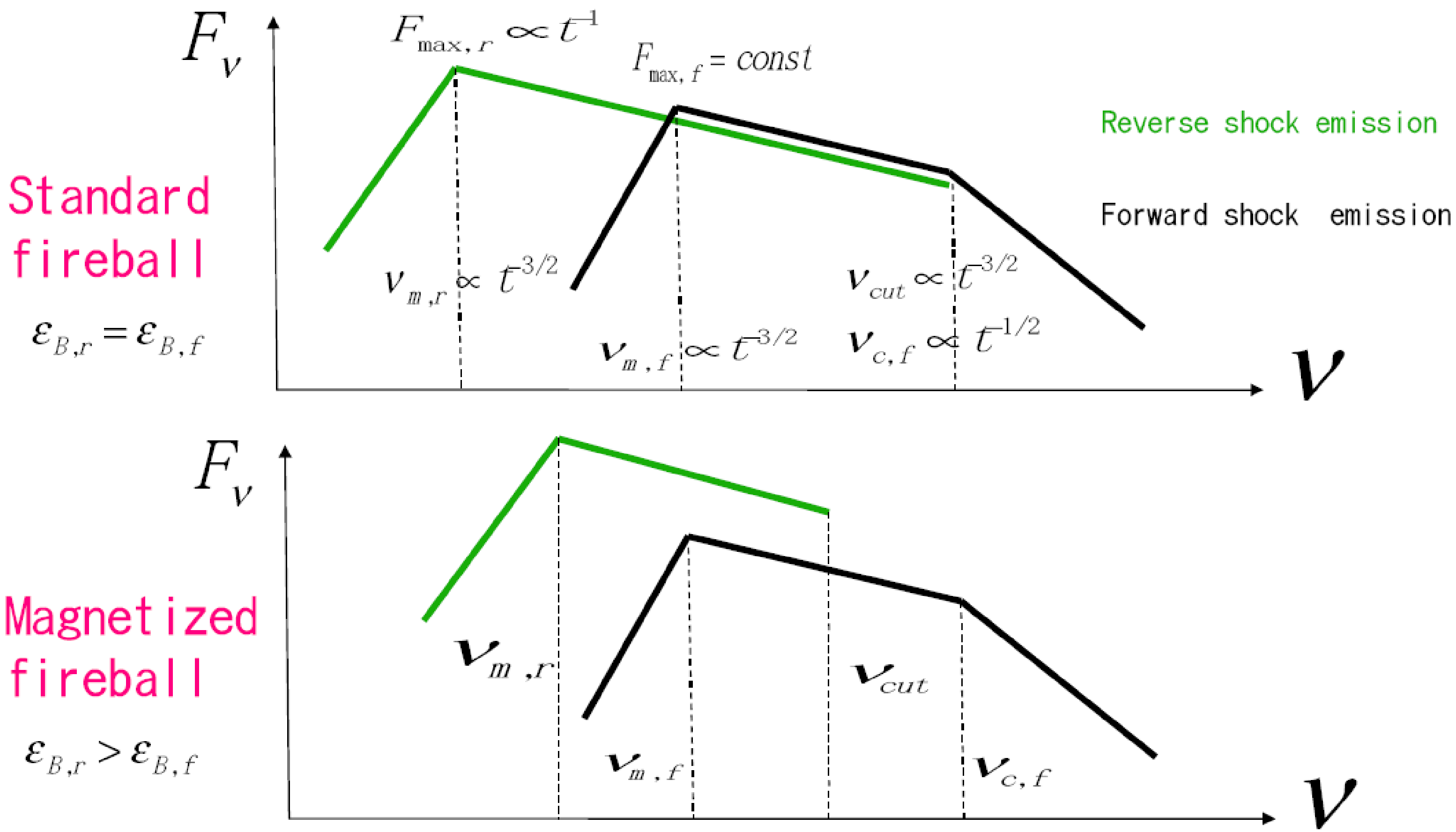
magnetization?

Spectrum right after reverse shock crossing

$$\frac{\nu_{m,r}}{\nu_{m,f}} \approx \Gamma^{-2} R_B^{1/2}, \quad \frac{\nu_{c,r}}{\nu_{c,f}} \approx R_B^{-3/2}, \quad \frac{F_{\max,r}}{F_{\max,f}} \approx \Gamma R_B^{1/2} \quad : \mathrm{R_B} = \frac{\varepsilon_{B,r}}{\varepsilon_{B,f}}$$

The two components have comparable nuFnu peak (emitting comparable energy)

$$\nu F_\nu \text{ at} \max(\nu_c, \nu_m) \approx (\nu_m \nu_c)^{1/2} F_{\max} \quad \text{for } p \approx 2$$



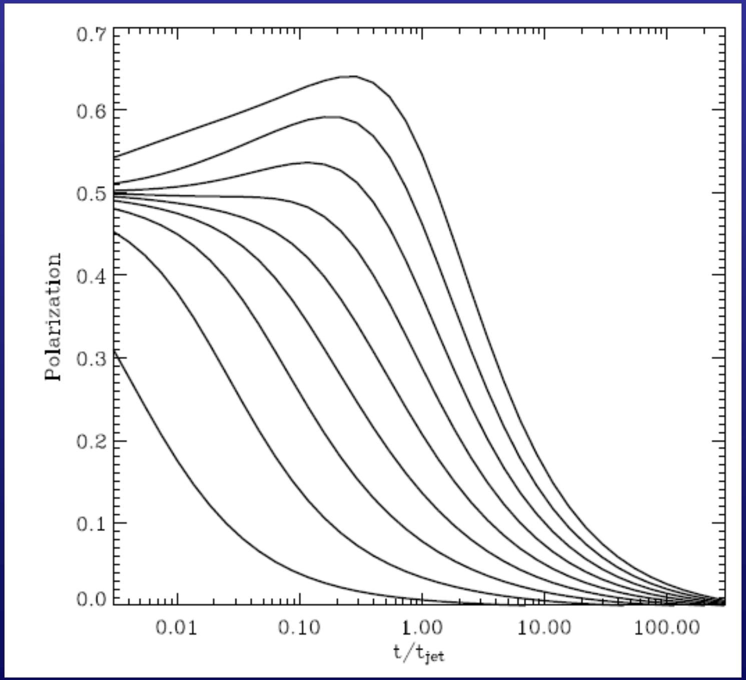
Kobayashi

role of magnetic field=?

- hydrodynamical jet – low polarization of early afterglow

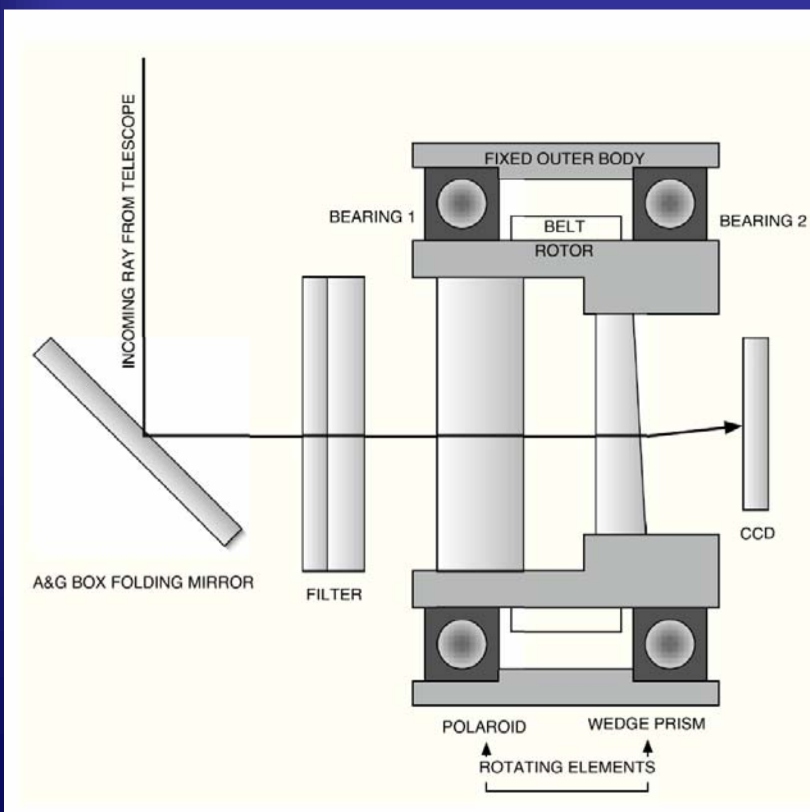
- magnetized jet -

30-50 %

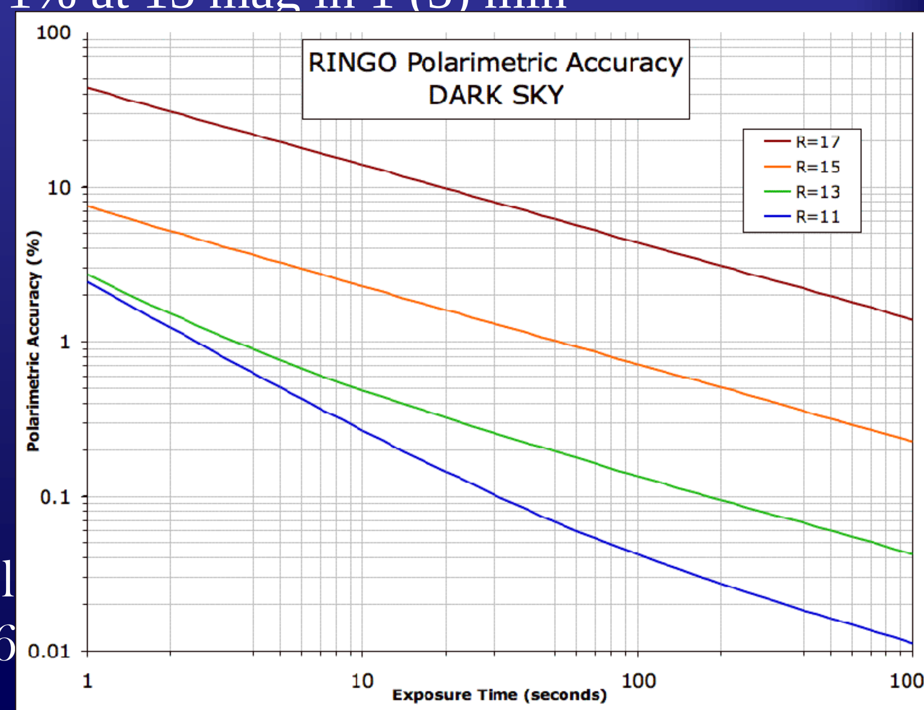


Lazzati et al. 2004

RINGO polarimeter

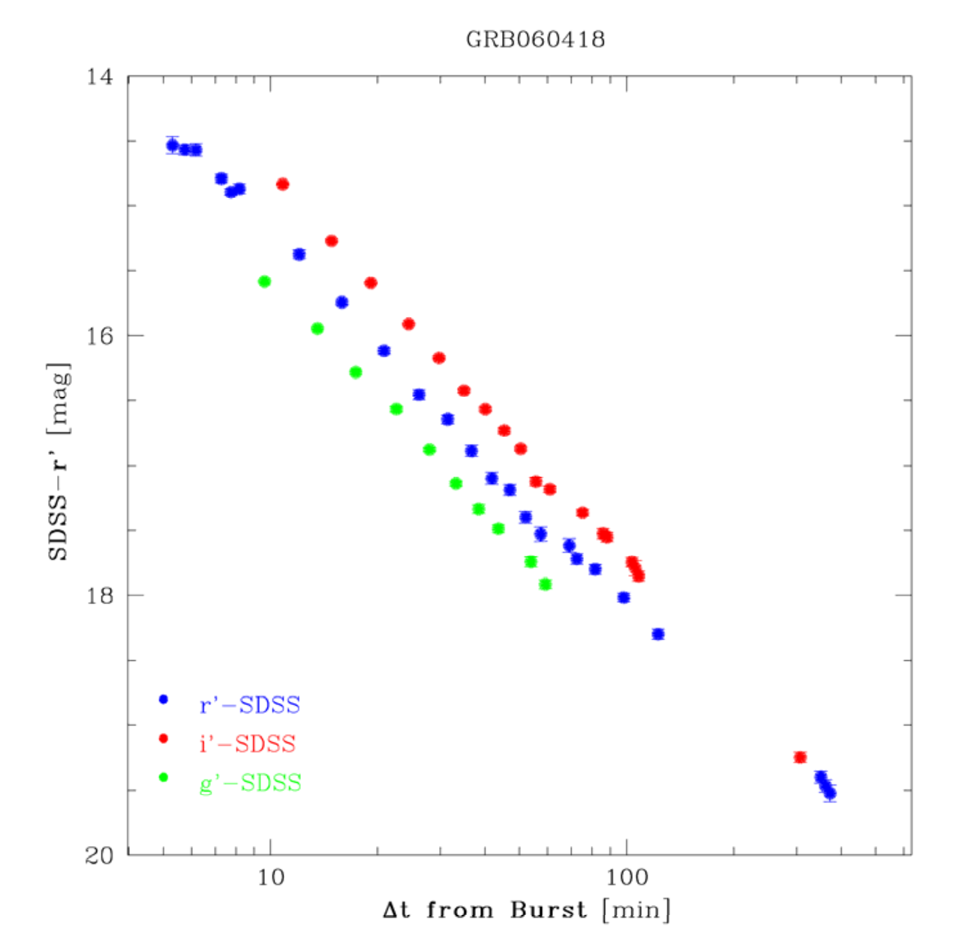


- RINGO Polarimeter – ring polarimeter based on the design by Clarke&Neumayer (2002) – since 2006
- polarimetric accuracy < 1% at 15 mag in 1 (5) min

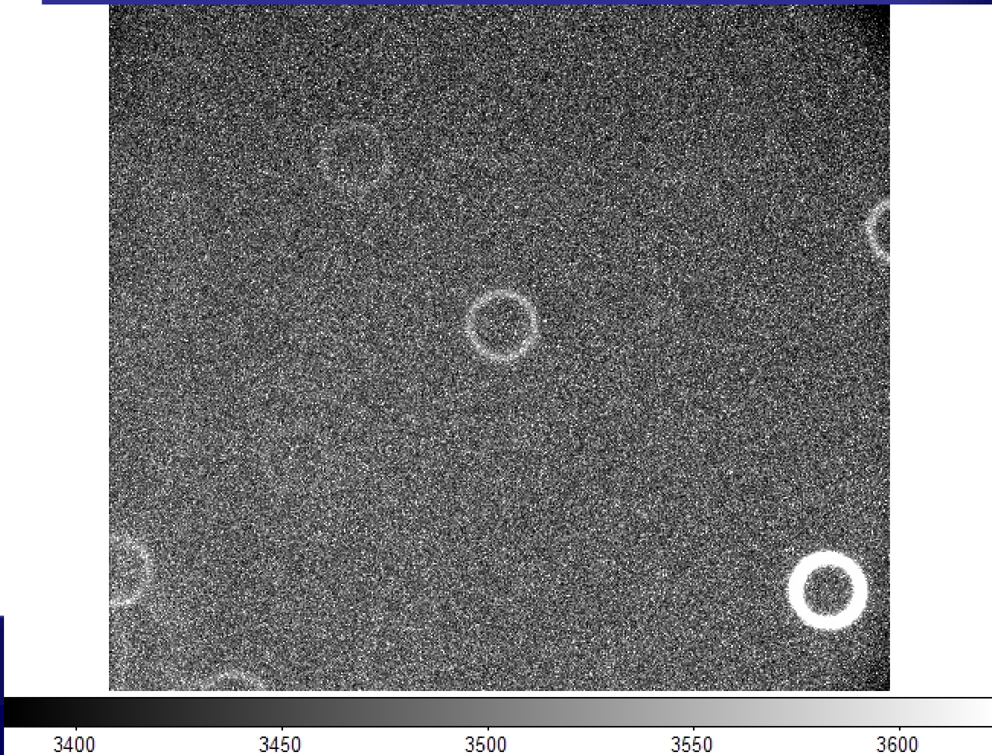


Steel
2006

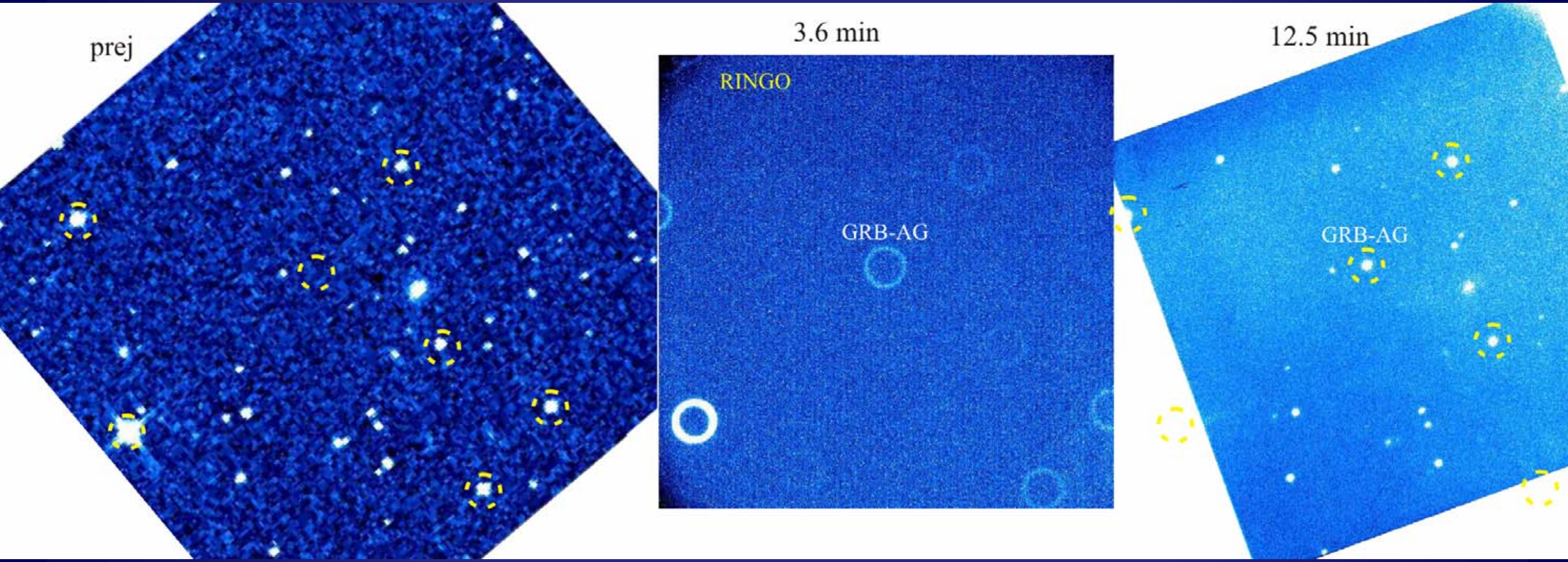
GRB 060418



RINGO polarimeter:



- rise observed by REM



Upper limit on early polarization < 8% or p=3.8 %;
Mundell et al, Science 2007

Conclusions

GRBs:

- most powerfull explosions in the Universe
- signaling the birth of black holes
- important for study of stellar evolution
- study of explosion development
- study of circumburst environment and host galaxies – to early galaxies – cosmological probes
- a growing database of multiwavelength observations by Swift and robotic telescopes - from case-by-case to statistical study

GRBs are very interesting also as sources of:

- neutrinos, cosmic rays, UHE photons?
- gravitational waves
- etc.