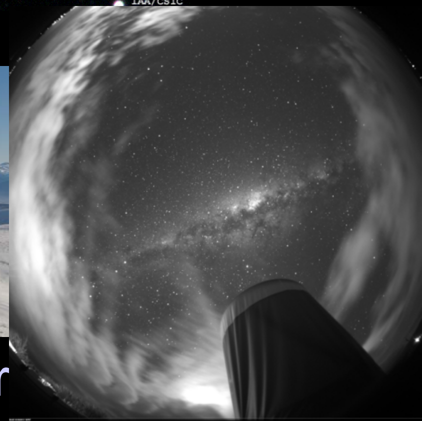
Early optical and mm observations of GRB afterglows

Lomonosov
/ UFFO-p

10.4m GTC

PdB Interferometer



0.6m BOOTES-3

Alberto J. Castro-Tirado
(IAA-CSIC Granada)
Ioffe GRB Workshop 2014
St. Petesburg, 23 Sep 2014

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Outline

1. Historical GRB afterglows

2. Early observations of optical GRB afterglows

3. 10.4m GTC complementary observations

4. Millimetre observations of GRB afterglows

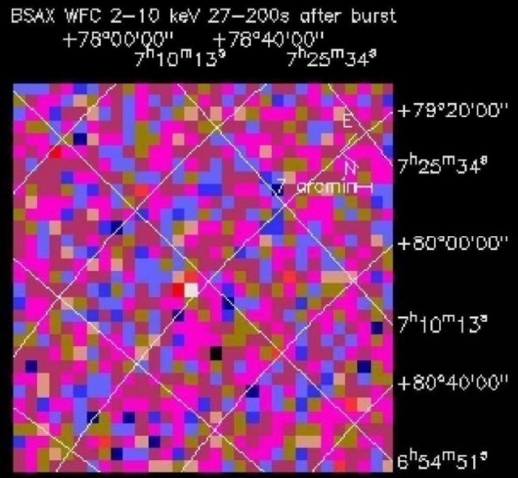
5. Prospects for the near-future: ground-based and space-borne

Summary

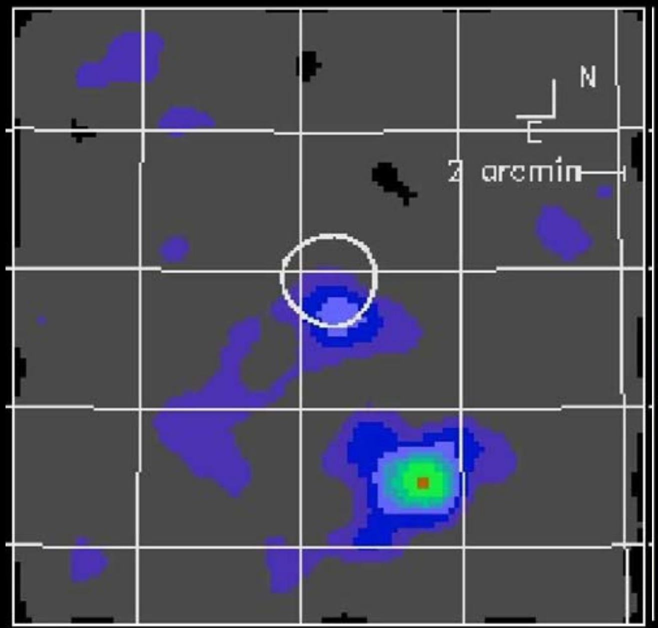
1. Historical afterglows

1. Historical GRB Afterglows (1)

In 1997 the first counterpart at longer wavelengths was detected thanks to *BSAX* satellite.



(Costa et al. 1998)



(Piro et al. 1998)

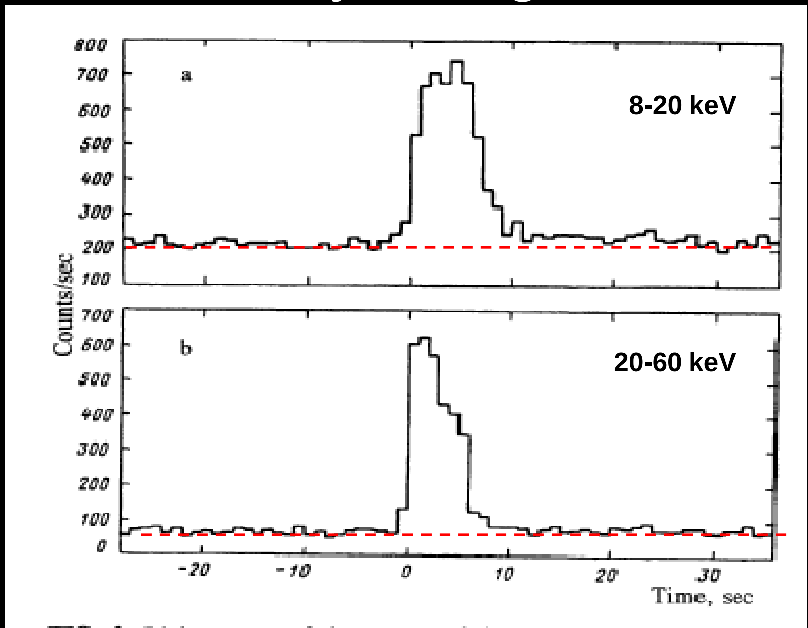
We always refer to 'the Afterglow era' to the period starting in 1997, following the big *BSAX* discovery of X-ray afterglows (Costa et al. 1997) followed by counterparts at other λλλ

But were out there afterglows prior to 1997?

1. Historical GRB Afterglows (2)

An X-ray afterglow (?) was pinpointed 5 yr before the *BeppoSAX* detection of GRB 970228.

GRB 920723B: evidences for an X-ray afterglow?



C-T (1994), PhD Thesis

Observations of a cosmic gamma-ray burst on 23 July 1992 with the WATCH instrument on the *Granat* observatory

O. V. Terekhov, V. A. Lobachev, D. V. Denisenko, I. Yu. Lapshov, and R. A. Syunyaev

Space Research Institute, Russian Academy of Sciences, Moscow

N. Lund, A. Castro-Tirado, and S. Brandt

Space Research Institute, Lyngby, Denmark

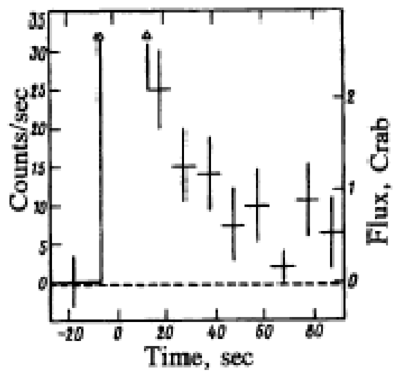


FIG. 4. Afterglow detected by the WATCH instrument in the 8-20 keV range after the end of the burst.

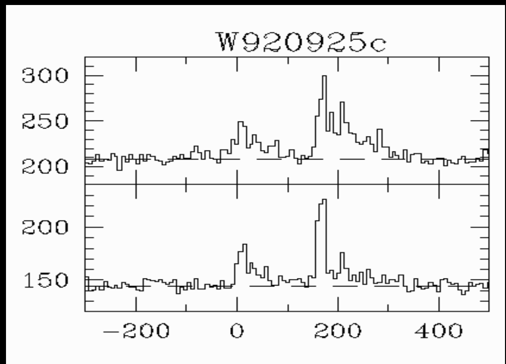
Terekhov et al. (1993), Pis`ma Astron. Zh. 19, 686

1. *Historical GRB Afterglows (3)*

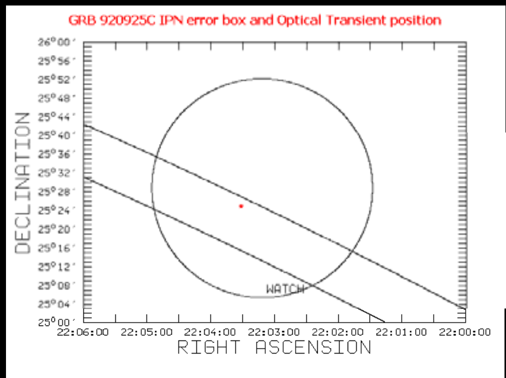
The first optical afterglow was already serendipitously imaged in 1992.

GRB 920925C was reported 4.5 yr prior to the famous GRB 970228, yet its OA needed 10 yr to be discovered once the corresponding POSS-II plates were checked! (and reported).

C-T (1994), PhD Thesis



Hurley et al. (2000)



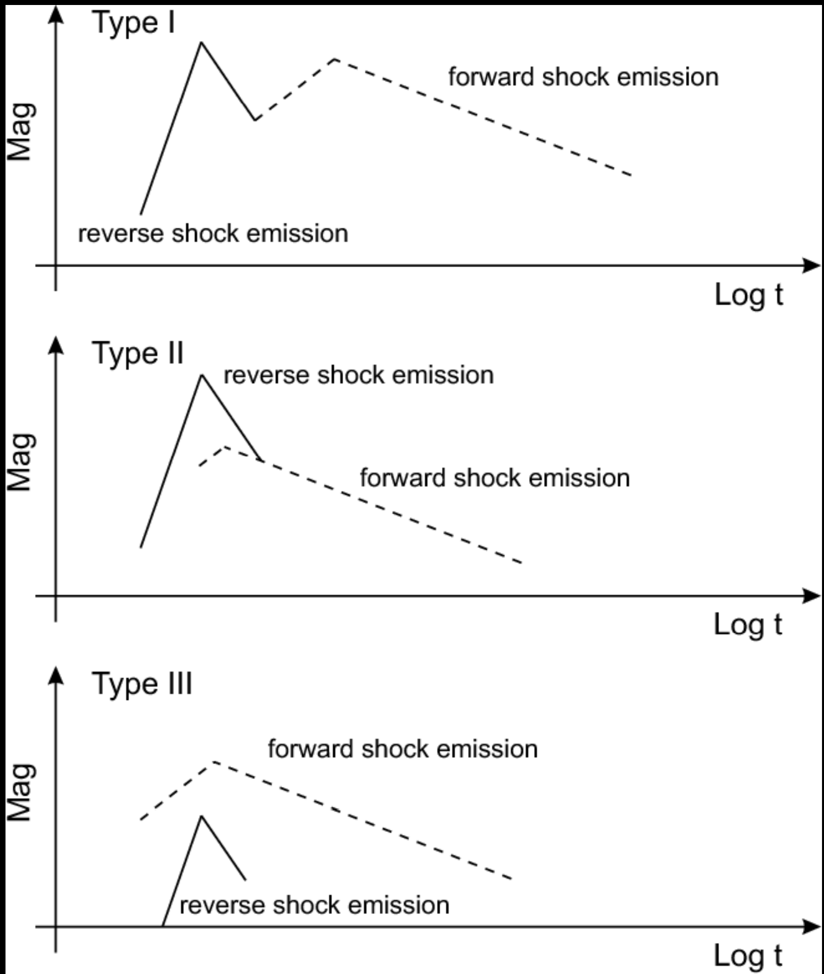
GRB 920925c: the first optical afterglow

Denisenko & Terekhov (2007)

2. Early optical observations of GRB afterglows

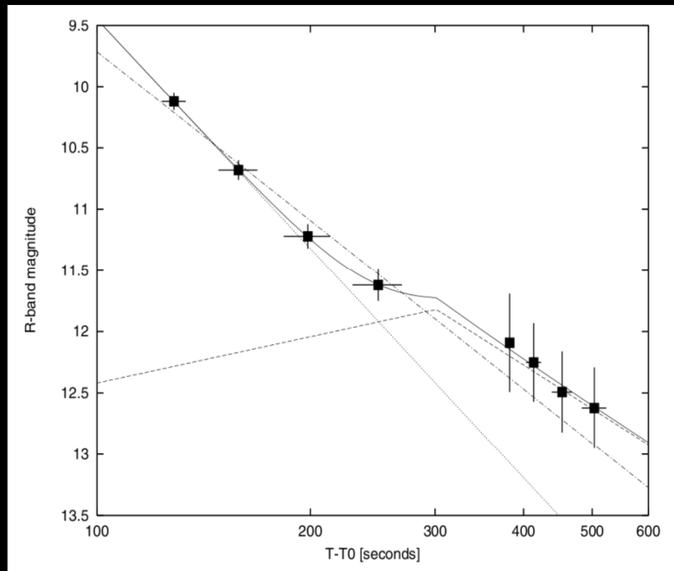
2. Early optical observations of afterglows (1)

Reverse and Forward Shocks



Zhang Kobayashi Meszaros (2003); Gomboc et al. (2009)

Strength of RS depends on magnetization content of the ejecta



GRB 060117
(Jelínek et al, 2006)

2. Early optical observations of afterglows (2)

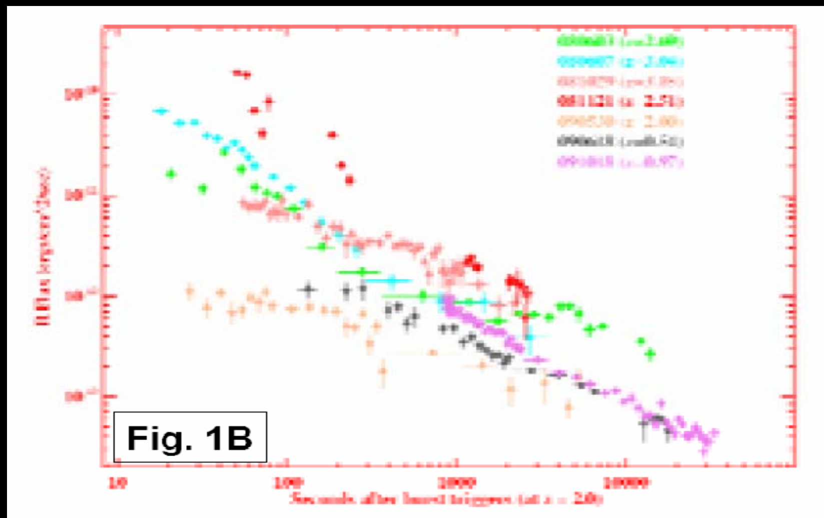
Forward Shock (Afterglow) Emission (1)

Peak time of the rising OA lightcurves → initial Lorenz factor Γ_0 (Molinari et al. 2007).

The rising lightcurves are also important to understand the onset of the afterglow (Sari et al. 1999) : $\alpha \sim 2$ ($\nu_c < \nu_{optical}$) or $\alpha \sim 3$ ($\nu_c > \nu_{optical}$) in the case of ISM or $\alpha \sim 0.5$ for a WIND density profile.

And to constrain off-axis and structured jet models (Painatescu et al. 1998).

$$F(t) = At^{\alpha}$$



(Pandey et al. 2011)

2. Early optical observations of afterglows (3)

Automated and Robotic telescopes: advantages for GRB afterglow follow-ups

<u>1. Automatization</u> of existing instruments (eg. PAIRITEL in the US or the 1.23 m CAHA tel in Spain)

Early detection of GRB 120311A ~200 s after the GRB (Kubánek et al. 2012, GCNC 13036)

2. Establishing <u>robotic telescopes</u> networks:

MASTER (Gorbovsky's talk)
BOOTES, etc

2. Early optical observations of afterglows (4)

The BOOTES compilation (2)

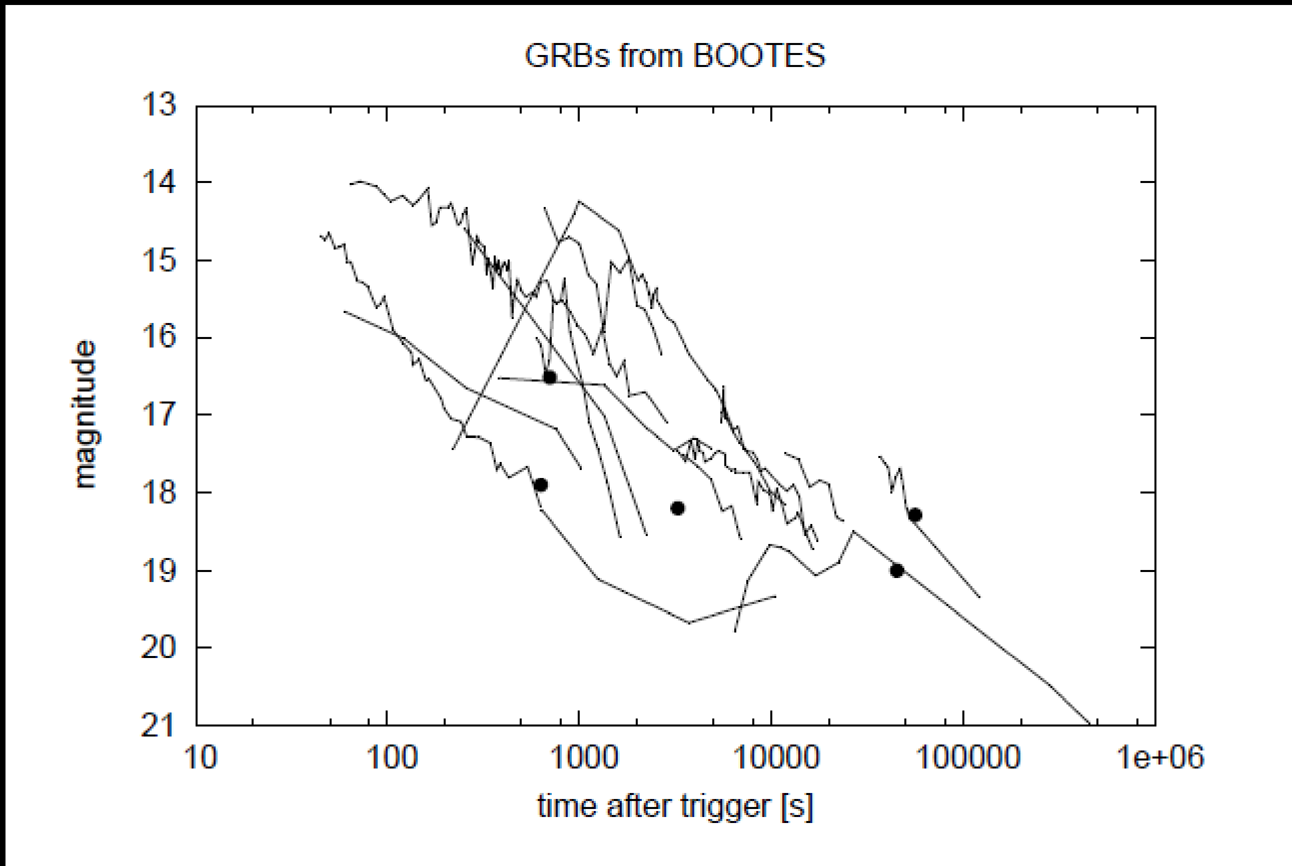
BOOTES (Burst **O**bserver and **O**ptical **T**ransient **E**xploring **S**ystem**)**, is becoming a worldwide network (3 so far) of 0.6m Ø identical robotic telescopes, EMCCD cameras and filters (clear and g'r'i'ZY) should help rapidly pointing to these events as soon as they go off. The next station (BOO-5) will be officially opened by 2015 in Mexico.

bootes.iaa.es

2. Early optical observations of afterglows (5)

The BOOTES compilation (1)

71 follow-ups in 10 yr (2004-13) leading to 21 detections



(Jelinek et al. 2014)

2. Early optical observations of afterglows (6)

The BOOTES compilation (2)

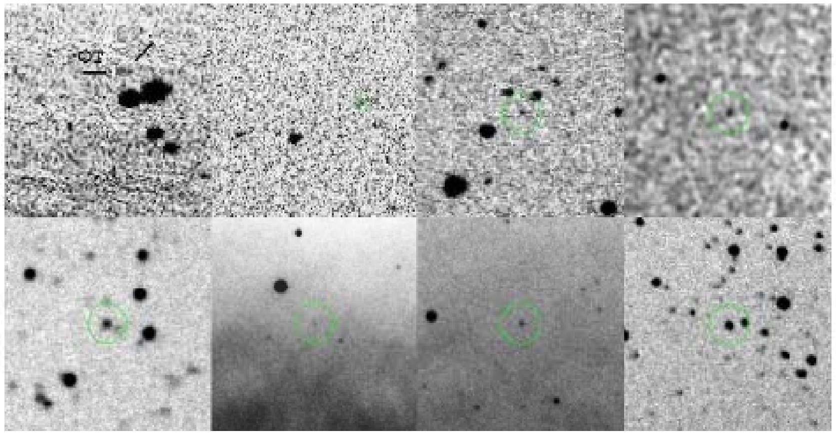
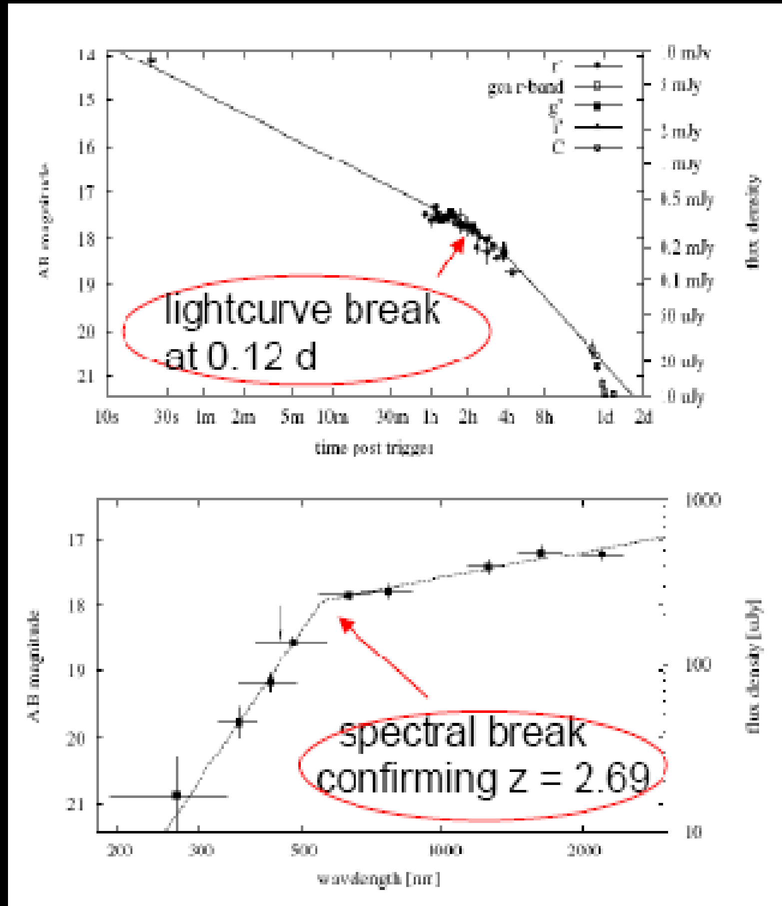


Fig. 3. GRB optical transient detections by BOOTES-1B: first row: GRB 050824, GRB 050922C, GRB 051109A, GRB 080330. Second row: GRB 080413B, GRB 080430, GRB 080602B, GRB 080605.

Jelínek et al. (2010, 2013)



GRB 080603B (Jelínek et al. 2012)

(BOOTES-1 & -2 data)

2. Early optical observations of afterglows (7)

The BOOTES compilation (3)

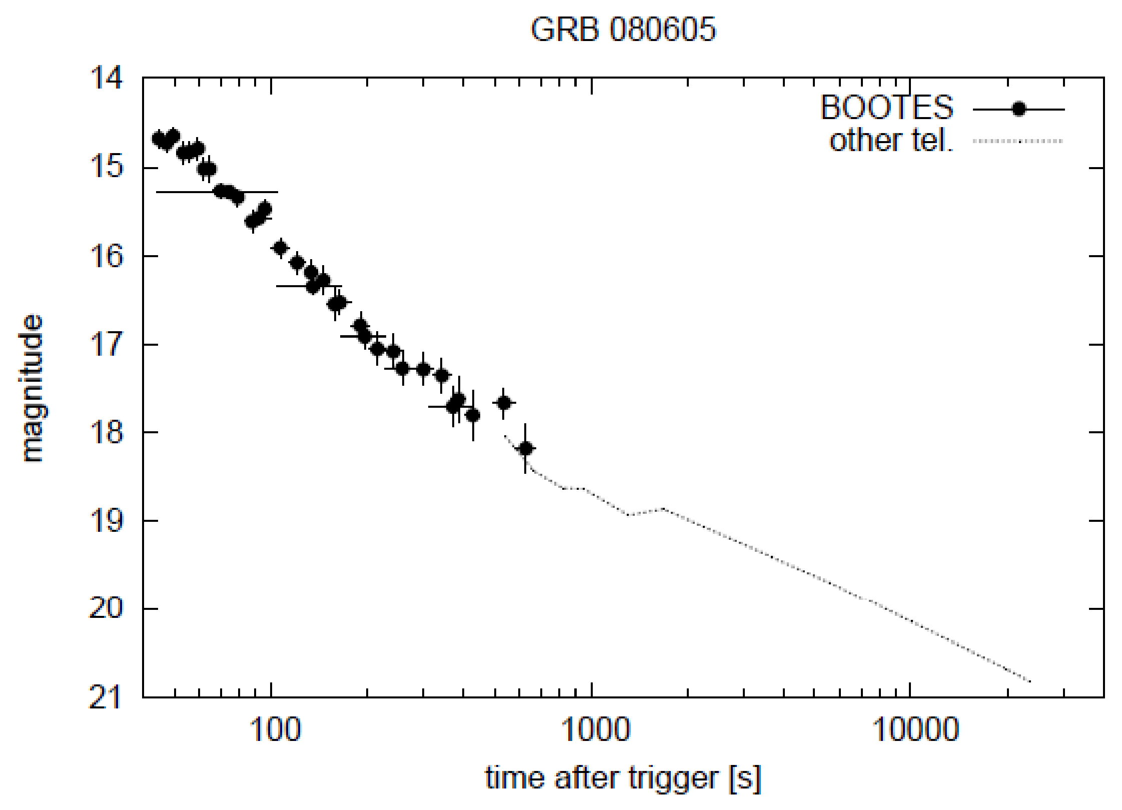
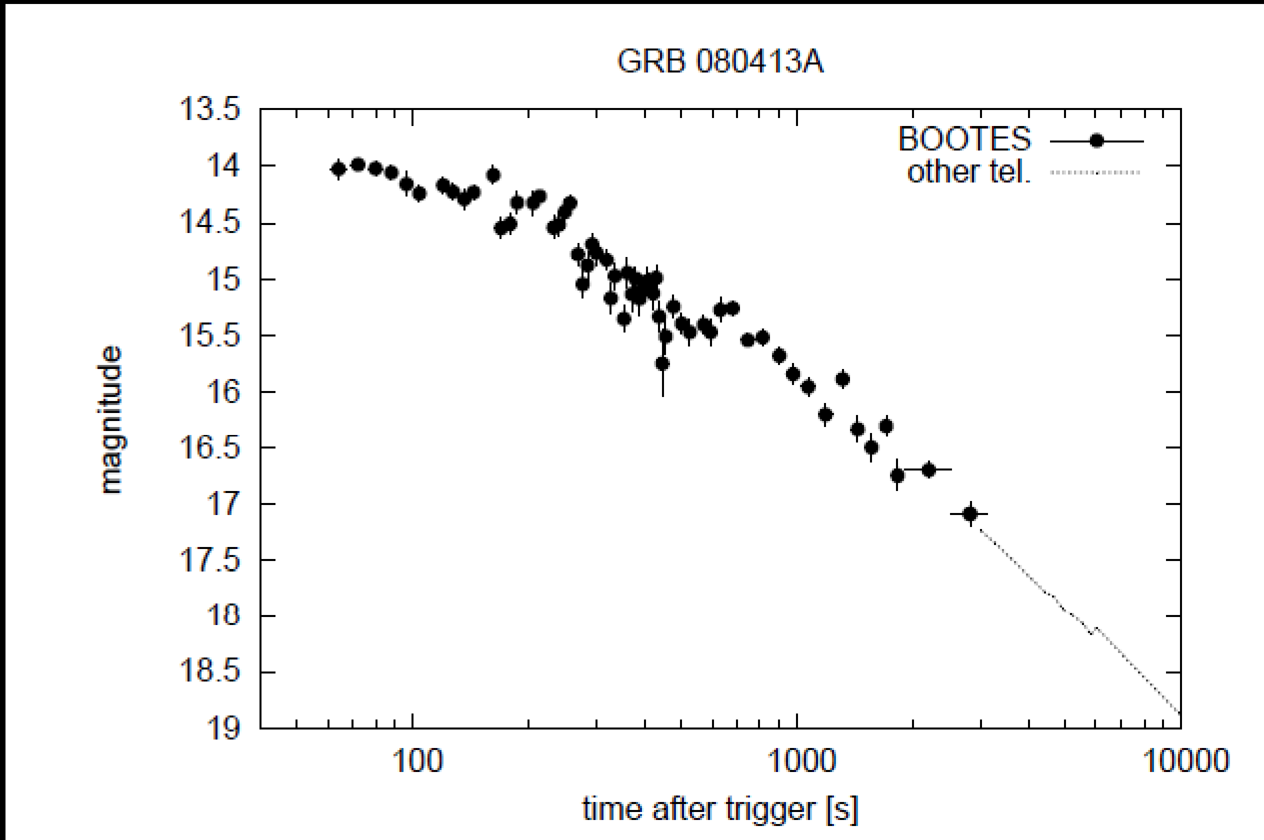


Fig. 7. The optical light curve of GRB 080605 (Jelínek et al. 2013).

(Jelinek et al. 2014)

2. Early optical observations of afterglows (8)

The BOOTES compilation (4)



(Jelinek et al. 2014)

2. Early optical observations of afterglows (9)

The BOOTES compilation (5)

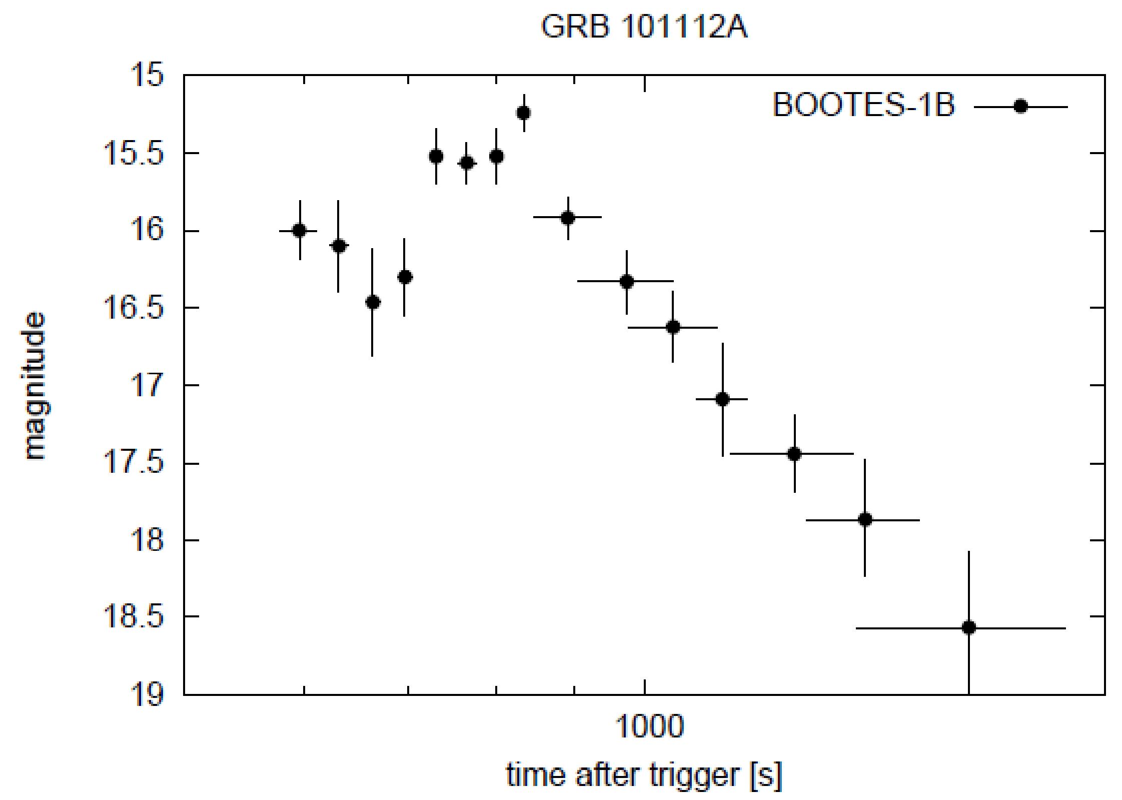


Fig. 10. The optical light curve of GRB 101112A.

(Jelinek et al. 2014)

2. Early optical observations of afterglows (10)

The BOOTES compilation (6)

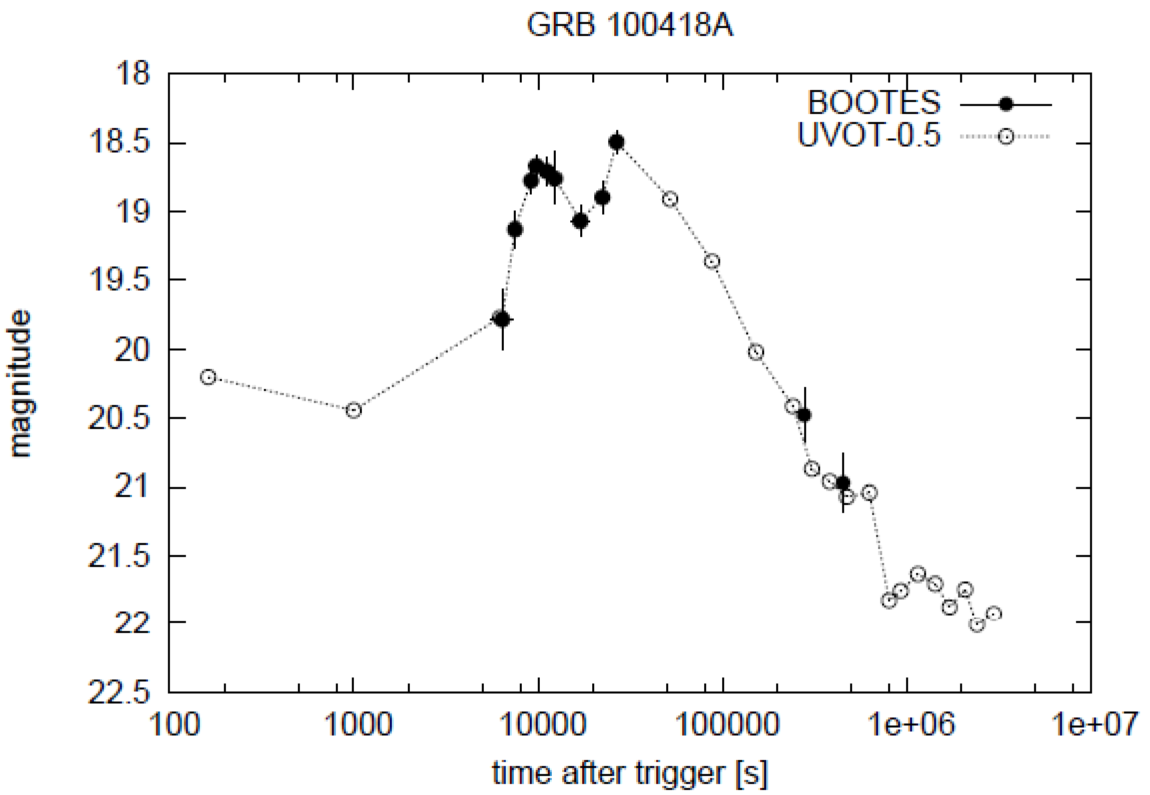


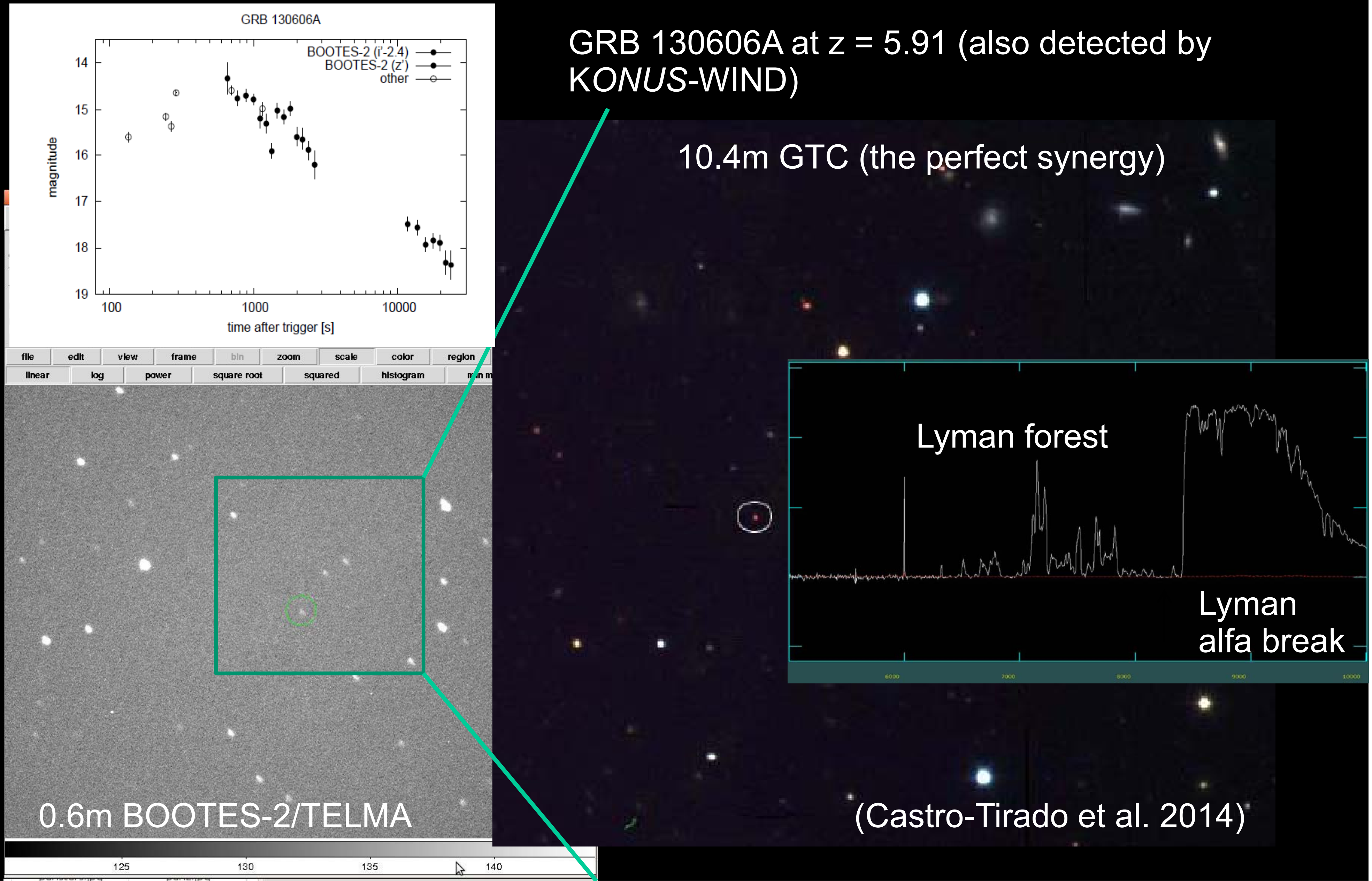
Fig. 8. The optical light curve of GRB 100418A. Combination of BOOTES and UVOT data (Marshall et al. 2011). UVOT points were shifted by an arbitrary constant.

(Jelinek et al. 2014)

2. Early optical observations of afterglows (11)

The BOOTES compilation (7)

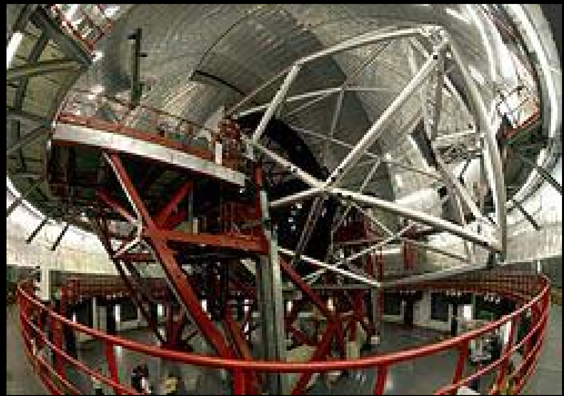
GRB 130606A at z = 5.91 (also detected by *KONUS*-WIND)

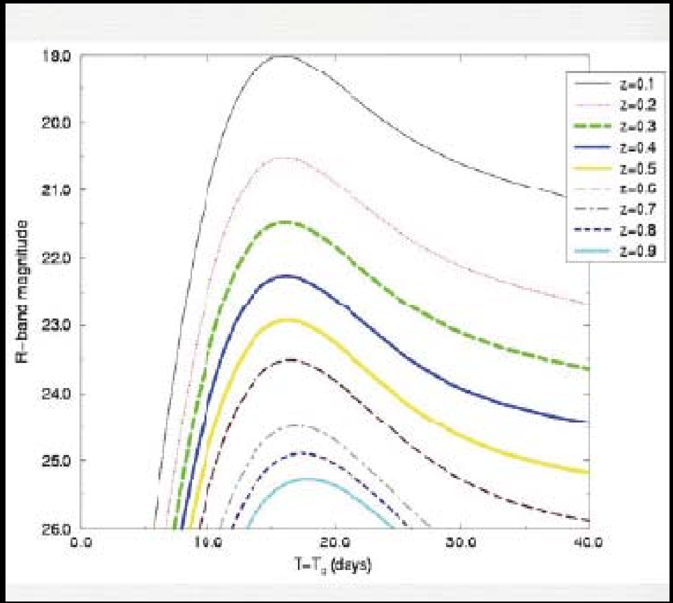


3. Complementing the early optical afterglows studies with the 10.4m GTC

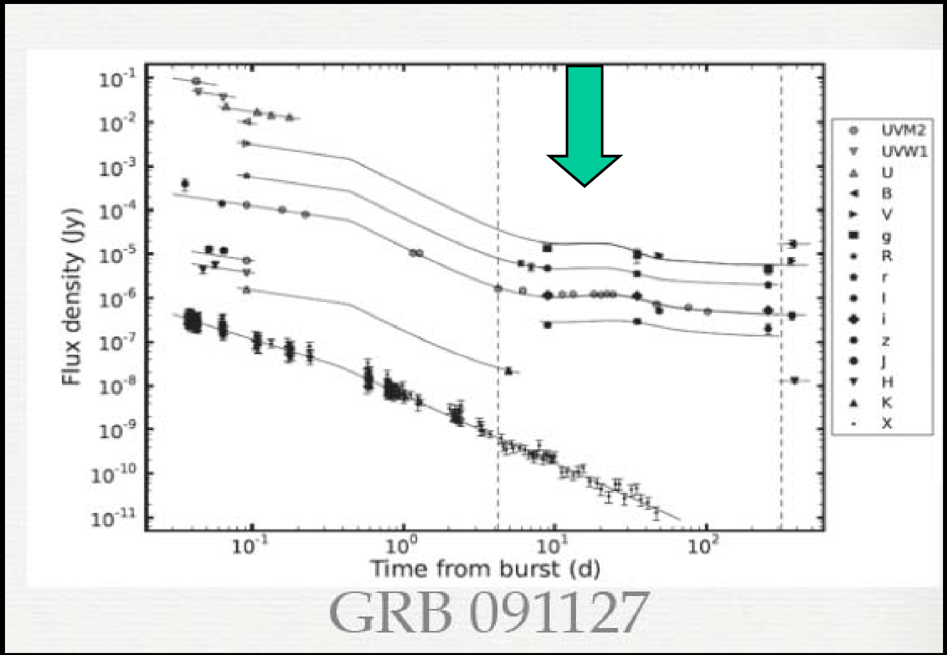
3. GTC complementary observations (1)

The largest diameter optical telescope so far (10.4m)





SNe/GRB reachable with GTC up to z ~ 1

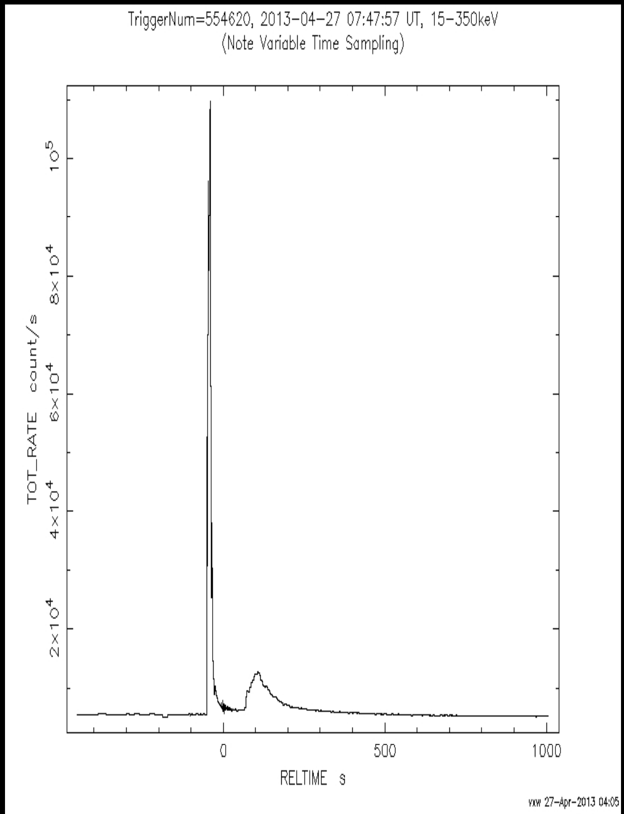


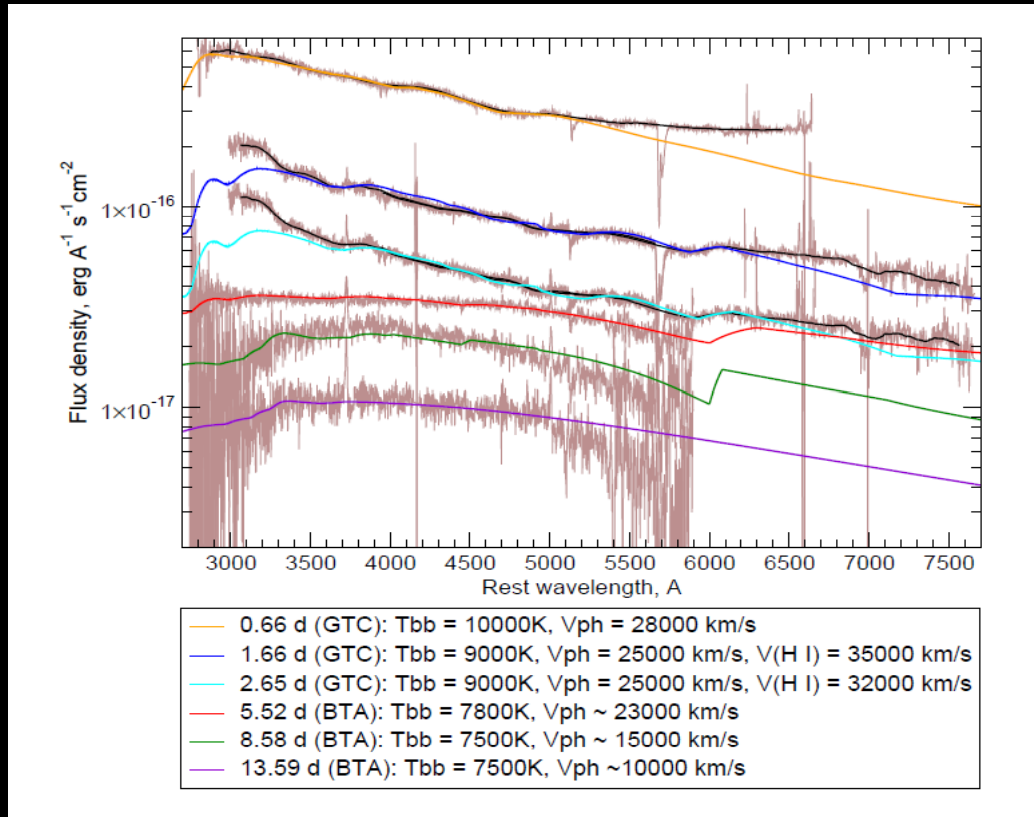
GRB 091127 / SN 2009nz at z = 0.490 (Vergani et al. 2011, A&A 535, A127). See also Cobb et al. (2010), Berger et al. (2011)

3. GTC complementary observations (2)

Early spectroscopic observations of GRB afterglows (1)

The extraordinarily bright GRB 130427A at the 10.4m GTC





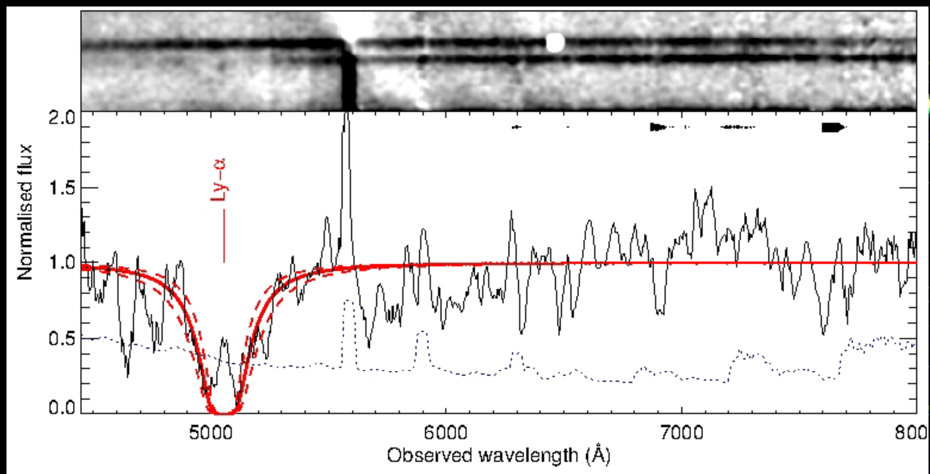
GRB 130427A: spectroscopy at 3 different epochs (T_0 + 0.6, 1.6 and 2.6 days) of the nearest (z = 0.34) "classical" GRB. Work in progress (combined with late-time BTA spectra).

3. GTC complementary observations (3)

Early spectroscopic observations of GRB afterglows (2)

Important role of the 10.4m GTC

Redshifts determination for a dozen of GRBs (the first one: GRB 100316A, the last one: GRB 140907A). Redshift confirmation for another dozen of them.



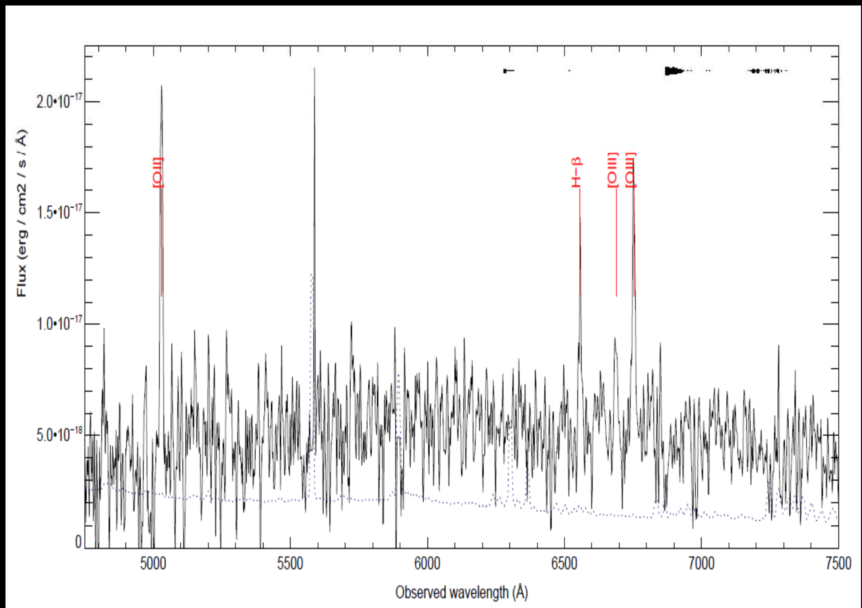
(Sánchez-Ramírez et al. 2014)

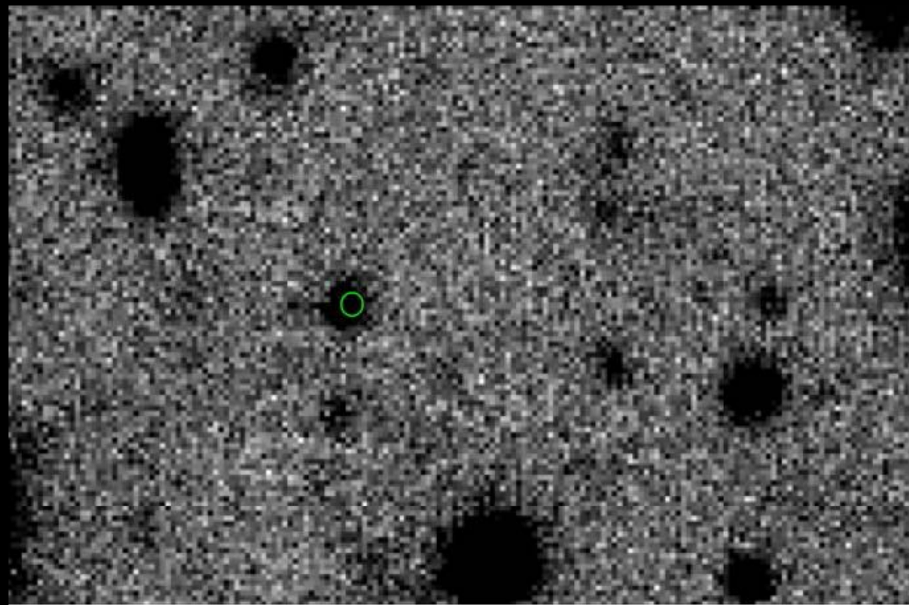
GRB 100316A: redshift determination by GTC (z = 3.2)

3. GTC complementary observations (4)

Late host galaxy observations

Imaging and spectroscopy for a dozen of host galaxies as well.





GRB 130925A (Evans et al. 2014)

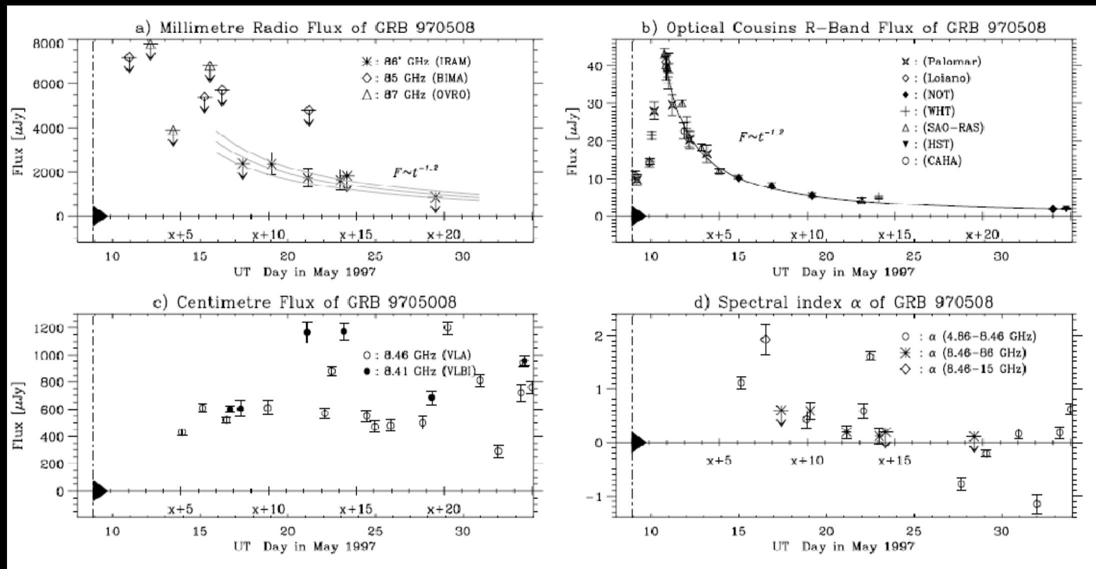
GRB 140713A (C-T et al. 2014)

4. Millimetre observations of GRB afterglows

4. mm observation of GRB afterglows (1)

Afterglows at mm and sub-mm wavelengths (1)

As soon as the first X-ray afterglow was discovered by *BSAX* in Feb 1997, we attempted Plateau de Bure Interferometer (PdBI) observations in the French Alps for the second event (May 1997). They led to the first detection ever of an afterglow at mm wavelengths!



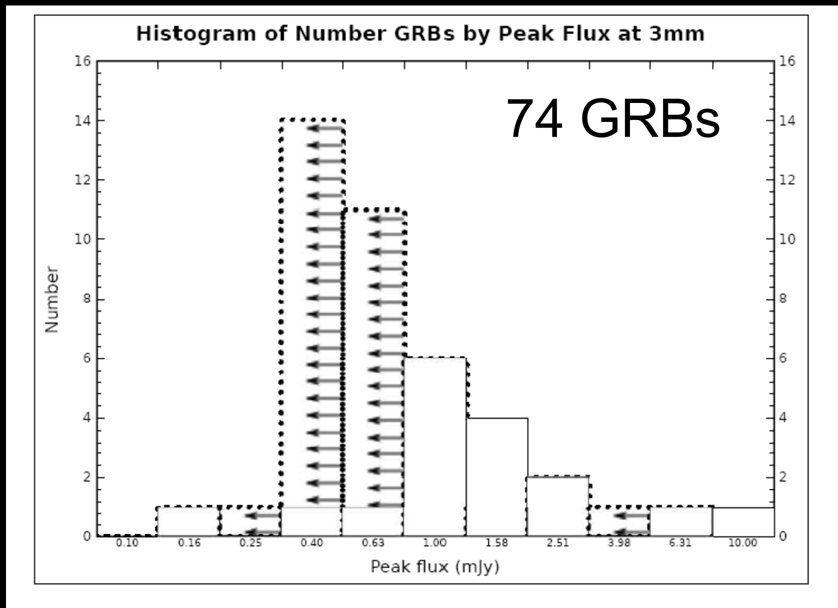
GRB 970508 at z = 0.805 (Bremer et al. 1998, A&A 332, L13)

4. mm observations of GRB afterglows (2)

Afterglows at mm wavelenghts (2)

A PdBI GRB legacy survey (Castro-Tirado et al. 2015, partly published in de Ugarte Postigo et al. 2012, A&A 538, A44, including also sub-mm data):

80 GRBs have been observed at 90 GHz in 1997-2014, with a 35% success in the detection rate.

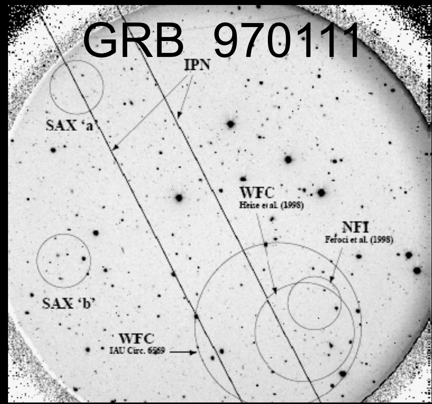


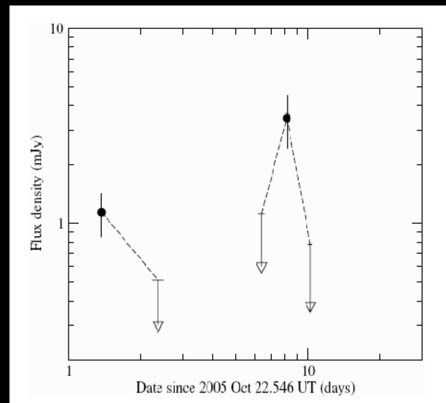
Castro-Tirado et al. (2015)

4. mm observations of GRB afterglows (3)

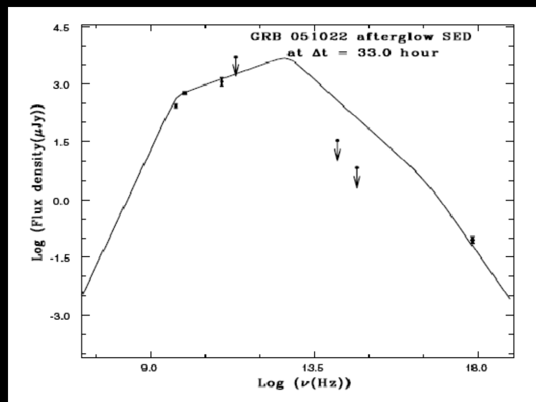
Dark GRBs at mm and sub-mm wavelenghts (1)

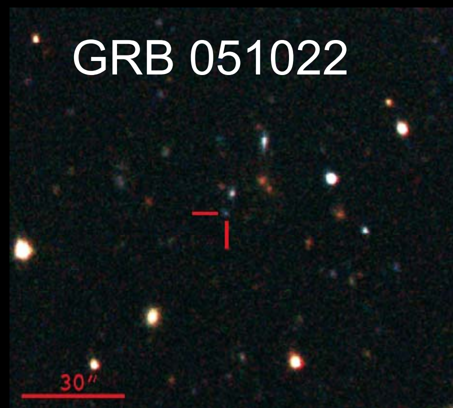
The first dark GRB happened prior to GRB 970228 and also reported by *BSAX* as GRB 970111 (C-T et al. 1997; Gorosabel et al. 1998).





GRB 051022 : A <u>dark</u> burst, with the host galaxy (z = 0.809) identified thanks to the mm flares and afterglow detected at Bure (Bremer et al. 2005, GCNC 4157). A powerful sub-mm emitter galaxy? (C-T et al. 2007).

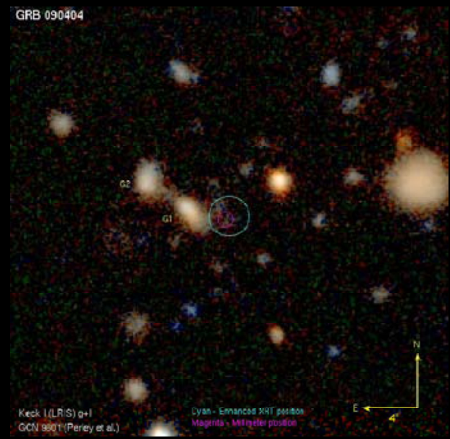




4. mm observation of GRB afterglows (4)

Dark GRBs at mm and sub-mm wavelenghts (2)

GRB 090404: VLA and PdBI detection of the afterglow for this dark GRB (C-T et al. 2013). No evident host galaxy.



Success rate of attempted dark GRBs at PdBI (bias-selected) : 4/8 (50%)

GRB 130528: PdBI detection of the afterglow for this dark GRB (Jeong et al. 2014). A host galaxy at z = 1.25.

4. mm observations of GRB afterglows (5)

The SNe / GRBs at mm wavelengths

Object ID	Flux Density
GRB 030329 / SN 2003dh	58 mJy
XRF 060218 / SN 2006aj	< 2 mJy
XRT 080109 / SN 2008d	0.65 mJy

GRB 130925A at mm wavelengths

Undetected, thus supporting a low density medium

4. mm observation of GRB afterglows (6)

Multiwavelength observations will allow to address fundamental questions:

1. What is the range of GRB explosion energies? For every GRB, the following six observables can be measured: the synchrotron peak, break and self-absorption frequencies, the maximum flux and the power-law decay exponent (all from the multiwavelength spectrum) and z (from optical spectroscopy).

2. What is the environment of the circumburst medium? This can be addressed by performing a detailed study of the time evolution of the multiwavelength afterglow emission over the first 2-4 weeks after the event.

3. What is the nature of dark GRBs? Are ultra high-z a distinct population?

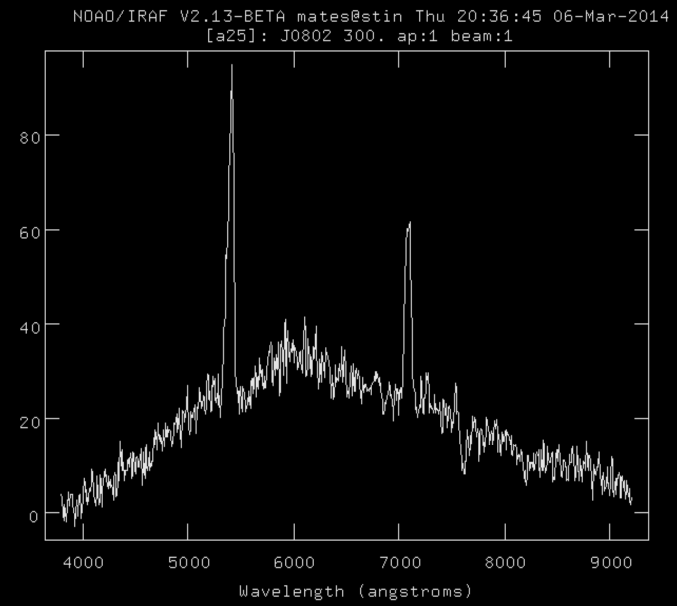
5. Prospects for the near-future: ground-based and space-borne

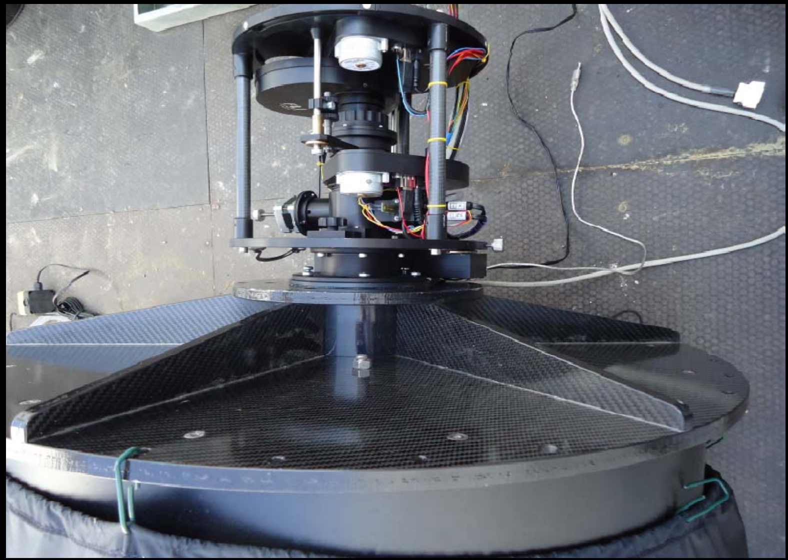
5.1 Ground-based: new & forthcoming BOOTES instrumentation

5.1. Ground-based instruments (1)

BOOTES new and forth-coming instrumentation

COLORES: a low-resolution imaging spectrograph for the 0.6m Telescopes.





5.1. Ground-based instruments (2)

EDIPO: a Full Stockes polarimeter. For a 1-2m class robotic telescope.

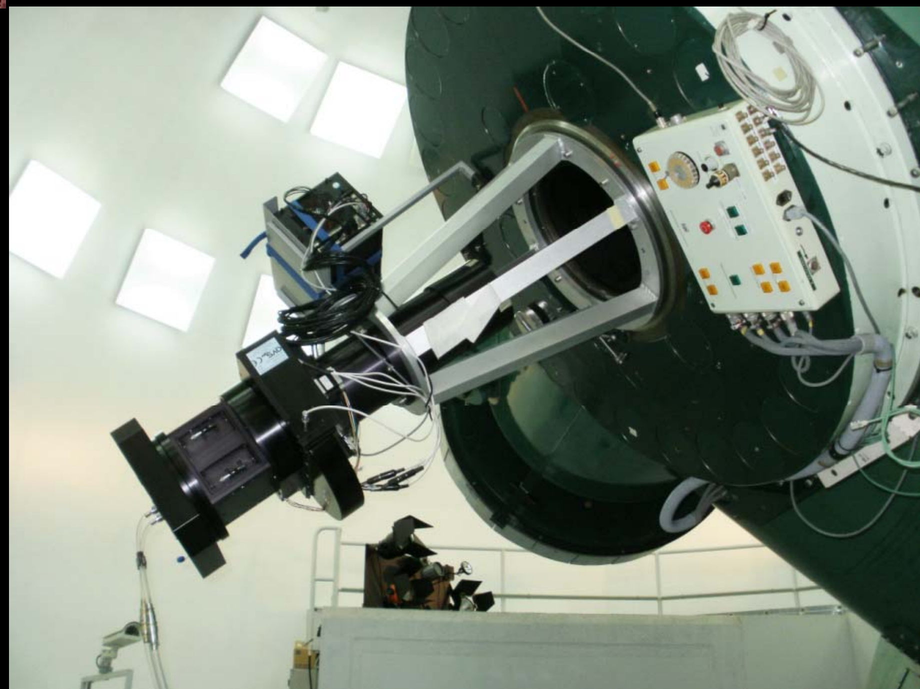
Next steps:

Additional tests at the IAA Lab

2^{nd} run in Oct

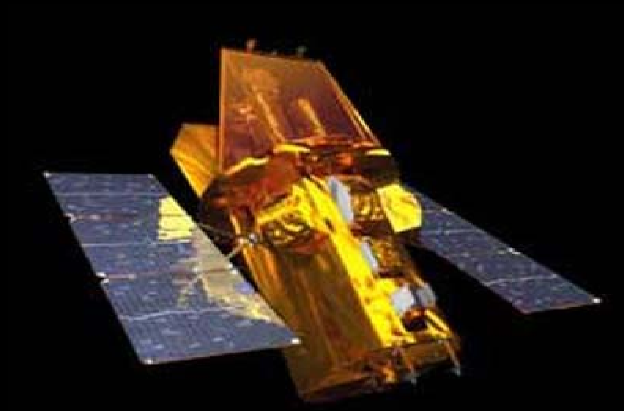
First light at CAHA in June 2014

M101 galaxy in Ursa Major. EDIPO first light @ 1.23m CAHA . 300s, R-band (30' FOV) - 12/06/14



5.2 Space-borne: UFFO-p onboard Lomonosov

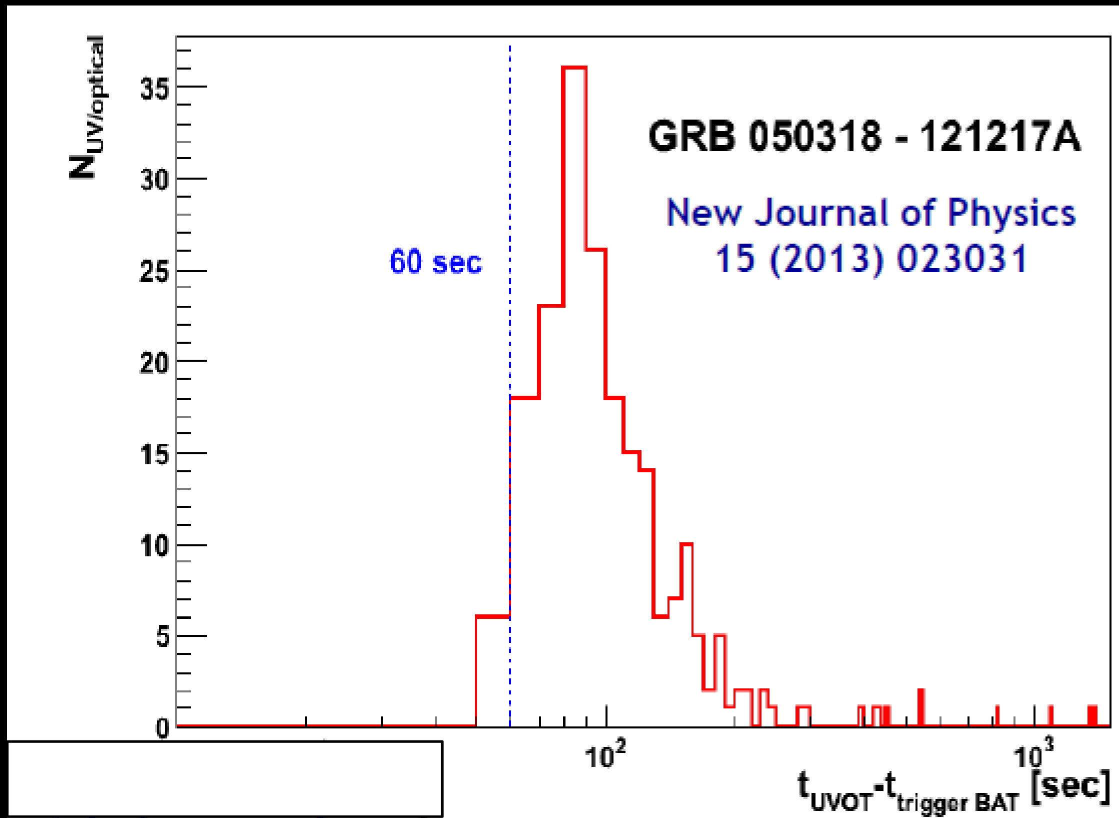
5.2. UFFO-p onboard Lomonosov (1)



GRB afterglows can be also monitored by doing the follow-up using the triggering satellite itself besides sending the position to the Earth *(BeppoSAX* in 6-8 hr, *Swift* in 1 min).

Early follow-up (within ~1 hr) only available to *Swift* so far (even very early sometimes with response of ~1 min) due to the slewing time of the *entire* spacecraft.

5.2. UFFO-p onboard Lomonosov (2)



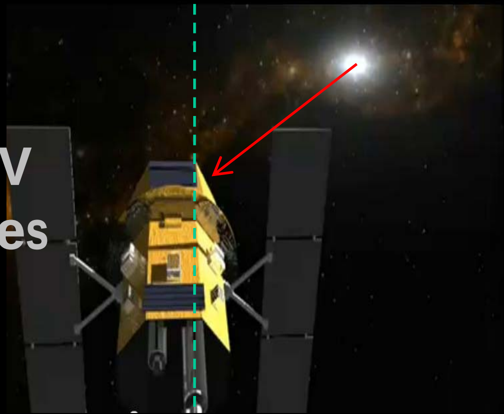
Jeong et al. (2013)

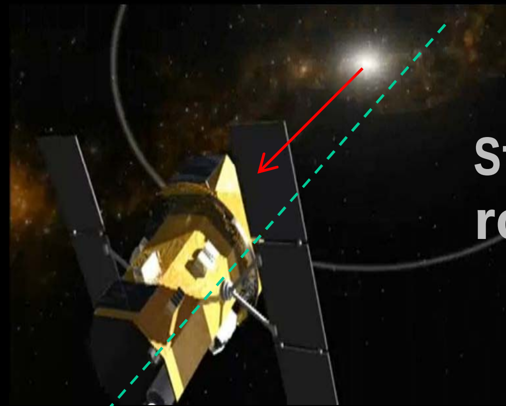
Is it possible to beat this 1 min barrier FROM SPACE?

5.2. UFFO-p onboard Lomonosov (3)

Concept of Fast Slewing

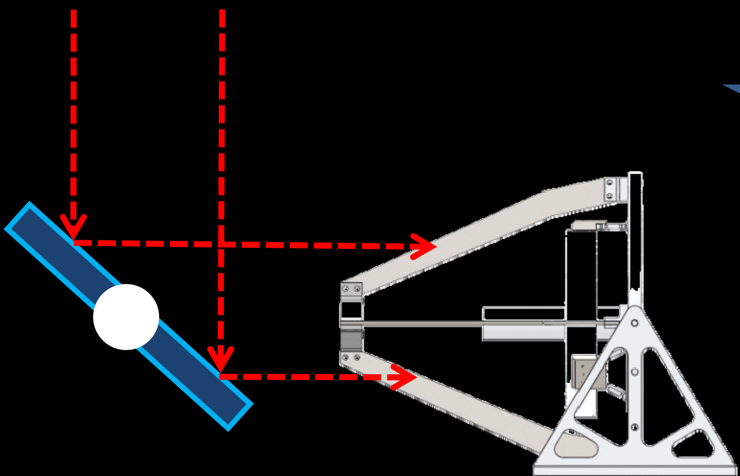
Step 1: wide FOV X/γ camera locates GRB

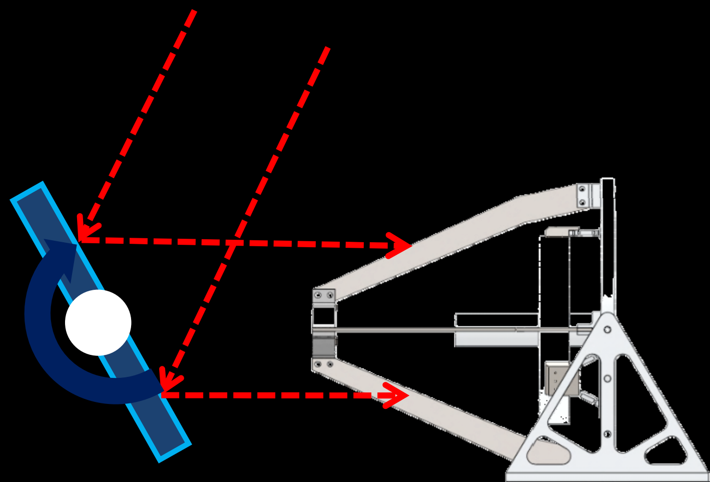




Step 2: Spacecraft rotates to point at GRB

SWIFT **rotates entire spacecraft to point UVOT and XRT**

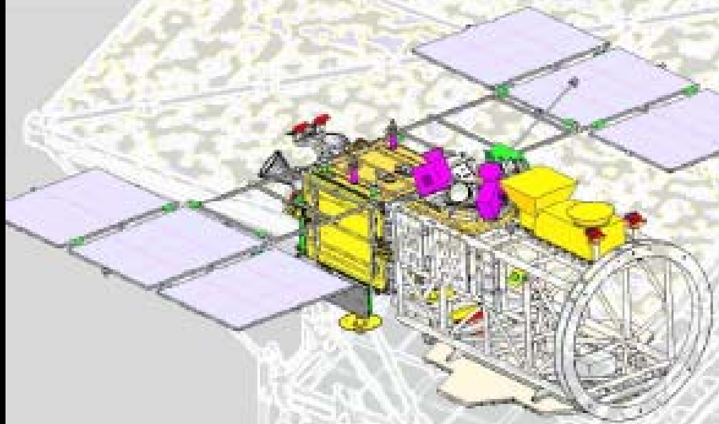




In UFFO-p, we move the optical path, not the spacecraft with fast slewing mirror system → much faster (~3 s, NEW Concept)

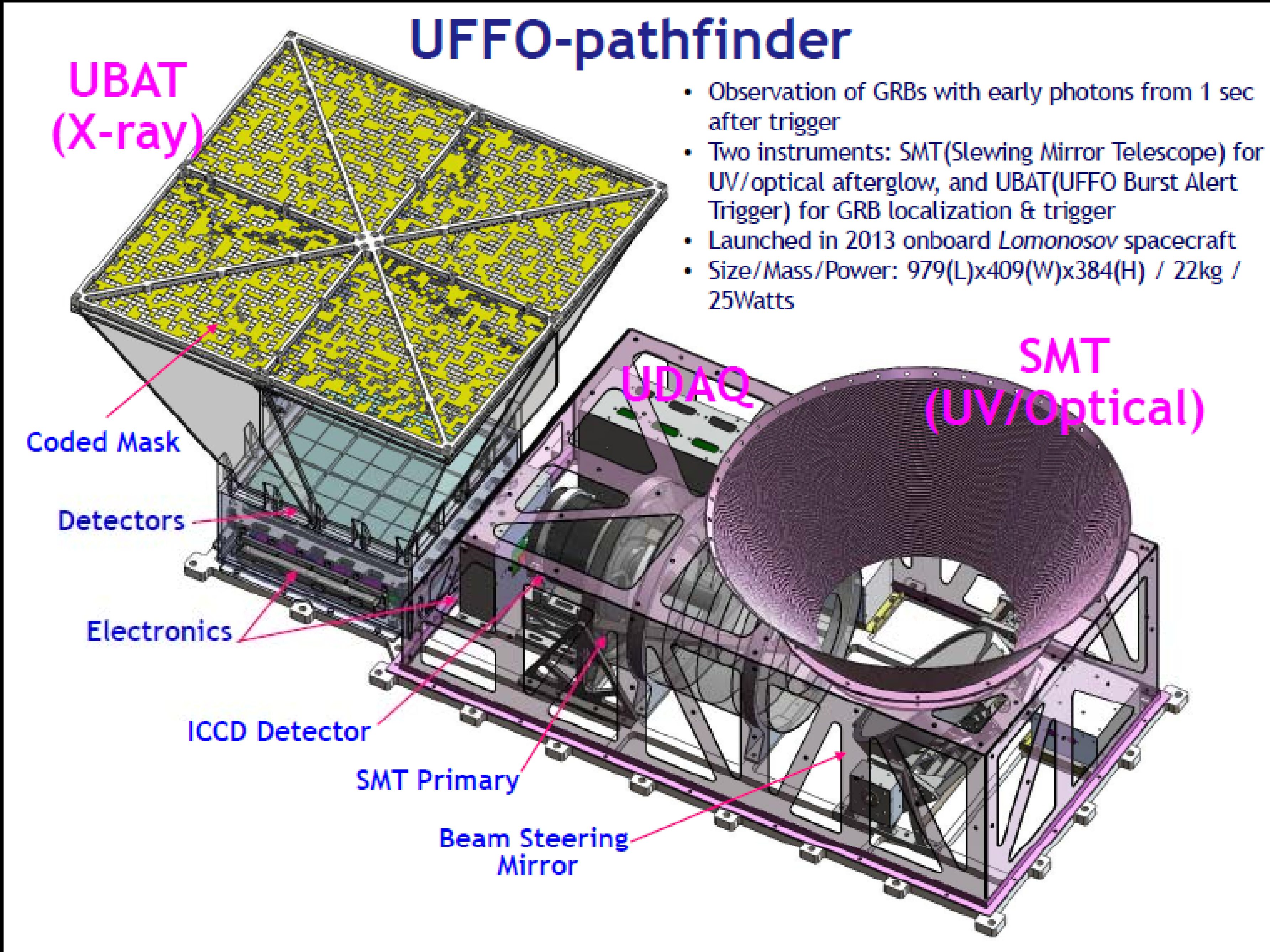
5.2. UFFO-p onboard Lomonosov (4)

UFFO-pathfinder



- Pioneering mission to prove the concept of Slewing Mirror Telescope by measuring early photons (1 sec after X-ray trigger) from at least 10 GRBs
- 10 cm aperture Slewing Mirror Telescope with small X-ray coded mask onboard *Lomonosov* spacecraft
- Collaboration: Denmark, France, Korea, Russia, Spain, Taiwan, US

5.2. UFFO-p onboard Lomonosov (5)



5.2. UFFO-p onboard Lomonosov (6)

5.2. UFFO-p onboard Lomonosov (7)

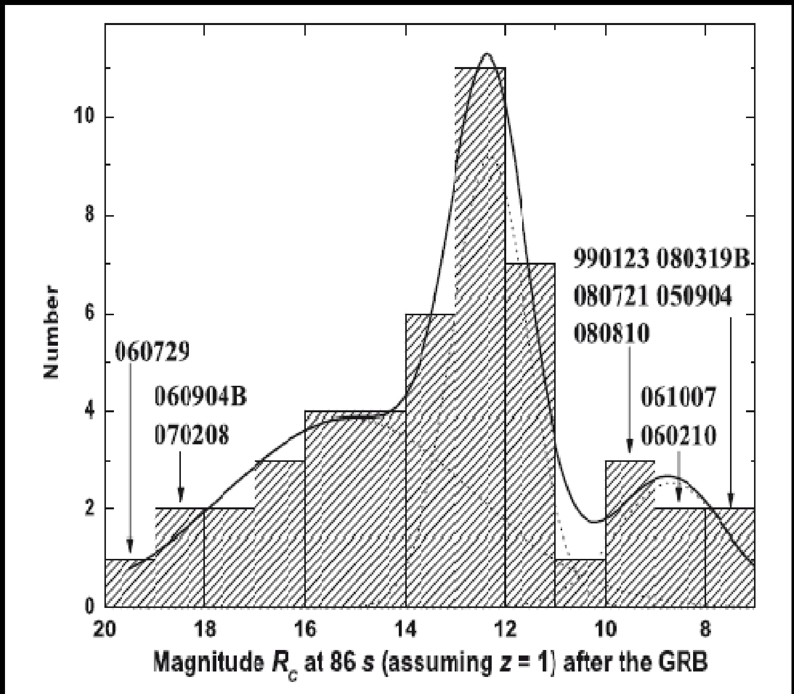
	Parameter	UFFO-pathfinder/*Lomonosov*	UFFO-100	*Swift*
UV/ optical /NIR	Telescope type	Ritchey-Chrétien + Slewing mirror	Modified Ritchey-Chrétien + Slewing mirror	Modified Ritchey-Chrétien
	Telescope Aperture	10 cm	40 cm	30 cm
	Field of View	17 × 17 arcmin² over 70 × 70 deg²	17 × 17 arcmin² over 90 × 90 deg²	17 × 17 arcmin²
	Wavelength range	200~650 nm	200~1100 nm	170~650 nm
	Number of pixels	256 × 256	256 × 256	256 × 256
	Physical pixel scale	4 arcsec	4 arcsec	4 arcsec
	Telescope Point Spread Function (centroiding applied)	0.5 arcsec	0.5 arcsec	0.5 arcsec
	Sensitivity	B = 19 mag. in 100 sec with 8σ	UV/optical: B = 21.5 and 23.5 mag. in 100 sec with 5σ for UV/optical and NIR, respectively	B = 24 mag. in 1000 sec with 5σ
	SMT data taking start time after trigger	1 sec	0.01~1 sec	40~200 sec, typically 80 sec
	Number of UV/optical observation	10~20 (estimated from the extrapolation of early light curves)	30~40	~40

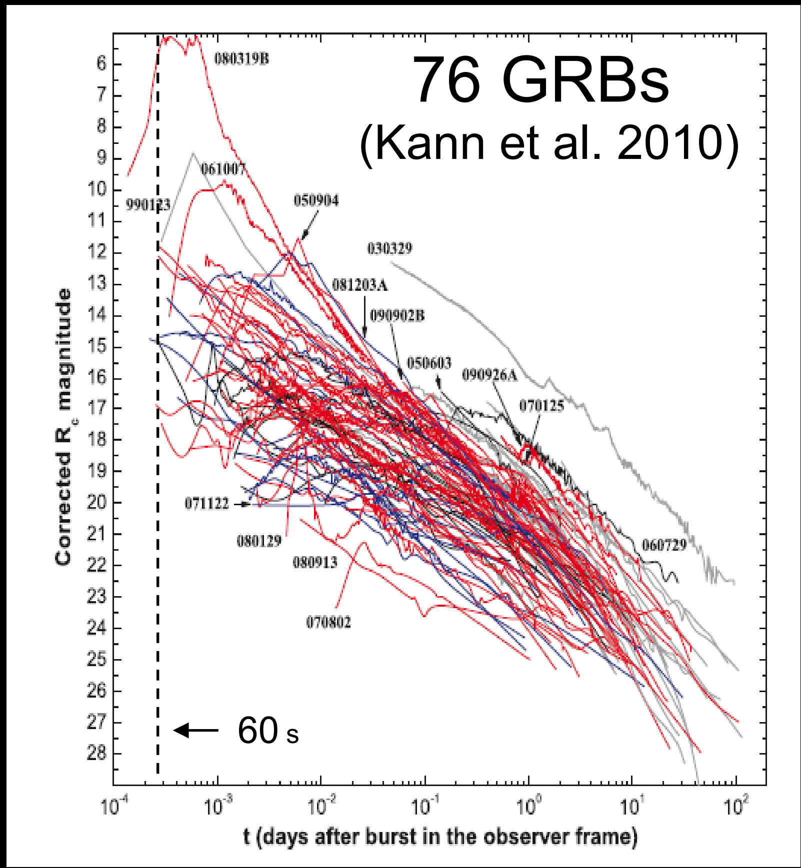
5.2. UFFO-p onboard Lomonosov (8)

UFFO-p Capabilities (1)

UFFO-p should detect <u>long-duration</u> GRBs unless they are extinguished by dust in their host galaxies *or* at high z (> 5). X-ray and optical measurements

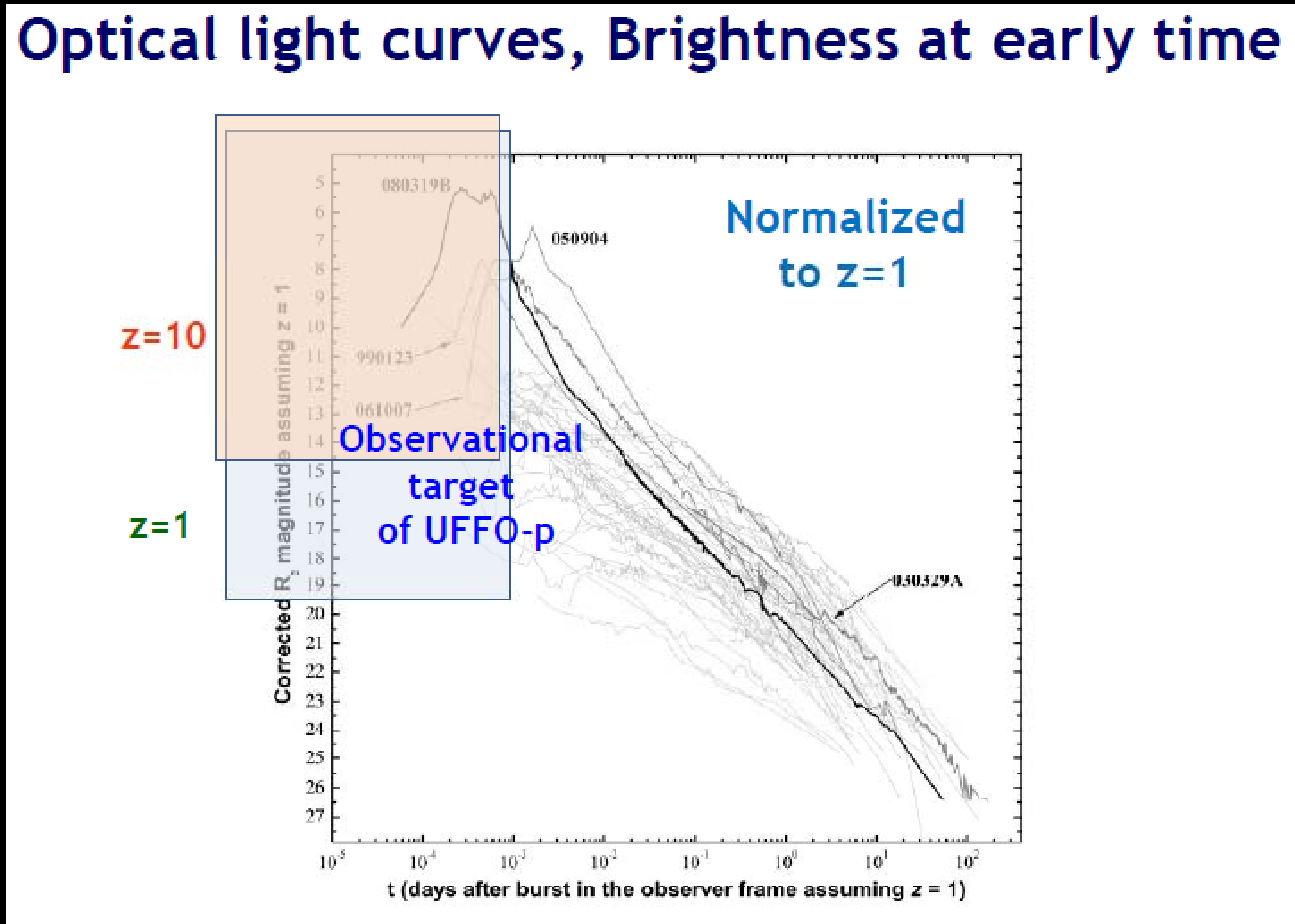
see the various contributions published at the Fall 2012 GRB (Marbella) EDP Proceedings (2013)





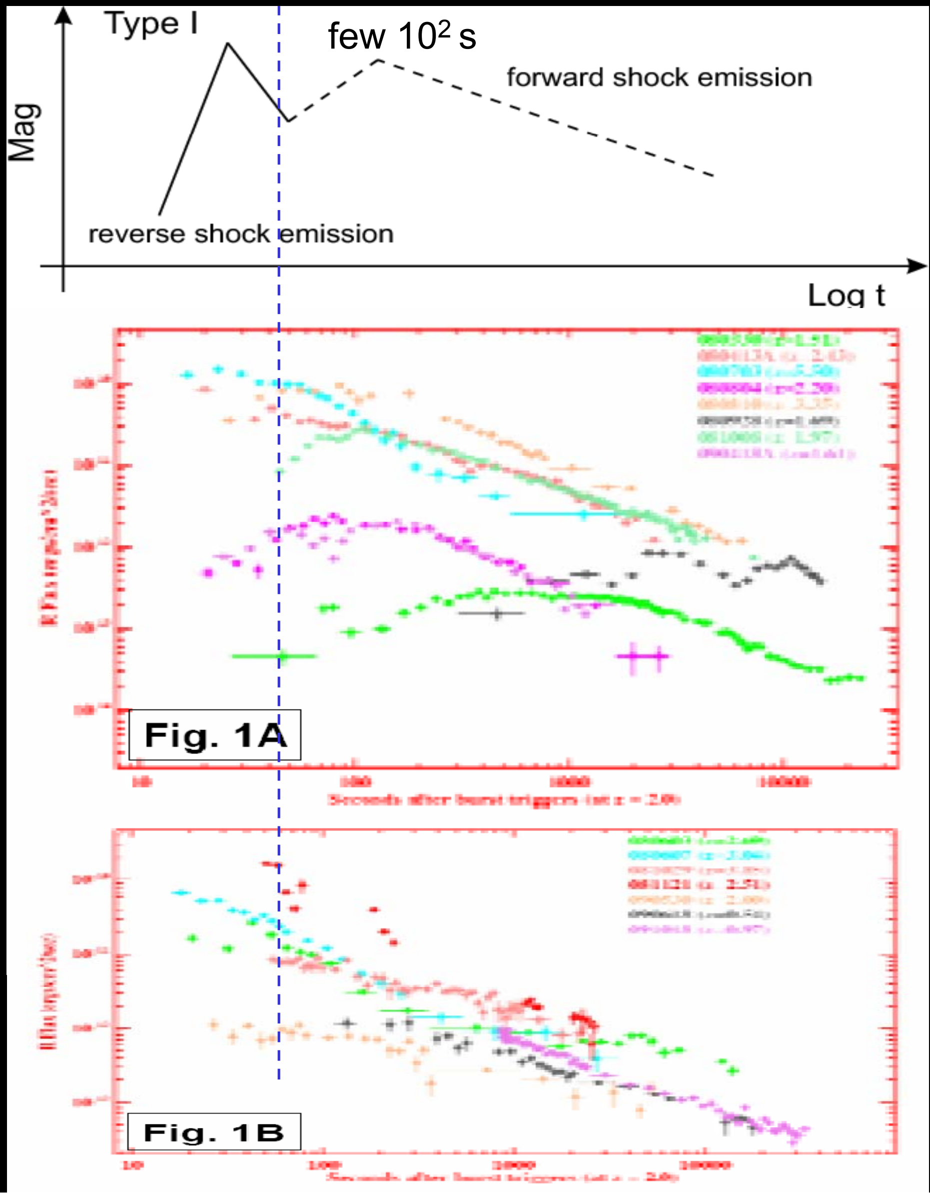
5.2. UFFO-p onboard Lomonosov (9)

UFFO-p Capabilities (2)



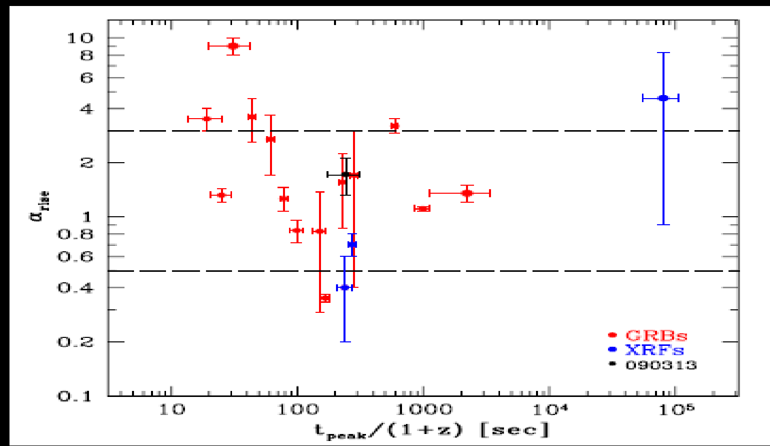
5.2. UFFO-p onboard Lomonosov (10)

UFFO-p Capabilities (3)



Expectation ~20 long GRBs/yr, but ~30% will be dark events

(Melandri et al. 2012)



Melandri et al. (2010)

Optical Imaging in ~3s
(20 x faster than *Swift*):

1 s HE photons collection

1 s position calculation

1 s SMT pointting

Summary

Summary

1. Afterglow emission can be detected in all the electromagnetic range (especially for long-duration events), in all timescales from seconds to months (the later in some cases). A variety of features can be studied by different techniques (photometry, spectroscopy, polarimetry) to gain insight into the progenitors, environments, abundances, metallicities, host galaxies... Multi-messenger information also highly valuable.

2. Automated and Robotic telescopes (such as the BOOTES Global Network) are very useful to study the early phases starting seconds after the trigger. This can be later completed by large diameter telescopes in the optical (eg. 10.4m GTC) and at mm wavelengths (eg. PdBI).

3. *Lomonosov*/UFFO-p is well suited for studying GRB optical emission in the first few seconds with unprecedented sensitivity and time resolution (to be launched in 2015).