Multiwavelength observations of GRB afterglows

Alberto J. Castro-Tirado
(IAA-CSIC Granada)
IAU Symp 279 – Death of massive stars
Nikko, 13 Mar 2012
Outline

1. Brief Introduction: The Afterglow and historical afterglows

2. Afterglow science in long-duration GRBs

3. Automated and Robotic Telescopes for GRB follow-ups

4. UFFO-p onboard Lomonosov

Summary
1. The Afterglow and Historical afterglows
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?
An X-ray afterglow (?) was pinpointed 5 yr before the BeppoSAX detection of GRB 970228.

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

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. Sunyaev
Space Research Institute, Russian Academy of Sciences, Moscow

N. Lund, A. Castro-Tirado, and S. Brandt
Space Research Institute, Lyngby, Denmark

C-T (1994), PhD Thesis
Terekhov et al. (1993), Pis’ma Astron. Zh. 19, 686
1. Historical Afterglows (2)

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! (and reported).

C-T (1994), PhD Thesis

Hurley et al. (2000)

Denisenko & Terekhov (2007)
2. Afterglow science in long-duration GRBs
2. **Afterglow science in long-duration GRBs (1)**

**Reverse and Forward Shocks**

Strength of RS depends on magnetization content of the ejecta

---

**Graphs:**

1. **Type I**
   - Forward shock emission
   - Reverse shock emission

2. **Type II**
   - Reverse shock emission
   - Forward shock emission

3. **Type III**
   - Forward shock emission
   - Reverse shock emission

---

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

---

*GRB 060117* (Jelinek et al, 2006)
2. **Afterglow science in long-duration GRBs (2)**

**Forward Shock (Afterglow) Emission (1)**

Peak time of the rising OA lightcurves $\Rightarrow$ initial Lorenz factor $\Gamma_0$ (Molinari et al. 2007).

The rising lightcurves are also important to understand the onset of the afterglow (Sari et al. 1999): $\alpha \sim 2$ ($v_c < v_{\text{optical}}$) or $\alpha \sim 3$ ($v_c > v_{\text{optical}}$) 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).

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

(Fig. 1B)

(Pandey et al. 2011)
2. Afterglow science in long-duration GRBs (3)

Forward Shock (Afterglow) Emission (2)

**GRB 021004**: Multi-λλλ modelling
(de Ugarte Postigo et al. 2006)
2. Afterglow science in long-duration GRBs (4)

Forward Shock (Afterglow) Emission (3)

(Energy injections everywhere)

GRB 021004 (z = 2.33): modeled by multiple energy injections (de Ugarte Postigo et al. 2005 A&A 443, 841)


GRB 030329 / SN 2003dh (z = 0.168): modeled by multiple energy injections but the initial phase cannot be properly modeled (Guziy et al. 2012, in prep)
2. Afterglow science in long-duration GRBs (5)

Forward Shock (Afterglow) Emission (4)

GRB 060904B: displaying all features on its light-curve (Jelinek et al. 2012)
2. Afterglow science in long-duration GRBs (6)

The energetic SN-GRB relationship (1)

Initial evidence for SN 1998bw/GRB 980425 (Galama et al. 1998, Pian et al.)


An underlying SN modeled for GRB 980326 (also independently proposed) (Bloom et al. 1999, Nat)
The energetic SN-GRB relationship (2)

SNe/GRB reachable with GTC up to $z \sim 1$

2. Afterglow science in long-duration GRBs (8)

The energetic SN-GRB relationship (3)

SNe components give us clues on the nature of the GRB progenitors

GRB 100418A, z = 0.624

GRB 100418A / SN component (de Ugarte Postigo et al. 2012, in prep)
2. Afterglow science in long-duration GRBs (9)

Spectroscopic observations of GRB afterglows (1)

Besides determining the distance scale, opt/nIR spectroscopy is most essential for understanding the GRB environment (abundances, metallicities, etc).

GRB 021004: High resolution spectroscopy revealed several high velocity systems in the range 200-3000 km/s.

(Salamanca et al. 2003, Castro-Tirado et al. 2010, Vergani et al. 2011)
2. Afterglow science in long-duration GRBs (10)

Spectroscopic observations of GRB afterglows (2)

In GRB 021004 ($z = 2.33$), the C1, C2 and D systems naturally explained by multiple shell formed by stellar winds of a WR progenitor after passing through a LBV phase after reaching the Eddington limit. A $\sim 60$ Mo ZAMS progenitor is suggested: O $\rightarrow$ LBV $\rightarrow$ WR $\rightarrow$ SN (Castro-Tirado et al. 2010, A&A 517, A 61).
2. Afterglow science in long-duration GRBs (11)

Spectroscopic observations of GRB afterglows (3)

Important role of the 10.4m GTC

Redshifts determination for GRB 100316A, 110503, 110801A and 110918A. Redshift confirmation for 100816, 110422A and 110918A.

GRB 100316A: redshift determination by GTC (z = 3.2)
2. Afterglow science in long-duration GRBs (12)

Polarimetric observations of different GRB afterglows

They show the varying level of polarized emission in the jet and the geometry

- Detected on a few “classical” GRBs, usually $P = 1-2\%$ (e.g. Gorosabel et al. 2004, A&A 422, 113) and rarely up to 10 % (Steele et al. 2009, Nat 462, 767). ~1.5% for SN 2003dh / GRB 030329 (Greiner et al. 2003).


2. Afterglow science in long-duration GRBs (13)

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 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)
Afterglows at mm wavelengths (2)


See Poster #10 by de Ugarte Postigo
2. Afterglow science in long-duration GRBs (15)

Dark GRBs at mm and sub-mm wavelenghts

GRB 051022: A dark 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, A&A 475, 101).

GRB 090404: VLA and PdBI detection of the afterglow for this dark GRB (C-T et al. 2012). No evident host galaxy.

Success rate of attempted dark GRBs at PdBI (bias-selected): 3/6 (50%)
## 2. Afterglow science in long-duration GRBs (16)

### The SN / GRBs at mm wavelengths

<table>
<thead>
<tr>
<th>Object ID</th>
<th>Flux Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRB 030329 / SN 2003dh</td>
<td>58 mJy</td>
</tr>
<tr>
<td>XRF 060218 / SN 2006aj</td>
<td>&lt; 2 mJy</td>
</tr>
<tr>
<td>XRT 080109 / SN 2008d</td>
<td>0.65 mJy</td>
</tr>
</tbody>
</table>
2. Afterglow science in long-duration GRBs (17)

Ultra-high redshift GRBs at mm wavelengths (1)

GRB 050904 (z = 6.29, Kawai et al. 2006): 1.3 mJy @ 90 GHz.

GRB 080913 (z = 6.7): < 0.4 mJy @ 90 GHz (Pérez-Ramírez et al. 2010, A&A 510, A105).

GRB 090423 (z = 8.2): 0.26 mJy (5.1σ), modelled as a RS (C-T et al. 2012).

Detected 2 (out of 3) ultra-high z events!
3. Automated and Robotic Telescopes and their usage for GRB follow-ups
3. Automated and Robotic Telescopes (1)

Advantages for GRB afterglow follow-ups

Automatization of existing instruments (e.g. PAIRITEL in the US or the 1.23 m CAHA tel in Spain)

* Fast reaction times (~120-200 s for ATs vs 5-30 s for RTs)
* Independent operation

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

The MITSUME robotic telescopes in Japan
3. Automated and Robotic Telescopes (2)

The BOOTES Network of RTs in several continents

BOOTES (Burst Observer and Optical Transient Exploring System), 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 last station (BOO-4) will be officially opened next week in China.

Coordinates
Lat: 26° 41'43"N
Long: 100° 01'47"E
Elev: 3231m
3. Automated and Robotic Telescopes (3)

Advantages for GRB afterglow follow-ups

Jelínek et al. (2010)

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.

GRB 080603B (Jelínek et al. 2012)

(BOOTES-1 & -2 data)
4. UFFO-p onboard Lomonosov
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.

Is it possible to beat this 1 min barrier FROM SPACE?
In UFFO-p, we move the optical path, not the spacecraft with fast slewing mirror system \(\Rightarrow\) much faster (NEW Concept)
Observation of GRBs with early photons from 1 sec after trigger
Two instruments: SMT (Slewing Mirror Telescope) for UV/optical afterglow, and UBAT (UFFO Burst Alert Trigger) for GRB localization & trigger
To be launched in 2012 onboard Lomonosov spacecraft
Size/Mass/Power: 979(L)x409(W)x384(H) / 20kg / 20Watts
4. UFFO-p onboard Lomonosov (4)

UFFO-pathfinder at NIIEM-Russia (Oct 2011)
UFFO-p should detect all long-duration GRBs unless they are extinguished by dust in their host galaxies or at high $z (> 5)$.

UFFO-p Capabilities

See poster # 28 by Heujin Lim

76 GRBs
(Kann et al. 2010)
5. Summary
Summary

1. Afterglow emission can be detected in all the electromagnetic range, 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 are very useful to study the early phases starting seconds after the trigger.

3. *Lomonosov/UFFO-p* is well suited for studying GRB optical emission in the first few seconds (to be launched this year).

4. We are *missing* an X-ray all-sky monitor being able to detect X-ray flashes following the SNe breakouts to record many more XRT 080109-like events. Super-WATCH? LOBSTER?
Fall 2012 Gamma-Ray Burst Symposium

"15 years of Gamma-Ray Bursts afterglows: progenitors, environments and host galaxies from the nearby to the early Universe"

Marbella (Málaga, Spain) 8-12 October 2012

e-mail: grb2012@iaa.es
http://grb2012.iaa.es/

Topics:
Historical Missions
Prompt Emission
Afterglow Emission
Jets Dynamics
Progenitors
Environments
Host Galaxies
Cosmology and the Early Universe
Instrumentation and Techniques
Non Electromagnetic Counterparts

Scientific Organizing Committee
Søren Brandt (DTU, Copenhagen, Denmark)
Alberto J. Castro-Tirado (IAA-CSIC Granada, Spain; chair)
Valerie Connaughton (Univ. of Alabama, Huntsville, USA)
Stefano Covino (INAF Brera, Italy)
Frédéric Daigne (IAF Paris, France)
Kevin Hurley (SSL-UC Berkeley, USA)
Nobuyuki Kawai (Tokyo Tech, Japan)
Sylvio Klose (TLS Tautenburg, Germany)
Kim Page (Univ. of Leicester, UK)
Shashi B. Pandey (ARIES Nainital, India)
I H. Park (Ewha Seoul, Korea)
Tsvi Piran (Racah IoP, Jerusalem, Israel)
George F. Smoot III (LBNL Berkeley, USA)
Vladimir V. Sokolov (SAO-RAS, N. Arkhhyz, Russia)

Local Organizing Committee
Eva Alcohólado-Feltrström (LOC secretary)
Juan Carlos Tello (IAA-CSIC)
Antonio Castro (SMA Málaga)
Ronan Cunniffe (IAA-CSIC)
Javier Corosabel (IAA-CSIC, chair)
Sergi Guzy (IAA-CSIC)
Martin Jeník (IAA-CSIC)
Oscar Lara Gil (IAA-CSIC)
Víctor Muñoz (UMA Málaga; co-chair)
Carlos Pérez del Pulgar (UMA)
Mariló Pérez-Ramírez (U de Jaén)
Rubén Sánchez-Ramírez (IAA-CSIC)