# Observing Application

| | |
|---|---|
| Date : | Jan, 30 2013 |
| Proposal ID : | VLBA/13B-013 |
| Legacy ID : | BB325 |
| PI : | Keith Bannister |
| Type : | Triggered |
| Category : | Energetic Transients and Pulsars |
| Total Time : | 9.9 |

**Prompt high- and low-time resolution VLBA follow-up of GRBs**


## Abstract:

A recent experiment searching for short-duration radio pulses following Swift gamma-ray bursts (GRBs), detected two dispersed pulse candidates with a significance greater than 6 sigma, 10-15 minutes after the GRB trigger. If such pulses could be conclusively associated with the GRB, they could open up a new frontier in extragalactic radio transients. These pulses can be used probe important aspects of the GRBs and their environments, and revolutionary investigations of the intergalactic medium and epoch of reionization. To confirm these detections, we propose using the VLBA to automatically follow-up Swift GRBs and search for short- and long- timescale emission in the minutes following a GRB. The VLBA will provide 10-100 times better sensitivity than previously published results, and the confidence of coincidence and interferometric detections, which would render any detections on much more solid ground than previous experiments.

Our strategy is to observe these events when the VLBA is otherwise unusable, which will have minimal impact on the VLBA observing schedule. We will use the pre-existing highly-successful V-FASTR backend to detect short timescale bursts, and expect to follow up one GRB event every 5 weeks.


## Authors:


| Name | Institution | Email | Status |
|---|---|---|---|
| Keith Bannister | Australia Telescope National Facility | keith.bannister@csiro.au | |
| Walter Brisken | National Radio Astronomy Observatory | wbrisken@nrao.edu | |
| Walter Max-Moerbeck | California Institute of Technology | wmax@astro.caltech.edu | Graduating: 2012 Thesis: false |
| Jean-Pierre Macquart | Curtin University of Technology | J.Macquart@curtin.edu.au | |
| Randall Wayth | Curtin University of Technology | r.wayth@curtin.edu.au | |
| Adam Deller | Netherlands Foundation for Research in Astronomy | deller@astron.nl | |
| Steven Tingay | Curtin University of Technology | s.tingay@curtin.edu.au | |

Principal Investigator: Keith Bannister
Contact: Keith Bannister
Telephone: +61 2 9372 4295
Email: keith.bannister@csiro.au


## Related proposals:

BB317 (previous proposal), BT111 - The VLBA Fast Radio Transients Experiment (V-FASTR)

## Joint:

Not a Joint Proposal

## Observing type(s):

Continuum, High Time Resolution

## Trigger Criteria

Whenever a gammma-ray burst is detected by the SWIFT satellite. I.e. Gamma-ray coordinates network message type 61 (SWIFT_BAT_GRB_POSITION).

## VLBA Resources

**Resource Name:** VLBA

| Details | Stations | Observing Parameters | Correlation Parameters | Special Features |
|---|---|---|---|---|
| **Wavelength:** 21 cm<br>**Processor:** Socorro-DiFX<br>**Observing Mode:** Standard | VLBA ☑<br>Br ☑ Fd ☑ Hn ☑ Kp ☑<br>La ☑ Mk ☑ Nl ☑ Ov ☑<br>Pt ☑ Sc ☑<br>HSA ☐<br>Ar ☐ Ef ☐ GBT ☐<br>VLA-Y27 ☐<br>VLA-Y1 ☐<br>Geodetic | Observing System: PFB System<br>Bandwidth: 32 MHz<br>Baseband Channels: 16<br>Polarization: Dual<br>Agg. Bit Rate (Mbits/sec): 2048 | Correlator Passes: 1<br>Integration Period (sec): 2.0<br>Spectral Points /BBC: 64<br>No of Fields: 1 | Full Polarization ☑<br>Pulsar Gate ☐<br>Convert to Mark4 ☐ |

## Sources:

| Name | Position | | Velocity | | Group |
|---|---|---|---|---|---|
| GRB_placeholder | **Coordinate System** | Equatorial | **Convention** | Radio | GRB1-15 |
| | **Equinox** | J2000 | | | |
| | **Right Ascension** | 00:00:00.0<br>00:00:00.0 | **Ref. Frame** | LSRK | |
| | **Declination** | +00:00:00.0<br>00:00:00.0 | **Velocity** | 0.00 | |
| | **Calibrator** | No | | | |

## Sessions:

| Name | Session Time (hours) | Repeat | Separation | GST minimum | GST maximum | Elevation Minimum |
|---|---|---|---|---|---|---|
| Automatic GRB Follow- | 0.66 | 15 | 1 day | 00:00:00 | 24:00:00 | 0 |

## Session Constraints:

| Name | Constraints | Comments |
|---|---|---|
| Automatic GRB Follow-up | Observations will be scheduled only if no other schedule is operating on the VLBA and if 1 or more VLBA antenna is available and can observe GRB position. | Observations scheduled automatically in response to GRB alert on the Gamma Ray Coordinate Network (Message type: SWIFT_BAT_GRB_POSITION). |

## Session Source/Resource Pairs:

| Session Name | Source | Resource | Time | Figure of Merit |
|---|---|---|---|---|
| Automatic GRB Follow-up | GRB_placeholder | VLBA | 0.66 hour | 14 mJy/bm |

Staff support: Friend Plan of Dissertation: no

**Prompt, high- and low-time resolution VLBA follow-up of GRBs**

*Keith Bannister, Walter Brisken, Walter Max-Moerbeck, J-P Macquart, Randall Wayth, Adam Deller, Steven Tingay*

# 1 Scientific Overview

A recent experiment searching for short-duration radio pulses following *Swift* gamma-ray bursts (GRBs), detected two dispersed pulse candidates with a significance greater than $6\sigma$, 10-15 minutes after the GRB trigger. If such pulses could be conclusively associated with the GRB, they could open up a new frontier in extragalactic radio transients. These pulses can be used probe important aspects of the GRBs and their environments, and revolutionary investigations of the intergalactic medium and epoch of reionization. To confirm these detections, we propose using the VLBA to automatically follow-up *Swift* GRBs and search for short- and long- timescale emission in the minutes following a GRB. The VLBA will provide 10-100 times better sensitivity than previously published results, and the confidence of coincidence and interferometric detections, which would render any detections on much more solid ground than previous experiments.

Our aim is to perform triggered observations of these events during filler time on the VLBA. We will use the pre-existing highly-successful V-FASTR backend to detect short timescale bursts, and expect to follow up one GRB event every 5 weeks.

# 2 Progress update

After receiving a favorable disposition in August 2012, we submitted a VLBA internal development proposal, which was accepted. The development proposal is due to complete in October 2013. So far, we have created a system to automatically create and email VLBA schedule files within seconds of a message from the gamma-ray coordinates network (GCN). Due to VLBA priorities in 2012, we have been unable to use these emails to observe any GRB triggers. The NRAO members on our team (Brisken, Max-Moerbeck) aim to begin integrating our email system with VLBA operations in Feb 2013.

# 3 Scientific Background

Gamma ray bursts are flashes of gamma rays that signal the most luminous explosions in the Universe. To date, no radio emission has been detected in the few minutes before or after a GRB, although the limits are not very strong (Cortiglioni et al., 1981; Inzani et al., 1982; Koranyi et al., 1995; Dessenne et al., 1996; Katz et al., 2003). The rewards for detecting such prompt emission are great. Many aspects of the explosion physics can be probed by measurements of the prompt radio emission, such as the jet opening angle, and Lorentz factor (Macquart, 2007), the density and distance of any intervening scattering material (Lyubarsky, 2008), and the structure of the fireball magnetic field (Sagiv et al., 2004). Additionally, dispersion of a short radio pulse would undergo dispersion in the intergalactic medium, which would not only provide direct evidence for the existence of the majority of the baryons in the Universe (Ginzburg, 1973), but, for bursts of sufficiently high redshift, would also differentiate between different models of cosmic reionization history (Inoue, 2004).

In 2010-2011, the Parkes 12 m telescope was used to search for short-duration radio emission 2–32 minutes after the GRB trigger (Bannister et al., 2012). It observed nine GRBs and detected single dispersed radio pulses with significances $> 6\sigma$ in the 10 to 15 minutes following two GRBs (e.g. Fig 1, Fig. 2). The implied flux density of these pulses is 7 Jy. Simple statistical arguments and a null trial based on randomizing channels on existing data rule out random fluctuations as the origin of these pulses at $> 95\%$ and $\sim 97\%$ confidence levels, respectively. The dispersion measures of both pulses are well in excess of the expected Galactic values, and the implied rate is incompatible with known sources of single dispersed pulses.

The source of these pulses remains unclear, as localized RFI, equipment glitches and atmospheric effects cannot yet be definitively ruled out. In order to confirm or refute the GRB source of these radio pulses, we will use the VLBA to provide coincidence and interferometric confirmations of these pulses at more than 10 times better sensitivity (per antenna) than available with the (Bannister et al., 2012) experiment. The long baselines available to the VLBA will almost definitely rule out site- and equipment-specific sources of false detections. As the SEFD of each VLBA antenna (340 Jy) is more than an order of magnitude superior to the Parkes experiment (3800 Jy), such pulses should be easily detected by the VLBA, if they are truly astronomical.

### 3.1 Fast and slow transient searches

We will perform a search for dispersed pulses at high time resolution using the existing V-FASTR system (Wayth et al., 2011, VLBA project code BT111). V-FASTR operates in a commensal mode alongside the DiFX correlator at Socorro and uses sophisticated machine learning techniques (Thompson et al., 2011) in order to minimize RFI contamination. V-FASTR can produce calibrated images in order to obtain arcsecond localization of candidate pulses. We will use existing V-FASTR observations to characterize the background transient rate.

We will also perform a low-time resolution ($> 1$ s) search for prompt radio emission using traditional VLBI imaging that will far surpass the limits set by previous experiments. The most stringent published limits on prompt emission at low time resolution are those of Dessenne et al. (1996), who based on observations of two GRBs, report upper limits on any radio emission of 16–73 Jy between 5 hrs before, and 2 hrs after the GRB. The $5\sigma$ sensitivity of our proposed experiment will be $\sim 14$ mJy beam$^{-1}$ on similar time scales (1.5 s), which will improve on the sensitivity of the Dessenne et al. (1996) result by three orders of magnitude.

## 4 Technical overview

### 4.1 GRB response operations

Our software currently receives the GRB triggers (Message type 61: SWIFT_BAT_GRB_POSITION), and emails the appropriate schedule file. Our aim in the short term (Feb 2013) is to organize for the VLBA operations team to run schedule file as soon as possible after it is created. In the medium term (Dec 2013) we aim to create a fully automated system that will schedule the observation without human intervention, depending on antenna availability and project constraints.

### 4.2 Slew rate and position uncertainty

The key result from (Bannister et al., 2012) was that the pulses occur roughly 10 min after the GRB trigger. The slew rate of the VLBA antennas will be sufficient to be at any sky location

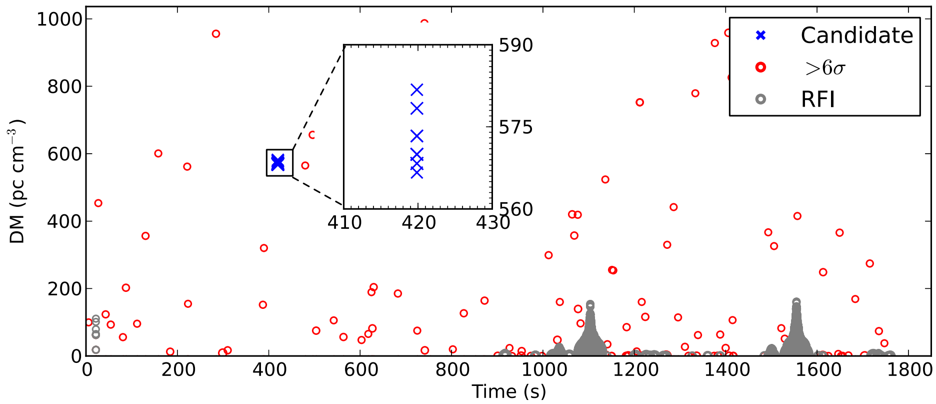


Figure 1: A single, dispersed pulse was detected after GRB 101011A due to a statistically significant clustering of $> 6\sigma$ pulses similar dispersion measures (DMs) and time. In this plot, DM is plotted vs. time for the 2–32 min after GRB 101011A. Isolated pulses $\geq 6\sigma$ appear as red circles, and a candidate comprising a cluster of pulses is indicated by blue crosses, with the size proportional to the S/N. GRB 101011A had a single pulse candidate 524 seconds after the *Swift* trigger at a DM of 569.98 pc cm$^{-3}$, with a significance of 6.6$\sigma$ and width of 25 ms. The time origin of this plot is the time that the telescope first arrived on source, $\sim 2$ minutes after the *Swift* trigger.

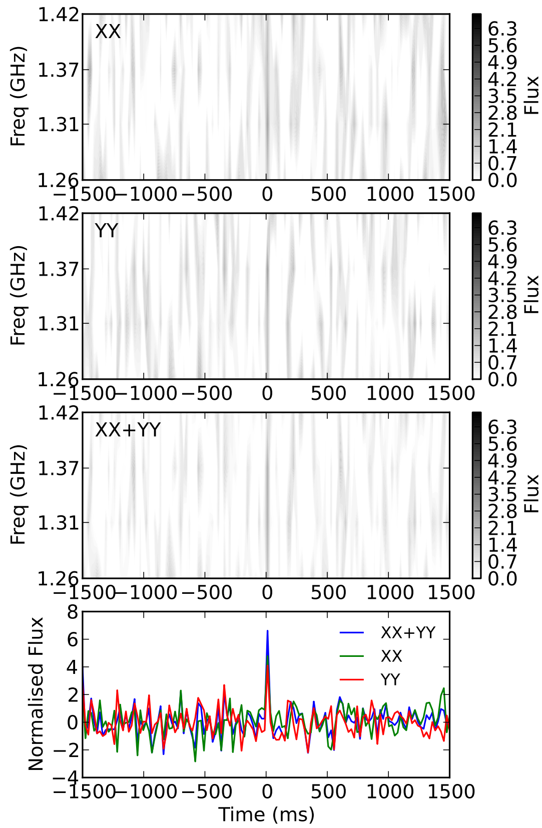


Figure 2: Detail of the 6.6$\sigma$ ($\sim 7$ Jy) pulse detected 524 seconds after GRB 101011A. The top three panels are the dedispersed time series of 4 frequency channels spread across the band. The pulse is clearly detected across all channels, in both linear polarizations (the top 2 panels) and in the sum of the two polarizations (third panel). The bottom panel is the time series where all the frequency channels have been summed. The origin of the time axis is the pulse arrival time.

within 4.5 min, well within the 10 min requirement. Ideally, a rapid follow-up would use a fully automatic system without human intervention, but our initial email-based system will enable us to approach, if not exceed our requirements.

The position uncertainty of *Swift* triggers is 3', which less than the VLBA FWHM beam of 30' at 1.4 GHz and therefore well-matched.

### 4.3 Observing details

Currently, the schedule file includes a continuous 30 min observation of the GRB location at 1.4 GHz, followed by separate 5 min observations of a VLBI calibrator and a bright pulsar (for a transient detection system check). We request the use of all idle, available antennas, as this will give the best chance of accurate localization of a detection. However, we can obtain useful data with any number of antennas (down to 1).

When our automated system is operational, we will use two separate sub-arrays if sufficient antennas are available. One sub-array will observe the GRB location continuously, while the other will also perform phase referencing. This approach will maintain continuous monitoring of the GRB location for the high-time resolution experiment, while simultaneously obtaining obtaining phase referenced observations for the low-time resolution imaging experiment. If there are sufficient antennas available, we may use additional subarrays centered on 1.4 GHz and 5 GHz respectively to obtain spectral indices.

Data will be recorded using the wide-band recording mode (2048 Mbps), although lower data rates (e.g. 512 Mbps) can be used if disk space is a concern. Data will be correlated using the DiFX correlator at Socorro with the V-FASTR system processing the data commensally. The low-time resolution DiFX visibilities will be processed offline for the imaging experiment.

## 5 Time Request

The Bannister et al. (2012) experiment observed 15 GRB triggers from the *Swift* satellite, of which nine were actually GRBs. Of the nine GRBs, dispersed pulses were detected following two GRBs.

We aim to meet or exceed the observations of Bannister et al. (2012), which means we require observations of at least $\sim 15$ *Swift* triggers. With *Swift* trigger rate of $2\,\mathrm{week}^{-1}$ the expected number of triggers above the horizon is $\sim 1\,\mathrm{week}^{-1}$. Assuming the 20% of VLBA time is available for this experiment, we would expect to observe a trigger every 5 weeks, and 15 triggers in 75 weeks (3 semesters). We therefore request that this experiment is scheduled for a further for 2 semesters. If the experiment is operationally a success (regardless of the scientific detection rate) we aim to propose for an additional 2 semesters.

## References


Bannister, K. W., et al. (2012). in prep.

Burke-Spolaor, S., et al. (2011). MNRAS, 416 2465. [ADS].

Cortiglioni, S., et al. (1981). Ap&SS, 75 153. [ADS].

Dessenne, C. A.-C., et al. (1996). MNRAS, 281 977. [ADS].

Ginzburg, V. L. (1973). Nature, 246 415. [ADS].

Inoue, S. (2004). MNRAS, 348 999. [ADS].

Inzani, P., et al. (1982). In R. E. Lingenfelter, H. S. Hudson, & D. M. Worrall, ed., *Gamma Ray Transients and Related Astrophysical Phenomena*, *American Institute of Physics Conference Series*, vol. 77, pp. 79–84. AIP, Melville, New York, USA. [ADS].

Katz, C. A., et al. (2003). PASP, 115 675. [ADS].

Koranyi, D. M., et al. (1995). MNRAS, 276 L13. [ADS].

Lyubarsky, Y. (2008). ApJ, 682 1443. [ADS].

Macquart, J. (2007). ApJ, 658 L1. [ADS].

Sagiv, A., et al. (2004). ApJ, 615 366. [ADS].

Thompson, D. R., et al. (2011). ApJ, 735 98. [ADS].

Wayth, R. B., et al. (2011). ApJ, 735 97. [ADS].