arXiv:astro-ph/0502506v1 24 Feb 2005

The Liverpool Telescope Automatic Pipeline for Real-time GRB Afterglow Detection

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Summary. — The 2-m robotic Liverpool Telescope (LT) is ideally suited to the rapid follow-up of unpredictable and transient events such as GRBs. Our GRB follow-up strategy is designed to identify optical/IR counterparts in real time; it involves the automatic triggering of initial observations, on receipt of an alert from Gamma Ray Observatories HETE-2, INTEGRAL and Swift, followed by automated data reduction, analysis, OT identification and subsequent observing mode choice. The lack of human intervention in this process requires robustness at all stages of the procedure. Here we describe the telescope, its instrumentation and GRB pipeline.

PACS 95.55.Cs – Ground-based ultraviolet, optical and infrared telescopes.
PACS 95.75.Mn – Image processing (including source extraction).
PACS 95.75.Rs – Remote observing techniques.
PACS 98.70.Rz – gamma-ray sources; gamma-ray bursts.

1. – GRB follow-up strategy with the Liverpool Telescope

The LT has a 2-m primary mirror, final focal ratio f/10, altitude-azimuth design, image quality < 0.4" on axis, rapid slew rate of 2°/sec and five instrument ports (4 folded and one straight-through, selected by a deployable, rotating mirror in the AG Box within 30 sec). The telescope began science operations in January 2004 and has entered the robotic (unmanned) operation phase with an automated scheduler in summer 2004. At present, instrumentation (Table I) includes Optical and Infrared imaging cameras. A prototype low resolution spectrograph will be commissioned in 2005 and a higher resolution spectrograph is being developed for 2006.

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TABLE I. – *The Liverpool Telescope instrumentation*

RATCam Optical CCD Camera -	2048×2048 pixels, 0.135"/pixel, FOV 4.6'×4.6', 8 filter selections (u', g', r', i', z', B, V, ND2.0) - from LT first light, July 2003
SupIRCam 1 - 2.5 micron Camera - (with Imperial College)	256×256 pixels, 0.4"/pixel, FOV 1.7'×1.7', Z, J, H, K' filters - from late 2004
Prototype Spectrograph - (with University of Manchester)	49×1.7" fibres, 512×512 pixels, R=1000; $3500 < \lambda < 7000$ Å- from 2005
FRODOSpec Integral field double beam spectrograph - (with University of Southampton)	R=4000, 8000; $4000 < \lambda < 9500$ Å- from 2006

As a National Facility, the LT carries out observations for a diverse range of time-domain related astronomy programmes. However, its robotic control and automated scheduling make the LT especially suitable for rapid response to Targets of Opportunity, such as GRBs (particularly the short bursts, see [1] for details) which have been assigned a high priority in the LT's science programme.

Following a GRB alert from the GRB Coordinates Network, a special over-ride mode interrupts the current observations and triggers an initial GRB observing sequence as quickly as 1 minute after receipt of the satellite alert. As this process is fully automatic, a crucial component of the system is the subsequent pipelined data reduction, analysis and automatic identification of possible GRB counterparts. The diverse range of instrumentation available allows a number of possible follow-up strategies depending on the burst characteristics. The automatic choice of follow-up strategy depends on the output from the pipeline, which is therefore required to be robust and to reliably detect (or rule out) candidate counterparts in real time. In the future, it will be possible to include gamma/X-ray properties in the automatic choice of strategy; currently however the deciding factor is the observed optical properties (e.g. magnitude, variability - see Fig. 1).

The basic overview of the GRB follow-up strategy with the LT is as follows: (i) slew to the position given in GCN alert; (ii) start short optical exposures in about 1 min (reaching limiting magnitudes of $r' \approx 20 - 21$ in t_{exp}= 10 sec – 1 min); (iii) automatic pipeline tries to identify the optical transient; (iv-a) if no candidate afterglow in the optical detected, continue observations with longer exposures in optical and infrared (t_{exp}=10 min giving $r' \approx 23$ and t_{exp}=5 min limiting $J \approx 19$); or (iv-b) if an optical transient is reliably identified: continue with multicolour optical/infrared imaging and, following the successful commissioning of the LT spectrographs, with subsequent spectroscopy, provided the optical transient is brighter than magnitude 15 for prototype spectrograph and 19 for FRODO spectrograph (in t_{exp}= 10 min).

Alternatively, the follow-up can proceed using the detailed/improved information on the afterglow location and magnitude from GCN (Swift, HETE-2, etc).

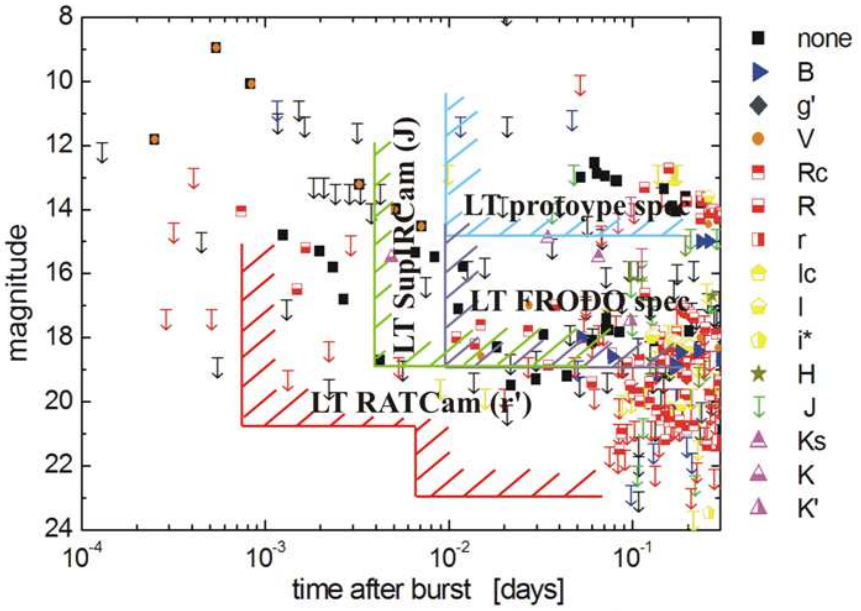

Fig. 1. – Optical and infra-red observations of GRB afterglows in first minutes and hours after the burst (from GCN Circulars): symbols mark detections and arrows upper limits. Shadowed regions indicate areas where the LT and its instrumentation is expected to make a valuable contribution.

2. – GRB pipeline description

The selection of the observing strategy in the LT robotic telescope is automatically performed through the activation of a suitable, preliminary 'detection mode'. The detection mode is a fixed procedure designed to avoid saturation even in extreme, GRB 990123-like cases. The aim is to fully exploit the capabilities of a large robotic telescope and understand quickly whether the afterglow is bright. Briefly, three short integration exposures (e.g. $t_{exp} =$ 10 sec.; filter: r′) are taken and analysed in real-time to:

- extract sources via a customised version of *sextractor 2.3.2* [2];
- elaborate a list of known sources using a local copy of the USNO-B1.0 astrometric catalog [3];
- perform a precise (sub arc-sec) astrometric fit;
- iterate over extracted sources to find possible matches to catalogued ones;
- compile a list of associated sources, and use it to calculate a magnitude offset to be applied to instrumental values;
- compile a list of unmatched sources (raw candidates list);
- review the 'raw candidates list' to rate each object according to a number of options (e.g. elongation, FWHM, distance to a bright star, extraction smoothness etc.);

- adjust the ratings given taking into account the results of on-line queries to 2MASS, GSC2.3 and Minor Planet Database;
- cross-check the three 'refined' lists to locate common objects and/or variable objects;
- compile a 'master list' of rated candidates representing the result of the detection mode run;
- sort the final, master list and elect the winner, if any;
- output the process details into a human readable file to allow the astronomer on duty to quickly release a GCN Circular where appropriate.

The whole process takes usually a few seconds to complete. The telescope is kept in idle mode in the meantime, waiting for the next scheduled instructions. At present, 17 different checks are performed during the 'raw candidates list' to 'master list' process. This number is expected to increase in future releases, and the software has been designed to allow easy integration of new checks. Among the implemented checks, a powerful one is the variability test. Preliminary simulations demonstrate positive results in case of a power-law decay (α = -1 – -2) of a r′ $\approx$ 16–17 object observed at (t-t_0) $<$ 200 sec. Further optimisation is foreseen taking into account real afterglow behaviours as soon as they will become available.

In case no object passes the threshold check, the detection is declared failed and the 'faint' follow-up mode is triggered. The faintest, matched star magnitude (automatically calibrated to USNO-B field objects) gives an immediate estimate of the r′ afterglow flux upper limit. The subsequent schedule makes use of both RATCam and SupIRCam cameras to search for the faint transient or to put stringent optical-IR upper limits.

If one or more objects survives the severe selection, the most probable one is assigned the role of 'official candidate'. Depending on its r′ magnitude, different strategies are activated making use of the available instruments (spectrograph, SupIRCam, RATCam). Either spectroscopy (brightest cases) or multi-colour optical-IR imaging are possible.

3. – Conclusions

Rapid reaction to GRB alerts and the automatic pipeline for afterglow detection combined with 2-m aperture, excellent site and a range of instrumentation and follow-up strategies enable the LT to make early and deep observations of GRB optical and infrared transients (Fig. 1), and thereby contribute significantly to the study of early-time light curves, optically-dark GRBs and short GRBs. Early identification of GRB counterparts with the LT will also be used to trigger further observations on other facilities.

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The Liverpool Telescope is funded via EU, PPARC and JMU grants and the generous benefaction of Mr Aldham Robarts. AG and CG acknowledge their Marie Curie Fellowships from the European Commission. CGM acknowledges the financial support from the Royal Society and MFB is grateful to the UK PPARC for provision of a Senior Fellowship.

REFERENCES

[1] Gomboc A., Mundell C. G., Guidorzi C., Monfardini A. *et al.*, *this volume*, **??** (2005) ??.
[2] Bertin E., *A&A Suppl. Ser.*, **117** (1996) 393.
[3] Monet D. G. *et al.*, *ApJ*, **125** (2003) 984.