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Early GRB optical and infrared afterglow observations with the 2-m robotic Liverpool Telescope(*)

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Summary. — We present the first optical observations of a Gamma Ray Burst (GRB) afterglow using the 2-m robotic Liverpool Telescope (LT), which is owned and operated by Liverpool John Moores University and situated on La Palma. We briefly discuss the capabilities of LT and its suitability for rapid follow-up observations of early optical and infrared GRB light curves. In particular, the combination of aperture, site, instrumentation and rapid response (robotic over-ride mode aided by telescope's rapid slew and fully-opening enclosure) makes the LT ideal for investigating the nature of short bursts, optically-dark bursts, and GRB blast-wave physics in general. We briefly describe the LT's key position in the RoboNet-1.0 network of robotic telescopes. We present the LT observations of GRB041006 and use its gamma-ray properties to predict the time of the break in optical light curve, a prediction consistent with the observations.

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1. – The Liverpool Telescope and RoboNet-1.0

Robotic operation of the Liverpool Telescope (LT) enables an over-ride mode to be automatically triggered when a GRB alert is received from GRB Coordinates Network. Rapid response time (~ 1 min) combined with 2-m aperture and instrumentation (optical, near-infrared (NIR) camera and spectrograph, for details see [1]) make the LT especially suitable for the discovery and investigation of prompt optical/IR emission, short-duration burst counterparts, and optically-dark long GRBs. Early-time optical spectroscopy of

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(**) E-mail: andreja.gomboc@fmf.uni-lj.si bright bursts is also possible, and statistical properties of GRBs and their afterglows will be a natural consequence of the LT's fully-automated rapid response to GRB triggers.

Liverpool John Moores University (JMU) also leads the RoboNet-1.0 project, the goal of which is to integrate three 2-m robotic telescopes—the LT and two Faulkes Telescopes(1)—into a global network optimised for round-the-clock rapid-response science, such as exo-planet searches and GRB follow-up. RoboNet-1.0 is funded by the UK PPARC and includes members of 10 UK university teams in Cardiff, Exeter, Hertfordshire, Leicester, Liverpool JMU, Manchester, Mullard Space Science Laboratory, Queen's University Belfast, St. Andrews and Southampton. The capabilities of the telescope network, particularly in its increased sky and time coverage, will greatly benefit GRB detectability.

2. – Searching for missing optical transients with the Liverpool Telescope

To date, the question of "optically-dark" long GRBs has not been resolved [2,3]. Also, there have been *no* conclusive detections of optical afterglows of short GRBs—the lack of rapid and deep optical follow-up being a key problem. We aim to help answer whether these missing optical afterglows imply a population of bursts that are 1) inherently dark; 2) dust absorbed; 3) at high redshift or 4) just observationally overlooked.

2˙1. *Long bursts.* – Although few GRBs have optical detections in the first ten minutes, two show rapid decay rates (3–5 magnitudes over 10 minutes). Given this rapid decline, it is feasible that the 50% of so-called "optically-dark" long bursts may be easily detected in sensitive, rapid observations with the LT. Alternatively, some bursts may be optically dark due to obscuration or high redshift and therefore identifiable only through infrared photometry. Near-simultaneous optical and NIR imaging with the LT during the first hour of the burst will identify optically-dark, IR-bright low-redshift bursts that are highly obscured. Similarly, optically-dark, but time-delayed IR-bright transients will be identified to $z = 10$. Using the LT's NIR camera, SupIRCam, to obtain a 5-minute exposure will identify an OT with $J < 19$ mag, equivalent to detection of a bright afterglow at $z = 5$, or $H < 18.5$ mag. A 15-minute exposure at H-band ($H < 19$ mag) will identify a bright afterglow at $z = 10$, approximately 30 minutes after the burst.

2˙2. *Short bursts and new GRB classes.* – As no optical/IR counterpart of a short burst has yet been detected unambiguously, their origin - Galactic or extragalactic—and hence their energetics, progenitor and environment are all still unknown. The LT, with its combination of sensitivity and rapid response, is excellently placed to detect these counterparts, which, if they exist, are predicted to be $3 - 4$ mag fainter than those of long bursts [4]; this puts them beyond the reach of many current follow-up programmes.

2˙3. *GRB blast-wave physics with the LT.* – We will use the LT to study GRB blast-wave physics of optically-bright prompt/afterglow emission to $z \sim 4$ by obtaining early multicolour light curves and spectroscopy of bright optical transients of long bursts. These sources are expected to be easily observable and numerous, thus enabling the

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(1) Faulkes Telescopes, funded by the Dill Faulkes Educational Trust, are almost exact clones of the LT. The Faulkes Telescope North (FTN) is situated at Maui in Hawaii and has been operating since the end of 2003. Faulkes Telescope South (FTS), situated at Siding Spring, Australia, achieved first light in September 2004.

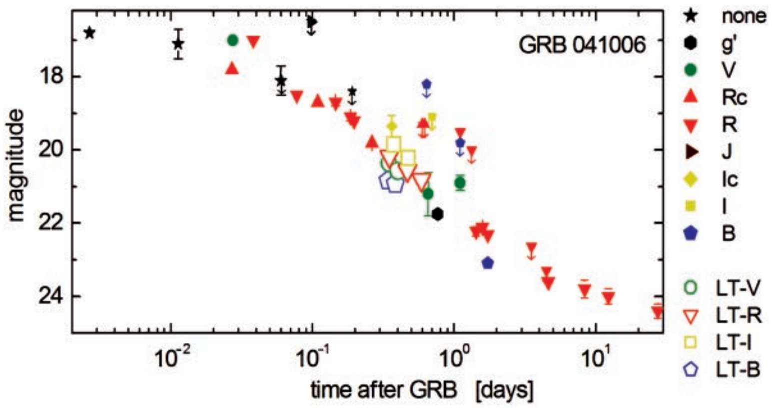

Fig. 1. – Optical light curves of GRB 041006, the first GRB afterglow observed with the LT. Data are taken from GCN Circulars: symbols mark detections and symbols+arrows mark upper limits. Data obtained with the LT are marked with open symbols.

early-time burst afterglows, energetics, evolution and redshift distribution to be derived for a statistically-significant sample. The use of GRBs as standard candles will be tested.

3. – GRB 041006 with the Liverpool Telescope

The first GRB afterglow observed with the LT was GRB 041006 [5,6]. Observations with the LT started 8.2 hours after the burst in BVRI bands [7], see fig. 1, with calibration done using LT standards and cross-checked against photometry reported in Henden [8] and Fugazza *et al.* [9]. The temporal power law decay with a slope of 1.2 is consistent with those of other long-duration GRB afterglows.

3·1. *Prediction of the light curve break time.* – From the best-fit results of the average energy spectrum posted by the HETE-2 team [10] and assuming the validity of the Ghirlanda relationship [11] between the peak energy of the $E\,F(E)$ spectrum of the GRB in the rest frame, $E_{\rm p}^{\rm rest}$, and the collimation-corrected total released energy in the rest-frame 1–10^4 keV, E_γ, we successfully predicted the time of the break in the afterglow power-law decay. The energy spectrum was fitted with a cut-off power law, $N(E) = NE^{-\alpha}e^{-E/E_0}$, with the following best-fit parameters: $E_0 = 100.2$ keV, $\alpha = 1.367$. The peak energy of the $E\,F(E)$ spectrum turned out to be: $E_{\rm p} = (2-\alpha)E_0 = 63.43$ keV, and the corresponding value in the rest-frame therefore resulted: $E_{\rm p}^{\rm rest} = E_{\rm p}(1+z) = 108.6$ keV, where we used the redshift $z = 0.712$ provided by [9].

On the one side, we know both the distance to the GRB and its energy spectrum, so we measure directly its isotropic-equivalent total released energy $E_{\gamma,\rm iso}$ (using the value for the 25–100 keV fluence provided by HETE-2 team, *i.e.* 1.99×10^{-5} erg cm^{-2} [10]):

$$E_{\gamma,\rm iso} = \frac{4\pi\, D_{\rm L}^2(z)}{(1+z)^2} \int_{1/(1+z)}^{10^4/(1+z)} EN(E){\rm d}E \quad \simeq \quad 8\times 10^{52}\ {\rm erg}\,. \tag{1}$$

On the other side, by inverting the Ghirlanda relationship (eq. 2 in [11]) from $E_{\rm p}^{\rm rest}$

we estimate the collimation-corrected total released energy E_γ:

$$E_\gamma = 4.3\left(\frac{E_{\rm p}^{\rm rest}}{267\ {\rm keV}}\right)^{1/0.706} \times\ 10^{50}\ {\rm erg} \quad\simeq\quad 1.2\times 10^{50}\ {\rm erg}\,. \tag{2}$$

Combining the two, we estimate the collimation angle via the formula $(1-\cos\theta) = E_\gamma/E_{\gamma,{\rm iso}}$, to be $\theta \simeq 0.055$ rad. Assuming standard density $n \sim 3\ {\rm cm}^{-3}$ and energy conversion efficiency $\eta_\gamma = 0.2$ (see [11]), the expected break time (eq. 1 in [11]) results:

$$t_{\rm jet,d} = (1+z)\left(\frac{\theta}{0.161}\right)^{8/3}\left(\frac{E_{\gamma,{\rm iso},52}}{n\eta_\gamma}\right)^{1/3} \approx 0.2\ {\rm days}\,. \tag{3}$$

Despite the uncertainty in the estimate of E_p, which was derived without WXM data, the predicted value for the break time is consistent with the range 0.2–0.4 days inferred from the optical afterglow light curve in fig. 1, see also [12] and [13].

4. – Conclusions

In view of many open issues in the field of GRBs and the current small number of early-time optical observations within a few minutes or even an hour after the GRB, it is clear that early multi-colour optical and infrared photometry and spectroscopy can provide valuable information on the nature of GRBs and their environments. With good GRB localizations provided by Swift and other spacecraft, the Liverpool Telescope will follow-up 1 in 6 GRBs immediately following the alert and provide continued monitoring of any fading afterglow. We will obtain information on later time evolution of GRB light curves in collaboration with other facilities, and all-sky coverage will be enabled through RoboNet-1.0.

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