IL NUOVO CIMENTO Vol. 28 C, N. 4-5 Luglio-Ottobre 2005
DOI 10.1393/ncc/i2005-10142-1

BART 2001–2004: An intelligent robotic observatory(*)

M. Jelínek([1])(**), P. Kubánek([2]) and M. Nekola([2])

([1]) *Instituto de Astrofísica de Andalucía - 18008 Granada, Spain*
([2]) *Astronomický Ústav AV ČR - Fričova 298, Ondřejov, Czech Republic*

(ricevuto il 23 Maggio 2005; pubblicato online il 2 Novembre 2005)

Summary. — BART is a robotic observatory located at the Astronomical Institute in Ondřejov, Czech Republic. It is a relatively low-cost (25 cm + two wide-field lenses) device developed for rapid follow-ups of GRBs. Since 2001 when it started to observe, it has done several such observations. Meanwhile, photometric monitoring tasks are performed, using an intelligent selection algorithm. Not only the telescope is automatic, the entire observatory does not require human presence: system prepares the schedule, observes, registers the images and stores them into database without human intervention: human assistance is reduced to maintenance and weather checking. BART is a primary developing platform for RTS2, the robotic telescope operation software, which allows for unattended observation as well as control of the entire observatory.

PACS `95.55.Cs` – Ground-based ultraviolet, optical and infrared telescopes.
PACS `95.75.De` – Photography and photometry.
PACS `98.70.Rs` – γ-ray sources; γ-ray bursts.
PACS `01.30.Cc` – Conference proceedings.

1. – Gamma-ray bursts

Gamma-Ray Burst (GRB) is an amazing phenomenon observable practically through the entire universe. Typically it is a short and intense flash of gamma-ray photons lasting for fraction of second up to few minutes. Total frequency of such events is estimated to be about 1/day, however, according to generally limited field of view of the detecting satellites, the number of detected (and thus possibly followable) events is significantly lower.

(*) Paper presented at the "4th Workshop on Gamma-Ray Burst in the Afterglow Era", Rome, October 18-22, 2004.
(**) E-mail: mates@iaa.es

There is a significant fraction of GRBs, which does have an optical emission: a rapidly fainting afterglow, disappearing into the light of host galaxy within few weeks after the event. Typically these afterglows are very faint—magnitude $R = 20.0$ should be expected for a well-observable event after 24 hours. Although the "late" (*i.e.* more than an hour old) afterglow is pretty well observed and understood, the early phase has been observed only once and there are hints of possible very interesting behaviour.

2. – Observatory

For observatory control we use a custom designed controller for opening/closing the observatory sliding roof, camera and telescope power supply control and dew-remover management. The main server can switch any device on and off, begin the observation in the evening and terminate it in the morning. All devices are thus truly without any power, saving the risk of being damaged by over-voltage or storm during periods of inactivity.

Core of the controller is a single-chip MCU Microchip PIC 16F873. It is connected to a PC with an old-good RS232 serial port. The protocol consists of a simple master-slave scenario, where the PC sends requests (commands, queries) and the controller gives simple replies. The interface actuates outlets and a roof motor by relays. The controller has been developed by our instrumentation lab (MN), fulfilling well our needs of full automation.

3. – Telescope

BART uses a 25 cm, 1:6.3 optical tube with SBIG ST9 CCD camera and Johnson filter set. Estimated detection limit for GRB optical transient is $R = 14.5$ in 10 s exposure and 17 in 120 s exposure. Our Wide-field cameras are projection lenses with $f = 109$ mm, used at 1:2. 3-sigma limit of 120 s image varies around $V = 13.0$.

We use Losmandy Titan robotic telescope mount, which is able to slew at 8 deg/s. While for photometry this mount is nearly perfect, for GRB hunting it presents a compromise: limited slew speed but excellent reliability, precision and price.

4. – Results

BART has during its service followed GRB alerts with varying success. Observational facts about followed alerts are summarized in table I. GRB data were carefully reduced, evaluated, and relevant results were published in GCN circulars. The low number of followed GRBs may be statistically explained by lack of available localizations after CGRO turn-off in 2001 and by relatively low number (40%) of usable nights in Ondřejov (our staff observed quite regular coincidence of GRB localizations with extremely bad weather conditions).

Unfortunately, the main target—observing GRB within seconds after explosion—has not been achieved due to very rare availability of that fast localization in the HETE-II era. We hope Swift and Integral might give us this opportunity soon in the future.

During its idle-time, BART monitors various known high-energy sources for variability, either blazars like 8C 0716+714, which was extensively monitored during its outburst in early 2004, or cataclysmic variables like GK Per, AE Aqr and others. If requested, the telescope can be used to provide fast photometry of a given object.

TABLE I. – *GRB's followed by BART.*

GRB #	BART delay	Total delay	Limits	Notes
GRB 020124	daytime	11.5 h	$R > 14$	long HETE delay
GRB 020305	30 m	10.5 h	$R > 14.3$	30 minutes waiting for night
GRB 020317	90 s	58 m	$R > 13.5$	dark GRB
GRB 020331	daytime	5.5 h	$R > 12.5$	daytime GRB, bad weather
GRB 030824	30 m	10.5 h	$R > 14.3$	
GRB 031111A	15 s	30 s	$I > 13$	overexposed, limit for $T = 4$ h
GRB 031111B	16 s	1.2 h	$R > 14.5$, $I > 14.2$	close to the Moon
GRB 031216	11 m	11.2 m	$R > 15.0$, $I > 14.6$	
GRB 040403	daytime	2.5 h	$R > 10$, $I > 10$	clouds
GRB 040425	daytime	−2 h	$R > 12.5$, $I > 13.0$	pre-limit
GRB 040606	daytime	5.5 h	$I > 12.0$	limit
GRB 040717	daytime	11 h	$R > 13.3$, $I > 13.1$	limit
GRB 041218	weather	25 h	$R > 13.3$, $I > 12.0$	limit
GRB 041219	weather	22 h	$R > 13.5$, $I > 12.2$	limit

5. – RTS2

5˙1. *RTS2 evolution from software point of view.* – RTS2 is based on RTS1. RTS1 was Python-based scripting system for telescope control. It was developed in years 2000-2001, and used on BART till early 2003. It offered WWW based user interface. It processed incoming email containing burst notices, which were put to observation list and observed when new observation was selected.

RTS2 is an attempt to learn from lessons gained on RTS1. It was designed to achieve the following goals: 1) allow multiple process to access devices, 2) use database for storing observation requests and results, 3) allow priority control of devices, so one process can at any time interrupt running observation—that is useful for GRB observations, 4) make closed-loop guidance possible, 5) enable automatic camera focusing, 6) make it customisable to fit on any telescope system one can found.

To keep those goals, it was concluded that it would be easier to implement small parts of the system as rather independent daemons, which would communicate on a TCP/IP network, rather then developing one master process, which wound be able to handle all operations.

5˙2. *RTS2 components.* – In an RTS2 system, one can found following basic kinds of components: *Central* server, which hosts lists of all devices, gives authorisation to clients, and synchronise priority access to devices. *Devices* daemons, one for each device. Devices are mostly mounts, domes and CCD cameras. *Commanding* processes, which serves either to real-time monitoring, or carried out observation. There are usually two clients running—one for long-time observations, called planc, and one for GRB observations, called grbc. When grbc receives from GCN a GRB position, it interrupts planc observations and starts to carry out its own observations. *Monitoring* client processes, which enable user to monitor the whole system and use commands to control it (move the mount, take image on CCD camera and display the resulting images).

5˙3. *RTS2 FITS DB*. – In database are kept tables containing information about targets, performed observations, and processed images.

After some short investigations, we decided to use PostgreSQL as primary database, which appeared at that time to be the most advanced open-source database. We implemented our own custom type, which holds WCS information. We provided interface for that custom type to function isinwcs from wcslibs, so one can quickly search for images which contains given object of interest. That search is quite fast—it takes few seconds to search database of more than 30000 images from BART telescope.

5˙4. *RTS2 performance on BART*. – Since introduction of RTS2 on BART in early 2003, more than ten thousand images were acquired and thousands of observations were performed. More than 10 GRBs were successfully observed, putting some high limit to OT brightness.

5˙5. *RTS2 use on other systems*. – RTS2 is used for BOOTES GRB-targeted telescopes in Spain. It is a platform for currently constructed optical monitoring telescope FRAM for Pierre-Auger observatory in Argentina. It is also used by Dublin university for South-Africa based GRB monitoring telescope.

As the RTS2 source codes are available under GPL, we encourage community of modest-size telescopes looking for a way to automate their nightly workload to have a glance on it. Although there is still some work in progress, it is easier to start from something that is already working rather than from scratch.

6. – Automated data reduction

Obtained images are passed through a pipeline that provide image correction (dark and flat field), star detection (using Sextractor), registration and astrometric solution (with our own software), rough photometric calibration and new object detection. We reach a R-filter limiting magnitude of 16.0 with a 20 s exposure with telescope and about 13.5 with a 120s exposure with the Wide-Field camera.

7. – Conclusions

We have designed, built and programed a robotic telescope for catching GRBs. It slowly develops from a low-cost, serially produced device (we used Meade LX200) to a more robust, universal, intelligent robotic system, giving us the possibility of unattended observations throughout several nights with significantly pre-reduced output.

Observing prompt GRB emission in 2001-2004 has shown up as quite non-demanding business (giving us virtually no chance), so other targets had to be found to fill in the observation time, which leads to a lot of important changes in the controlling software. Thanks to this we today can do automated photometry, real-time pipelined processing, and the system is really claimed to be universal.

* * *

We acknowledge supported by the grant number 3003206 of the Grant Agency of the Academy of Sciences of the Czech Republic.