Izbruhi žarkov gama (Gamma-Ray Bursts – GRBs) so nenapovedljive, kratke (0,01 - 1000 s) a izjemno silovite eksplozije v vesolju, ki jih detektirajo sateliti (trenutno najpomembnejši so Nasina Swift in Fermi ter Esin INTEGRAL). Odkriti so bili v poznih 1960-tih in so ostali neznanka naslednjih 30 let. Danes vemo, da se dogajajo v oddaljenih galaksijah: dolgi GRB-ji (ki trajajo več kot 2s) po vsej verjetnosti nastajajo v "kolapsarjih" (v tem modelu se jedro masivne, hitro vrteče zvezde sesede, pri čemer nastane črna luknja); medtem ko kratki GRB-ji (ki trajajo manj kot 2s) verjetno nastanejo pri "zlitju" dveh neutronskih zvezd ali/ali črnih lukenj.

Nova tehnologija omogoča satelitom, da detektirajo, določijo položaj in sporočijo točen položaj GRB-ja na Zemljo preko "Gamma-Ray Burst Coordinates Network" v manj kot minutih. Optični teleskopi na Zemlji opazujejo položaj GRB-jev in detektirajo njihove t.i. optične afterglowe, ki tipično ugasnejo v nekaj urah. Kratko trajanje optičnih afterglowov zahteva, da se opazovanja s teleskopi pričnejo čim prej. Zato so po svetu razvili številne robotske teleskope, ki se avtomatično odzovejo na sporočilo s satelita in pričnejo z opazovanji. Trije največji med njimi (s polmerom zrcala 2 metra) so teleskopi Liverpool, Faulkes North in Faulkes South, s katerimi opazujemo optične afterglowe od leta 2004 v sodelovanju z Liverpool John Moores University.

GRB-ji so ena najbolj vročih tem današnje astrofizike, o čemer priča posebej GRB-jem posvečen Nasin satelit Swift. Zahvaljujoč Swiftu, ki je bil izstreljen novembra 2004, imamo sedaj z vsakim dnem rastočo "multi-wavelength" bazo podatkov o GRB-jih, ki nam že prinaša mnoga pomembna odkritja. Razumevanje GRB-jev je za astrofiziko pomembno v okviru evolucije zvezd, ki pripelje do takšnih katastrofalnih dogodkov, študija okolja v drugih galaksijah (lastnosti plina in prahu v galaksijah) pa vse do študija zgodnjih galaksij in zgodnjega vesolja, saj nam GRB-ji zaradi svoje izjemne moči (podobno kot kvazarji) služijo kot edinstvene kozmološke "sonde", ki "osvetlijo" sicer šibke oddaljene galaksije. Doslej najbolj oddaljen znani objekt v vesolju je GRB 090423, ki leži pri kozmološkem rdečem premiku z=8,2 oz. 13 milijard svetlobnih let daleč. Za širšo fiziko so GRB-ji pomembni v okviru študija fizike relativističnih udarnih valov, kot vir kozmičnih delcev, nevtrinov, fotonov z TeV energije ter za potencialno detekcijo gravitacijskih valov.
Swift, Fermi and Gamma Ray Bursts

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Introduction

Gamma rays are electromagnetic radiation with frequency above $10^{19}$ Hz. In the universe, they are produced in different kinds of objects, including active galactic nuclei, pulsars, and supernova explosions. The shortest known phenomena in gamma rays are Gamma-Ray Bursts (GRBs). GRBs are unpredictable, brief (0.01-1000 s) but extremely powerful explosions in the universe, detected by satellites (currently most important are NASA’s Swift and Fermi and ESA’s INTEGRAL). They were first detected in the late 1960’s by military satellites monitoring compliance with the nuclear test ban treaties. With the publication of results from the Vela and Konus satellites several years later [1], this became public information and it triggered an avalanche of theoretical models for their explanation - in 1994 there were more than a hundred models [2]. However their nature remained a complete mystery for three decades, mainly because they remained detectable only for tens of seconds and exclusively at gamma-ray energies [3].

The important question of distance to GRB sources (and consequently their energy) has been under debate for a long time. Results from the Compton Gamma-Ray Observatory (launched in 1991), and its Burst and Transient Experiment, which recorded over 2700 bursts, showed that GRBs are isotropically distributed across the sky, therefore suggesting the cosmological origin of GRBs [4].

A great breakthrough happened in the last years of the 20th century with the discovery of GRB afterglows and their host galaxies. The Italian-Dutch satellite BeppoSAX was able to produce the first rapid and small error boxes of GRB positions in the sky. This was a crucial breakthrough because when these small (arcmin) error boxes of GRB were observed in other wavelengths, longer-lived fading afterglows were found. In 1997, BeppoSAX detected the first X-ray afterglow coinciding with the position in the sky of GRB 970228 [5]. Numbers indicate the date of the burst: GRB YYMMDD. In case of more than one burst occurring on the same day, letters a, b, c... are used to discern them.). This was also the first GRB with an optical counterpart detected [6]. Further observations revealed that it was placed in a host galaxy at cosmological redshift $z = 0.7$. Since then, distances and host galaxies of more than a hundred GRBs were found. Some of those turned out to be among the most distant known objects in the Universe.

The discovery that GRBs are occurring in distant galaxies, together with their observed luminosity, led to the realization that these immense explosions are the most luminous ($E_{iso} \sim 10^{44-47}$ J) transient objects known in the Universe and represent the most significant new astrophysical phenomenon since the discovery of quasars and pulsars. Although bursts exhibit a variety of complex and irregular flux curves, they can be separated into two main categories depending on their duration (in gamma rays): short GRBs ($t_{90} < 2s$) and long GRBs ($t_{90} > 2s$).

Current consensus on the processes occurring in the GRB explosion is that, given the huge release of energy in gamma-rays in a few seconds, the compactness problem (the huge pair-production optical
depth could not be reconciled with the observed gamma-rays) can be solved only by invoking relativistic bulk motion, i.e. an emitting region moving toward us with an ultra-relativistic Lorentz factor ($\Gamma \sim 10^2$). According to the so-called "fireball" model [7,8], the gamma-ray pulses observed during the prompt emission are thought to be the result of interactions between different relativistic shells with different Lorentz factors (internal shocks), while the afterglow emission at longer wavelengths is interpreted as the result of the late interaction between these expanding shells and the surrounding interstellar medium (external shocks). Alternative interpretations of the gamma-ray pulses as due to external shocks are not definitively ruled out, although it seems more problematic to explain some of the observed GRBs properties.

The nature and origin of these explosions is at present still an open question. There are observations indicating that (at least some) long GRBs are connected to highly energetic supernovae and with that supporting the "collapsar" model (in this model GRBs are produced in the process of core-collapse of a rapidly rotating massive star, which produces a black hole and launches an ultra relativistic explosion). Among current models for short GRBs the most accepted is that they occur in a "merger" of two neutron stars or/and black holes.

Detection and follow-up observations of GRB’s optical afterglows

Since gamma rays do not penetrate the Earth’s atmosphere, special satellites above the atmosphere must be used for their detection. The Swift satellite is a special satellite dedicated to GRBs. It has three telescopes on-board: Burst Alert Telescope, X-Ray Telescope and Ultra Violet Optical Telescope [9]. Other important satellites for GRBs detection are ESA’s INTEGRAL and NASA’s Fermi satellite.

![Diagram of GRB detection and follow-up observations](http://www.astro.ljmu.ac.uk/research/ltcartoon.gif)

Figure 1: The Liverpool Telescope receives a GRB alert from the Swift satellite via the GCN network. It autonomously commences observations of the possible optical afterglow. LT TRAP automatically analyses obtained images in real time. Images and results are put on a special web page, where they can be downloaded by astronomers in Liverpool, Ljubljana or elsewhere. (http://www.astro.ljmu.ac.uk/research/ltcartoon.gif)
New technology enables the satellites to detect, locate and send accurate GRB position to ground via Gamma-Ray Burst Coordinates Network (GCN)—in less than a minute. Optical ground-based telescopes follow-up GRBs and detect their so-called optical afterglows, which typically fade away in a few hours. Brief duration of optical afterglows demands that telescope observations start as soon as possible. For this aim, a number of robotic telescopes were developed around the world. Since 2004, we use (in collaboration with the GRB group at Astrophysics Research Institute, Liverpool John Moores University), three largest robotic telescopes in the world (with 2 meter mirror diameter): Liverpool Telescope situated at Roque de los Muchachos Observatory on Canary island La Palma, Faulkes Telescope North at Mauna Kea, Hawaii, and Faulkes Telescope South at Siding Spring in Australia. Combination of their robotic control and automated scheduling, together with their aperture and the range of instrumentation (optical and infrared cameras with a selection of filters, and a RINGO polarimeter on the Liverpool Telescope), enables the study of prompt optical and infra-red emission of GRBs afterglows to much fainter magnitudes than smaller robotic telescopes can reach, while early polarimetry provides additional tool to test current models of GRBs and their environment.

A vital component of a successful rapid follow-up strategy is obtaining observations without any human intervention. We use the following fully-automated procedure: following the GRB alert issued by a satellite (INTEGRAL or Swift) and received from the GCN via socket connection, a special Over-Ride mode is automatically started (interrupting any currently on-going observations). This points the telescope to the location of the GRB in the sky in about 1-3 min after the initial event and starts the first sequence of short exposures. As soon as these initial images are acquired, the GRB pipeline, called LT TRAP, is invoked in order to process them and to look for possible optical transient candidates. The pipeline automatically detects new sources and gives their light curves in real time. For more details, we address the reader to the paper devoted to it [10].

Results of GRB optical follow-up observations

To date we observed over 100 GRBs. Some results derived from our sample of observed GRBs can be found in [11] and elsewhere in the literature. Among most prominent results of these observations are: GRB 050502a [12], GRB 060206 [13], GRB 061007 [14], GRB 070419a [15] and GRB 061126 [16].
Magnetization and polarization

In the case of GRB 061126, we found that the optical afterglow can be described as produced by two components: a forward shock and a reverse shock. So far there was only a handful of similar GRBs optical afterglows observed (Figure 2) [17]. Among them was also a “naked eye burst” GRB 080319B [18]. Theory suggests that this can occur if the magnetic energy density in the reverse shock is equal to or larger than that in the forward shock [19,20]. The role of magnetic field in GRB explosion and magnetization of resulting outflow is a fundamental and yet unsolved issue of GRB physics. Theoretical models predict that magnetized outflow produces emission which should be polarized [21]. Therefore, polarization measurements at very early times are of key importance to distinguish between different models, and may prove to be a truly needed independent probe of the physical conditions of the GRB afterglow. To this aim the RINGO polarimeter was developed and used on the Liverpool Telescope. In the case of GRB 060418, we succeeded to measure the early polarization of the optical afterglow just 203 s after the burst [22]. This was 100-times earlier than the polarization measurement of any other GRB. Our results show that the polarization was less than 8%, which rules out the large scale ordered magnetic field in this GRB.

Figure 2: Optical afterglow of GRB 061126. Afterglows of GRB 990123, GRB 021004, GRB 021211, GRB 041219A, GRB 050525A, GRB 050904, GRB 060111B, GRB 060117, and GRB 080319B are shown schematically for comparison.
Figure 3: Sky images of the GRB 060418 location, from left to right: before the GRB; exposure with the RINGO polarimeter 3.6 min after the GRB; image taken 12.5 min and 6 hours after the GRB, respectively. Location of the optical afterglow is marked with GRB-AG.

Conclusions

GRBs are one of the hottest topics in astrophysics today, witnessed by the NASA’s satellite Swift, dedicated to GRBs, satellite Fermi, and ESA’s INTEGRAL. Thanks to the Swift, which was launched in November 2004, we now have a growing multi-wavelength GRB database, which is already bringing many important discoveries. For astrophysics it is important to understand GRBs in view of the stellar evolution, which can lead to such catastrophic events, study of galactic environment (dust and gas properties in galaxies) and also the study of early galaxies and early universe. Namely, GRBs can be, due to their extreme brightness (similar as quasars), used as unique cosmological probes, which illuminate otherwise dim distant galaxies. The farthest known object in the universe to date is the GRB 090423, which lies at cosmological redshift of z=8.2 or 13 billion light years away. For physics in general, GRBs are important for the study of relativistic shock wave physics, as a source of cosmic rays, neutrinos, photons with TeV energy and for the potential detection of gravitational waves.

Bibliography: