THE GAMMA-RAY BURST HUNT AT LA SILLA
THE TAROT-S VERY FAST MOVING TELESCOPE

The study of cosmic Gamma-Ray Bursts (GRBs) is an important challenge for the understanding of the formation of black holes and for the star formation and evolution in the early universe. GRBs are also an invaluable cosmological probe. ESO has agreed to install a set of robotic telescopes at La Silla, TAROT-S and REM (Chincarini et al., see page 40). TAROT-South is a very fast moving (1s) optical robotic observatory able to observe from the beginning of the explosion. The spacecraft fleet detecting GRBs will send timely signals to TAROT, which in turn will be able to give a sub-arc second position to the community. The data from TAROT-S will also be useful to study the evolution of GRBs, the physics of the fireball and of the surrounding material.

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Since the late seventies, ESO has pioneered the study of Gamma-Ray Burst (hereafter GRB) sources. Deep searches of GRB error boxes have been performed at the 3.6 m and many other telescopes at La Silla. At that time, they were localized by the first interplanetary network (IPN), and getting a position could take months. However, European groups were among the first involved in the GRB optical and infrared counterpart hunts. One of the first systematic surveys of GRB error boxes was aimed at searching for events recurring in four error boxes. The GRB Monitoring System (GMS) was approved in 1982, and installed in a small building lying down the hill from the 3.6 m. Now time has passed over the GMS, some of these telescopes have been reused by ESO for education and public outreach purposes, and, at La Silla, the building is known as the "Sarcofago" (figure 1).

While no mummy has awakened, the Sarcofago will soon reopen every night to resume its former activity as a GRB optical counterpart spotter: a duplication of TAROT (Télescope à Action Rapide pour les Objets Transitoires – Rapid Action Telescope for Transient Objects; figure 2), already in operation at the Calern Observatory in France, will be installed by the next Chilean summer. Able to start an observation within a second, TAROT-South will observe GRB sources in the optical range, while the event may be still active in Gamma-Rays. TAROT-S will be a wide field, very fast companion of the Rapid Eye Mount (REM – Chincharini et al., this issue), more specialized in the study of the infrared range and broad-band spectroscopy. Both experiments form the Fast Robotic Observatory System for Transients (FROST).

ADVANCES AND QUESTIONS

Since the results of the BATSE experiment onboard the Compton-GRO spacecraft and of the Beppo-SAX satel-

Figure 1: *The GMS building, alias the "Sarcofago", located down the hill of the 3.6m telescope, in front of the new La Silla control room. It will host the TAROT-S experiment (photography M. Lopez / CNRS).*

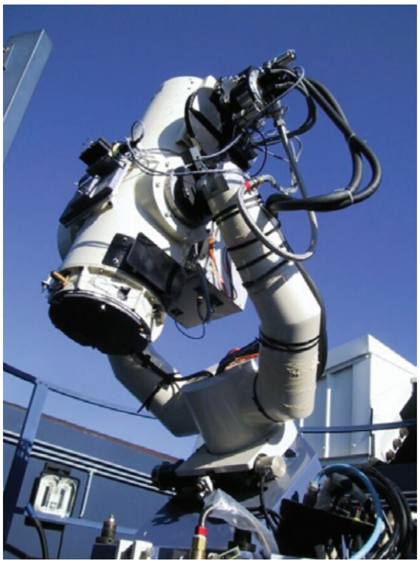

Figure 2: *The TAROT telescope at the Calern Observatory (France) has already given results from the observation of sources detected by the BATSE, HETE and INTEGRAL experiments. TAROT-S is a duplication of this robotic observatory (photography M. Boër / CNRS).*

lite, many advances have been made in the field of cosmic Gamma-Ray Burst sources (see companion paper in this issue, Chincharini et al.). It is now known that they lie at cosmological distances and that they reach a tremendous luminosity, about 10^{51} – 10^{52} ergs per event. This happens in two steps: first a powerful burst of hard radiation, the prompt GRB, is emitted, and may last from tenths to hundreds of seconds; at some point, a much fainter decaying emission takes over from the prompt emission, and is called the afterglow. Finally, in several cases, a supernova has appeared, confirming the association of a large part of the bursters with the final stages of massive star evolution.

Because of opacity problems, what we see is not the initial release of energy, but most probably the result of the shocks produced by the ultrarelativistic ($\Gamma \geq 100$) fireball. We are in a position to observe the result of the blast wave produced by the explosion of the bomb, but the initial event is not directly accessible to us. Though the "standard fireball model" has been a powerful tool to understand the physics of GRBs and their panchromatic emission both prompt and delayed (the afterglow), many questions still remain to be answered, and a full picture of GRBs as a whole remains to be drawn. As an example little is known about the so-called short-hard class of bursts: they last about a second or less, have a spectrum harder, on average, than the longer GRBs, and have not been seen at long wavelengths.

Another problem is why half of the GRBs are not displaying an afterglow (the so-called "dark GRBs")? Are dark GRBs only "optically dark"? While the data from the REM experiment will give hints at IR wavelengths within a minute after the GRB alert, it is important to get the full picture in order to determine, from the first seconds of every event, the reason of the absence of long wavelength emission: is it due to the redshift of the source? to its location inside a high density environment? Is it connected to the way the GRB machinery works or how it is seen by the observer? Does dark GRBs emit at all, or does the afterglow decays so fast that it quickly becomes invisible to any telescope? On that last point, data acquired by the existing TAROT system (Calern – France), give a tight constraint on the light curve of several afterglows (figure 3).

One important milestone is the transition between the prompt emission and the afterglow. It is a direct measure of the beginning of the external shock, and of the medium surrounding the GRB source itself. These observations, not only requires a telescope able to react quickly to an alert, but also a fast sampling of the signal, i.e. a rapid image acquisition rate. With a dead time of only one second, TAROT is able to acquire a seventeenth magnitude, four million pixels image every ten seconds. After the SWIFT launch TAROT and REM will observe a GRB source location every ten days: this will allow a precise light curve to be obtained from the prompt event to the afterglow, and the determination of the precise point when the decaying emission starts.

One of the major roles of TAROT-S will be to quickly detect the source (within one second after the alert), and to derive a precise position. At present, with TAROT-Calern, we reach routinely accuracy better than one arc-second after a standard processing time of one minute. This position will be transmitted in real time via the net, and will be available to other instruments at ESO. This means that within about a quarter of an hour, while the source is still bright, high or medium resolution spectroscopy may be performed on, deriving not only an accurate redshift, but also physical quantities. Equally important is the acquisition of polarimetric data, providing an insight in the geometry and emission processes of the fireball. It should be noted that evidence has been seen for strong evolution of the source polarisation, though this point still lacks confirmation. The conjunction of the data from TAROT-S and REM will allow optimising the choice of the instrument configuration on large telescopes.

We note also that the data on GRB afterglows have been acquired by a number of telescopes with various accuracy and calibration procedures. Since these sources are highly variable, and that variability contains information on the source physics, on its environment, on the host galaxy, and eventually on the line of sight, it is of paramount importance to have a consistent set of data well calibrated with standard procedures. For the first hours of the GRB, TAROT will give a precise relative photometry. Since it is expected that larger telescopes at ESO will take over to relay from TAROT and REM after that time, a set of combined measures will be available, giving for the first time an accurate picture of a GRB light curve from the first seconds to several tens of hours at least.

THE TAROT-SOUTH ROBOTIC OBSERVATORY

The "first" TAROT (figure 2) is in operation at the Calern observatory (Observatoire de la Côte d'Azur) since 1999, and has observed GRB source locations from BATSE, HETE and INTEGRAL. We decided to keep for TAROT-S the same characteristics, i.e. a very fast moving (80°/s), wide-field (2° - figure 4) telescope: not only this eases the duplication,

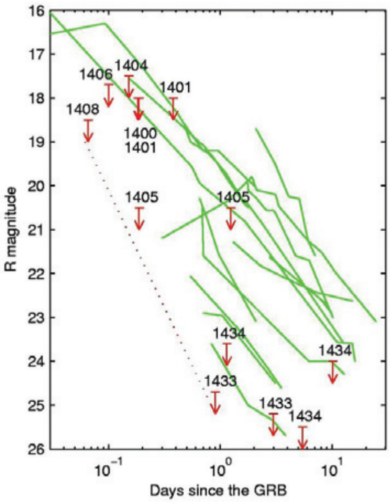

Figure 3: *Dotted line: upper limit on the light curve of the GRB 020531 afterglow. The arrows are the upper limits from individual measurements with the GCN Circular number (1408 for TAROT). For comparison, the continuous green lines are the light curves of other events: the GRB 020531 light curve has the tightest limit for a "dark" GRB.*

Table 1: *Summary of the main technical features of TAROT.*

Optical configuration	Newton hyperbolic
Telescope aperture	25 cm
Speed ratio	f/3.5
Pointing speed	Up to 80°/s
Acceleration	Up to $120°/s^2$
Pointing time	1 – 1.5s
Filter wheel	Clear, B, V, R, I, custom
CCD device	Thomson THX 7899 MCRH
CCD size	2048 x 2048 pixels, 29 x 29 mm
Pixel size	14 µm, i.e. 3.5″
Field of view	2°x2°
CCD operating temperature	-45°C
Limiting magnitude in 10s	R = 17
Limiting magnitude reached	R = 20 (Calern)
Readout speed	2 – 0.5s (full frame)
Readout noise	Prototype $14e^-$, expected final $10e^-$
Actual image processing time	1 minute average

but also TAROT-S will still be able to work with SWIFT, INTEGRAL and HETE, as well as with the forthcoming GLAST, AGILE and many satellites which may be launched during its operational life. Apart from the precision in coordinates, the requirements on an automatic observatory aimed at the study of GRBs have not much evolved: it should react as quickly as possible, and give deep images of the sky at the fastest possible rate. This is still challenging, and the compromise made for TAROT was to have a compact, fast telescope. The telescope is usually on target within one second, whatever its position actually is, probably the shortest time for a telescope dedicated to the observation of GRBs, and quite important for the study of the early behaviour of these sources. Table 1 displays the main technical features of TAROT.

The overall software architecture will be the same at Calern and ESO. The advantage is that the cost and development times are drastically reduced, while the instrument which will arrive at La Silla will be fully operational. Additionally, any change may be tested at Calern, where we have easy access before implementation at ESO, reducing the risk and the load on the teams, both in Europe and at ESO. Any software change may be remotely implemented at no risk, and with no operational interruption.

The software chain is detailed in figure 5: a first software, the AUTOMATE takes care of the housekeeping, of the observatory status and health (telescope, building, temperatures, coolers, roof, weather…), sends orders to move the telescope and drives the camera through a socket connection with the CAMERA software. This later software plays an identical role for the camera, but can be operated alone via a remote interface. The MAJORDOME makes the interface with the outside world, first with the GCN, and other satellite alert systems, but also with the request system through a web interface. In routine mode, i.e. between alerts (about 80% of the time), the MAJORDOME schedules observations in an optimal way. In other words, apart from specific constraints, the user chooses only the observation parameters (coordinates, exposure time, filters, repetition factor, eventually time constraint…), and an efficient algorithm produces the telescope time line: a priori, the user does not know when the observation will be performed, but the MAJORDOME schedules it in a way that most observations are performed in the best astronomical conditions (e.g. at minimal airmass), and the whole telescope efficiency is maximised.

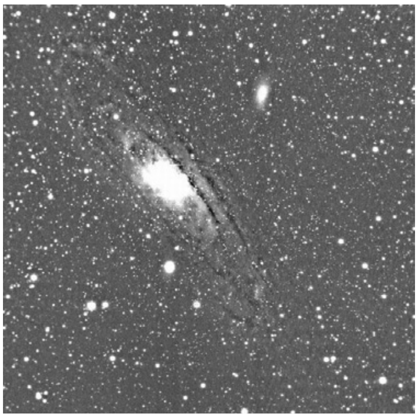

Figure 4: The M 31 Andromeda galaxy, as seen by TAROT (image TAROT/CNRS).

As soon an image is taken, the processing software (the GRENOUILLE) proceeds with calibration, removal of cosmic-ray hits, normalization, searches for sources, computes the astrometry, and ends-up with a complete catalogue of the sources in the image. This frame and the products are archived on a disk, and sent later to Europe. Both the image (in compressed FITS and/or jpeg) and its catalogue are available on the web interactively. The page allows the superposition of the USNO-A2.0 catalogue extract on the displayed image, retrieving source coordinates via the mouse, requesting an extract of the Digital Sky Survey around any position, or getting a chart of the asteroids found in the field. Additionally the catalogue gives all unidentified sources in the field, and an algorithm able to derive the possible optical transient candidates among a set of images according to various criteria will be implemented. All these features have proven to be very useful for the GRB counterpart searches at Calern, as well as for other programs. All the software components are independent from each other, and the dialog is performed through standard socket connections. This way, the actual location of a module has no relevance, provided that the INTERNET connection is reliable. As an example, the MAJORDOME has been developed in Toulouse, and has for months scheduled TAROT from the CESR. Each module has also its own interface, accessible either on site or remotely. The whole system can be maintained and monitored remotely, and the failure of one component does not lock the access to the TAROT observatory.

The telescope, together with its immediate hardware will be installed in the “Sarcofago” GMS building (figure 1). In order to ease both the installation and operations, all the computers and auxiliary hardware are currently being implemented in a specialized, climate controlled, container. The telescope hardware is under construction, and will be assembled by the fall of 2003. At that time we will have a fully operational telescope which

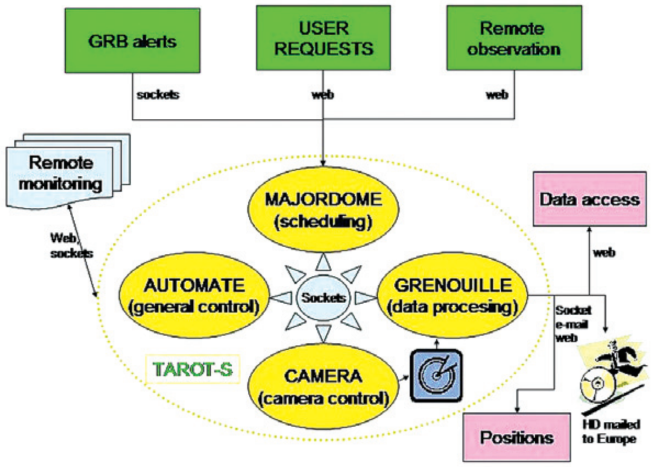

Figure 5: *Software configuration of the TAROT observatory.*

will be thoroughly tested before shipping at La Silla. Hence installation time will be reduced to a minimum, and the telescope will be quickly fully operational.

A MULTI-PURPOSE, MULTI-SATELLITE OBSERVATORY

With TAROT and REM united together within the FROST consortium (Fast Robotic Observatory System for Transients), ESO will be equipped with a fully automated, scientifically consistent set of instrument spanning the IR and optical range, able to detect and analyse quickly the data from GRB counterparts. One of the major challenges which may be addressed by FROST is the measure and understanding of the relative emission in IR and visible band, and, moreover, why this emission may be suppressed in the visible, and/or infrared.

The data obtained with small telescopes have proven to be extremely useful: though small, these telescopes are able to "see" sources at cosmological distances, and to probe the extragalactic line of sight, as well as to get information on the host galaxy. The detection of the supernova rise and the systematic monitoring of the light curve by small telescopes are also an aid to understanding the fate of massive stars, the making of black holes, and the last stages of stellar evolution across the universe at its various epochs. As shown above, the upper limits obtained, within seconds, by TAROT already compete with the data from large telescopes, thanks to its very quick response (1s), much quicker than other telescopes. Moreover, the combination of data actually gives the tightest limits on the "dark" afterglows. The rapid analysis of the image and the immediate dissemination of the sub-arc second position may be rapidly exploited by large telescopes, such as the VLT. With this accuracy, a spectrometer slit can be almost blind-positioned, giving data within the first ten minutes of the event, e.g. with the VLT, and why not later ALMA. Able to work with the accuracy provided by any spacecraft, HETE, INTEGRAL, SWIFT, and later GLAST and AGILE, TAROT will provide unique data during the very first seconds of the event at visible wavelengths, giving hints on the central engine release of energy, on the forward and reverse shocks, and on the transition between the prompt phase and the afterglow. Systematic investigations will be performed with REM, providing a deep insight in the broad band early afterglow. With its wide field of view, combined with a good sensitivity, TAROT-S is also able to start a systematic search for orphan afterglows, and to provide hints toward direct evidence of the focussing of the fireball.

More generally, the secondary program of TAROT-S will be mainly devoted to the study of variable sources, such as active galactic nuclei, or a census of variable stars. Thanks to its ability to sample a wide fraction of the sky with a good sensitivity, given by its field-of-view / duty cycle combination, TAROT will be also able to detect extrasolar planets using the occultation method. Though the scheduling of observations is optimally performed without any human intervention, TAROT features a mode in which it can be remotely controlled. Our experience (with TAROT-Calern) with users around the world shows that TAROT is also a very powerful tool for education and public outreach.

TAROT-Calern has proven its reliability and efficiency for its scientific objective. Building upon our experience, TAROT-South will enhance the prompt optical coverage of Gamma-Ray Burst sources and will gain from a darker sky and better weather. With the dramatic increase in GRB alerts expected next year with SWIFT, TAROT-S, together with its companion REM, will contribute to maintaining the leading role in GRB observation and science that ESO and European astronomy have gained since the afterglows have been discovered.

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