The last born at La Silla: REM, The Rapid Eye Mount

Cerro La Silla in June welcomed a new small telescope on its top: The Rapid Eye Mount (REM) Italian Telescope: a telescope which has been conceived and designed to immediately point and observe the Gamma-Ray Bursts detected by satellites. Its immediate data gathering capability and its accurate astrometry in the optical and in the near-infrared will also allow an early alert and pointing of the Very Large Telescope.

G. Chincarini[1,2], F. Zerbi[2], A. Antonelli[3], P. Conconi[2], G. Cutispoto[4], S. Covino[2], F. D'Alessio[3], A. De Ugarte Postigo[5], E. Molinari[2], L. Nicastro[6], G. Tosti[7], F. Vitali[3], R. Mazzoleni[2], G. Sciuto[7], M. Stefanon[2], B. Jordan[8], L. Burderi[3], S. Campana[2], J. Danziger[9], A. Di Paola[3], A. Fernandez–Soto[10], F. Fiore[3], G. Ghisellini[2], P. Goldoni[11], G.L. Israel[3], D. Lorenzetti[3], B. Mc Breen[12], N. Masetti[13], S. Messina[4], E. Meurs[8], A. Monfardini[14], E. Palazzi[13], J. Paul[11], E. Pian[9,13], M. Rodonò[4], L. Stella[3], G. Tagliaferri[2], V. Testa[3], S.D. Vergani[2]

[1]Universita degli Studi di Milano Bicocca,Dipartimento di Fisica, Italy; [2]INAF Osservatorio Astronomico di Brera, Merate,Italy; [3]INAF Osservatorio Astronomico di Roma, Roma,Italy; [4]INAF Osservatorio Astronomico di Catania,Italy; [5]CSIC-IAA Camino bajo de Huetor s/n Granata Spain;, [6]IASF CNR Palermo, Italy; [7]Universita di Perugia, Dipartimento di Fisica, Italy; [8]DIAS-Dunsink Observatory, Dublin, Republic of Ireland; [9]INAF Osservatorio Astronomico di Trieste, Italy; [10]Observatorio Astronomico - Universitat de Valencia, Spain; [11]Service d'Astrophysique, CEA-Saclay, France; [12]University College of Dublin, Republic of Ireland; [13]IASF CNR Bologna, Italy; [14]CARSO-Universita di Trieste, Italy

In the late nineteen sixties, the Vela satellites, designed and flown to monitor the outer space in agreement with the "Outer Space Treaty" that forbade nuclear explosion in space, detected quite accidentally the presence of bursts of high energy photons. Their energy was in the range of 100 KeV – 1 MeV and they would last for a few tens of seconds. Klebesadel, Strong and Olson announced the discovery in 1973 and since then the attention of the astronomical community became focused on these highly energetic and completely unknown wonders of the sky.

A Gamma-Ray telescope does not allow the estimate of the position of a source on the Celestial Sphere with good accuracy. At the same time the scarcity of the events detected by the satellites launched before the nineties did not allow astronomers to know their distribution on the sky. These uncertainties led to two different schools of thought. Many astronomers were defending the galactic origin of these sources while others were sustaining their extragalactic origin. The launch of the Compton Gamma Ray Observatory (GRO) in 1991 with the BATSE detector aboard revolutionized our understanding not only by providing detailed temporal and spectral information but also by showing that these sources are uniformly distributed on the Sky. This made a convincing case for their extragalactic origin. But it is thanks to the Italian Dutch satellite Beppo SAX that the extragalactic origin was confirmed beyond any doubt. The scientists of this mission were able to discover the X-ray counterparts and consequently achieve accurate astrometry, which finally led to the identification of the host galaxy and redshift measurements.

Since the GRBs are at cosmological distances, the observed fluence (~10^{-7} ergs/cm^2), that is the total flux received during the burst, indicated that the emitted energy had to be extremely high and of the order of 10^{51}–10^{52} ergs/s under the model of a beamed source. We are thus witnessing one of the most spectacular emission of energy in the Universe. Such energy corresponds to the annihilation of a very significant fraction of a solar mass in a few seconds and corresponds to the luminosity we have when summing up the light of all the galaxies in the nearby universe.

While the phenomenon is rather rare assuming an isotropic emission, roughly one event per year per million galaxies, the frequency considerably increases if we consider we are seeing only those bursts for which the line of sight is within the emission cone of the relativistic beaming jet and we miss all the rest.

The generic model we have at present is simple and fascinating. A fireball of very hot radiation, possibly contaminated by some baryonic matter, at some point appears and expands at ultra-relativistic velocity. That the velocity is extremely close to the velocity of light is demonstrated by the fact that the spectrum we observe is not thermal that is, we do not observe the equivalent of an opaque expanding photosphere. The optical depth for radiation is smaller than one. On the other hand the rapid variations that have been observed at high energies would call for a very small volume of the source with the production of copious electron positron pairs. That is we should have high opacity, and therefore optical depth larger than one, and expanding near blackbody photosphere. However if the ball is moving at high relativistic speed, with a Lorentz factor of about 100, the volume of the source at its rest frame becomes larger, the photon energy involved much smaller and, as a consequence, the number of electron pairs produced highly reduced causing a much smaller optical depth. The expanding shells are transparent to radiation.

A beautiful confirmation of this super relativistic velocity came from the radio observations of GRB970508 by Frail et al. About a week after the detection of the burst (both BATSE and Beppo-SAX detected it in gamma-rays and Beppo-SAX localized it with the X-ray camera) the radio emission was optically thick and showed intensive oscillations that disappeared after about three weeks. Interpreting the oscillations as due to scintillation it became feasible to estimate the size of the fireball at this phase to be about 10^{17} cm and in agreement with the theoretical considerations described above.

The ultra relativistic beamed shells moving outward slow down and are hit by the following shells causing internal shocks with the emission of high energy photons while the impact of the shells with the interstellar medium of the host galaxy causes what are known as the external shocks and produce the X-ray and optical emissions, the afterglow phase of the burst. The observed flux decays as a power law with exponent which in general is between –2 and –1. But while all of the bursts detected in the γ-rays have been also detected at X-ray frequencies, a large percentage of these, about 50 to 60%, are not detectable at optical wavelengths.

The success of the Beppo-SAX satellite and the knowledge gained on the GRBs both observationally and theoretically, clearly pointed to the information needed if we wanted to make any progress in this field of endeavour. The opportunity to make a satellite capable of procuring the needed data was caught by US scientists who proposed, in collaboration with Italy and the United Kingdom, a NASA MIDEX Mission, Swift, to carry out the research. As spelled out in the international logo, with Swift we are ready for "catching the bursts on the fly". The Mission is scheduled for launch in Spring 2004.

The planned satellite had to be able to detect GRBs over a large fraction of the sky with a good sensitivity, measuring the afterglow at the X-ray and optical wavelengths. Indeed Swift after detecting the Bursts with the BAT (Burst Alert Telescope) instrument points the spacecraft in about 10 – 70 s so that the Narrow Field Instruments, XRT (X-Ray Telescope) and UVOT (Ultraviolet Optical Telescope) follow the event. UVOT is sensitive in the range 170 – 600 nm. Soon after each instrument onboard the spacecraft detects the burst, the position of the source is communicated to Earth so that the Ground Based Telescopes can point in that direction and get the complementary observations.

Fast and quick is the mandatory priority since the phenomenon evolves very quickly and the emission due to the physical events occurring at the very outset may be the most revealing about the physics at work. The multi-wavelength coverage is crucial since the complex phenomenon, and its interaction with the environment, radiates at all wavelengths. For instance, it will be essential to estimate the time lag between the emission peaks at different frequencies.

The Swift instrumentation does not provide any coverage in the red and infrared bands, which is instead critical, given that 50 to 60% of the bursts have no detected optical afterglow, let alone the importance of monitoring the temporal decay in the infrared. We must find out whether this fact is due to dust (from the centre of the Galaxy we easily receive γ-radiation and we observe in the X-ray but we suffer about 30 magnitudes extinction in the optical) or a percentage of bursts are missed in the optical simply because of their very high redshift. This second possibility, the detection of very high redshift sources with $z > 6$, is an extremely exciting challenge and fundamental to cosmology.

« Fiat lux et lux fuit »

The end of the "Dark Age" in the cosmic history of the Universe occurs with the generation of the first light and the subsequent re-ionisation of the hydrogen that had been formed at recombination. This epoch, that according to theoretical consideration and numerical simulation is located in the range $6 < z < 20$, is at present under intense theoretical investigation and close to our observing capabilities as demonstrated by the observations of the quasar detected by the Sloan Digital Sky Survey at $z \sim 6.43$. But light and re-ionisation are only part of the story. Assuming population III stars and nuclear reactions create light, it is during this epoch that we start forming heavy elements in the Universe and spread them around. It is the beginning of the chemical evolution. It would be a different story if at the very beginning the creation of light was related to accretion of matter into massive black holes. This non nuclear mechanism is highly efficient in producing light, however the lack of significant star formation would imply a delay in the chemical evolution of the Universe. The high-z very bright GRBs could be the objects giving us the fundamental information about this epoch and using them as beacons they will tell us the details of the intergalactic medium (IGM) and therefore the history of the Universe. But to do that we have to detect them fast, measure accurately their position and quickly point the very large telescopes in order to get the information we need before they fade away. These considerations guided the conceptual design of the REM telescope.

With an estimated frequency of bursts detected by Swift of about 150 per year on the average from any ground based facility, due to the location and to the day and night alternation, we will be able to observe about 40 bursts a year. REM is located in the Southern hemisphere . While soon after alert the telescope will be observing the burst for as long as possible uninterruptedly, after a while the main players will be the large telescopes and REM will only make a few observations on each given burst. That is REM will be free to observe other targets, and to perform a secondary science program, for

Figure 1: *"Notre Dome de La Silla". The Dome hosting the REM telescope.*

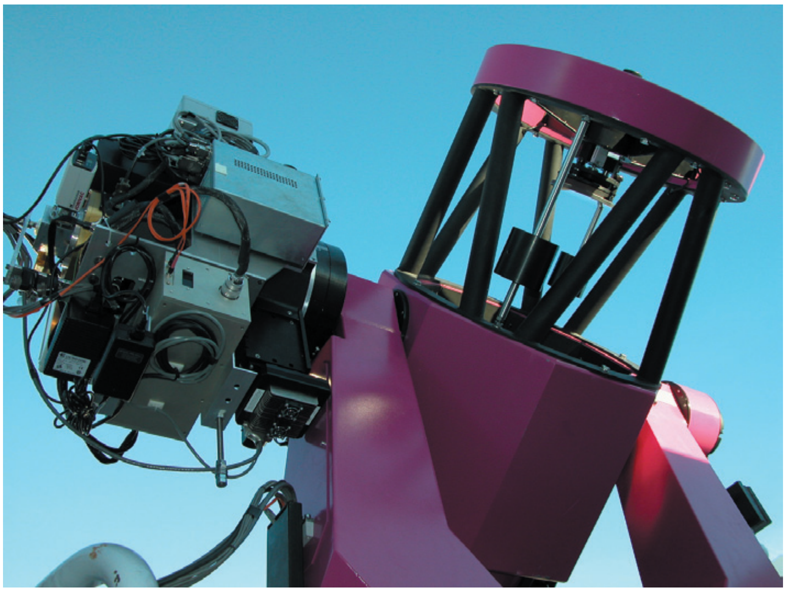

Figure 2: The telescope with its instrumentation.

more than 40% of the time. To this end we already planned a set of observational programs and later on REM will also be open to observing proposals.

The Rapid Eye Mount Telescope (REM)

The specifications for REM were very simple even if very demanding on both the hardware and software. The science drive demanded an instrumentation that had to be sensitive also to the near infrared and that had to be sensitive to all wavelengths up to 2300 nm, the K' band. The science needs dictated the telescope had to go immediately, and without human interference, on target after Swift, or any other satellite, sent a burst trigger deciding automatically, and, according to a priority tree designed in the software (Figure of Merit – FOM) and regularly updated, what to do. The quick look automatic software had to be capable of identifying right away, and measuring accurately, the position of the burst and its magnitude as to immediately alert the community and all the major telescopes, the ESO VLT in particular. Furthermore the combination of the two instruments described below, and the related software, had to allow the estimate of the redshift of the cosmic events via the Lyman-α line and the drop out technique.

The specifications as dictated by the science drive suggested immediately the choice of an alt-azimuth mounting in order to minimize the momentum of the instrumentation during slew. Our interest in using the VLT Unit Telescopes suggested either Cerro Paranal or Cerro La Silla as suitable sites. When such idea was illustrated and documented to the Director General Catherine Cesarsky, even before approval of our proposal for funds in Italy, we were extremely pleased to see interest and excitement toward the proposal and to be encouraged to proceed. Later on, and after many interactions with the ESO staff, Cerro La Silla (Figure 1) was selected as the most convenient location for REM.

The telescope uses a Ritchey – Chretien configuration with a 60 cm f/2.2 primary mirror and two Nasmyth f/8 focal stations (Figure 2). The telescope has been manufactured by Teleskoptechnik Halfmann Gmbh in Augsburg (Germany) and the optics by Carl Zeiss AG (Germany). To optimise the response in the near infrared the telescope optics were coated with silver and protected by a special overcoating. Accurate pointing, fast slewing and precise tracking are achieved using azimuth and elevation motors made by ETEL which allow a maximum speed of 12 deg/s and Heidenain encoders with 237 steps per arcsec.

The instrumentation has been attached, together with the field de-rotator, in one of the Nasmyth foci (Figure 3). A beam splitter (dichroic) manufactured by ZAOT (Italy) according to our design leaves the Infrared beam (950 – 2300 nm) to continue along the optical axis where the IR Camera (REM-IR) is installed while it deflects the optical beam (450 – 950 nm) to an orthogonal axis where the optical instrument (ROSS) is installed (Figure 4).

The Infrared Camera

At present the camera is working with 4 filters (Z, J, H and K'). However the filter wheel, located in the parallel beam, hosts 8 positions so that provision has been made for further filters and grisms. The camera optics convert the telescope f/8 beam into a f/5.3 beam allowing a scale on the focal plane of 64.4 arcsec/mm. This allows us to have a 9.9′× 9.9′ field of view on a 512×512 (1800 nm pitch) HgCdTe array produced by Rockwell. We are using 1 quadrant of a Rockwell Hawaii II

Figure 3: The telescope during operations and pointing the sky, Courtesy of P. Aniol.

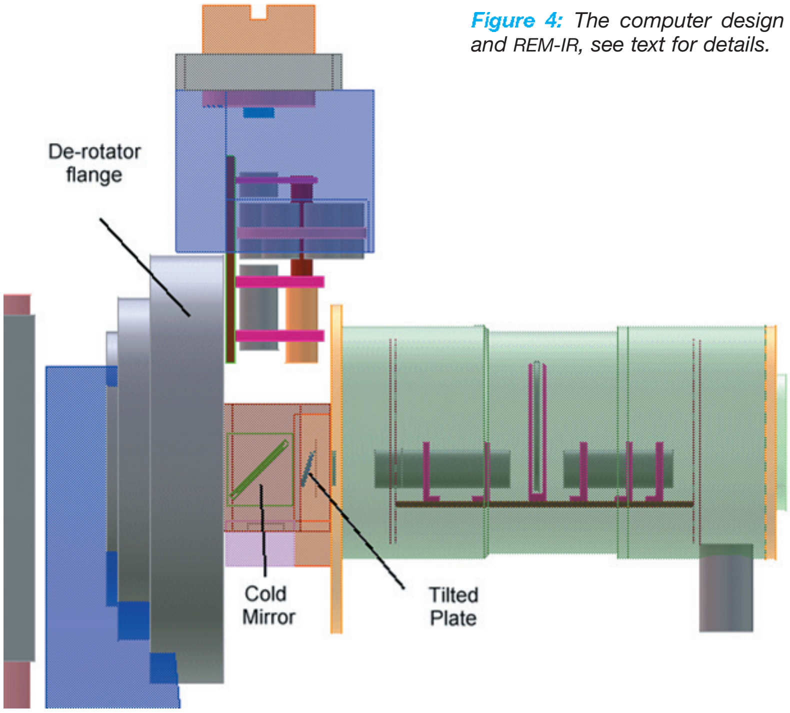

Figure 4: The computer design of ROSS and REM-IR, see text for details.

1024×1024 chip so that in case of deterioration of the quadrant we are now operating we can switch to another 512×512 quadrant. The IR array uses a Leach Controller with a read-out speed of 1.64 microsecond per pixel.

The collimator and the camera (Silica – CaF2 and CaF2 – Silica) focus the image on the CCD after passing through the Cryostat window. The whole camera is mounted in a dewar manufactured by the Infrared Laboratories in Tucson (Arizona) so as to operate in a cold environment and is kept at a working temperature of about 77 K. The working temperature of the IR array is 77 K as well. The cryogenics are supported by a Stirling – Cycle cryo-pump made by Leybold AG (Germany).

The ROSS spectrograph

The optics of ROSS, also designed by us, consist of separated doublets made of ZKN7 – FPL53. The filter wheel accommodates the V-, R-, and I-filters and an Amici prism 66 mm long. The prism is made of Silica, BAF2 and CAF2 and the spectral range from 450 to 950 nm is displayed over 60 pixels. In order to match the optical thickness of the Amici prism and to avoid refocusing while passing from the imaging mode to the spectroscopy mode, the filters were glued on properly designed cylinders of optical glass. The detector head is a commercial Apogee AP47 camera hosting a Marconi 47-10 1K×1K 13 µm pitch CCD.

Software and Operation Conceptual Design

When the telescope was conceived, the idea was that it had to go on target according to built-in decisional software and according to a trigger given directly by the Swift satellite or any other satellite for that matter. Conversely, the telescope and related science software had to be capable of immediately evaluating the observations and be capable of communicating them immediately and eventually trigger large ground based telescopes like the VLT or any Space Borne Observatory. This has been accomplished.

The REM Observing Software (REMOS) after receiving the alert message via a socket connection from the GCN (*http://gcn.gsfc.nasa.gov/gcn/*) will also check the status of the telescope, the on-going observations and any other activity including its meteorological environment. If the priority tree built into the software commands the telescope to move to the new alert, the telescope is on target in less than 60 seconds and starts the observation with both instruments according to the instructions that are listed in the Figure of Merit. At this point the astrometry and photometry of the Transient is done immediately by an automatic routine and the information passed via Internet to all the relevant parties, astronomers and observatories. At all time we will have a person remotely supervising the performance of the facility.

Installation at La Silla and First Light

In June 2003 everything started to move quickly. After a long journey over the Atlantic Ocean and Panama and a trip through the Chilean land, the telescope arrived at Cerro La Silla. Here the very efficient and competent staff at ESO Observatory had already constructed a simple, but very neat and complete with all the needed connection, dome: "Notre-Dome de La Silla".

The Telescope was mounted in about a week and soon after we mounted the instrument on the Nasmyth focus. For the first time we had on the mountain a bunch of young – and not so young - Italians, trying to get things working. Indeed some were busy with the hardware, some with the instrument software and others in making the whole network connection active. At the same time Mr. Aniol from Halfmann was busy in setting up the telescope and, in collaboration with the software subcontractors, was working on the telescope pointing software, pointing model and de-rotator software. Indeed the space inside this small dome was packed with persons working on different tasks without interfering with each other and each one with a very high capability of understanding the relevant information from the cross talking in different languages: Italian, German, English and Spanish.

Soon after the equipment had been turned on we were able to point the telescope, even if not very accurately yet, and get the first images. By Tuesday June 24th we had the first fairly good images (Figure 5) and standard stars both with the infrared camera (REM-IR) and the ROSS instrument.

Preliminary data reduction of the standard stars without correcting for flat fielding in the NIR, gives the following limiting magnitudes for 1 second integration and S/N=5: V=17.2, R=17.2, I=16.0, J=14.5, H=13.5, K'=13.0. These observations show that the sensitivity of the instrument already matches (or is even better in K') the sensitivity we expected as estimated in the original proposal. That also means that by a proper reduction of the data and after fine-tuning of the observing, and data analysis software, the system will exceed the expectations.

As it is very clear to all astronomers, as for the roof of an house, the first light is a milestone in the making of a telescope

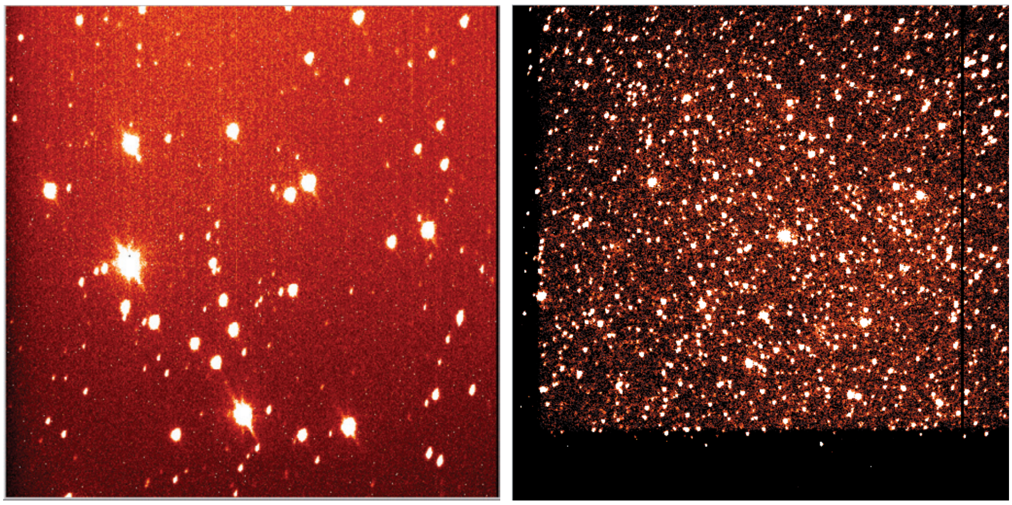

Figure 5: First images, showing the open star cluster M6, taken with the ROSS in the V-band (left) and with the REM in the K'-band (right). Note the striking difference between the images, showing the strong role played by the dust absorption along the galactic plane.

and the related instrumentation but, at the same time, it is only the very beginning of the commissioning period, during which time the telescope will be adjusted, the instrument tuned up and the whole software assembled to work properly. We are in this phase with all the small problems that need to be solved and with the software to be fine-tuned. The issues that need to be very carefully fine-tuned are: the alignment of the optical axis of the telescope with the axis of the de-rotator, the synchronization of the de-rotator with the telescope tracking and the pointing (we need a very accurate model) of the telescope. We will have a few months to do all of this together with the science verification program that, to some extent, already started. All of the above, mounting of the telescope, instruments and first tests took about 10 days. At the time of writing (June 26) we were already able to send to the telescopes commands from a remote computer.

On June 25th, and thanks to the Director of La Silla, we celebrated the first light with the staff of the Observatory. For us it has been an emotional moment and we are very grateful to the staff for the warmth of that evening. Indeed REM is the first telescope an Italian group of its own put on ESO ground. It was about time. The only regret is that we could not build an even fancier Dome. We will do better next time when we will get more support in Italy.

This endeavour we undertook is very important for the research we plan to carry out in the GRBs and also for the secondary science program. It is also the first fully automatic infrared telescope ever built and while its aperture is very small but suited to the science goal, its control and various automatisms in the observing procedures and data analysis make REM a very advanced astronomical tool.

But even more important we feel is the fact that it will not only further strengthen the collaboration with the ESO staff, and in particular with the staff in La Silla, but above all it will be an open gate for the youngest scientists and graduate students who will interact both remotely and in loco, youngsters will like to travel to Chile, during maintenance or other programmed activities. We hope it is the beginning of something very interesting.

Acknowledgments

The Swift mission triggered the idea of REM and many of its members, especially Prof. Alan Wells, encouraged enthusiastically the REM project. Naturally we are very grateful to Catherine Cesarsky for the encouragement she gave since the very beginning when we proposed to locate the telescope at ESO in Chile and for her openness toward the GRBs research. Alvio Renzini acted as our reference point for ESO and Jorge Melnick, to whom we are deeply indebted, did everything possible to make our work at La Silla comfortable and pleasant and for the building of "Notre-Dome". Needless to say we could not operate without the help of the La Silla staff, the vice Director G. Andreoni in particular, to which we are very grateful and without the expertise of G. Crimi (OAB) who helped in the operation of mounting the telescope and of Giuseppe Malaspina whose expertise allowed us to communicate among our computers and with the rest of the world. Fundamental has been the collaboration of: M. Bagaglia, C. Campeggi, R. Cunnife, D. Fugazza, G. Gentile, E. Martinetti, A. Melandri, G. Nucciarelli, S. Sardone. The financial support came from the Italian Ministry of the University and Research (MIUR) through the COFIN organization. The ROSS instrument has been financed by an ASI grant and the CNAA helped us with "Notre-Dome at La Silla". Finally we would like to thank AMD for providing part of the computer hardware.

References

Gehrels, N., Chincarini, G., Giommi, P. et al., 2003, *Ap.J.* in preparation.
Piran, T., 1999, *Physics Reports*, 314, 575
Zerbi, F., Chincarini, G., Conconi, P. et al. *A&A*, in preparation.

See also:

Kaper, L., et al., 2002. Gamma-ray bursts: the most powerful cosmic explosions, *ESO Messenger*, 109, 37
Pedersen, H., et al., 2000, Gamma-ray Bursts – Pushing limits with the VLT, *ESO Messenger*, 100, 32