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The Swift Mission and the Robotic Telescope REM

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Abstract The Swift satellite and the REM telescope projects are devoted to the study of Gamma–Ray bursts. Both missions are mainly designed to investigate on the prompt GRB emission. In the following, we give a brief outline of GRB science and describe the main technical capabilities of Swift and REM.

Key words: gamma rays: bursts – space vehicles: instruments – telescopes

1 INTRODUCTION: THE GAMMA RAY BURSTS

In the late 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 for some time their distribution on the sky. These uncertainties led to two different schools of thoughts. 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 (CGRO) 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 was a strong indication of their extra galactic origin. But it is thanks to the Italian Dutch satellite Beppo-SAX that the Extragalactic origin was confirmed beyond any doubt, Costa et al. 1997, van Paradijs 1997. 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. Nature surprised us once more.

Clearly it is of the outmost importance, and this is the primary goal of the Swift Mission as we will later detail, to fully understand the GRB phenomenon within the contest of the stellar evolution and to fully understand not only the phenomenology of the motor but also

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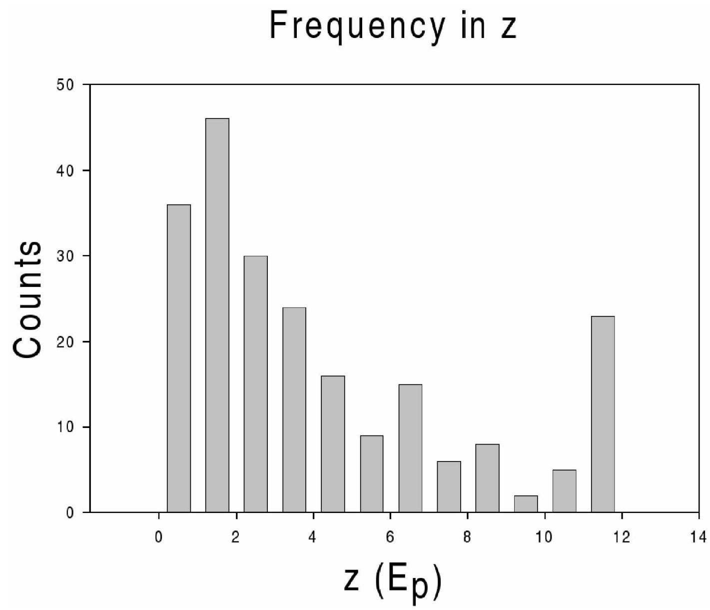

Fig. 1 Estimated z ditribution of BATSE detected bursts.

the dynamics of the jet and the impact with the ISM. On the other hand aware of the large contribution given to Cosmology by the QSOs and of the extreme Luminosity of the GRBs it comes naturally to the mind to use them at different wavelengths as far away beacons helping us in the understanding of the IGM. The hope is to be able to detect them, at least a few, in a redshift range between 7 and 10 or beyond. The idea is to understand this very early epoch where the first objects formed and possibly measure, among the various possible parameters, also the abundance of the elements as a function of redshift in this zone. It could be very illuminating. Re-ionization may be due, as it seems the most natural thing and as shown by simulations, by the ionization of the newly formed Hydrogen atoms through the very massive stars and galaxies formed at $z \sim 10$–20. If this is the case the abundances should reflect the fast evolution of these very massive stars and we might be able to measure the amount of heavy elements. But what about the early formation of very massive black holes? Certainly heavy elements will be formed as well but likely not so much and the main ionization agent could be radiation related to the Black Holes. The initial Chemical evolution of the Universe could be drastically different.

Early Universe GRBs may be likely detectable, see also the section on the REM telescope, not only because they are bright and we hope they exist somewhere at high z, but also because it seems that, according to the work of Fenimore and Ramirez-Ruiz (2000) and by Yonetoku (2003 and references therein) that the BATSE catalogue might already contain high z Bursts, Figure 1. These findings must be obviously considered extremely uncertain both because of the way the redshifts have been calibrated and because of the completely unknown Luminosity Functions where we have still too many degrees of freedom to track down how parameters change as a function of redshift. Nevertheless the findings are fundamental and fully justify the effort undertaken not only toward a better understanding of the bursts but also toward a search for high z bursts. This task is obviously intimately connected with the understanding of the progenitors population.

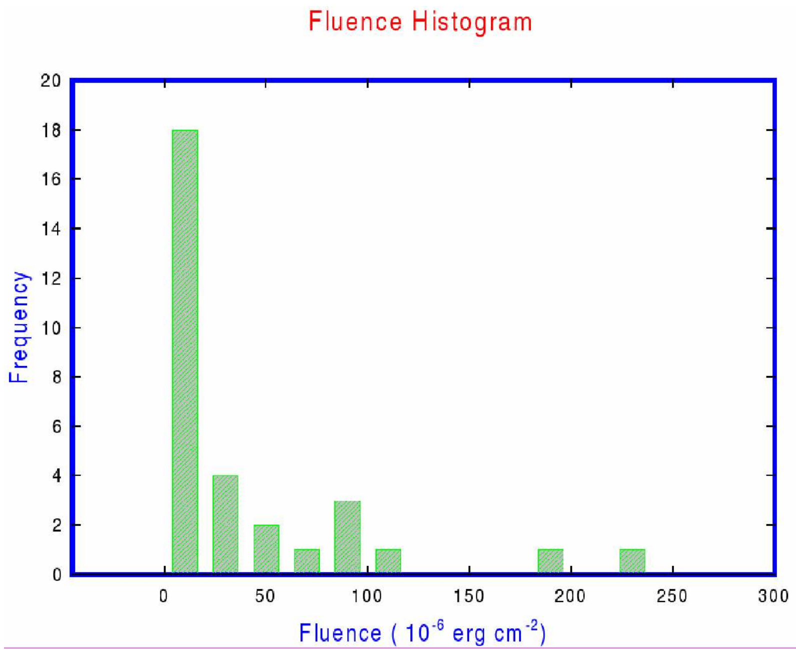

Fig. 2 Fluence istogram.

But the primary goal is to understand GRBs. One of the most intriguing and yet unknown phenomenon is the why the burst occurs and what is the population generating it.

The most spectacular catastrophic phenomenon we know about stellar evolution is that of the supernova explosion. The white dwarf created in the core of a star more massive than $8\,M_{\odot}$ keeps evolving in composition and grow in mass and density until it achieves the Chandrasekhar mass of about $1.4\,M_{\odot}$. At this mass the core becomes unstable and within 1 second implodes reaching nuclear densities. The bouncing core, due to the highly incompressible nuclear density matter, generates a very strong shock front that drives the system to a supernova explosion. The end result is the presence of a neutron star. The model by Vietri and Stella, 1998, consider the formation of a supramassive neutron star where the rapid rotation delays further implosion. When at some point the centrifugal support becomes weaker, we have implosion to a black hole. A more direct implosion is that of collapsars, Zhang et al. 2002, where we have the direct collapse to a black hole surrounded by an accretion disk. The main ingredients, degenerated matter, rotational energy, accretion disk and strong magnetic fields, play an important role in all of these models and it may be only a matter of detail the fine tuning to explain the detailed phenomenon. To the eye of the observer, however, in order to distinguish among possible models it seems that of primary importance is the estimate of the time of occurrence of the various peaks of emission at different wavelengths, the observations of the X-Ray Flashes (XRFs) that according to Woosley et al. (2002) could be related to the GRBs and possibly find ways to estimate the presence, direct or indirect, of the Ni decay in those cases where a supernova phenomenon may be also present. Naturally the indicators of Fe abundance will be fundamental diagnostic as well. Indeed while we believe that not all supernovae are associated to the GRB phenomenon, and vice versa, we must understand whether the difference is in the progenitors or whether the difference is regulated by the laws of Chaos.

As mentioned above GRBs are very Luminous, indeed they are the most Luminous sources we know.

In Figure 2 we plot the distribution of Fluence (the flux received during the time the burst lasted) for the small number of objects for which we know the redshift. Depending on z this translates in Luminosities of about $10^{53}\,\mathrm{erg\,s^{-1}}$ assuming a symmetric emission of Energy. We know, however, that the burst is a jet like emission within a small solid angle so that the total Energy emitted in a single burst decreases considerably while the number of unseen bursts increases considerably. We are getting close, but not that much, to the theoretical limit of how much energy a source could emit in 1 second. A mass M within a Schwarschild radius (RS) even if it is instantaneously converted into Energy can not escape from it so that whatever we see must have a Radius larger than that. That is the Luminosity of any object of mass-energy Mc^2 must be smaller than its average Luminosity, that is the ratio of the Energy content in the sphere of Radius R divided by the light crossing time. $L < L_{\max} = Mc^2 \times c/R_S = c^5/2G \sim 2 \times 10^{59}$ erg s^{-1}. Clearly any energy transformation needs time and we should account for an efficiency parameter in the transformation so that we may not be that far from the maximum Nature can indeed produce. See C. J. Hogan, 1999, for an interesting discussion on the Energy Flow in the Universe.

The spectrum of a GRB is well fitted by a Synchroton model with a peak, see for instance GRB 930131, at about 200 keV, Bromm & Schaefer 1999.

The impact of the Jet with the surrounding medium not only makes the phenomenon visible at all wavelengths but also trigger a series of effects that help in understanding the energetic, its origin and evolution. The light curve fades with a power law. The Lorentz factor, initially we have $\Gamma \sim 100$, of the jet slowly decreases and might become smaller that the inverse of the initial opening angle of the jet. The light curve will show at this point an achromatic break. Radio observations have been fundamental to the understanding of the afterglow emission; suffice to say that it was thanks to the observations of Frail et al. (1997) of GRB 970508 that a mildly relativistic expansion of the shell was detected. Jumping on the other hand of the electromagnetic spectrum it is expected that Cherenkov Telescopes will routinely observe GRBs as to understand their emission at TeV energies.

We refer the reader to the excellent review by Hurley, Sari and Djorgovski (2003) for details about the afterglows and the Host Galaxy.

Following the experience of Beppo-SAX and the knowledge gained with the follow up from ground Observatories, we (the project originated from a Mission concept of GSFC scientists) designed the Swift Mission. Swift had to be, given the characteristics of the sources we wanted to investigate and the rapid variability of the phenomena involved, a multi wavelength Observatory and the spacecraft had to have the capability of detecting the bursts and pointing very fast on the target the Narrow Field Instruments (NFI). We also wanted to have on board an optical telescope to be complete and homogeneous in the statistical sample we would observe during the two years duration of the prime Mission. That is all the bursts will be observed in the spectral range from the gamma radiation to the visible light in a very uniform way.

The main mission objectives for Swift are:

- Determine the origin of gamma ray bursts.
- Classify gamma-ray bursts and search for new types.
- Determine how the blast wave evolves and interface with the surroundings.
- Use gamma-ray bursts to study the early Universe.
- Perform a sensitive survey of the sky in the hard X-ray band.

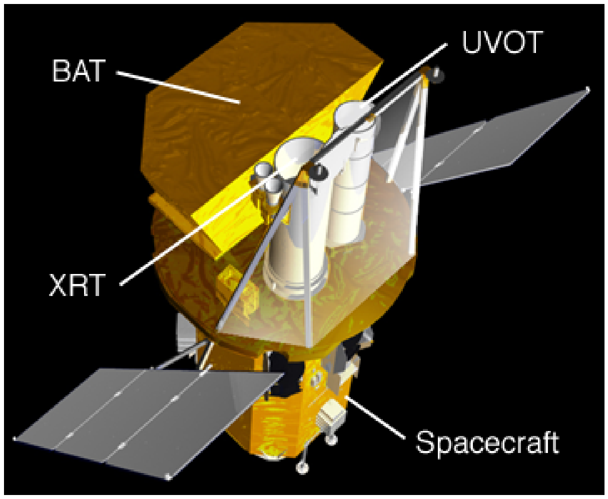

Fig. 3 The Swift payload.

2 THE SWIFT MISSION

Swift is part of the NASAs medium explorer (MIDEX) program and is being developed by an International collaboration whose hardware parties are the US, Italy and the UK. Principal Investigator of the Mission is Neil Gehrels (NASA, GSFC).

The satellite will be launched by a Delta 7320 rocket in July 2004 on a Low Equatorial Orbit (LEO) at about 600 km with an inclination of 22 degrees. The lifetime of the orbit is of 7 years so that the mission, pending approval of further funding, could continue for more than two years. The spacecraft has been developed by Spectrum Astro and is capable of a Peak Slew Rate of 50 degrees in less than 75 s. That is the NFI will be on target in about 1 minute. Operations and pointing are autonomous and the uplink/downlink are carried out using the TDRSS MA link for real time operation and data transfer while data dumping and routine commands uploading will be carried out via the Malindi ASI ground station in Kenia. We plan to use this facilty for about 7 orbits per day and however we have the capability of using up to 10 12 contacts.

The characteristics of the payload, Burst Alert Telescope (BAT), X-Ray Telescope (XRT) and UltraViolet / Optical Telescope (UVOT) are given in Table 1. 10 seconds after BAT detects a burst the Spacecraft begins to slew and after 20 seconds the location of the burst as measured by BAT with an accuracy of about 4 arcmin is distributed to the world via the Gamma-ray Coordinate Network (GCN). In about 50 seconds the NFI start collecting data and after 100 seconds from detection XRT send the location within 5 arcsec accuracy. At the same time the BAT light curve will be distributed. After four minutes from detection UVOT is capable of sending to the Ground a finding chart while it will take about 20 minutes to XRT to distribute the first spectrum. The automated operations for a given burst will be completed after 20000 seconds. We expect a detection rate > 100 bursts year^{-1}.

The primary Ground Segment Station is Malindi in Kenia (ASI Italy) and the Mission Operation Center (MOC) has been located at Penn State University. The MOC provides real time command and control of the spacecraft and monitors the observatory. The science prior-

Table 1 Swift payload technical parameters

	BAT	XRT	UVOT
Telescope	Coded Mask	Wolter I	Modofied R-C
Collecting Area	52^2	110 cm^2 at 1.5 keV	30 cm
Detector	CdZnTe	XMM EPIC CCD	Intensified CCD
Field of View	2.0 sr partially coded	23.6 × 23.6 arcmin	17 × 17 arcmin
N. of elements	256 × 128 elements	600 × 600 pixels	2048 × 2048 pixels
Telescope PSF	20 arcmin - FWHM	18 arcsec HPD at 1.5 keV	0.9 arcsec at 350 nm
Energy Range	15 150 keV	0.2 10 keV	170 650 nm
Sensitivity		2×10^{-14} erg cm^{-2} s^{-1} in 10^4 s	B=24 in 1000 s
Brightness limit			M_v = 7.4

ities and guidelines are implemented following input from the Team while scientists from the Hardware Countries and their associates (Burst Advocate) will monitor and give guidelines for each burst.

The Swift data will be made available worldwide via three different data centers located in the US, in Italy and in the UK.

In Italy the data will arrive to the ASI ASDC in Frascati and immediately send to the Swift Project Office and Operation Center which is located at the Observatory in Merate. Both these units collaborate, in coordination with our international partners and under the local software coordination of the ASDC, to develop the data analysis tools for the XRT. Indeed it is through these data centers and especially through the ASDC that the Italian community will have access to the data and analysis tools.

3 BURST ADVOCATE AND FOLLOW UP

Each burst will have a scientist in charge of formulating recommendations to the MOC (Mission Operation Center) and following all the details of the observations, data analysis and related publications. This figure is called a Burst Advocate (BA). The hardware Institutions will have responsibility of observing the bursts with the following frequency: Italy will be in charge one week every five. The US will be in charge for 3 weeks (2 GSFC and 1 Penn State) every five and the UK for one. The BA will be in contact with the Observatory duty scientist at the MOC and respond to the local PI or local Project lead. This is responsible for the correctness of the operation. The BA advises the MOC, triggers follow up operation according to a procedure that will be given to him and will have the possibility to consult, when needed, with local scientists and with scientists on duty all over the world. Indeed there will be a group of scientists who will form a consulting panel that could be called upon at any time (those who gave availability) for consultation. This activity is a 24 hour activity immediately after the trigger (or while waiting for the BAT trigger) so that it is really the duty of a team supporting the BA. This part has been organized in Italy quite carefully and we should be able, also with the collaboration of French partners, to operate quite well.

An other major concern for the science connected to the GRBs was the availability of the Very Large Telescopes (VLT) at ESO and their capability to get as soon as possible to the target. Not only. We also wanted to have an Italian capability, to possibly continue the tradition of the Beppo-SAX group, within a collaborative International effort as part pf the Swift Team.

We started contacts with ESO early during the phase A study of the project, formed a team of persons interested in the follow up and finally discussed with ESO about the possibility not only to consider, and therefore support, the importance of the program and the great science return we might have in Europe, but also have the capability to react fast to the trigger coming from the satellite. It is thanks to the extremely advanced conception of the VLT and to the capabilities of the person in charge at Paranal, obviously with the support of the Director General, that the VLT became what I believe to be the most competitive telescope for the study of the GRBs. From the time the VLT is triggered, while observing in service mode, to the time it gets to target after interrupting whatever program was going on without loosing the data collected, only 6 minutes will pass. The whole operation is completely automatic without any human intervention. But to do that, and avoid wasting of time, the coordinates of the target must be very accurate as to avoid searching the object in the field of view. This is extremely important both because of the study of the physics of the GRB near the peak, or even before that, of the light curve and because of the capability to probe, using high resolution spectroscopy at optical wavelengths and possibly in the NIR, the intergalactic medium. Again we can not loose those few objects with $z \sim 6$ that will tell us, among many other things, about the depth of the reionization region and the formation and evolution of metals. And we should be able to answer also to simple questions as when did the dust form and what is its distribution in the Universe at early times. These things can be computed with simulations and however we want to be able to see them where they are. We are ready to go and we feel we are a rather strong and capable International team.

4 THE REM TELESCOPE

Three aspects of the whole process are very clear in the studies of the GRBs and from what we described above: 1) Rapidity. The ground based telescopes must go on target as soon as possible; 2) Accuracy of the Astrometry. The photometric telescopes must be capable to immediately improve the location of the burst in order to allow the immediate pointing of the Very Large Telescopes; 3) Wavelength coverage of the electromagnetic spectrum. This must be as complete as possible since the primary and secondary emission have different characteristics.

What was missing, and we noticed it years ago, was the Near Infrared coverage. We obviously could not consider the possibility to have such a coverage on the spacecraft since that would have complicated the payload beyond time and cost limitations. Indeed it was not even possible to expand the coverage of the UVOT beyond 650 nm for the same reason even if at some point that possibility was investigated but dismissed almost immediately. Lack of NIR coverage was undoubtedly a big problem and could have been a big bias. Indeed in 1999 we already knew that about 60% of the bursts were not visible optically (this figure should now be revisited and might not be larger than 20%, Lamb 2003). These optically unseen bursts could have been due to dust. Indeed we are all aware that from the region near the Galactic Center we receive gamma and X-ray radiation but we have about 30 magnitudes extinction at optical wavelengths. We see sources, however, in the NIR. The other obvious explanation was, and still is, that an object at high redshift would be completely absorbed by the intervening medium at large z. Indeed we see from Figure 4 that UVOT would be blind already for objects with $z \sim 6$. Obviously there is also the possibility that the spectral shape of the source is rather peculiar, flat for instance as proposed by Hjorth et al. (2002), so that we miss the faint optical band. One explanation may be more likely than the others or a particular mixing of the three weighted case by case may explain the dark bursts. The fact is again that we want to know by seeing. It is because of this need and to avoid a bias a priori that in 1999 we started to discuss the idea of building a NIR Robotic Telescope, Chincarini, Zerbi et al., 2003 and references therein).

A group of Italian Institutes, lead at that time by the Astronomical Observatory of Brera in Merate, submitted a proposal for funding the construction of such a telescope equipped with a NIR camera at the Nasmyth focus. Soon after the proposal had been approved, the group enlarged incorporating expertise, and hardware, from other Italian and European groups.

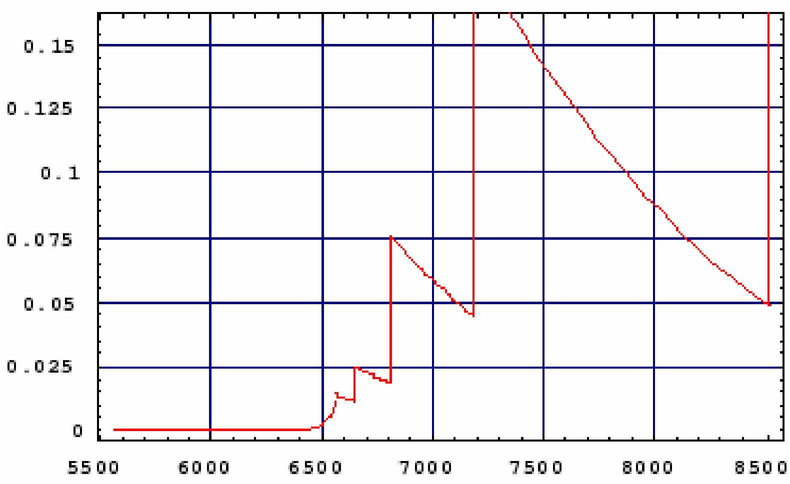

Fig. 4 IGM transmission for a source at $z = 6$.

Filippo Zerbi was asked to coordinate the construction of the telescope and related instruments and the operation of the whole team (see listing in the Acknowledgements).

The 60 cm telescope has two Nasmyth f/8 focal stations, Carl Zeiss AG optics and is capable of a maximum speed of 12 degrees s^{-1} with an accurate pointing thanks to Heidenain encoders with 237 steps per arcsec. At one of the Nasmyth focal planes we mounted on axis a NIR camera and on the beam perpendicular to the axis (the beam is split by a dichroic) we mounted a very low dispersion spectrograph using an Amici prism and a set of optical filters.

At the time of writing the telescope has been already installed at La Silla and the limiting magnitudes obtained during the first light tests, June 2003, showed we were well within expectation reaching the limiting magnitudes in 1 second integration and for a signal to noise ratio S/N=5 of : V= 17.2, R= 17.2, I= 16.0, J= 14.5, H= 13.5, K= 13.0.

During commissioning, we are now close to the end of it, we had a series of rather serious problems both with the telescope (alignment, hardware and software) and the NIR camera (hardware). Now everything seems to be working properly and we plan to start soon the science verification phase and the remote control end to end test. We should soon be fully operative.

REM over the two years period of the Mission (but again it could last longer) and albeit strong fluctuations due to the fact that Swift could be observing in the Northern hemisphere in periods of pseudorandom length, should be able to observe more or less 25% of the bursts located by Swift. Its contribution will be essential soon after the trigger and to get uniform data we may stay on a new target for a long period, likely for a few hours and returning to previous bursts as often as needed. The observing strategy will be fine tuned since we might also observe bursts detected by Swift and not necessarily observed by the NFI which could be busy with an other burst (BAT has a 1.4 sr full coded mask so that it could also detect bursts reachable by REM while observing in the Northern Hemisphere). But no matter what, the GRBs and related ToO will probably use at most 50% of the telescope time. That is why we pre-programmed also a set of observing programs, both galactic and extragalactic, that will be carried out by the team or subgroups of the REM team. In addition REM will be open in the near future to proposals submitted to ESO on a regular basis. Needless to say the GBB program will have absolute priority during the lifetime of the satellite.

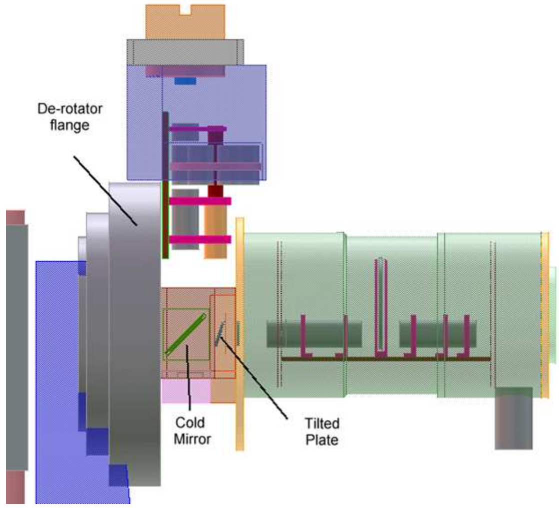

Fig. 5 The Nasmyth focus is bent 90 degrees to accomodate ROSS.

Fig. 6 The Swift satellite in the clean room at the GSFC, with the XTR and UVOT telescopes already mounted on the satellite.

Data Archives will be organized also for REM. These will be in all the main hardware Institutions and be regulated by common rules.

Acknowledgements I would like to deeply thank all the members of the Swift team, Neil Gehrels, Nick White, John Nousek, Alan Wells, Dave Burrows, Paolo Giommi and many others both abroad and in Italy because during this period of working together not only I learned a lot but I also got to know capable scientists and to admire and respect many. I feel very good and satisfied in being part of this team. Sergio Campana, Stefano Covino and Gianpiero Tagliaferri gave suggestions on how to improve the manuscript. I also should underline the effort carried out by the Hardware Institutions, GSFC (USA), Penn State University (USA), OAB (Italy), ASI-ASDC (Italy), Leicester (UK), Mullard Space Science Laboratories (UK) and the contribution by MPE (Germany) where we calibrated the XRT. Clearly nothing would have been possible without the support of the Space Agencies, NASA, ASI and PPARC.

Likewise I felt about the REM Team. Here I was surprised in seeing the enthusiasm of younger scientists in getting together to accomplish a new project and, after we got the telescope to la Silla, the continuous effort that often required for some the departure for rather long periods from their family and day by day life. Indeed we had a real working team. I thank all, technicians and scientists, for letting me witness the best part of Italy (and this I am sure occur also in other endeavors) at work.

The hardware Institution related to the REM project are: The observatory of Brera in Merate, the Observatory of Catania, the Observatory of Roma (now all part of INAF), the University of Perugia, the Dunsink Observatory of Dublin and the CNR-IASF of Bologna. The collaboration is however larger and to the REM team participate scientists also from the University of Milano-Bicocca, the CSIC-IAA in Granata (Spain), the CNR-IASF of Palermo, the Observatory of Trieste, the University of Valencia, the CEA-Saclay (Ireland), the University college of Dublin and the Carso University of Trieste.

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