Supporting Space Science Projects

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Abstract

Small (sub-8m) telescopes have long performed the important scientific task of supporting observations from space missions. This has covered not just multi-wavelength studies and optical/IR source identifications, but also preparatory observations and follow-up work to more precisely determine the nature of the objects located and identified. More recently, Target-of-Opportunity (ToO) programmes allowed the spectacular first optical imaging of a γ-ray burster. The requirements for this work varies in terms of the capability, capacity and access to the ground-based facilities. This will be discussed with particular reference to the forthcoming X-ray Multi-Mirror (XMM-Newton) mission which will require ground-based support reaching unprecedented levels (V$\sim$25–26).

Key words: Small telescopes; space science

1 Introduction

Space astronomy missions have always been supported in various ways by a variety of ground-based observations over all accessible wavelengths. This has dramatically increased the scientific output of such work, with often the ground-based data providing the pivotal observations in the interpretation. By the late 1980s this led to an astronomical conference dedicated to *multi-wavelength astrophysics* and the subsequent creation of networks of astronomers involved in such work (Cordova 1987).

Currently, there are operating space observatories that cover a wide range of wavelengths from γ-ray (CGRO), X-ray (ASCA, RXTE, BeppoSAX) to UV/optical/near-IR (HST). These will be augmented in the next few years by AXAF ("Chandra"; mid-1999), XMM-Newton (early 2000), ASTRO-E (2000), INTEGRAL (2001?) and SWIFT (2003). The latter is particularly worth noting as it combines for the first time in a single spacecraft the ability to detect

a γ-ray burst, locate it with a wide-field X-ray telescope and then image it through an optical telescope, thereby encapsulating exactly the procedure that has been developed very recently for their ground-based study.

2 Range of Ground-Based Support Activities for Space Missions

There is a wide range of work currently undertaken at ground-based observatories in support of space astronomy missions. These are divided into the following categories:

(1) **Preparatory**
These are observations that are needed in order to prepare an observing proposal (e.g. for HST) or to help develop the appropriate configuration for particular space observations (e.g. imaging of XMM fields).

(2) **Simultaneous**
(a) general multi-wavelength observations that are all simultaneous, enabling a detailed study of the physical emission processes and of different emitting regions (e.g. X-ray binaries, AGN).

Fig 1 shows the example of simultaneous RXTE and SAAO fast photometry of the X-ray burster GS1826-24 at 2s time resolution during an interval that displayed a type I X-ray burst (Kong et al. 2000). The burst arises in a thermonuclear runaway on the surface of a neutron star and is often Eddington limited. The X-ray flux irradiates and heats the surrounding accretion disc, producing the flash that is seen in the optical. Precise timing allows the X-ray reprocessing and disc geometry to be studied in detail.

(b) multi-wavelength ground-based observations during the same epoch of the space observations (usually days to weeks before and after). These are necessary in order to establish the "state" of the source and allow a detailed interpretation of the data to be made.

Fig 2 shows X-ray and radio observations of the galactic superluminal X-ray binary GRS 1915+105. The dramatic X-ray variations are interpreted as being associated with the collapse of the inner accretion disc, thereby giving rise to radio/IR flares and ejection events. This is perhaps one of the best examples of how observing across many wavelengths is essential for a full physical interpretation (Mirabel et al. 1998)

(3) **Source Identifications**
At IR and X-ray wavelengths deep surveys were carried out by the IRAS and ROSAT satellites leading to the discovery of large numbers of IR and X-ray sources. However, the nature of these sources could not be elucidated until these were identified by ground-based follow-up observations.

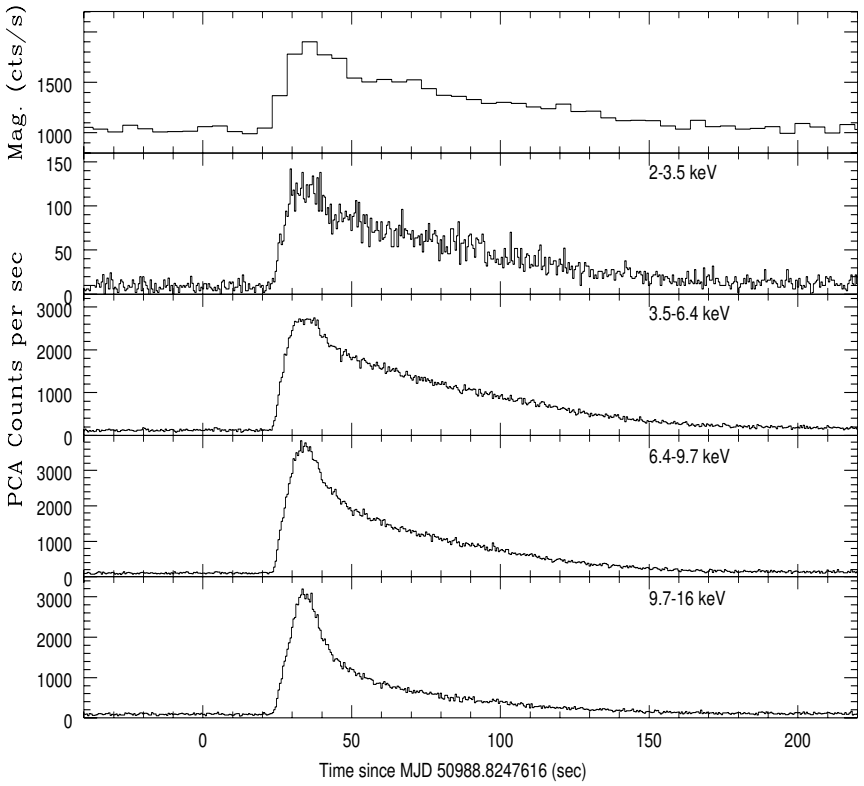

Fig. 1. *Simultaneous optical (SAAO) and X-ray (RXTE) observations of an X-ray burst from GS1826-24 (Kong et al. 2000). The optical peak lags the X-rays due to light-travel time across the disc and reprocessing in the disc material.*

These entailed both imaging of the IR/X-ray "error boxes" and low resolution spectroscopy of candidate objects. The great majority of these could be observed with e.g. the 2.5-m Isaac Newton Telescope (INT), and only the faintest systems required 4.2-m William Herschel Telescope (WHT) time (see e.g. Mason et al. 1995).

(4) **Source Follow-Up**
Some surveys (e.g. ROSAT) led to catalogues of objects with particular X-ray properties (e.g. soft spectra) that could be characteristic of widely varying astronomical phenomena (e.g. QSOs and AM Her systems). However, these could be easily distinguished by optical spectroscopy, whilst at the same time compiling a database of e.g. redshift distributions of the extragalactic counterparts (see e.g. Mason et al. 2000).

(5) **ToO Alert**
It has been recognised for many years that certain types of high energy phenomena (e.g. γ-ray bursters (GRBs), X-ray transient outbursts) require very rapid follow-up if the full physical manifestation of the event is to be examined. Such "Targets of Opportunity" (or ToOs) feature as a significant component in the operations of almost all space-based observatories. The GRBs are an extreme example because they are so short-lived that, in spite of being known for more than 25 years, a GRB was not captured optically until 1997 (van Paradijs et al. 1997). But the most spectacular such event yet occurred in January 1999 with optical

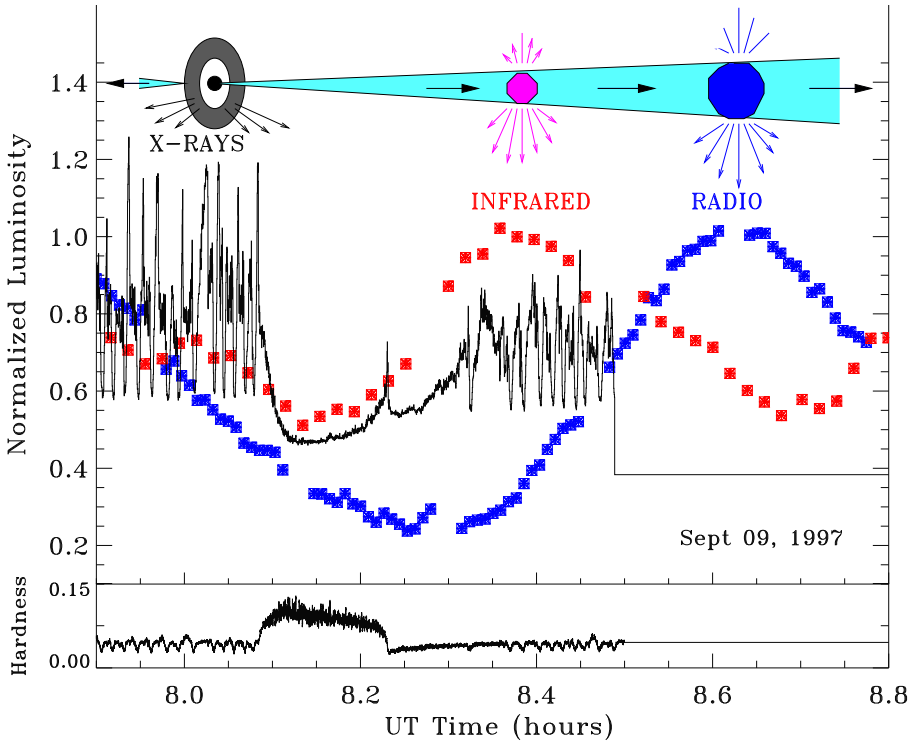

Fig. 2. *Radio, IR and X-ray light curves of the superluminal transient GRS 1915+105 (Mirabel et al. 1998) showing the remarkable variations in these bands that are associated with the ejections of relativistic clouds.*

imaging of a luminous GRB within the first minute of its occurrence (Akerlof et al. 1999). In spite of a redshift of 1.6 the object peaked at almost 8th magnitude, implying extraordinary luminosity, the nature of which is currently being hotly debated. Within only a few minutes it had faded to almost 15th magnitude.

The X-ray transients also require follow-up within days of outbursts being detected. Ostensibly early observations are for identification purposes, but extended monitoring of the complete outburst light curve can yield dividends such as was demonstrated in the 1998 RXTE soft X-ray transient J2123-058 (Zurita et al. 2000; see figure 3). Its evolution was dramatic, indicating the greater information yield from high inclination systems where the X-ray heating was clearly evident, dominating after the disc had greatly reduced but then disappearing.

Such work is delivering outstanding science but requires enormous effort to arrange and implement. It is partly for this reason that a network of telescopes (ROBONET) has been proposed for the purposes of undertaking precisely such erratic yet demanding observing programmes.

The very wide range of ground-based observations described above have different requirements, but they can all be defined in terms of:

(a) **Capability** - i.e. the size of the telescope/facility, the instrumentation available at any given time, and the speed of response to particular requests.

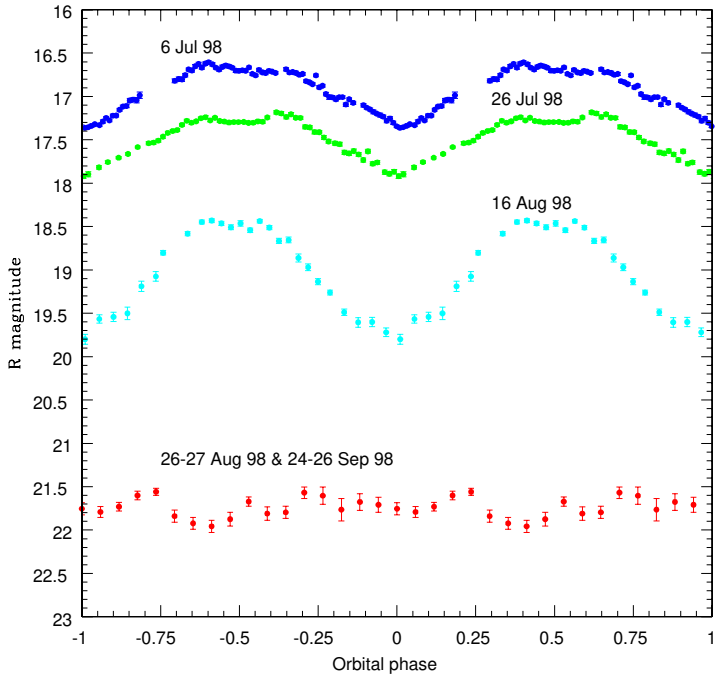

Fig. 3. *Evolution of the 6hr orbital light curve of the soft X-ray transient XTE J2123-058 from its peak in July 98 through its decay over the subsequent 3 months (Zurita et al. 2000).*

(b) **Capacity** - obviously the throughput of the telescope controls how quickly particular observations can be performed (i.e. how long does it take to obtain the data quality required for a single target), and hence how many targets can be handled. This is particularly relevant to ToO programmes, as it is not feasible to have too many ToO targets potentially pending at any given time or else "normal" observing is seriously impacted (and hence the usefulness of robotic facilities such as ROBONET, although even it might have a limit to how many ToOs could be handled!).

(c) **Access** - must be timely in order to be useful, and this requires the support of the time assignment groups (TAGs). If extended (contiguous) monitoring around the clock is needed, this adds the problems of coordinating amongst different TAGs usually in different countries (again a key advantage to the ROBONET approach). This requires TAGs to consider the occasional need for *strategic* priorities to over-rule purely *scientific* prioritisation, especially associated with particular space missions.

Recent experience with support for space mission observing has suggested that the latter point needs to be taken more seriously. There is no point having specialised instruments if you cannot use them when they are needed! The corollary to this is that completely general purpose telescopes (which could undertake an extremely wide range of scientific programmes) are not likely to be useful for such work. i.e. smaller telescopes with constrained instrumenta-

tion could be much better targetted for particular tasks (e.g. large telescope surveys, space mission follow-up) than larger telescopes. It is interesting that this appears to parallel the direction in which most small telescopes are heading, largely as a result of funding and other operational constraints. This could even extend to current front-line telescopes such as the WHT evolving from their present "workhorse" status once Gemini (and then GTC) begin operating.

3 Implications of XMM-Newton/AXAF Sensitivity

The next generation of X-ray observatories, such as XMM-Newton and AXAF (now renamed "Chandra") are just becoming operational, and their sensitivity compared to previous missions will be such as to reduce most small telescopes to the state that they are only useful for imaging work. Considering that most XMM-Newton observations will typically be in the region of 30–50ks per source, this leads to a minimum detectable flux of around 10^{-15}erg cm^{-2} s^{-1} in the 0.1–10 keV band. This means that each observation is likely to detect as many sources as were seen in a ROSAT Deep Survey pointing! i.e. $\sim 10^3$ per square degree at high latitude which means $\sim$100–200 sources per observation. And with an expected number of 500-1000 pointings per year, a serendipitous catalogue of $\sim 10^5$ sources per year at the ROSAT Deep Survey level could be generated. And based on past experience that requires optical identification charts to reach V$\sim$25–26! The INT is fine for surveying such fields, but spectroscopic identification would be limited to the brighter objects only. Even the WHT could only reach V$\sim$24, and Gemini would be needed for the faintest candidates (V$\sim$26) which may be the most interesting!

This implies that the new X-ray telescopes will finally be more sensitive than our current optical facilities. And they are also pushing extragalactic studies to higher redshifts, with the current ability to detect QSOs to $z \sim 4$. Furthermore, XMM-Newton Deep Observations should allow distant clusters of galaxies to be identified. But their redshift implies that they must be studied in the near-IR from the ground, and this will be limited by *capacity*.

The key *capability* required for ground-based support is to have a "responsive infrastructure". Hence it is ideal to have *Q-scheduling* as that allows ToOs such as GRB follow-up to take place easily. The Isaac Newton Group have shown it **can** work. But it needs the right infrastructure in place to ensure that it will **always** be capable of working (and not just depend on particular personnel or instrumentation). Therefore space mission activities require:

(i) an infrastructure at the observatory to process and then handle external requests/proposals for ToO follow-up scheduling;

(ii) flexible (i.e. fast-switching) instrumentation for appropriate observing setups needed for particular ToOs.

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