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High Speed Multicolour Photometry of the X-ray Burster MXB 1636-53

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1. Introduction

X-ray burst sources are thought to be low-mass binary systems in which a mass-losing late-type main-sequence star transfers matter via an accretion disk onto a neutron star. The high potential energy of the material is converted to high kinetic energy, which subsequently thermalizes and escapes as X-rays. Depending on the temperature, the strength of the magnetic field and the accretion rate of the neutron star, a thermonuclear flash can occur on its surface from time to time. Within seconds a total energy of about 10^{39} erg is released. The resulting radiation is predominantly in the X-ray band. Burst intervals are mostly irregular and range from hours to days. There is no clear relation between the shape of the burst, the intervals and the continuously emitted X-ray level. Black-body fits to the energy distribution of the bursts yield temperatures up to 10^7 K and a radius of the emitting area of approximately 10 km thus supporting the neutron star model.

Optical bursts correlated with X-ray bursts have been observed for several sources. The shape of an optical burst is similar to that recorded in the X-ray range, whereas its energy content is a fraction of 10^{-4} only. Nevertheless, this is more than expected from an extrapolation of the X-ray spectrum. Usually the optical burst is delayed by a few seconds. This can be understood as a consequence of the longer light path from the X-ray source via the place of reprocessing to the observer, compared to the path on the direct way.

MXB 1636-53 (optical counterpart: V 801 Ara) is one of the best studied examples in both the X-ray domain and the optical region. Several coincident X-ray/optical bursts were recorded and

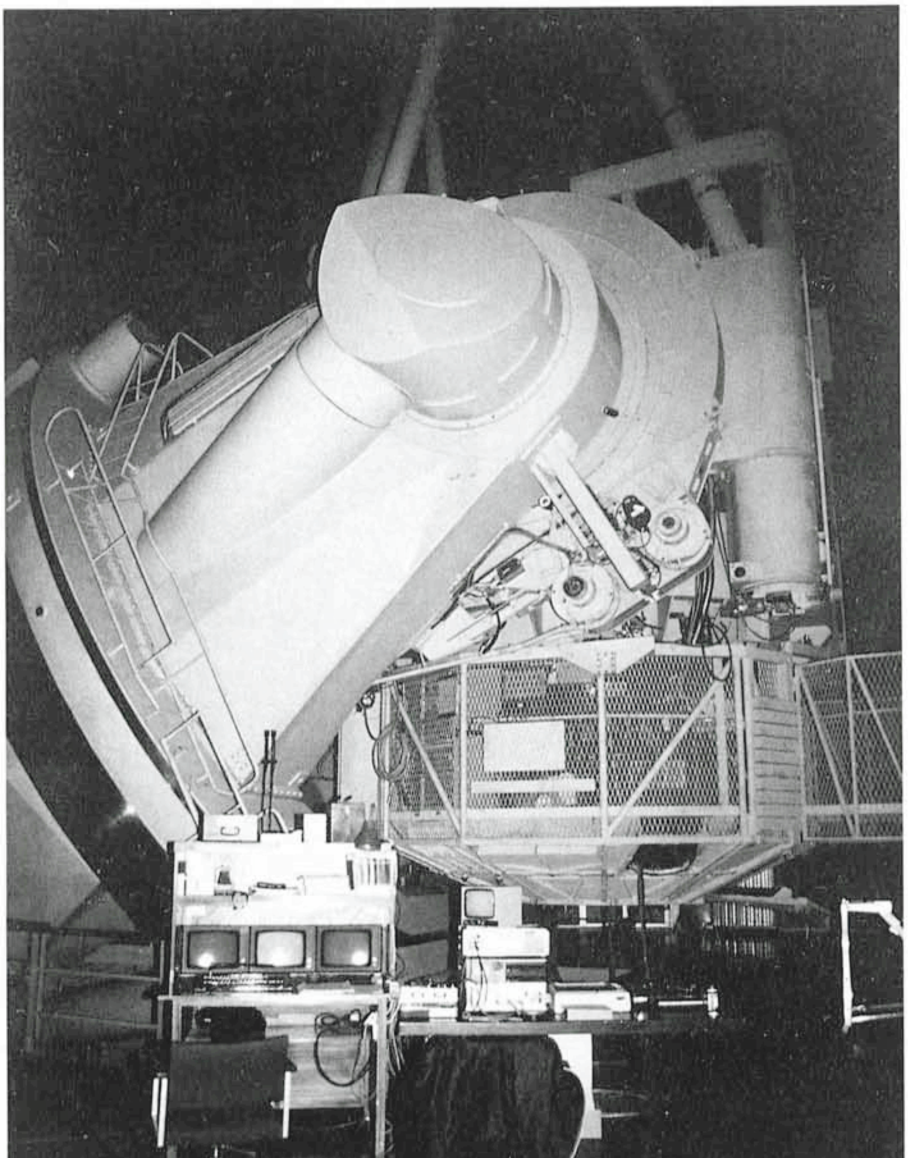

Figure 1: *The data-acquisition system of the photometer placed inside the dome of the 3.6-m telescope during observations.*

the data concerning this system contributed appreciably to our knowledge on bursters. Initially optical data were obtained in unfiltered light and could merely give crude estimates of the properties of the disk. The delay from X-ray burst to optical burst was found to be about 2.5 seconds (Pedersen et al., 1982, Matsuoka et al., 1984). Black-body fits to the energy distribution yielded a temperature of about 50,000 K for the disk during burst, twice as large as during quiescence. UBV burst light curves obtained later on showed that the single-temperature black body reprocessing model is only approximatively correct. Slow modulations in the persistent optical flux of about 4 hours were interpreted as due to binary motion (Lawrence et al., 1983).

The aim of our observing campaign was twofold: (i) More data concerning the spectral development during optical burst should be collected to further investigate the physical state of the accretion disk and the processes converting X-rays into optical light. (ii) Long data sequences should be recorded to improve the period of the suspected orbital variation and to obtain information about variations of the system in UBVRI which might even allow to derive more system parameters.

The original plans for coordinated simultaneous X-ray observations had to be abandoned since unfortunately EXOSAT got out of control shortly before our observation and the Japanese TENMA X-ray observatory was not operating at the time in question. In the following we report on the optical observations and on the provisional results.

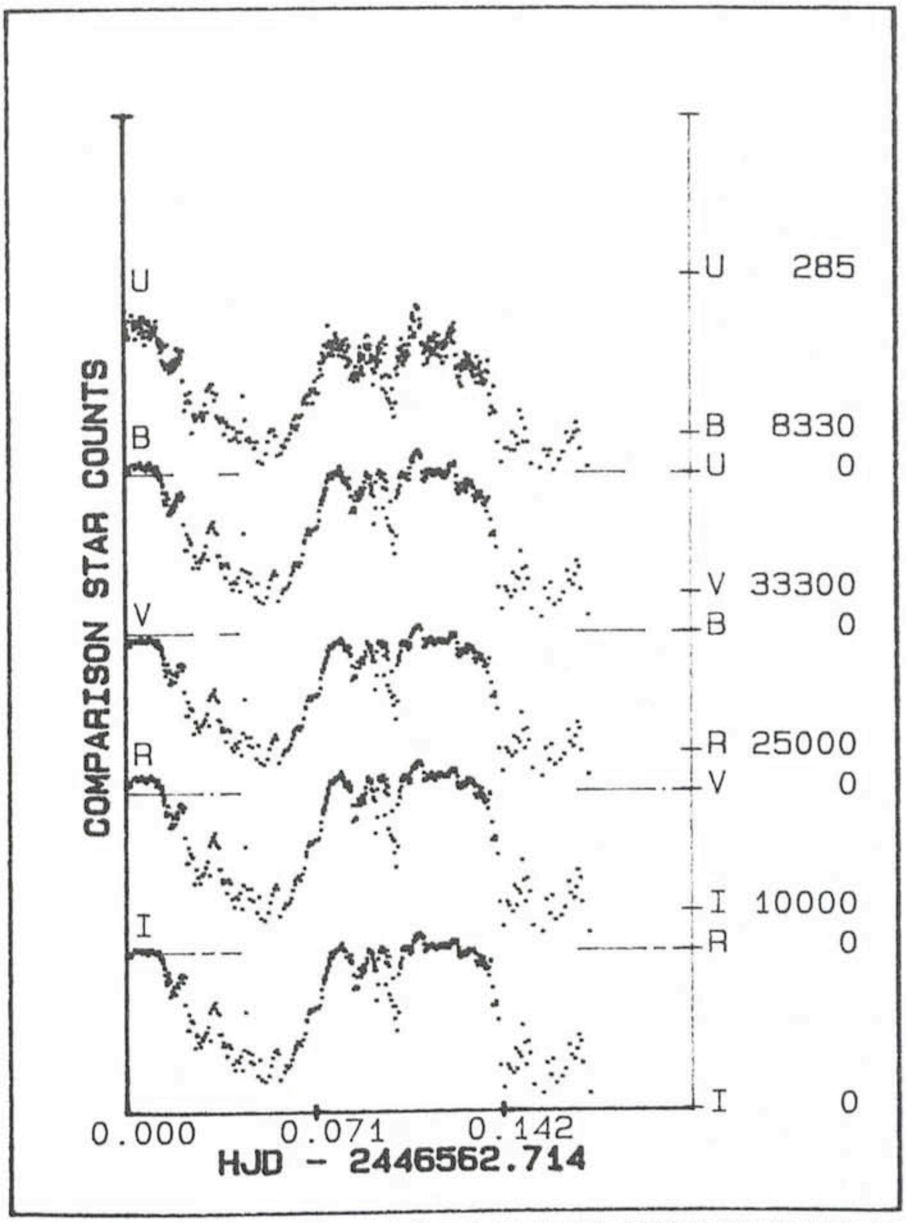

Figure 2: *Atmospheric transparency variations during the first night (4 h) represented by the comparison star counts.*

2. Preparation and Observations

Four nights (May 12–15, 1986) at the 3.6-m telescope were granted to the project. We used the three-channel UBVRI photometer developed at the Universitäts-Sternwarte München (Barwig et al., 1987). The instrument provides for simultaneous multicolour recording of object, comparison star and sky, thus it allows photometric work even under otherwise unfavourable meteorological conditions.

Photometry of MXB 1636-53 demanded measurements at high time resolution simultaneously in 15 data channels. To do this, a new programme package had to be written. The final version allows to reach 10 msec time resolution without deadtime with an economic output of roughly 1 Mbyte within 20 minutes corresponding to one 8″ floppy disk. The disks can be loaded alternately into one of the two drives while the other one is recording. The programme provides for real time graphics and statistical information.

Before starting the observations we were not sure whether our TV acquisition system would be sufficiently sensitive and the built-in autoguider would co-operate with the 3.6-m telescope. But from the very beginning the instrumentation worked without problems. Since the cables were not sufficiently long for the control room, the computer system and displays had to be placed in the dome and thus also the observers. We were afraid to extend the cables since this would make the system more vulnerable to electrical pick-up noise. Straylight from displays, etc. and other sources of interference were carefully checked before we started our observations and their influences were kept below detection. Figure 1 shows the instrumental setup in the dome.

Regrettably, the observations were impeded by excessive wind and by clouds. Useful observations could be performed only during parts of the first, second and fourth night, while the third night was lost completely. As an example, Figure 2 shows the count-rates obtained for the comparison star during the first night. Only at the very beginning a short time interval of fairly stable transparency was encountered. The second part of the second night and the end of the last night were very cloudy.

Due to the special observing technique and the properties of the star field around MXB 1636-53 it was necessary to use a hitherto unknown star as comparison. After some time we suspected

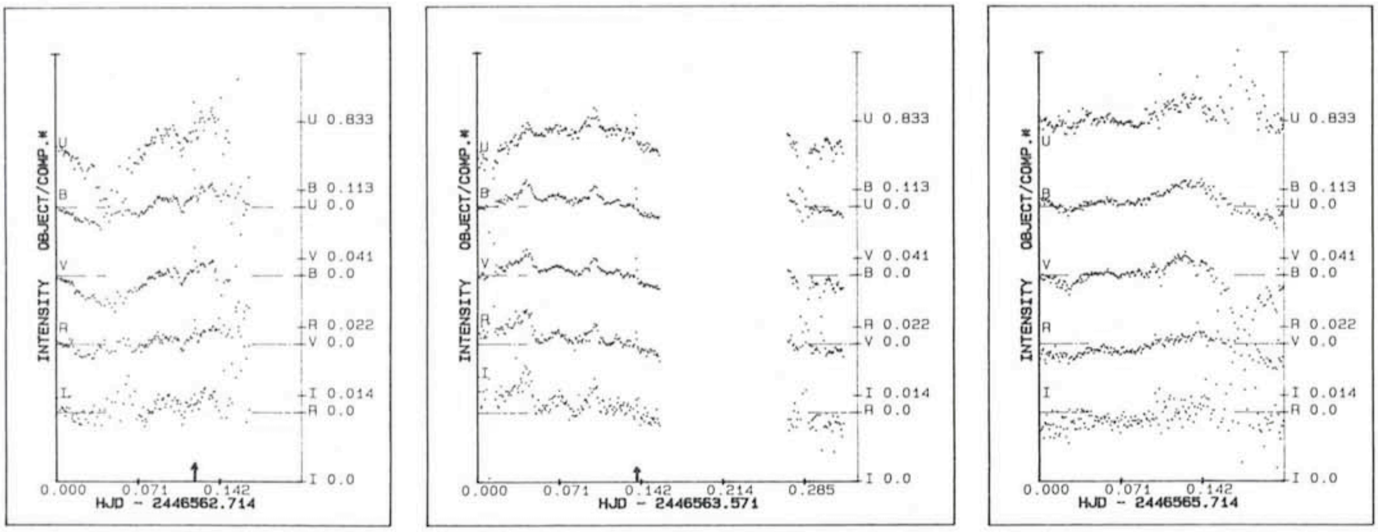

Figure 3a, b, c: *Condensed light curves (rel. intensity) of MXB 1636-53 which show the whole observing period, covering the nights of May 11/12, 12/13, 14/15 respectively. Arrows indicate the position of the identified bursts.*

that it might be variable, and thus the photometer was prepared for a different comparison star. Their calibration, performed at a later date, yielded results constant within 0.1 magnitude.

Integrations of 40 msec for the object and 200 msec for sky and comparison star were used. The aperture of the diaphragms throughout the observing period was 7″. Table 1 shows typical photon fluxes as measured in UBVRI under good transparency conditions.

According to atmospheric refraction the count-rates in U and I are attenuated at larger zenith distances. This effect is at least partly compensated by the reference channel.

3. Reduction and Results

The reduction procedure makes use of separately measured dark counts and of transformation coefficients which, for each colour, relate the sensitivity of the three channels. A file is produced which contains HJD-time and the five object intensities relative to the comparison star. Using magnitudes or fluxes of the comparison star they can be converted into absolute values. The reduction programme offers options by which the effective integration time (which equals the time resolution) can be increased to a fixed value or to a variable amount depending on sky transparency. The latter mode was used because of the variable transparency in order to yield data of fairly comparable rms.

For the determination of the transformation coefficients photometric conditions are required. Good conditions were never encountered during the whole observing period. Thus the quality of the transformation coefficients is limited, causing incomplete compensation of the atmospheric variations during very cloudy skies. This was the case at the beginning and end of the first night and at the end of the second and third night. Figures 3a, b, c show the full extent of the light curve, binned to 80 sec/dot. Significant, slow variations were present during all three nights. The time constant of these variations is variable, being shorter during the second night, while the amplitude is larger during the first and the last night. Correlated colour variations occur at some of the peaks.

A periodogram analysis of the new data revealed a possible period of 3.76 h. This is consistent with the 3.78 h period determined by Pedersen et al., (1981). However, the significance of our period is not high, because of the large gaps and superposed irregular variations. Figure 4 shows a phase diagram of data in V, calculated for the period P

TABLE 1: Average fluxes (counts/sec)

Channel	U	B	V	R	I
MXB 1636-53	50	200	175	100	25
Comparison star 1 (−22″, +94″)	65	2285	6875	4950	2335
Comparison star 2 (+151″, −19″)	250	2915	4855	2140	745
Sky (7″ diaphragm)	60	180	400	235	115

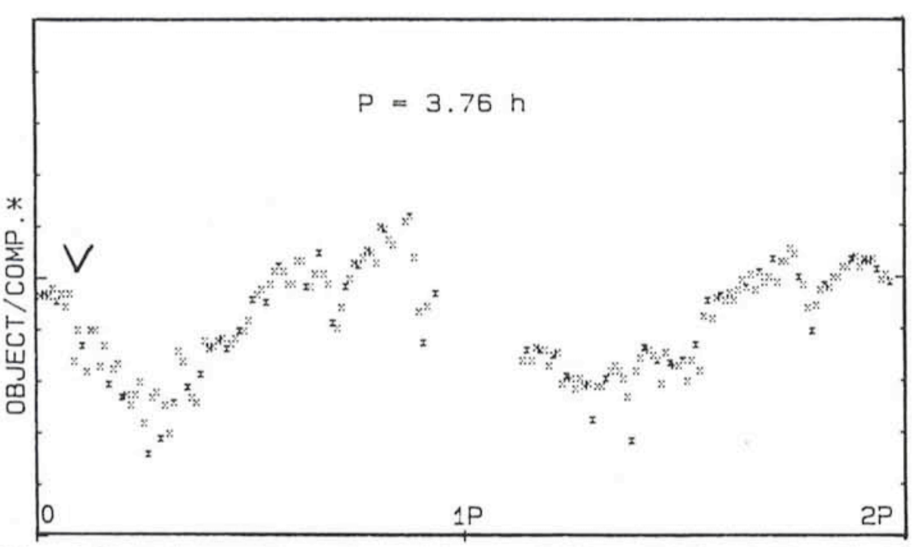

Figure 4: *Phase diagram of the condensed light curve of MXB 1636-53 with twice the period of 3.76 hours.*

= 2·3.76 h. The two representations of the light curve are thus based on statistically independent data. Their shape and the occurrence of some repeating features is striking. Especially the dip near maximum, not explicitly mentioned by Pedersen et al., is well represented in their phase diagram.

Apart from these slow variations two bursts were detected. In Figure 3a and b their position is indicated by arrows. The burst light curves with high time resolution are superposed for comparison in Figure 5. The scales are the same in both cases, but the zeropoints were shifted to separate UBVRI. The data were smoothed by a recursive low-pass filter. Burst 1, observed during the first night, is less intense and has a slower onset than burst 2, which has a rise time of less than two seconds. This limits the extension of the visible emitting area to about $6 \cdot 10^{10}$ cm. In colour B (highest count-rates) a double-peak structure is shown for burst 2 with a separation of about 3 seconds. Similar features were found by Sztajno et al. 1985 in the X-ray band. The colours of the optical bursts are consistent with a very hot source. Cooling effects during descent are indi-

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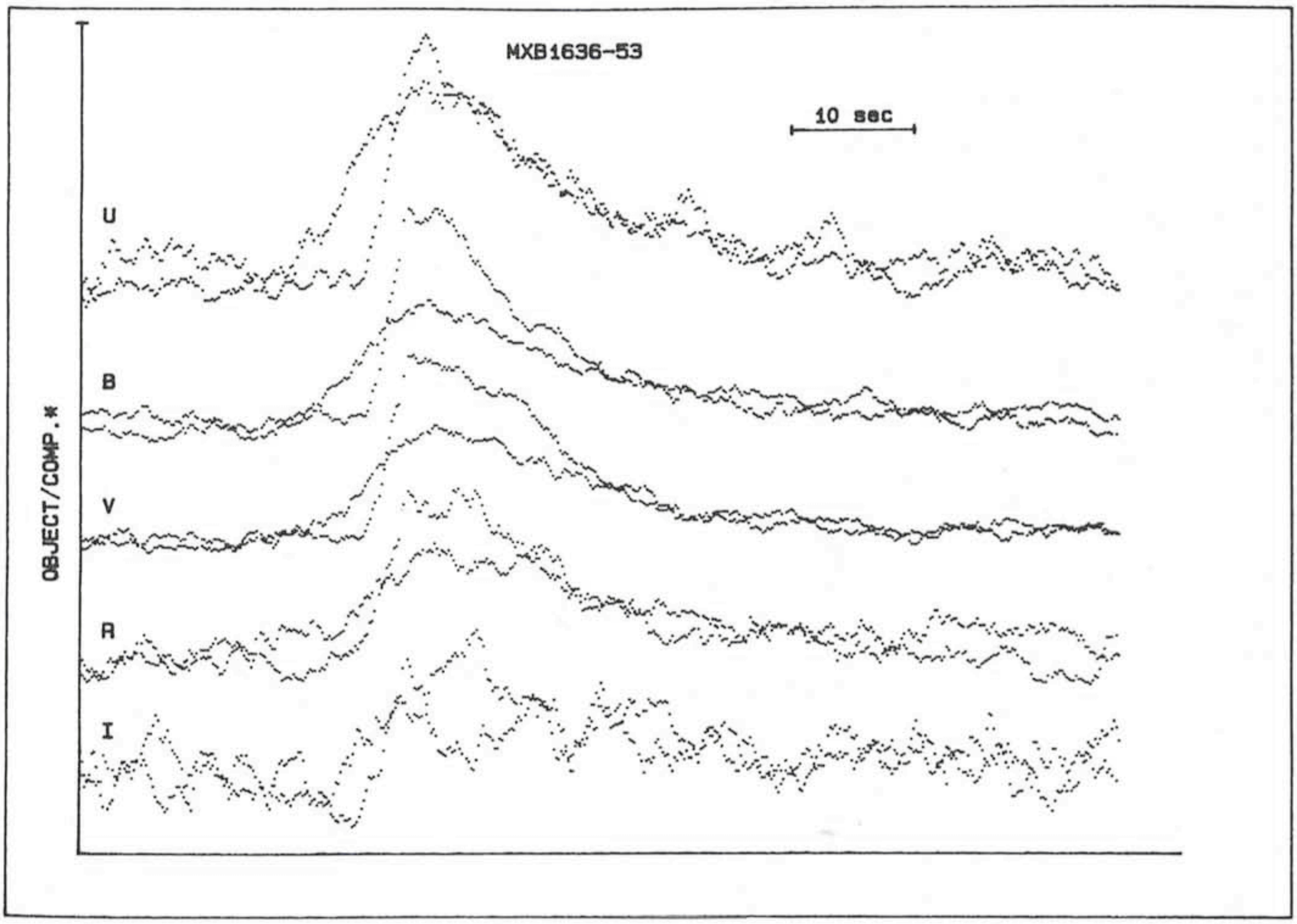

Figure 5: *The two observed bursts superposed to demonstrate similarities and differences (1 point ≙ 320 msec). Burst 1, observed during the first night is less intense and has a slower onset than burst 2. The curves were smoothed (FWHM = 50 points) in order to reduce the noise.*

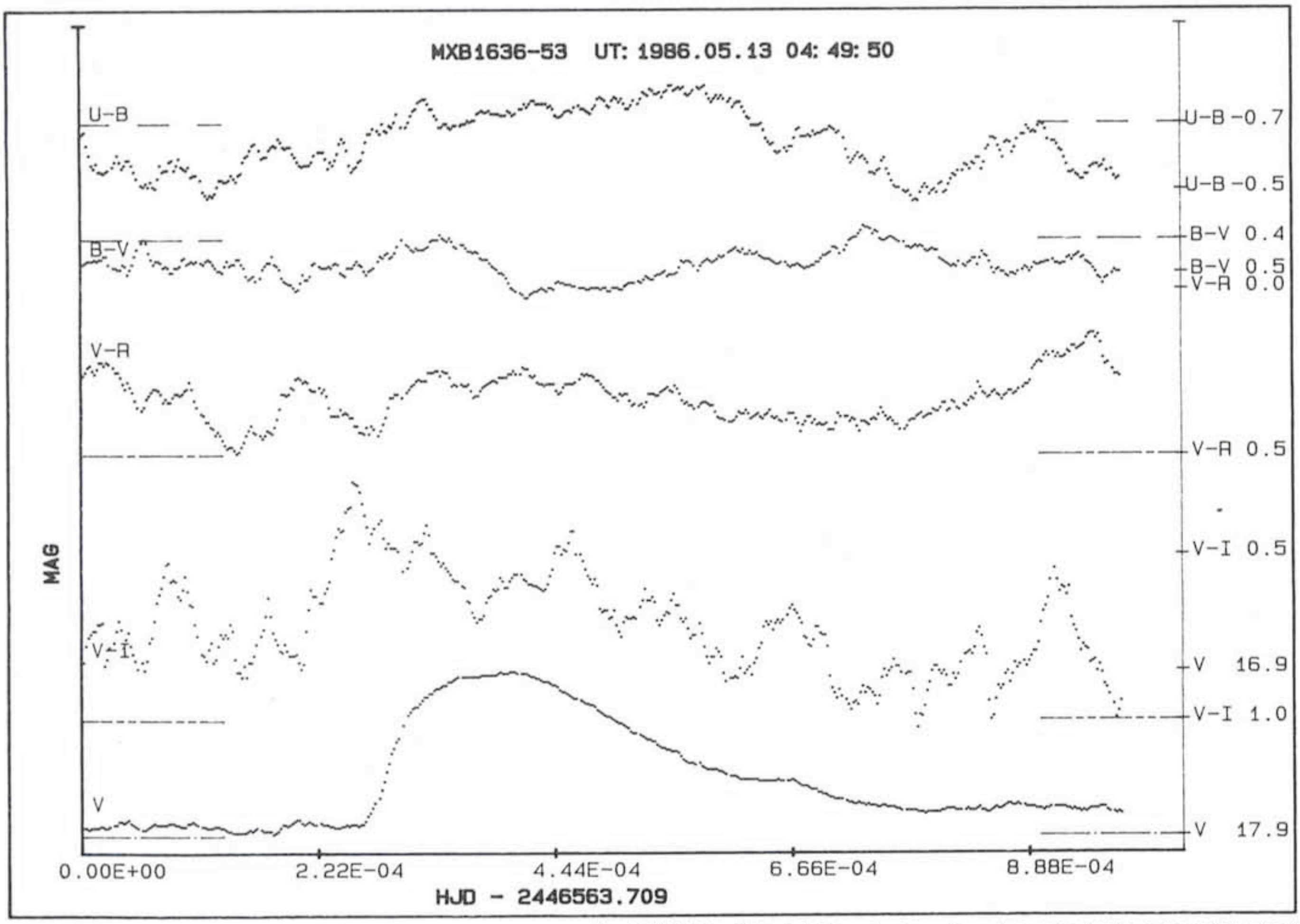

Figure 6: *Burst 2 and its colour variations. The curves were smoothed (FWHM = 50 points) in order to reduce the noise in the colours (1 point ≙ 320 msec).*

cated (see Fig. 6). A detailed analysis, however, requires more than two samples in order to enable the separation of individual characteristics from the general behaviour and to improve the signal-to-noise ratio. These considerations led to a successful application for further observations in July 1987, possibly in collaboration with ASTRO-C, the new Japanese X-ray observatory.

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Line and Continuum Imaging

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The study of line emitting objects often requires to image separately the line emission from the continuum one, in order to discriminate the different physical components. This is generally not possible with the broad bands of the standard photometric systems, like UBVRI. Rather one should use narrower bands selected according to the wavelengths of the emission lines. I discuss here the techniques to obtain pure and calibrated line and continuum images. "Pure" means that the line image is free from the contribution of the continuum and *vice versa.*. Since narrow-band imaging is not a new technique, I will restrict myself to the considerable improvements recently offered by the availability of linear and calibratable detectors, of interference filter sets and of powerful and versatile image reduction systems. Although I will concentrate here on images of active galaxies obtained with the ESO telescopes and CCD cameras at La Silla and reduced using MIDAS, the following discussion can be applied with small modifications to any class of line emitting objects and to other sites, detectors and reduction systems. I will first give some hints on how to conduct the observations and then discuss the reduction procedure. A technical note containing more detailed information is available from the author for those interested in actually using these techniques.

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Observing Hints

It is necessary to obtain exposures both with a filter centred on the emission line and with a filter on the nearby continuum. The latter is used to derive the