The X-Ray Bursters

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Astronomical observations from satellites, rockets, balloons and aircraft have given us a completely new image of the universe and its strange inhabitants. Not since the first telescopes were put together, almost 400 years ago, has there been such a burst of new discoveries. The astronomical "zoo" of peculiar objects is steadily growing and the "X-ray bursters" belong to one group of animals that poses fundamental problems. Dr. Willem Wamsteker from ESO/Chile reviews this fascinating subject.

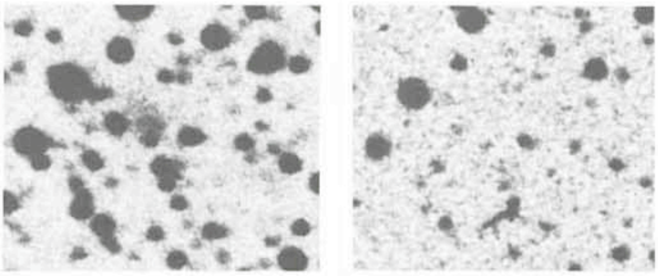

Fig. 1: *A red (left) and a blue (right) plate of the field of the rapid burster (MXB 1730–335) taken with the ESO Schmidt telescope by H.-E. Schuster. (Plate scale: 1 cm = 24 arcsec; north is at the top, east to the left). The diffuse blob on the left-hand picture is the unresolved core of the highly-reddened ($A_V \approx$ 15 mag) globular cluster Liller-1. One also notices a higher density of stellar background images, probably the brighter giants in the cluster. The rapid burster is thought to be a member of this cluster. Although a central black hole cannot be excluded, it is more likely to be a star that, having completed its evolution, has collapsed into a neutron star.*

The successful launches of the first-generation X-ray satellites has generated interest in a field of astronomy which previously was inaccessible because of the complete blocking of the earth atmosphere. The first-generation satellites consisted of UHURU, ANS, Ariel, SAS-3 and OSO-8. The discoveries of these satellites cover a wide range of objects, from quasi-stellar sources to neutron stars. The observed phenomena are of great interest because they allow the study of black holes, neutron stars and other forms of condensed material.

The conditions prevailing at such objects have been anticipated by theoretical investigations, but no evidence for the existence of such bodies had ever been seen before. We shall here discuss only the aspects of *one* particular class of objects: *the X-ray burst sources;* these are considered to be part of a larger class, the so-called galactic bulge sources.

Discovery of X-ray Bursters

The first X-ray burster (we hereafter refer to these objects as "bursters") was found from an inspection of the records of the ANS (Astronomical Netherlands Satellite). The positional identification of these sources with optical stars was only made feasible when for most of these sources accurate (i.e. a few minutes of arc) positions became available from the SAS-3 satellite. The first burster was found to be associated with the globular cluster NGC 6624. Although the source is definitely associated with the globular cluster (because of the positional coincidence), no real optical counterpart has yet been identified with it. Later, six more globular clusters were found to be also X-ray sources, of which four had burst characteristics.

One of these was of particular interest because it led to the additional discovery of a new, highly obscured globular cluster, which was until then unknown. The burster MXB 1730–335—MXB means MIT X-ray burster—which is also referred to as "the rapid burster", stands apart from other bursters because of its peculiar characteristics, to which we shall come back later. When the position of this X-ray source became known with sufficient accuracy, Dr. W. Liller found on a deep red photograph an extended object which was resolved into stars. Later, an infrared source was found independently by Kleinmann at CTIO and Wamsteker at ESO. The analysis of these results showed that one was indeed looking at a globular cluster which is now normally referred to as Liller 1 in the expectation that Dr. Liller will find more of these objects. However, the association of MXB 1730-335 with a globular cluster, as well as the other burster coincidences with globulars, made the likelihood of studying these objects at optical wavelengths rather small. The density of stars in the central regions of globular clusters is very high and it is therefore extremely difficult to study individual stars, especially when they are also faint.

Fortunately this situation changed when some of the galactic bulge sources showed burst characteristics. At present about 30 X-ray sources are known which have shown at some time burst characteristics. Of these, 12 have a more or less certain optical counterpart. However, only 5 of these are single stars which allow the possibility of separate optical investigations.

What are Bursters?

Burst sources are X-ray sources which maintain a more or less stable brightness level—sometimes variable within time scales of the order of days—upon which infrequent and irregular brightenings of about 10 times the normal emission level are superposed. These bursts show an extremely short rise time; within 1–2 seconds the brightness increases approximately tenfold and after this the brightness decays more or less exponentially in a time of 5–10 times the rise time. Although the bursts represent an extremely spectacular phenomenon, they contain only a fraction of the total energy emitted by these objects. This is simply due to their short duration and infrequent occurrence. (Energy in bursts $\approx 10^{-2}$ x energy in constant source.) Most bursters show this type of behaviour where bursts occur with intervals which are separated by 10^3–10^4 times the decay time of 5–20 seconds of the bursts. The spectrum of these sources softens during the decay; this means that the temperature associated with the X-ray spectrum becomes cooler while the source gets back to its quiet X-ray brightness level. These bursts are said to have type-I characteristics.

The second type of bursts (type-II bursts) are only seen in the "rapid" burster and are the reason for its name. In addition to type-I bursts, this source shows at times what appears to be "Sten-gun" fire in the X-rays. Up to 1,000 bursts per day have been seen for this source! These type-II bursts are less energetic and do not show the spectral cooling seen in the type-I bursts, as was found by the MIT astronomers.

Burster-generated International Collaboration

The presence of these enigmatic objects has stimulated a large number of collaborative efforts involving astronomers at many observatories all over the world. Upon the independent suggestions of various astronomers, ESO astronomer Holger Pedersen, Professor Walter H. G. Lewin and his collaborators at MIT, among others, took it upon themselves to organize observations from ground-based sites simultaneously with monitoring at X-ray wavelengths by satellites. The satellites involved are SAS-3 (now defunct), the British UK-6 satellite and the Japanese satellite HAKUCHO. The first campaign, two years ago, did not give many significant results. One of the reasons for this was that at that time no real optical counterparts had been unambiguously identified, so many observations were done with large diaphragms to match the X-ray error circles. One of the most significant results of the first campaign was an upper limit to the optical activity derived from a photograph of a television monitor where no optical activity was seen at the time an X-ray burst occurred (by a soviet group). It was understandable that under those conditions chances of success were slim. The situation changed with the smaller error boxes generated by the SAS-3 RMS experiment. The much smaller number of stars in the error boxes made unambiguous identification of single stars with the bursters possible.

In 1978—during the second campaign—the first coincidence event (in X-ray jargon: HIT) was obtained by McClintock of MIT at CTIO on the burster MXB 1735-44. The stars associated with the bursters are very faint. The counterpart of MXB 1735-44 has a visual magnitude of $V \approx 17^{m}.5$ and is the brightest of all. Therefore, observations at optical wavelengths of phenomena associated with the X-ray bursts can only be made with large telescopes during the dark of the moon, for which many programmes supply competing pressure on the telescope time allocating committees. At telescopes with apertures of less than 2 metres it is imperative to work with the full sensitivity of a detector (photomultiplier), to obtain sufficient photons and to detect bursts in the noise. It is then not feasible to get information about the spectrum of a burst in the optical wavelength region. Although the X-ray bursts are much brighter than the stable flux,in the

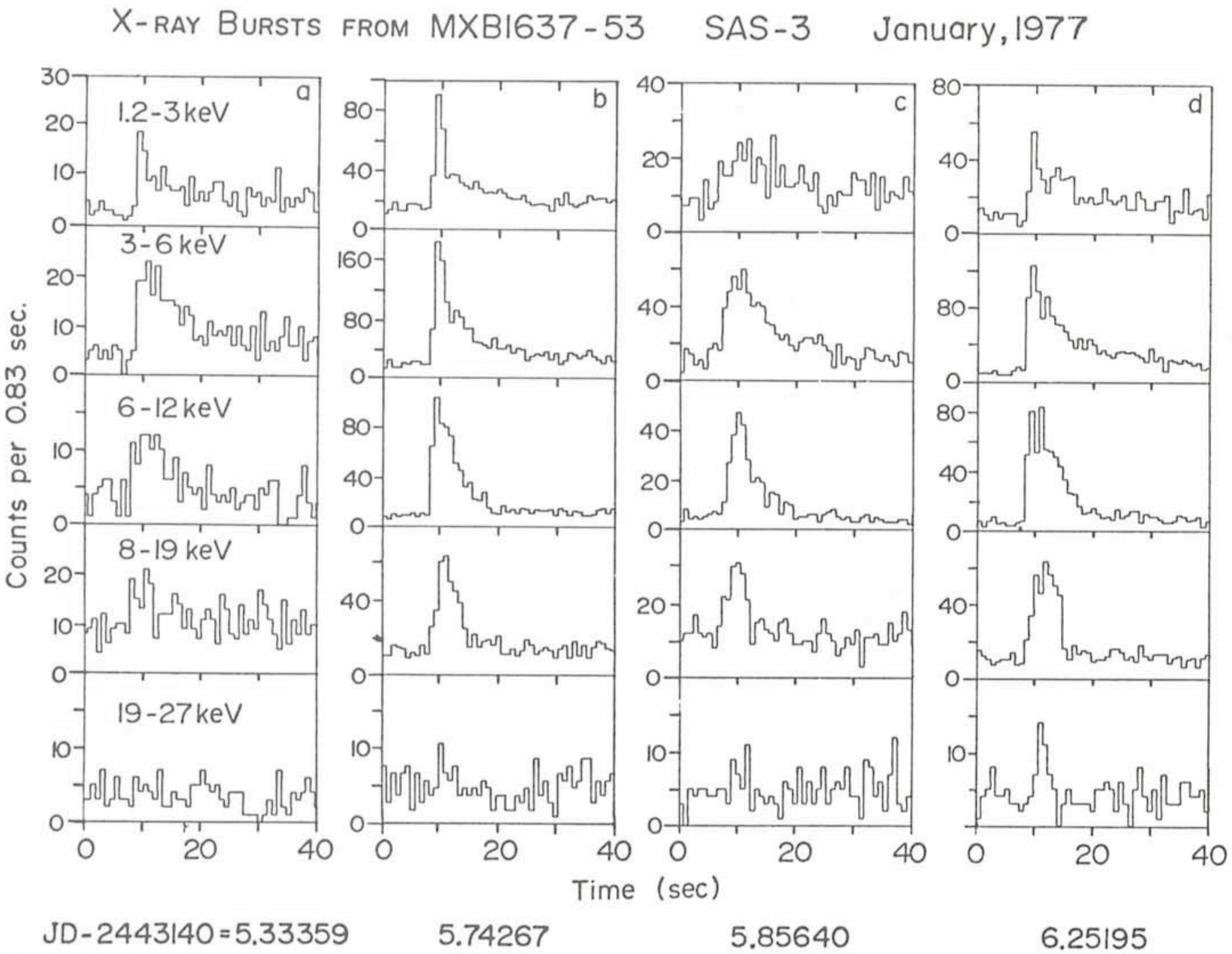

Fig. 2: *This figure shows the raw counts plots for some X-ray observations of the burst source MXB 1637–53. As indicated, the observations are shown for five different energy levels. For the burst on day 5.74267 the very rapid rise is quite obvious—the data brins are 0.8 sec in duration. Note also the much longer tail in the decay at lower energies (1.2–3 keV) in comparison with the foster decrease at higher energies (19–27 keV). This indicates the cooling of the source. (Figure adapted from Hoffman, Lewin and Doty,* Ap. J. **217**, *L23, 1977.)*

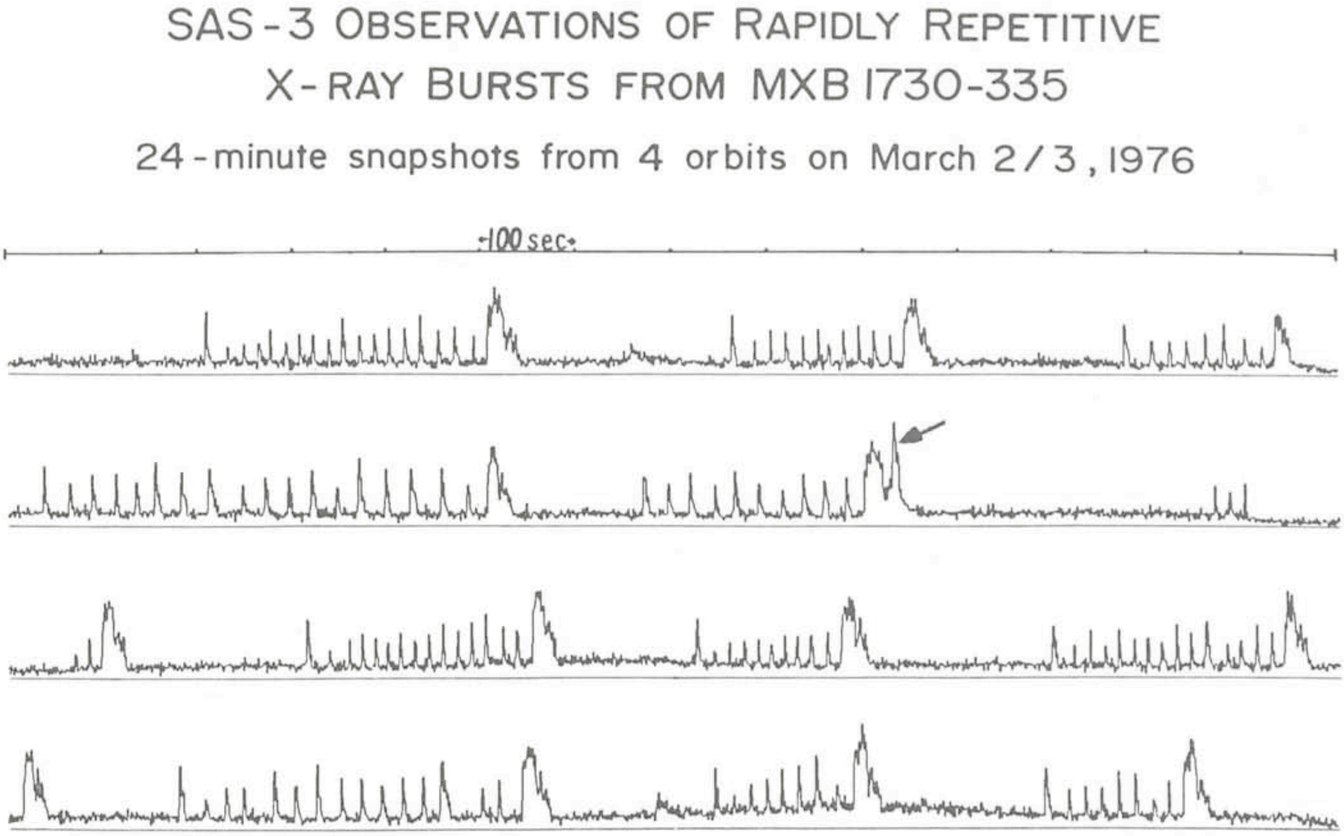

Fig. 3: *These observations of the "rapid burster" clearly show how this source got its nickname. After the stronger bursts usually follows a period in which the source is burst-inactive. It appears that the length of the quiet period is dependent on the strength of the preceding burst. The arrow indicates a burst seen by the same detector coming from another nearby burst source. Through the comparison of data from different detectors researchers are usually able to separate such effects out of the data. (Figure adapted from Lewin,* Annals of the New York Acad. of Sciences, **302,** *210.)*

optical one expects—extrapolating the earlier mentioned spectral softening—the reverse to be the case. The burst will only be seen as a relatively small fluctuation in the steady signal. One of the few existing instruments which would allow us to obtain colour information on the optical bursts is the ESO 4-channel photometer used at the 3.6 m telescope.

Observations at ESO

In August 1978 the 3.6 m telescope was scheduled for an attempt to crack this problem. During four nights I had the possibility to observe MXB 1735-44 with the 4-channel photometer. A preliminary fast photometry mode was generated for the photometer by the Chilean electronics engineer Mr. Juan Fluxa. It was during those four nights that the "astronomer's luck" still proved to play an important role when observing. The telescope did not show any problems, although still in testing phase, the weather—unusual for this season—was of excellent photometric quality, so all human endevours had succeeded. However, although the source was X-ray active—some 8 bursts were seen by the SAS-3 satellite—none of these occurred at night time! The large amount of data—60,000 integrations of 1 sec each—did however allow an analysis of possible variations with a longer time base. These results, which are now being analysed, will therefore still give important information about the nature of these sources. It is gratifying to note that the programme, which was followed up during the third campaign this year by Holger Pedersen at ESO, has now given the desired results (see page 34).

It is expected that all this activity will lead finally to a better understanding of the processes taking place in these objects. They represent a form of matter under conditions which cannot be simulated in the laboratory at similar temperatures, pressures and stable conditions. It is therefore very well possible that understanding these objects will give us new insights into the fundamental properties of matter.

Possible Mechanisms

Although various mechanisms have been proposed for these sources, most astronomers in this field favour the so-called *thermonuclear flash* model. In this model, matter is accreted onto the surface of a neutron star (accretion = the process through which matter is slowly spiraling onto the surface of very dense objects). The material falling on the surface of the neutron star is "burned" into helium, in a process similar to that of a hydrogen bomb. This continuous conversion of hydrogen into helium then gives rise to the steady X-ray flux of these sources. When the pressure and the temperature of the helium become sufficiently high, an unstable condition results and a helium bomb is detonated. This last process gives rise to energy which we see later in the form of X-ray bursts and optical bursts. The question of whether we see the primary radiation, or whether all radiation we see in the bursts is reprocessed radiation through the local heating of the atmosphere of a normal companion star, is one important aspect of this problem which we hope to solve through our observations.