ANS RESULTS ON X-RAY BINARIES

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ABSTRACT

A short description is given of the Astronomical Netherlands Satellite ANS and the X-ray instruments of the Space Research Laboratory in Utrecht. ANS observed in February 1975 a soft (¼ KeV) X-ray flux in Her-x-1 during the 'off'-state with an intensity of a factor 10 lower than observed previously in the 'on'-state. The measured uncorrected intensity is $(1.1 \pm 0.2) 10^{-11}$ ergs/cm^2 sec in 0.2 - 0.28 keV at earth.

The ANS observations on Cyg-X-1 are summarized. During the May 75 flaring state a very high intensity at 0.5 keV is measured consistent with a power-law photon-spectrum with index 3.5 and an interstellar absorption of 7.10^{21} atoms/cm^2, but not consistent with spectra that show an additional cut-off below 1 KeV and an absorption of $7\ 10^{21}$ atoms/cm^2. Intensity changes on a time scale of minutes, as observed in Cyg-X-1 lowstate, are not observed during the flaring state.

INTRODUCTION.

The Astronomical Netherlands Satellite (ANS) was launched on August 30, 1974 in a sun-synchronous polar orbit, with perigee at 265 km and apogee at un unintended height of 1120 km.

The spacecraft carries instruments from three different groups:

a. a UV-stellar spectrophotometer (University of Groningen)
b. two X-ray detectors from S.A.O., Cambridge, Massachusetts
c. two X-ray detectors from Space Research Laboratory, Utrecht.

First we describe shortly some capabilities and limitations of the spacecraft, since that has a great impact on the experiments. Secondly we will mention the main characteristics of the Utrecht X-ray experiments. And then we will describe some of our results on X-ray binaries.

Among the first, elsewhere published, scientific results of the Utrecht instrumentations are the detection of an X-ray flare in YZ-C Mi and in UV Ceti (Heise et al., 1975), the discovery of a soft X-ray flux of Sirius, clearly distinguishable from its UV contamination (Mewe et al., 1975a, 1975b), and the detection of a soft flux from Capella (Mewe et al. 1975b).

SPACECRAFT.

The choice of the polar orbit and the attitude control system were mainly determined by the requirements of the UV-instrument. The nature of this instrument, the observation of a large number of faint stars, requires that the satellite should be pointed accurately and it should be possible to change attitude easily. A three axis stabilized satellite is chosen with an attitude control system such that one axis is continuously pointed towards the sun for a clear and reliable reference necessary for this small satellite (125 kg). See for a full description Bloemendal and Kramer (1973). This attitude control system implies that X-ray objects can only be observed, if they are located within a distance of 2.5 degree from a plane perpendicular to the connecting line with the sun. Because of the annual rotation of the Earth around the sun, every object in the sky can be observed in principle once per half year for $5/\cos \beta$ days, where β is the ecliptic latitude.

A horizon sensor measures the angle between the horizon and the viewing direction of the scientific instruments. The onboard computer calculates the required torques for the reaction wheels to slew to a desired direction. This can be done with an accuracy of better than 1°. To achieve the 1 arcmin accuracy, a star sensor is used. After a slew manoeuvre the satellite is left in the scanning mode (4° per minute). The star tracker must now recognize a predetermined set of two reference stars within 1.5 degree of the target position and with magnitude brighter than 8.5^{m}. Also a slow scan can be made after a star recognition with scanspeed of 0.6° per minute. Every 12 hours, when the satellite passes over its main groundstation, a new observing program is loaded and the accumulated data is dumped. If the available memory capacity (7 blocks of 4096 16 bits words) is insufficient for a full 12 hour period, the memory can be dumped over other groundstations.

In summary the spacecraft offers

1. continuous pointing with an accuracy of 1 arcmin;
2. an offset-pointing capability, whereby the viewing direction steps repeatedly on and off the source for maximum 256 sec with a transition time of 16 seconds. The off-source position could be at maximum 1.5 degrees away from the source;
3. a scan mode with scanspeed 4°/min;
4. a slow scan mode with scanspeed $.6^{\circ}$/min.

THE UTRECHT X-RAY EXPERIMENTS SXX.

The Utrecht soft X-ray experiments are pictured in fig. They consist of a soft detector (small area proportional counter with 3.8 micron polypropylene) in the focal plane of a circular parabolic reflector with a projected area of 144 cm^2 and a reflection coëfficient of around 50%. A filter wheel can select two fields of view (0.5 and 2 degrees FWHM, circular), a UV-filter and a closed, calibrate position. The UV-filter (0.5 mm $Mg\cdot F_2$) blocks out the soft X-ray signal completely and enables us to determine the contribution of the UV-signal to the measured countrate. The overall efficiency of the soft-detector is shown in fig. 2 , solid curve. The main efficiency is between .2 and .28 keV, as also determined by the pulse height discriminator limits of .13 and .41 keV, but note the low efficient side lobe at .5 keV, which contributes slightly due to finite counter-resolution into the range .13 - .41 keV. This latter effect is responsible for the soft X-rays in Cygnus-X-1, which I will describe later.

The second instrument consists of a medium energy range X-ray detector with a 1.7 micron Titanium window and an effective area of 40 cm^2. The field of view is collimated to a rectangular form of 34' x 90' and is sensitive in the range 0.6 - .8 keV with an extra channel around .45 keV (see fig. 2 , broken line). Pulse height information of 7 energy channels can be sampled every 1, 4 or 16 seconds.

In the high time resolution mode all photons are binned in 125 msec intervals for either the soft- or medium-energy detector. In the pulsar mode 7 photons per second are registered with an accuracy of 1 msec.

SOFT X-RAYS FROM HERC-X-1 IN THE OFF-STATE.

ANS could observe Herc-X-1 in February and August 1975.
In February the source was in the off-state of its 35^d cycle, approximately 7 days before an expected turn-on. In fig. 3 the raw data is shown for a measurement on Her-X-1, with the satellite in an offset-pointing mode, printing alternatively 80 seconds on the source and 80 seconds 50 arcmin away from the source. It is clearly seen that we have detected here with our soft X-ray detector (parabolic reflector system) a definite flux between .2 - .28 keV. The medium energy detector showed no evidence for a X-ray flux between 1 - 7 keV. The soft X-ray countrate is .7 c/s with a statistical significance at a level of 6 sigma (0.66 ± 0.11 c/s). This corresponds to $1.1\ 10^{-11}$ ergs/cm^2 sec in .2 - .28 keV measured at earth. The radio data of Heiles (1975) and Tolbert (1971) indicate a hydrogen column density of $7\ 10^{20}$ atoms/cm^2. If we take the source to be at least 2 kpc (Bahcall et al. 1974), then in view of the high galactic latitude of the source the total column density will be between the source and earth. If we correct the measured flux for such an interstellar absorption one would have a flux of $1.5\ 10^{-10}$ ergs/cm^2 sec at earth. Compared to the X-ray flux between 2 - 6 keV of 10^{-9} ergs/cm^2 sec this is a rather large fraction. This fraction however is rather

sensitive to the adopted column density of interstellar matter. For example for a density of 3.10^{20}, 5.10^{20}, 7.10^{20} atoms/cm^2 the interstellar transmission is 28%, 14%, 7.5% respectively in the .2 - .28 keV band, assuming the Brown and Gould (19) abundances.

Previous observations made in the on-state of Hercules-X-1 35 day cycle by NRL (Shulman et al. 1974) and also Catura and Acton (1975) have measured an intensity in this energy range which is a factor of 10 higher. Our measurement during the OFF-state is consistent with earlier obtained upper limits (Shulman et al. 1974). It follows from our observations that the soft X-ray flux at 1/4 keV of Her-X-1

a. is not constant throughout the 35^d cycle, but varies
   with at least a factor of 10

b. is not always off, when the hard X-ray flux is off

c. the soft X-ray intensities are remarkable bright.

The interpretation of the soft X-ray flux is rather difficult. The black body intensity of a neutron star at a temperature of $\sim 10^6$ K, without interstellar absorption would yield $2.6\ 10^{-13}\ R_{10}^2/D_{2kpc}^2$ ergs/cm^2 sec in the range .2 - .28 keV where R_{10} is the neutron star radius in unit of 10 km and D de distance in units of 2 kpc, and hence is too small to account for the measured luminosities for both ON and OFF-states.

Also, in the usual picture of the accretion disk model, the accretion disk itself could not give rise to such high luminosities in the soft X-ray range compared to the harder X-ray luminosities.

If the emission is caused by an optical thin gas surrounding the X-ray source, the contribution of line radiation is dominant over the continuum by a factor of 20 in our soft X-ray channel. In fig. 4 we plotted the expected countrate of an optical thin source of emission measure $10^{50}/cm^3$ placed at a distance of 1 pc as a function of temperature. One sees that mainly Si VIII, Si IX, S X are contributing. If the soft Her-X-1 flux were due to such emission, the required emission measure at 2 kpc during the OFF-state would range between $3.10^{57}/cm^3$ and $1.2\ 10^{58}/cm^3$ for assumed interstellar column densities between $3\ 10^{20}$ and 7.10^{20} atoms/cm^2. From the measurements of Shulman et al. (1974) and Catura et al. (1975) one would infer emission measures that are a factor of 10 higher in the ON-state. For a spherical volume with radius 10^3 cm around the neutron star for example, this would imply electron densities of the order of $10^{15}/cm^3$ in the OFF-state and $5.10^{15}/cm^3$ in the ON-state. At such densities the electron scattering opacity is of the order of unity.

The light curve of the ANS observations of Her-X-1 in August 1975 is shown in fig. 5 . The source is seen during a turn-on in its 35 day cycle. The exact turn-on must have happened between binary phase 0.2 and 0.5 on August 28, 1975, as was also reported by Serlemitsos et al. (1975). Unfortunately at this time the window of our soft detector was broken, so that no soft X-ray measurements could be made during the turn-on.

CYGNUS-X-1

Cyg-X-1 has been observed by ANS in November 1975 and in May 1975. In May 1975 we discovered the source to be in a high intensity state. The flux around 2 keV was a factor of 10 higher than observed in November 1974 (J. Heise et al. 1975a, 1975b). Fig. 6 shows the complete lightcurve of our May data. One data point is typically 10 to 20 minutes worth of data, hence statistical errors are of the size of the data points. The spectrum has changed to a very steep powerlaw (photon number index 2.5) compared to November 1974 (index $\overset{0.5}{\sim}$) and did not change markedly during this flare period. The best fit spectrum is shown in fig.7 with powerlaw photon index of 3.5 and a cut-off corresponding to 7.10^{21} atoms/cm^2. Due to a decrease in opacity of the interstellar medium below the oxygen K-absorption edge around 0.5 keV, a significant flux could be detected in the parabolic section of our instruments. The measured flux around 0.5 keV is entirely consistent with the above mentioned spectrum. As also a column density of 7.10^{21} atoms/cm^2 is the one expected from purely interstellar matter, this would imply that the intrinsic source spectrum of Cyg-X-1 in the high state is a very steep powerlaw, increasing all the way down to at least 0.5 keV, and this implies that the bulk of the X-ray energy is emitted below 1 keV. Attempts to fit the data with spectra that do not have this energetic soft X-ray component, e.g. a powerlaw with a break to index 1 below 1 keV, always need a lower column density to account for the measured flux around 0.5 keV (typically $4.\ 10^{21}$ atoms/cm^2).

A remarkable difference between the flare data of May 1975 and the low state data of November concerns the time variability of the order of 100 sec.

In November 1974 we often observed intensity changes of 30 to 50 % on a timescale of 100 sec: intensity dips (see fig. 8 as an example) rather symetric in time and correlated with spectral changes in the sense that at lower intensities the spectrum is harder. In fig.9 the correlation is shown for spectral fits taken with a constant absorption of 7.10^{21} atoms/cm^{2}. Significant changes of that sort are not observed in our May data of Cygnus-X-1 during the flaring state, although the total time coverage of the source has been much better.

A qualitative interpretation could be given (Thorne and Price, 1975) on the basis of the standard accretion-disc model for Cyg-X-1. Here the spectrum has two major components. A high energy component originating from a thick, but optically thin inner region and a thin, but optically thick outer region of the accretion disc. The relative contributions to the total spectrum are dependent on the location of the transition radius between those two regions. Variations of the order of the drift time of gas through the X-ray emitting region are to be expected. These are stronger in or near the notch of the spectrum than elsewhere.

If the low and high states of Cyg-X-1 are due to changes in accretion rate, the location of the transition radius is such that the "notch" of the spectrum falls into our energy range, say between 2 and 5 keV. The time scale for variations than is of the order of minutes, as observed, (drift-time through X-ray emitting region) and one would also expect this to be correlated with the hardness of the spectrum measured in the range 1-7 keV.

In the high state, the transition radius in Cyg-X-1 would be much closer to the central object, the "notch" of the spectrum is shifted outside our energy range (> 7 keV) and in this range one does not see any more spectral changes in relation to intensity variations, as is observed. Also the time scale of the variations will be shifted to much shorter times (order of seconds).

OTHER X-RAY BINARY SOURCES.

For completeness we show the lightcurves of other X-ray binary sources as obtained so far from quick-look data. Fig. 10 gives the source 3U 1700-37, Fig. 11 the lightcurve for Cen-X-3 observed in July 1975 in the scan-mode of the satellite (only a few seconds of data per datapoint).

REFERENCES.

Bahcall, J.N., Joss, P.C. and Avni, Y., 1974, Ap. J. 191, 211.

Bloemendal, W., Kramer, C., 1973, Philips Tech. Rev. 33, 117.

Catura, R.C. and Acton, L.W., 1975, Ap. J. 202, L5.

Heiles, C., 1975, Astron. and Ap. Suppl. 20, 37.

Heise, J., Brinkman, A.C., Schrijvers, J., Mewe, R., Gronenschild, E., den Boggende, A., 1975, Ap. J. 202,

Mewe, R., Heise, J., Gronenschild, E., Brinkman, A.C., Schrijver, J., den Boggende, A., 1975a, Ap. J. 202.

Mewe, R., Heise, J., Gronenschild, E., Brinkman, A.C., Schrijver, J., den Boggende, A., 1975b, Nat. 256, 711.

Serlemitsos, P.J., 1975, I.A.U.-circular 2824, August 29, 1975.

Shulman, S., Friedman, H., Fritz, G., Henry, R.C., Yentis, D.J., 1975, Ap. J. 199, L101.

Thorne, K.S., Price, R.H., 1975, Ap. J. 195, L101.

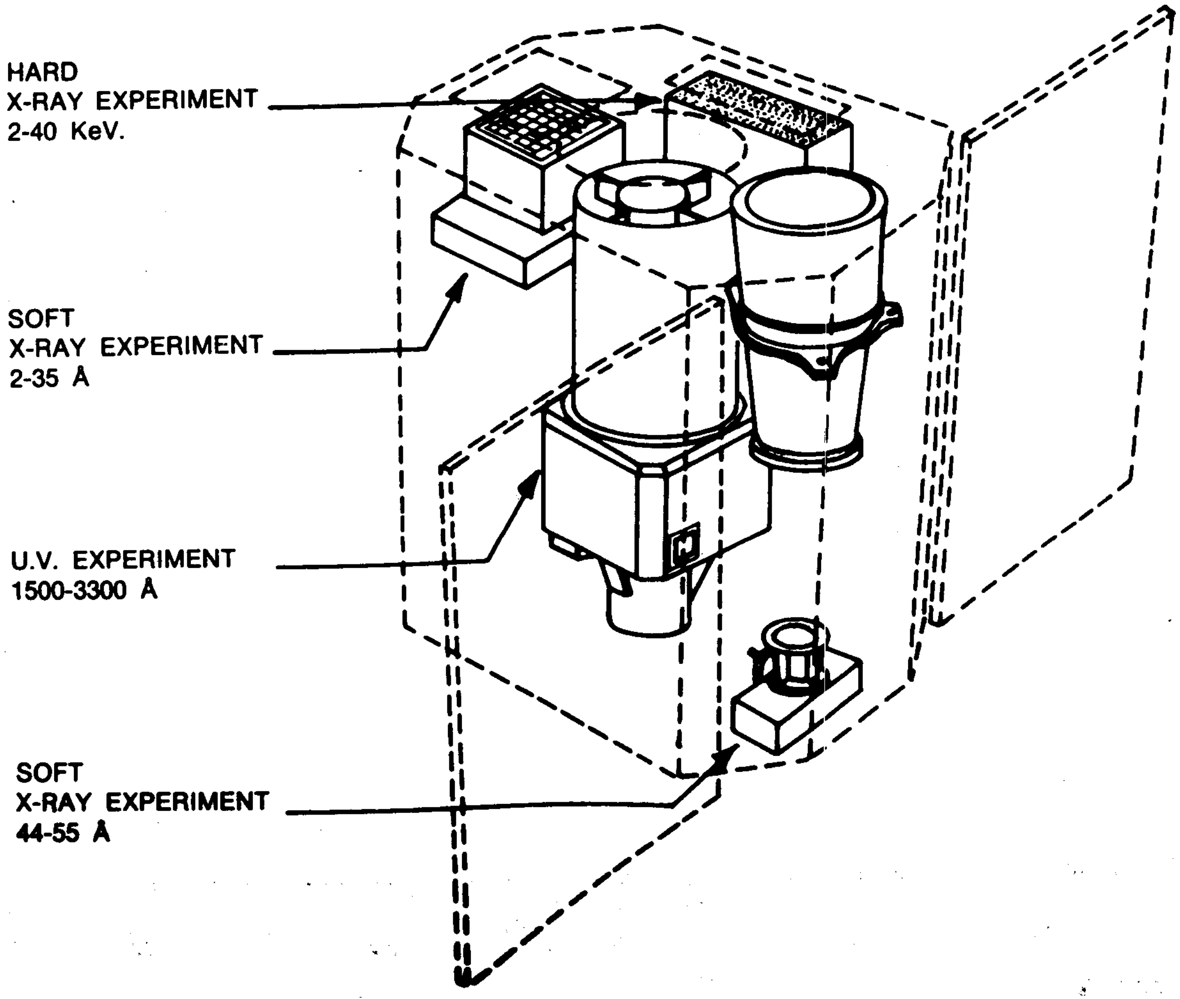


Figure 1. Location of Experiments

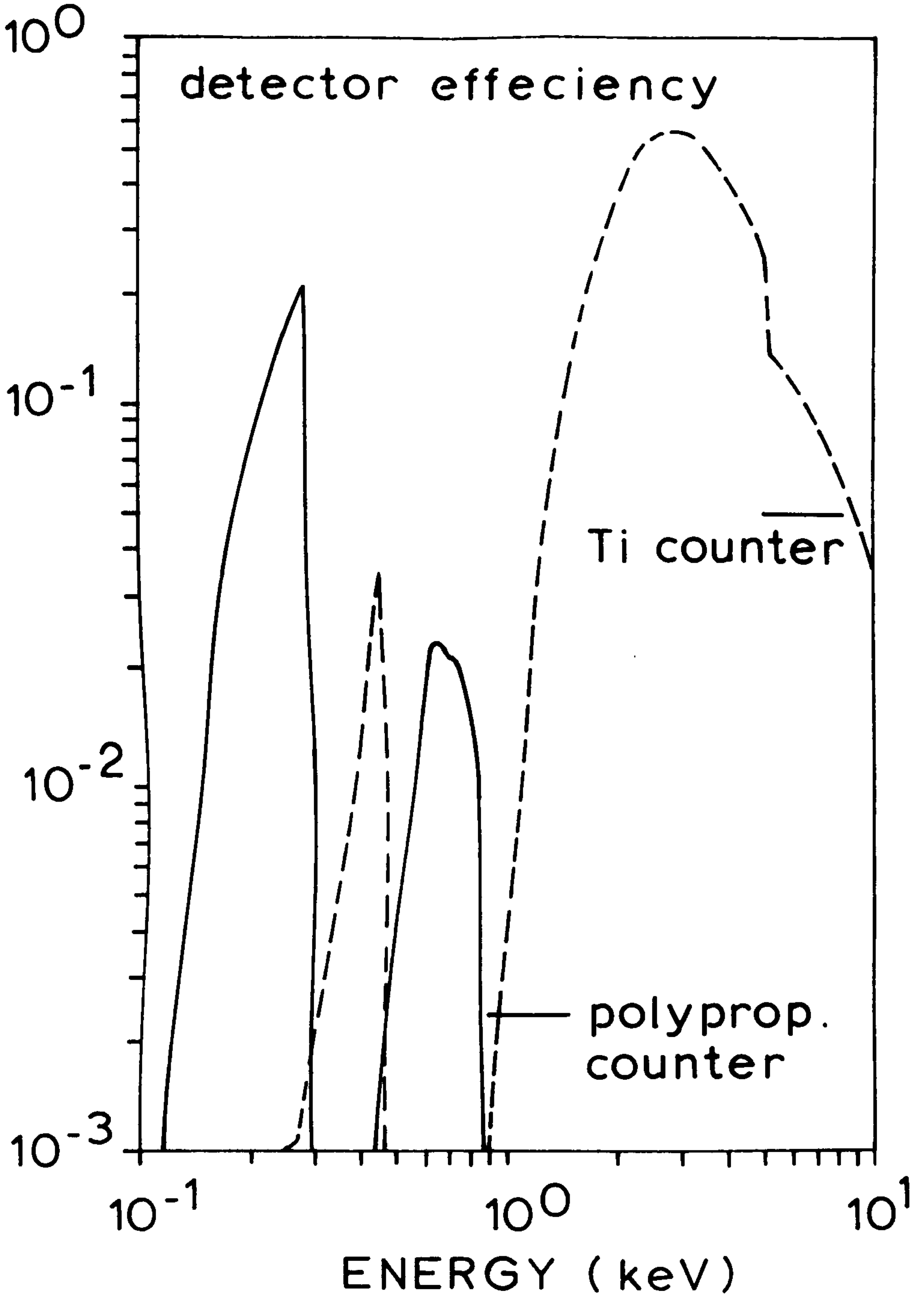


Fig. 2. Overall detector efficiency of the two Utrecht X-ray instruments.

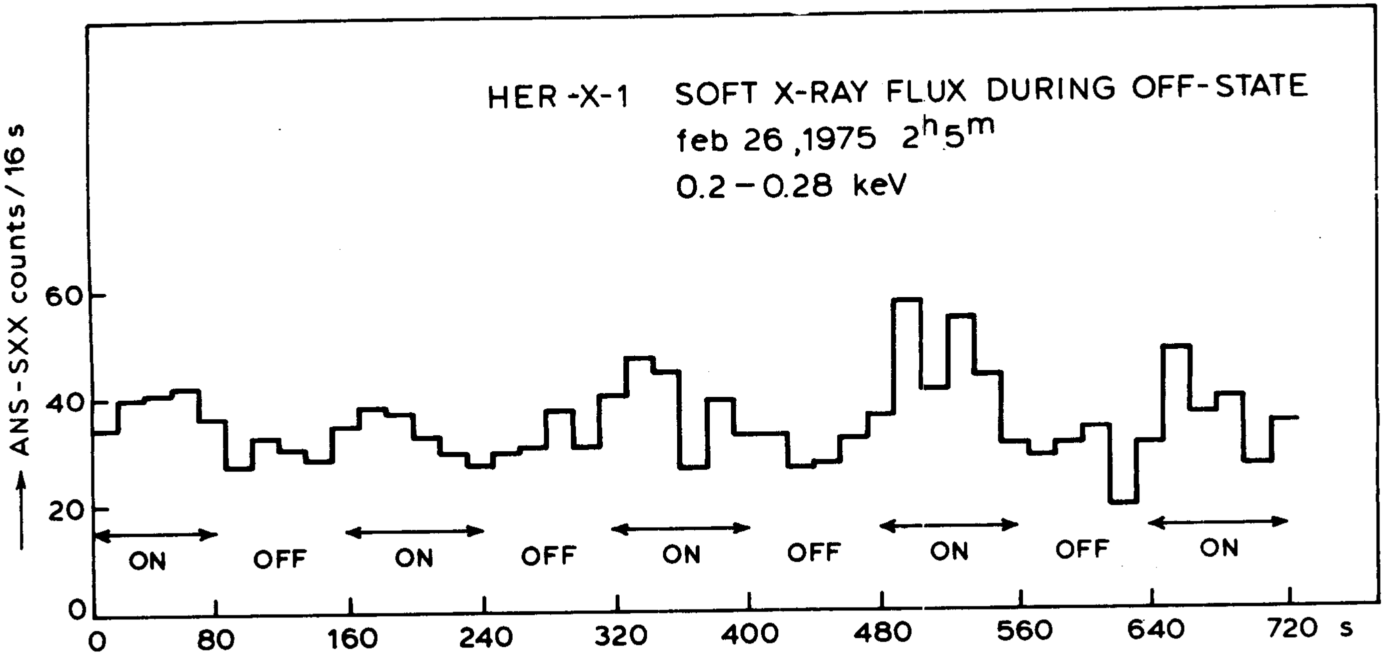
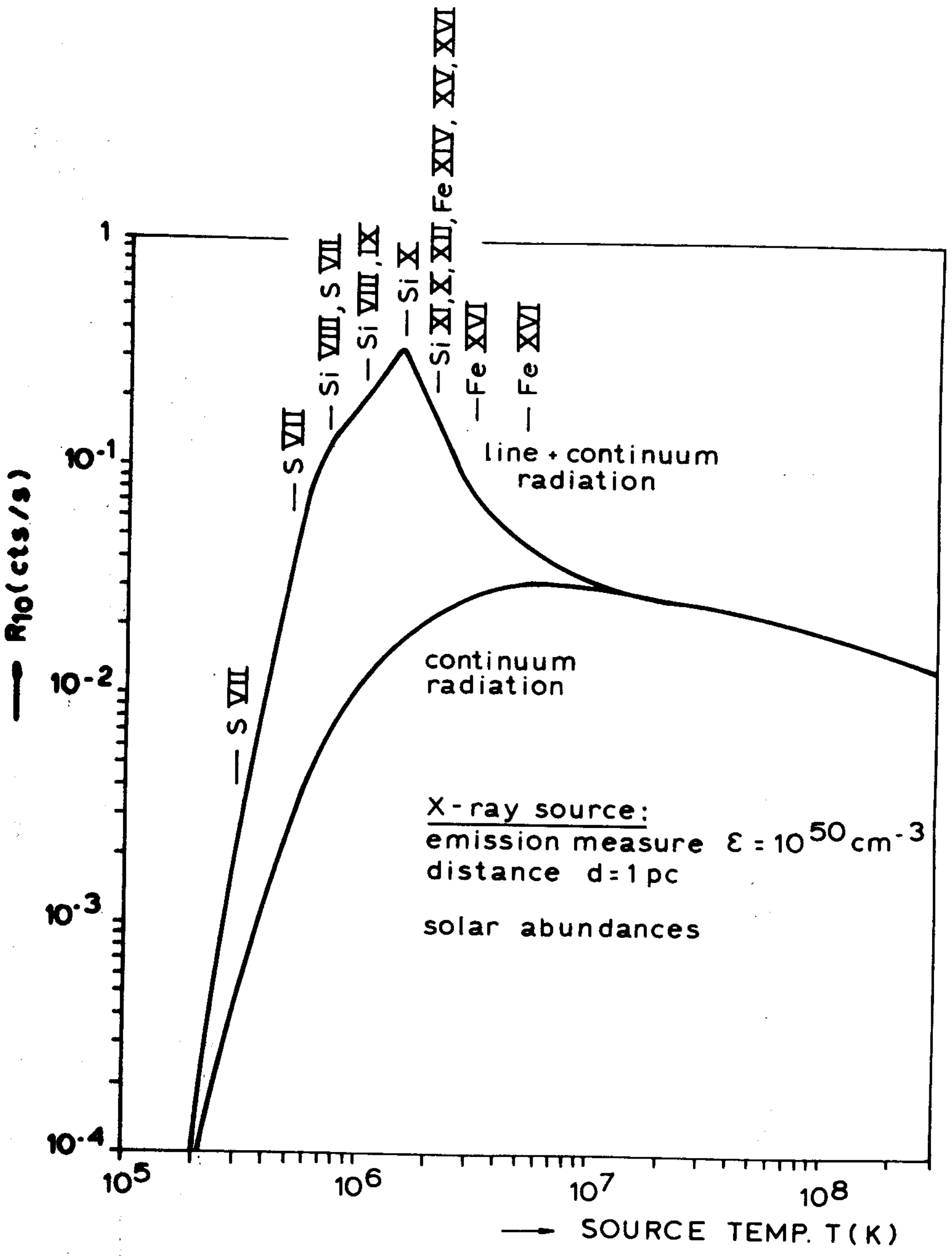


Fig. 3. Raw data of Hercules-X-1 observation in 0.2 - 0.28 keV channel, alternatively pointing on and off the source.



PREDICTED COUNT RATE R_{10} IN ANS SOFT X-RAY CHANNEL (0.2 — 0.28 keV).

Fig. 4. Predicted countrate in soft X-ray channel for an optically thin source at 1 pc with emission measure 10^{50} cm^{-3}.

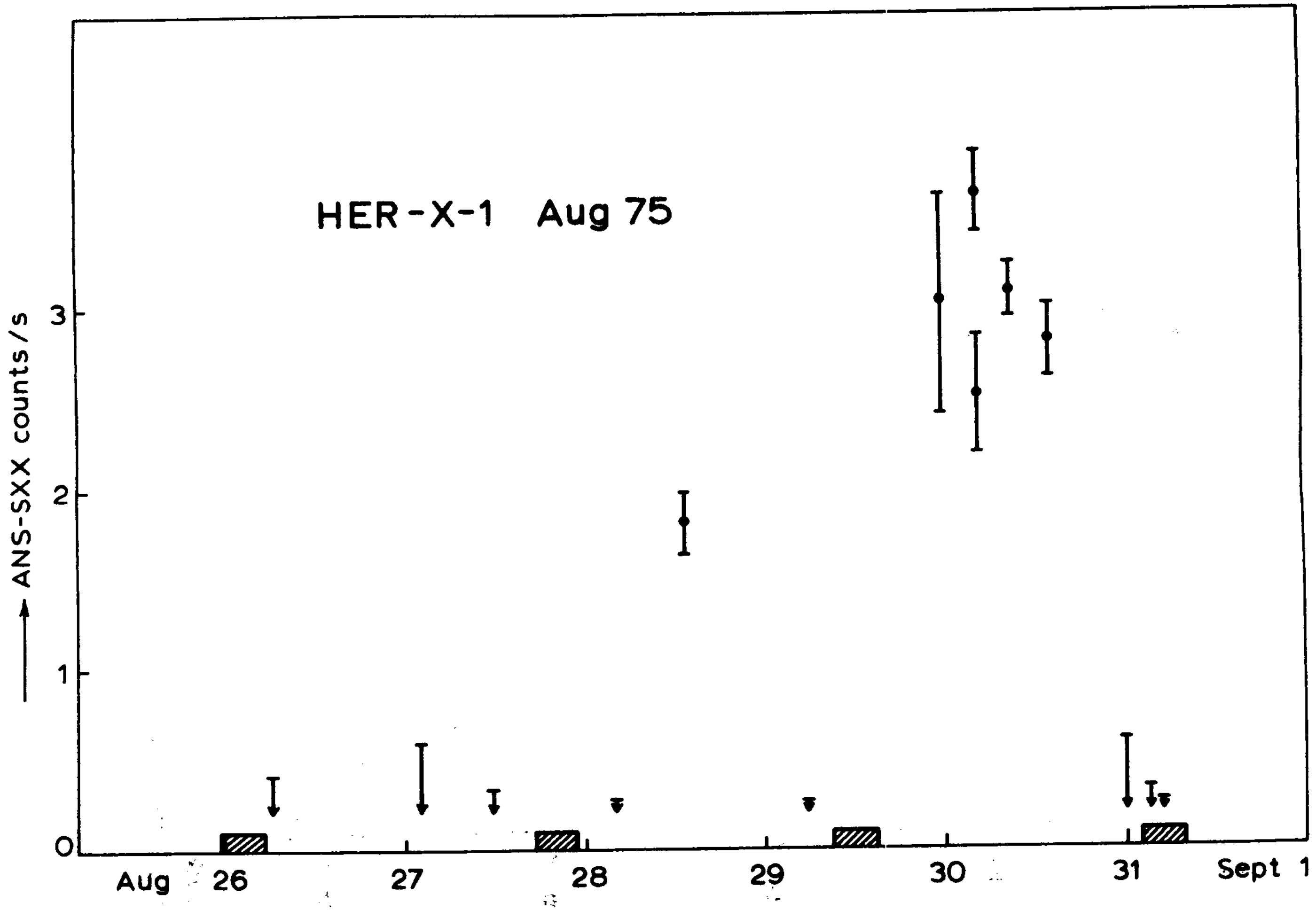


Fig. 5. Her-X-1 preliminary light curve of August 1975 observations.

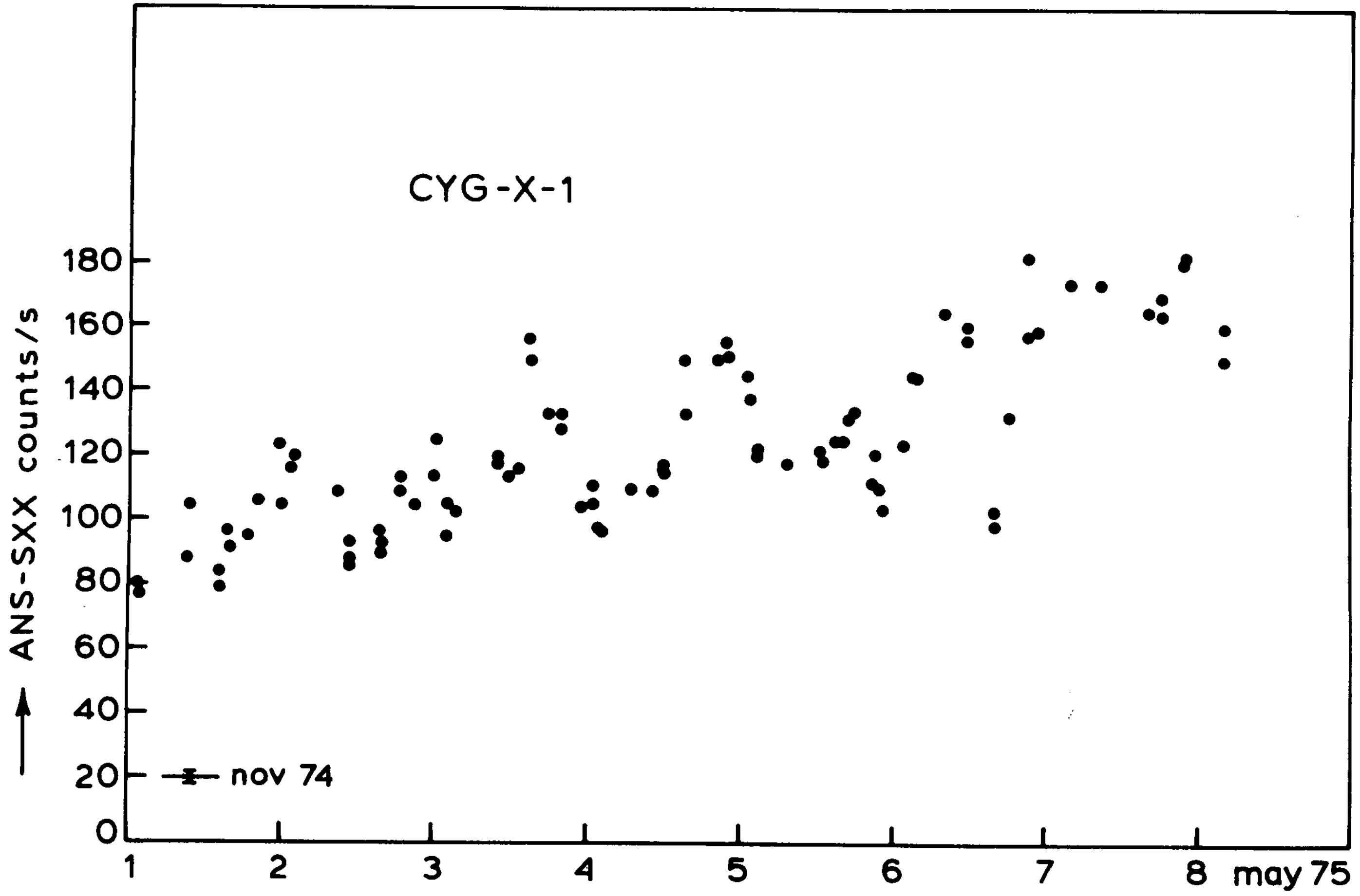


Fig. 6. Light curve of Cyg-X-1 of May 1975. The November 1974 intensity is indicated.

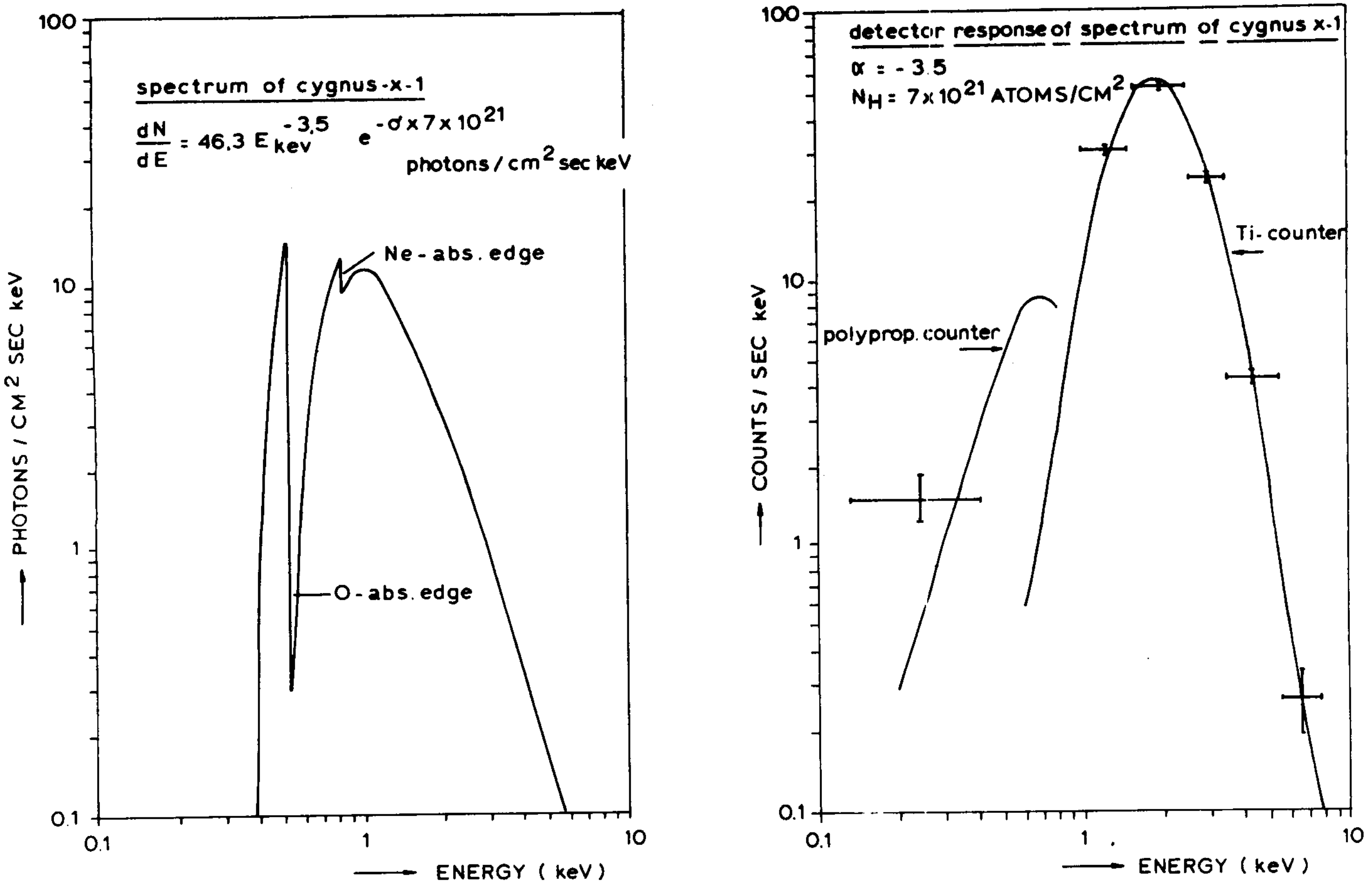


Fig. 7. Spectrum of Cyg-X-1 during flaring state in May 1975.

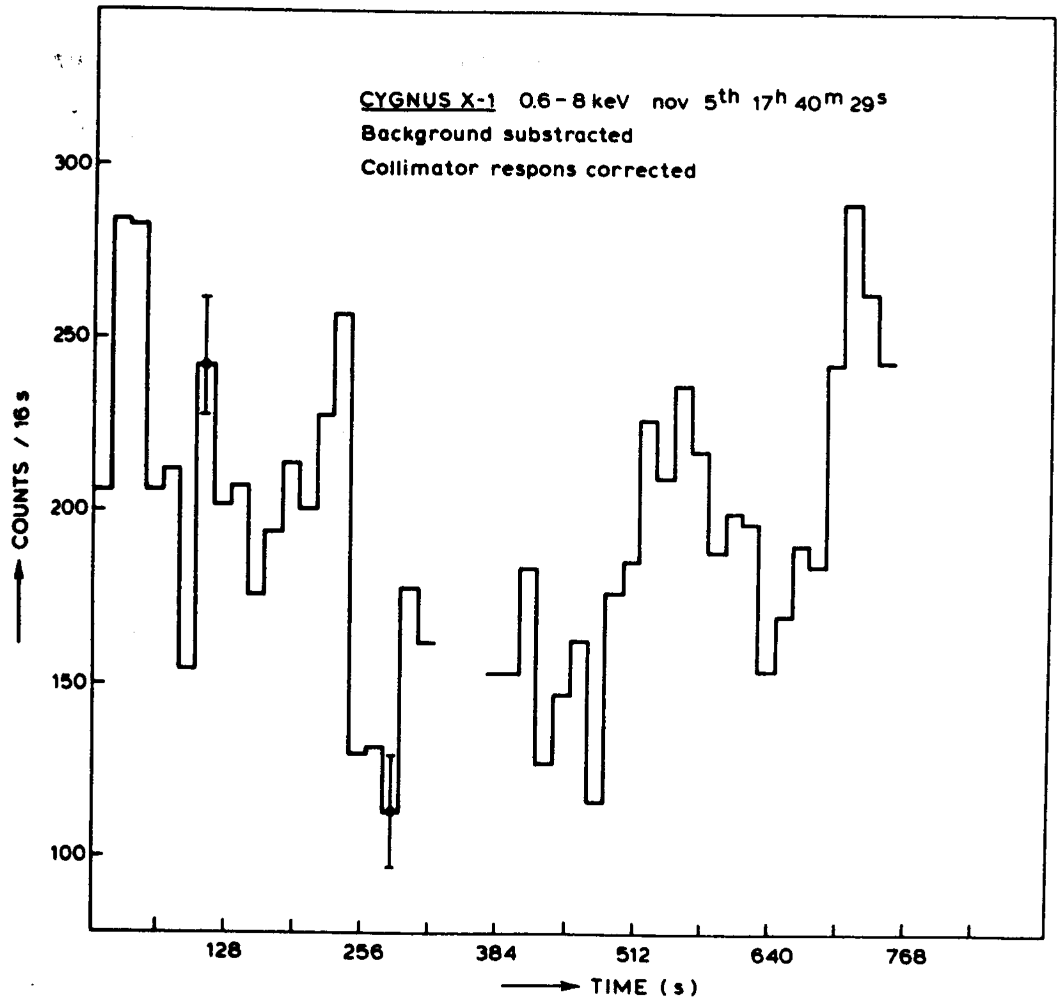


Fig. 8. Intensity change on timescales of minutes in Cyg-X-1 low state (Nov. 1974).

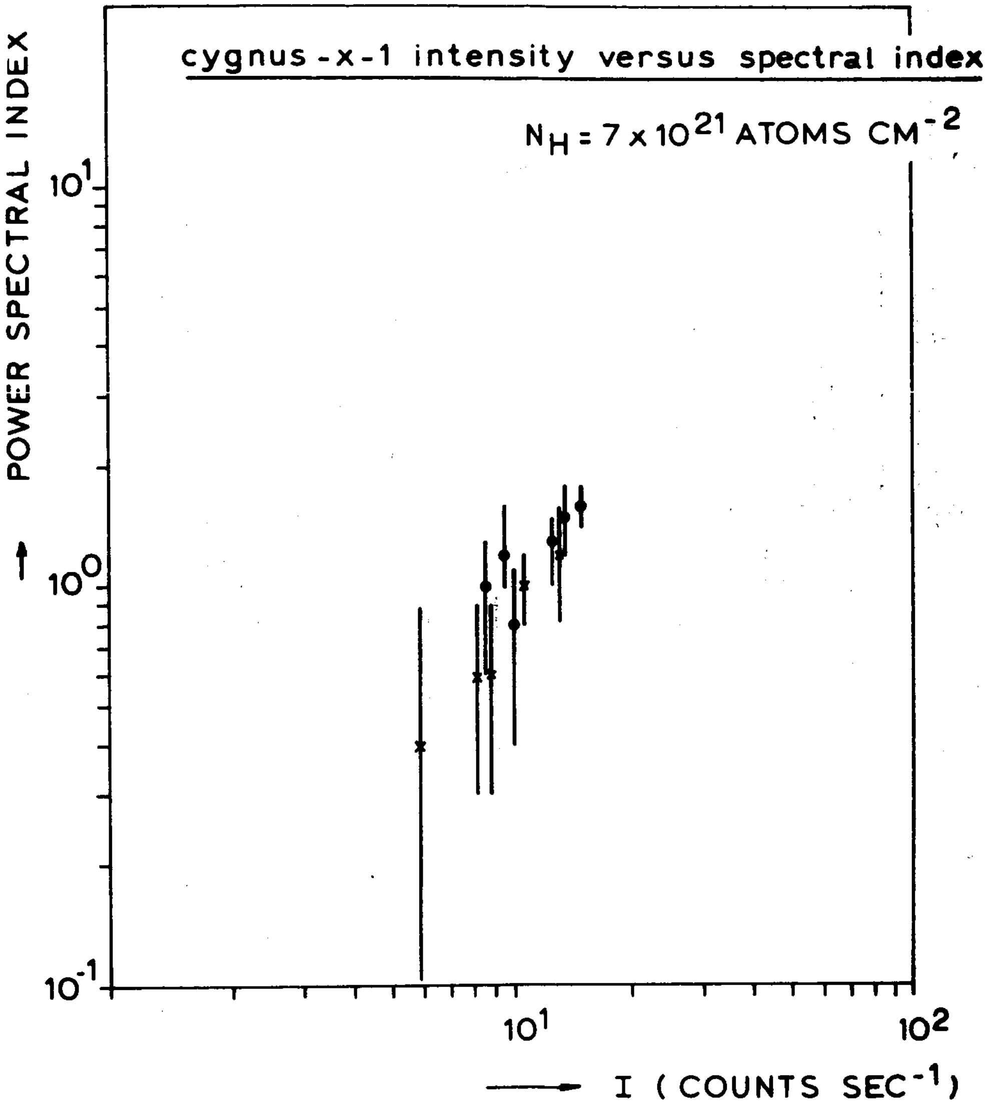


Fig. 9. Spectral shape change as a function of total intensity of Cyg-X-1 for various intensity dips, such as the one in fig. 8.

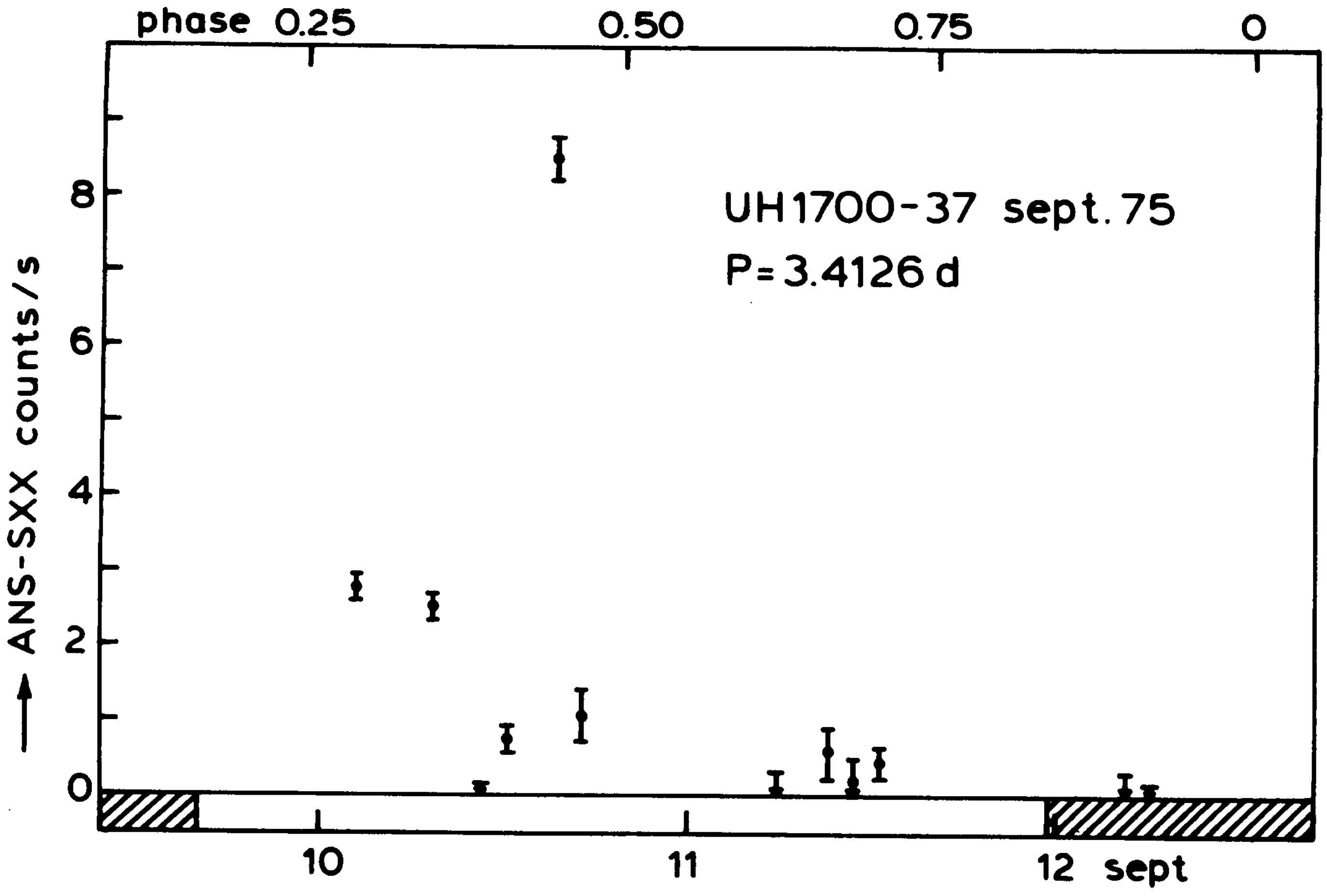


Fig. 10. Preliminary lightcurve of 3U 1700-37 as observed from quick look data by ANS in September 1975.

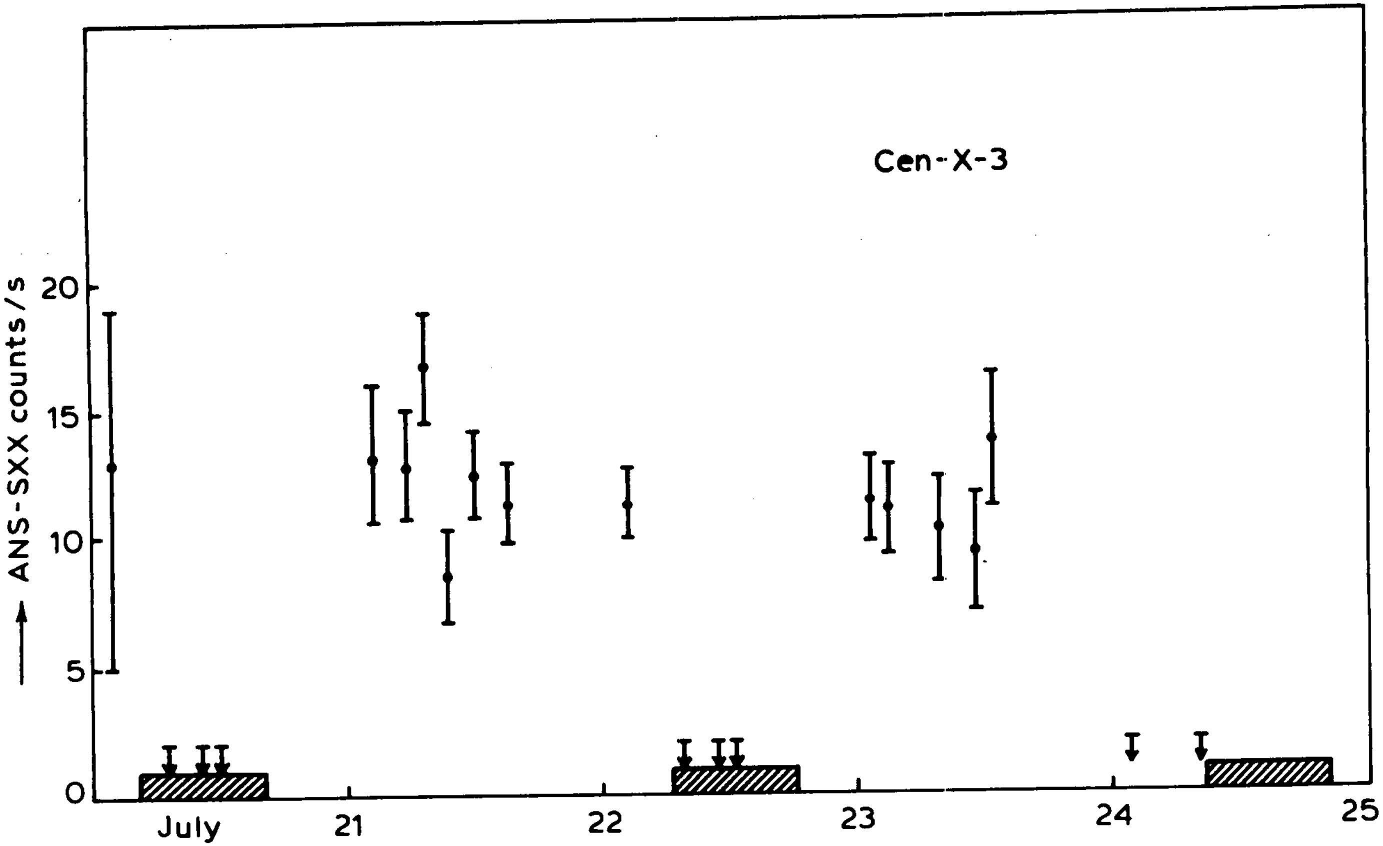


Fig. 11. Lightcurve of Cen-X-3, observed in July 1975.