LETTERS TO NATURE

Observation of an Off State in Circinus X-1

CIRCINUS X-1 is a highly variable X-ray source. Harries *et al.*¹ reported variability by at least a factor of 4 in the range 2 to 10 keV. Strong variability was confirmed by Giacconi *et al.*² who observed intensity changes by a factor of 20 or more in a time scale of seconds. In addition, Margon *et al.*³ detected X-ray pulsations from Circinus X-1 with a period of 0.685 s. But later observations by Uhuru⁴ indicate that the pulsations do not have a stable period. Circinus X-1 is therefore similar to Cygnus X-1 which exhibits pulse trains with periods between 0.3 and 10 s (ref. 4).

We report here an observation by the Copernicus satellite which shows that Circinus X-1 has an off state exceeding 13 h (preliminary results were given in IAU Circular 2555). A description of the Copernicus X-ray instrumentation has been given elsewhere⁵. The instrument was pointed at the 3U position (R. Giacconi *et al.*, AS&E preprint 3249) of Circinus X-1 between 21 h 56 min UT, June 14, and 11 h 06 min UT, June 15, 1973. The 2 to 7 keV detector viewed the source continuously with the exception of four periods of 0.5 h which were lost as a result of Earth occultation and the passage of the satellite through the South Atlantic Anomaly. In addition, a further loss of data was caused by the 23.6 s dead time between each 63 s integration period.

No X-ray emission was detected from Circinus X-1 throughout the 13 h observation period. The 3σ upper limit in the range 2 to 7 keV is $0.0094 \text{ photons cm}^{-2} \text{ s}^{-1}$ derived from data acquired during the whole observation. The background was subtracted using the procedure outlined by Fabian *et al.*⁵. Furthermore there is no evidence for the presence of the source on timescales shorter than the total observation period. The data from the individual integration periods showed the expected statistical distribution about zero. Upper limits on timescales of 1 min and 30 min are $0.063 \text{ photons cm}^{-2} \text{ s}^{-1}$ and $0.014 \text{ photons cm}^{-2} \text{ s}^{-1}$, respectively.

The peak intensity of Circinus X-1 measured by Uhuru² between 2 and 6 keV is $0.86 \text{ counts cm}^{-2} \text{ s}^{-1}$, which corresponds to a flux of $1.6 \text{ photons cm}^{-2} \text{ s}^{-1}$ (using the quoted conversion factor and assuming a power law photon index of $\alpha = -2$). Our upper limit is therefore a factor of 170 below the Uhuru peak intensity. This result indicates that Circinus X-1 has an off state exceeding 13 h, and suggests an eclipsing phenomenon. Such behaviour is now well established in several other X-ray sources⁶⁻⁸. Margon *et al.*³ report a thermal spectrum for Circinus X-1 which is consistent with mass exchange in a binary system. Further, the observed spectral variability^{1,9} and low energy cutoff³ may be associated with X-ray absorption in an accretion disk associated with the X-ray source. Clearly the existence of periodic behaviour in Circinus X-1 would greatly assist optical identification of this object, particularly because the 3U error box is very small (0.0002 square degrees).

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Upper Limits to the Pulsed X-ray Flux from PSR0833-45, MP0835-40 and MP0736-40

ON November 11, 1970, a collimated proportional counter sensitive to X rays in the energy range 2.8 to 9.9 keV was flown on a Sun-stabilized Skylark sounding rocket from Woomera, South Australia. During part of the flight the detector field of view was scanned across Vela, including the position of three radio pulsars. The time of each event was telemetered to ground with a time uncertainty of approximately 300 μ s, and this allowed a search for fluctuations in the X-ray flux at the period of the observed radio pulsations. The pulsars were PSR0833-45, the Vela pulsar (0.089 s period), MP0835-40 (0.766 s period) and MP0736-40 (0.375 s period).

Two scans were made across the pulsars and in each scan data from an arc of 9° were analysed to allow for possible errors in determining the roll orientation of the vehicle. The data from each scan were subsequently divided into three data sets, each representing 5.2 s of observations. In such a short sample it was not necessary to allow for the motion of the vehicle in calculating the apparent period of the pulsar, the phase error accumulated in five seconds by neglecting this correction being less than $1/20$ of the pulse width. The six data sets for each pulsar were folded at the period of the radio pulsations and searched for significant departures from a uniform counting rate. None was found.

Following Hearn¹ we have calculated the likelihood ratio, $L(s)$, for various values of the time averaged pulsed flux s . A graph of $L(s)$ against s is shown in Fig. 1 for the data from PSR0833-45. For a confidence limit of $C=0.99$ (corresponding to 99% confidence) and a set of six independent light curves, each having ten phase bins, an upper limit to the pulsed flux is chosen to be that value of s for which

$$L(s) = (1 - C)/60 = 1.67 \times 10^{-4}$$

The tables give the upper limits to the time averaged pulsed flux from the three radio pulsars together with upper limits to their steady flux, derived in a similar manner.