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ENERGY SPECTRUM AND TIME VARIATION OF SCO X-1

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ABSTRACT

Two rocket flights carrying X-ray payloads were conducted from Thumba Equatorial Rocket Launching Station (TERLS), Trivandrum, India, on November 3, 1968, and November 7, 1968, respectively. The energy spectrum of the Sco X-1 X-ray source observed during both flights in the energy range 2–20 keV is presented. A comparison of our results with the previous observations indicates that the flux of Sco X-1 exponentially decreased over the period 1965–1968 with a time constant of about 4.1 years.

In this Letter, we report the results of two rocket observations of the Sco X-1 X-ray source from the Thumba Equatorial Rocket Launching Station (TERLS), Trivandrum (76°51′ E., 8°32′ N.), India, conducted at 0319 U.T. on November 3, 1968, and at 0305 U.T. on November 7, 1968. Both the rocket flights contained identical X-ray payloads, consisting of a proportional counter filled with xenon and methane and having a useful area of 60.8 cm^2. The full width at half-maximum of the slat-type collimator fitted to the proportional counter was 8°.7 in the spin axis and 17°.2 in the rocket axis. Accurate in-flight calibration with an Fe^{55} radioactive source was done during the up-leg of the trajectory up to an altitude of 60 km. The details of the trajectory and of the aspect determination are explained elsewhere (Rao *et al.* 1969). In the present Letter, we give the results on the energy spectrum of the Sco X-1 X-ray source and its time variation.

Figure 1 shows the observed counting rate as a function of the rocket azimuth for different energy windows of nominal value 2–4, 4–6, 6–12, and 12–18 keV for the flights of both November 3 and November 7, 1968. The data on Sco X-1 for each spin have been fitted to a theoretical triangular response, characteristic of a slat-type collimator, in order to obtain the absolute flux of the source. The energy spectrum of Sco X-1 in both flights can be adequately described by a spectrum of the type

$$f(E) = K \exp^{-E/E_0} dE \, .$$

In the energy range 2–12 keV, the value of $E_0 = 4.4 \pm 0.2$ keV corresponds to a temperature of a hot, thin plasma of 5.1×10^7 ° K. The energy spectrum beyond 12 keV, however, is consistent only with $E_0 \sim 18$ keV, in agreement with the observations of Busseli *et al.* (1968). The energy-spectrum observations of Sco X-1 for both flights are indicated in Figure 2. The flattening of the spectrum at higher energies is explicable in terms of the multilayer complex model for Sco X-1 proposed by Shklovsky (1967), the higher energies being emitted from the higher-temperature plasma in the core of the object.

After the optical identification of Sco X-1 by Sandage *et al.* (1966), a large number of observations were made of this object in the visible, in the near-ultraviolet (Hiltner and Mook 1967), in the near-infrared (Neugebauer *et al.* 1969), and recently in the radio region (Ables 1969 and Andrew and Purton 1968). It is also known that the observed ultraviolet and visible continuum, if extrapolated to X-ray energies, agrees with the observed exponential X-ray spectrum. The *UBV* photometric observations of Hiltner and Mook (1967) and of Stępień (1968) have revealed that Sco X-1 varies between 12.2 and 13.2 mag, and during about 50 percent of the time, when it is brighter than 12.6 mag, it

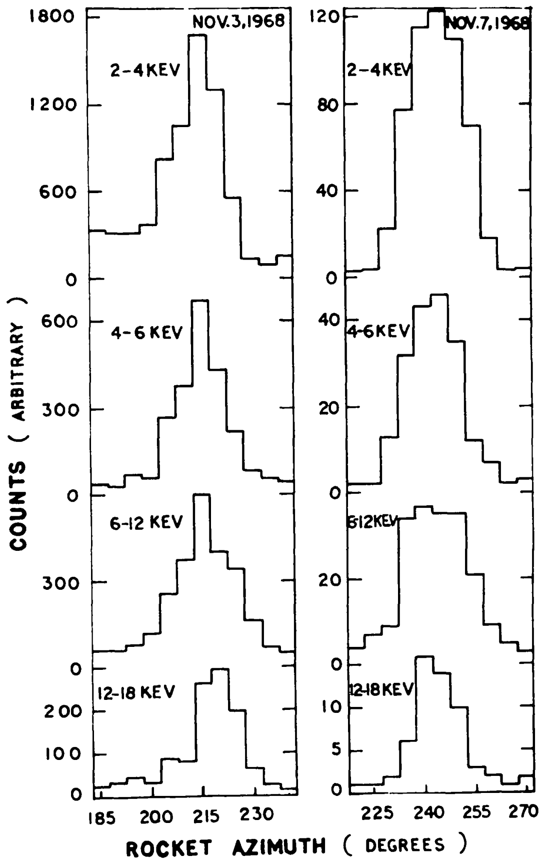

FIG. 1.—Observed X-ray flux from Sco X-1 in different energy bands

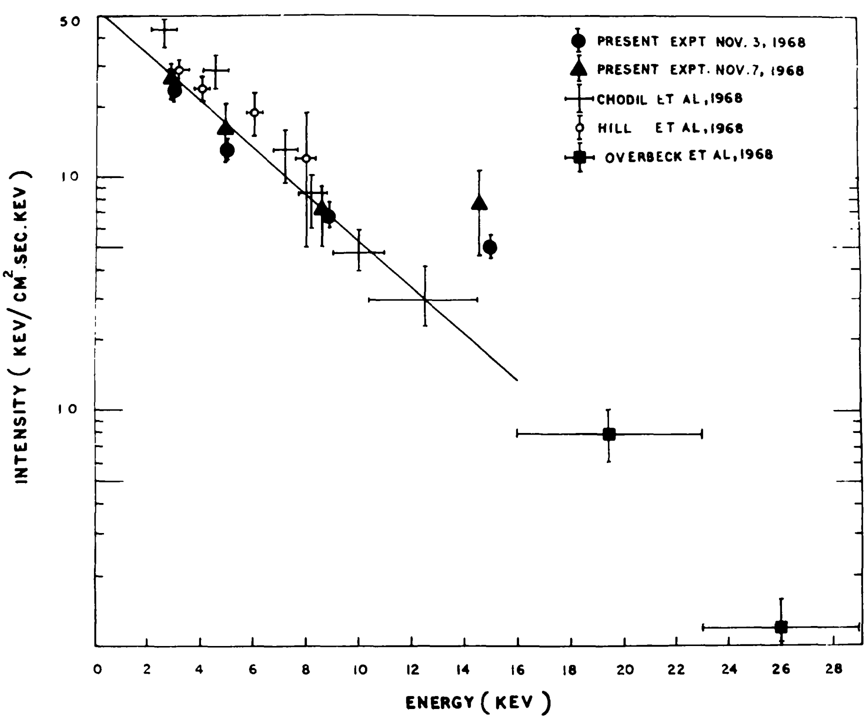

FIG. 2.—Energy spectrum of Sco X-1

shows a large flickering activity (Oda 1968). Recently Lewin, Clark, and Smith (1968) observed an X-ray flare from Sco X-1 for nearly 20 min. Rao, Prakasarao, and Jayanthi (1969) have shown that the optical intensity of Sco X-1 has approximately a 3.0-hour periodicity, which is consistent with the radio observations of Sco X-1 reported by Ables (1969).

Assuming that Sco X-1 is at a distance of about 1000 light-years and has a total energy flux of about 6×10^{36} ergs sec^{-1}, Matsuoka, Oda, and Ogawara (1966) have shown that the radius of Sco X-1 is between 3×10^{10} and 10^{13} cm. Irrespective of the mechanism of heating the cloud, the cooling time of the cloud and the heating time should be of the same order to keep the X-ray source going. Since the cooling time is estimated to be between 10 and 10^5 sec, it is possible to expect a time variation of X-ray flux from Sco

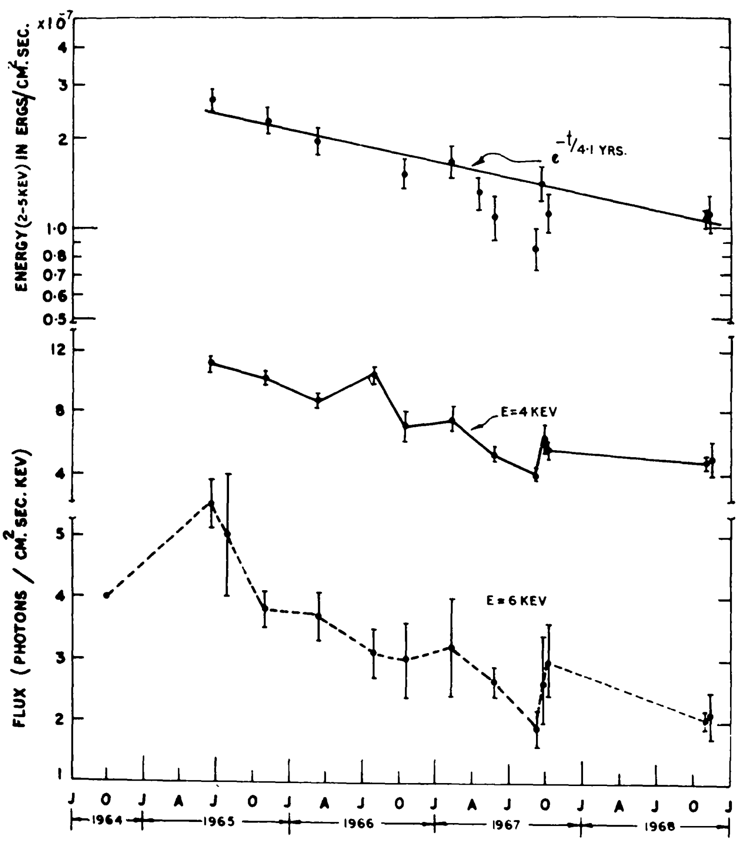

FIG. 3.—Time variation of the X-ray flux from Sco X-1

X-1 on this time scale. We do not observe any statistically significant time variation of the flux between November 3 and November 7, 1968. We may, however, point out that on time scales of about a month Overbeck and Tananbaum (1968) do find significant time variation of X-ray intensity in the energy range 16–30 keV at balloon altitudes.

In Figure 3 is shown the time variation of the absolute flux of X-rays from Sco X-1 since 1965. Since many of the observations in the past did not have their sensors and attitudes well calibrated, only those measurements from which reasonably accurate flux values can be derived are plotted in the figure. Table 1 gives all the relevant numerical parameters. The most conspicuous result from Figure 3 is that the flux and the energy of Sco X-1 have steadily decreased from 1965 to 1968. Sporadic short-time variations are superposed upon this general decrease in flux. The observations indicate that the general pattern of the time variation of Sco X-1 is consistent with an exponential decay of X-ray luminosity with a time constant of about 4.1 years, which would mean that the flux of Sco X-1 would decrease by 2 orders of magnitude in a period of about nineteen years.

Various theoretical estimates ranging from 10 to 50 years for the lifetime of Sco X-1 have been made, depending upon the model one takes for the source. For example, if we assume Manley's (1966) model of a protostar shedding its magnetic field, where the magnetic energy is used to produce the high-energy electrons, which upon interaction with the same field can produce X-rays, we can estimate that the magnetic field of a star like Sco X-1 can supply energy to electrons for a period of the order of thirty years. These estimates are consistent with the experimental observations.

TABLE 1

TIME VARIATION OF SCO X-1

Experimenter	Flight Date	Flux of 4-keV Photons (cm² sec keV)$^{-1}$	Flux of 6-keV Photons (cm² sec keV)$^{-1}$	Energy (2–5-keV Range) (10^{-7} erg cm^{-2} sec^{-1})	Temperature (10^7 ° K)
Fisher *et al.* (1966)	October 1, 1964	...	4.0	...	1.6
Chodil *et al.* (1965)	June 12, 1965	11.25±0.6	5.5±0.4	2.65±0.23	4.8
Hayakawa, Matsuoka, and Yamashita (1966)	July 26, 1965	...	5.0±1.0	...	3.8
Grader *et al.* (1966)	October 28, 1965	10.3 ± .4	3.8±0.3	2.28± .22	4.6
Gursky, Gorenstein, and Giacconi (1967*a*)	March 8, 1966	8.8 ± .5	3.7±0.4	1.93± .21	5.0
Chodil *et al.* (1967)	July 28, 1966	10.5 ± .5	3.1±0.4	...	5.8
Gursky *et al.* (1967*b*)	October 11, 1966	7.1 ± .9	3.0±0.6	1.49± .17	4.8
Matsuoka *et al.* (1968)	February 6, 1967	7.6 ± .8	3.2±0.8	1.64± .20	5.0
Cooke *et al.* (1967)	April 10, 1967	...	...	1.30± .15	...
Chodil *et al.* (1968)	May 18, 1967	5.2 ± .4	2.6±0.2	1.08± .18	8.1
Fritz *et al.* (1968)	September 8, 1967	4.0 ± .4	1.9±0.3	0.85± .14	10.4
Chodil *et al.* (1968)	September 29, 1967	6.3 ± .8	2.6±0.6	1.41± .17	4.6
Hill, Grader, and Seward (1968)	October 2, 1967	5.4 ± .6	2.9±0.6	1.12± .16	10.4
Rao, Jayanthi, and Prakasarao (1969)*	November 3, 1968	4.9 ± .3	2.1±0.2	1.07± .15	5.1
Rao *et al.* (1969)*	November 7, 1968	5.2 ±0.7	2.2±0.3	1.12±0.16	5.1

* Present experiment.

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