SIMULTANEOUS HARD X-RAY AND OPTICAL OBSERVATIONS OF SCO X-1 AND A MODEL OF SEMI-OPAQUE X-RAY SOURCES

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Abstract. Simultaneous observations of hard X-ray and optical emission from Sco X-1 were carried out at Hyderabad, India, on April 16 and 19, 1972. During the first and the second observations Sco X-1 was on the average in a bright phase of B = 12.5 mag. and a slightly darker phase of B = 12.7 mag. respectively. During the first observation the X-ray intensity in the energy range 20-40 keV measured with balloon borne scintillation counters showed an enhancement of a factor of about two in coincidence with an optical flare of B ~ 0.2 mag., whereas the apparent temperature derived from the X-ray spectrum observed in the energy range 20-35 keV showed no appreciable change. Both the X-ray intensity and the apparent temperature observed on April 19 are considerably lower than those observed on April 16. Taking into account the effect of radiative transfer in a hot plasma, the electron density and the optical depth for electron scattering of the plasma cloud are derived as $n_e \approx 3 \times 10^{16}$ cm$^{-3}$ and $\tau_{es} \approx 10$ for the quiescent bright phase. The flare is explained by an increase of the plasma mass by about 30% and an increase of $\tau_{es}$ by $\tau_{es} \approx 1$ without appreciable change of the plasma temperature. The results on April 19 is interpreted as indicating that the quiescent dark phase may be characterized by a decrease of the plasma mass, its contraction and lower temperature.

1. Introduction

Sco X-1 is the brightest extra-solar X-ray source in the sky which has been most extensively observed in a wide spectral range. The observed X-ray spectrum has been interpreted in terms of thermal bremsstrahlung from a hot plasma cloud that is semi-opaque for optical emission. Simultaneous X-ray and optical observations are of great importance for understanding the physical properties of such an X-ray source since Sco X-1 is known to be an irregular variable. From rocket observations of X-rays at energies below 20 keV with simultaneous optical observations, the electron density and the radius of the plasma cloud have been estimated to be of the order of $10^{15}$–$10^{16}$ cm$^{-3}$ and $10^8$–$10^9$ cm, respectively (Chodil et al., 1968; Mark et al., 1969; Kitamura et al., 1971). Kitamura et al. (1971) reported a negative correlation between the optical intensity and the temperature derived from the X-ray spectrum below 20 keV in the quiescent phase, which implies a negative correlation between the hard X-ray and optical intensities. On the other hand, Hudson et al. (1970), Evans et al. (1970), and Pelling (1971) observed X-ray enhancements in the energy range below 20 keV in coincidence with optical flares. Evans et al. (1970) also observed that the X-ray spectrum tends to be harder at the flares. Recent satellite observations in the energy range 3–10 keV by Canizares et al. (1973) have given a positive correlation between the X-ray intensity and the hardness of the X-ray spectrum.

A series of balloon observations of hard X-rays with simultaneous optical observa-
tions have been carried out at Hyderabad, India, on May 1, 1971 and April 16 and 19, 1972. The results obtained on May 1, 1971 were reported by Matsuoka et al. (1972a, b, which will be hereafter referred to as I and II). The essential results of the observations in 1972 were also published elsewhere (Matsuoka et al., 1973). Here we present detailed descriptions of the experiments in 1972 along with a theoretical interpretation of the experimental results. In Sections 1, 2, 3, and 4 are described instrumentation, the performance of flights, the procedure of data reduction and the experimental results, respectively. The last section is devoted to a brief discussion on a hot plasma model of Sco X-1, where the physical parameters that characterize Sco X-1 are derived taking into account the effect of radiative transfer. Detailed theoretical discussion on this problem is given elsewhere (Hayakawa et al., 1974).

2. Instrumentation

The X-ray detector of the present experiment was essentially the same as the one used in the previous experiment described in II. Schematic diagram of the detector is shown in Figure 1. The detector consisted of two NaI(Tl) scintillation counters, each having a size of 127 mm (diam) × 3 mm (thickness). Slat collimators of copper defined a field of view of 17.1° FWHM in elevation and 13.1° FWHM in azimuth. Each NaI(Tl) crystal was optically coupled to a photomultiplier tube RCA2065 of 5 in.