OSO-8 X-RAY POLARIMETER AND BRAGG CRYSTAL SPECTROMETER OBSERVATIONS

R. Novick, H. L. Kestenbaum, K. S. Long, E. H. Silver,
M. C. Weisskopf, and R. S. Wolff
Columbia Astrophysics Laboratory, Columbia University,
New York, New York 10027, U.S.A.

1. POLARIMETER

The OSO-8 satellite contains a focusing mosaic graphite crystal X-ray polarimeter that is oriented along the spin axis of the wheel section of the satellite. The polarimeter operates at 2.6 and 5.2 keV. Polarization in a source appears as a modulation of the counting rate at twice the satellite spin frequency. The amplitude and phase of the modulation are simply related to the polarization and position angle, respectively. Two independent polarimeters are employed, and their axes are offset by 128°. Focusing is achieved by mounting the crystals on a parabolic sector, which reduces the background without reducing the sensitivity. The low background that results from the focusing not only improves the statistical quality of the data but also substantially reduces the danger that an asymmetry in the charged particle background may produce a spurious polarization result. This is particularly important in the case of weak sources. The instrument has been described in detail elsewhere (Novick 1975); here we will briefly discuss the results obtained on the Crab Nebula, Cyg X-1, and Cyg X-2.

The observed polarization of the Crab Nebula at 2.6 keV is 15.7% ± 1.5% at a position angle of 161.1° ± 2.8°, while the polarization at 5.2 keV is 18.3% ± 4.2% at a position angle of 155.5° ± 6.6°. If we assume that the polarization is independent of energy, then the result is 16.1% ± 1.4% at a position angle of 160.2° ± 2.6° (Weisskopf *et al.* 1976). The optical polarization measured by Oort and Walraven (1956) in the central part of the nebula corresponding to the X-ray emitting region is 19% at a position angle of 162°. The existence of X-ray polarization and the agreement of the optical and X-ray results as well as the power-law spectrum confirm with very high confidence the earlier conclusion (Novick *et al.* 1972) that the X-ray emission occurs by the synchrotron process.

In the case of X-ray binaries, polarization is expected to arise from scattering within the accretion disk. Lightman and Shapiro (1975,

Edith A. Müller (ed.), Highlights of Astronomy, Vol. 4, Part I, 95-97. *All Rights Reserved.*

1976) have studied this effect in Cyg X-1 and have predicted for a two-temperature model that the polarization at 2.6 keV should lie between ~0.2% parallel to the disk and ~3% perpendicular to the disk, depending on the geometry and viscosity of the disk. We have made an extended observation of the polarization of Cyg X-1 and find no evidence for polarization. The upper limit on the polarization at 2.6 keV is 3.0% at the 99% confidence level. This result does not allow us to distinguish between the two cases considered by Lightman and Shapiro. Additional observations are planned that may be sensitive enough to provide an estimate of the source parameters.

Recently we obtained evidence for polarization in Cyg X-2. The preliminary result at 2.6 keV is 4.8% ± 1.0% at a position angle of 141.7° ± 6.6°. This result is based on a three-day observation in 1975 December. The preliminary result is within the range of values expected for accretion disks. Chandrasekhar (1946) has shown that an optically thick disk viewed edge on will exhibit about 11.7% polarization, and Angel (1969) has shown that scattering in an optically thin ellipsoid will produce up to 7% polarization with the polarization vector oriented perpendicular to the long axis of the ellipsoid. The relatively large value of the observed polarization suggests that we are observing the source close to a preferred axis. Further observations are scheduled in 1976 December to confirm the present preliminary result, and we hope to obtain a result at 5.2 keV. The comparison of the 2.6 and 5.2 keV results may allow us to distinguish between the optically thick and thin cases.

2. SPECTROMETER

The Bragg crystal spectrometer consists of two large, flat panels of mosaic graphite crystals located along the sides of a 40° wide sector of the wheel section of the OSO-8 satellite. A bank of proportional counters is located midway between the crystal panels so as to detect the diffracted X-rays. The Bragg energy spectrum is accomplished by the wheel rotation. Two complete Bragg scans from 1.55 Å to 6.70 Å are obtained with each rotation of the wheel, but it is necessary to superimpose many scans to obtain significant results. The instrument has been described more thoroughly by Kestenbaum *et al.* (1976a). The principal lines scanned are the Si XIII at 6.65 Å, Si XIV at 6.18 Å, S XV at 5.07 Å, S XVI at 4.73 Å, Ca XIX at 3.20 Å, Fe XXV at 1.88 Å, and Fe XXVI at 1.79 Å. These lines are excited over a range of temperatures, and in some cases the intensity is sensitive to the electron density. Thus in principle the OSO-8 spectrometer should provide a useful diagnostic function for a number of sources. Unfortunately the sensitivity is limited and as yet no lines have been detected, but in a few cases we have obtained useful limits on line strengths as well as obtaining the first high-resolution continuum shapes.

In 1975 October we obtained a spectrum of the transient X-ray source A0620-00 in which no lines were evident. We found that the continuum can be accurately fitted with a thermal bremsstrahlung spectrum at a temperature of 15×10^6 K. The Si XIV lines are attenuated by at least a factor of 11 from the strength that would be expected if the source were optically thin. If we neglect resonance trapping and photoionization, we find that this result can be accounted for by electron scattering with a scattering depth of 8. These results are given in more detail by Kestenbaum *et al.* (1976b).

Future observations are planned on several sources that have revealed iron lines in proportional counter experiments. Under somewhat optimistic assumptions, it may be possible to detect lines in Cyg X-3 and Cas A. If this can be accomplished, we should be able to determine the ion species responsible for the lines.

This work was supported by the National Aeronautics and Space Administration under contract NAS5-22408. This paper is Columbia Astrophysics Laboratory Contribution No. 127.

REFERENCES

Angel, J. R. P.: 1969, *Astrophys. J.* 158, 219.
Chandrasekhar, S.: 1946, *Astrophys. J.* 103, 351; see also: 1960, *Radiative Transfer* (New York, Dover Publications).
Kestenbaum, H. L., Cohen, G. G., Long, K. S. Novick, R., Silver, E. H., Weisskopf, M. C., and Wolff, R. S.: 1976a, *Astrophys. J.*, to be published December 15.
_____: 1976b, *Astrophys. J. Letters* 208, L27.
Lightman, A. P., and Shapiro, S. L.: 1975, *Astrophys. J. Letters* 198, L73.
_____: 1976, *Astrophys. J.* 203, 701.
Novick, R.: 1975, *Space Sci. Rev.* 18, 389.
Novick, R., Weisskopf, M. C., Berthelsdorf, R., Linke, R., and Wolff, R. S.: 1972, *Astrophys. J. Letters* 174, L1.
Oort, J. H., and Walraven, Th.: 1956, *Bull. Astron. Inst. Neth.* 12, 285.
Weisskopf, M. C., Cohen, G. G., Kestenbaum, H. L., Long, K. S., Novick, R., and Wolff, R. S.: 1976, *Astrophys. J. Letters* 208, L125.