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X-RAY OBSERVATIONS OF ALGOL

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ABSTRACT

We have used the Solid State Spectrometer on Einstein to study Algol. Two observations six months apart were made, both during a primary optical eclipse. No corresponding X-ray eclipses were seen. During the second observation the source was flaring and was on average a factor 3 brighter. The spectrum on both occasions was consistent with a two-component thermal equilibrium model with temperatures of ∿ 7.5 and 40 million degrees. Attempts to insert a third component indicate the temperature distribution to be bimodal. We discuss models for the X-ray emission and suggest that it most likely originates from an active corona surrounding the K star.

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I. INTRODUCTION

Algol (β Per) is a triple system containing a 2.9 day eclipsing binary (K IV+B8V) in a 1.9 year orbit with an A V star. Since the early seventies this system has been well known to be a highly variable radio source, which led to predictions that it should be detectable as an X-ray source (Hjellming 1972; Hjellming, Webster and Balick 1972). After two unsuccessful attempts to find any X-ray emission (Canizares et al. 1973; Kifune, Wolff and Weisskopf 1975), it was finally detected from SAS C in October 1975 (Schnopper et al. 1976). This result was confirmed by Harnden et al. (1976) who also found evidence that the flux was variable. We present measurements made by the Solid State Spectrometer (SSS) onboard the Einstein Observatory that show the X-ray spectrum to be composed of two thermal components, with temperatures of 7.5 and 40 million degrees and which confirm the X-ray flux to be variable by a factor of 3.

II. RESULTS

Two observations of Algol were made by the SSS (see Joyce et al. 1978), in 1979 February and August. The SSS gives 128 channels of pulse height information in the 0.5 to 4.5 keV band with an almost constant energy resolution of ∿ 160 eV. The times of the observations and the background-subtracted flux accumulated in 200 second bins are shown in Figure 1. The binary phase of the 2.9 day orbit is indicated, where phase zero corresponds to the eclipse of the B star by its comparison (primary eclipse; phase 0.96 to 0.04). There is no evidence from either observation for any X-ray minimum associated with the eclipse of the B star. In fact, it is evident from Figure 1 that in August we observed a flaring episode that peaked near the eclipse and decayed by ∿ 30% over the following 12 hours. The timescale for this event is similar to that of the radio flares (eg. Hjellming et al. 1972). Part of the difference in the count rate between the two observations can be attributed to an accumulation of ice on the surface of the SSS which can significantly reduce the detection efficiency below 1 keV. The actual thickness of ice during any observation is determined from independent calibrations, from which we have determined that a constant source should have exhibited only a factor ∿ 2 increase in count rate. Thus the flux in August is actually about a factor 3 higher than in February.

We summed up the spectra for each of the two observing runs and compared the data to various trial models which were folded through the detector response function. The resulting χ^2 indicated that simple thermal, power law and black-body models could not represent the data. A Raymond and Smith (1977) model for the line emission and continuum from an optically thin isothermal plasma with variable abundances also failed to yield an adequate fit for either measurement (χ^2 typically 180 for 60 degrees of freedom). However a two component Raymond and Smith model yielded, for both observations, χ^2 of ∿ 80 for 58 dof with temperatures of ∿ 7.5 and 40 million degrees. These fits are given in Table 1 and illustrated for the second observation in Figure 2. The lines a and b in Figure 2 indicate the individual contributions of each of the two components. There is little evidence for any line emission from silicon or sulphur at ∿ 1.8 or 2.4 keV because the high temperature component dominates the spectrum at these energies and the line-generating efficiencies for such high temperatures are low. The abundances of the principle line generating elements Fe, Si and S were free parameters and Table 1b shows that all are consistent with solar values. Line c in Figure 1 represents the low temperature model with the iron abundance set to zero and it is apparent that the primary contribution of this component is from the iron L complex at about 1 keV. Because of this the emission measure of the low temperature component is very sensitive to the iron abundance. Thus to facilitate comparison the emission measures and temperatures given in Table 1a assume solar abundances.

During the second observation, when the source was flaring, the overall luminosity of the low temperature component increased by about a factor 2 while that of the high temperature increased by slightly more. The principle change in the spectral parameters was a corresponding increase in the emission measures of the two components. There was no evidence for a significant change in either of the two temperatures. In order to investigate whether two temperatures uniquely described the data, we input a third Raymond and Smith model with a temperature halfway between the other two. This did not improve the fit and by increasing the emission measure of the third component until χ^2 deteriorated by 2.7 we set a 90% confidence upper limit of < 0.3 the emission integral of the low temperature component. Thus we conclude that the temperature distribution is to the first order bimodal. We note in passing that if we replace the high temperature component with a nonthermal power law we do not obtain an acceptable fit.

III. DISCUSSION

Although X-ray emission from Algol was predicted from a thermal interpretation of the early radio observations, the total X-ray flux that was eventually observed fell several orders of magnitude below that expected (Canizares et al. 1973; Woodsworth and Hughes 1976). Harnden et al. proposed an alternative model wherein the X-ray emission is produced by material transferred from Algol B to its companion which is shock heated when it collides with the B star to temperatures of $\sim 10^6$ K. This model predicts an X-ray eclipse during the primary optical eclipse. If mass transfer is via a fast stellar wind or Roche Lobe overflow, an X-ray eclipse either centered on or slightly following the optical event would be expected. Figure 1 clearly shows this not to be the case. For a slow stellar wind ($v < 250$ km s^{-1}) the shock front would be spread out over the whole B star and only a very shallow eclipse seen. However, while this might be consistent with the observed 7.5 million degree component, it cannot account for the 40 million degree component.

We suggest that a large proportion of the X-ray emission results from an active corona surrounding the cooler star. This is based on the fact that Algol displays a number of properties that are common to the RS CVn group of stars. These are typically 1-14 day binaries containing a G dwarf with a K subgiant (see Hall 1976 for a full review of their properties), that have recently been discovered to be a class of variable X-ray sources (see Walter et al. 1980). The cooler of the two stars shows evidence for chromospheric and star spot activity, and the X-ray emission has been attributed to an active corona surrounding this star. Apart from the facts that the binary period of Algol is in the RS CVn range and that one component is a K subgiant, there are two other striking similarities. Firstly, a number of RS CVns display X-ray and radio flaring episodes similar to those seen from Algol (e.g. White, Sanford and Wieler 1978; Newell et al. 1980). Secondly, the X-ray spectra of the RS CVn stars AR LAC, UXARI and HR1099 are similar to that of Algol in that they are also two component with similar temperatures and emission measures (Swank and White 1980). The two component spectrum of the RS CVn systems has been interpreted in terms of the coronae being contained with magnetic loops (Swank and White). Using a simple scaling of solar loop models it is found that the low and high temperatures infer two different loop sizes comparable with the stellar and orbital dimensions respectively.

The principle difference between Algol and the RS CVns is in the mass and light ratios of the two components. The higher light ratio means that it has not been possible to observe the cooler star, so all of the normal pointers to an active chromosphere such as a photometricwave or Ca II emission may be hidden. The mass ratio of Algol is four times greater than the typical RS CVn system and the K star (Algol B) is near or at its Roche limit (Tomkin and Lambert 1978). However Young and Koniges (1977) have found in a study of late type binaries that Ca II H and K emission is greatest where strong tidal coupling is present, as is the case for Algol.

Thus we conclude that the X-ray emission from Algol is probably similar in origin to that from the RS CVn systems i.e. an active corona surrounding the cooler star. This finding further supports the view (see Bopp et al. 1979; Ayres and Linsky 1980) that the principal causes of active coronae are related to rapid stellar rotation.

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TABLE 1a: TWO COMPONENT SPECTRAL FITS FOR SOLAR ABUNDANCES

	March 1979	August 1979
$EI_1 \times 10^{53}$ cm^{-3}	0.53 ± 0.20	1.3 ± 0.4
$T_1 \times 10^6$ °K	8.5 ± 0.9	6.9 ± 0.6
$L_1 \times 10^{30}$ ergs s^{-1}	1.0 ± 0.2	2.3 ± 0.3
$EI_2 \times 10^{53}$ cm^{-3}	2.7 ± 0.4	6.3 ± 0.9
$T_2 \times 10^6$ °K	44 ± 14	42 ± 16
$L_2 \times 10^{30}$ ergs s^{-1}	2.7 ± 0.4	6.6 ± 0.7

TABLE 1b: MEASURED ABUNDANCES

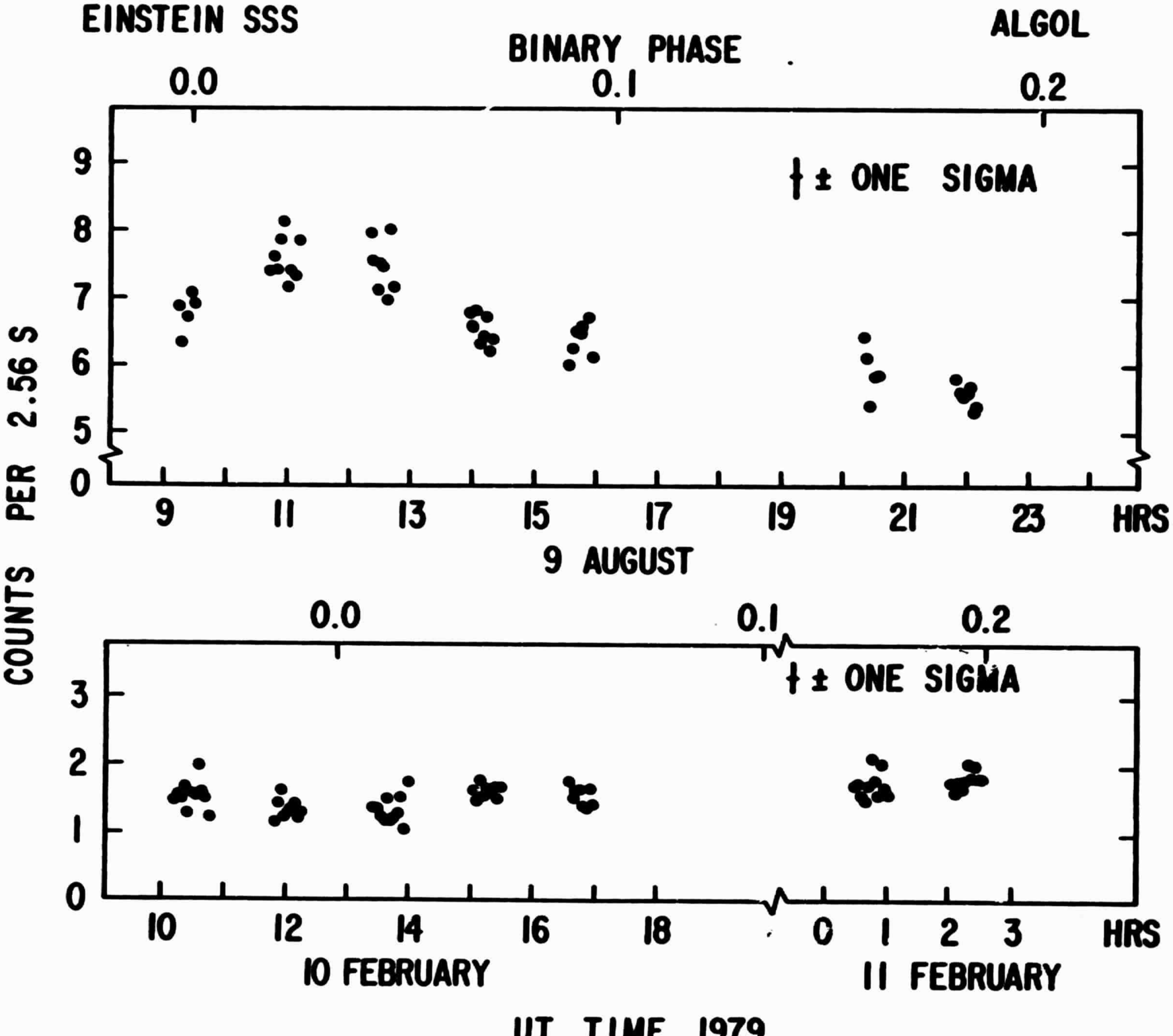
Fe	0.6 ± 0.5	1.4 ± 0.5
Si	0.5 ± 0.4	1.5 ± 1.1
S	< 0.7	< 1.5

90% confidence uncertainties

FIGURE CAPTIONS

Figure 1 - The flux recorded by the SSS in 200 second accumulation intervals. The binary phase of Algol is indicated where phase zero corresponds to primary optical eclipse.

Figure 2 - The pulse height spectrum (indicated with 1σ error bars) recorded on 1979 August 9. The best fit two-component model is indicated with the solid histogram. Line a is the high temperature component; Line b the low temperature component; and Line c the low temperature component with the iron abundance set to zero.


EINSTEIN SSS
ALGOL
BINARY PHASE
0.0
0.1
0.2
± ONE SIGMA
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9 AUGUST
COUNTS PER 2.56 S
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3
2
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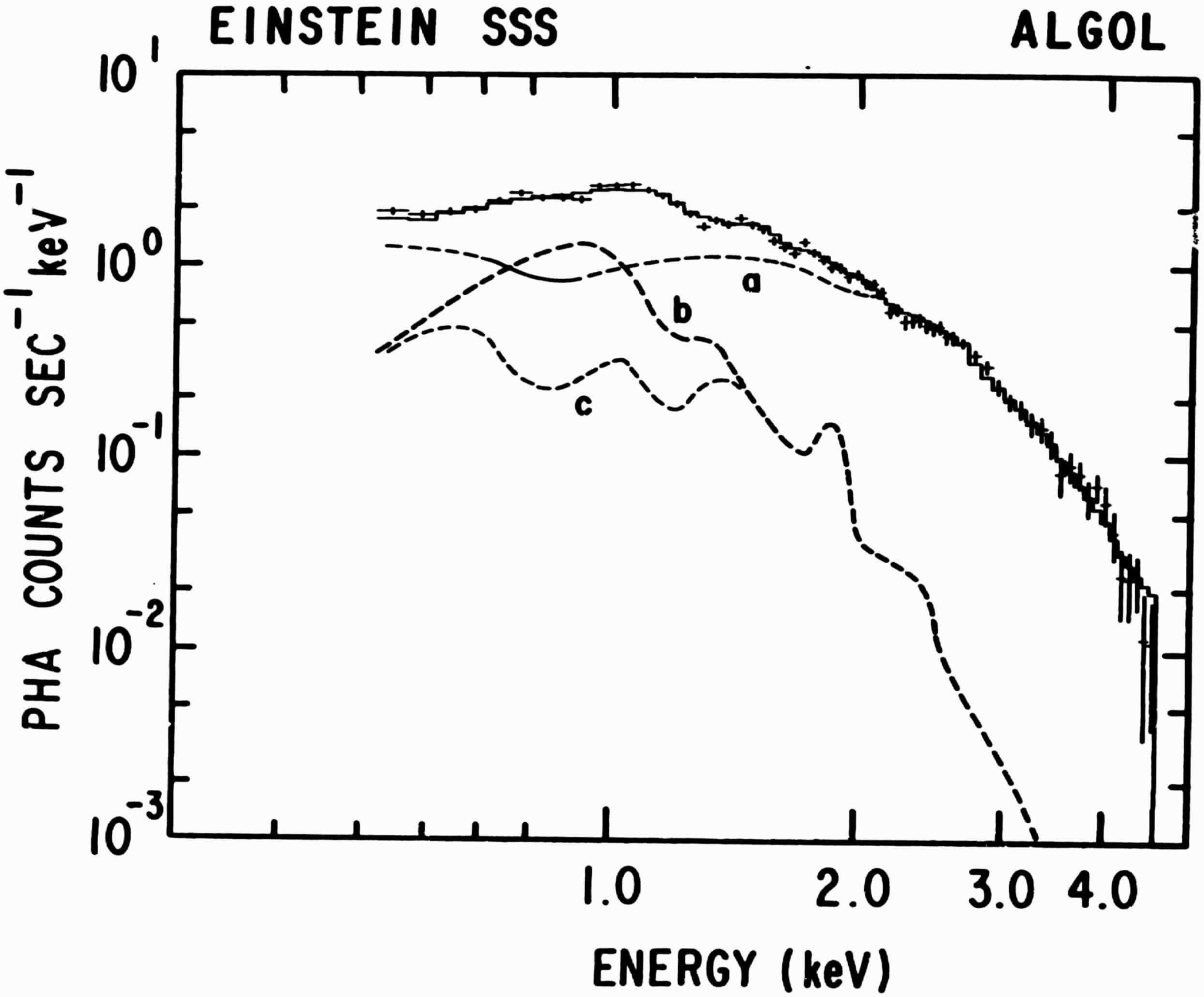
EINSTEIN SSS
ALGOL
PHA COUNTS SEC^{-1} keV^{-1}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
a
b
c
1.0
2.0
3.0
4.0
ENERGY (keV)

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