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X-RAY SPECTRUM OF KEPLER'S SNR

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ABSTRACT

Observations made with the Solid State Spectrometer (SSS) aboard the Einstein Observatory confirm Kepler's SNR as an X-ray source with an intensity between 1-3 keV of 7.2×10^{-11} ergs/cm^2-s. The X-ray spectrum is similar to those of Cas A and Tycho, with strong line emission from the helium-like species of Si, S and Ar. Direct comparisons to Tycho's SNR suggest a distance to Kepler's SNR of $\gtrsim$ 5 kpc.

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I. INTRODUCTION

Historical SNR are generally known to be X-ray sources. Radio and optical measurements indicate that Kepler's SNR shares many properties in common with other such remnants and therefore is a likely candidate for X-ray emission. Recently two independent groups (Bunner 1979; Tuohy et al. 1979) have reported X-ray emission from the vicinity of Kepler's SNR, but the relatively large field of view of their respective instruments precluded positive identification. In this paper, we report on the results of an observation of Kepler's SNR with the Solid State Spectrometer (SSS) at the focus of the HEAO-2 (Einstein) X-ray telescope and discuss the results in the context of the emission observed from Cas A and Tycho's SNR with the same instrument.

II. EXPERIMENT AND ANALYSIS

For a detailed description of the SSS detector and electronics we refer the reader to Joyce et al. (1978). To summarize, the experiment consists of a cooled Si(Li) detector, which can be placed at the focus of the Einstein X-ray telescope. So located, the SSS has an effective area of $\sim$ 100 cm^2 between 1-3 keV which drops monotonically to $\sim$ 10 cm^2 at 4.5 keV. The field of view of the SSS is a $\stackrel{\vee}{\sim}$ 6 arc min diameter circle. The SSS has an energy resolution of $\sim$ 160 eV (FWHM).

The spectral analysis procedures have been discussed previously by Holt et al. (1979) and Becker et al. (1979a). In general, theoretical X-ray spectra are folded through the experiment response and compared to the observational data. Model parameters are varied to minimize the chi-square between the data and the model. In this case, we utilized a model which predicts the emission expected from a hot plasma in collisional equilibrium (Raymond and Smith 1977, 1979).

The extent of the radio emission from Kepler's SNR is $\sim$ 3 arc min (Hermann and Dickel 1973), somewhat smaller than the SSS field of view, so that these measurements should reflect the total X-ray emission from Kepler's SNR.

III. RESULTS AND DISCUSSION

The SSS pulse height spectrum of Kepler's SNR is shown in Figure 1. As in the case of other SNR, the spectrum cannot be well represented by a single temperature, but requires at least two thermal components. The best estimate for the kT of the softer component is controlled by the line emission and is 0.54 keV. The data are not capable of restricting the kT of the high temperature component and therefore kT of this component has been arbitrarily fixed at 4 keV similar to values previously reported for Cas A and Tycho (Davison et al. 1976). If we require identical elemental abundances for both components, the best fit values so determined for Mg, Si, S, Ar, and Fe are given in Table 1. The best fit column density was $6 \pm 1 \times 10^{21}$ atoms/cm^2 (2σ errors). In these fits, the abundances of He, C, O, N, and Ne are all assumed to be solar (see Becker et al. 1979a). The best fit model has been superimposed upon the data in Figure 1. Based on this model, we infer an X-ray intensity of 7.2×10^{-11} ergs/cm^2-s between 1-3 keV.

It is hardly surprising that Kepler's SNR is an X-ray source. Nonetheless these measurements are important because they allow a new channel for comparisons among the young remnants of Cas A, Tycho, and Kepler. It is widely believed that Cas A evolved from the explosion of a very massive star (Chevalier 1977) while Tycho's and Kepler's SNR resulted from Type I SN (Minkowski 1966). The SSS has now observed all three of these remnants, with the results for Cas A and Tycho already reported (Becker et al. 1979a, 1979b).

Direct comparisons among Kepler and the other remnants are complicated by the uncertainty in the distance and column density to Kepler's SNR. Tuohy et al. (1979) suggest a distance between 3.5 and 6 kpc based on the brightness of the historical SN. However, Bunner (1979) estimated a hydrogen column density of $<10^{21}$ atoms/cm^2 from observations of the X-ray spectrum, suggesting Kepler's SNR is closer than previously accepted values. Our data do not indicate such a low column density. At the other extreme, van den Bergh and Kamper (1977) suggest Kepler's SNR is within the galactic nuclear bulge, $\sim$ 9 kpc distant.

If Kepler's SN is indeed similar to Tycho's SN, we would conclude the correct distance to Kepler's SNR is greater than $\sim$ 5 kpc (assuming Tycho's SNR is $\gtrsim$ 1.5 kpc distant (Hughes, Thompson, and Calvin 1971)). The angular extent of Kepler's SNR is only $\sim$ 35% that of Tycho's SNR, while its X-ray intensity is only $\sim$ 8% of Tycho's SNR (based on HEAO-1 observations of Tycho by Pravdo et al. 1979), thus suggesting Kepler's SNR to be $\sim$ 3 times more distant than Tycho's SNR. At a distance of 5 kpc, the X-ray luminosity of Kepler's SNR between 1-3 keV is 3.3×10^{35} ergs after correcting for the effects of interstellar absorption.

Qualitatively, the spectra of Cas A, Tycho, and Kepler are very similar. All show strong line emission from helium-like species of Si, S, and Ar, but relatively little emission below 4 keV from ions of Mg and Fe. In all three sources, the inferred abundance (relative to solar values) of S is 2-3 times that of Si, while Ar is 4-8 times that of Si. Furthermore, results from observations of MSH11-54 (Clark Tuohy, and Becker 1980) show the same relative excess of S. When taken together, the spectra of SNR's suggest that the galactic abundance ratio of S to Si is 2-3 times that usually estimated for the solar system, with an even greater relative excess existing for Ar. However, these conclusions will remain questionable until a complete non-equilibrium model for X-ray emission is developed. The relative under-abundance of Mg in all three remnants may be indicative of the uncertainties in our models. Since even in these young SNR, a substantial amount of inter-stellar material (presumably containing Mg) has been swept-up, a complete lack of Mg in the SN ejecta still could not explain such low Mg abundances in the X-ray emitting plasma. The model also fails to account for an apparent line feature at 2.9 keV. This energy corresponds to the $1s^2$-1s3p transition of helium-like S. In the Tycho SNR spectrum, an excess is present at 2.2

keV, the corresponding transition for helium-like Si. Enhancement of these transitions might be indicative of a non-equilibrium situation in which the electron temperature is higher than that indicated by the line spectrum as is probably the case in young SNR (Itoh 1977).

In summary, we can not account in detail for the various line strengths observed in the spectra of young SNR. However, it is clear that qualitatively similar conditions exist in Cas A, Tycho, and Kepler in spite of the vastly different origins between Cas A and the two Type 1 remnants. Future work will extend these comparisons to older, more evolved, remnants.

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FIGURE CAPTIONS

Figure 1 - X-ray spectrum of Kepler's SNR as observed by the SSS on HEAO 2. Superimposed upon the data is the expected response of the SSS to a two-component thermal model. The lower second trace is the estimated contribution to the spectrum from emission by H, He, C, O, N, and Ne. The three peaks in the spectrum at 1.85, 2.45, and 3.1 keV are attributable to line emission from Si XIII, S XV, and Ar XVII respectively.

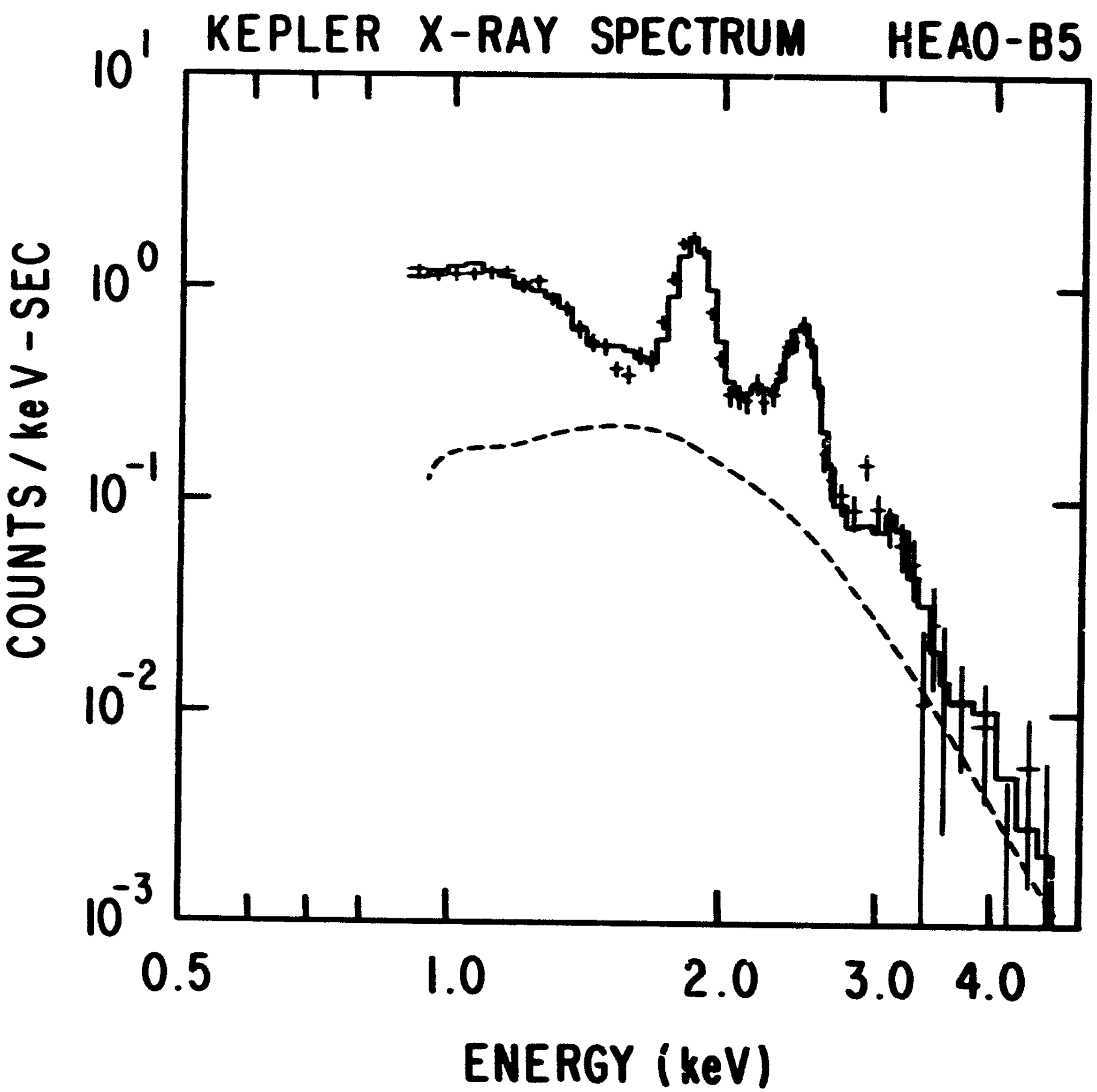
KEPLER X-RAY SPECTRUM
HEAO-B5
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
COUNTS / keV - SEC
0.5
1.0
2.0
3.0
4.0
ENERGY (keV)

TABLE 1: ELEMENTAL ABUNDANCES INFERRED FOR KEPLER'S SNR

ELEMENT	ABUNDANCE[+]	RATIO TO SOLAR ABUNDANCE[++]	EQUIVALENT WIDTH (eV)	PHOTONS ($cm^{-2}s^{-1}$)
Mg	0.8×10^{-5}	$0.2 \pm .2$	---	---
Si	1.3×10^{-4}	$3.7 \pm .2$	1300	.0035
S	1.4×10^{-4}	$6.2 \pm .5$	1300	.0012
Ar	5×10^{-5}	19 ± 5	400	.00013
Ca	1.6×10^{-5}	7 ± 6	---	---
Fe	1×10^{-4}	3 ± 1	---	---

[+] Strongly dependent on assumed abundances of C, N, O, and Ne. See Becker et al. (1979a).

[++] Based on estimates of solar abundances by Meyer (1978). Error estimates are 1σ.

BIBLIOGRAPHIC DATA SHEET

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