X-RAY IRON-LINE EMISSION FROM THE SN 185 REMNANT

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Most of the results that we have been hearing about today are very recent ones. The story of the object which I would like to talk about begins quite a long time ago. The earliest supernova event which was recorded historically occurred in the year 185 AD; the chief point of the work which we carried out is to try to show that the supernova remnant RCW86 is in fact the remnant of this historical event.

This remnant has the galactic designation G315.4-2-3; the non-thermal radio source is known as MSH 14-63, and the optical filaments are designated RCW86. It is thought to be at a distance of about 2.5 kiloparsecs, determined by Westerlund (1969) who established its association with a group of OB stars at about that distance. Westerlund went on to suggest that the supernova was probably a type II event because of the association with early-type stars, which are generally believed to give rise to type II supernovae.

The association of this remnant with the supernova of 185 AD has long been suggested. Clark and Stephenson (1977) reviewed the evidence for this association, which I would characterize as good, but not certain. RCW 86 is the best candidate among four known supernova remnants in the vacinity of the historically recorded event.

The radio and optical appearances of this object are shown in Figure 1. The optical picture is from a broad-band red plate taken by Robert Kirshner and myself at the CTIO 4-m telescope. Superimposed on it are 5 GHz radio contours as measured by Caswell, Clark and Crawford (1975). The size of the radio shell is about 40 arc min which corresponds to a diameter of about 28 par sec at a distance of 2.5 kiloparsec. The optical nebulosity consists primarily of two groups of filaments, one at the north and another near the southwestern edge of the radio shell.

The situation in X-rays is that there is an X-ray source coincident with the supernova remnant RCW86 which was first discovered by Naranan, et al (1977) from the NRL experiment on the Apollo-Soyuz. It is very bright at about 1 keV. This was independently observed by the MIT OSO-7 experiment above 2 keV where it has a flux of about 7 Uhuru counts (Winkler 1978). This source has been tentatively identified with the supernova remnant, but its location near the galactic plane makes an identification based on positional coincidence alone less than positive.

The results I am reporting today make the identification much more definite. These are based on data from a 3-hour pointed observation of RCW86 with HEAO-1, carried out in March 1978. Data from the Medium-Energy Detectors of the A-2 experiment are shown in Figure 2. These are raw pulse-height data which have been untouched except for background subtraction. Attempts to fit the data points with a spectrum consisting only of a thermal continuum fail; but if we allow the computer to add a single line to the thermal spectrum, a successful fit is obtained. The statistical significance of the line is $\geq 10\sigma$. Furthermore, the line energy, left as an adjustable parameter in the fit, is fixed by the computer at 6.7 keV. This corresponds to K-line emission from highly ionized states of iron similar to lines which have been observed in other supernova remnants such as Cas A and Tycho. The thermal spectrum of lines plus continuum indicate that we are definitely observing hot plasma in this source and reinforces the identification of the X-ray source with the supernova remnant.

In Figure 3, we have the same spectrum which has now been unfolded through the response of the detector to give us an incident spectrum. One sees the iron line standing up very dramatically. The best-fit temperature here is 5.9 keV. If we assume that the hot plasma has been heated by a shock wave, then the shock velocity must be very high, about 2000 km s^{-1}. This indicates that the supernova remnant must be young, because if we run the picture backwards (just extrapolate backwards to when the supernova must have gone off) then the explosion occurred about 2000 years ago. We feel that this establishes the identification with the 185 AD event beyond all reasonable doubt.

Also shown in Figure 3 is the low-energy flux as determined by the NRL group. The remnant is very bright at about 1 keV and falls sharply at higher energies. It is impossible to fit all these data with a thermal model at a single temperature, which suggests that plasma components at more than one temperature are present in this remnant. The spectral parameters are summarized in Table 1.

The equivalent width in the iron line (a measure of the line strength relative to the continuum) is about 780 eV. This can be compared with what would be expected from a hot plasma with cosmic abundances. I have indicated the predicted equivalent width based on two models for a plasma at the measured temperature. The different between the two predictions lies primarily in different choices for the iron abundance.

The iron line we observe falls within the range predicted by the models. This indicates that the iron abundance, assuming thermal equilibrium, is consistent with the cosmic abundance of iron.

We may interpret the X-ray emission above 2 keV within the context of the canonical blast-wave model, with a shock wave expanding outward, heating swept-up interstellar material, and producing X-rays. We obtain the results which are shown in Table 2 for the age, the density of the interstellar medium, and the energy required for the supernova explosion. Since the distance is somewhat uncertain, I have indicated how these parameters scale with distance. In the right hand column I have scaled these so that the explosion occurs in the year 185 AD. The results are similar to what is observed for other supernova remnants, except that the blast energy is somewhat higher than for most of the other cases in which it has been determined.

In summary, we first find that iron-line emission at 6.7 keV definitely stems from this source, which confirms that the X-ray source is indeed associated with the remnant. Second, the temperature measured from HEAO-1 is about 6 keV, (for the hard X-ray component at any rate) which requires a shock velocity of at least 2000 km s^{-1}. This indicates that the remnant must be a young one and leads to our conclusion that the identification with the 185 AD event is correct. And third, the equivalent width which we observe is consistent within the uncertainties with a cosmic iron abundance.

I would like to thank everyone involved in the HEAO project for the opportunity to participate as a guest investigator. In particular, I would like to thank Steve Pravdo, Rich Mushoteky, Elihu Boldt and the other members of the X-ray astronomy group at Goddard Space Flight Center with whom I collaborated on this work.

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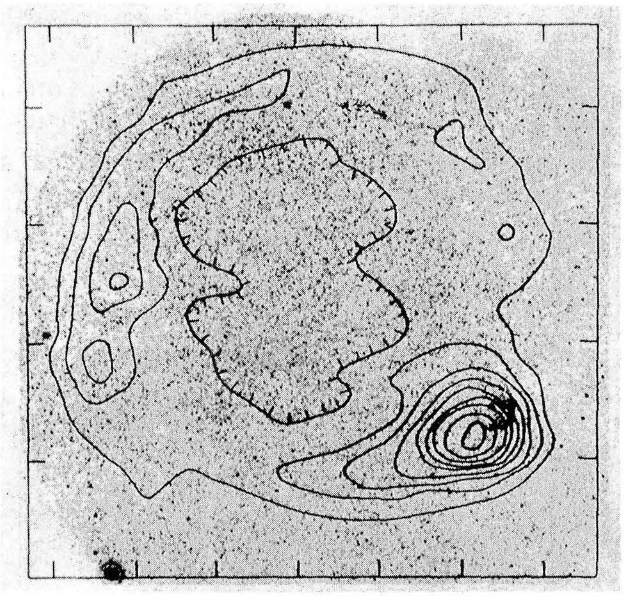

Figure 1. Radio contour map of MSH 14-63 - RCW 86
(from Caswell, Clark and Crawford 1975)
superimposed on a broad-band red 4-m plate.

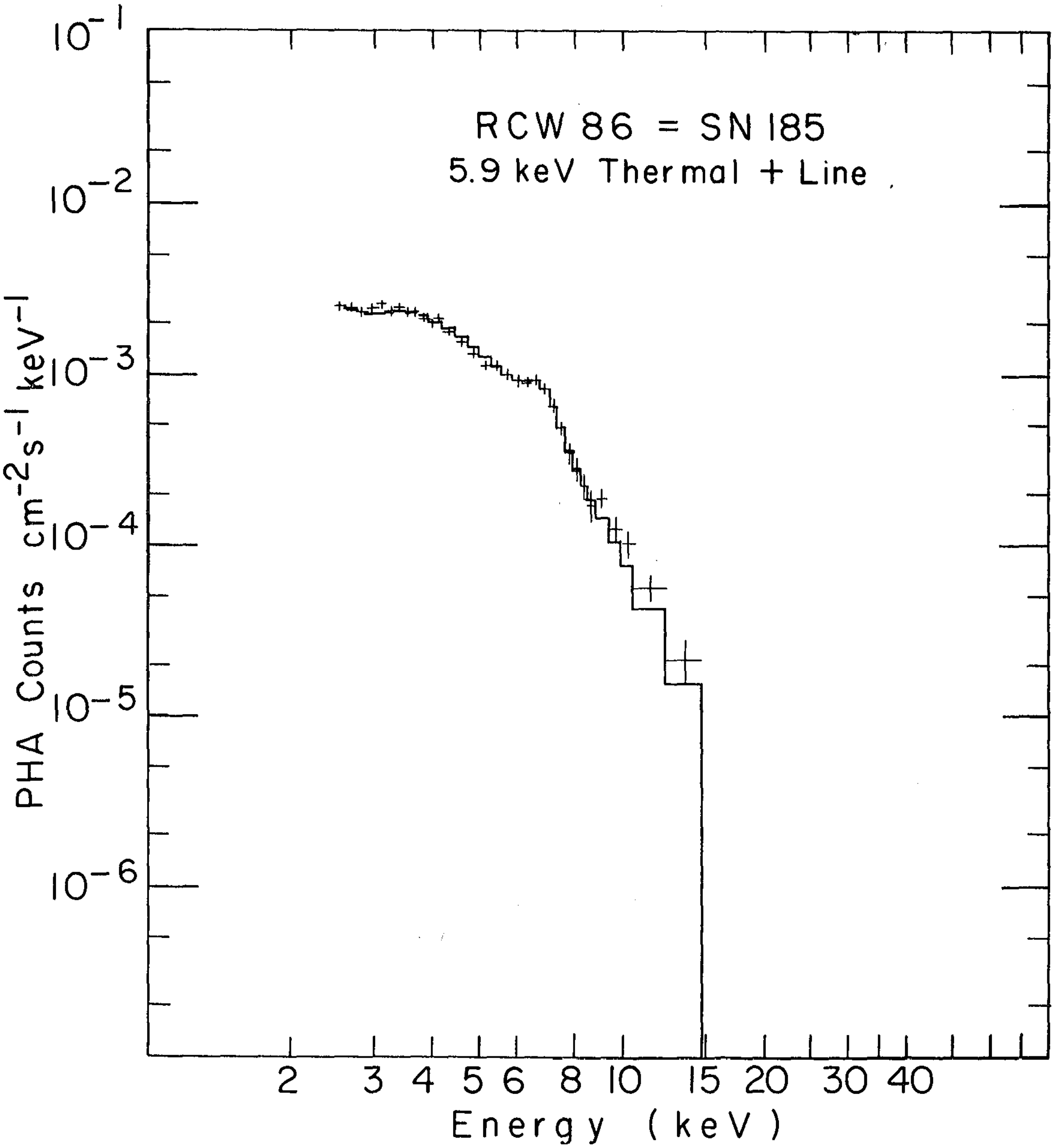

Figure 2. Raw pulse-height spectrum of RCW86 from HEAO A-2 Medium Energy Detectors. Solid line indicates best fit to the data.

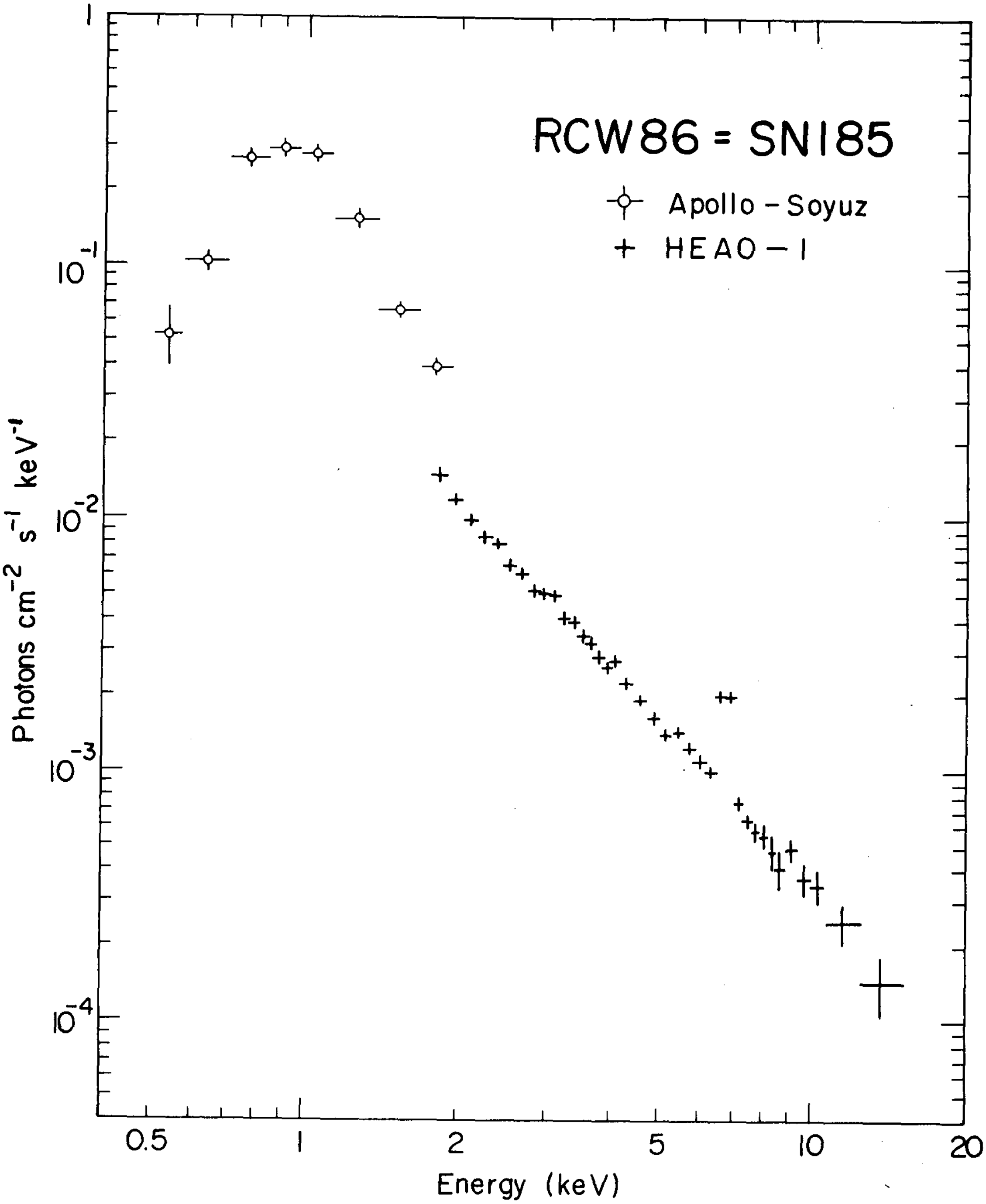

Figure 3. Deconvolved incident spectrum of RCW86. Apollo-Soyuz data are from Naranan et al. (1977); HEAO-1 is this work. Note strong line at 6.7 keV.

TABLE 1. G315.4-2.3 HEAO-1 (A-2) SPECTRUM

Continuum:	Thermal, $kT = 5.9$ keV
	Flux (2-10 keV) $= 1.1 \times 10^{-10}$ ergs $cm^{-2}s^{-1}$
	Additional Low-T Component (Apollo-Soyuz)
Line:	$\langle E \rangle = 6.75$ keV
	Flux $= 6.7 \times 10^{-4}$ photons $cm^{-2}s^{-1}$
	EW = 0.78 keV
Predicted EW (Cosmic Abundances):	
	Raymond and Smith (1977): 1.41 keV
	Bahcall and Sarazin: 0.74 keV

TABLE 2. G315.4-2.3 BLAST-WAVE MODEL

	General ($d_* \equiv d/2.5$ kpc)	Age-Scaled
Age (Sedov)	$2900\ d_*$	1793 years
Luminosity (2-10 keV)	$9.2 \times 10^{34}\ d_*^2$	3.6×10^{34} ergs s^{-1}
Density	$0.11\ d_*^{-1/2}$	$0.14\ cm^{-3}$
Blast Energy	$2.5 \times 10^{51}\ d_*^{5/2}$	0.8×10^{51} ergs
Swept-Up Mass	$34\ d_*^{5.2}$	$10\ M_\odot$