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DISCOVERY OF X-RAY EMISSION FROM TWO SOUTHERN SUPERNOVA REMNANTS

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ABSTRACT

Two new soft X-ray sources positionally coincident with the supernova remnants PKS 1209−52 and RCW 103 have been discovered using the A-2 experiment on *HEAO 1*. Their measured fluxes are, respectively, $\sim 1.4 \times 10^{-10}$ ergs cm^{-2} s^{-1} (0.2–1.0 keV) and $\sim 1.8 \times 10^{-10}$ ergs cm^{-2} s^{-1} (0.6–2.0 keV). Spectral data are used to derive physical parameters for each remnant. For PKS 1209−52 the parameters are suggestive of the remnant being in an advanced evolutionary phase, with shock-heated interstellar material producing the soft X-ray emission. RCW 103, in contrast, is known from radio and optical data to be in an earlier evolutionary phase, and the soft X-ray flux is most likely due to emission originating in a reflected shock wave or in plasma evaporated from shock-heated interstellar clouds.

Subject headings: nebulae: supernova remnants — X-rays: sources

I. INTRODUCTION

To date, X-ray emission has been observed from approximately 12 supernova remnants (SNR). In this *Letter* we report the discovery with *HEAO 1* of X-ray emission from two additional remnants: PKS 1209−52 and RCW 103. Preliminary results from this work have been given by Tuohy *et al.* (1978).

The old SNR PKS 1209−52 (G296.5+10.0) lies at an estimated distance of about 2 kpc, with a diameter of order 40 pc and a z-distance (height above the plane) of $\sim$300 pc (Clark and Caswell 1976). For old remnants, soft X-ray emission results from thermal bremsstrahlung and line emission originating in shock-heated interstellar material cooling through temperatures of $\sim 10^7$–10^6 K. The expected X-ray luminosity is a function of the total mass of material swept up and heated by the expanding shock. As the expansion continues, the fall in temperature shifts the emission to lower energies, but with increased intensity due to the larger mass of radiating gas.

For young SNRs, the soft X-ray emission can be explained by either a "reflected" shock mechanism (McKee 1974) or by evaporation from shock-heated interstellar clouds (Chevalier 1975). Of all the radio remnants younger than $\sim$1000 years on the near side of the Galaxy, only Kepler and RCW 103 (G332.4−0.4) have *not* been identified previously in soft X-rays. Kepler's remnant lies at a suspected distance of about 10 kpc and is close to the confused galactic center region. Both of these factors render its X-ray detection difficult. RCW 103, in contrast, has an HI absorption kinematic distance of only 3.3 kpc (Caswell 1967), with a consequent linear diameter estimate of 9 pc. All available evidence suggests that RCW 103 is the remnant of a comparatively recent supernova (within the past 1000 years), but occurring so far south as to have escaped detection and documentation in northern hemisphere civilizations. On the basis of its relative proximity and a suspected evolutionary phase for which a reflected shock wave may be important, RCW 103 has been predicted as a prime candidate for X-ray detection (Clark and Culhane 1976).

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II. OBSERVATIONS AND RESULTS

The low-energy detectors of the *HEAO* A-2[1] experiment are described in detail by Rothschild *et al.* (1979). Briefly, the data reported here were obtained by LED 1, which has a total effective area of 380 cm^2 and two coaligned fields of view measuring 1.55° and 2.80° FWHM in the spacecraft scan direction. The angular response of LED 1 perpendicular to the scan path is $\sim$3° FWHM for each field of view. The detector is sensitive to X-rays between 0.1 and 3 keV and is thus ideally suited for the study of X-ray emission from the 10^6 to 10^7 K plasmas characteristic of SNRs.

a) *PKS 1209−52*

The region of sky containing the supernova remnant PKS 1209−52 was scanned by LED 1 between 1978 January 17 and 21. A new soft X-ray source, designated H1209−52, was clearly detected at an intensity of approximately twice the background level of $\sim$10 counts s^{-1}. Figure 1*a* shows the 90% confidence error box for the source derived by fitting the LED 1 response function to the scan data on successive days. The error box for the centroid of the X-ray emission is contained within the PKS 1209−52 radio contours which are included schematically in the figure. The positional coincidence of H1209−52 with PKS 1209−52 at this

[1] The A-2 experiment on *HEAO 1* is a collaborative effort led by E. Boldt of GSFC and G. Garmire of CIT, with collaborators at GSFC, CIT, JPL, and UCB.

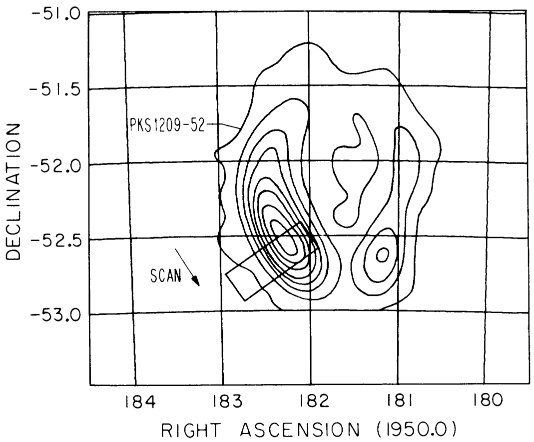

FIG. 1*a*.—H1209−52 error box (90% confidence) superposed on the radio contours of PKS 1209−52 (Whiteoak and Gardner 1968). Every second contour is plotted for clarity.

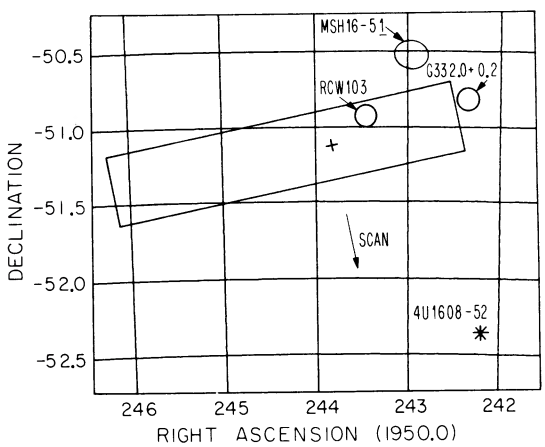

FIG. 1*b*.—H1615−51 error box (90% confidence) with the best-fit source position denoted by a cross. The supernova remnants RCW 103, MSH 16−5*1*, and G332.0+0.2 are shown schematically, together with a nearby 4U source.

distance above the plane argues strongly for a correct identification. Furthermore, we have checked other classes of objects which could produce X-ray emission in the LED energy range, but no other likely counterparts were found. When corrected for spacecraft aspect, our data are consistent with a constant-source count rate, as expected from a SNR.

The centroid of the X-ray emission is located in the southeastern area of the radio remnant and is consistent with the peak of the radio emission. In addition, there is evidence at the 3 σ level for a $\sim1°$ extent of the X-ray emission in the scan direction. This direction lies along the $\sim1.5°$ extent of the peak radio-emitting contours. The radio emission from the NW side of the remnant is much weaker, but the optical filamentary structure is brightest in this region (Irvine and Irvine 1974). We can set an upper limit to the 0.2–1.0 keV emission from the NW area of the remnant of $\sim7 \times 10^{-11}$ ergs cm^{-2} s^{-1}.

To characterize the gross spectral properties of PKS 1209−52, we have fitted the data to a thermal bremsstrahlung model with an energy-dependent Gaunt factor (Kellogg, Baldwin, and Koch 1975), allowing for absorption in the interstellar medium (Brown and Gould 1970). We have also fitted the line-emission model of Raymond and Smith (1977, hereafter RS) with the elemental abundances set to the nominal cosmic values adopted by those authors. The line-emission model provides the better fit to the data. The best-fit spectral parameters are summarized in Table 1, and the observed count-rate spectrum for the exponential model is displayed in Figure 2*a* with the 90% confidence χ^2 contours (Lampton, Margon, and Bowyer 1976).

b) *RCW 103*

A second new soft X-ray source, denoted H1615−51, was detected during scans through the RCW 103 region between 1978 February 28 and March 4. The measured intensity of the source was similar to that found for H1209−52. Analysis of the data was influenced by the

TABLE 1

SUMMARY OF SPECTRAL OBSERVATIONS

MODEL*	FLUX (ergs cm^{-2} s^{-1})	BEST-FIT PARAMETERS: T (10^6 K)	BEST-FIT PARAMETERS: N_x (10^{21} cm^{-2})	χ^2	d.o.f.
PKS 1209−52 (0.25–1.0 keV)					
E+G..........	$\sim1.4\times10^{-10}$	1.3	5.5	33	24
RS............	$\sim1.4\times10^{-10}$	1.9	3.2	26	24
RCW 103 (0.6–2.0 keV)					
E+G..........	$\sim1.8\times10^{-10}$	1.7	13	17	14
RS†...........	$\sim1.8\times10^{-10}$	2.5	14	17	14
RS†...........	$\sim1.8\times10^{-10}$	16	4.8	16	14

* E + G: Exponential + Gaunt. RS: Raymond and Smith (1977).
† Two separate minima obtained; see text.

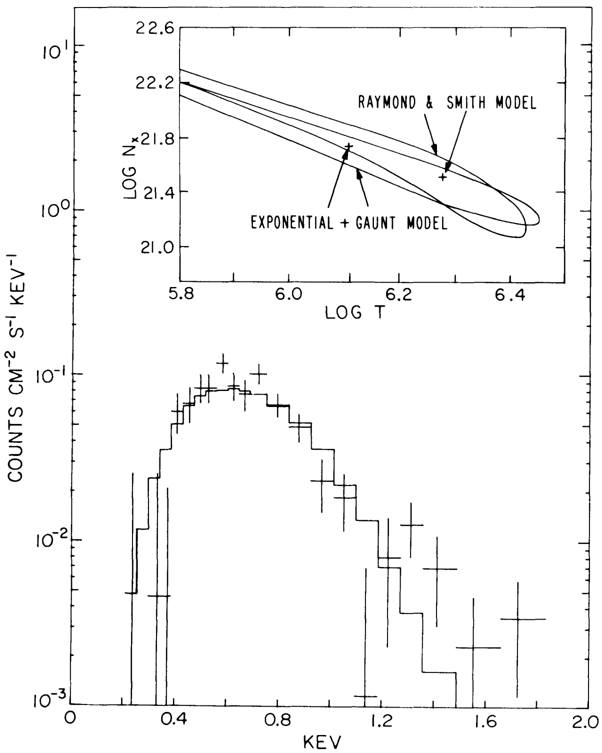

Fig. 2*a*.—Measured count-rate spectrum for PKS 1209−52 showing the best-fit exponential model. The inset shows the 90% confidence χ^2 contours for the exponential model and for the line-emission model of Raymond and Smith (1977).

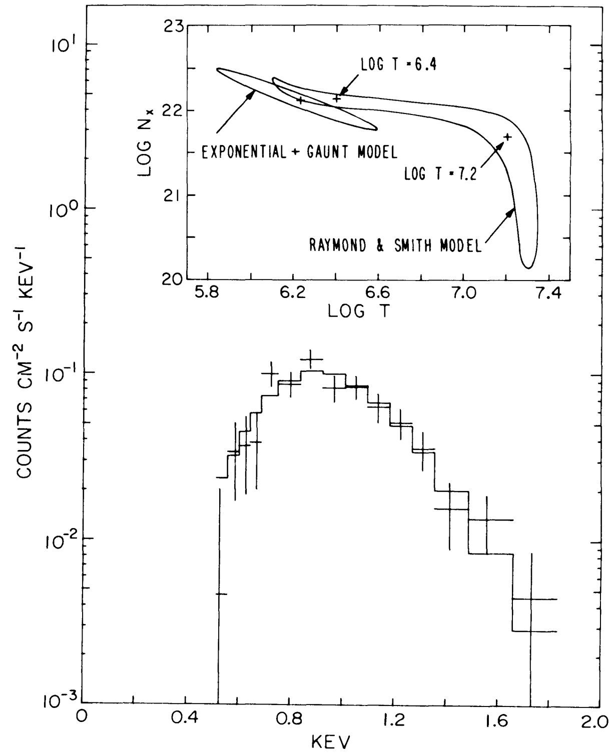

Fig. 2*b*.—Measured count-rate spectrum for RCW 103 showing the best-fit exponential model. The inset shows the 90% confidence χ^2 contours for the exponential model and for the line-emission model of Raymond and Smith (1977).

low number of useable scans, and also by the relative proximity of 4U 1608−52 which was separated from H1615−51 by ∼1°.5 in the scan direction. However, the intensity of 4U 1608−52 is estimated to be less than 20% that of H1615−51 in the energy range 0.7–2 keV. Figure 1*b* shows the error box derived for H1615−51 using data from the 1°.5 field of view of LED 1. The error box is asymmetric perpendicular to the scan path owing to the low number of useable scans on the eastern side. The nearby SNR RCW 103 lies within the error box and is therefore proposed as the probable counterpart. No other compelling candidates were found within the error box. Two other supernova remnants, MSH 16−5*1* and G332.0+0.2, lie outside our error box on the better-determined western side and are thus considered unlikely candidates. Furthermore, both objects lie at extreme distances ($\gtrsim$7 kpc; Caswell and Haynes 1975) and, since their positions correspond to a galactic tangent point (Green 1972), it is improbable that soft X-ray emission could be detected, as we expect the absorption to be high.

Our data allow us to set only an upper limit of ∼1° to the size of the X-ray source. We note that our best-fit line of position in the scan direction (Fig. 1*b*) is offset from the center of RCW 103. This displacement, if real, may be due to the influence of 4U 1608−52, or alternatively, could indicate that the X-ray emission is concentrated in the southern part of the remnant where both the radio and optical emissions are most intense (Goss and Shaver 1970; van den Bergh, Marscher, and Terzian 1973).

The best-fit spectral parameters deduced for RCW 103 are included in Table 1, together with the corresponding source flux. Figure 2*b* shows the observed count-rate spectrum compared with the best-fit exponential model, and also the 90% confidence χ^2 contours for both exponential and line-emission spectra. The simple exponential model allows $5.84 \lesssim \log T \lesssim 6.58$. However, the χ^2 contour for the line-emission model is more complex and shows a boomerang profile with two separate minima at log T values of 6.4 and 7.2. The low temperature minimum is consistent with the simple exponential fit where the observed spectrum is due mostly to continuum radiation with interstellar absorption. The high-temperature possibility arises because the observed count-rate peak in Figure 2*b* can be equally well-explained by iron L shell emission at ∼1 keV. The χ^2 contours derived for RCW 103 illustrate the potential danger in taking the temperature from the simple model as being indicative of the true plasma temperature of the source. Nonequilibrium conditions can further complicate the estimate of the source temperature.

III. DISCUSSION

PKS 1209−52 was identified as a supernova remnant from the radio observations of Whiteoak and Gardner (1968). It shows the double-lobe radio structure characteristic of many remnants in an advanced evolutionary phase for which compressed interstellar magnetic fields and ambient cosmic rays are usually invoked as the source of the radio synchrotron emission. The object was discovered optically by Irvine and Irvine (1974). Danziger and Dennefeld (1976) reported that the optical spectrum is dominated by λ3727 [O II] and λλ5007, 4959 [O III] features, with [S II] line intensities commensurate with a low-density emitting region. PKS 1209−52 has a higher galactic latitude than any other known SNR, with the exception of the Lupus Loop and the remnant of the supernova of AD 1006, both of which have previously been identified as X-ray sources.

The distance estimate for PKS 1209−52 of ∼2 kpc given earlier was inferred from the mean radio surface brightness of the source, and is probably uncertain to order 50%. The column density estimated from the X-ray data does not reduce this distance uncertainty, but is consistent with a distance of ∼1–3 kpc for an assumed mean hydrogen number density along the line of sight of 0.2–0.7 cm^{-3}. At an assumed distance of 2 kpc, the intrinsic X-ray luminosity in the range 0.2–1 keV is $\sim 8 \times 10^{35}$ ergs s^{-1} (from the RS best-fit spectrum). Applying the well-known adaptions of the Sedov adiabatic expansion model (see, e.g., Culhane 1977) and using the derived RS temperature estimate of 1.9×10^6 K allows the following parameters to be estimated: shock velocity $V_s \sim 400$ km s^{-1}, initial outburst $E_0 \sim 7 \times 10^{50}$ ergs (similar to the value inferred for the majority of Galactic supernovae), and age ∼20,000 years. Assuming the standard shell model for the X-ray emitting region (see, e.g., Gorenstein, Harnden, and Tucker 1974) and a volume emissivity of 1.7×10^{-24} ergs cm^{-3} s^{-1} for the 0.2–1.0 keV band (from RS, with $\log T = 6.2$), then the intrinsic luminosity can be written $L_x \approx 1 \times 10^{32}\ n^2\ D_{pc}^3$ ergs s^{-1}, where n is the ambient density and D_{pc} is the diameter of the remnant. Equating to the observed value yields $n \sim 0.4$ cm^{-3}, which is substantially higher than that expected at a z-distance of ∼300 pc ($n \sim 0.04$ cm^{-3}). However, this interpretation is critically dependent on the assumed temperature and the spatial distribution. If line emission is more important and the actual source temperature is slightly higher ($\sim 3 \times 10^6$ K), then the emission can be explained by much lower densities. The parameters derived above are suggestive of PKS 1209−52 being somewhat older than other remnants in an advanced evolutionary phase, such as the Vela remnant and the Cygnus Loop. Such a conclusion is in accord with inferences from radio and optical data.

The small diameter of RCW 103 (∼9 pc) argues for its young age, as does a high velocity dispersion for the optical filaments (∼900 km s^{-1}; Danziger and Murdin 1978). The remnant has been classified by van den Berg (1978) as a "filament shell type," with a similar optical morphology to such well-known SNRs as RCW 86 and the Cygnus Loop. While RCW 86 is probably the remnant of the supernova of AD 185, and is therefore at a comparatively early evolutionary phase, the Cygnus Loop is very much older ($>10^4$ years). However, for all three objects the optical spectral information (see, e.g., Danziger and Dennefeld 1976) is consistent with the filaments depicting regions where the expanding shock encountered interstellar clouds of high density ($2\text{–}3 \times 10^2$ cm^{-3}). High-resolution radio observations with the Fleurs Synthesis Telescope (Caswell 1978) show the remnant to have a well-defined shell structure reminiscent of other young objects such as Cas A and Kepler's and Tycho's remnants. Modeling with the Sedov solution on the basis of age, diameter, and expansion velocity inferred from optical and radio data produce an expected temperature behind the main shock of $\sim 10^7\text{–}10^8$ K. The intrinsic luminosity in the range 2–10 keV may then be estimated as $\sim 10^{35}$ erg s^{-1} (for an ambient interstellar density of 0.5 cm^{-3}), giving a flux above the atmosphere of $\sim 10^{-10}$ erg cm^{-2} s^{-1}. This value is consistent with a measurement by the *HEAO* A-2 Medium Energy Detector (MED) of a source with a flux of $9.6 \pm 1.5 \times 10^{-11}$ ergs cm^{-2} s^{-1} between 2 and 10 keV (Pravdo 1978). However, the identification of the MED source with RCW 103 is not definite owing to source confusion in the 2–10 keV data.

If real, the MED flux from RCW 103 is also consistent with the high source temperature derived assuming that the LED flux is partially due to iron line emission. Alternatively, if the low temperature ($\log T \sim 6.4$) possibility allowed by the LED data applies, then the MED flux is incompatible with the extrapolated LED spectrum. In this case, a two-temperature model for RCW 103 is required whereby the hard X-ray component is due to the original blast wave, and the soft component is produced either by the reflected shock mechanism, or in hot plasma evaporated from dense clouds by the expanding shock. We note in conclusion that a two-temperature model is likely by analogy with Cas A, which is in a similar evolutionary phase to RCW 103, and is known to have a two-component spectrum (Charles *et al.* 1975; Davison, Culhane, and Mitchell 1976; Pravdo *et al.* 1976).

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