THE X-RAY STRUCTURE OF THE SUPERNOVA REMNANT G78.2+2.1

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ABSTRACT

The south-eastern portion of the supernova remnant G78.2+2.1, in Cygnus, has been detected as a weak X-ray source by the Einstein Observatory. The X-ray structure is similar to that of the radio filaments in this region, and confirms that X-ray emission in this portion of the "Cygnus super-bubble" does originate in a known supernova remnant. Marginally significant variations in X-ray hardness across the mapped area have been detected and can be related to known radio and optical features of the remnant. In its X-ray properties, G78.2+2.1 resembles IC443.

1. INTRODUCTION

The supernova remnant (SNR) G78.2+2.1 lies in a heavily obscured region beyond the star γ Cygni, and is one of the brightest SNRs at radio wavelengths. Radio-continuum observations by Higgs et al. (1977) showed that it has a roughly circular structure, with two regions of enhanced radio emission: an area of intense filaments in the south-eastern quadrant and a weaker area of emission in the north-west quadrant. Embedded in the south-eastern filaments is the thermal radio source known as the γ-Cygni Nebula. Bychkov (1978) suggested that this emission nebula is ionized by photons from the supernova shock. Observations of 21-cm line emission from neutral hydrogen led Landecker et al. (1980) to propose a model in which the supernova blast occurred in a "slab" of interstellar material.

The first detection of X-ray emission from this SNR was made by Davidsen et al. (1977), who found a 0.5 to 2 keV source (Cyg X-7) coincident with it. Their observations indicated a temperature of 1.5 - 5 x 10^6 K and a column density of foreground hydrogen > 10^{22} cm^{-2}. A harder X-ray source just beyond the southern rim of the remnant was detected (Forman et al., 1979) by Uhuru (4U 2019+39). It may be

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related to the supernova remnant.

Cash et al. (1980) detected a large ring of soft X-ray emission in the constellation of Cygnus, which they termed the "Cygnus superbubble", and which includes the region of Cyg X-7. They claimed that, since the X-ray intensity from the direction of the SNR G78.2+2.1 is comparable to that from the rest of the large ring of emission, "it seems unreasonable to assign any of the flux to the supernova remnant". In order to clarify whether detectable X-ray emission from the SNR actually exists, we undertook a search of Einstein Observatory data.

2. OBSERVATIONS

An IPC observation of a field in the SNR was made on October 30, 1979, by the Center for Astrophysics. This field is indicated by the rectangle outlined in Figure 1. The contours define the 21-cm radio emission in this region (Higgs et al., 1977). The field for the 2800-s X-ray observation includes the region of most intense radio emission.

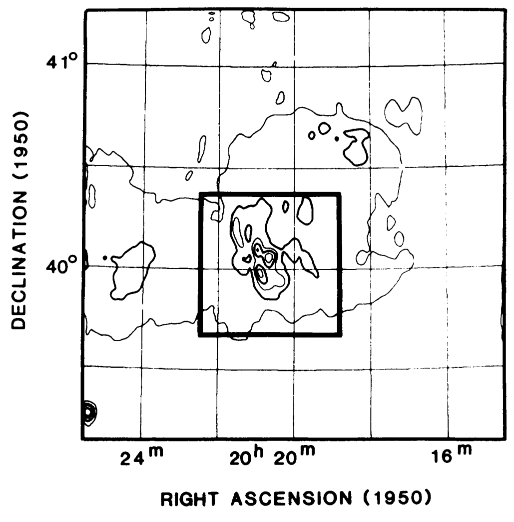

Figure 1. The X-ray field. The radio contours are 20, 40, 60, 80 and 100 K (T_B). The SNR is the approximately circular area of emission, 1° in diameter, in the centre. The emission to the left arises in the HII region IC 1318b.

Initial analysis of the X-ray data showed no conspicuous X-ray emission that could be identified with the SNR. A closer examination, however, indicated that smoothing of the data, combined with a subtraction of a blank comparison field, might reveal some weak X-ray structure. A suitable comparison image (a 6400-s observation of an effectively blank field, at about the same time as the γ-Cygni observation and with approximately the same instrumental parameters) was rotated to bring the IPC detector elements into alignment with those for the SNR image, and then both images were convolved to a resolution of 5'. The photon counts in the rotated and smoothed comparison field (after scaling by the ratio of observing times) were then subtracted from those in the smoothed γ-Cygni field. The resulting difference map is shown in contour form in Figure 2a. The peak photon flux in Figure 2a (at the lower right edge) is about 9 x 10^{-4} counts $arcmin^{-2}$ s^{-1}, a 10-σ result.

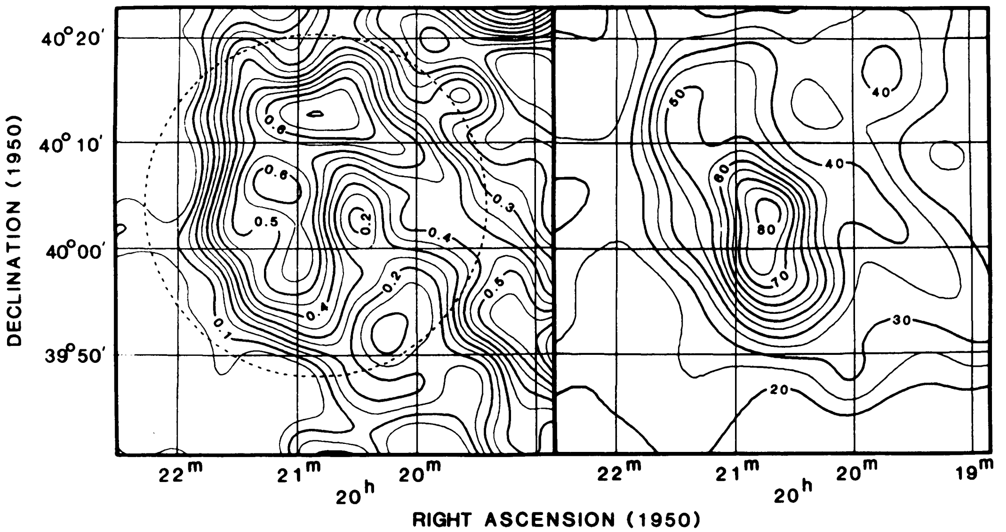

Figure 2. (a, left) X-ray emission (0.2 - 4.7 keV), smoothed to 5'. Contours are counts per 32" x 32" pixel for the 2800-s observation (step = 0.05). The dashed circle indicates a region chosen for detailed spectral analysis. Estimated σ = 0.07. (b, right) 21-cm radio emission, smoothed to 5'. The contours are brightness temperature (step = 5K). The peak coincides with the γ-Cygni Nebula.

The 21-cm radio emission, convolved to the same resolution, is shown in Figure 2b. Although a detailed correlation between the radio emission and the detected X-ray emission does not exist, certain similarities are apparent. In both maps the emission is sharply bounded to the south-east, and the bulk of the X-ray emission is near the main radio filaments. Moreover, the "bar" of X-ray emission extending from top centre to the lower right edge of the map corresponds to a radio feature seen in Figures 1 and 2b. Clearly the X-ray emission is related to the radio emission and can therefore be attributed to the SNR.

3. ANALYSIS AND DISCUSSION

To estimate the temperature of the X-ray emitting gas, a thermal spectrum has been fitted to the photon counts (0.2 to 4.7 keV) detected within the dashed circular area in Figure 2a. The observations are best fitted by temperatures 3.5×10^6 K < T < 4.5×10^7 K, and column densities of foreground hydrogen between 3×10^{22} cm^{-2} and 3×10^{21} cm^{-2}, respectively. For a column density of hydrogen of 10^{22} cm^{-2}, a reasonable estimate, the best-fitting thermal spectrum corresponds to T ~ 1.5×10^7 K. (The HI observations of Landecker et al. (1980) yielded an estimated column density of neutral hydrogen of $\leqslant 6 \times 10^{21}$ cm^{-2} in front of the SNR, assuming the HI to be optically thin.) This temperature is somewhat higher than that deduced by Davidsen et al. (1977) for Cyg X-7.

On the assumption of a uniform T ~ 1.5×10^7 K within the circular area of Figure 2a, the best-fitting thermal spectrum corresponds to a flux (corrected for absorption) of 6×10^{-11} erg cm^{-2} s^{-1} in the energy range 0.2 to 4 keV. Assuming the volume X-ray emissivity of Raymond and Smith (1977) and a distance of 1.5 kpc (Landecker et al., 1980), the r.m.s. density of the hot gas within the spherical volume corresponding to the dashed circle in Figure 2a is 0.1 to 0.4 cm^{-3} for 4.5×10^7 K > T > 3.5×10^6 K, respectively. Since X-ray-emitting filaments may fill less than 10% of the volume, the mean density is probably $\geqslant$ 0.7 cm^{-3}. In a discussion of high-velocity HI cloudlets observed inside this SNR, Landecker et al. (1980) estimated that the density of the post-shock gas must exceed 2 cm^{-3}, assuming a blast velocity of 450 km/s. The higher X-ray temperature indicated by the current observations implies a higher shock velocity, approximately 1100 km/s. If this is the case, the velocities of the accelerated HI features would suggest that the hot post-shock gas has a density in excess of 0.4 cm^{-3}, in good agreement with the density deduced from the present observations.

The X-ray luminosity of the SNR can only be estimated roughly since the current observations cover only the south-east portion. The luminosity of the spherical region (33' in diameter) indicated in Figure 2a is between 5×10^{33} and 5×10^{34} erg s^{-1}, for a distance of 1.5 kpc. The radio SNR has a diameter of 62', so that the total X-ray luminosity probably lies between 3×10^{34} and 3×10^{35} erg s^{-1} (for the energy range 0.2 to 4 keV). This luminosity and a temperature of the order of 10^7 K indicate that the SNR is similar, in its X-ray properties, to IC443 (see, for example, Culhane, 1977).

Despite the poor photon statistics, we have attempted to detect any large temperature variations across the X-ray field. The same smoothing and subtraction of the comparison field were done separately for photons in the ranges 0.2 to 1.2 keV and 1.2 to 4.7 keV. The resulting maps are shown in Figure 3. There are three regions where marginally significant (2-σ) variations are seen (after first-order allowance for IPC gain variations across the image). These are indicated by the shaded areas in Figure 4.

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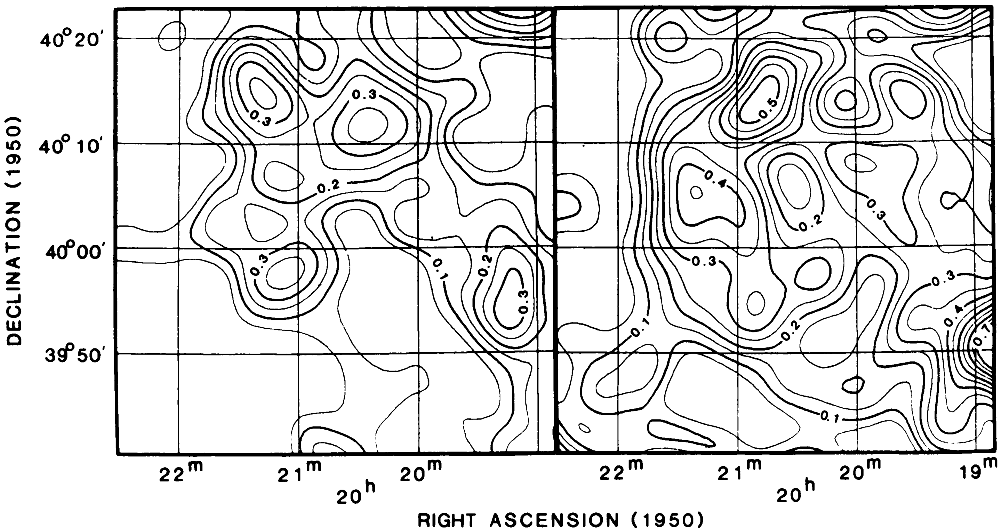

Figure 3. (a, left) X-ray emission (0.2 - 1.2 keV). Units are as in Figure 2. Estimated σ = 0.06. (b, right) X-ray emission (1.2 - 4.7 keV). Estimated σ = 0.05.

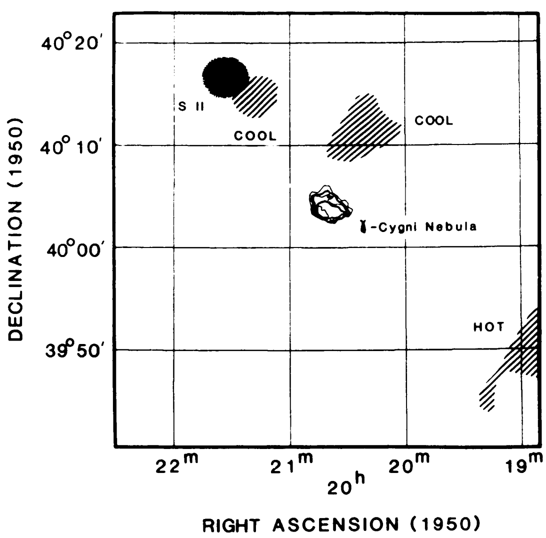

Figure 4. Regions (shaded) where X-ray temperature varies by > 2σ from average. The γ-Cygni Nebula is denoted by 6-cm radio contours (unpublished VLA data, Higgs et al. 1982). Contours are 0.5 to 2.5 mJy/beam (step = 0.5) where 11 mJy/beam ~ 3 K T_B.

Two "cool" regions and one "hot" region are shown. The cool region in the upper centre of the figure, situated above a "hole" in Figures 2a and 3b, extends in the direction of the γ-Cygni Nebula, shown by the radio contours. This thermal radio source, located in the midst of the non-thermal radio filaments, is somewhat of an enigma. In the model of the G78.2+2.1 SNR proposed by Landecker et al. (1980) (see their Fig. 9), the γ-Cygni Nebula is an interstellar cloud just encountering the blast, and ionized by UV from the shock. The present X-ray observations do not conflict with such an interpretation. The "hole" in the X-ray distribution, and the cooler temperature, may indicate that the shock has been slowed down owing to an interaction with a dense interstellar cloud. The γ-Cygni Nebula could then be a tenuous ionized fragment of the larger cloud. The other cool region that is seen corresponds closely with the area where van den Bergh (1978) detected SII emission from the SNR - perhaps another region of interaction with a dense cloud. This cool region is also close to the position of a high-velocity HI feature (+72 km/s) detected by Landecker et al. (1980).

The hot X-ray region at the lower-right edge of Figure 4 is also in agreement with the model of Landecker et al. (1980) where the blast is here propagating into a lower-density interstellar medium, with a correspondingly higher post-shock temperature.

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