X-RAY OBSERVATIONS OF SNR E0102.2-72.2 IN THE SMC

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Abstract

The supernova remnant (SNR) E0102.2-72.2 is the brightest in the Small Magellanic Cloud (SMC) at X-ray wavelengths. This object, which is remarkable because of its high velocity ($\sim$4000 km s^{-1}) oxygen-rich optical emission, appears to be similarly remarkable at X-ray wavelengths. The high resolution imager (HRI) data can be quite well described by a thick ring with a radius of $\sim 19''$ (6 pc at a distance of 63 kpc). The imaging proportional counter (IPC) X-ray spectral data can be best fit by a *single* emission line of energy $\sim$0.9 keV. It seems likely that this is the emission from a plasma of almost pure neon.

Introduction

SNR E0102.2-72.2 was discovered during the course of the *Einstein* IPC X-ray survey of the SMC (Seward and Mitchell 1981). The optical counterpart was discovered by Dopita, Tuohy, and Mathewson (1981) and shortly thereafter an optical velocity map was constructed by Tuohy and Dopita (1983). Follow up X-ray observations with the HRI were carried out by Inoue, Koyama, and Tanaka (1983). No higher resolution X-ray spectral observations have been made.

X-ray Morphology

The high resolution imager (HRI) X-ray data were summed in radial rings about the SNR center; figure 1 shows this average surface brightness profile and the best fit model for the emission. The data were compared to a simple geometric ring model characterized by three parameters: the outer radius (R_o), the radial thickness of the ring (ΔR), and its opening angle (θ). The plane of the ring was assumed to lie in the plane of the sky. With this parameterization a uniform spherical shell would have an opening angle of 90°. The models were convolved with the spatial spreading function of the HRI determined using a ground calibration image of a point source. In addition the statistical errors on the data were added in quadrature with a 1% systematic error.

A uniform spherical shell of emission yielded a reduced χ^2 of 6.66 for 17 degrees of freedom which can be rejected with high confidence. However, a thick ring with radius $19''$, thickness $6.3''$, and opening angle 67° gave an acceptable reduced χ^2 of 1.59 for 16 degrees of freedom (reject at between 90% and 95%). The observed emission at the center of the remnant, as well as beyond about $20''$, can be attributed entirely to spreading due to the combined point response function of the HRI and *Einstein* X-ray mirrors. In particular there is no evidence

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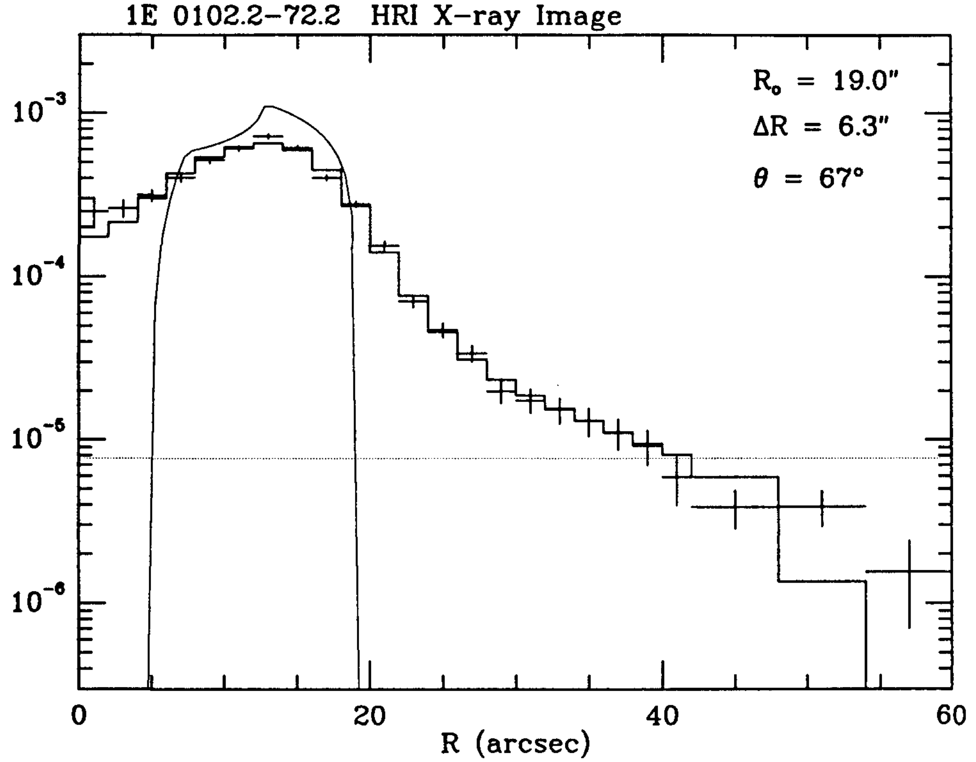

Fig. 1.–Plot of the average radial X-ray surface brightness profile of E0102.2-72.2. The thin solid line is the thick ring model seen in projection and the histogram is after convolving with the HRI point response function. The average background level is shown.

for any additional shocked component of interstellar or circumstellar material with a radius greater than 20″, although the precise limit on such a component depends on its assumed radius and X-ray spectrum.

Results of fits using the same model for the north, south, east and west quadrants confirm that the ring-like emission geometry persists throughout the remnant. There is some azimuthal variation in the fitted parameters, for example, a larger radius toward the north, but the only significant difference is in brightness (a factor of two variation from north to south).

X-ray Spectrum

The *Einstein* imaging proportional counter observed the SNR E0102.2-72.2 on three separate occasions. One observation occurred when the gain of the counter was rather high. Fits to the data for this pointing were inconsistent with the other observations and moreover yielded unacceptable χ^2 values for all models (the overall best fit had a reduced χ^2 of 3.97 for 9 degrees of freedom, which can

TABLE 1

Fits to IPC Data for E0102.2-72.2

Observations	Raymond and Smith Models			Single Line [a]	
	kT (keV)	N_H (10^{21} cm^{-2})	χ^2 / ν	E (keV) [b]	χ^2 / ν
I611, HRI	$0.53^{+0.18}_{-0.29}$	$1.7^{+4.6}_{-1.4}$	26.8 / 8	$0.887^{+0.026}_{-0.034}$	14.9 / 9
I7989	$0.41^{+0.39}_{-0.14}$	$1.5^{+3.2}_{-1.0}$	35.3 / 6	$0.863^{+0.017}_{-0.018}$	12.9 / 7

Notes:

[a] Width fixed at 0.1 keV.

[b] Statistical errors only. Error due to IPC gain uncertainty ~0.1 keV.

be rejected at greater than 99.95%). Since the detector calibration is not well known for such high gain values, the results of this observation are considered suspect and will be neglected in the following discussion. The remaining two observations are consistent with each other.

The data were initially fit using solar abundance Raymond and Smith (1977) optically thin thermal emission models. Results of these fits are in Table 1. The best fit temperatures were about 0.5 keV and the best fit hydrogen column densities were $\sim 1.5 \times 10^{21}$ atoms cm^{-2}. However these fits have unacceptably high χ^2 values and can be rejected at greater than the 99.9% confidence level. Acceptable fits can be obtained with a model of a single narrow emission line (with a width of less than ~0.15 keV) at an energy of about 0.9 keV.

In order to investigate the significance of this result, the IPC data for a sample of several other SNRs were analyzed in the same manner as for E0102.2-72.2. The remnants chosen were the galactic remnants Kepler and Tycho, and the remnants N132D and N62A in the Large Magellanic Cloud. These represent a broad cross-section of remnant types both as regards morphology and spectrum. Although the spectra of these objects are known to be complicated by nonstandard elemental abundances and nonequilibrium ionization, nevertheless it is possible to obtain acceptable fits to the IPC data (for three of the four remnants) using solar abundance Raymond and Smith plasma models. Tycho's remnant, the sole exception, has very small statistical errors, covers a large spatial region of the detector (~10′), and has the most severe nonequilibrium ionization effects of the remnants considered. None of these remnants' spectra, however, can be fit by a single emission line model; the χ^2 values for this model are all unacceptable by rather large amounts. This analysis supports the proposed single emission line model for E0102.2-72.2.

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What might be the origin of the 0.9 keV line emission for E0102.2-72.2? In the energy range around 0.9 keV the prominent emission lines are those of neon and iron. Specifically, for neon there are the forbidden, resonance, and intercombination lines of the helium-like ion (Ne IX) at about 0.91 keV and the Lyman α line of the hydrogen-like ion (Ne X) at 1.02 keV. In addition there are many iron L-shell transitions in this region. The brightest iron lines, at temperatures of about 0.5 keV, are at 1.01, 0.82, and 0.73 keV and occur in Fe XVII.

However, it seems unlikely for several reasons that the observed X-ray emission is coming from a pure iron plasma. First, the complex of iron L-shell lines covers a larger range in energy than do the neon lines and hence would be less likely to resemble a single narrow emission line. Second, the optical spectrum shows no evidence for any elemental constituents with a higher atomic number than that of neon, such as magnesium, silicon, or calcium. Hence a pure neon plasma is an attractive choice. Such a plasma under equilibrium ionization with a temperature of ~1 keV or less would have sufficiently strong line emission from the helium- and hydrogen-like species to satisfy the IPC data. In addition, higher temperature plasmas in a nonequilibrium state would have similarly strong line emission from these ions.

Conclusions

1. The X-ray emission of E0102.2-72.2 comes from a thick ring with an outer radius of 19″ (~6 pc), radial thickness of 6.3″ (~2 pc), and opening angle of 67°, which lies nearly in the plane of the sky. A uniform spherical shell is definitely precluded by the data.
2. The IPC X-ray spectrum is fitted best by a single narrow emission line at an energy of ~ 0.9 keV. This can best be described as the emission from a plasma of almost pure neon.

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