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AN OXYGEN-RICH YOUNG SUPERNOVA REMNANT IN THE SMALL MAGELLANIC CLOUD

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ABSTRACT

The second brightest X-ray source in the Small Magellanic Cloud (SMC), 1E 0102.2−7219, has been identified as a bright, optically emitting supernova remnant (SNR) by means of narrow-band imaging with the Anglo-Australian Telescope. The remnant, centered at $\alpha = 01^h02^m25^s.2$; $\delta = -72°18'00''$ (1950), is invisible at Hα but prominent in its [O III] emission and so belongs to the class of young SNRs resulting from the explosion of a Population I type star. This is the first such remnant discovered in the SMC.

Subject headings: galaxies: Magellanic Clouds — nebulae: supernova remnants — X-rays: sources

I. INTRODUCTION

In a recent X-ray survey of the Small Magellanic Cloud (SMC) using the imaging instruments of the *Einstein* Observatory, Seward and Mitchell (1981) discovered a very intense soft X-ray source, second only to SMC X-1 in luminosity. On the basis of its luminosity (2.1×10^{37} ergs s^{-1} in the 0.2–2.0 keV band) and the distribution of energy in its spectrum, they concluded that this source, 1E 0102.2−7219, is most likely a supernova remnant (SNR) in its free expansion phase.

If this is the correct interpretation, then the X-ray source should almost certainly be associated with a strong nonthermal radio source. The survey of Clarke, Little, and Mills (1976) at 73 cm with a beamwidth of 3′ shows a point source of 0.67 Jy at $01^h02^m22^s.6$, $-72°18'17''$ (1950). This position is certainly spatially distinct from N76A, a bright H II region to the southwest. Emission from this H II region appears to dominate the higher frequency data. McGee, Newton, and Butler (1976) find a source of 0.31 ± 0.05 Jy at 3.4 cm with a 2′.6 beam and a source of 0.32 ± 0.03 Jy at 6.0 cm with a 4′.1 beam. The source position for these latter measurements is identical, $01^h02^m24^s$, $-72°19'12''$ (1950), which puts it less than 1′ from N76A at $01^h02^m12^s$, $-72°20'$ (1950) (Henize 1956). Thus, the 76 to 3.4 cm baseline suggests the presence of a nonthermal source, but confusion problems at the higher frequency preclude the unambiguous determination of the spectral index.

II. OBSERVATIONS AND RESULTS

In view of the compelling X-ray evidence for an SNR, we undertook a search for optical nebulosity associated with 1E 0102.2−7219, using the 3.9 m Anglo-Australian Telescope (AAT) with its Image Photon Counting System (IPCS; Boksenberg 1972) in the direct imaging mode. The format, limited by the size of the external memory of the device, was 440 × 440 picture elements (pixels). The scale at the center of the field was 0″.502 pixel^{-1} N-S and 0″.492 pixel^{-1} E-W. The scale over the full field was not constant; the electron optics gave a pincushion distortion, so the full field of view was slightly less than 3′.5 in diameter. However, distortion is negligible over the central arcmin of the field.

Interference filters were used to isolate the Hα, [O III] λ5007, and [S II] $\lambda\lambda$6717, 6731 lines with bandpasses of 27, 16, and 35 Å FWHM, respectively.

Each image, so obtained, was corrected for variations in image-tube response across the field by dividing by a flat field, created by adding together many twilight sky observations through each filter and normalizing the mean to unity.

Initially, the field was centered at the X-ray source position, but, when the presence of a filamentary shell in [O III] near the edge of the field was noted, this feature was centered in the field. Our primary data therefore consist of a 700 s exposure in [O III], 800 s in Hα, and 1000 s in [S II] at this new field center. The distance between the shell position and the quoted X-ray position, 1′.5, is within the quoted 2′.0 radius of the error circle for the X-ray source (Seward and Mitchell 1981).

Figure 1 shows portions of the reduced images obtained in [O III] and Hα. No trace of emission associated with the object is visible in the [S II] image, and it is not reproduced here.

It is immediately apparent that this remnant has an enormous [O III]/Hα ratio. The maximum signal in the bright southeastern filament corresponds to 100 photons pixel^{-1} above the sky background. This signal has been converted to absolute flux by comparison with an image of N49 taken 1 hour later under photometric conditions with the same filter. The resulting contour map was compared in its southeastern region with the Hα surface photometry of Dopita (1979), and the spectrophotome-

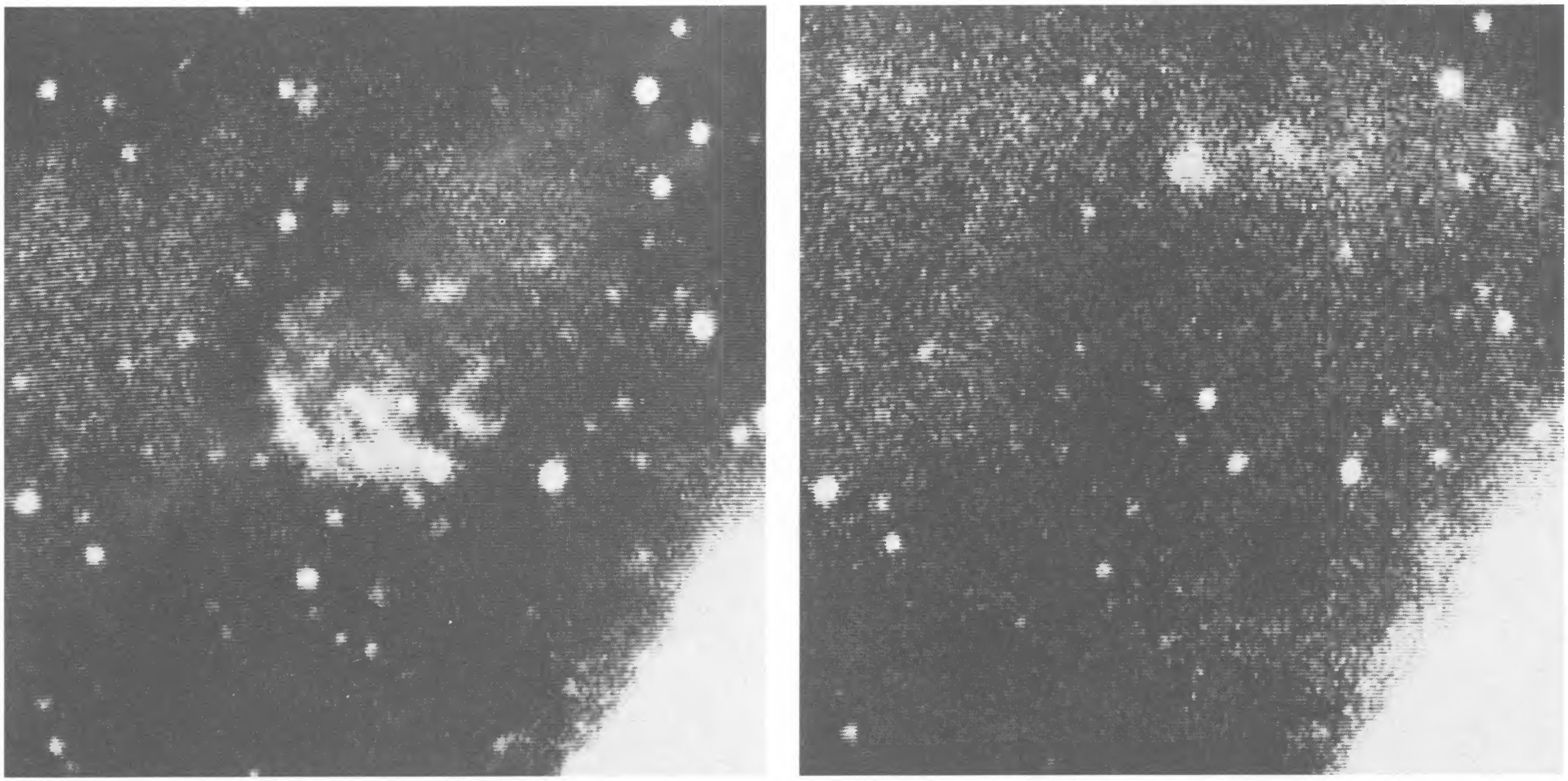

FIG. 1.—The SNR 1E 0102.2−7219 in the light of [O III] (*left*) and Hα (*right*). Each picture covers 1′.66 on a side. Note that the [O III] filaments lie in a hole in both the diffuse [O III] and the diffuse Hα emission.

try of Osterbrock and Dufour (1973) was used to give the Hα/[O III] ratio in N49. The peak absolute flux of 1E 0102.2−7219 in [O III] λ5007 is thus estimated to be $(3.6 \pm 1.5) \times 10^{-5}$ ergs cm^{-2} s^{-1} sr^{-1}. As a check on this figure, the flux was estimated directly from the photons detected, arcsec^{-1} s^{-1} using the known filter transmission (0.52), and assumed values for the quantum efficiency of the photocathode and the mirror reflectivities. The computed flux (3.9×10^{-5} ergs cm^{-2} s^{-1} sr^{-1}) agrees well, but this is probably fortuitous, since the uncertainties inherent in this latter procedure are at least 50%. In any event, these fluxes are probably a lower limit since velocity dispersions are expected to be at least as great as the bandwidth of the [O III] filter.

The Hα flux is less than 5 photons pixel^{-1} at the corresponding position. This gives a flux of $< 2.0 \times 10^{-6}$ ergs cm^{-2} s^{-1} sr^{-1} or $< 1.1 \times 10^{-6}$ ergs cm^{-2} s^{-1} sr^{-1}, depending on which of the above methods is used. Assuming a normal recombination-cascade Balmer decrement, these imply an [O III]/Hβ ratio of greater than 60.

The center of the system of [O III] filaments was accurately measured using reference stars in the field, the positions of which were determined with respect to nearby SAO stars by PDS astrometry of a UK Schmidt Telescope plate of the SMC. The center, thus determined, is at $\alpha = 01^h02^m25^s.2$; $\delta = -72°18'00''$ (1950), and the mean diameter of the shell is 24″.

Two other SMC X-ray sources suspected by Seward and Mitchell (1981) to be supernova remnants were also observed during this project. These were 1E 0012.7−7308 and 1E 0035.4−7230, for which brief 300 s exposures were obtained in both [O III] and Hα. No nebulosity was detected within the error circle of either object. This result could simply be from the faintness of the nebulosity, but, on the other hand, the argument for the sources being SNRs is only based on their soft X-ray spectra (and furthermore, the objects were not detected as radio sources in the survey of Clarke, Little, and Mills 1976). A search for extended X-ray emission is needed to clarify the nature of the two X-ray sources.

III. DISCUSSION

The identification of a filamentary optical nebulosity with a very large [O III] λ5007/Hβ ratio at the position of a soft X-ray and radio source establish 1E 0102.2−7219 as a member of the class of young, oxygen-rich SNRs, and the first such discovered in the SMC. The other known members are Cas A (Chevalier and Kirshner 1978) and MSH 11-5*4* (Goss *et al.* 1979; Murdin and Clark 1979) in the Galaxy, the SNR in NGC 4449 (Kirshner and Blair 1980), and, in the LMC, N132D (Danziger and Dennefeld 1976; Lasker 1978, 1980) and 0540−69.3 (Mathewson *et al.* 1980).

Adopting a distance of 59 kpc to the SMC (McNamara and Feltz 1980) gives a diameter of 6.9 pc for the remnant, very similar in size to the 6.3 pc diameter central annulus of N132D which Lasker (1980) found to be expanding as an annular ring at 2250 km s^{-1}. Indeed, these two SNRs are somewhat similar in the morphology of their outer regions. Both appear to show a much fainter outer ring with a more normal [O III] λ5007/Hα ratio (see Fig. 1). Around the [O III] bright filaments is a region of very low surface brightness in both [O III] and Hα. The outer boundary of this region may well represent the position of the supernova blastwave, since the ionization produced by passage through the blastwave would suppress the optical emission. It will be interesting to see if the *Einstein* Observatory HRI image reflects the larger diameter of this emission "hole" (35–40″).

The positional agreement of the 73 cm radio source (Clarke, Little, and Mills 1976), and our optical determination is excellent, differing by only 12″ in right ascension and 17″ in declination. If we use the flux of 0.67 Jy, the radio surface brightness at 408 MHz lies between 4.9 and 1.9×10^{-19} W m^{-2} Hz^{-1} sr^{-1}, depending on whether a diameter of 6.9 pc (for the [O III] filaments) or 11 pc (for the dark annulus) is used. Comparing this with the surface brightness of the other two SMC remnants previously identified as optical sources (Mathewson and Clarke 1972, 1973*b*), we can conclude that the radio Σ-D relation for the SMC is not significantly different from that of the LMC (Mathewson and Clarke 1973*a*; Milne, Caswell, and Haynes 1980).

Clearly, more work on this SNR is required, particularly spectrophotometry and measurements of the (presumably large) velocity dispersion, in order to establish the age and chemical composition of the ejecta. This will establish important new data on the evolution of massive stars in galaxies of low metallicity.

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