NEW HIGH RESOLUTION X-RAY STUDIES OF MAGELLANIC CLOUD SUPERNOVA REMNANTS

R. N. M. Williams[1], Y.-H. Chu[1], C.-H. Chen[1], R. A. Gruendl[1], J. R. Dickel[1], F. D. Seward[2], M. A. Guerrero[3], R. Shelton[4], and MCELS Collaboration[5]

[1]Department of Astronomy, University of Illinois at Urbana-Champaign, 1002 West Green St., Urbana, IL 61801
[2]Smithsonian Astrophysical Observatory, 60 Garden St., Cambridge MA 02138
[3]Instituto de Astrofísica de Andalucía, Consejo Superior de Investigaciones Científicas (CSIC), Apartado Correos 3004, E-18080 Granada, Spain
[4]Department of Physics and Astronomy, University of Georgia, Athens, GA 30602-2451
[5]Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile

ABSTRACT

We have undertaken a series of studies of Magellanic Cloud (MC) supernova remnants (SNRs), utilizing the high spatial and spectral resolution and sensitivity of instruments aboard *Chandra* and *XMM-Newton*, as well as supplemental observations at optical and radio wavelengths. Here we present the findings of some of our recent work using these X-ray observatories. Our study has focused on older, well-evolved remnants, allowing us to examine the later stages of SNR evolution. The sensitivity and depth of our observations have enabled us to detect previously unseen X-ray emission from large, faint shells. In addition, the superior spatial resolution of these instruments has allowed us to distinguish particular X-ray features, including two new candidates for pulsar-wind nebulae (PWNe), and to perform spatially resolved spectroscopy for these SNRs. Using these data, we study several SNRs in which X-rays generated at the shock front no longer dominate the emission, leading to a central brightening in X-rays typical of "mixed morphology" SNRs. Further, we investigate regions where two or more SNRs exist in close proximity, with the possibility of multi-SNR interactions. In each case, we analyze the physical properties and progenitor types of the SNRs.

Key words: Supernova Remnants;X-rays.

1. THE MIXED-COMPOSITE SNR B 0532-71.0 IN N206

Radio observations of N206 revealed a "linear feature" projected outward from the SNR center (Klinger et al., 2002). The high spatial resolution of *Chandra* reveals a point-like X-ray source at the outer tip of this radial feature. This source and its surroundings have nonthermal X-ray spectra ($\Gamma \sim 2$), with the ratio of thermal to nonthermal flux increasing with distance from the source. The characteristics of the surrounding emission suggest a bow-shock structure around a moving pulsar and its PWN, making this a "composite" SNR. The presence of the probable pulsar, and the high O/Fe ratio found elsewhere in the SNR, indicate that the SNR is the result of a Type II SN.

As well as emission from the PWN, there is also thermal X-ray emission central to the SNR, brighter than at the SNR limb. This, combined with the shell-like radio and optical structure, is the signature of "mixed-morphology" SNRs. The morphology indicates that the SNR shock has slowed to a speed insufficient to generate strong X-ray emission at the limb, so the SNR is dominated by "fossil" emission – gas heated to high temperatures by the shock in earlier, more energetic stages. This work is published in Williams et al. (2005a).

2. DEML316: A TALE OF TWO SHELLS

DEML316 shows two overlapping shells, A (NE) and B (SW), at radio and optical wavelengths. We use *Chandra* and *XMM-Newton* X-ray data to study the nature of the hot gas this system. The two shells show markedly different characteristics.

- The Shell A spectrum is best fit by a thermal plasma model (kT $\sim$ 1.4 keV) with abundance ratios characteristic of Type Ia SNR (O/Fe of 1.5 and Ne/Fe of 0.2). We do not find significant spectral differences across the SNR, suggesting substantial equilibration through thermal conduction and/or turbulent mixing.
- Most of Shell B is well described by a thermal plasma model (kT $\sim$ 0.6 keV) with abundance ratios characteristic of Type II SNR (O/Fe of 30–130 and Ne/Fe of 8–16). However, a bright knot within Shell

Table 1. A Summary of SNR Properties

Parameter	N206	DEM316A	DEM316B	N9	0046.6	0047.2	0047.5
N_H (10^{21} cm^{-2})	2.2	3.6	2.2	2	5.5	5.5	5.1
kT (keV)	0.45	1.4	0.6	0.34	0.31	1.2	0.85
O/Fe	29	1.5	30-130	1.3	55	38	47
n_e (cm^{-3})	0.4	0.16	0.14	0.15-0.66	0.21	0.17	0.05
M_g ($M_\odot$)	270	50	110	160	440	110	290
P (10^{-10} dyn cm^{-2})	3.3	6.8	3.4	1	2.2	5.0	1.2
E_{th} (10^{50} erg)	6	3.0	4.2	3	7	5	11

B requires the addition of a high-energy spectral component consistent with a power-law spectrum of photon index 1.6–1.8. This feature and the suggested Type II origin of the SNR suggest the presence of an embedded PWN.

The difference between the SNR progenitor types, first reported by Nishiuchi et al. (2001) makes it less probable that these SNRs are interacting with one another, as suggested by Williams et al. (1997). This work is published in Williams et al. (2005b).

3. SNR B 0454-67.2 IN N9: A HOT FOSSIL

The SNR on the southwest side of the N9 H II region has X-ray emission primarily distributed along a "ridge" along the SNR interior. As in N206, the SNR seems to be a product of "fossil" radiation from earlier stages. Unlike N206, the N9 SNR lacks any sign of a pulsar or PWN, and its spectrum is dominated by iron lines. The O/Fe abundance ratio ≤ 1.3), indicating that significant iron ejecta is present, which in turn types to a Type Ia origin. This is an unexpected result, as the SNR's position at the edge of an H II region indicates a massive-star SN to be more likely. This work will be published in Seward et al. (2005).

4. A NASCENT SUPERBUBBLE IN THE N19 H II COMPLEX

The N19 H II complex is host to several regions which display SNR signatures (X-ray emission, high [S II]/Hα ratios, and nonthermal radio emission), but it has been difficult to separate the various components observationally. Using *Chandra*'s resolution in combination with observations at other wavelengths, we identify three distinct objects:

- SNR J 0046.6-7308: While previous X-ray observations detected the brightest southern segment of the SNR shell, our deep *Chandra* exposure showed the entire SNR limb, matching the radio morphology.
- SNR J 0047.2-7308: This is the brightest SNR in the radio and optical regimes. It also has a probable X-ray point source embedded in a central region of emission which is harder than that at the SNR limb - another PWN candidate.
- SNR J 0047.5-7308: This SNR candidate was originally only associated with bright X-rays overlapping with SNR J 0047.5-7308. New *Chandra* observations show faint X-rays extending over a region of faint radio emission, suggesting a much larger SNR.

Spectral fits to each of the three SNRs show abundance ratios consistent with a Type II SN origin. Analysis of the stellar content indicates that the combined action of stellar winds and these SNRs will probably produce a superbubble as the SNRs merge.

5. SUMMARY

We have outlined four examinations of X-ray emission from SNRs in the Magellanic Clouds, supplemented by observations at other wavelengths. Physical properties derived from spectral fits to the X-ray data for these remnants are summarized in Table 1. These studies are part of an overall program to quantify the characteristics of the SNR populations of the Magellanic Clouds, in order to evaluate SNR contributions to their host galaxy.

ACKNOWLEDGMENTS

The authors acknowledge support from: STSCI grant STI GO-08110; NASA grant NAG 5-11159; SAO grants G03-4096 & GO3-4094; and Spanish MCyT grant AYA2002-00376. RNMW is supported by NASA grant NNG05GC97G through the LTSA.

REFERENCES

Klinger, R. J. et al. 2002, AJ, 124, 2135

Nishiuchi, M. et al. 2001, PASJ, 53, 99

Seward, F. D. et al. 2005, ApJ, submitted

Williams, R. M. et al. 1997, ApJ, 480, 618

Williams, R. M. et al. 2005a, ApJ, 628, 704

Williams, R. M. et al. 2005b, ApJ, accepted