Barrels, jets and smoke-rings: Understanding the bizarre shapes of radio supernova remnants

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To Dr Michael Bishop,

For showing me where to start

Abstract

This thesis considers the various morphologies of radio supernova remnants (SNRs), and attempts to determine whether their appearance results from the properties of the progenitor star and its supernova explosion, or from the structure of the interstellar medium (ISM) and ambient magnetic field into which a SNR consequently expands. High-resolution observations of Supernova 1987A show a young remnant whose appearance and evolution are completely dominated by the structure of its progenitor wind. A statistical study of the Galactic population of bilateral SNRs demonstrates that the symmetry axes of these remnants run parallel to the Galactic Plane. This result can be explained by the interaction of main sequence stellar wind-bubbles with the ambient magnetic field; expansion of SNRs into the resulting elongated cavities results in a bilateral appearance with the observed alignment. Radio observations of SNR G296.8–00.3 show a double-ringed morphology which is best explained by expansion either into an anisotropic main-sequence progenitor wind or into multiple cavities in the ISM. Data on SNRs G309.2–00.6 and G320.4–01.2 (MSH 15–5*2*) make a strong case that the appearance of both remnants is significantly affected by collimated outflows from a central source; for G309.2–00.6 the source itself is not detected, but for G320.4–01.2 there is now compelling evidence that the remnant is associated with and is interacting with the young pulsar PSR B1509–58. I conclude that, while the youngest SNRs are shaped by their progenitor's circumstellar material, the appearance of most SNRs reflects the properties of the local ISM and magnetic field. Remnants which interact with an associated pulsar or binary system appear to be rare, and are easily distinguished by their unusual and distorted morphologies.

"And now I understand the supernova scene, Oh-a-oh"

— "Video Killed The Radio Star"
The Presidents Of The United States Of America, 1998.

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Statement of Originality

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Bryan Malcolm Gaensler
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Publications

Apart from minor changes made for consistency of spelling and style, Chapters 2 through 5 of this thesis are exact reproductions of papers published in refereed journals. Chapter 6 is a slightly longer and more detailed version of a paper to appear in a refereed journal.

- Chapter 2: Gaensler, B. M., Manchester, R. N., Staveley-Smith, L., Tzioumis, A. K., Reynolds, J. E., & Kesteven, M. J., 1997, ApJ, **479**, 845

- Chapter 3: Gaensler, B. M., 1998, ApJ, **493**, 781

- Chapter 4: Gaensler, B. M., Manchester, R. N., & Green, A. J., 1998a, MNRAS, **296**, 813

- Chapter 5: Gaensler, B. M., Green, A. J., & Manchester, R. N., 1998b, MNRAS, **299**, 812

- Chapter 6: Gaensler, B. M., Brazier, K. T. S., Manchester, R. N., Johnston, S., & Green, A. J., 1999, MNRAS, in press

Acronyms, Abbreviations and Conventions

`AIPS`	Astronomical Image Processing System
ASCA	*Advanced Satellite for Cosmology and Astrophysics*
ATCA	Australia Telescope Compact Array
AXAF	*Advanced X-ray Astrophysics Facility*
b	Galactic Latitude
BSG	Blue Supergiant
CSM	Circumstellar Medium
Dec., δ	Declination
DM	Dispersion Measure
erg	Unit of energy: 1 erg $\equiv 10^{-7}$ J
gauss, G	Unit of magnetic flux density: 1 G $\equiv 10^{-4}$ T
FWHM	Full Width at Half Maximum
HST	*Hubble Space Telescope*
IRAS	*Infrared Astronomical Satellite*
ISM	Interstellar Medium
jansky, Jy	Unit of flux density: 1 Jy $\equiv 10^{-26}$ W m^{-2} Hz^{-1}
l	Galactic Longitude
LSR	Local Standard of Rest
$M_\odot$	Unit of mass: 1 $M_\odot \equiv$ 1 solar mass $\simeq 1.99 \times 10^{30}$ kg
`MIRIAD`	Multichannel Image Reconstruction Image Analysis and Display
MOST	Molonglo Observatory Synthesis Telescope
NGST	*Next Generation Space Telescope*
parsec, pc	Unit of distance: 1 pc $\simeq 3.09 \times 10^{16}$ m
PA	Position Angle (measured north through east)
PSR	Pulsar
PWN	Pulsar Wind Nebula
RA, α	Right Ascension
RM	Rotation Measure
RMS	Root Mean Square
ROSAT	*Roentgen Satellite*
RSG	Red Supergiant
RSN	Radio Supernova
SKA	Square Kilometre Array
SN(e)	Supernova(e)
SNR	Supernova Remnant
VLA	Very Large Array
VLBI	Very Long Baseline Interferometry
XMM	*X-ray Multi-mirror Mission*

Spectral index: The radio spectral index, α, of a source is defined by $S_\nu \propto \nu^\alpha$, where S_ν is the flux density received at a frequency ν.

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