INTEGRATED X-RAY SURFACE BRIGHTNESSES OF SUPERNOVA REMNANTS AND COMPARISON WITH RADIO AND INFRARED VALUES

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ABSTRACT. A weak linear correlation is found between the x-ray and radio surface brightnesses of galactic supernova remnants. A flatter slope is found for the infrared-radio correlation.

1. INTRODUCTION

Supernova remnants produce significant amounts of x-ray, radio, and infrared emission. Although the individual emission processes in each wavelength band are different - shock heated gas, synchrotron radiation from relativistic particles trapped in magnetic fields, and collisionally heated dust, respectively - we expect some correlation between the emission at the different wavelengths. For the SNRs in the Large Magellanic Clouds there does appear to be a correlation between the x-ray and radio surface brightnesses (Berkhuijsen 1986). The infrared and x-ray emission also appear to be related (Dwek 1988). To check these correlations more fully for a significant sample of galactic remnants we have compared the integrated fluxes and surface brightnesses of SNRs in the Einstein, IRAS, and radio databases.

2. THE DATA

2.1 X-ray

Imaging data, primarily from the HRI and IPC detectors of the Einstein Observatory (Seward 1988), for SNRs in the Milky Way have been analyzed by numerous authors and by us to give an integrated flux emitted by the source in the energy band from 0.2-4 kev. To do this the source spectrum has been convolved with the instrumental response function to give the power within the chosen wavelength range and a correction has been made for interstellar absorption. Where sufficient IPC counts are present to determine a spectrum, both the temperature and extinction are used to find the correct flux. Various approximations have been used by individual authors and conflicting results exist; they are caused by discrepancies between HRI and IPC measurements, choices between 1- and 2-temperature models, etc. In some cases we have made rather abritrary decisions but have tried to keep the results as consistent as possible. Where insufficient spectral information exists we have adopted an average temperature of 0.7 kev and a mean column density of hydrogen of 10^{22} cm^{-2}. The total x-ray fluxes are determined

https://doi.org/10.1017/S025292110001229X Published online by Cambridge University Press

Table 1. X-ray Properties of SNR's

Galactic l	b	Flux (erg/cm^2/s)*10^{-11}	Diameter (')	Temp. (keV)	N_H (atoms/cm^2)*10^{20}
4.5	+6.8	30.	3.3	0.52	28.
6.4	-0.1	18.	42	0.78	100.
11.2	-0.3	1100.	4.2	0.32	400.
21.5	-0.9	2.3	1.1	----	140.
27.4	+0.0	14.	4.3	1.0	200.
29.7	-0.3	7.4	0.5	----	500.
31.9	+0.0	28.	9.9x7.3	0.44	230.
33.7	+0.0	≥12.	9.6	<0.5	>100.
34.6	-0.5	51.	33x1	1.0	100.
39.2	-0.3	13.	8.2	0.78	100.
39.7	-2.0	5.2	93x21	2.2	100.
41.1	-0.3	≥5100.	6.4	<0.25	>500.
43.3	-0.2	9.0	4.5x3.8	2.8	400.
49.2	-0.7	0.14	55x36	0.78	100.
53.6	-2.2	59.	19x26	0.26	100.
65.3	+5.7	≥8.0		0.25	5.5
68.8	+2.6	1.7		1.4	60.
74.3	-8.5	910.	160	0.26	4.0
74.9	+1.2	0.36	10.7	----	130.
78.2	+2.1	≥11.		1.3	100.
82.2	+5.3	~11.		0.78	100.
89.0	+4.7	~16.		0.60	29.
109.2	-1.0	23.	33	0.70	30.
111.7	-2.1	530.	4.6x3.8	0.63	100.
119.5	+10.2	≥18.		0.78	100.
120.1	+1.4	220.	7.7	1.0	100.
130.7	+3.1	1.6	6.3x4.8	----	36.
132.7	+1.3	15.	60	0.60	60.
160.4	+2.8	~51.		0.80	35.
184.6	-5.8	7700.	1.9	----	30.
189.0	+3.0	46.	40	0.80	35.
260.4	-3.4	1300.	42x25	0.70	30.
263.5	-2.7	3800.		0.21	0.59
290.1	-0.8	6.8	19x12	0.78	100.
291.0	-0.1	1.7	29	----	20.
292.0	+1.8	40.	6.7	0.51	38.
296.1	-0.7	120.	20	0.78	60.
296.5	+10.0	27.	71	0.15	140.
315.4	-2.3	18.	38	1.2	2.8
320.3	-1.2	73.	30x23	0.30	90.
326.3	-1.8	96.	34x43	0.43	100.
327.1	-1.1	1.3	13x6	0.78	100.
327.4	+0.4	7.0	19	1.0	150.
327.6	+14.5	95.	34	0.16	6.5
332.4	-0.4	16.	8.7	0.51	100.

(   ) means larger than mapped field (----) means power law assumed

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by finding the integrated counts/second from the FITS images provided by F. Seward and using the diagrams in the Einstein User's Manual (Harris and Irwin 1984). All told, reasonable values are available for 40 remnants. By comparison of differing values for the same object we estimate that individual brightnesses should generally be accurate to within a factor of 3. The results are presented in Table 1; specifics of individual sources can be obtained from the authors.

2.2 Radio and Infrared

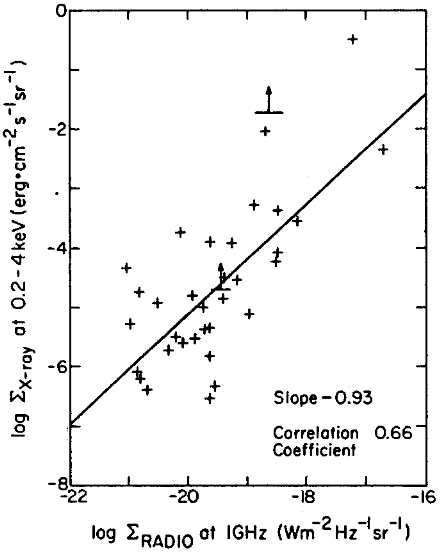
Radio flux densities at a frequency of 1 GHz and diameters have been taken from Green's (1984) catalog. Most of the sources for which the other data are available are reasonably bright and accurate to ~30%.

Arendt's (1989) catalog of the infrared emission of all SNRs detected by the IRAS satellite presents tables of the infrared emission integrated over the four IRAS bands of 12, 25, 60, and 100 μm. The accuracy is often limited by confusion with the background, particularly in the 12 and 100 μm bands; most values are accurate to ~50%.

3. RESULTS

The surface brightnesses in each wavelength regime and have been correlated against each other and other parameters such as temperature (x-ray and infrared), age guestimates, etc. The best correlations found are shown in figure 1. Although the surface brightnesses do appear to be correlated, there is a very large scatter among the points. The correlation between the infrared and x-ray brightnesses is comparable to that between the infrared and radio.

For expected correlations, we have assumed that most observed remnants are in their point-blast adiabatic phase and integrated the non-equilibrium model spectra calculated by Hamilton et al. (1983) to determine the predicted x-ray emission in the .2-4 kev band. There is some increase in line emission as the continuum decreases so the x-ray brightness does not change much with temperature or time during this evolutionary phase; it is basically dependent only upon the square of the ambient density times the energy of the explosion. In contrast, the radio surface brightness does depend significantly on the shock speed and other time dependent phenomena. Also, the circumstellar medium must be very clumped to provide sites for instabilities which are responsible for particle acceleration and magnetic field amplification (Dickel et al. 1989). The radio brightness is proportional to density$^{17/12}$ $\cdot$ energy$^{7/4}$ $\cdot$ time$^{-1.2}$ (further calculations by Jones and Dickel). The density dependence in the two regimes is similar and is probably largely responsible for the correlation found. The much more significant time dependence of the radio emission than of the x-ray emission does not entirely remove the correlation. The clumps required to explain the observed radio emission may be dense enough to limit the shock speed and x-ray temperature to low values where time evolution caused by further



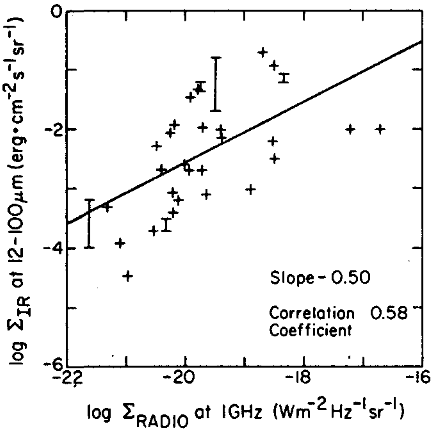


Fig. 1. SNR Brightness Correlations

cooling could have an effect. The true x-ray emission should be characterized by a range of temperatures rather than a single "best-fit" value. The energy dependence is rather different in the two wavelength regimes but the total range of energies is small.

The infrared emission is expected to closely track the x-ray emission from the hot gas responsible for heating the dust (Dwek 1988). However, the slope of the infrared dependence upon the radio (and thus x-ray) emission is flatter than linear. This could be explained by a depletion of dust in the brightest remnants. More collisions caused by the higher density could evaporate dust.

Clearly we need high spatial and spectral resolutions at both x-ray and infrared wavelengths plus multi-temperature models to properly evaluate these effects in real SNR. We eagerly await AXAF and SIRTF.

ACKNOWLEDGEMENTS: F. Seward, R. Arendt, and NASA contract JPL 958014.

REFERENCES

Arendt, R. G. 1989 Ap. J. Suppl., in press.
Berkhuijsen, E. M. 1986 Astron Astrophys., **166**. 257.
Dickel, J. R., Eilek, J. A., Jones, E. M. and Reynolds, S. P. 1989 Ap. J. Suppl., in press.
Dwek, E. 1988 in Supernova Remnants and the Interstellar Medium, ed. by R. Roger and T. Landecker (Cambridge: Cambridge Univ. Press), 363.
Green, D. A. 1984 Mon. Not. Roy. Astron. Soc., **209**, 449.
Hamilton, A., Sarazin, C. and Chevalier, R. 1983 Ap. J. Suppl., **51**, 115.
Harris, D. E. and Irwin, D. 1984 Einstein Observatory Revised Users Manual (Cambridge, MA: Harvard-Smithsonian Center for Astrophysics).
Seward, F. 1988 unpublished FITS tape from Einstein Obs. Databank.

https://doi.org/10.1017/S025292110001229X Published online by Cambridge University Press