EXOSAT OBSERVATIONS OF YOUNG SNRs

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Introduction

In this work we study the 2 - 10 keV spectra of eight relatively well known SNRs. These spectra were obtained with the medium energy experiment on-board the X-ray satellite EXOSAT. Details of the EXOSAT mission can be found in Taylor et al 1981 and the ME experiment is described in Turner, Smith and Zimmerman 1981. The ME experiment is well suited for this study since it provides a high sensitivity and a narrow field of view (45 ′ FWHM). These spectra are considered in the context of a model in which the 2-10 keV continuum arises from shock heated interstellar material.

Discussion

Fig. 1 shows the ME spectra of six of the eight objects (Cas A, Tycho, Kepler, SN1006, G11.2-0.3, and RCW103. The spectra obtained for RCW86 and W49B may be found in Klaas et al 1987 and Smith et al 1985 respectively. A fuller analysis of the total EXOSAT data for these objects may be found in : Cas A - Jansen et al 1987; Tycho - Smith et al 1987a; Kepler - Smith et al 1987b; RCW103 - Peacock et al 1987; G11.2-0.3 - Peacock and Smith 1987. The data of SN1006 has been independently examined in Jones et al 1984. In fig.1 the spectrum above 3 keV has been fitted with a simple thermal bremsstrahlung + emission line model. Below 3 keV the spectrum is far more complicated since it includes emission lines due to S, Si, Fe-l (many lines) and other elements. The situation is further confused by uncertainties in the hydrogen column density and detailed instrument response profile. For the ME this low energy data appears as an unresolved excess.

The line often seen at about 6.5 keV is associated with Fe-k emission. The exact energy and strength of this line depends upon the temperature of the shock and the degree of ionisation equilibrium between ions and electrons. Throughout this work thermal equilibrium will be assumed between the electron and ions, (i.e. the electrons are

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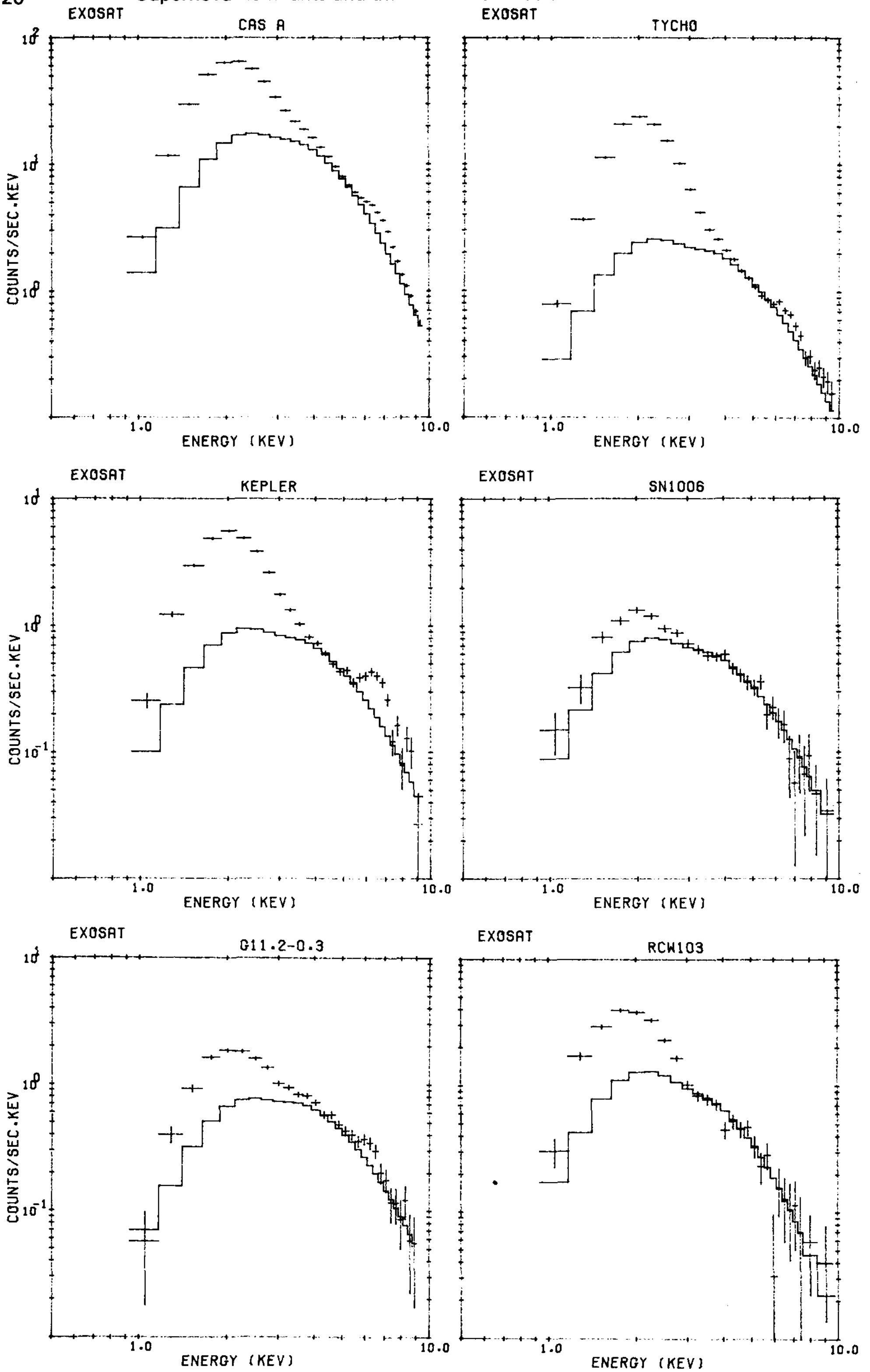

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rapidly heated by the ions after the shock passage by some non-coloumb process). The results of this spectral fitting are given in table 1. In all cases the quality of the fit was acceptable. In fig.1. the continuum fit is shown without the inclusion of the line so that its strength may be appreciated. In the brighter objects the fit extends beyond 10 keV but is not shown in order to aid comparison. It is interesting to note the relatively large variation in the equivalent width of the Fe-k line, (> 4000 eV in W49B to < 348 in SN1006).

Let us examine first the x-ray continuum assuming that it arises in shock heated ISM material and that the shock is just the primary Sedov shock. Hamilton, Sarazin and Chevalier 1983 is used as a basis for this consideration. We will adopt the terminology used in this paper, in particular η = E51*no^2 is the ionisation parameter. Taking a distance and radius of the shock together with the temperature and strength of the continuum we can estimate the hydrodynamical parameters of the remnants. This is done in table 2. Note that the distance for Tycho is taken from Braun 1985, other distance estimates etc. are referenced in the table. The results seem quite reasonable. Note that the line energies are generally in agreement with observations and that the observed line strengths are never less than that prediced. The absence of an observable Fe line in SN1006 is just related to the low ISM density and consequently low η.

It is also interesting to note that an initial explosion energy E51 = 0.184 .10^{51} (the weighted mean) is consistent with all 8 objects.

Six of the eight objects are possibly identified with historical SN (the case for G11.2-0.3 is the weakest) and so we know their ages. These ages are compared with the derived hydrodynamical ages in Table 3. The agreement is quite good except that for the youngest objects (Cas A, Kepler and Tycho) the ages are over estimated and G11.2-0.3 seems too young to be associated with SN386. The over estimates may be related to a period of free expansion before the onset of the Sedov phase. Since the estimated values of E51 are all consistent with a value of ~0.2 let us use this value to refine the distance estimate (and other hydrodynamical properties including age). If this proves to be a reliable way of determining distances then it would be very useful since future x-ray missions will include imaging capabilities, for this reason, with very high sensitivity and so greatly increase the number of objects in this sample. The distance is determined from the following equation:-

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$$D_{kpc} = (E51^2 * 0.0001098/(R^3 * F * Ts * \exp(0.63/Ts))^{1/5}$$

Where R is the radius in arc minutes,
Ts is the shock temperature in units of 10^7 degrees K and F is the flux observed for E > 2keV (with n_H set to zero)

Note that the shock temperature is lower than the continuum temperature by a factor of about 1.3.

Conclusions

The hypothesis that the 2-10 keV continuum is associated with shock heated ISM material rather than reverse shock heated enriched ejecta is consistent with observations for these eight objects. It is interesting that the value of E51 derived is usually around 0.2 10^{51} ergs and might suggest a useful way of determining distances. However one must be cautious since it is not certain that Cas A, Tycho and Kepler are fully in a Sedov phase and so the estimate of E51 for these objects may be in error. (For instance the observed kinetic energy of the ejecta in Cas A is > 10^{51} ergs! Jansen et al 1987)

Table 1. SNR 2 - 10 keV spectral parameters.

SNR	Tc keV	Flux ≥2 keV ergs/cm²/s * 10^{-11}	Fe-k EW eV	Fe-k E keV
Cas A	$3.74^{+.05}_{-.05}$	77.0	916^{+16}_{-16}	$6.62^{+.03}_{-.03}$
TYCHO	$6.5^{+.5}_{-.5}$	15.0	529^{+49}_{-10}	$6.48^{+.03}_{-.13}$
KEPLER	$5.3^{+3.0}_{-1.6}$	2.56	1910^{+640}_{-460}	$6.50^{+.05}_{-.14}$
RCW86	$3.36^{+.25}_{-.25}$	6.5	617^{+395}_{-395}	---
SN1006	$5.3^{+4.1}_{-1.8}$	3.9	<348	---
G11.2-0.3	$6.5^{+4.8}_{-2.4}$	$3.4^{+0.9}_{-0.4}$	513^{+574}_{-253}	$6.18^{+.30}_{-.33}$
RCW103	$3.1^{+2.5}_{-1.1}$	2.11	<1100	---
W49B	$1.81^{+.12}_{-.09}$	9.1	4700^{+200}_{-600}	$6.75^{+.01}_{-.04}$

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Table 2. Hydrodynamical solutions

SNR	Cas A	Tycho
Diameter (′)	4.14 (+/- .2) [1]	7.54 (+/- .1) [1]
Distance (kpc)	2.90 (+/-.04) [1]	2.3 (+/- .2) [1]
Age (yrs)	440 (402 - 480)	482 (438 - 531)
No (cm^{-3})	8.2 (6.5 - 9.1)	1.2 (1.1 - 1.3)
E51 (ergs)	.22 (.15 - .32)	.17 (.12 - .24)
neta51	15.2 (13.3-17.4)	.25 (.22 - .28)
Mswept (M_o)	6.6 (5.7 - 7.6)	2.9 (2.7 - 3.2)
EW (Fe-k) eV	~600	250
E (Fe-k) keV	6.59	6.48
	Kepler	**RCW86**
Diameter (′)	3.46 [1]	36 (+/- 2) [2]
Distance (kpc)	4.10 (+/- .9) [1]	2 (+/- 1) [3]
Age (yrs)	437 (273 - 637)	2788 (1270-4586)
No (cm^{-3})	1.3 (1.0 - 1.9)	.120 (.087-.194)
E51 (ergs)	.086 (.020- .34)	.63 (.04 - 4.3)
neta51	.16 (.08 - .27)	.009 (.003-.019)
Mswept (M_o)	1.8 (1.2 - 2.3)	21 (3.5 - 59)
EW (Fe-k) eV	160 - 250	120 - 220
E (Fe-k) KeV	6.47 - 6.50	6.43 - 6.46
	SN1006	**G11.2-0.3**
Diameter (′)	31.4 (+/- 1) [4]	4.2 [5]
Distance (kpc)	1.5 (+/- 0.5) [4]	7.5 (+/- 2.5) [6]
Age (yrs)	1450 (705 - 2461)	876 (443 -1460)
No (cm^{-3})	.10 (.06 - .17)	.77 (.50 - 1.21)
E51 (ergs)	.23 (.03 - 1.8)	.66 (.08 - 4.3)
neta51	.0024 (.0009-.0053)	.39 (.15 - .81)
Mswept (M_o)	4.9 (2.2 - 7.7)	11.1 (5.2 - 16.9)
EW (Fe-k) eV	<120	120 - 300
E (Fe-k) keV	<6.43	6.45 - 6.53
	RCW103	**W49B**
Diameter (′)	9.0 (+/- 1.0) [7]	3.6 (+/- 0.4)
Distance (kpc)	3.5 (+/- 0.5) [7]	4.8 (+/- 1.5) [8]
Age (yrs)	1270 (722 - 2000)	911 (539 - 1363)
No (cm^{-3})	.43 (.24 - .74)	4.3 (3.1 - 6.4)
E51 (ergs)	.18 (.03 - 1.1)	.17 (.03 - .83)
neta51	.033 (.014 - .072)	3.2 (1.5 - 6.0)
Mswept (M_o)	6.3 (4.8 - 7.3)	10.3 (3.5 - 22.9)
EW (Fe-k) eV	150 - 400	1500
E (Fe-k) keV	6.44 - 6.50	6.55 - 6.56

[1] Braun 1985, [2] Caswell et al 1975, [3] Claas et al

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1987, [4] Pye et al 1981, [5] Slee and Dulk 1974, [6] Ilovaisky and Lequeux 1972, [7] Peacock et al 1987. [8] Wilson 1970.

Table 3. SNR Ages and distances

SNR	True age yrs	Hydro. age yrs	Distance* kpc	Revised age* yrs
Cas A	307	440 (402 - 480)	2.58 - 2.75	(382 - 426)
Tycho	413	482 (438 - 531)	2.29 - 2.40	(467 - 517)
Kepler	381	437 (273 - 637)	5.09 - 5.86	(471 - 703)
RCW86	1800	2800 (1270 - 4586)	1.15 - 1.28	(1538-1805)
SN1006	979	1450 (706 - 2461)	1.19 - 1.48	(952 -1661)
G11.2	1599?	876 (443 - 1460)	3.86 - 4.97	(396 - 653)
RCW103	-	1270 (722 - 2000)	3.00 - 4.04	(849 -1769)
W49B	-	911 (539 - 1363)	4.59 - 5.32	(806 -1067)

* Assumes Eo = $0.184 * 10^{51}$ ergs.

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