INTERSTELLAR ABSORPTION OF X-RAYS EMITTED BY SUPERNOVA REMNANTS*

P. GORENSTEIN, E. M. KELLOGG and H. GURSKY
American Science and Engineering, Cambridge, Mass., U.S.A.

An X-ray observation of the Cassiopeia Region by the ASE group from a sounding rocket on December 5, 1968, has resulted in the determination of locations for two sources that are precise to about 0.1 of a square degree. The positions of two well-known radio sources Cas A and SN1572 (Tycho's Supernova), objects which are remnants of relatively recent galactic supernova, are consistent with these locations. Inasmuch as that region of the galaxy does not appear to contain nearly as large a concentration of objects as the galactic center, it is reasonable to make the identification between the X-ray sources and the supernova remnants on the basis of there being a small a priori probability of having an accidental coincidence within 0.1 square degrees. Cas A is almost certainly the same source as Cas XR-1 which the NRL group saw in an earlier survey [1]. During the December flight the Crab nebula was also observed for a short time interval.

The X-ray spectra of supernova remnants are of special interest. Many characteristics of these objects such as their age and distance are already known from previous observations in the radio and visible region so that it is possible to immediately give some physical significance to the X-ray results. Also in the radio and visible regions these objects have a finite angular width of a few arc minutes. If the X-ray emitting region is of comparable dimensions then considering the mass and distances involved, it must be rather transparent to its own emission up to rather long wavelengths. Consequently, observed photon deficiencies in the X-ray region are due rather unambiguously to the absorption effects taking place in the interstellar medium. In the case of the Crab, observations during a lunar occultation experiment [2] and with a modulation collimator [3] have indeed shown that most of the X-ray emission is from an extended region. In the case of Cas A and SN1572 there is as yet no information concerning the angular size in X-rays. Prior to the discoveries that a significant portion of the X-ray emission of the Crab is in a pulsar mode [4] it may have seemed safe to assume that the angular size of the X-ray source in Cas A and SN1572 was comparable to the radio source. We are examining the time profile of the distribution of counts from these two sources and so far have seen no obvious indication of a preferred frequency. In the absence of any contrary indication we assume these sources are large and hence transparent to their own X-ray emission.

On the order of 10^3 counts in the range 1.5–10 keV were detected from each of the three objects. Their spectral distribution was analyzed according to a method described previously [5] which makes a least squares comparison of the experimental

* Supported by the Office of Space Science Applications of National Aeronautics and Space Administration.

L. Gratton (ed.), Non-Solar X- and Gamma-Ray Astronomy, 134–137.

results to the expected instrumental response to functions of the following form:

$$dN/dE \sim e^{-(Ea/E)^{2.67}} E^{-\alpha} \quad (1)$$

$$dN/dE \sim (e^{-(Ea/E)^{2.67}} e^{-E/kT})/E. \quad (2)$$

In the case of Cas A and Tycho's Supernova it is not possible to determine from these data alone whether (1) or (2) provides the better fit. Results are given in Table I. With

TABLE I

X-ray characteristics of three supernova remnants (preliminary)

Source	Rel. Counts (1.5–11 keV)	Probable Dist. (pc)	Power Law Spectral Index	*Ea* (keV)	Exponential Temp (10^6K)	Ea (keV)
Crab Nebula (SN1054)	1	1700	2.0 ± 0.1	< 0.9	–	–
Cas A (~ 1700)	0.1	3400	3.3 ± 0.6	$1.35^{+.32}_{-.45}$	15 ± 6	$1.1^{+.2}_{-.5}$
Tycho's Supernova (SN 1572)	0.04	3500	2.3 ± 0.4	< 1.6	27^{+17}_{-6}	1.1

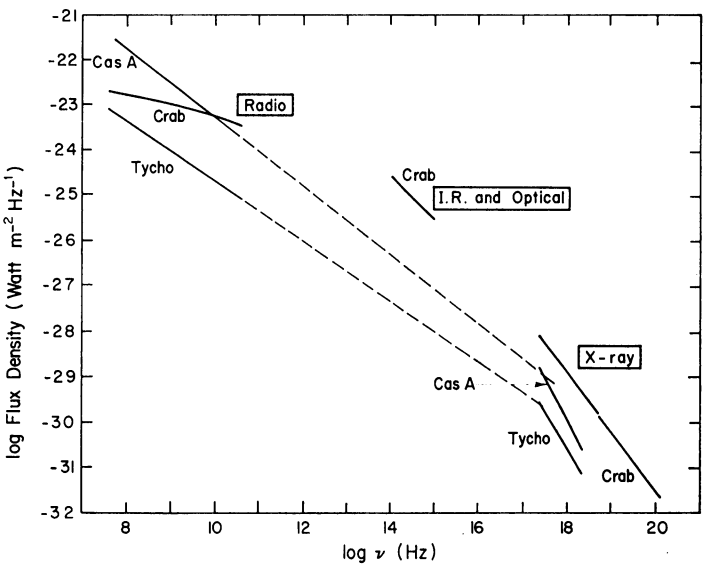

Fig. 1. The electromagnetic spectra of three supernova remnants.

respect to (1) the Crab is in agreement with previous determinations and has a smaller value of α than the other two. The best values of the temperature T associated with (2) are decidedly lower than the value 10^8 K suggested by Shklovsky [6] in his model which attributes the X-ray emission to thermal bremsstrahlung at the outer boundary of an expanding shell that has been ejected by a supernova explosion.

The electromagnetic spectra of the three objects is shown in Figure 1. It is remarka-

https://doi.org/10.1017/S0074180900004149 Published online by Cambridge University Press

ble that the extrapolation of the radio spectrum of Cas A and Tycho's Supernova is in agreement with the observed X-ray intensity, although the X-ray results by themselves suggest that the spectral index has steepened in the X-ray region. Of course, this apparent agreement could be entirely fortuitous as we have no assurance that the same source mechanism is responsible for both the radio and X-ray emission. Indeed in Shklovsky's model they would not be related.

The parameter *Ea* represents the energy at which the interstellar opacity is one mean free path. In this energy range, ~ 1 keV, it is mainly determined by the concentration of O & Ne. Models of the interstellar medium relate the amount of O & Ne to the quantity of hydrogen along the line of sight [7, 8].

In principle the amount of neutral hydrogen along the line of sight to strong radio sources can be determined from the 21-cm absorption features that the interstellar medium imposes upon the spectra of the emitted continuum [9, 10]. However, such an estimate is dependent upon the value of an assumed temperature for the absorbing hydrogen clouds and may not be sensitive to all the diffuse hydrogen. The absorbing medium is largely confined to galactic spiral arms. For the Crab, it is the orion arm and for Cas A and Tycho's Supernova it is the orion plus perseus arm. Table II lists

TABLE II

Source	N_H [a]	*Ea* (theo.) [b]	*Ea* (obs.)
Crab	1.6×10^{21} H atoms/cm^2	0.73 keV	< 0.9 keV
Cas A	1.0×10^{22}	1.55 keV	$1.2_{-0.5}^{+0.3}$
Tycho's Supernova	1.0×10^{22} [c]	1.55 keV	< 1.6

[a] Refs. [9, 10].
[b] Calculated according to cross-sections of Bell and Kingston [8].
[c] N_H to Tycho is assumed to be the same as Cas A.

the amount of hydrogen as determined from the radio measurements, the value of *Ea* expected on the basis of Bell and Kingston's [8] cross-section and the preliminary value of *Ea* as determined in this measurement, assuming power law spectra.

The principal conclusion to be drawn from these data is that the interstellar medium is clearly not more opaque to X-rays of ~ 1 keV than had been expected and could possibly be less opaque. Consequently, the abundance of neon and oxygen relative to hydrogen over a significant portion of the galaxy as determined by line of sight X-ray absorption is consistent with and certainly not more than presently accepted values.

References

[1] Byram, E. T., Chubb, T. A., and Friedman, H.: 1966, *Science* **152**, 66.
[2] Bowyer, S., Byram, E. T., Chubb, T. A., and Friedman, H.: 1964, *Science* **146**, 912.
[3] Oda, M., Bradt, H., Garmire, G., Spada, G., Sreekantan, B. V., Gursky, H., Giacconi, R., Gorenstein, P., and Waters, J. R.: 1967, *Astrophys. J.* **148**, L5.
[4] Reports have been presented at this symposium of the observation of the pulsar in the Crab

Nebula in the X-ray regions by the NRL, MIT, Columbia U., and Rice U. groups.
[5] Gorenstein, P., Gursky, H., and Garmire, G.: 1968, *Astrophys. J.* **153**, 885.
[6] Shklovsky, I. S.: 1968, *Supernovae*, Chapt. II, Wiley-Interscience, New York.
[7] Felten, J. E. and Gould, R. J.: 1966, *Phys. Rev. Lett.* **17**, 401.
[8] Bell, K. L. and Kingston, A. E.: 1967, *Monthly Notices Roy. Astron. Soc.* **136**.
[9] Muller, C. A.: 1958, *Astrophys. J.* **125**, 830.
[10] Clark, B. G.: 1965, *Astrophys. J.* **142**, 1398.