THE ELECTRON SPECTRA IN THE SYNCHROTRON NEBULA OF THE SUPERNOVA REMNANT G 29.7 - 0.3

L. Koch-Miramond and R.Rocchia, Service d'Astrophysique, Saclay, France
F.A. Jansen and R.Braun, Huyghens Laboratory, Leiden,
R.H. Becker, University of California, Davis

1. Introduction. The current observational situation concerning the presence or absence of synchrotron nebulae, presumably fed by an active pulsar (PSR) in the central region of supernova remnants (SNRs) is evolving rapidly, thanks to the high resolution maps obtained with the Very Large Array (VLA) in the radio range and with the Einstein and Exosat observatories in the X-ray range. The larger spectral coverage (0,04 - 20 keV) of Exosat and its spectro-photometric capabilities are decisive in this respect. Observations in the whole range of frequencies between radio and X-rays would help determining the range of synchrotron frequencies and hence of injected particle energies, establish the physical size of the nebula and advance our understanding of particle acceleration by PSRs.

The remnant G 29.7 - 0.3 has been studied intensively. The radio properties has been discussed by (1), (2), (3). High resolution maps obtained with the VLA show two spectrally distinct components, a flat spectrum core surrounded by a shell. The central component is 25% linearly polarized and has a centrally peaked radio brightness distribution characteristic of Crab-like remnants. While not visible at optical wavelengths due to the high visual absorption on the line of sight, G 29.7 - 0.3 is a very bright object in X-rays (2) (3), X-ray diffuse emission coïncident with the radio core was observed with the Einstein Observatory. For a distance of 19 kpc the estimated luminosity of the nebula was $\sim 4\ 10^{36}$ erg s^{-1} in the 0.2 - 4.0 keV range and its linear diameter ~ 2 pc. The present paper shows Exosat results obtained with the imaging instrument (CMA) and the medium energy proportional counters (ME). Assuming that the featureless power-law spectrum obtained in the 2 to 10 keV range is synchrotron radiation from relativistic electrons, one derives constraints on magnetic field strength and age of the nebula. The energy spectra of the electrons responsible for the emission in the radio and X-ray ranges are discussed.

2. Results of the Exosat Observation. G 29.7 - 0.3 was observed on 29 August 1984, for $4\ 10^4$ s with the Exosat imaging instrument (CMA) and the medium energy proportional counters (ME) (4). The source was not seen in the CMA, the 3σ upper limit on the counting rate being $4\ 10^{-4}\ s^{-1}$. The counting rate due to the source in the ME Argon counters half-array was 2.7 s^{-1}. After background subtraction the observed spectral distribution is shown on figure 1. The best fit was obtained assuming a featureless power-law spectrum $dN/dE = 1.3\ 10^{-2}\ E^{-1.77}$ photon $cm^{-2} s^{-1} keV^{-1}$ and an absorbing hydrogen column density of $\sim 2.3\ 10^{22}\ cm^{-2}$. A 3σ lower limit on the N_H value of $\sim 3\ 10^{22}\ cm^{-2}$ has been deduced from the upper limit of the CMA counting rate. Then the consistency between the CMA and ME data imposes: $\alpha = -1.0 \pm .15$ and $N_H = (3.3 \pm .3)\ 10^{22}\ cm^{-2}$. The figure 2 shows the incident X-ray spectrum.

Search for pulsations. Regular pulsations were searched for in the ME data by performing a fast Fourier transform. No statistically significant period has been found between 32ms and 10^4 s. The resulting upper limit of pulsed fraction in this period range is ~ 1.5%.

3. Discussion. The value of N_H we have deduced can be compared with the lower limit of $N_{HI} = 2\ .\ 10^{22} cm^{-2}$ inferred from neutral hydrogen radio absorption

measurements by (3). The incident X-ray flux from the source is $(3.8\pm.1)\,10^{-11}$ erg.cm^{-2} s^{-1} in the 2 to 10 KeV range, corresponding to an intrinsic luminosity of 2 10^{36} erg.s^{-1} for a distance of 19 kpc. This large distance was estimated by (5) from the surface brightness/diameter relationship for SNRs and confirmed by the VLA results of (3). The total X-ray luminosity in the 0.1 to 10 keV range is about 5 10^{36} erg.s^{-1} assuming that the same power-law holds. We assume a synchrotron nebula on the basis of our X-ray data and of the radio polarization. The emission at all wavelengths is synchrotron emission from relativistic electrons accelerated by the central stellar remnant.

Assuming that the nebula contains a uniform magnetic field H, that all particles have energy such that maximum synchrotron emission is at 1 keV and that the energy of the nebula is equally divided between relativistic electrons and magnetic field (7), one finds $H \sim 7\ 10^{-5}$ Gauss and $E_p = E_H \sim 6\ 10^{46}$ ergs, with an angular radius of the nebula of 10 arc sec. from (2). The synchrotron lifetime of the X-ray emitting electrons is then $\tau \sim 150$ years. Doing that we have ignored electrons non radiating in X-rays; if now we consider the entire electromagnetic spectrum we get $H=2\ 10^{-4}$ G, $E_p = 1.6\ 10^{47}$ erg and τ for electrons emitting at 1 keV of 35 years. The age of the SNR has been estimated by (8) from the surface brightness Σ at 408 MHz assuming that the dynamical evolution of the shell is described by the Sedov equation i.e. unaffected by the presence of a central pulsar, then $\Sigma = 1.25\ 10^{-15} t^{-6/5}$ giving t = 660 years. Hence continuous injection of energy near the center is inferred from the short synchrotron lifetime of the electrons as compared to the SNR's age.

<u>4. Energy and spectra of the electrons.</u> If ν is the frequency corresponding to the maximum of the synchrotron spectrum $\nu = 4.6\ 10^{-6} H\ E^2$ (9). Assuming H = H equipartition $= 2\ 10^{-4}$ G, one finds that the radio emitting electrons have energy $E \sim 10^9$ eV and the X-ray emitting electrons $E \sim 3\ 10^{13}$ eV. Since the energy spectrum of the X-ray emitting electrons is dominated by synchrotron losses the observed X-ray spectral index of -1.0 ± 0.15 implies a power-law distribution of the radiating electrons with $N(E) \propto E^{-3\pm.45}$. Because synchrotron losses steepen a continuously injected spectrum of electrons by one power the inferred injection spectrum is proportional to $E^{-2\pm.3}$. Also there should be a break at low energies to a radiation spectrum $S_\nu \propto \nu^{-0.13\pm.12}$ (figure 3). For the equipartition field H = 2 10^{-4} G and an age of 660 years that should occur at a frequency of about 10^{14} Hz. Considering the spectrum of G 29.7 - 0.3 over 9 decades in frequencies (figure 3) and taking into account the uncertainties on measured spectral indices, a break (if unique) should be expected in the frequency range 10^{12} to 10^{15} Hz encompassing the infrared range.

The radio flux of the synchrotron nebula integrated over the range 10^7 to 10^{11} Hz with the same spectral index $\alpha = -0.25$, as observed around 1 GHz by (2), is 4 10^{33} erg s^{-1}. Then the L_X / L_R ratio is $\sim 10^3$, well above the theoritical minimum of ~ 17 deduced from (6), who were modeling the evolution of a <u>single</u> power-law particle spectrum in the Crab-like SNRs. Hence a different origin for the X-ray and radio producing electrons is not required. This conclusion still marginally holds if one considers a flat radio spectrum ($\alpha = 0$, $L_X / L_R \sim 500$ and $(L_X / L_R)_{min} \sim 600$ in (6). These considerations require that the difference of spectral indices between the radio and X-ray domains is 0.5. But this difference could be as large as 1, as suggested by our X-ray observations and by (3). In that case the electron spectral distribution could be more complex and its understanding would require the knowledge of the photon spectrum in the interval between radio and X-rays. Infrared informations are much valuable from this point of view.

5. Infra-red emission. The IRAS catalogue of point and small extended sources (extension ≤ 1 arc min) gives at α(1950) = 18h43m46.5s; δ(1950)=-03°02'33" a source flux of 4.84 Jy at 12μ and 8.63 Jy at 24μ (10). The corresponding points shown on figure 3 lie 2 decades above the extrapolated radio emission but the infra-red source does not coïncide with the central synchrotron nebula and lies closer to the brightest shell emission region A. So these data cannot be confidently used to constrain the electron spectrum. More work on the infra-red diffuse emission of this region is required.

6. Conclusions. The great similarity of the physical properties of G 29.7 -0.3 and of the three synchrotron nebulae containing a compact object observed to pulse in X-rays (11), (12) and Table 1, makes G 29.7 - 0.3 a very promising candidate for further search for pulsed emission. Further observations at infra-red wavelengths might reveal the break(s) in the emitted spectrum expected from the radio and X-ray power-law indices and give us more information on the production of the electron populations responsible for the emission of the nebula (13, (14), (15).

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References

1. Becker,R.H., Kundu, M.R., 1976, Ap.J. 204, 427.
2. Becker, R.H., Helfand, D.J., Szymkowiak, A.E., 1983, Ap.J.Lett. 268,L93.
3. Becker, R.H., Helfand, D.J., 1984, Ap.J. 283, 154.
4. Koch-Miramond, L.,Rocchia, R., et al., 1984, 18th ESLAB Symposium on X-ray astronomy, in press.
5. Milne, D.K., 1979, Australian J. Phys. 32, 83.
6. Reynolds, S.P., Chanan, G.A., 1984, Ap.J. 281, 673.
7. Pacholczyck, A.G., 1970, Radio Astrophysics, Freeman
8. Clark, D.H., Caswell, J.L., 1976. M.N.R.A.S. 174, 267.
9. Ginzburg, V.L., Syrovatskii, S.I., 1964, The Origin of Cosmic Rays, Pergamon.
10. Perault, M., 1985, Private communication
11. Seward, F.D., 1983, in Supernova Remnants and their X-ray emission, Symposium IAU 101, ed. J.Danziger and P. Gorenstein, p.405.
12. Seward, F.D., Harnden Jr, F.R., Helfand, D.J., 1984, Ap.J.Letters, 287,L19.
13. Pacini, F., Salvati, M., 1973, Ap.J. 186, 249.
14. Reynolds, S.P., Chevalier, R.A., 1984, Ap.J. 278, 630.
15. Reynolds, S.P., 1985, Ap.J. 291, 155.

TABLE 1. PROPERTIES OF DIFFUSE SYNCHROTRON NEBULAE

Names	Distance kpc	Size pc	Lx erg s^{-1}	H * Gauss	Ep * ergs	τ * Years
G 184.6-5.8 (Crab)	2.0	0.6	$2\ 10^{37}$	$2\ 10^{-4}$	$2\ 10^{46}$	30
G 29.7-0.3 (KES 75)	19	1.8	$5\ 10^{36}$	$7\ 10^{-5}$	$6\ 10^{46}$	150
LMC 0540-693	55	1	$1\ 10^{37}$	$2\ 10^{-4}$	$1\ 10^{47}$	33
G 320.4-1.2 (MSH15-52)	4.2	6.4	$1.6\ 10^{35}$	$9\ 10^{-6}$	$2\ 10^{46}$	410^{3}

* Based on the consideration of X-ray emitting electrons only (11).

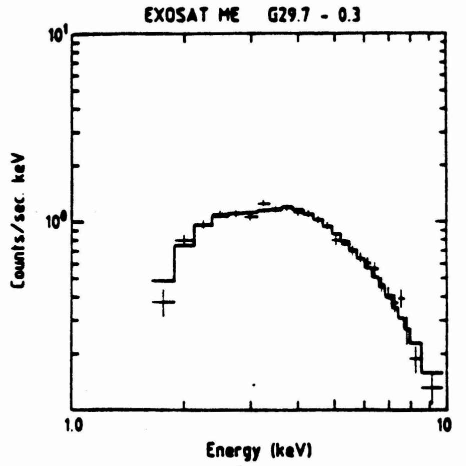

Figure 1: The observed ME spectrum of G 29.7-0.3 (full array). The thin bars represent the observed data points with ± 1 σ errors. The thick histogram is the predicted distribution for a power-law spectrum with energy index α=-.77 and an absorbing column density of N_H= 2.3.10^{22}cm^{-2}.

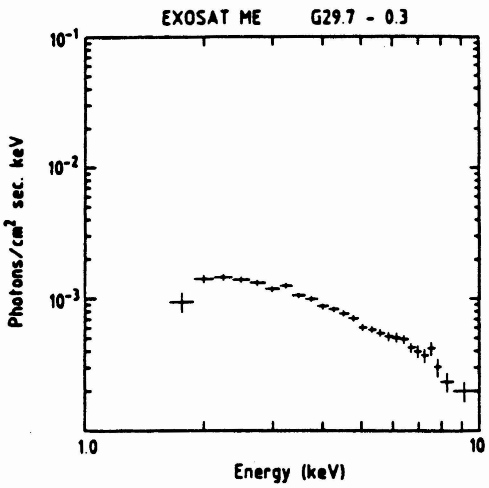

Figure 2: The incident photon spectrum of G 29.7-0.3 as deduced from the EXOSAT ME data.

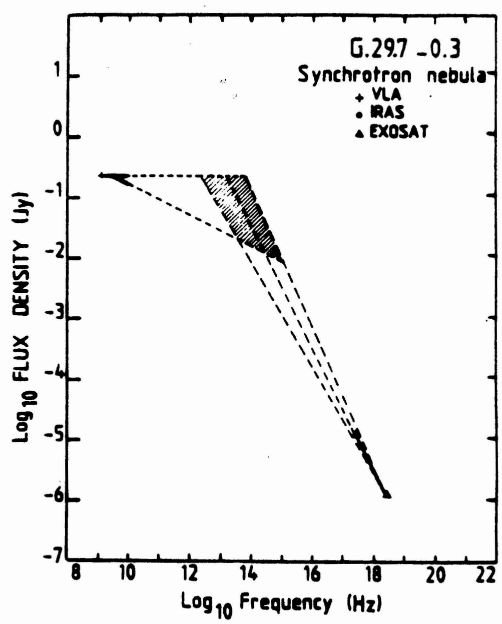

Figure 3: Emission spectrum of the synchrotron nebula in G 29.7-0.3 over 9 decades in frequency. Radio spectrum from (1,2,3), IRAS flux might be due to shell emission, X-ray spectrum from the present work. A spectral break is expected in the shaded area.