LETTERS TO THE EDITOR

ASTROPHYSICS

Nature of Sources of Cosmic Synchrotron Radiation

FROM an analysis of the emission bands in the spectra of 3C273 and 3C48 described in refs. 1 and 2, it may be concluded that the size of the gas envelopes around 'radio stars' (emitting continuous spectrum) must be at least 10^{20} cm. Indeed, the total energy radiated in any emission band is $L \propto N_e^2 r^3 x^{1/2}$, where N_e is the electron density, r is the radius of the gas envelope and x is the non-uniformity factor which has been assumed to be $\sim 10^{-2}$.

Assuming for $H\beta$ -line that $L_{\beta} \sim 3 \times 10^{43}$ ergs/sec and $r = 10^{20}$ cm, we obtain $N_e \sim 10^5$ cm $^{-3}$. At such a high electron density and taking into account the de-activation due to collision, forbidden lines, especially λ 3727, would be of a very low intensity in comparison with Balmer lines, which actually is not the case. It follows, therefore, that $r > 10^{20}$ cm. On the other hand, in view of the star-like character of the apparent image of 3C273, $r < 2 \times 10^{21}$ cm. For this value of r , $N_e \sim 10^8$ cm $^{-3}$. In all probability, for 3C273 the radius of the expanding gas envelope is $\sim 10^{21}$ cm, the gas has a mass of about $10^8 M_{\odot}$ and the age of the source is of the order of 10^5 years. The linear dimensions of the radio-emitting nucleus of 3C273-B may be obtained by the method involving an analysis of the re-absorption of synchrotron radiation³. It follows that the radio-emitting nucleus has dimensions close to those of the gas envelope, that is, $\sim 10^{21}$ cm.

Thus, from the analysis of the emission lines in the spectra of the radio stars it follows that they are the remnants of star-like objects with a mass of about $10^8 M_{\odot}$ which exploded about 10^5 years ago.

The object M-82 (ref. 4) is apparently an example of a later stage in the development of such objects. In this case, the explosion occurred 1.5×10^6 years ago, and its yield was lower than that of 3C273 by at least an order of magnitude.

The most striking point is probably that the activity of the nuclei of these objects, manifested by the powerful generation of relativistic particles, still continues. It should be noted that a similar situation is to be observed in the Crab Nebula. The characteristic varying details noted by Baade in the central region of the Crab Nebula may be solely explained by the continuous ejection from a small area (most probably a former supernova) of relativistic particles which 'sweep out' the magnetic field up to the distance about 10^{17} cm from the region of generation. It is only at that distance that the Nebula's magnetic field, becoming sufficiently strong, can resist the pressure of relativistic particles. The magnetohydrodynamic waves induced by this pressure may well be the cause of the wisps or jets seen in the central region of the Crab Nebula.

Another suggestion supporting the idea of the continuing generation of relativistic particles in the nucleus of the Crab Nebula is the very short life-time of relativistic electrons responsible for its optical synchrotron radiation. It follows, therefore, that the intensity of the corpuscular radiation from the nucleus of the Crab Nebula must be $> 2 \times 10^{36}$ ergs/sec.

It is very likely that the optical radiation from the 'nucleus' of 3C273, which size is less than 10^{16} cm (ref. 5), is also of synchrotron character. It is of interest, therefore, to compare purely empirically the two sources of relativistic particles—nuclei of the Crab Nebula and of 3C273 (Table 1).

The E column of Table 1 gives the flux density of relativistic particles from the nuclei of the Crab Nebula

Table 1

	E	M	N_e	ρ_g
Crab Nebula	2×10^{37} ergs/sec	$c. 1 M_{\odot}$	$c. 0.1$ cm $^{-3}$	10^{14} g cm $^{-3}$
3C273	10^{46} ergs/sec	$c. 10^8$	$c. 10^8$ cm $^{-3}$	1 g cm $^{-3}$

and 3C273. The M column indicates the masses of the exploded stars, the N_e column presents the density of the gas in the surroundings, and the last column gives the density corresponding to the gravitational radii ($r_g = 2GM/c^2$) or collapsed stars. It will be noted that E and M values are approximately proportional. On the other hand, E seems to be independent of either N_e or ρ_g . It is natural to assume that the radio star and the Crab Nebula are phenomena of similar nature but different in scale. If so, an analysis of Table 1 may be useful in tackling the fundamental problem of the mechanism by which the cores of exploded stars generate relativistic particles. It may be said from the very beginning that the accretion mechanism suggested in ref. 6 cannot account for the observed generation, because in this case E would be $\propto N_e M^2$, and is known not to be so.

The continuing generation of relativistic particles, coupled with the impossibility of attributing it to accretion, implies that no collapse has ever occurred around the cores of the exploded star. More likely, the collapse had been prevented by the rotation of the star. Somewhere during contraction, the cores of the exploded star assumed the shape of disks, owing to the rapid rotation, and then burst into many fragments moving in a small region by orbits lying nearly in the same plane. It may be noted, incidentally, that when M is approximately equal to $10^8 M_{\odot}$, and the dimension of the region 10^{14} – 10^{15} cm, such a system in absence of spherical symmetry must act as a powerful generator of gravitational waves. This radiation may be of paramount importance for the further evolution of the exploded star. The rate of gravitational radiation can be as high as 10^{54} – 10^{56} ergs/sec. The equivalent mass loss may be of significance for the further evolution of these objects. It cannot be ruled out that the rapidly varying and very strong gravitational fields in such a system, coupled with magnetic fields, may accelerate particles to very high energies. Under such conditions, Fermi's statistical mechanism of acceleration must be very efficient.

In conclusion, it seems to be relevant to point to an intriguing analogy between the phenomena occurring in radio galaxies and in the supernovae outbursts. During a period of maximum brightness, the optical radiation of the latter objects is apparently of synchrotron nature, as was originally suggested by I. M. Gordon⁷ in 1954. After several years this radiation will cease. But, as it has been shown, the nucleus, that is, a former supernova, continues to emit the relativistic particles. The emission of radio stars is an analogue of the synchrotron radiation of supernovae in a period of maximum brightness. After the optical emission of the exploded core of a supernova ceases, it continues to eject relativistic particles for a long time. A similar phenomenon can be observed in M-87, M-82 and in some other sources.

JOSEPH SHKLOVSKY

University of Moscow,
U.S.S.R.

¹ Schmidt, M., *Nature*, **197**, 1040 (1963).

² Greenstein, J., and Matthews, Th., *Nature*, **197**, 1041 (1963).

³ Slysh, W., *Nature*, **199**, 682 (1963).

⁴ Lynds, C., and Sandage, A., *Astrophys. J.*, **137**, 1005 (1963).

⁵ Smith, H., and Hoffleit, D., *Nature*, **198**, 650 (1963).

⁶ Shklovsky, J. S., *Astronomicheskij Zhurnal*, **39**, 591 (1962) (in Russian).

⁷ Gordon, I. M., *Doklady AN S.S.S.R.*, **94**, 413 (1954) (in Russian).