Astrophysical consequences of n–n̄ oscillations

SIVARAM and KRISHAN[1] have suggested that the anomalously high flux of low-energy antiprotons observed in cosmic rays[2] is produced when free neutrons, which are possibly ejected in supernova explosions, undergo neutron–antineutron (n–n̄) oscillations as expected in some grand and partially unified theories[3]. Such oscillations are strongly suppressed in an external magnetic field[3–6] but by choosing the interstellar field strength, B, to be as low as 10^{-7} G and an oscillation time, $\tau_{n-\bar{n}} = 10^5$ s, these authors obtain[1], $\bar{n}/n \approx 10^{-4}$. Because n̄ and n β-decay to p̄ and p respectively, this implies $\bar{p}/p \leq 10^{-4}$, which compares with the observed value[2], $\bar{p}/p = (2.2 \pm 0.6) \times 10^{-4}$ at ~130–370 MeV/n. (Contrary to their[1] remark, the ratio p̄/p cannot exceed the ratio n̄/n, regardless of the number of neutrons ejected per proton in a supernova.)

However, before this suggestion, old limits on the stability of nuclear matter had been used to infer[4–6] $\tau_{n-\bar{n}} > 10^6$–5×10^7 s. Also, direct observations of free neutron beams had yielded the limit[7], $\tau_{n-\bar{n}} > 1.2 \times 10^5$ s, and this has been recently improved to[8] $\tau_{n-\bar{n}} > 10^6$ s. Furthermore, the interstellar magnetic field strength must be $> 10^{-6}$ G to account for observations of pulsar signals[9] and the galactic synchrotron background[10]. (We disagree that this value is ". . given by equipartition arguments . . (with) . . no physical basis . . "[1].) Thus, using these conservative limits, we obtain $\bar{n}/n \approx \bar{p}/p < 10^{-8}\ (\tau_{n-\bar{n}}/10^6\ \mathrm{s})^{-2}\ (B/10^{-6}\ \mathrm{G})^{-2}$. Moreover, this obtains at ~1 MeV/n, corresponding to the typical ejection velocity of $\sim 10^4\ \mathrm{km\ s^{-1}}$ in a supernova. Thus the observation that $\bar{p}/p \sim 10^{-4}$ at ~200 MeV/n cannot be accounted for by this mechanism.

Note that even in the total absence of a magnetic field, neutrons would sooner β-decay than oscillate into antineutrons. This sets an absolute upper limit $\bar{n}/n < 10^{-6}\ (\tau_{n-\bar{n}}/10^6\ \mathrm{s})^{-2}$, thus making this process uninteresting in any conceivable astrophysical or cosmological context.

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SIVARAM AND KRISHAN REPLY—We have not stated anywhere in our paper[1] that all of the 10^{57} neutrons ejected by a single supernova are at an energy ~200 MeV, in which case there would indeed be an excess of energy involved. The only claim made is that here is a possible mechanism for directly producing p̄ at low (MeV) energies without any need for deceleration from energies of several GeV (with its attendant difficulties) inevitable in most models.

Second we felt that there was no need for Sarkar to have written down all the formulae for n–n̄ transition probabilities. These are well known and are the same formulae that we used. In fact for a $B = 10^{-7}$ G and $\tau_{n-\bar{n}}$ of 10^5 s, he also obtains $\bar{n}/n \sim 10^{-4}$. Regarding his chief point of contention that the strength of the interstellar magnetic field must be $\sim 10^{-6}$ G; we are surprised that Sarkar has overlooked the fact that in the latter half of our paper we have pointed out that if this field is assumed it would considerably lower $\bar{p}/p\ (< 10^{-6})$. (For 10^{-6} G, $\Gamma_B \gg \Gamma_{n-\bar{n}}$, and for 10^{-7} G, they are just equal.) We went on to point out that to build up the observed low-energy background of 10^{55} antiprotons in our Galaxy (as implied by the observed density of $10^{-4}\ \mathrm{eV\ cm^{-3}}$) we would require a few thousand explosions which would occur in periods $\sim 10^6$ yr which is the same order as the diffusion time for the produced particles to spread over the Galaxy and produce the observed background. More generally one can say that the number of antiprotons produced is

$$\bar{p} = N\left(\frac{\Gamma_{n-\bar{n}}}{g u_N B}\right)^2 ft, \qquad \Gamma_{n-\bar{n}} = \hbar/\tau_{n-\bar{n}}$$

where N is the number of neutrons per supernova, f the frequency of explosions and t the diffusion time $\sim 10^5$ yr. Thus if all low-energy antiprotons ($\bar{p} = 10^{55}$) in the Galaxy were produced by supernovae, then with $N = 10^{57}$, $f = 1/10$ yr, we would have an astrophysical constraint on the oscillation time $\tau_{n-\bar{n}}$. If $\tau_{n-\bar{n}} > 10^7$ s (as indirect evidence suggests), of course, the p̄ production would be too low. Measurements of p̄ should perhaps be made over a few MeV as this is the range where most supernova neutrons are produced.

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Formation of sapropels in the Tyro Basin

WE were most interested in the two companion papers pertaining to the recent formation of sapropels in the Tyro Basin, an isolated depression within the Hellenic Trench in the eastern Mediterranean Sea. Certainly the physiography within this trench system would be conducive to allowing localized near-bottom anoxia because of limited bottom water ventilation as related to outcrops of Messinian salt, as well pointed out by Jongsma *et al.*[1] and de Lange and ten Haven[2].

We are concerned, however, with their statement: "Assuming an undisturbed sedimentation and taking a relatively high sedimentation rate of 5 cm $\mathrm{kyr^{-1}}$, we conclude that the recovered sediment column of 400 cm of solely sapropel to sapropelic sediment indicates a period of at least 80,000 yr."

Instead, we suggest that the 4-m long section was deposited in much less time. There is ample evidence of resedimentation events in similar isolated basins during the recent geological past and the present throughout the Hellenic Trench system[3–5], as well as on the Mediterranean Ridge immediately south of the trench[6,7]. In particular, redeposited sapropels have been identified in dated piston cores from these regions. Gravity-driven processes triggered by the active tectonism in the region have resulted in stratigraphically displaced and expanded-thickness sapropel sections[8,9], sometimes in excess of 4 m, and in dilution of organic matter content. As a result of this prevalent resedimentation process, cores from the trench show some of the highest sedimentation rates (to $> 400\ \mathrm{kyr^{-1}}$) yet measured in the Mediterranean Sea[4]. Thus, their conclusion of a 400-cm long sapropelic section representing 80,000 yr of undisturbed sedimentation is unrealistic. It is equally plausible that at least part of the sapropelic section cored in the Tyro Basin is redeposited, and equivalent to the upper sapropel (S_1) dated at ~8,000 yr BP and mapped over much of the eastern Mediterranean.

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