NEUTRAL CURRENTS AND THE COOLING OF NEUTRON STARS

(Letter to the Editor)

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Abstract. Although the neutrino cooling rate by purely leptonic processes is altered by the neutral currents, the overall cooling of model neutron stars is shown to remain practically unaffected.

Recent experiments (Hasert *et al.*, 1973) have confirmed the existence of neutral currents in weak interactions, predicted by gauge theories (Abers and Lee, 1973; Weinberg, 1967). While it is too early to know the exact strength of the coupling constant and the correct model for describing the weak neutral processes, already some progress in this direction has been made and the possible ranges within which the coupling constants will vary are available (Sehgal, 1974; De Rujula *et al.*, 1974). In this communication it is proposed to examine the effects of the neutral currents on the cooling of neutron stars.

The thermal structure of a neutron star is now available from the work of Tsuruta and Cameron (1966) and others. It is well known that the neutron stars cool initially by the neutrino processes and after a few tens of years the photon cooling takes over. The neutrino processes which play a major role are: (a) URCA process, (b) Plasma process, (c) Photo production, (d) Pair annihilation and (e) Neutrino bremmstrahlung, and they depend on the temperature and density of the star. While the URCA and neutrino bremmstrahlung processes remain unaffected by the presence of leptonic neutral currents, Dicus (1972) has shown that the other three processes get modified in the presence of neutral currents. He has derived the expressions using Weinberg's model of the gauge theory. We find that the expressions can be generalized without reference to any specific models and we have utilized them to derive the decrease of core temperature with time shown.

The cooling rates are calculated using the expression for the luminosity, L, in the form,

$$L = (a^2 - a + 0.5 + b^2)(\varepsilon_{\text{photo}} + \varepsilon_{\text{pair}}) + \\ + \{a^2 + (a - 1)^2\}\varepsilon_{\text{pl}} + \varepsilon_{\text{URCA}} + \varepsilon_{\text{NB}} + \varepsilon_{\text{photon}}, \quad (1)$$

where ε_i represents the energy loss per second from the star. The coupling constants a and b appearing in (1) are defined through the Lagrangian for $\nu_e e$-interaction

$$\mathscr{L} = \frac{G_{\text{F}}}{\sqrt{2}}\{\bar{\nu}_e\gamma_\alpha(1 - \gamma_5)\nu_e\}\{\bar{e}\gamma_\alpha(a - b\gamma_5)e\}.$$

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The energy losses due to photo neutrino, pair annihilation and plasma processes are adopted from the approximate expressions given by Beaudet *et al.* (1967). The expressions for URCA and bremmstrahlung processes were taken from the works of Tsuruta and Cameron (1966). The photon energy loss is calculated by assuming the emission to be from a black body of effective temperature T_e and the relation between T_e and T_{core} is given by Tsuruta and Cameron (1966) who have taken into account the detailed thermal structure of the star.

The internal energy of the neutron star is given by Bahcall and Wolf (1965) in the form

$$U = 5 \times 10^{47} T_9^2 (\varrho/\varrho_{\text{nuc}})^{-2/3} (M/M_\odot) \text{ ergs}. \tag{2}$$

We have computed the cooling time for a neutron star of 1 $M_\odot$ and core density of 3×10^{14} g cm^{-3} (the nuclear density ϱ_{nuc}). The temperature T_9 is expressed in units of 10^9 K. The time taken to cool from an initial temperature T_i to a final temperature T_f is given by

$$\Delta t = \int_{T_i}^{T_f} \frac{dU}{L}. \tag{3}$$

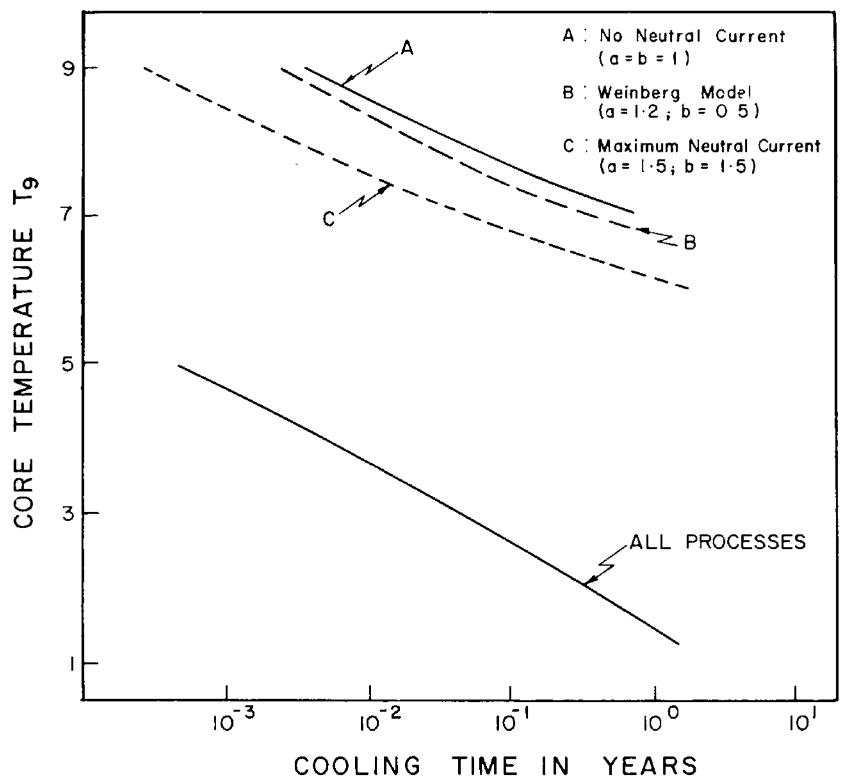

Fig. 1. The cooling curve for a neutron star of 1 $M_\odot$ and core density of 3×10^{14} g cm^{-3}. All processes include the photon cooling also. The curves labelled A, B, C show cooling due only to the plasma, photoproduction and pair annihilation process.

In order to demonstrate the effect of leptonic neutral currents, we have first included only the three leptonic neutrino cooling processes for the purpose of computing the cooling period with three distinct choices: (a) with conventional charged current theory of Feynman-Gellman, (b) with the inclusion of neutral currents according to the Weinberg model with the Weinberg angle $\sin^2 \theta_w = 0.35$ and (c) with the maximal value for the coupling constants a and b (viz.) 1.5 and 1.5 respectively (De Rujula *et al.*, 1974). The results are shown in Figure 1 where the temperature is plotted against the cooling period. We see that the inclusion of neutral currents reduces the time scale at most by a factor of ten, over the cooling times of no neutral current models for the temperature range $7 < T_9 < 9$. However, for the temperatures of interest, viz. 10^{10}–10^7 K, the importance of URCA processes cannot be neglected and when we include these processes then we find that the cooling is extremely fast and the cooling period changes at most by a second or two in a total time of a few years. Hence on the cooling of realistic neutron star models, the inclusion of leptonic neutral currents does not seem to have any noticeable effect. However, according to Bond (1974) the inclusion of a semileptonic neutral current may have a significant effect on the cooling times.

It should be mentioned that on qualitative grounds the cooling periods of white dwarfs may be affected by these purely leptonic neutral currents and work is in progress to obtain quantitative estimates.

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