THE CURRENT STATUS OF NEUTRON STAR COOLING THEORIES

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There are serious discrepancies among some of the recent neutron star cooling calculations by various groups. We have been investigating the possible source of these discrepancies. In this paper, we report our findings. We also report the preliminary result of our most recent cooling calculations without assuming an isothermal stellar evolution code. In this work, we used the currently existing best energy transport theories, as well as general relativity, both in thermodynamics and hydrodynamics.

DISCUSSION

Lamb: While I appreciate being called a cool character by Sachiko, I would remark that the neutron star cooling curves computed by Ken van Riper and myself are not quite as cool as shown in her figure. Let me summarize our results as follows. At an age τ = 1000 yrs, we find for our soft star a luminosity $\cong$ 16 times lower (temperature $\cong$ 2 times lower) and for our stiff star a luminosity $\cong$ 40 times lower (temperature $\cong$ 2.5 times lower) than those found earlier by Tsuruta (1979). In the soft star, much of the difference appears to be due to our inclusion of general relativistic effects (particularly the gravitational redshift), although part appears to be due to our use of new radiative and conductive opacities. In the stiff star, general relativistic effects are smaller. We find, however, that it cools somewhat faster because superfluidity markedly reduces its heat capacity but does not affect its dominant energy loss processes, i.e. neutrino crust bremsstrahlung and photon emission from the stellar surface. Nevertheless, the luminosities of the soft and stiff stars differ very little during the neutrino cooling era. We can compare the recent results of Glen and Sutherland (1980) with ours only for the case of zero magnetic field, since we treated the effects of the field on the density structure of the outer layers of the

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star whereas they did not. For zero magnetic field, our luminosities for the soft star agree (e.g. they are within a factor of $\cong 2$ at $\tau = 1000$ years) but our luminosities for the stiff star differ somewhat (ours is a factor $\cong 13$ lower at $\tau = 1000$ yrs). We are continuing our discussions with Peter Sutherland and expect to resolve our remaining differences soon.

Tsuruta: It is not correct to compare your results and my results in the reference as you indicate (Tsuruta 1979), because we are talking about two different things. Namely, I was talking about the local surface temperatures, while you are talking about the temperature observed at infinity (i.e. at the earth). Otherwise, your comment agrees qualitatively with my earlier remarks.

Schatzman: I am not clear about pion condensation and the rate of cooling that may result.

Tsuruta: If pion condensates occur in neutron stars, the cooling is so fast that there is no discrepancy with even the lowest observed lower limit to a neutron star surface temperature (e.g. SN1006, if a neutron star exists there). See, for example, S. Tsuruta, 1980, in *X-Ray Astronomy*, ed. by R. Giacconi and G. Setti, p. 73, Reidel, Dordrecht.