COOLING OF NEUTRON STARS: ACCURATE TREATMENT OF THERMAL CONDUCTION

N. Itoh*, K. Nomoto**, S. Tsuruta***, T. Murai****
* Department of Physics, Sophia University, Tokyo 102, Japan
** NASA, Goddard Space Flight Center, Greenbelt, Maryland 20771, U.S.A.
*** Department of Physics, Montana State University, Bozeman, Montana 59717, U.S.A.
**** Department of Physics, Nagoya University, Nagoya 464, Japan

Most of the neutron star cooling calculations with the only exception of Malone's (1974) have assumed an isothermal stellar core. Here we report on a neutron star cooling calculation which makes full use of the stellar evolution code and the recent thermal conductivity calculations by Flowers and Itoh (1976, 1979).

The thermal conduction equation is accurately solved in the present work. Thus a finite timescale is required for the neutrino cooling effect in the deep interior of the star to reach the surface.

We have used the stiff equation of state by Pandharipande, Pines, and Smith (1976). As an example we show the results of the calculation for a 0.4 $M_\odot$ neutron star in Figures 1 and 2.

The valley near the center of the star in Figure 1 is due to the small specific heat of the $^1S_0$ neutron superfluid. The trough around $\rho \sim 10^{10}\,\mathrm{g\,cm^{-3}}$ is due to the efficient neutrino emission.

As is clearly seen in Figure 2, the surface temperature does not fall smoothly but shows a steplike decrease. This is caused by the finiteness of the thermal conduction timescale. The present finding will have important consequences when one compares the theoretical cooling curve with the X-ray observation.

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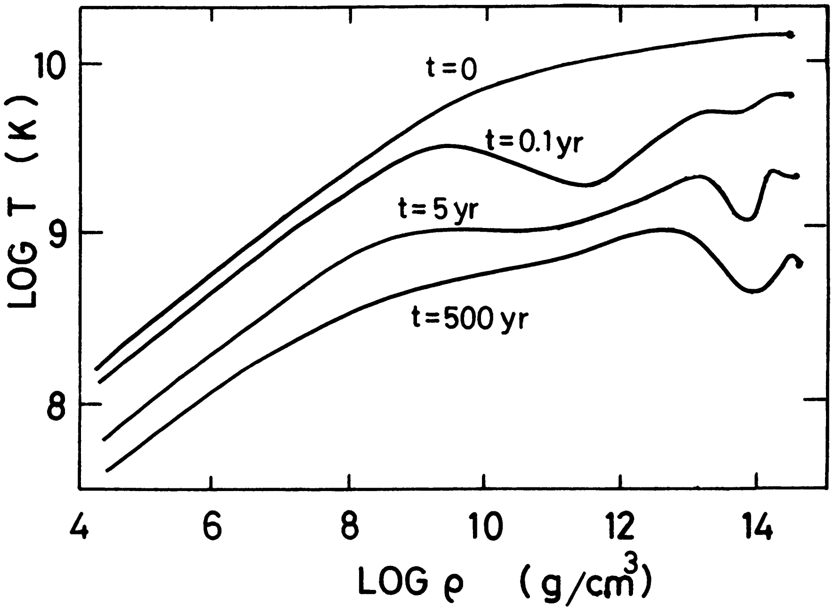

Figure 1: Internal temperature of a 0.4 $M_\odot$ neutron star

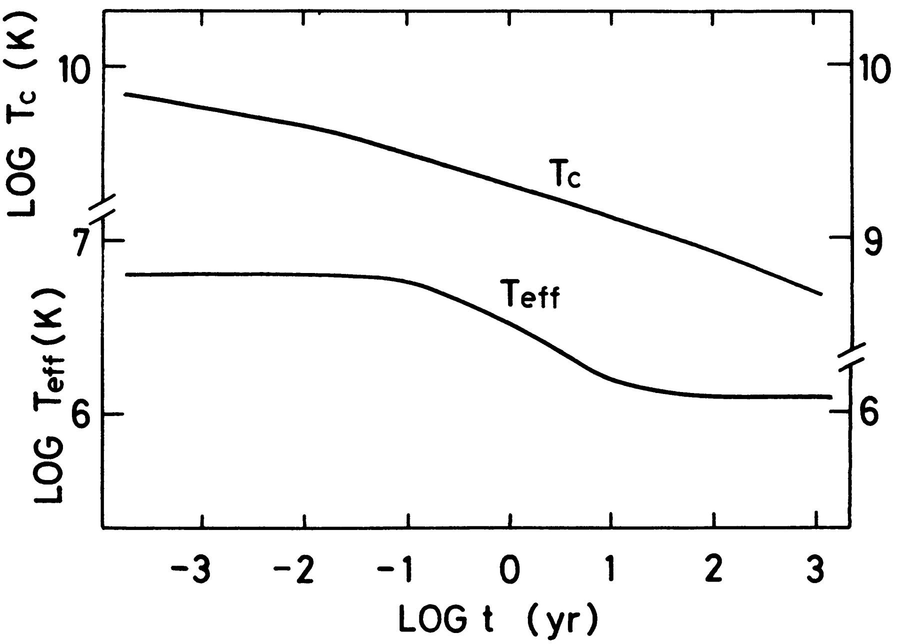

Figure 2: Central and surface temperatures of a 0.4 $M_\odot$ neutron star

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DISCUSSION

CHENG: Would the possibility of convective motions during the first 10^3 s (or so) make much difference in the cooling?

ITOH: The thermal conductivity is high enough to prevent convection.

SCHEUER: If you have a complicated magnetic field structure in the crust, will the temperature be higher?

ITOH: The effect of a complicated field structure will not be drastic, since the effect of the directionality is averaged.

RUDERMAN: Is the time delay for thermal propagation through the crust in your $M = 0.4\ M_\odot$ model sufficiently large that possible π-condensate cooling in the center would not affect the surface temperature at all during the first 10^3 years?

Would the time delay effects be very much reduced with a $1.4\ M_\odot$ neutron star?

ITOH: In the case of a $0.4\ M_\odot$ neutron star, the possible π-condensate cooling would not affect the surface during the first 10^3 years.

It is rather difficult to answer the second question decisively at the present stage, but I presume that it would take a couple of hundred years for the possible π-condensate cooling to reach the stellar surface in the case of a $1.4\ M_\odot$ neutron star.

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