Temperature Effects on Hyperon Superfluids in Neutron Stars

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Superfluidity of hyperons (Y), such as Λ and Σ^-, admixed in neutron star cores is of special interest since it affects so much the cooling properties of neutron stars and the effects could be checked by their surface temperature observations. In this paper, after giving a sunmary of our Y-superfluid results [1-2], we focus our attention to the temperature (T) effects on the hyperon energy gap (Δ), since we need to take account of the T-dependence of Δ in a realistic approach to the cooling problem. Main results are as in the following:
(1) From the energy gap calculations at $T = 0$, it is found that both of Λ and Σ^- are likely to be superfluid with the critical temperature $T_c(\Lambda) \sim (0.01 - 0.1)$ MeV and $T_c(\Sigma^-) \sim$(1-several) MeV, exceeding the internal temperature of neutron stars $T_i \simeq 0.01$ MeV. The existence of these Y-superfluids ($T_c > T_i$) suggests that the socalled "hyperon cooling" combined with the Y- superfluidity is a promising canditate to explain a "rapid cooling" expected for some neutron stars (such as Vela X-1 and Geminga).
(2) From the energy gap calculations extended to the finite-temperature case ($T > 0$) two important points are noted. First, the approximation usually taken, $T_c \simeq 0.57\Delta(T = 0)$, is okay for $\Delta(T = 0) << E_{FY}$ (Fermi energy) but is not applicable to the case $\Delta(T = 0) \sim E_{FY}$ corresponding to the Σ^--superfluidity. Second, under the situation $T_c \sim T_i$, which is associated with Σ^--superfluid at birth stage of neutron stars and with Λ-superfluid in thermally evolved stage, the energy gap including the T-effects, $\Delta(T)$, is by far smaller than $\Delta(T = 0)$. This means that to use $\Delta(T = 0)$ in a suppression factor $\exp(-\Delta/T)$ for ν-emissibity, as often used for simplicity, is wrong and instead $\Delta(T)$ should be used accurately.
Finally we discuss a serious consequence on the existence of Λ-superfluidity, brought about by a less attractive $\Lambda\Lambda$ interaction inferred from ${}^{6}_{\Lambda\Lambda}$He (NAGARA event)[3] recently observed, and give a comment on a new scenario for the Y-cooling.

References

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