# New scenarios of neutron star cooling

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We discuss new scenarios of neutron star cooling (the so called *minimal cooling scenarios*) in which Cooper-pairing neutrino emission in superfluid nucleon stellar cores initiates an enhanced cooling even if the powerful direct Urca process (or any other enhanced neutrino process in non-superfluid matter) is forbidden. The initial versions of these scenarios were proposed by Page et al. (2004) and Gusakov et al. (2004). We outline the initial and more elaborated versions. We employ phenomenological density-dependent critical temperatures $T_{\rm cp}(\rho)$ and $T_{\rm cnt}(\rho)$ of singlet-state proton and triplet-state neutron pairing in a stellar core, as well as critical temperature $T_{\rm cns}(\rho)$ of singlet-state neutron pairing in a stellar crust. By regulating the density dependence $T_{\rm cn}(\rho)$, we can interpret observations of thermal radiation of isolated neutron stars with forbidden or open direct Urca process. In particular, we can explain observations of isolated neutron stars coldest for their age, PSR J0205+6449 (3C 58), Vela, and RX J0007.0+7302 (CTA 1), by the Cooper-pairing neutrino emission in nucleon cores where the direct Urca process is forbidden. Special attention is paid to the effects of proton superfluidity and surface layers of light (accreted) elements on cooling of low-mass neutron stars. These effects enable one to explain observations of isolated neutron stars hottest for their age, e.g., RX J0822–4300 or PSR B1055–52. We extend the minimal cooling model by using equations of state of supranuclear matter which open the direct Urca process in the interior of most massive neutron stars. For some valid equations of state of dense matter, there exists a representative class of massive neutron stars whose cooling is intermediate between the cooling enhanced by the Cooper-pairing neutrino emission and the very fast cooling due to the direct Urca process.

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