Thermal emission of neutron stars with internal heaters

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We model thermal structure and thermal surface radiation of neutron stars with steady internal heaters. Using 2D and 1D cooling codes we analyze the propagation of heat from these heaters varying their locations, geometries and intensities. We take two equations of state (EOSs) of neutron star matter, SC+HHJ and BSk21, from Refs. [1] and [2], respectively. The former is based on a simple energy-density function. The latter is more elaborated; it is employed to test the sensitivity of the results to variations of EOSs. For both EOSs we investigate two neutron star models, with the standard neutrino emission from the core and with the fast neutrino emission provided by the direct Urca process. We demonstrate that the generated heat mainly propagates radially to the interior of the star (and is carried away by neutrinos from there), although a small part of the heat diffuses outwards to be emitted as the thermal surface radiation. In local regions near the heater the results can be well described with the 1D code. The heater creates a hot spot, which looks like heater's projection on the stellar surface. We discuss the existence of two heat propagation regimes. In the first *conduction outflow* regime, the heat rates $H_0 \lesssim 10^{20}$ erg cm^{-3} s^{-1} and the heater's temperature $T_\mathrm{h} \lesssim 10^9$ K are not too high, and the thermal surface emission of the star is controlled by the heater's power and the neutrino emission in the stellar core. In the second *neutrino outflow* regime, the heater is more powerful ($H_0 \gtrsim 10^{20}$ erg cm^{-3} s^{-1}, $T_\mathrm{h} \gtrsim 10^9$ K) and the thermal energy is mainly carried away by neutrinos. Then the surface and the outer layers of the crust become thermally decoupled from the interior and even strong variations of the heater's power cannot significantly affect the surface emission. The most economical heater should be placed in the outer crust and be moderately strong ($H_0 \sim 10^{20}$ erg cm^{-3} s^{-1}). We outline possible applications of the results to young and hot neutron stars, to neutron stars in soft X-ray transients, to magnetars and high-B pulsars.

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