Thermal emission from old neutron stars: constraints on dense-matter and gravitational physics

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The equilibrium composition of neutron star matter is achieved through weak interactions (direct and inverse beta decays), which proceed on relatively long time scales. If the density of a matter element is perturbed, it will relax to the new chemical equilibrium through non-equilibrium reactions, which produce entropy that is partly released through neutrino emission, while a similar fraction heats the matter and is eventually radiated as thermal photons (Reisenegger 1995). We examined two possible causes of such density perturbations:

1. the reduction in centrifugal force caused by spin-down (particularly in millisecond pulsars), leading to "rotochemical heating" (Fernández & Reisenegger 2005), and
2. a hypothetical time-variation of the gravitational constant, as predicted by some theories of gravity and current cosmological models ("gravitochemical heating"; Jofré 2005).

If only slow weak interactions ("modified Urca" reactions) are allowed in the neutron star, "rotochemical heating" can account for the observed ultraviolet emission from the closest millisecond pulsar, PSR J0437-4715 (Kargaltsev et al. 2004), which also provides a constraint on $|dG/dt|$ of the same order as the best available in the literature. For slower, "classical" pulsars beyond their initial cooling epoch, detectable thermal emission due to rotochemical heating is also possible if their initial rotation rate was fast enough to build up a substantial chemical imbalance. This effect can in principle be used as a measure of the initial rotation rate of these stars.