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Probing Strong Field Gravity and the Structure of Ultra-Dense Matter with the Thermal Evolution of Neutron Stars

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Thermal evolution of neutron stars is studied in the $f(R) = R + \alpha R^2$ theory of gravity.
We first describe the equations of stellar structure and evolution for a spherically symmetric spacetime plus a perfect fluid at rest.
We then present numerical results for the structure of neutron stars using four dense matter equations of state and a series of gravity theories for
α ranging from zero, i.e., General Relativity, up to $\alpha \approx 10^{16}$ cm^2.
We emphasize properties of these neutron star models that are of relevance for their thermal evolution as the threshold masses for enhanced neutrino emission
by the direct Urca process, the proper volume of the stellar cores where this neutrino emission is allowed, the surface gravitational acceleration that impact the observable effective temperature, and the crust thickness.
Finally, we numerically solve the equations of thermal evolution using the public code \texttt{NSCool} and explicitly analyze the effects of altering gravity.
We find that uncertainties in the dense matter microphysics, as its chemical composition and superfluidity/superconductivity properties, as well as the
astrophysical uncertainties on the chemical composition of the surface layers, have a much stronger impact than possible modification of gravity
within the studied family of $f(R)$ theories.
We conclude that within this family of gravity theories, conclusions from previous studies of neutron star thermal evolution are not significantly
altered by alteration of gravity.
Conversely, this implies that neutron star cooling modeling may not be a useful tool to constrain deviations of gravity from Einstein theory
unless these are much more radical than in the $f(R)$ framework.

Authors: NAVA-CALLEJAS, Martin Javier (Instituto de Astronomia - UNAM); Dr PAGE, Dany (Instituto de Astronomía - UNAM); Dr BEZNOGOV, Mikhail V. (Instituto de Astronomía - UNAM)

Presenter: NAVA-CALLEJAS, Martin Javier (Instituto de Astronomia - UNAM)

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