Log N – Log S distribution as a new test for cooling curves of neutron stars

S.B. Popov*, H. Grigorian†,**, R. Turolla‡ and D. Blaschke§,¶

*Universitetski 13, 119992 Moscow, Russia
†D-18051 Rostock, Germany
**Alex Manoogian 1, 375025 Yerevan, Armenia
‡Marzolo 8, 35131, Padova, Italy
§D-33615 Bielefeld, Germany
¶141980, Dubna, Russia

Abstract. We propose to use population synthesis studies as an independent approach to test the physics governing the star cooling. Theoretical Log N-Log S distributions depend on the assumed neutron star thermal evolution. We have computed distributions for several different cooling scenarios and found that comparison with the observed Log N-Log S of isolated neutron stars is effective in discriminating among cooling models.

Keywords: Neutron stars, Thermal evolution, Population synthesis
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INTRODUCTION

The determination of the equation of state at or above nuclear densities is a long sought goal in high energy astrophysics. In this respect direct observations of neutron stars (NSs) are bound to provide invaluable insight into several key issues of fundamental physics. For the time being X-ray observations of NSs are, and will still be for some time, central in fostering our understanding of the star interior (see [1] for a review). Isolated neutron stars which emit at X-ray energies as they cool are particularly promising in this respect. Their thermal radiation, in fact, directly comes from the star surface, carrying information on the physical conditions of the emitting matter, in particular on the star surface temperature (see [2] for a review).

A customary way of testing predictions of cooling calculations is to construct a temperature vs. age (T–t for short) plot for the largest sample of sources. Despite its wide application and undisputed usefulness, this test has a number of limitations. In this paper we suggest to use the Log N–Log S distribution of close-by NSs as an additional probe for NS cooling models. The idea is based on the comparison of present observational data with NS population synthesis calculations in which cooling curves are one of the ingredients. Our approach extends the actual calculation of observational properties of the population of close-by young NSs.

LOG N – LOG S TEST

Here we briefly describe the Log N–Log S test of cooling curves of isolated NSs. Details can be found in [3].

The Log N–Log S distribution is a widely used tool in many branches of astronomy. One immediate advantage of the Log N–Log S test is that, at variance with the T–t test, no degree of arbitrariness is introduced when observational data are analyzed: both the fluxes and (of course) the number of sources are well measured. In addition, this approach is a "global" one. In our scenario it would not be possible to explain some particular sources by invoking slight changes in the cooling physics. Once the parameters of the model other than those related to the cooling process are fixed, a particular cooling curve either fits the population as a whole or not. Furthermore, the Log N–Log S sample is a uniform one, i.e. objects are flux (and probably volume) limited, and no strong selection criteria are introduced.

We run a population synthesis model (see [4] for a brief review of population synthesis in astrophysics) of close-by young isolated NSs. A calculated Log N–Log S distribution is compared with the data observed by ROSAT.

For illustrating the capabilities of the proposed approach, we applied it to nine sets of cooling curves from [5]. The application of the Log N-Log S test ruled out at least six out of nine investigated cooling models, resulting in just three models which were able to pass both tests.

One of the most challenging questions for the application of the test suggested in this paper is to use it next for a possible discrimination between purely hadronic compact star cooling scenarios and hybrid ones for stars having a color superconducting quark core which have already successfully passed the T–t test. Our conclusion is that the Log N–Log S may therefore become a powerful strategy in uncovering the properties of dense nuclear matter under the extreme conditions in neutron star interiors. The Log N–Log S test is mostly effective when used together with the standard T–t test.

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