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Examiner's report on the Ph.D. thesis of Martin Urbanec

This thesis deals with equations of state for neutron-star matter and study of neutron-star models, with applications to neutrino-trapping in compact stars, quasi-periodic oscillations in compact X-ray sources and placing constraints on the nature of neutron-star matter using various types of astronomical observation. The work presented consists of reprints of two papers published in refereed journals and two other articles in preprint form, prefaced by a systematic extended introduction to the problems treated and methodology used, which also contains some further original material.

The first part starts with a short introduction to the basic ideas about neutron stars and how they fit in to the overall picture of stellar evolution, and then there is a chapter describing the various regions of a neutron star and the different approaches to obtaining an equation of state for neutron-star matter. This is concise but satisfactorily done. Chapter 3 presents the methodology for calculating static neutron-star models, giving results for a range of equations of state, and also describes how to calculate corresponding rotating models within the slow-rotation approximation. In the latter part, it is pointed out that two dimensionless ratios, involving the moment of inertia and the quadrupole moment respectively, are both almost unique functions of compactness for a wide range of plausible equations of state. Also, it is pointed out that the one involving the quadrupole moment gets close to its value for a Kerr metric black hole as the mass of the model is increased up to its maximum value. These are both important points. Chapter 4 discusses models for hypothetical stars composed of deconfined strange quark matter, introducing the concept and the basic properties that they would have, as well as addressing issues of what would happen if a standard neutron star undergoes a transition to becoming a strange star. There are some interesting points here and this work has potential for further development. Chapter 5 discusses using various kinds of observation to constrain models for the equation of state, examining a range of equations of state from the literature. This is an active area of research, with advances in observational techniques currently opening up exciting new possibilities. The work presented is in the mainstream of these developments and shows good knowledge of the subject area. Chapter 6 is then the Summary and Conclusion and there is an appendix describing some technicalities of the nuclear-matter calculations.

The second part of the thesis, containing the attached papers, starts with a substantial published article discussing possible gravitational trapping of neutrinos within extremely compact stars having radii less than 1.5 times that of the circular photon orbit in the non-rotating limit. It is not certain whether such extreme objects actually exist in nature, but studying them is nevertheless worthwhile. The paper is very systematic, giving a good explanation of what is being done and of the possible consequences. The second paper contains an extended analysis of previous work by other authors on obtaining mass constraints for neutron stars based on the relativistic precession model for quasi-periodic X-ray oscillations. Following a careful analysis including treatment of the neutron-star rotation (which had not been included by the previous authors), the conclusion is reached that no meaningful limits can be placed on the mass without having additional knowledge about the angular momentum. I think that this is correct and that the paper makes a significant contribution to the literature. The third paper deals with constraining neutron-star equations of state by means of confrontation with observational data, focussing on a particular set of equations of state derived by other authors using the relativistic mean-field method. Again, the work is systematic and well-presented, reaching the conclusion that one of the parameterisations is to be clearly preferred over the others. The paper is a useful contribution to the ongoing work in this area. Finally, the fourth attached paper returns to the subject of quasi-periodic oscillations but following the alternative proposed mechanism involving resonance of epicyclic oscillations. Again models of rotating neutron stars are used, constructed with a range of equations of state. It is demonstrated rather conclusively that the well-known observed 3:2 frequency ratio is almost certainly *not* produced by this mechanism for neutron stars, at least in its simplest form. In my view, this is the most important and striking result of the thesis.

My overall view of the thesis is that it is substantial and well-presented. I learned some interesting new things from it. There are some points of detail which I would like to discuss with the candidate when I have the opportunity, but this is not going to affect my overall positive judgement. I think that the thesis makes a significant original contribution to the subject area and I am pleased to recommend that it be approved for award of the Ph.D. degree.

John Miller

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