Hessisches Kompetenzzentrum
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# *Modelling of Neutron Star Properties*


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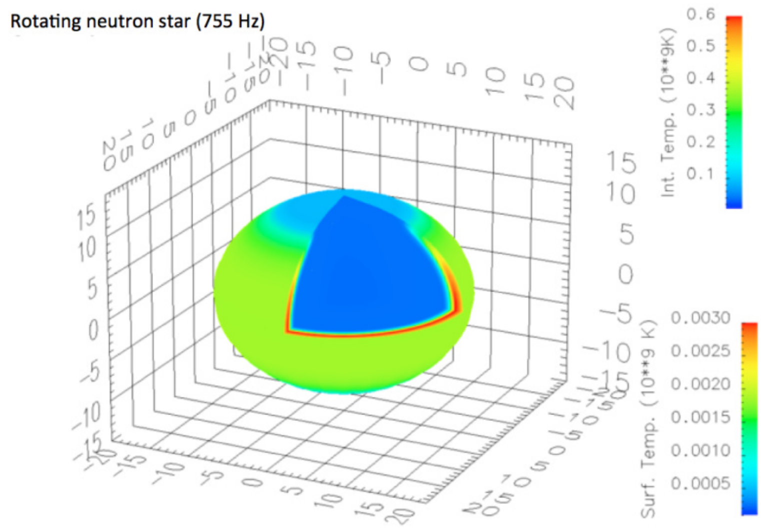


## Introduction

The investigation of neutron stars is a central topic in modern astrophysics. Whereas the crust of the star consists of exotic extremely-neutron rich nuclei densities in the core of the star can reach densities perhaps up to ten times the density of ordinary nuclei. Under these conditions, in addition to neutron, protons, and electrons, the star might contain exotic baryons like hyperons or even a core of quark matter.

In our project we address all these different conditions, from ordinary nuclei in the crust to quark matter in the interior. To this end we adopt a model for the strong interactions1 that has been developed in our group and has been successfully applied to problems of heavy-ion, nuclear and astrophysics.

## Methods

The chiral mean-field (CMF) approach contains as degrees of freedom nucleons, hyperons and the corresponding mesonic states. Here, the masses of the baryons are generated through the interaction with the scalar mesons. Quarks are included in an analogous
formulation. Thus, the model contains the correct asymptotic degrees of freedom in a unified approach in contrast to many approaches that connect the hadronic and quark sector by hand.

## Results

Using this model we studied the properties of compact stars.[1] One advantage of our approach is that, in agreement with lattice QCD calculations, the model does not necessarily lead to a first-order phase transition to quark matter. Lattice simulations show that for baryon-poor systems like in the fireball created in ultrarelativistic collision of heavy nuclei, the transition to quark matter is a smooth crossover. Such a transition can be described within our quark-hadron approach. We could show that it is possible to obtain a neutron star with quarks present even without a first-order phase transition. In general, however, the finding is that a large quark component requires a strong repulsive force between the quarks, which contradicts lattice gauge simulations of quantum chromodynamics.[2,3]

A specific important observable of neutron stars is their cooling behavior, which is affected by a fast rotation of the star. To study this point we extended our investigation to model the temperature evolution of the rotating star within a novel two-dimensional code. The figure[4] shows the example of a snapshot of the cooling exhibiting a warm polar region and a cooler equator, which can have observable consequences.

## Discussion

Currently we extend our studies to a microscopic modeling of the neutron star crust. In a first step we have improved our model parameters to achieve an excellent description of the binding energies of all known nuclei. This required large-scale computations of several thousand nuclei using our two-dimensional nuclear structure code. In the neutron star crust much more exotic and neutron-rich nuclei are present. Therefore, we calculate the properties of exotic neutron-rich isotopes including the transition to the so-called pasta phase of nuclear rod- and slab-like shapes in the inner crust of the star. The dynamics of the system is implemented using a GPU-accelerated code, which we have developed in the recent years.

## Reference

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[2.] P. Rau, J. Steinheimer, S. Schramm, and H. Stöcker (2014), Conserved Charge Flucuations in a Chiral Hadronic Model including Quarks and Hadrons, Phys. Lett. B733: 176.
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[3.] J. Steinheimer and S. Schramm (2014), Do lattice data constrain the vector interaction strength of QCDfi, Phys. Lett. B736: 241.
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