A Systematic Analysis of Hybrid Stars Using a Hadronic Equation of State Suitable for Core-Collapse Supernovae

Oliver HEINIMANN[1], Matthias HEMPEL[1] and Friedrich-Karl THIELEMANN[1]

[1] *University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland*

E-mail: oliver.heinimann@unibas.ch

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Our long-term goal is to develop a new supernova equation of state that meets the observational 2 $M_\odot$ neutron star constraint and that includes quark matter. In this work, we perform a parameter scan to systematically investigate the hadron-quark phase transition in cold neutron stars using the state-of-the-art supernova equation of state HS(DD2) for the hadronic phase. We find neutron star configurations with maximum masses above 2 $M_\odot$ and even above the maximum mass of HS(DD2). Our results show good agreement with other parameter scans.

KEYWORDS: equation of state, hybrid star, neutron star, QCD

1. Introduction

The composition of matter at extreme densities, as e.g. observed in neutron stars or core-collapse supernovae (CCSN), is highly uncertain. At such densities, new degrees of freedom as e.g. quarks should be considered. However, the measurements of 2 $M_\odot$ neutron stars [1,2] set a crucial constraint on equations of state (EOSs), especially those that consider such new degrees of freedom. Our aim is to develop a new supernova EOS that considers quark matter and fulfills the 2 $M_\odot$ neutron star constraint. In this work, we analyze the cold hybrid star configurations using the method developed by Alford et al. in [3]. For the hadronic phase we take the state-of-the-art supernova EOS HS(DD2) [4] and compare our results with the ones of [3] where different hadronic EOSs were used.

2. Hybrid Star Model

To systematically analyze hybrid stars, we use the simple model introduced by Alford et al. in [3]. Only the hadronic EOS is varied to the HS(DD2) EOS. In the following, a brief overview of the hybrid star model is given.

2.1 Hadronic Matter

Hadronic matter is described by the HS(DD2) EOS [4, 5] , which is a supernova EOS available at finite temperature and variable proton fraction and density in form of a table. HS(DD2) is based on density-dependent relativistic mean-field theory and is in good agreement with experimental constraints. HS(DD2) has a high maximum mass of 2.42 $M_\odot$ for cold neutron stars. In this work, we use the HS(DD2) table in beta-equilibrium and at $T = 0.1$ MeV, which is cold on nuclear scale and therefore comparable to $T = 0$.