CompStar EoS Workshop
Final Report

GSI, Darmstadt, Germany
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1 Summary

The workshop took place at the GSI theory group, the place where CompStar originally began in October 2006. The founding members of the CompStar network, Luciano Rezzolla and David Blaschke, started an initiative as well as the current meeting in order to coordinate and organize the effort towards an equation of state (EoS) for hot and dense nuclear matter which can be used in a large variety of astrophysical applications. The EoS was given the name CompStar EoS. The effort includes several aspects of fundamental nuclear research as well as input requirements from potential users modeling astrophysical scenarios such as neutron stars, neutron star cooling, neutron star mergers, neutron star collapse to black hole and core collapse supernovae. These applications describe very different physical conditions. E.g. neutron star matter is basically cold and in β-equilibrium, where matter in supernovae is hot and covers neutron-rich as well as proton-rich conditions.

The current meeting brought together the CompStar expertise in the different fields of nuclear and astrophysical research. In addition, several participants of the EMMI workshop at GSI on neutron matter in astrophysics and of the WE-Heraeus summer school at GSI on nuclear astrophysics in the cosmos preceeding the NIC XI conference

in Heidelberg joined the Compstar workshop and contributed to the lively discussion. In total, 40 physicists working in the fields of nuclear physics and astrophysics attended the meeting with a large fraction of young researchers.

A major objective was the discussion about the continuing procedure in order to construct the CompStar EoS. Therefore, coordinators were elected. Their job is to interact between the nuclear physics modelers, who will work on the nuclear physics description of hot and dense nuclear matter, and the astrophysical users of the resulting EoS. The coordinators will ensure the smooth collaboration, which includes mainly the exchange of information, between these two main contributors to the CompStar EoS initiative. Furthermore, a timeline was established for the first results.

To conclude, the meeting was a great success. It brought together the nuclear physicists, who will develop the tools and construct the CompStar EoS based on the requirements from astrophysics, and the actual CompStar EoS users.

2 Scientific Content

Corresponding to the different points of view of the two scientific communities involved in the use and construction of the CompStar EoS, the meeting was divided into two parts. During the morning session, applications of the EoS and the needs of the users were addressed. The session was opened with an extended talk by L. Rezzolla from the MPI in Potsdam (Germany) about 'The role of the EoS in the modeling of binary neutron stars'. It was followed by the short presentation of M. Liebendörfer from the University of Basel (Switzerland). He illustrated and discussed the EoS in core collapse supernova simulations of massive stars, including massive star explosions and the collapse to black hole. In a second short contribtutions, A. Drago from the University of Ferrara (Italy) focused on the possibility of including exotic matter at extreme conditions which are found in (proto)neutron star interiors. In particular, he addressed the question of 'Quark deconfinement as the inner engine of long GRBs'.

In the following discussion limitations and problems in the use of existing EoS were collected and possible improvements were suggested. Basic requirements for EoS, to be developed in the future, were specified. This point covered technical details of the calculation of matter properties, issues of precision, the storing and use of tabulated data, as well as questions related to the minimal content of physical models for the EoS.

The morning session was completed by a talk of Y.-Z. Qian on 'Diverse Supernova Sources for Neutrinos'.

Talks during the afternoon session were devoted to the equation of state in nuclear physics with models based on hadronic and quark matter pictures. It began with an overview presentation by S. Typel from GSI Darmstadt (Germany). He discussed the physical range in terms of the physical conditions which should be considered and the state of matter at these conditions. Furthermore, he specified general technical details for the construction of the CompStar EoS. Then a number of short contributions followed. These talks were given by E. N. E. van Dalen from the University of Tübingen (Germany), V. Dexheimer from FIAS (Germany), M. Hempel from the University of

Heidelberg (Germany), R. Lastowiecki from the University of Wrocław (Poland), J. Lattimer from the Stony Brook University (US), M. Oertel from LUTH (France), I. Vidana from the University of Coimbra (Portugal) and H. H. Wolter from the University of Munich (Germany). E. N. E. van Dalen discussed specific aspects of nuclear matter at intermediate densities where special nuclear structures are found, which at present have not been considered consistently in simulations of astrophysical scenarios. The talks by V. Dexheimer, M. Hempel, R. Lastowiecki, M. Oertel, and I. Vidana discussed various aspects of nuclear matter, such as the low-density EoS, different many-body techniques and the inclusion of exotic matter with additional degrees of freedom such as quarks and hyperons at high densities. J. Lattimer focused on constraints with respect to astronomical observations, in particular neutron star mass measurements, which must be fulfilled by the EoS for nuclear matter. H. H. Wolter established the ties to heavy-ion collisions that allow to study additional aspects of the EoS.

The entire meeting closed with a discussion about the continuing procedure in order to construct the CompStar EoS. The following people were elected for the coordination of the EoS development: M. Baldo (low density), A. Illarionov (medium density) and M. Oertel (high density). For the EoS users and applications, the following people were elected: A. Drago (core collapse supernovae and proto-neutron stars), S. Bernuzzi (mergers) and L. Gualtieri (perturbations). The next step is the construction of a preliminary EoS, including the very basic and necessary input physics, by the end of 2010. The EoS table will be accompanied by easy-to-use computer routines to extract the relevant physical properties of dense matter in the astrophysical applications. This first version will establish the basic structure and standard for following extensions and refinements of the CompStar EoS. It is envisioned that several models will be made available for practical use in the future.

3 Assessment of the results and impact of the event

This meeting was the original starting point for the CompStar EoS initiative. The scientific goal formulated is the construction of an EoS for hot and dense nuclear matter, which will become available to a large variety of astrophysical users not only to the CompStar community. It is an extremely challenging task and will require enormous effort from all working contributors from nuclear physics as well as from astrophysics. The project will last for several years. The current event was of fundamental importance in order to coordinate and guide the effort. In particular, a minimum physics model was proposed which includes the nuclear physics input required for a large number of astrophysical applications. Once this very first version of the CompStar EoS is designed, it will become available and be used in simulations of massive star explosions, formation of solar mass black holes and neutron star physics. This model is a major and very significant addition to presently available EoSs for hot and dense nuclear matter, each of which can be used only in a very limited number of astrophysical applications because these EoSs are usually valid only for a narrow range of thermodynamic conditions. This particular problem could be overcome here for the CompStar EoS initiative, where

various different astrophysical users are directly involved in this project. Their "wish-list" will serve as the major guide for the construction and the requirements for the CompStar EoS.

After the minimum version will have been approved, additional versions of the CompStar EoS will be designed where improved and even at present speculative physics input will be included. This may involve exotic matter such as hyperons, Bose condensates and quarks. Furthermore, an online platform will be created where the results will become available for the public.

The event was also recognized internationally, indicated by the contribution from two distinguished researchers, i.e. J. Lattimer and Y.-Z. Qian. Both work on various aspects related to hot and dense nuclear matter and applications in astrophysics, in particular neutron stars and core collapse supernovae. They were able to give helpful comments and discussed critical points of view throughout the meeting.

4 Final Program

09:00 Opening, adoption of the agenda
09:15 The role of the EoS in the modeling of binary neutron stars
(L. Rezzolla, Postdam)
10:00 Short contributions from users of the EoS:
The equation of state in astrophysical applications
(M. Liebendörfer, Basel)
Quark deconfinement as the inner engine of long GRBs
(A. Drago, Ferrara)
10:30 Break
11:00 Discussion (Theme: What is needed for the application
of EoS in astrophysics?)
12:00 Diverse Supernova Sources for Neutrinos
(Y.-Z. Qian, Minneapolis)

12:30 Lunch

13:30 Where do we stand? EoS theory
(S. Typel, Munich/Darmstadt)
14:15 Short contributions from the suppliers of EoS:
EoS from realistic interactions
(E.N.E. van Dalen, Tübingen)
Chiral symmetry restoration and deconfinement in neutron stars
(V. Dexheimer, Frankfurt)
Statistical model with excluded volume and interactions
(M. Hempel, Heidelberg)
High-density equation of state for SN simulations
(R. Lastowiecki, Wrocław)
Equation of state constrained by observation of neutron stars
(J. Lattimer, Stony Brook)
An extended equation of state for simulations of stellar collapse
(M. Oertel, Meudon)
The nuclear matter EoS: a comparison of different many-body techniques
(I. Vidana, Coimbra)
Symmetry energy and the determination of the EoS in heavy-ion collisions
(H.H. Wolter, Munich)
15:30 Break
16:00 Discussion (Theme: What can be delivered by theory?
Towards the "CompStar EoS")
18:00 End of meeting