UTK EOS Integration

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MUSES Collaboration

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Outline

- Discussions about the UTK EOS.
- The EOS tables, the source codes and where to find them.
- The Docker integration (How to run the code inside a docker container).
- How to read and plot the EOS tables.
- The calculation engine integration (progress, challenges).
- Future work plan (adding Pions to the EOS, machine learning, plans etc.)

UTK EOS Strengths

- We cover a large range of densities, temperatures, and electron fractions.
- Our EOS includes nuclei and nucleons together, which is necessary at low temperatures.
- We match our model with the virial expansion for nucleon at low-densities.
- Our model matches experiments from FRIB.
- Our EOS is also consistent with neutron star observations.

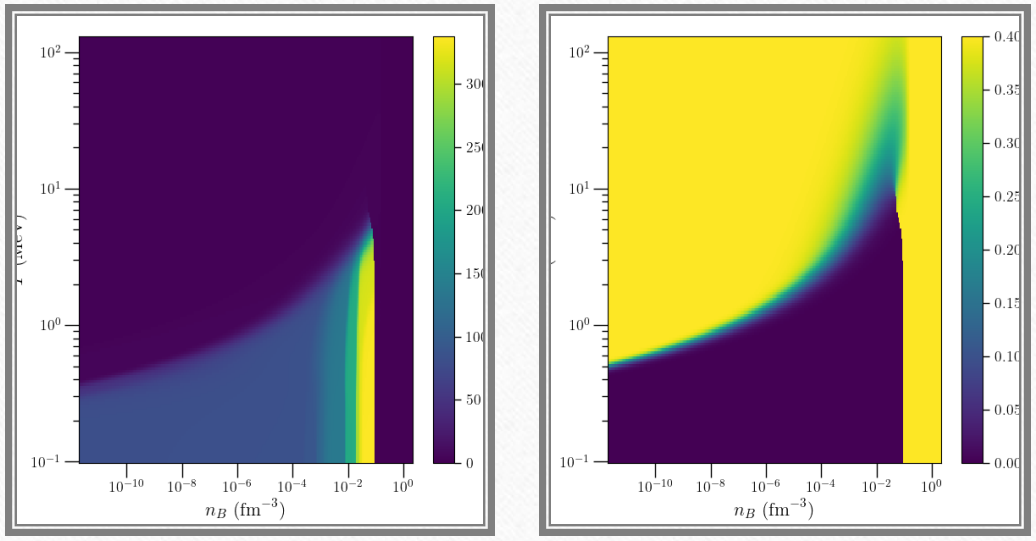
Where to Download

- Our source code is available at https://github.com/awsteiner/eos
- Full documentation available at https://neutronstars.utk.edu/code/eos .
- This is based on the works of Xingfu Du, Andrew Steiner, and Jeremy Holt, Phys. Rev. C (2019) and (2022).
  - [1802.09710v1] Hot and Dense Homogeneous Nucleonic Matter Constrained by Observations, Experiment, and Theory (arxiv.org)
  - [2107.06697] Hot and Dense Matter Equation of State Probability Distributions for Astrophysical Simulations (arxiv.org)
- We have multiple EOS tables available to download at https://neutronstars.utk.edu/code/eos/download.html

Running the code

- All you need is docker installed in your local machine.
- ✓ Run: `git clone` https://github.com/awsteiner/eos
- ■ Switch to the v2 branch: `git switch v2`
- Create the docker image: `docker build -t eosv2 - < Dockerfile`
- ■ Run a container from it: `docker run -it --name=utk_eos eosv2 bash`
- Full documentation at https://github.com/awsteiner/eos/blob/v2/README.md

Make sense of the result



- You do not need to compile the code to use the EOS tables - they can be read by any application which reads HDF5 files.
- Or you can use our matplotlib based O2graph to read and plot the tables (documentation at https://neutronstars.utk.edu/code/eos/plotting.html (work in progress)).
- (**left**) average nuclear mass number as a function of density and temperature at a fixed electron fraction of 0.4, (**right**) same plot for proton fraction.
- Documentation of O2graph available at https://neutronstars.utk.edu/code/o2sclpy/o2graph.html

MUSES Integration

- Docker integration works mostly (needs more testing on different setups).
- Working on calculation engine integration:
  - Creating input and output YAML files so they can be used with other modules.
  - Creating specific functions for MUSES so EOS tables can be interpolated fast for specific needs.
- Immediate goal is to make sure MUSES can use our EOS tables from 2022.
- Expecting to integrate current EOS main branch within next few months.

Vision for our project

- Our vision:
  - Include strangeness to our EOS,
  - Use machine learning to improve the EOS calculation efficiency.
- We built some of the code infrastructure for strangeness.
- There are approximately 3 density regimes for strangeness:
  1. Non-degenerate, 2. near saturation with nuclei and 3. high density matter.
- Current focus is on non-degenerate strangeness through hadron resonances (code written, not yet tested).
- We are planning on implementing CMF or NJL models for higher densities.

Plan ahead

- We are currently looking into neural network and Gaussian process interpolators.
- Hadronic resonances need pion-nucleon interactions which we are working on.
- We are improving our crust EOS with better Coulomb corrections.
- Our code is slow, so while computing EOS for certain point, we also want to make tables that MUSES can interpolate from.
- NP3M is also funding related work on neutrino opacities consistent with underlying EOS (we find many phenomenological models predicting incorrect neutrino opacities.)

Thank you

For your attention!