CompOSE

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PHAROS WG1+WG2 Workshop

PHAROS
THE MULTI-MESSENGER PHYSICS AND ASTROPHYSICS OF NEUTRON STARS

CompOSE2021
Online Repository for the Equation of State and Transport Properties of Neutron Stars

CompOSE2021

February 24 – 26, 2021

Institute of Space Sciences
Barcelona
(virtual)

cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Outline

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- Handling of EoS Data
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Introduction

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- tables of equations of state (EoS) for astrophysical applications
  - distributed over many places
  - central repository needed
  - coordinated effort of community

$\Rightarrow$ **CompOSE** = **Comp**Star **O**nline **S**upernovae **E**quations of State

- history
  - initial work within CompStar project (funded by ESF)
    - core team (Thomas Klähn, Micaela Oertel, Stefan Typel)
    - support team (David Blaschke, Tobias Fischer, Matthias Hempel, Daniel Zabłocki)
  - first status report: Rostock 2010
  - publication of first manual
    - arXiv:1307.5715 [astro-ph.SR], Phys. Part. Nucl. 46 (2015) no.4, 633-664
  - further presentations: Lyon 2014, Basel 2016, Trento 2017, Coimbra 2018
- many discussions about extensions but little progress recently
  (except details, additional EoS tables, development of web pages)

Main Features

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- **free-access website (compose.obspm.fr)**
  - hosted at LUTH, Observatoire de Paris, Meudon, France
- **repository of EoS tables**
  - thermodynamic properties, chemical composition, microscopic quantities
  - tabulation in temperature, baryon density, and hadronic charge fraction
  - flexible data format
- **tools for handling of EoS data**
  - software for extraction, interpolation and calculation of additional quantities
  - online generation of customized EoS tables (access restricted)
  - different output formats
- **documentation**
  - manual and 'how-to' instructions
  - bibliography of EoS publications
  - links to related projects

Website I

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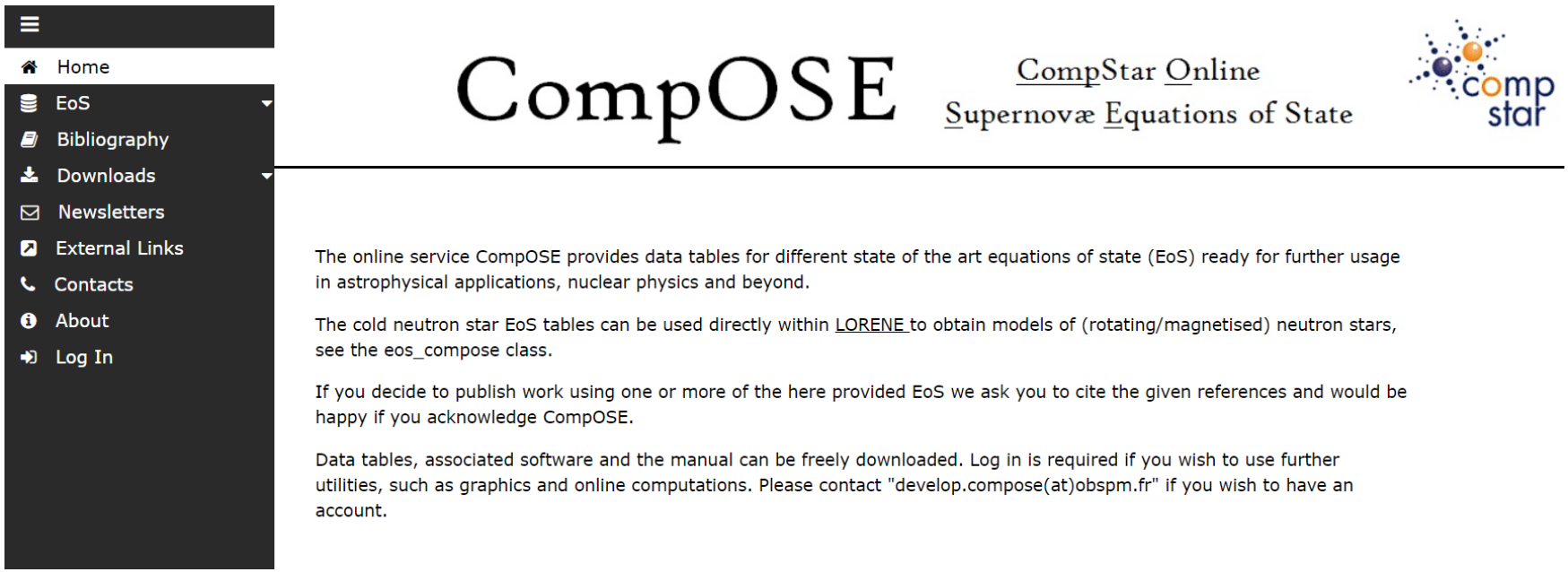

- **compose.obspm.fr**
- **support and development**
  - Micaela Oertel, Marco Mancini, Jean-Yves Giot, Thomas Klähn
  - LUTH, Meudon, France

Website II

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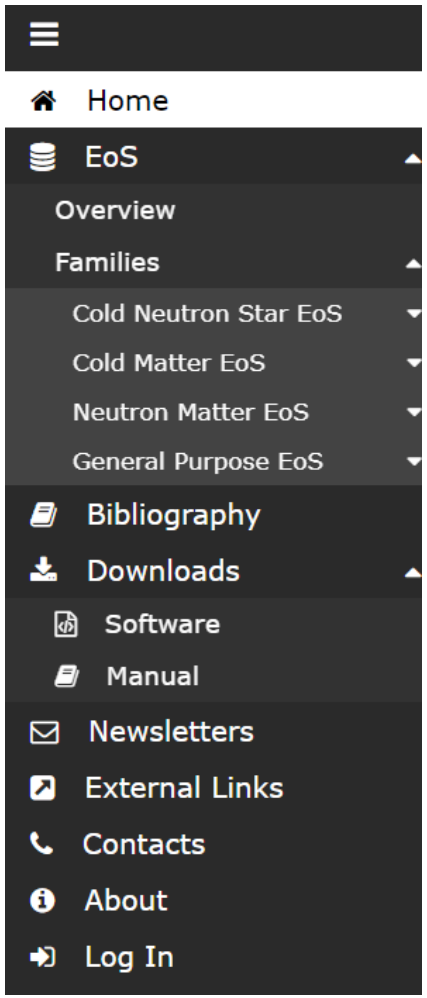
- **items**
  - EoS tables of different type
    - Cold Neutron Star EoS (38, 1-dim.)
    - Cold Matter EoS (6, 2-dim.)
    - Neutron Matter EoS (27, 2-dim.)
    - General Purpose EoS (85, 3-dim.)
  - Bibliography
  - Downloads
    - Software
    - Manual
  - Newsletters
  - External Links
  - Contacts
  - About
  - Log In



EoS Tables I

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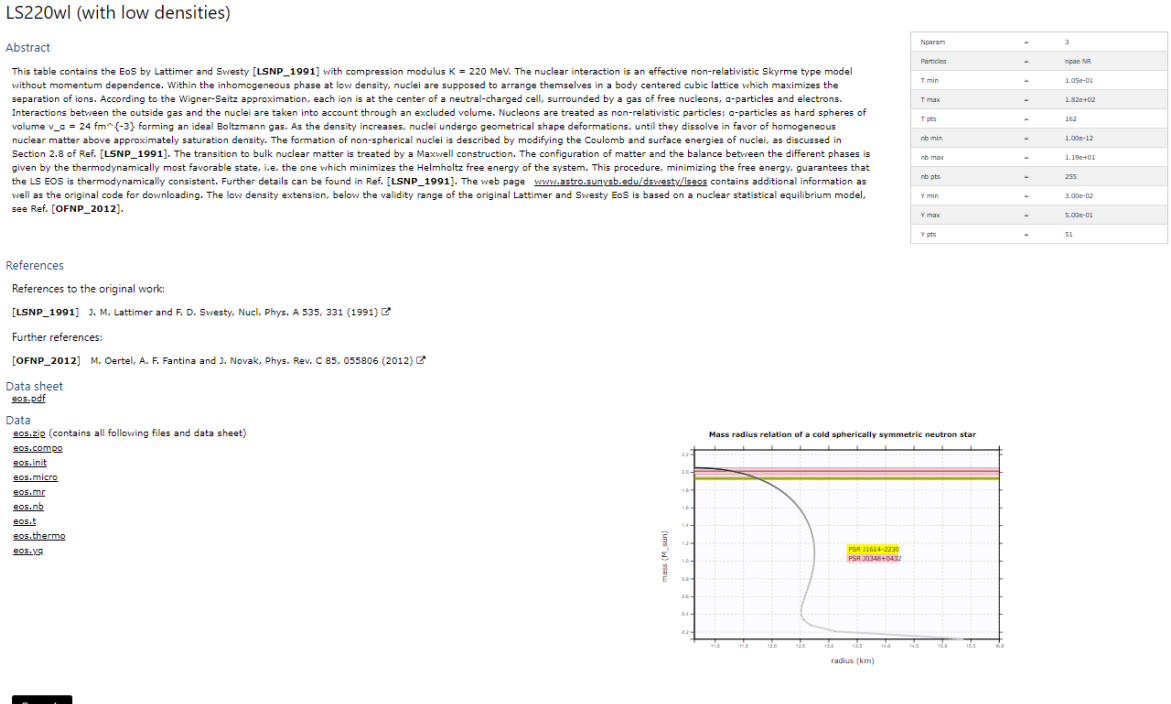
- individual pages for EoS tables
- content
  - abstract
  - references
  - data sheet
  - data files
  - scheme of tabulation
  - mass-radius relation of neutron star (if available)
  - button for online computation



LS220wl (with low densities)

Abstract

This table contains the EoS by Lattimer and Swesty [**LSNP_1991**] with compression modulus K = 220 MeV. The nuclear interaction is an effective non-relativistic Skyrme type model without momentum dependence. Within the inhomogeneous phase at low density, nuclei are supposed to arrange themselves in a body centered cubic lattice which maximizes the separation of ions. According to the Wigner-Seitz approximation, each ion is at the center of a neutral-charged cell, surrounded by a gas of free nucleons, α-particles and electrons. Interactions between the outside gas and the nuclei are taken into account through an excluded volume. Nucleons are treated as non-relativistic particles; α-particles as hard spheres of volume v_α = 24 fm^{-3} forming an ideal Boltzmann gas. As the density increases, nuclei undergo geometrical shape deformations, until they dissolve in favor of homogeneous nuclear matter above approximately saturation density. The formation of non-spherical nuclei is described by modifying the Coulomb and surface energies of nuclei, as discussed in Section 2.8 of Ref. [**LSNP_1991**]. The transition to bulk nuclear matter is treated by a Maxwell construction. The configuration of matter and the balance between the different phases is given by the thermodynamically most favorable state, i.e. the one which minimizes the Helmholtz free energy of the system. This procedure, minimizing the free energy, guarantees that the LS EOS is thermodynamically consistent. Further details can be found in Ref. [**LSNP_1991**]. The web page www.astro.sunysb.edu/dswesty/lseos contains additional information as well as the original code for downloading. The low density extension, below the validity range of the original Lattimer and Swesty EoS is based on a nuclear statistical equilibrium model, see Ref. [**OFNP_2012**].

Nparam	=	3
Particles	=	npae NR
T min	=	1.05e-01
T max	=	1.82e+02
T pts	=	162
nb min	=	1.00e-12
nb max	=	1.19e+01
nb pts	=	255
Y min	=	3.00e-02
Y max	=	5.00e-01
Y pts	=	51

References

References to the original work:

[**LSNP_1991**] J. M. Lattimer and F. D. Swesty, Nucl. Phys. A 535, 331 (1991)

Further references:

[**OFNP_2012**] M. Oertel, A. F. Fantina and J. Novak, Phys. Rev. C 85, 055806 (2012)

Data sheet
eos.pdf

Data
eos.zip (contains all following files and data sheet)
eos.compo
eos.init
eos.micro
eos.mr
eos.nb
eos.t
eos.thermo
eos.vp

Compute

EoS Tables II

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- files with **parameter grid**
  - temperature T (unit MeV) $\rightarrow$ `eos.t`
  - baryon density n_b (unit fm^{-3}) $\rightarrow$ `eos.nb`
  - hadronic charge fraction Y_q (no unit) $\rightarrow$ `eos.yq`

  explicit listing or recursive definition (linear/logarithmic)
- files with **EoS data**
  - thermodynamic properties $\rightarrow$ `eos.thermo`
  - chemical composition $\rightarrow$ `eos.compo` (optional)
  - microscopic information $\rightarrow$ `eos.micro` (optional)

  location of data points by parameter indices
- file with detailed information (data sheet) $\rightarrow$ `eos.pdf`
- collection of all files $\rightarrow$ `eos.zip`

Data in EoS Files

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- **thermodynamic quantities** (`eos.thermo`)
  - scaled pressure P/n_b (unit MeV)
  - entropy per baryon s/n_b (unit k_B)
  - scaled chemical potentials $\mu_b/m_n - 1$, μ_q/m_n, μ_l/m_n (no unit)
  - scaled free energy and energy densities $f/(n_b m_n) - 1$, $e/(n_b m_n) - 1$ (no unit)
  - additional quantities (optional)
- **chemical composition** (`eos.compo`)
  - thermodynamic phase (index)
  - particle types (index) and density fractions ($Y_i = n_i/n_b$, no unit)
  - average mass and charge number (A_{heavy}, Z_{heavy}) and density fraction (X_{heavy}) of heavy nuclei
- **microscopic quantities** (`eos.micro`)
  - pairs of indices (defining particle type and quantity) and quantities

Handling of EoS Data I

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- **software**
  - FORTRAN code, version 1.16, 2018/10/16
    (`compose.f90`, `composemodules.f90`, `out_to_json.f90`, `get_tables.f90`, `Makefile`)
  - modes of operation
    - 'file version': needs input files provided by the user
    - 'terminal version': simple interaction with user (default)
  - output formats: ASCII and HDF5
- **input files**
  - from website: `eos.t`, `eos.nb`, `eos.yq`, `eos.thermo`, `eos.compo`, `eos.micro`
  - provided by user: `eos.parameters`, `eos.quantities`
    (only for 'file version' of code, created automatically with 'terminal version')
- **output files**
  - table with customized EoS data: `eos.table`
  - additional information: `eos.report`, `eos.init`
  - input for neutron sar calculation: `eos.beta` (if available)

Handling of EoS Data II

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- **web interface**
  - restricted access $\Rightarrow$ registration required:
    send e-mail to `develop.compose@obspm.fr`
  - generation of EoS tables online
  - graphical representation of EoS data
    (realisation of merger with EOSDB website of Chikako Ishizuka)

- **LORENE library**
  - new class: `eos_compose`
  - cold neutron-star EoS can be used as direct input for Nrotstar code
    $\Rightarrow$ properties of rotating neutron stars

Documentation

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- **manual**
  - detailed information on file formats, tabulation scheme, interpolation, ...
  - actual version: 2.00, 2018/01/26, 81 pages
- **'how-to' leaflet** (planned)
  - simple instructions on how to run the `compose` code
  - examples for different EoS types
- **online bibliography**
  - links to original publications (89 entries)
- **links to other EoS projects**
  - to be updated
- **preparation of data sheets**
  - generation of LaTeXfile `datasheet.tex` with program `eosform.cpp`

Interaction with Users

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- **submission of EoS data**
  - contact CompOSE core team by sending e-mail to `develop.compose@obspm.fr`
  - details on preparation of files and transmission of data will be clarified
- **extraction of EoS data**
  - direct download of files from CompOSE website
  - use of web interface (restricted access)
- **newsletter** (hardly ever used so far)
  - mailing list `compose.info`
  - for subscription send email with subject 'Subscribe' to `develop.compose@obspm.fr`
- **registration**
  - contact CompOSE core team by sending e-mail to `develop.compose@obspm.fr`
  - full access to all services with password

Future I

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- **modification/extension of EoS tables**
  - change of tabulated data?
  - dependence on other variables (e.g. magnetic field)
    $\rightarrow$ more than three dimensions?
  - choice of other primary variables, e.g.,
    - temperature $\rightarrow$ entropy
    - baryon density $\rightarrow$ baryon chemical potential
  - additional data (e.g. transport properties)
    - selection
    - representation
    - dependence on other variables
- **different representation of data**
  - polynomials or other functional forms?
  - development of specific subroutines for application, independent of `compose` code

Future II

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- **extension/modification of compose program**
  - choice of output units (nuclear vs. astrophysical)
  - extraction of 'isolines'
    (e.g. constant entropy per baryon, constant lepton chemical potential)
  - conversion of tables
    (e.g. change of primary variables)
  - construction of phase transitions
    (local vs. global thermodynamic consistency)
  - improvement of interpolation
    - dependence on quantities
      (some are rapidly changing in certain regions)
    - treatment of multi-dimensional cases
- **extension of data base**
  - more EoS tables
  - other EoS types for other applications
- **more suggestions?**

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Thank you for your attention!