Deliverable D13.3

WP13 – JRA09 – THEXO

Libraries of reaction cross sections and weak interaction rates as well as nuclear equations of state and report on nucleosynthesis studies for processes involving exotic nuclei

The Deliverable 13.3 consisted of two subtasks:

Subtask 3-1: **Prediction of astrophysically important reactions across the nuclear chart**
Expected result: Library of a full set of cross section predictions

Subtask 3-2: **Asymmetry energy of nuclear matter and the nuclear equation of state**
Expected result: Depository of EoS Tables

Subtask 3-1 included the funding and employment of T. Rauscher, subtask 3-2 support for M. Hempel (both at UniBas). Both projects were undertaken in close collaborations with ENSAR partners ATOMKI-HAS, GSI, GUF, JYU and TUD, including the Basel participants: F.-K. Thielemann, Thomas Rauscher, Matthias Hempel, and Non-Basel ENSAR partners: S. Typel (GSI), R. Reifarth (GUF), G. Martinez-Pinedo (TUD), G. Gyürky (ATOMKI).

Subtask 3-1 included the following topics/actions:

- determination of key input parameters/uncertainties (parallel and in synergy with work performed in tasks 1 and 2):
  - (related to task 1) evaluation of masses, fission barriers, level densities of excited states, giant electromagnetic resonances for capture reaction rates; determine regions of the nuclear chart, which due to low level densities at relevant energies require the treatment of isolated resonances and/or direct capture.
  - (related to task 2) determination of optical potentials and state properties (e.g., spectroscopic factors)
- global sensitivity study to variations in widths, level densities, proton/ alpha optical potentials, mass measurements, fission fragment distributions
- test of target g.s. vs. excited state contributions at finite temp., importance of direct capture contributions
- construction of complete sets of reaction cross sections
- test of impact in astrophysical nucleosynthesis applications

One of the highlights is the resolution of the long-standing "apparent" alpha potential problem for heavier nuclei which dissappears if Coulomb Excitations are included properly.

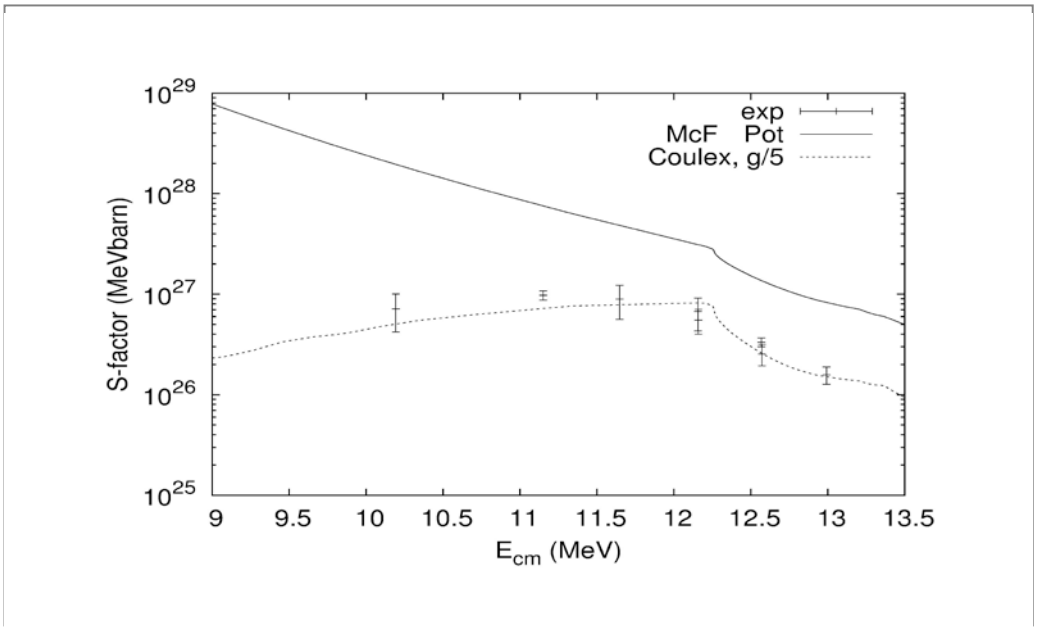

Fig. 1: Nuclear S-factor of the reaction 144Sm(α,γ) as a function of CM bombarding energy. The solid line results from statistical model predictions utilizing the experiment-based MacFadden alpha optical potential. The dashed line (reproducing the experimental cross section) results from correcting for the contributions from Coulomb Excitations (see ref. 14).

Bullet 1 of the list of actions shown above (global sensitivity study) was initialy carried out just within the framework of task 3-1, testing input and utilizing it, in order to be finally prepared to insert the high precision microscopic results of task 1 and 2 for the best possible predictions in nuclear astrophysics applications. While the deliverables in terms of complete reaction library predictions exist at the present stage, it is still planned to improve them with the final inclusion of results from tasks 1 and 2.

List of Publications which acknowledgement to ENSAR/THEXO:

1. The Path to Improved Reaction Rates for Astrophysics, T. Rauscher; Int. J. Mod. Phys. E 20 (2011) 1071
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12. Have Superheavy Elements been produced in Nature? I. Petermann , K. Langanke , G. Martnez-Pinedo , I. V. Panov , P.-G. Reinhard , and F.-K. Thielemann; Eur. Phys. J. A 48 (2012), 122
13. Proton-rich abundances and nuclear physics, T. Rauscher, C. Fröhlich; AIP Conference Series 1484 (2012), 73
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20. Europium s-process signature at close-to-solar metallicity: Insights from presolar Stardust SiC Grains from AGB stars, J. N. Ávila, T. R. Ireland, M. Lugaro, F. Gyngard, E. Zinner, S. Cristallo, P. Holden, T. Rauscher; Ap. J. Lett. 768 (2013) L18
21. Systematic study of (p,γ) reactions on Ni isotopes, A. Simon, A. Spyrou, T. Rauscher, C. Fröhlich, S. J. Quinn, A. Battaglia, A. Best, B. Bucher, M. Couder, P. A. DeYoung, X. Fang, J. Görres, A. Kontos, Q. Li, A. Long, S. Lyons, A. Roberts, D. Robertson, K. Smith, M. K. Smith, E. Stech, B. Stefanek, W. P. Tan, X. D. Tang, M. Wiescher; Phys. Rev. C 87 (2013) 055802
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23. High precision 113In(α,α)113In elastic scattering at energies around the Coulomb barrier for the astrophysical γ process, G. G. Kiss, P. Mohr, Zs. F ülöp, T. Rauscher, Gy. Gyürky, T. Szücs, Z. Halász, E. Somorjai, A. Ornelas, C. Yalçin, R. T. Güray, N. Özkan; Phys. Rev. C 88 (2013) 045804
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30. Cross section measurement of the 130Ba(p,γ)131La reaction for γ-process nucleosynthesis, L. Netterdon, G. G. Kiss, J. Mayer, T. Rauscher, A. Sauerwein, P. Scholz, K. Sonnabend, Zs. Török, A Zilges; Phys. Rev. C 90 (2014) 035806
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32. Measurement of (α,n) reaction cross sections of erbium isotopes for testing astrophysical rate predictions, G. G. Kiss, T. Szücs, T. Rauscher, Zs. Török, L. Csedreki, Zs. Fülöp, Gy. Gyürky, Z. Halász;J. Phys. G, in press.
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34. Determination of the 141Pr(α,n)144Pm cross section for the astrophysical p-process using the γγ coincidence technique, A. Sauerwein, M. Elvers, J. Endres, J. Hasper, A. Hennig, L. Netterdon, K.-O. Zell, A. Zilges, H. W. Becker, D. Rogalla, H. Dombrowski, U. Giesen, T. Rauscher; Proc. CGS14, eds. P. E. Garrett, B. Hadinia (World Scientific, Singapore, 2013), p. 376
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36. Investigation of Alpha-Induced Reactions on 107Ag at Astrophysical Energies, C. Yalçin, N. Özkan, R. T. Güray, Gy. Gyürky, G. G. Kiss, T. Szücs, Z. Halász, Zs. Fülöp, J. Farkas, E. Somorjai, Z. Korkulu, T. Rauscher; J. Phys. Conf. Ser., in press
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36. Cross section measurements for γ-process studies using a LEPS detector, T. Szücs, G. G. Kiss, T. Rauscher, Zs. Török, Z. Halász, Zs. Fülöp, Gy. Gyürky, E.Somorjai; J. Phys. Conf. Ser., in press
38. The Impact of Fission on r-Process Calculations, M. Eichler, A. Arcones, R. Käppeli, O. Korobkin, M. Liebendörfer, G. Martínez-Pinedo, I. V. Panov, T. Rauscher, S. Rosswog, F.-K. Thielemann, C. Winteler; J. Phys. Conf. Ser., in pres

Subtask 3-2 included the following topics:

- determination of the asymmetry energy of nuclear matter via medium-energy heavy-ion collisions, determination of its density dependence, analysis of the effect of pairing / finite temperatures (in independent activities, utilizing constraints from astrophysical observations, as well as comparing to results obtained from the energy density functionals studied and tested within **subtask 1-4**)
- provide EoS table for astrophysical applications

As a highlight we show results from density functionals SFHo and SFHx (Steiner et al., ref. 12) with constraints on the aymmetry energy S (29-31 MeV) and its density dependence L (40-60 MeV), which leads to realistic mass-radius relations and good estimates of maximum neutron star masses slightly above 2 Msol (as discovered recently) as seen below.

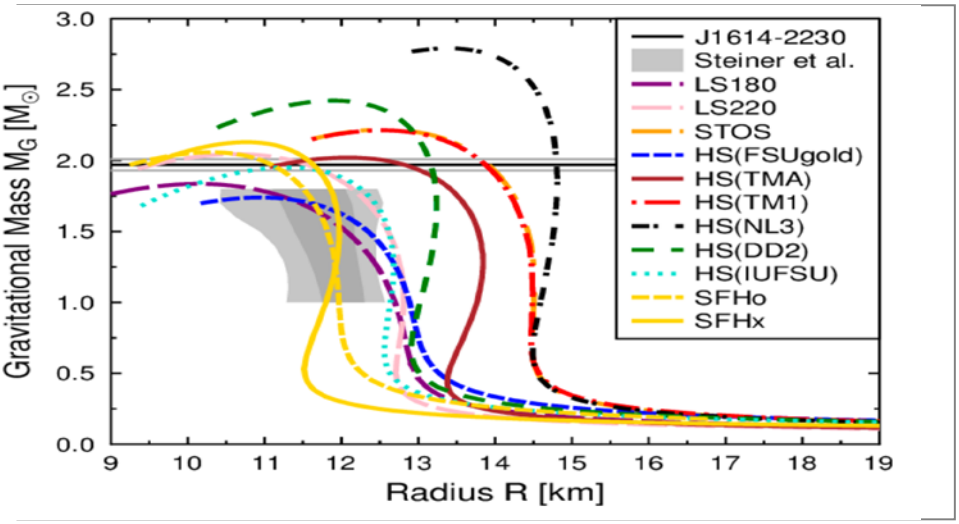

Fig.2: Neutron star mass-radius relations (from Lattimer & Lim 2013) resulting from a variaty of nuclear equations of state. It can be seen that the density functionals SFHo and SFHx by Steiner, Hempel & Fischer 2013 (ref. 12) agree best with observational constraints (shaded areas) and a maximum mass close to 2 Msol.

What remains to be done is to compare these density functionals and their properties with the energy density functionals developed in subtaks 1-4.

List of Publications which acknowledgement to ENSAR/THEXO:

1. Light clusters in nuclear matter: Excluded volume versus quantum many-body approaches, Hempel, M., Schaffner-Bielich, J., Typel, S., Röpke, G.; Phys. Rev. C 84 (2011), 055804
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6. Deconfinement to Quark Matter in Neutron Stars - The Influence of Strong Magnetic Fields, V. Dexheimer, R. Negreiros, S. Schramm, M. Hempel; AIP Conference Proceedings 1520 (2012), 264

7. Neutron Star Radii, Core-collapse Supernovae, and the Equation of State of Dense Matter, Steiner, A.; T. Fischer, Gandolfi S., Hempel, M.; Proc. XII International Symposium on Nuclei in the Cosmos, PoS(NIC XII) (2012), 038
8. A comparative study of statistical models for nuclear equation of state of stellar matter, Buyukcizmeci, N., Botvina, A. S., Mishustin, I. N., Ogul, R., Hempel, M., Schaffner-Bielich, J., Thielemann, F.-K., Furusawa, S., Sumiyoshi, K., Yamada, S., Suzuki, H.; Nucl. Phys. A 907 (2013), 13
9. The internal structure of neutron stars and white dwarfs, and the Jacobi virial equation. II, Claret, A., Hempel M.; Astron. & Astrophys. 552 (2013), A29
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15. Symmetry energy impact in simulations of core-collapse supernovae, Fischer, T.; Hempel, M.; Sagert, I.; Suwa, Y.; Schaffner-Bielich, J. Eur. Phys. J. A 50, 46 (2014)
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