Activity report of the research group at the University of Basel (UBAS) within the THEXO workpackage of the ENSAR grant for the period of 01.01.2011 – 14.06.2013

Objectives: The UBAS group has been working on Subtask 3-1:
Prediction of astrophysically important reactions across the nuclear chart,
(task 1) determination of key input parameters for predicting reaction cross sections with heavy and exotic nuclei,
(task 2) determination of optical potentials and state properties, with the aim to construct complete sets of reaction cross sections across the nuclear chart and to determine the uncertainties of results induced by uncertainties of key input parameters used in statistical model and treatment of resonances.

UBAS further worked on Subtask 3-2:
Asymmetry energy of nuclear matter and the nuclear equation of state,
determination of asymmetry energy tested with medium-energy heavy-ion collisions, testing the density dependence of asymmetry energy and determining the effect of pairing and finite temperatures.

Effectives

Dr. *Thomas Rauscher* worked on the project (3-1) during the complete first funding period. From 01.04.2011 – 31.12.2011 he has been employed by the University of Basel as a postdoc paid from the ENSAR grant, during the remaining time he was paid by University of Basel funds. Since January 2013 he has a position as reader at the University of Hertfordshire, but is still employed by Basel with 10% of his time.

Dr. *Mathias Hempel* worked on project (3-2), but was not paid by the ENSAR grant.

For both projects close collaborations (on theoretical and experimental issues) were undertaken with ENSAR partners ATOMKI-HAS, GSI, GUF, JYU and TUD.

Basel Participants: F.-K. Thielemann, Thomas Rauscher, Matthias Hempel

Non-Basel Participants from ENSAR partners: *Stefan Typel* (GSI), *Réné Reifarth* (GUF), *Gabriel Martinez-Pinedo* (TUD), *Gyürgy Gyürky* (ATOMKI)

Achievements - The UBAS team has:

a - Performed global sensitivity study of cross sections and reaction rates to variations in widths and level densities. *Guidance for experiments and theorists*

b - Improved calculations of ground state contributions to astrophysical rates at finite temperatures in a thermal bath and new formalism to combine theory and experimental information, including an improved uncertainty estimate *(with measurements made by GSI and GUF groups)*.
Important corrections to previously used procedures, with large impact on future astrophysical studies (e.g. 151Eu production in Asymptotic Giant Branch Stars

c - Studied the importance of direct capture contributions to reaction cross sections in regions of the nuclear chart, where low level densities are encountered (close to magic numbers and at very low capture Q-values far from stability).

d - Studied uncertainties of proton-optical potentials derived from scattering experiments at medium/high energies for their application at low energies of astrophysical importance.

e - Studied uncertainties of alpha-optical potentials derived from scattering experiments at medium/high energies for their application at low energies of astrophysical importance.
d and e were performed by comparison with experiments of ATOMKI-HAS at such low energies.
resolved the “apparent” long standing alpha potential problem by inclusion of Coulomb Excitations.

f - Studied the impact of new mass measurement for reactions on the proton-rich side of stability in nuclear reaction networks, *employing experimental results from GSI and JYU*.
Identified crucial reaction rates for gamma and νp-process nucleosynthesis in massive stars

g - Tested uncertainties in fission barrier heights and fission fragment distributions for applications to the astrophysical r-process *(in collaboration with GSI groups)*.
Important for abundance shape between 2nd and 3rd r-process peak and possible production of superheavies

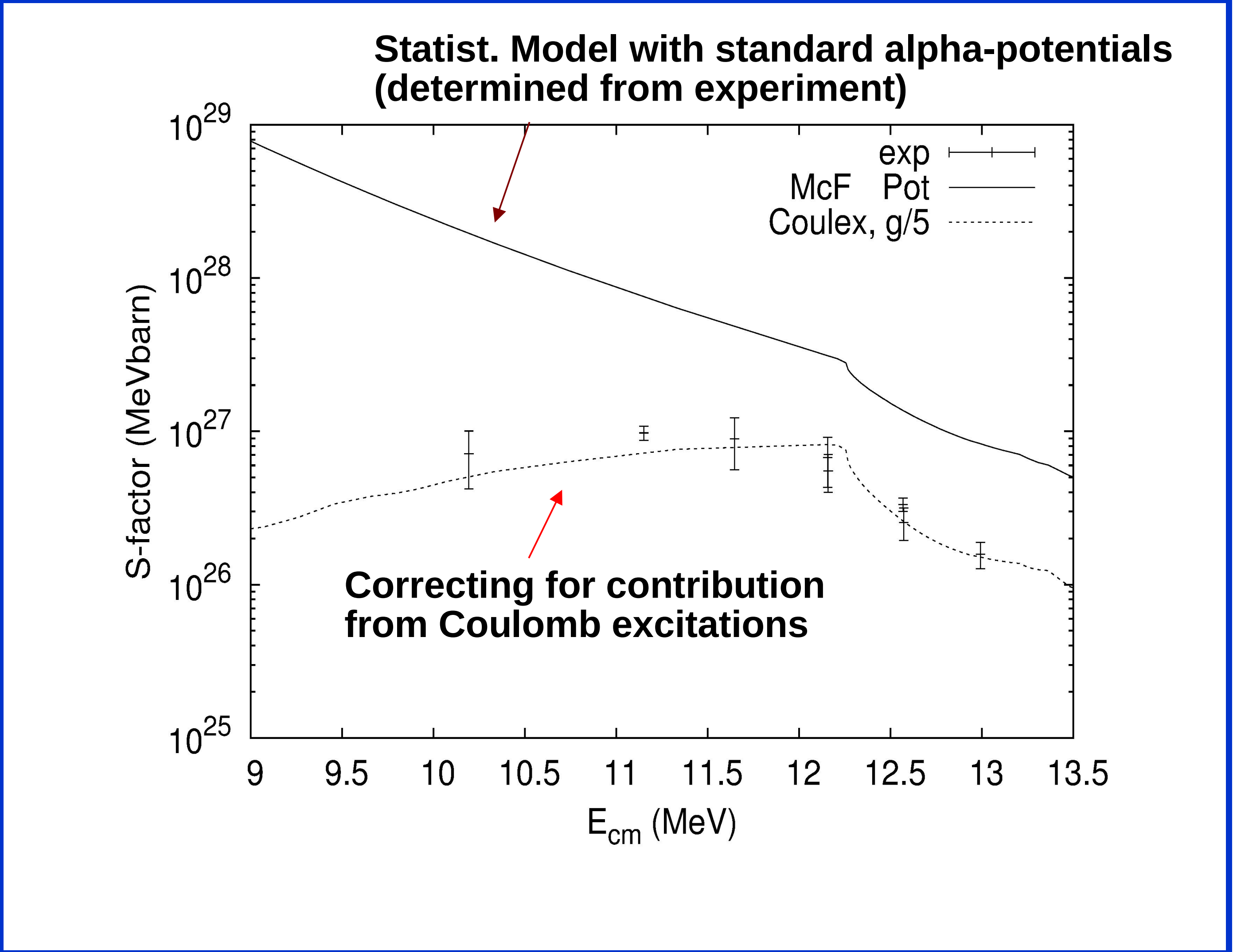
Resolving the long-standing mystery of alpha-potentials for heavy nuclei

Impact of low-energy Coulex on 144Sm(α,γ)

Utilizing standard alpha-potentials is ok! If Coulomb excitations are included

- First 2+ at 1.66 MeV
- B(E2)=0.262

- Sensitivity check!
- Above 12 MeV:
  - γ-width
  - neutron width



h - constrained the symmetry energy S and its density dependence L from experimental, theoretical, and observational constraints

neutron skin thickness (Zn, Pb), dipole polarizability of 208Pb, giant resonance properties, Isospin diffusion in heavy ion collisions, systematics of binding energies;

chiral effective field theory, quantum Monte Carlo;

neutron star observations;

→ ***S=29-31 MeV, L=40-60MeV***

i – Utilized these constraints for development new covariant density functionals for nuclear Interactions to be imployed in the astrophysical, high density, equation of state (EoS)

Important for neutron star interiors

j - investigated the importance of light nuclear clusters and nuclei close to nuclear densities (at subsaturation densities)

Important for neutron star crust and supernova core collapse

k - Calculated the combined effects for nuclear EoSs and provide them in tabular form ready for applications in astrohysics for temperature-dependent conditions supernova/ hot proto-neutron star applications).

Applications determine shock radii in supernova explosions

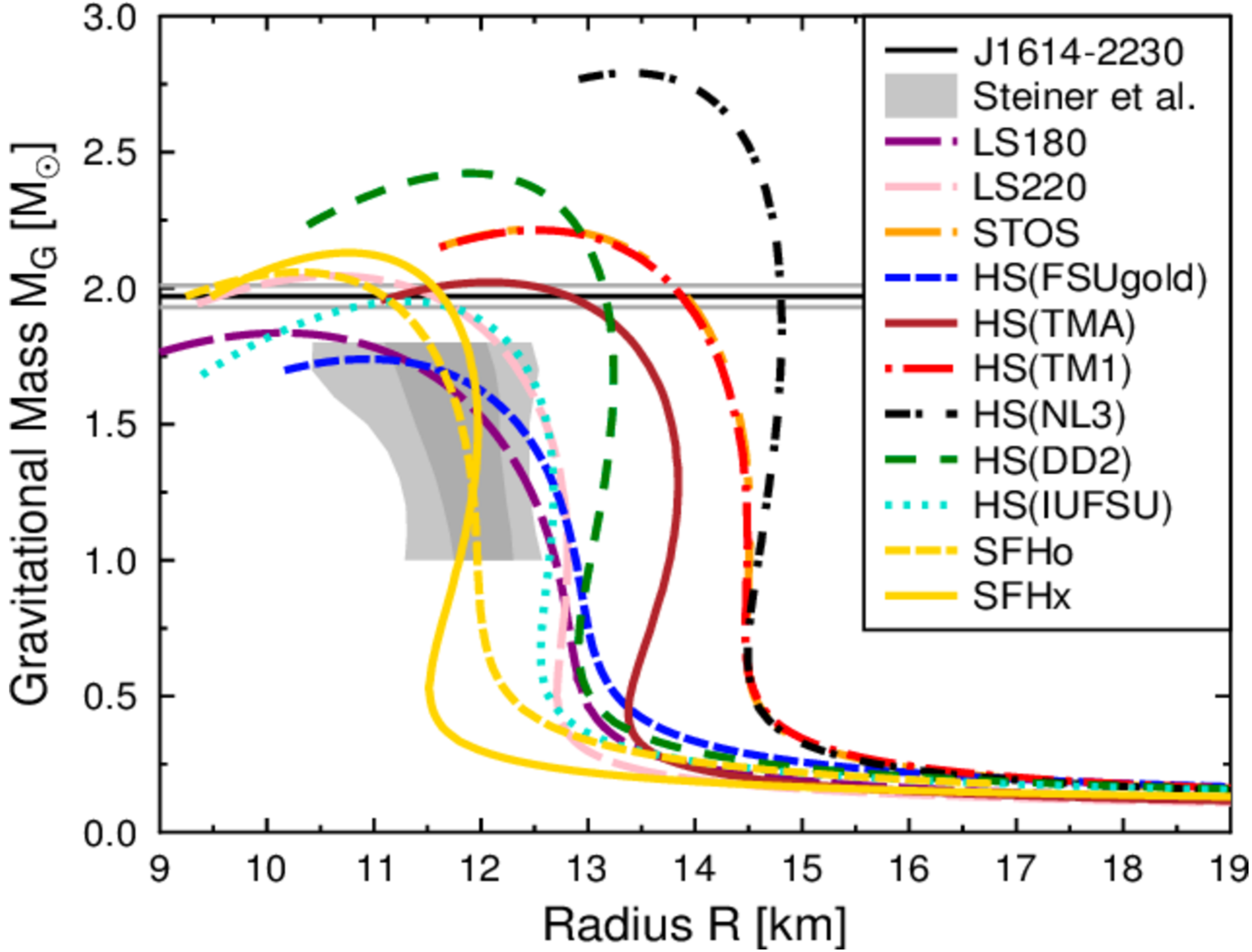
l - Analyzed possible constraints for maximum neutron star masses

Where is the transition to black holes?

(all points in collaboration with GSI and GUF)

Neutron Star Mass-Radius Relation for different Equations of State (from Lattimer & Lim 2013)

Our results from density functionals SFHo and SFHx (Steiner et al.) with the constraints on aymmetry energy S (29-31 MeV) and density dependence L (40-60 MeV) give realistic mass-radius relations and good estimates of maximum neutron star masses slightly above 2 Msol (2 neutron stars with close to 2 Msol have been discovered recently).



Resources used: Total expenses of 60 606.74 euro corresponding to 9 months of a postdoc's salary and travel expenses (1 900.00).
These expenses use a large portion of the financial plan, due to Swiss postdoc salaries.

However, we will, as done already, continue to contribute actively to the ENSAR/THEXO workpackage(s) for the whole funding period (with support from other funds) and complete all research topics where we are involved, especially a **(A)** ***final set of reaction rates*** and **(B)** ***equation of state tables*** after feedback and input from our THEXO partners.

Deliverables:

(A) A full set of cross section predictions for neutron-, proton, and alpha-induced reactions with present nuclear input is available from the BASEL website http://www.nucastro.org
A final set will be created with input by our THEXO partners and provided results from microscopic nuclear stucture calculations.

(B) at present we provide equation of state tables based on covariant density functionals at the website http://phys-merger.physik.unibas.ch/~hempel/eos.html
We are also involved in a bigger effort (together with our THEXO partners from GSI and GUF) within the CompStar Network, where also the final optimized EoS table(s) will appear (together with a manual for their application) http://www.compose.obspm.fr

Publications with ENSAR acknowledgement

(for subtask 3-2 in italics)

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