Research Project: Astrophysical Processes, their Simulation and Related Nuclear Physics Issues

Final Report for Swiss National Science Foundation Grant 200020-132816/1 (October 2012 - September 2014)

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The Theoretical, Computational and Nuclear Astrophyiscs group is part of the Astroparticle Physics focus within the Department of Physics at the Univerity of Basel, also participating in the EU FP7 Research Program ENSAR/THEXO (Theory of Exotic Nuclei within the European Nuclear Physics effort in Large Scale Facilities, 2010-2014), the COST Action "The New Physics of Compact Stars" (started 2013), the ESF Research Program "Eurogenesis: Origin and Evolution of the Elements in the Universe" (2011-2013), as well as the SCOPES Project "Synthesis of Heavy Elements in Core Collapse Supernova and their Imprint on Galactic Chemical Evolution" (started in 2013), the PASC (HPC) Project "DIAPHANE", and the ERC project . "FISH = FaInt Supernovae and Hypernovae" (since 2013).

0 Summary

Simulations of astrophysical objects rely on a consistent treatment of (magneto-)hydrodynamic modeling and the required microphysics. In sufficiently "hot" environments, like the big bang or stellar objects (from stellar evolution to explosions) this includes nuclear/particle physics (from reactions to nuclear properties in general and the equation of state) as well as radiation transport (including neutrino transport). Thus, besides the numerical/hydro modeling, the quality of the employed nuclear/particle physics impacts the resulting energy generation and transport and as well as nucleosynthesis. Nucleosynthesis abundance patterns from nuclear burning provide a unique tool to test models by comparison with (spectral) observations of indivudual objects and links them also to the integrated (chemical) evolution of galaxies. The Basel group combines strength in all these fields and achieved major advances. (i) New compilations of reaction rates were provided to the astrophysical community, including now fission channels of the heaviest nuclei, as well as high density equations of state, which cover the transition from nuclear to quark matter. (ii) Nuclear networks for hydrostatic and explosive nucleosynthesis were developed which incorporate all weak and strong interaction rates (including neutrino interactions and fission) and can be applied to nucleosynthesis and energy generation in stellar evolution and explosions, covering especially nucleosynthesis processes like the r-, rp, p- and

νp-process. (iii) Major advances were made in the past years in applications of the microphysics and nuclear burning tools mentioned above to (a) stellar evolution of massive stars with rotation, (b) self-consistent general relativistic modeling of core-collapse supernovae for extended periods after bounce with a full neutrino transport treatment, (c) tests of such core-collapse models with respect to the influcence of the equation of state (e.g. the QCD-phase transition), (d) tests of such models with respect to the influence of rotation and magnetic fields and the production of polar jets, (e) type Ia supernova nucleosynthesis in multi-dimensional simulations of the burning front propagation, (f) spherically symmetric X-ray burst simulations on neutron stars with complete rp-process modeling, (g) relativistic 3D simulations of neutron star mergers and their gravitational wave signal and related r-process calculations, as well as (h) early (inhomgeneous) galactic evolution modeling, making use of the composition of events (a)-(g).

a) Research Group, Scientific Projects, Major Results, Activities

1 Personnel and Equipment

1.1 Personnel

Investigators:

F.-K. Thielemann, M. Liebendörfer, M. Pignatari[2], PD T. Rauscher[4].

Postdocs:

A. Arcones[1], R. Cabezon[3], M. Hempel[1], T. Kuroda[4], N. Nishimura[1] (until March 2013), K.-C. Pan[4], I. Panov[1] (1.4.-30.5.13; 1.4.-30.5.14).

PhD Students:

U. Battino1, K. Ebinger[1], M. Eichler[1], S. Fehlmann[1], M. Frensel[4], O. Heinimann[4], A. Perego[1] (finished his thesis in 2012), J. Reuchert, B. Wehmeyer[4]

Master Students:

N. Wüest, I. van Rijs, E. Kaiser, N. Maksimovic

Sekretary:

Aucha Lang (Secretary) (+41 61 267-3750)

personnel marked without a superscript is financed by the department, with superscript 1 is financed by the SNF, superscript 2 indicates the SNF Ambizione fellow M. Pignatari, 3 indicates HP2C and 4 indicates ERC personnel. A. Arcones was partially also funded by a Feodor Lynen stipend of the Humboldt Foundation.

1.2 Personnel Changes and Honors

The collaboration with I. Panov and his group at ITEP Moscow is financed via a SCOPES Grant of the SNF

A. Perego resumed a postdoc position at TU Darmstadt (nucl. astrophysics)

A. Arcones received a Helmholtz Young Investigator grant (GSI) and started as junior professor at TU Darmstadt

F.-K. Thielemann received the 2012 Lise Meitner Prize of the European Physical Society and an ERC advanced grant (starting 2013)

1.3 Computer Access

We perform our computational modeling with the aid of our local linux workstation cluster. In addition, there is extended access to the IBM-SP4 MPP parrallel computer and a CRAY XT3 of the SWiss Supercomputer Center CSCS Lugano, via one of the 11 HP2C grants (High Performance and High Producticity Computing) given out to research groups in Switzerland and the PASC HPC grant DIAPHANE.

2 Guests

We received short research visits by: K. Blaum, MPIK Heidelberg; J.J. Cowan, U. of Oklahoma; R. Diehl, MPE Garching; M. Falanga, ISSI Bern; K. Farouqi, MPI Mainz; C. Fröhlich, North Carolina State; Z. Fülöp, Atomki Debreven; R. Hirschi, U. of Keele: K. Hotokezaka, Hebrew University; A. Hujeirat, U. of Heidelberg; H. Jerjen, ANU Canberra; K. Kotake, Kyushu Univerity; A. Lohs, TU Darmstadt; G. Martinez-Pinedo, TU Darmstadt; L. Mashonkina, Moscow Obs.; F. Matteucci, Trieste Observatory; T, Mishenina, Odessa Observatory; G. Meynet, U. of Geneva; K, Nakamura, Waseda University; N. Nishimura; U. of Keele; M. Oertel, Obs. de Paris; I. Panov, ITEP Moscow; T. Piran, Hebrew University; N. Prantzos, Obs. de Paris; S. Rosswog, U. Stockholm; A. Schwenk, TU Darmstadt; M. Takiwaki, NAO Tokyo; C. Travaglio, Obs. di Torino; M.-R. Wu, TU Darmstadt; A. Yudin, ITEP Moscow.

3 Teaching, Committee Memberships

3.1 Teaching

In 2012-2014 the following courses were taught regularly by members of the research group: B. Binggeli, F.-K. Thielemann: Astronomisches Proseminar; R. Cabezon: Advanced Methods in Computational Sciences; M. Falanga, F.-K. Thielemann: Compact Objects in Binary Systems; M. Liebendörfer: Computer, Kompakte Sterne und Schwarze Löcher, Strahlungstransport in Sternen und seine numerische Behandlung, Introduction to Astrophysical Plasmas; M. Liebendörfer, F.-K. Thielemann: Proseminar in Theoretischer Physik; T. Rauscher, M. Hempel, F.-K. Thielemann : Nukleare Astrophysik I+II; F.-K. Thielemann: Analytische Mechanik, Thermodynamik und Stat. Mechanik, Advanced Methods in Computational Sciences. In addition, specialized schools take place for the graduate students within the ESF network "The New Physics of Compact Stars" as well as the COST Action "New CompStar".

3.2 Committees

Liebendörfer and Thielemann: Members of the ESF CompStar Network and board.

Rauscher: Member of the n_TOF Collaboration at CERN; External expert for written and oral Matura exams at Gymnasium Liestal, BL.

Thielemann: Associate Editor of Nuclear Physics A; Associate Editor for Astrophysics of Reviews of Modern Physics; Member of the Swiss Commission for Astronomy SCFA (since 2007); Member and Head of the Board, Competence Center in Computational Sciences, Univ. Basel (since 2009/2011); Member of the Management Committee of COST Action "New CompStar" (since 2013); Member of Program Advisory Committee, RIKEN Radioative Beam Facility, Wako, Japan; Member of Advisory Committee, EMMI (ExtreMe Matter Institute) of the Helmholtz Foundation; President of Platform Mathematics, Astronomy, Physics (MAP) of the Swiss Academy of Natural Scienes.

4 Research Projects

4.1 Stellar Evolution and Supernovae

Evolution and Death of Massive Stars

The Evolution of intermediate mass and massive stars with large-scale nuclear reaction networks (including s- and p-process) and with the aid of reaction rates for the strong, electromagnetic and weak interaction developed in Basel (capture of nucleons and nuclei, electron capture and beta-decay, neutrino scattering on nuclei). Evolution of stars to the final stages of Fe-core collapse (one of the very few world-wide efforts); stellar evolution including rotation, mass loss and magnetic fields; estimates of black hole formation and gamma-ray burst progenitors from such evolution calculations as a function of stellar metallicity.
Major achievements: Predicting s- and p-process abundances from a fully consistent treatment with large nucleosynthesis networks throughout stellar evolution and the supernova explosion; stellar evolution of massive stars with rotation (s-process via primary ^{22}Ne at lowest metallicities, pre-supernova models, predicting black hole formation and gamma-ray burst rate as a function of metallicity); isotopic abundances in dust formed from stellar winds and supernovae in to the composition in meteoritci inclusions. (U. Battino, K. Ebinger, M. Pignatari, T. Rauscher, F.-K. Thielemann)

Supernovae and their Nucleosynthesis

Self-consistent core-collapse supernova calculations with general relativistic radiation hydrodynamic and complete neutrino transport of all flavors, solving the Boltzmann transport equation; long-term neutrino wind simulations and resulting nucleosynthesis; tests of core-collapse supernova models with different nuclear equations of state including the QCD-phase transition; 3D simulation with isotropic diffusion approximation for neutrino transport: first 3D modeling of core collapse with MHD and rotation; analysis of the resulting burning products from the innermost ejected zones as a function of the neutrino and anti-neutrino flux (νp-process); r-process calculations for the neutrino wind in the late phases of a supernova; testing of jet explosion models with rotation and magnetic fields; nucleosynthesis in self-consistent 3D Type Ia supernova models, including the inner zonen which produce neutron-rich Fe-group nuclei and are strongly affected by electron capture on protons and nuclei.
Major achievements: First detailed nucleosynthesis results from 3D type Ia supernova models; discovery of a proton-rich environment in the innermost core-collape supernova ejecta due to the influence of neutrino and anti-neutrino irradiation; nucleosynthesis and weak r-process in QCD-phase transition caused supernova explosions; r-process in jet ejecta from core collapse with rotation and magnetic fields. (M. Eichler, M. Frensel, M. Liebendörfer, N. Nishimura, T. Rauscher, F.-K. Thielemann)

4.2 Compact Stars in Binary Systems

Nuclear Burning in Accreting White Dwarfs and Neutron Stars

Hydrogen accretion onto white dwarfs and test for He-shell flashes (like in AGB stars) which could produce a highly s-processed initial composition for later type Ia supernova explosions; hydrogen accretion onto white dwarfs or neutron stars with either stable hydrostatic burning or thermonuclear ignition (novae or X-ray bursts), including the modeling of resulting energy generation and composition changes; surface composition of possible ejecta; dependence of explosive burning on nuclear uncertainties far from stability at the proton drip-line (proton capture rates, beta-decay rates, nuclear masses); inclusion of deeper layers of the neutron star to test the influence of partially burned matter (from previous bursts) to analyse the cause of so called superbursts.
Major achievements: Preparing typa Ia supernova progenitor models; Predicting the upper

end of the rp-process in realistic X-ray burst models; finding the required carbon abundance in the ashes after about 1000 X-ray-bursts, which permit the ignition of superbursts. (U. Battino, S. Fehlmann, M. Pignatari, T. Rauscher, F.-K. Thielemann)

Neutron Star-Mergers

Modeling neutron star mergers in binary stellar systems via smooth particle hydrodynamics (SPH) in 3D; implementation of sophisticated neutrino leakage schemes; including the feedback of nuclear energy generation consistantly into the hydrodynamic modeling; variations of the nuclear equation of state and predictions of gravitational waves as well as the mass of ejecta (providing a major r-process source); treatment of neutrino transport and oscillations in the accretion disk around the black hole formed after the merer event.
Major achievements: gravitational wave signal differences for equations of state with and without the quark-hadron phase transition; explanation of lightcurves due to continuous (r-process) energy generation in ejecta and fallback; test of r-process production and abundance composition for varying nuclear input and late neutrino wind ejecta. (M. Eichler, I. Panov, A. Perego, T. Rauscher, F.-K. Thielemann)

4.3 Chemical Evolution of Galaxies

Evolution of element abundandances in our Galaxy as a function of metallicity with the aid of inhomogeneous chemical evolution models as a constraint for ejecta abundances of core-collapse and Type Ia Supernovae as well as neutron star mergers; very early galactic evolution and mixing of stellar winds and explosive ejecta in order to understand r-process contributions; analysis of abundance variations in (very) low metallicity stars; interpretation of the results with respect to Fe-group ejecta from core collapse supernovae as a function of progenitor mass; test for the origin of r-process nuclei via the r/Fe scatter as a function of metallicity (supernovae - including jet ejecta - vs. neutron star mergers).
Major achievements: explaining features in very early galactic evolution via wind ejecta of rotating low-metallicity stars; finding an r-process source with rotating core collapse supernova models and high magnetic fields which can explain very low metallcity r-process observations. (I. Panov, M. Pignatari, T. Rauscher, F.-K. Thielemann, B. Wehmeyer)

4.4 Nuclear Properties for Astrophysical Applications

Nuclear Reactions and Nuclear Structure

Calculations of nuclear cross sections for stable and unstable targets with neutrons, protons, α-particles and nucleus projectiles, applying the statistical model for compound nucleus reactions or the direct reaction mechanisms; prediction of nuclear properties which are needed for such calculations; investigations of nuclear fission rates and fission fragment distributuions, as well as the chance to produce superheavy nuclei; employing mass models with correlations for nuclei far from stability.
Major achievments: Involvement and theoretical analysis of neutron-induced reactions from the N-ToF experiment at CERN, s- and p-process reactions; the prediction of neutron-induced fission for a large set of nuclei in r-process applications; test of the role of fission fragments and beta-decay half-lives for the final r-process ejecta composition. (M. Eichler, I. Panov, T. Rauscher, F.-K. Thielemann)

Nuclear Equation of State

Utilizing constraints from recent observation of the pulsar PSR J1614-2230 with a mass of 1.97 ± 0.04 $M_\odot$ for the quark and nuclear matter equations of state (EoS); taking into account effects from the strong coupling constant and color-superconductivity; hybrid stars, i.e. compact stars with a quark matter core and a hadronic outer layer: utilizing chemical equilibrium abundance distributions for the nuclear part of the EoS and testing the effect on electron captures during core collapse.
Major achievement: Prediction of high density EoS properties for tests in neutron star mergers and core collapse supernovae; the influence of electron captures on core collapse

supernovae when utilizing an equilibrium abundance sample of nuclei (rather than one average nucleus as generally used). (M. Hempel, M. Liebendörfer, O. Heinimann, F.-K. Thielemann)

Nuclei far from β-Stability and the rp- and r-Process

Nuclear properties (nuclear structure, masses, decay properties, fission) of unstable nuclei, which are either very neutron or proton-rich; utilization of these properties in nucleosynthesis calculations for the production of heavy elements via rapid neutron capture (r-process); the effect of neutron-induced fission and beta-delayed fission and neutron emission, as well as fission fragment distributions on r-process abundances; solar abundances as a test for nuclear structure far from stability; application of the properties of proton-rich nuclei in the νp-process of core collapse supernovae; application of the properties of proton-rich nuclei for explosive hydrogen burning (rapid proton capture, i.e. rp-process) in X-ray bursts after the accretion of hydrogen envelopes onto neutron stars in binary stellar systems.
Major achievements: Modeling the rp-process in X-ray bursts, tests of the effect of nuclear uncertainties for the solution of the required C-abundance for superbursts; modeling the r-process with the inclusion of neutrino-induced reactions for realistic neutrino wind environments, core collapse supernovae, jet ejecta, and neutron star mergers. (M. Eichler, I. Panov, T. Rauscher, J. Reichert, F.-K. Thielemann)

5 Master Theses, Dissertations, Habilitations

5.1 Master Theses

completed:

O. Heinimann: The Equation of State of Neutron Stars;
J. Reichert: Minimum Nuclear Networks for X-ray Bursts;
B. Wehmeyer: The r-Process in the Chemical Evolution of Galaxies.

ongoing:

Nicole Wüest: Type Ia Supernovae and Cosmology;
Isabelle van Rijs: The s-Process in AGB Stars;
Etienne Kaiser: The Evolution of Massive Stars;
Nikola Maksimovic: Black Hole Formation during the Collapse of Massive Stars.

5.2 Dissertations

completed:

A. Perego: Neutrino treatment in multidimensional astrophysical simulations: a new spectral scheme.

ongoing:

U. Battino: Accreting White Dwarfs as Type Ia Supernova Progenitors;
K. Ebinger: Supernova Explosions in Spherical Symmetry;
M. Eichler: r-Process in Supernovae and Neutron Star Mergers;
S. Fehlmann: X-Ray Bursts (and Superbursts) on Neutron Stars;
M. Frensel: Coherent Neutrino Oscillations in Black Hole Accretion Disks;
O. Heinimann: Influence of the Equation of State on Supernova Explosions;
J. Reichert: Nucleosynthesis in X-ray bursts and Multi-D Supernova Explosions;
B. Wehmeyer: Inhomogeneous Chemical Evolution of Galaxies.

5.3 Habilitations

M. Falanga: Accretion and Emission processes onto Black Holes, Neutron Stars, and White Dwarfs in binary systems;
M. Liebendörfer: The Formation of a Neutron Star.

6 Organized Conferences, Joint Research Projects with Outside Groups

6.1 Conferences, Workshops, Cooperations

see output data, but especially the Basel Brainstorming meeting in September 2014, which led to a very efficient exchange and interaction/collaboration with the members of our guest program.

6.2 Research Projects and Collaborations with Outside Groups

The research projects of section 4 are carried out in collaboration with the following research groups and individuals:

- 4.1: C. Fröhlich (U. of North Carolina), R. Hirschi (U. of Keele), R. Hix (Oak Ridge National Lab.), K. Kotake (Kyusu University), G. Martinez-Pinedo, K. Langanke (GSI Darmstadt), G. Meynet (Observatoire de Genève), A. Mezzacappa (Oak Ridge National Lab.), K. Nakamura (Waseda University), A. Perego (TU Darmstadt), J. Schaffner-Bielich (U. of Heidelberg), A. Steiner (Berkeley), K. Takiwaki (NAO Tokyo).

- 4.2: D. Blaschke (University of Wroclaw), M. Falanga (ISSI Bern), F. Herwig (U. of Victoria), I. Panov (ITEP Moscow), S. Rosswog (U. of Stockholm) J. Schaffner-Bielich (U. of Frankfurt), H. Schatz (Michigan State Univ.), C. Travaglio (Torino)

- 4.3: J.J. Cowan (U. of Oklahoma), L. Mashonkina (Moscow Observatory), T. Mishenina (Odessa Observatory), J.W. Truran (U. Chicago), A. Wallner (ANU Canberra).

- 4.4: A. Steiner (Berkeley), Z. Fulop (Atomki Debrecen), J. Görres (U. of Notre Dame), F. Käppeler (FZ Karlsruhe), I. Korneev (ITEP Moscow), K.-L. Kratz (U. Mainz), K. Langanke, G. Martinez-Pinedo (GSI Darmstadt), T. Marketin (Zagreb), I. Panov (ITEP Moscow), S. Typel (GSI Darmstadt), M. Wiescher (U. of Notre Dame)

In addition there exist larger research cooperations which are listed in section 7.3.

7 Contributions to Conferences and Colloquia, Membership in Cooperations

7.1 Conferences and Workshops

7.2 Colloquia and Seminar Talks

see output data

7.3 Cooperations

T. Rauscher is Member of the n-TOF Collaboration at CERN (PS-213)

EXL The research group Nuclear Astrophysics is Member (node) in the EU research network EURONS/EXL within the 6th European Framework program.

CARINA The research group Nuclear Astrophysics is Member (node) in the EU research network EURONS/CARINA within the 6th European Framework program.

THEXO The research group Nuclear Astrophysics is Member (node) in the EU research network ENSAR/THEXO within the 7th European Framework program.

SCOPES, The research group Nuclear Astrophysics undertakes investigations jointly with the Observatoire de Geneve, the Institute for Experimental and Theoretical Physics (ITEP) in Moscow, and the Astronomical Institute of the University of Odessa within the framework of the SCOPES Program of the SNF (Project "Synthesis of Heavy Elements in Core Collapse Supernovae and their Imprint on Galactic Chemical Evolution").

The research group Nuclear Astrophysics is a Participating Research Institution within the Joint Institute for Nuclear Astrophysics (JINA, funded by the US NSF).

ESF Research Network "The New Physics of Compact Stars", this network was selected in February 2008 by the ESF (until 2013). The Basel reseach groups were contributing in a prominent way and since 2013 are members of the follow-up COST Action.

ESF Research Program "EuroGENESIS: Origin and Evolution of the Elements in the Universe" (2011-2013). The research group Nuclear Astrophysics was represented by two project leaders of collaborative research projects: I. Cherchneff (CoDustMas), F.-K. Thielemann (MASCHE).

Within the Swiss program for High Performance Computations PASC, we collaborate with groups from the Universities of Zurich and Geneva in the joint project DIAPHANE.

b) Results published and c) Results in press

8 Publications

8.1 in Journals

published:

8.2 Conference Proceedings

published:

8.3 Popular and other Publications

see output data

9 Miscellaneous

F. Thielemann became President of the platform Mathematics, Astronomy, Physics (MAP) of the Swiss Academy of Natural Sciences in 2013

M. Hempel and F.-K. Thielemann received the Golden Crayon for Best Teaching in 2014

Friedrich-Karl Thielemann, M. Pignatari

Outputdaten zu Beitrag 200020_144514: Astrophysical Processes, their Simulation and Related Nuclear Physics Issues

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Zeitspanne:	01.10.2012 - 30.09.2014
Bewilligter Betrag:	698'636 CHF

1. Angaben Person

	Angaben zur Person	Abschluss	Qualifikationsschrift	Nächste Tätigkeit
PostDoc	**Hempel Matthias** 01.01.2013-30.09.2014			Wissenschaft: Postdoc, Oberassistent/in, Lehrbeauftragte/r, etc. Schweiz
PostDoc	**Nishimura Nobuya** 01.10.2012-31.03.2013			Wissenschaft: Postdoc, Oberassistent/in, Lehrbeauftragte/r, etc. Ausland
Doktorand/in	**Fehlmann Sophie** 01.10.2012-30.09.2014		Leitung: Friedrich Thielemann	Wissenschaft: Fertigstellung Dissertation Schweiz
Doktorand/in	**Eichler Marius** 01.10.2012-30.09.2014		Leitung: Friedrich Thielemann	Wissenschaft: Fertigstellung Dissertation Schweiz
Doktorand/in	**Ebinger Kevin** 01.10.2012-30.09.2014		Leitung: Matthias Liebendörfer	Wissenschaft: Fertigstellung Dissertation Schweiz
Doktorand/in	**Battino Umberto** 01.10.2012-30.09.2014		Leitung: Friedrich Thielemann	Wissenschaft: Fertigstellung Dissertation Schweiz
sonstiges akademisches Personal	**Panov Igor** 15.04.2014-30.06.2014			Wissenschaft: Professur Ausland
sonstiges akademisches Personal	**Panov Igor** 01.04.2013-30.06.2013			Wissenschaft: Professur Ausland

2. Wissenschaftliche Publikationen

Wiss. Publikation - peer reviewed

Originalbeitrag in wiss. Zeitschrift

Rosswog, S., Korobkin, O., Arcones, A., Thielemann, F. -K., Piran, T. (2014), The long-term evolution of neutron star merger remnants - I. The impact of r-process nucleosynthesis, in *MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY,* 439(1), 744-756

DOI:	10.1093/mnras/stt2502
Open Access Form:	Repositorium
Link / Externe URL auf Publikation:	http://adsabs.harvard.edu/abs/2014MNRAS.439..744R

Garcia-Senz, D., Cabezon, R. M., Arcones, A., Relano, A., Thielemann, F. K. (2013), High-resolution simulations of the head-on collision of white dwarfs, in *MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY,* 436(4), 3413-3429

DOI:	10.1093/mnras/stt1821
Open Access Form:	Repositorium
Link / Externe URL auf Publikation:	http://adsabs.harvard.edu/abs/2013MNRAS.436.3413G

Pignatari, M., Zinner, E., Bertolli, M. G., Trappitsch, R., Hoppe, P., Rauscher, T., Fryer, C., Herwig, F., Hirschi, R., Timmes, F. X., Thielemann, F. -K. (2013), SILICON CARBIDE GRAINS OF TYPE C PROVIDE EVIDENCE FOR THE PRODUCTION OF THE UNSTABLE ISOTOPE Si-32 IN SUPERNOVAE, in *ASTROPHYSICAL JOURNAL LETTERS,* 771(1), L7

DOI:	10.1088/2041-8205/771/1/L7
Open Access Form:	Repositorium
Link / Externe URL auf Publikation:	http://adsabs.harvard.edu/abs/2013ApJ...771L...7P

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. (2013), A comparative study of statistical models for nuclear equation of state of stellar matter, in *NUCLEAR PHYSICS A,* 907, 13-54

DOI:	10.1016/j.nuclphysa.2013.03.010
Open Access Form:	Repositorium
Link / Externe URL auf Publikation:	http://adsabs.harvard.edu/abs/2013ApJ...771L...7P

Pignatari, M., Wiescher, M., Timmes, F. X., de Boer, R. J., Thielemann, F. -K., Fryer, C., Heger, A., Herwig, F., Hirschi, R. (2013), PRODUCTION OF CARBON-RICH PRESOLAR GRAINS FROM MASSIVE STARS, in *ASTROPHYSICAL JOURNAL LETTERS,* 767(2), L22

DOI:	10.1088/2041-8205/767/2/L22
Open Access Form:	Repositorium
Link / Externe URL auf Publikation:	http://adsabs.harvard.edu/abs/2013ApJ...767L..22P

Mishenina, T. V., Pignatari, M., Korotin, S. A., Soubiran, C., Charbonnel, C., Thielemann, F. -K., Gorbaneva, T. I., Basak, N. Yu. (2013), Abundances of neutron-capture elements in stars of the Galactic disk substructures, in *ASTRONOMY & ASTROPHYSICS,* 552, A128

DOI:	10.1051/0004-6361/201220687
Open Access Form:	Repositorium
Link / Externe URL auf Publikation:	http://adsabs.harvard.edu/abs/2013A%26A...552A.128M

Panov, I. V., Korneev, I. Yu., Martinez-Pinedo, G., Thielemann, F. -K. (2013), Influence of spontaneous fission rates on the yields of superheavy elements in the r-process, in *ASTRONOMY LETTERS-A JOURNAL OF ASTRONOMY AND SPACE ASTROPHYSICS,* 39(3), 150-160

DOI:	10.1134/S1063773713030043

Arcones, A., Thielemann, F-K (2013), Neutrino-driven wind simulations and nucleosynthesis of heavy elements, in *JOURNAL OF PHYSICS G-NUCLEAR AND PARTICLE PHYSICS,* 40(1), 013201

DOI:	10.1088/0954-3899/40/1/013201
Open Access Form:	Repositorium
Link / Externe URL auf Publikation:	http://adsabs.harvard.edu/abs/2013JPhG...40a3201A

Panov, I. V., Korneev, I. Yu, Lutostansky, Yu S., Thielemann, F-K (2013), Probabilities of delayed processes for nuclei involved in the r-process, in *PHYSICS OF ATOMIC NUCLEI,* 76(1), 88-101
DOI: 10.1134/S1063778813010080

Nishimura, Nobuya, Fischer, Tobias, Thielemann, Friedrich-Karl, Froehlich, Carla, Hempel, Matthias, Kaeppeli, Roger, Martinez-Pinedo, Gabriel, Rauscher, Thomas, Sagert, Irina, Winteler, Christian (2012), NUCLEOSYNTHESIS IN CORE-COLLAPSE SUPERNOVA EXPLOSIONS TRIGGERED BY A QUARK-HADRON PHASE TRANSITION, in *ASTROPHYSICAL JOURNAL,* 758(1), 9
DOI: 10.1088/0004-637X/758/1/9
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Abstract:
Massive stars (M > 8-10 M⊙) undergo core collapse at the end of their life and explode as supernova with ~ 1051 erg of kinetic energy. While the detailed supernova explosion mechanism is still under investigation, reliable nucleosynthesis calculations based on successful explosions are needed to explain the observed abundances in metal-poor stars and to predict supernova yields for galactic chemical evolution studies. To predict nucleosynthesis yields for a large number of progenitor stars, computationally efficient explosion models are required. We model the core collapse, bounce and subsequent explosion of massive stars assuming spherical symmetry and using detailed microphysics and neutrino physics combined with a novel method to artificially trigger the explosion (PUSH). We discuss the role of neutrinos, the conditions in the ejecta, and the resulting nucleosynthesis.

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Abstract:
Context. The Jacobi virial equation is a very powerful tool for exploring several aspects of the stellar internal structure and evolution. In a previous paper we have shown that the function [αβ]GR Lambda 0.9(R) is constant (≈0.4) for pre main-sequence stars (PMS), white dwarfs (WD) and for some neutron star (NS) models, where αGR and βGR are the form-factors of the gravitational potential energy and of the moment of inertia. Aims. To investigate the structural evolution of another type of celestial bodies, we extend these calculations to gaseous planets. We also analyse the cases for which this function is not conserved during some stellar evolutionary phases. Concerning NS, we study the influence of the equation of state (EOS) on this function and refine the exponent of the auxiliary function Λ(R). We also present a macroscopic criterion of stability for these stars. Methods. Non-stop calculations from the PMS to the white dwarf cooling sequences were performed with the MESA code. The covered mass range was 0.1-1.7 MâŠ™. We used the same code to compute models for gaseous planets with masses between 0.1-50 MJ. Neutron star models were computed using two codes. The first one is a modified version of the NSCool/TOV subroutines. The second code is a plain TOV solver that allows one to use seven previously described EOS. The relativistic moment of inertia and gravitational potential energy were computed through a fourth-order Runge-Kutta method. Results. By analysing the internal structure of gaseous planets we show that the function [αβ] GR/Λ0.8(R) ≡ Γ(M,EOS) is conserved for all models during the whole planetary evolution and is independent of the planet mass. For the PMS to the white dwarf cooling sequences, we have found a connection between the strong variations of Γ(M,EOS) during the intermediary evolutionary phases and the specific nuclear power. A threshold for the specific nuclear power was found. Below this limit this function is invariant (≈0.4) for these models, i.e., at the initial and final stages (PMS and WD). For NS, we showed that the function Γ(M,EOS) is also invariant (≈0.4) and is independent of the EOS and of the stellar mass. Therefore, we confirm that regardless of the final products of the stellar evolution, NS or WD, they recover the initial value of Γ(M,EOS) ≈ 0.4 acquired at the PMS. Finally, we have introduced a macroscopic stability criterion for NS models based on the properties of the relativistic product [αβ] GR. © ESO, 2013.

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Abstract:
Aims. We introduce the multidimensional optical depth algorithm (MODA) for the calculation of optical depths in approximate multidimensional radiative transport schemes, equally applicable to neutrinos and photons. Motivated by (but not limited to) neutrino transport in three-dimensional simulations of core-collapse supernovae and neutron star mergers, our method makes no assumptions about the geometry of the matter distribution, apart from expecting optically transparent boundaries. Methods. Based on local information about opacities, the algorithm figures out an escape route that tends to minimize the optical depth without assuming any predefined paths for radiation. Its adaptivity makes it suitable for a variety of astrophysical settings with complicated geometry (e.g., core-collapse supernovae, compact binary mergers, tidal disruptions, star formation, etc.). We implement the MODA algorithm into both a Eulerian hydrodynamics code with a fixed, uniform grid and into an SPH code where we use a tree structure that is otherwise used for searching neighbors and calculating gravity. Results. In a series of numerical experiments, we compare the MODA results with analytically known solutions. We also use snapshots from actual 3D simulations and compare the results of MODA with those obtained with other methods, such as the global and local ray-by-ray method. It turns out that MODA achieves excellent accuracy at a moderate computational cost. In appendix we also discuss implementation details and parallelization strategies. © 2014 ESO.

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3. Wissenschaftliche Veranstaltungen

Selber organisiert

The Origin of Cosmic Elements, Spanien, Barcelona, 10.06.2013
Ort der Tätigkeit der Referenten: Schweiz, andere europäische Länder, Nordamerika, Südamerika, Australien, Asien
Ungefähre Anzahl Teilnehmende: 70
Link: http://www.fen.upc.edu/users/jjose/Conf2.html

Russbach School on Nuclear Astrophysics, Oesterreich, Russbach, 10.03.2013
Ort der Tätigkeit der Referenten: Schweiz, andere europäische Länder, Nordamerika, Asien
Ungefähre Anzahl Teilnehmende: 50
Link: http://russbach-wks.sciencesconf.org/

Heavy elements nucleosynthesis and galactic chemical evolution, Russland, Moscow, 08.09.2013
Ort der Tätigkeit der Referenten: Schweiz, andere europäische Länder
Ungefähre Anzahl Teilnehmende: 25
Link: http://dau.itep.ru/sn/collaboration/moscow13

Observational Constraints on Sources of Nucleosynthesis , Deutschland, Garching, 25.03.2013
Ort der Tätigkeit der Referenten: Schweiz, andere europäische Länder, Asien
Ungefähre Anzahl Teilnehmende: 25
Link: http://www2011.mpe.mpg.de/gamma/science/lines/workshops/EuroGenesis13/EuroGenesisWS_Program.html

Nuclei in the Cosmos XIV, Ungarn, Debrecen, 07.07.2014
Ort der Tätigkeit der Referenten: Schweiz, andere europäische Länder, Nordamerika, Südamerika, Afrika, Australien, Asien
Ungefähre Anzahl Teilnehmende: 200
Link: http://www.nic2014.org/

Nuclear Structure and Astrophysical Applications, Italien, Trento, 08.07.2013
Ort der Tätigkeit der Referenten: Schweiz, andere europäische Länder, Nordamerika
Ungefähre Anzahl Teilnehmende: 40
Link: http://www.ectstar.eu/node/96

Russbach School on Nuclear Astrophysics, Oesterreich, Russbach, 09.03.2014
Ort der Tätigkeit der Referenten: Schweiz, andere europäische Länder, Nordamerika, Südamerika, Asien
Ungefähre Anzahl Teilnehmende: 60
Link: http://russbachwks2014.sciencesconf.org/

Breakup Reactions of Exotic Nuclei and Related Topics, Italien, Trento, 16.07.2014
Ort der Tätigkeit der Referenten: Schweiz, andere europäische Länder, Nordamerika, Asien
Ungefähre Anzahl Teilnehmende: 25
Link: http://www.ectstar.eu/node/770

Brainstorming and Fun: Stellar Evolution/Explosions, Nuclear/Particle Physics Input, Origin of the Elements and Evolution of Galaxies, Schweiz, Basel, 29.09.2014
Ort der Tätigkeit der Referenten: Schweiz, andere europäische Länder, Nordamerika, Asien
Ungefähre Anzahl Teilnehmende: 50
Link: http://phys-merger.physik.unibas.ch/~group/brainstorm2014.html

4. Veranstaltungen zum Wissenstransfer

5. Kommunikation mit der Öffentlichkeit

Medienarbeit: Printmedien, Online-Medien

Past and Present Challenges in Nuclear Astrophysics, SPG Mitteilungen, Vol 39, Progress in Physics (31), 2013
Ort / Verbreitung: International
Link: http://www.sps.ch/artikel/progresses/past-and-present-challenges-in-nuclear-astrophysics-31/

Making the Elements in the Universe, Europhysics News 44,23, 2013
Ort / Verbreitung: International
Link: http://www.europhysicsnews.org/articles/epn/abs/2013/03/epn2013443p23/epn2013443p23.html

Referate/Veranstaltungen/Ausstellungen

Formation of the Elements in the Universe, 2013
Ort / Verbreitung: International
Link: https://www.oepg.at/index.php?page=archive&subpage=events&lang=de

Wo alles herkommt: Die Entstehung der Element e im Universum, 2013
Ort / Verbreitung: International
Link: http://geopark-wlt.de/component/eventlist/details/269-marienstatter-zukunftsgespraeche-2013-steine-begreifen-.html?pop=1&tmpl=component

Die Entstehung der Elemente: Urknall, Sternwinde und Sternexplosionen , 2014
Ort / Verbreitung: International
Link: http://www.astronews.com/kalender/veranstaltungen/index.php?ecAction=details&ecEventId=279

Warum gibt es Gold und Silber im Universum?, 2014
Ort / Verbreitung: Deutschschweiz
Link: https://kinderuni.unibas.ch/programm/archiv-der-frueheren-vorlesungen/

Print (Buch, Brochuren, Infoblätter)

Die Entstehung der Atome – Eine Synthese von Mikro- und Makrokosmos, 2014
Ort / Verbreitung: International
Link: https://forschdb2.unibas.ch/inf2/rm_projects/object_view.php?r=2849760&type=4

Supernovae and their nucleosynthesis, 2013
Ort / Verbreitung: International
Link: https://forschdb2.unibas.ch/inf2/rm_projects/object_view.php?r=2358441&type=4

6. Zusammenarbeit

Zusammenarbeit gestartet

Oak Ridge National Laboratory, Vereinigte Staaten von Amerika
Felder der Zusammenarbeit: vertiefter/weiterführender Austausch von Ansätzen, Methoden oder Resultaten; Austausch von Mitarbeitern

JINA, University of Notre Dame, Vereinigte Staaten von Amerika
Felder der Zusammenarbeit: vertiefter/weiterführender Austausch von Ansätzen, Methoden oder Resultaten; Publikation; Austausch von Mitarbeitern

University of Keele, Grossbritannien und Nordirland
Felder der Zusammenarbeit: vertiefter/weiterführender Austausch von Ansätzen, Methoden oder Resultaten; Publikation; Austausch von Mitarbeitern

Odessa Observatory, Ukraine
Felder der Zusammenarbeit: vertiefter/weiterführender Austausch von Ansätzen, Methoden oder Resultaten; Publikation; Austausch von Mitarbeitern

Observatoire de Geneve, Schweiz
Felder der Zusammenarbeit: vertiefter/weiterführender Austausch von Ansätzen, Methoden oder Resultaten; Publikation; Austausch von Mitarbeitern

ITEP Moscow, Russland
Felder der Zusammenarbeit: vertiefter/weiterführender Austausch von Ansätzen, Methoden oder Resultaten; Publikation; Austausch von Mitarbeitern

Atomki Debreczen, Ungarn
Felder der Zusammenarbeit: vertiefter/weiterführender Austausch von Ansätzen, Methoden oder Resultaten; Publikation; Austausch von Mitarbeitern

GSI Darmstadt, Deutschland
Felder der Zusammenarbeit: vertiefter/weiterführender Austausch von Ansätzen, Methoden oder Resultaten; Publikation; Forschungsinfrastrukturen; Austausch von Mitarbeitern

Max Planck Institute for Astrophysics, Deutschland
Felder der Zusammenarbeit: vertiefter/weiterführender Austausch von Ansätzen, Methoden oder Resultaten

7. Anwendungsorientierte Outputs

8. Drittmittel

Quelle:	Andere Verwaltung / öffentliche Hand
Name der Organisation:	European Research Council, Advanced Grant
Betrag:	2000000
Bewilligungsjahr:	2012

9. Nachfolgeprojekte

Astrophysical Processes, their Simulation and Related Nuclear Physics Issues

Beginn Jahr:	2014
voraussichtliche Dauer (Mt.):	27
Betrag:	576597
Hauptsächliche/Primäre Finanzierung durch:	Andere Verwaltung / öffentliche Hand
Name der Organisation:	SNF
Link:	http://p3.snf.ch/Project-157151

Stars, Stellar Explosions, and the Origin of the Elements

Beginn Jahr:	2014
voraussichtliche Dauer (Mt.):	36
Betrag:	195000
Hauptsächliche/Primäre Finanzierung durch:	Andere Verwaltung / öffentliche Hand
Name der Organisation:	SNF
Link:	http://p3.snf.ch/Project-152485

10. Auszeichnungen

Lise Meitner Prize, European Physical Society, 2012

Dotierung in CHF:	0
Beteiligte Personen:	Thielemann, Friedrich K.