JINA-CEE

Center for the Evolution of the Elements

June 2016

A note from the Director, Hendrik Schatz

Dear JINA-CEE community and friends,

The last quarter has been a very busy time for the JINA-CEE community. Among many other things we had a very successful Frontiers in Nuclear Astrophysics meeting at the University of Notre Dame that was very well organized by JINA-CEE postdocs and students and had a record attendance. It was great to see the talks, posters, and exciting discussions that covered topics from astronomy, over nuclear physics, to ways to enhance diversity. The meeting serves as our collaboration meeting but is open to all interested researchers - if you missed it, the next meeting will be held in Spring 2017 at MSU.

I hope that things have calmed down for at least some of you with the beginning of the summer, and that you can enjoy travel, maybe to some of the many JINA-CEE workshops and schools listed in the upcoming events section of this newsletter. I would like to especially encourage young researchers to participate in these events to interact with your peers across the world, create new collaborations, and to experience the breadth of nuclear astrophysics.

We have also completed behind the scenes work on the JINA-CEE Virtual Journal (see Page 2), which now has improved article selection, and provides a weekly collection of articles published in nuclear astrophysics in more than 30 journals. It also offers key-word searches, for example, you can search for review articles of your favorite astrophysical process.

I hope you enjoy the exciting science and updates on JINA-CEE participants in this newsletter, and I wish you a successful and enjoyable summer.

Inside this issue

Image Credit: NASA/Swift/Mary Pat Hrybyk-Keith and John Jones

The impact of individual nuclear properties on r-process nucleosynthesis

Contributed by Rebecca Surman (JINA-CEE & UND)

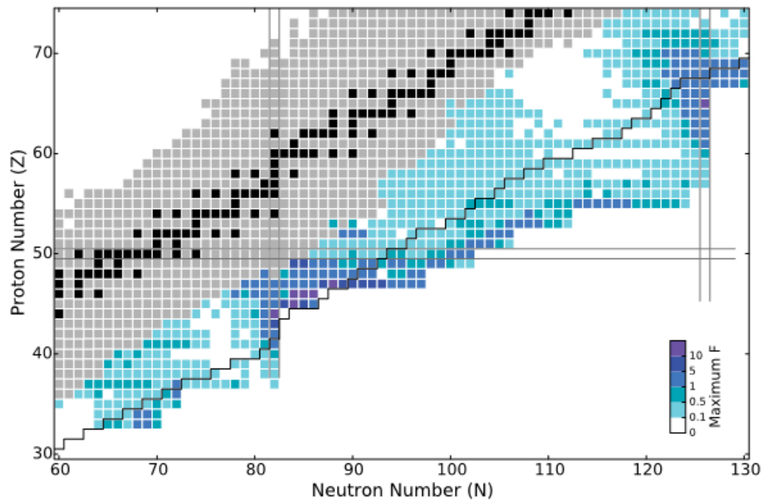


Fig. 2: Individual nuclear masses that significantly impact abundances for a neutron star merger r process.

The detailed pattern of isotopic abundances produced in rapid neutron capture, or r-process, nucleosynthesis depends upon the nuclear physics properties of thousands of unstable neutron-rich nuclear species. While some properties of neutron-rich nuclei near stability are known, experimental data is currently unavailable for most of the required masses and β-decay properties and essentially all of the needed neutron capture rates. However, the situation is evolving rapidly. Radioactive isotope facilities are expanding experimental reach into previously unknown regions of the nuclear chart, and new techniques are being developed to fully exploit the capabilities of current and upcoming facilities. A pressing question therefore emerges—which of the thousands of isotopes potentially involved in an r-process are most important to measure?

One approach to this question is to directly examine the influence of individual nuclear properties on r-process abundance predictions via sensitivity studies. In an r-process sensitivity study, a baseline astrophysical trajectory is chosen and then run thousands of times, each with one piece of nuclear data systematically varied. Results of the simulations are then compared to the baseline simulation with no data changes, to highlight the nuclei whose properties have the greatest leverage on the final abundance pattern in that particular environment. Sensitivity studies of this type have been performed for nuclear masses (Fig. 2), β-decay rates, neutron capture rates, and β-delayed neutron emission probabilities. JINA-CEE postdoc Matthew Mumpower along with JINA-CEE researchers Rebecca Surman, Gail McLaughlin, and Ani Aprahamian have spearheaded many of these studies and have now published a review of this work [1]. Detailed tables of the results are available at www.matthewmumpower.com.

Researchers: M. Mumpower (UND, LANL), R. Surman (UND), G.C. McLaughlin (NCSU), & A. Aprahamian (UND)

[1] M. Mumpower et al., Progress in Particle and Nuclear Physics, 86, 86-126 (2016)

Virtual Journals updated

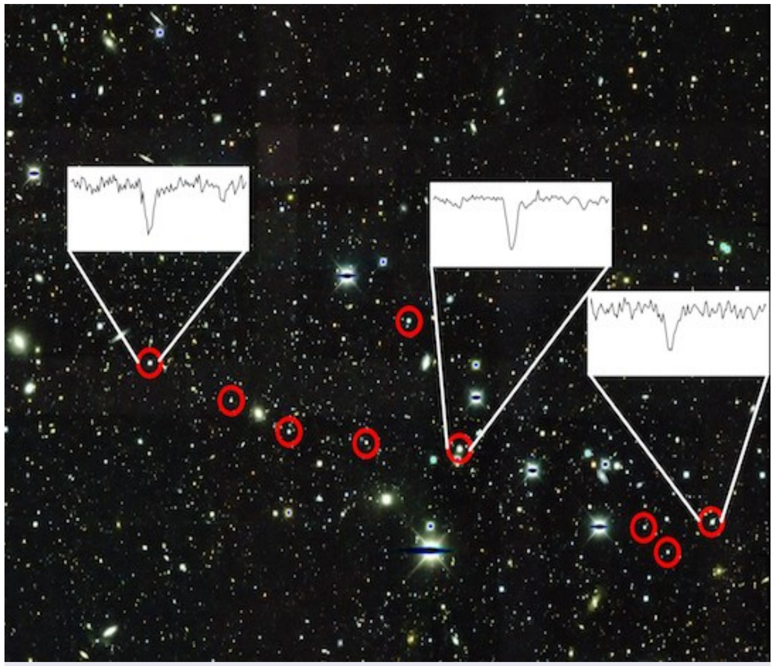
The JINA-CEE Virtual Journal of Nuclear Astrophysics and the SEGUE Virtual Journal provide an up-to-date access to articles of interest to our community, whereas the SEGUE journal focuses on articles of particular interest for observers. Our editors select articles on a weekly basis from more than 30 journals — sign up for a weekly notification now!

http://jinaweb.org/html/vj.html

A rare and prolific r-process event preserved in an ancient dwarf galaxy

Contributed by Alexander Ji (MIT & JINA-CEE)

One of the great triumphs of modern astrophysics is the knowledge that the elements in the periodic table are created through nuclear processes in stars. The heaviest elements, such as gold and uranium, are synthesized by the rapid neutron-capture process in extreme environments with very high neutron densities. However, the astrophysical site of this “r-process” is still unknown. Determining the source of r-process elements is a fundamental goal of nuclear astrophysics.



Dark Energy Survey image of the region surrounding the faint dwarf galaxy Reticulum II. The nine brightest known stars in the galaxy are marked with red circles. Spectra showing the unique chemical content of three stars are shown. Background image: Fermilab/Dark Energy Survey.

The chemical abundances of metal-poor Milky Way halo stars provide observations to understand the r-process. Some of these ancient stars contain large quantities of r-process material, showing the r-process has a universal abundance pattern and suggesting that the heavy elements were synthesized very early in the universe. However, our present paradigm of hierarchical galaxy formation implies that the Milky Way’s halo is an amalgam of stars from the nascent Milky Way as well as stars stripped from infalling dwarf satellite galaxies. Understanding the origin of the halo stars requires a complete understanding of galaxy formation to model this complicated environment.

An alternative path is to study the r-process content of stars in the surviving dwarf satellite galaxies themselves, where galaxy formation is relatively simple compared to the Milky Way. The so-called “ultra-faint dwarf galaxies” are the simplest of these satellites, forming stars for less than 2-3 billion years. Stars in the first nine ultra-faint galaxies studied contained unusually low amounts of heavy elements, consistent with small amounts of r-process production operating in core-collapse supernovae.

Recently, two JINA affiliated groups studied the chemical composition of stars in the newly discovered ultra-faint dwarf galaxy Reticulum II. To everyone’s surprise, most of the stars in Reticulum II display extremely enhanced heavy element abundances. Furthermore, the relative abundances exactly follow the universal r-process pattern. It is clear that the stars in this galaxy preserved an archaeological record of a rare and prolific r-process event. The rate and yield of the event inferred from these observations are consistent with an r-process event having taken place in a neutron star merger or a magnetically driven supernova. In particular, the inefficient star formation in a dwarf galaxy environment allows sufficient time for a binary neutron star system to merge, addressing previous concerns that neutron star mergers could not be responsible for producing r-process material at the earliest times. It thus appears that neutron star mergers can be the main source of the heaviest elements in the periodic table, from the early universe until today.

Researchers: A.P. Ji (MIT), Anna Frebel (JINA-CEE & MIT), A. Chiti (MIT), J.D. Simon (OCIW), I.U. Roederer (UM)
Further reading: Ji, A. P. et al. 2016, Nature, 531, 610 & Roederer, I. U., et al. 2016, AJ, 821, 37

New evidence for the i-process in the early Galaxy

Contributed by Ian Roederer (UM & JINA-CEE)

Understanding the origin of the elements is one of the major challenges of modern astrophysics. New work led by Dr. Ian Roederer, an assistant research scientist at the University of Michigan and a member of JINA-CEE, reveals that some of the heavy, trace elements found in ancient stars may owe part of their existence to a little-known process called the i-process.

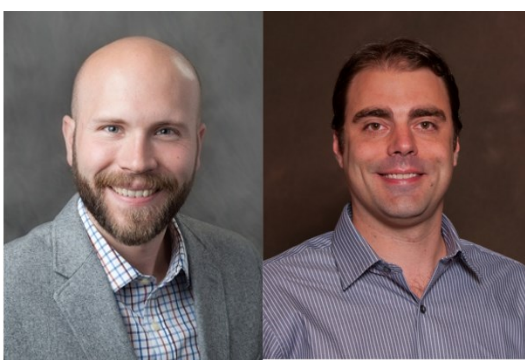
The Hubble Space Telescope, Image Credit: NASA

The researchers used ultraviolet and optical spectroscopy from the Hubble Space Telescope and several telescopes on the ground to study the chemical makeup of one ancient star in the Milky Way's halo, HD 94028. The team was able to detect 44 elements in this one star, and this extensive chemical inventory enabled them to model the abundance pattern and identify the possible signature of the i-process.

This new research signals that the i-process may have operated in the earliest generations of stars and had a role in producing moderately heavy elements like germanium, arsenic, and selenium. JINA-CEE researchers are working to develop simulations to model the i-process in stars, and new observations like these are critical to help guide the way.

Details are available in the published work: "The Diverse Origins of Neutron-Capture Elements in the Metal-Poor Star HD 94028: Possible Detection of Products of i-process Nucleosynthesis," by I.U. Roederer, A.I. Karakas, M. Pignatari, and F. Herwig. Astrophysical Journal **821,** 37 (2016)

Sean Couch and Christopher Wrede receive DOE's Early Career Research Program Funding



Sean Couch and Christopher Wrede, Assistant Professors of Physics and Astronomy at the Michigan State University and JINA-CEE participants, receive DOE's Early Career Research Program Funding. The program is designed to bolster the scientific workforce by providing support to exceptional researchers during the crucial early career years, when many scientists do their most formative work.

Sean Couch, a theoretical astrophysicist, is going to use the funding to work on better quantifying the sensitivity of core-collapse supernovae to uncertainties in the underlying nuclear physics.

Chris Wrede, a nuclear experimentalist, will devote the funds to develop a new detector of beta delayed charged particles at NSCL to address uncertainties associated with critical nuclear reaction rates in classical novae and x-ray bursts.

Congratulations to both of them — we are looking forward to hear more about their research!

AZURE2 one of the best R-Matrix codes

The JINA R-matrix code, AZURE2, was recently put to the test in a comparison with different R-matrix codes at an IAEA workshop in Vienna, AU. AZURE2 performed exceptionally well, on an equal footing with other longstanding international codes made by national laboratories worldwide. Further, it was the only code to have a graphical interface and be open source and freely available.

The IAEA has focused largely on neutron induced reaction evaluations but are beginning an initiative to provide evaluated cross sections for charged particle reactions as well. For evaluations of neutron reactions, the Oak Ridge R-matrix code, SAMMY, has been used extensively in the past. While this code has seen much development, it uses an alternate R-matrix formalism (Reich-Moore) that is not used by most other R-matrix codes. On the other hand, AZURE2 has been designed specifically for charged particle induced reactions and uses a standard implementation of R-matrix, making it an attractive alternative.

AZURE2 was tested together with codes from Los Alamos National Laboratory (EDA), Laurence Livermore National Laboratory (Ferdinand), Oak Ridge National Laboratory (SAMMY), and the Japanese Atomic Energy Agency (AMUR). The codes were found to give similar results but since they have all been developed independently, and since there are many different conventions used for R-matrix calculations, some differences exist.

A first goal has been established to define a standard convention for R-matrix parameterizations that can be used for IBANDL and to ensure one-to-one comparisons between different codes. These efforts are ongoing and will continue at yearly workshops at the IAEA.

AZURE2 is freely available as a precompile binary or from source at **azure.nd.edu.** There are currently 240 distinct registered users from 44 different countries.

JINA-CEE publications

M.B. Bennett et al., *Isospin Mixing Reveals P30(p,γ)S31 Resonance Influencing Nova Nucleosynthesis,* Phys. Rev. Lett. **116**, 102502 (2016)

A. Boeltzig et al., *Shell and explosive hydrogen burning* **,** Eur. Phys. J. A 52, 75 (2016).

P. Gastis et al., *Measurement of the equilibrium charge state distributions of Ni, Co, and Cu beams in Mo at 2 MeV/u,* Nucl. Instrum. Meth B **373**, 117 (2016)

A. Koloczek et al., *Sensitivity study for s process nucleosynthesis in AGB stars,* Atomic Data and Nucl. Data Tables, **108**, 1 (2016)

J. Pereira, and F. Montes, *Theoretical uncertainty of (α,n) reactions relevant for the nucleosynthesis of light r-process nuclei in neutrino-driven winds*, Phys. Rev. C **93**, 034611 (2016)

B.D. Crosby et al., *Tracing the evolution of high-redshift galaxies using stellar abundances,* Astrophys. J. **820**, 1 (2016)

Z. Meisel et al., *Time-of-flight mass measurements of neutron-rich chromium isotopes up to N=40 and implications for the accreted neutron star crust,* Phys. Rev. C **93**, 035805 (2016)

JINA-CEE faces: Post doc Ingo Tews

JINA-CEE Post doc Ingo Tews (University of Washington)

Education: Master's studies in physics at TU Darmstadt, Germany with Achim Schwenk.
PhD on " Quantum Monte Carlo calculations with chiral effective field theory" at TU Darmstadt, Germany.

When you were young, what did you want to be when you grew up? I always wanted to become a scientist, but I was not sure if I should pursue physics or chemistry .

When did you decide to pursue astrophysics/physics? The more I learned about stars, space and its exploration, the more I became interested in this topic. I then made the decision of studying physics when I was around 15.

What is your research focus? My research focusses on the equation of state of neutron matter, from low densities to nuclear densities and above, to better understand the structure of neutron stars. To obtain the equation of state I use chiral effective field theory (EFT), which is a modern and systematic approach to the nuclear forces, in combination with Quantum Monte Carlo methods. This combination enables precision studies of neutron and nuclear matter as well as of neutron-rich nuclei, which play a critical role in the evolution of stars and nucleosynthesis and will be probed in the future FRIB facility.

With whom and where will you work within JINA-CEE? I am working with Sanjay Reddy at the INT in Seattle on the neutron-star equation of state, and at the moment on the crust equation of state.

Where do you see yourself in 5 years? I hope that in 5 years I am able to obtain a permanent position to do research as well as to teach and work with students.

And what about 20 years? If someone would have asked me this question 20 years back, I guess my predictions would not have been very accurate :) Twenty years is too long a time to plan ahead. I hope that by that time I have left footsteps in a broad range of topics in nuclear astrophysics.

Is there anything else you'd like to share? We are organizing a biweekly JINA web seminar series which takes place Fridays at 2pm EST and is meant to help junior people to establish collaborations. I would like to encourage junior people to participate and maybe send me an email if they want to present their research.

JINA-CEE Fitbit group

Have a fitbit? Join the JINA-CEE Fitbit group for a friendly competition against other JINA-CEE members. A JINA coffee mug will be given to anyone who can beat former director, Michael Wiescher.

Upcoming JINA-CEE events

The r-process Nucleosynthesis: Connecting FRIB with the Cosmos
May 31 — June 17 2016, East Lansing, Michigan

Niigata School on Nuclear Astrophysics (NIC XIV School)
June 13 — 17 2016, Niigata, Japan

R-Matrix on Methods and Applications
June 27 — July 1 2016, Santa Fe, New Mexico

The 12th Torino Workshop on Asymptotic Giant Branch Stars
July 31—August 5 2016, Budapest, Hungary

3rd Astrophysical Nuclear Reaction Network School
August 19 — 26, Schmitten, Germany

JINA-CEE/TRIUMF Satellite Workshop on Recoil Separators for Nuclear Astrophysics
October 11 — 12, TRIUMF Laboratory, Vancouver, Canada

Carl Fields receives NSF Graduate Research Fellowship

Carl Fields, an Astrophysics and Physics major at Arizona State University and JINA-CEE participant, was awarded both an NSF Graduate Research Fellowship and a Ford Foundation Predoctoral Fellowship.

His research interests include compact objects, astrophysical sources of gravitational waves, and supernovae progenitor evolution, explosion, and nucleosynthesis. He is working with JINA-CEE PI Francis Timmes and is a lead developer of MESA-Web, a web-based interface to the widely-used Modules for Experiments in Stellar Astrophysics (MESA) stellar evolution code.

He will be earning his Bachelors of Science degrees (with Honors) this May, before he starts his graduate studies at MSU with Sean Couch.

JINA-CEE Outreach

JINA-CEE Outreach will be busy this summer with a number of summer programs. Our flagship Physics of Atomic Nuclei (PAN) program will host 44 high school students from 19 different US states and territories (including Puerto Rico) and 20 teachers from 11 states. Thanks in advance to NSCL grad students who will be constructing fragmentation boxes for the teachers to take back to their classrooms and use with our marble nuclei lesson plans. The popular Art 2 Science Camp will host 168 students this summer, not counting 20 teen counselors that will also gain leadership experience while learning. We also co-sponsor a camp with St. Joseph County Parks and offer a two-week course on Nuclear Astrophysics through the MST Program at MSU.

JINA-CEE is supported by the National Science Foundation through the Physics Frontier Center Program

JINA-CEE institutions

JINA-CEE Core Institutions:

Michigan State University, Department of Physics and Astronomy, NSCL
University of Notre Dame, Department of Physics, ISNAP
Arizona State University, SESE
University of Washington, INT

JINA-CEE Associated and Participating Institutions:

CCAPP Ohio State University, EMMI-GSI Helmholtz Gemeinschaft Germany, Florida State University, INPP Ohio University, Los Alamos National Laboratory / LANSCE-3, McGill University Canada, MoCA Monash University Australia, North Carolina State University, NAVI Germany, NUCLEI LANL, Argonne National Laboratory, Princeton University, Center for Nuclear Astrophysics China, Cluster of Excellence Origin and Structure of the Universe Germany, TRIUMF Canada, University of Chicago, University of Minnesota, University of Sao Paulo Brazil, University of Victoria Canada, Western Michigan University, Ball State University, Hope College, Indiana University South Bend, SUNY Geneso

JINA-CEE also has participants from:

California Institute of Technology, Central Michigan University, Gonzaga University, Al-Balqa Applied University Jordan, Lawrence Berkeley National Laboratory, Louisiana State University, Massachusetts Institute of Technology, MPI for Extraterrestrial Physics Germany, UNAM Mexico, Ohio State University, Shanghai Jiao Tong University China, Stony Brook University, TU Darmstadt Germany, University of Hull UK, University of Illinois, University of Michigan, Wayne State University

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