August 2021

JINA-CEE

Center for the Evolution of the Elements

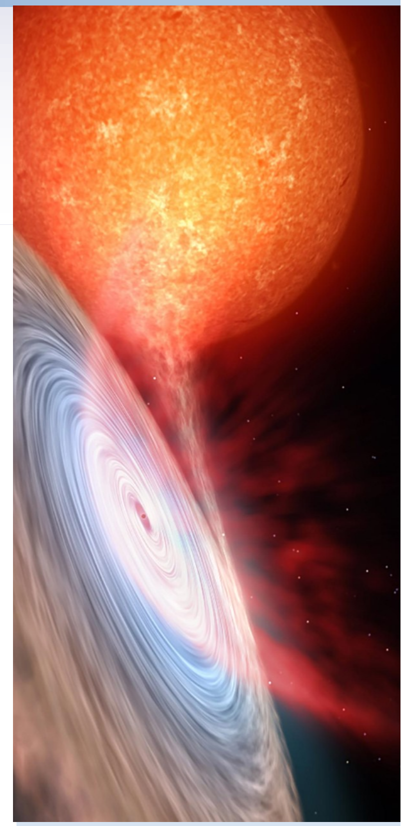

Image credit: Gabriel Pérez Díaz, Instituto de Astrofísica de Canarias

A note from the Director, Hendrik Schatz

Dear Members of the JINA-CEE Community and Friends,

I would like to take this opportunity to highlight and express my appreciation for the tremendous contributions of early career scientists, in particular students and postdocs, to the ongoing success of JINA-CEE. None of the science highlights in this newsletter would have been possible without their scientific contributions. We are proud that today more than 200 students and postdocs are part of JINA-CEE, and some are introduced in this newsletter. This bodes well for the future of the field of nuclear astrophysics. We have worked hard to create opportunities for engagement and professional development for young scientists across disciplines and I continue to be impressed by the response to these opportunities. Highlights entirely organized by young scientists include the online-seminar series, the annual collaboration meeting "Frontiers in Nuclear Astrophysics", or the Junior Workshop at the JINA Horizons Conference in December 2020. Along these lines, a new partnership with minority serving institutions across the US is focusing on introducing undergraduate students to cutting edge research in nuclear astrophysics (see article in this letter). Recently JINA-CEE also strengthened its international connections considerably with the NSF supported IReNA network and I am happy to report that students and postdocs took advantage of this opportunity to initiate an international young researchers network. If you are interested in joining this network contact Rahul Jain at Michigan State University or Camilla Hansen at MPA Garching in Germany. If you are an early career scientist in nuclear astrophysics I encourage you to explore opportunities offered by JINA-CEE and IReNA. I always look forward to hearing from you about new ideas, and how we can improve support for early career scientists further.

Inside this issue

NICER Measures the Radius of the Most Massive Neutron Star

Contributed by Anna Watts (University of Amsterdam, Netherlands)

The *Neutron Star Interior Composition ExploreR* (NICER) collaboration has measured the radius of the neutron star with the highest known mass, PSR J0740+6620. NICER, an X-ray telescope installed on the International Space Station, uses a technique known as Pulse Profile Modelling. This exploits relativistic effects on X-rays emitted from the star's surface – and their variation as the star rotates – to determine the mass and radius of the star. It also enables us to make a map of the hot emitting regions, which are linked to the neutron star's magnetic field configuration.

JINA-CEE members at the University of Amsterdam led one of two independent analysis teams within the collaboration, using their open-source X-ray Pulse Simulation and Inference (X-PSI) code. Using a prior on the pulsar's mass provided by NANOgrav and CHIME/pulsar radio timing, they found the radius of this ~2.1 solar mass star to be 12.4 (+1.3 – 1) km. This is very similar to the radius measured by the same team in late 2019 for PSR J0030+0451, even though that star was found to be much lighter, with a mass ~1.4 solar mass (see Figure). An accompanying multi-messenger Equation of State analysis with JINA-CEE collaborators at TU Darmstadt shows that the new radius measurement places tight constraints on the pressure of neutron star matter at around twice saturation density.

JINA-CEE Researchers: T.E. Riley, G.Raaijmakers, A.L.Watts, S.Nissanke (University of Amsterdam), T.Hinderer (now at Utrecht University), A. Schwenk (TU Darmstadt).

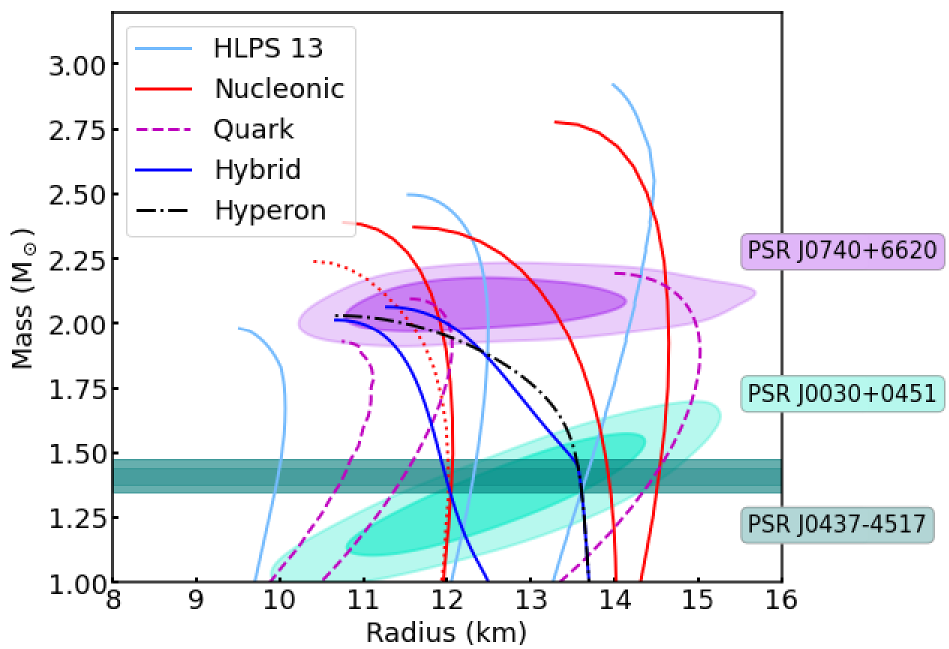

Figure 1. Mass-radius credible regions (dark: 68%, light: 95%) measured by the NICER X-PSI team for PSR J0740+6620 and PSR J0030+0451, compared to the predictions of various EOS models. The radii of the two stars are similar, and small radii are strongly disfavored. The dark green band indicates the mass of the next star for which the NICER collaboration anticipates reporting a radius, PSR J0437-4517.

Further reading:

Riley et al., *A NICER View of the Massive Pulsar PSR J0740+6620 Informed by Radio Timing and XMM-Newton Spectroscopy,* arXiv:2105.06980

Raaijmakers et al., *Constraints on the dense matter equation of state and neutron star properties from NICER's mass-radius estimate of PSR J0740+6620 and multimessenger observations*, arXiv:2105.06981

NASA news feature

The $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ and $^{19}\mathrm{F}(p,\alpha)^{16}\mathrm{O}$ Reaction Rates and their Effect on Calcium Production in Pop III Stars

Contributed by James deBoer (University of Notre Dame, USA)

First generation, or Population III, stars have a different evolution than those of later generations owing to their initial primordial abundance composition. Most notably, the lack of carbon, oxygen, and nitrogen, means that, instead of the CNO cycle, primordial massive stars must rely on the less efficient *p-p* chains for hydrogen burning, thereby requiring the star to contract to reach temperatures high enough to eventually trigger 3α-reactions. Even small amounts of the 3α-reactions begin feeding the CNO mass range and enable the CNO cycle to generate energy, but this occurs at higher temperature compared to later stellar generations. It is currently an open question if the observed enhanced abundances of Ca in the most metal-poor stars could be a result of the high temperature H-burning conditions in the first massive stars. The idea is that these first massive stars injected the produced Ca through a supernova explosion into the interstellar material from which the metal poor stars, observed today, formed. The level of this Ca enrichment depends on the hot breakout path from the CNO cycles via the $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ reaction. In this work, the rates of both the $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ (see Fig. 1) and competing $^{19}\mathrm{F}(p,\alpha)^{16}\mathrm{O}$ reactions are re-evaluated using the phenomenological *R*-matrix approach, simultaneously considering several $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$, $^{19}\mathrm{F}(p,\alpha)^{16}\mathrm{O}$, and $^{19}\mathrm{F}(p,p)^{19}\mathrm{F}$ data sets, in order to better characterize the rate uncertainties. It is found that the rate uncertainty for the $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ reaction is considerably larger than previously reported (see Figs. 2 and 3). This is the result of undetermined interferences between observed resonances, a possible threshold state, possible subthreshold states, direct capture, and background levels. Additional experimental measurements are therefore needed to determine if $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ CNO breakout is responsible for Ca enrichment in metal poor stars. Astrophysically, the breakout reaction revision makes it less likely that Ca observed in the most Fe-poor stars can originate in hot CNO breakout H-burning nucleosynthesis, thereby casting doubt on the prevailing faint supernova scenario to explain the abundances observed in these stars.

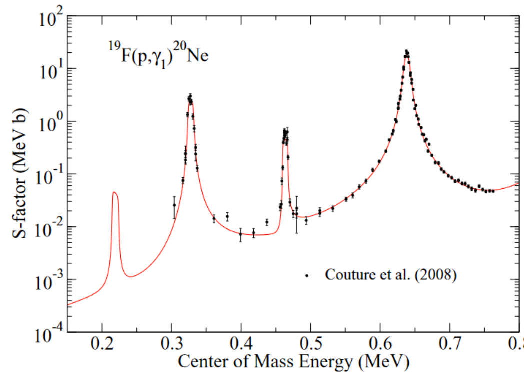

Figure 1: Uncertainties in the extrapolated S-factor of the $^{19}\mathrm{F}(p,\gamma_1)^{20}\mathrm{Ne}$ reaction.

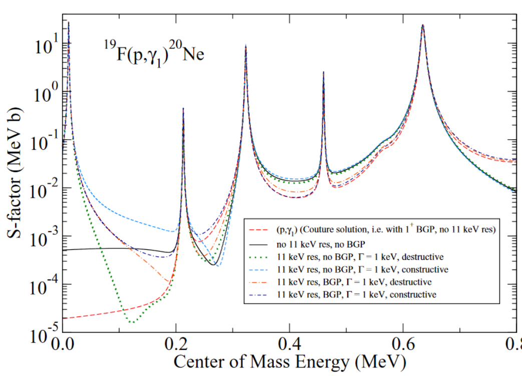

Figure 2: A sampling of different low energy S-factors that are possible for the $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ reaction.

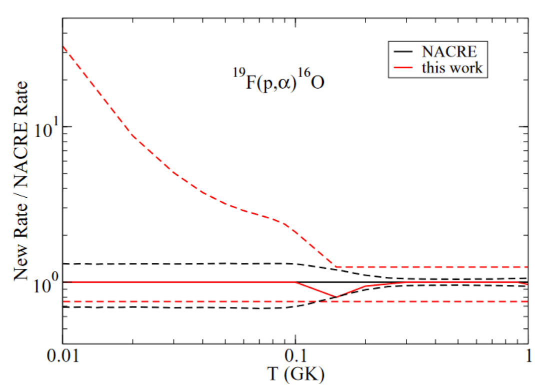

Figure 3: Uncertainty range in the rate of the $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ reaction relative to the rate recommended in the NACRE compilation of reaction rates.

Further reading:

R. J. deBoer, O. Clarkson, A. J. Couture, J. Görres, F. Herwig, I. Lombardo, P. Scholz, and M. Wiescher. Phys. Rev. C 103, 055815 $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ and $^{19}\mathrm{F}(p,\alpha)^{16}\mathrm{O}$ reaction rates and their effect on calcium production in Population III stars from hot CNO breakout.

APS Physics Featured Synopsis

New IAEA Reference Database for Beta-Delayed Neutron Emission

Contributed by Iris Dillmann (TRIUMF and University of Victoria, Canada)

After a decade in the making, the Reference Database for Beta-Delayed Neutron Emitters has been published and is available online. The project was kicked-off in 2011 by JINA-CEE member Iris Dillmann and nuclear data evaluator Balraj Singh (McMaster University, Canada) after realizing that the existing compilations for neutron-branching ratios of beta-delayed neutron emitters were outdated and lacking documentation. After an initial Consultants Meeting at the International Atomic Energy Agency (IAEA) in Vienna, Austria a 5-year Coordinated Research Project (CRP) was initiated. The Summary paper from this CRP, co-written by Iris Dillmann as appointed IAEA rapporteur, has now been published as part of a Special Issue in Nuclear Data Sheets [1].

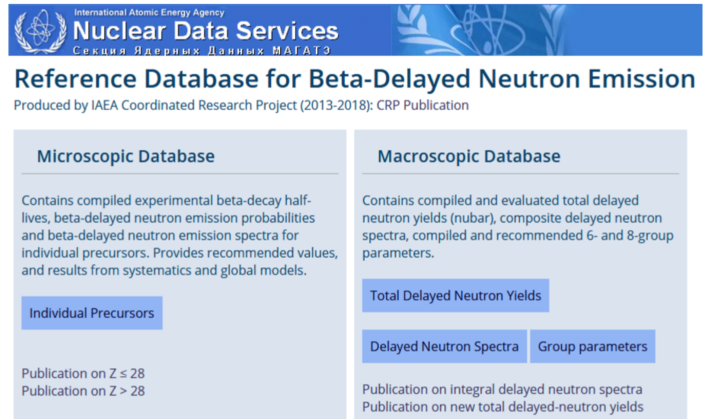

Figure 1: The reference database for beta-delayed neutron emission has been published and it is available at https://www-nds.iaea.org/beta-delayed-neutron/database.html

Beta-delayed neutron emitters play an important role not only in the control of reactors but also in nuclear structure and nuclear astrophysics. They occur on the neutron-rich side of the chart of nuclides whenever the neutron separation energy is smaller than the respective beta-decay energy window. Until now, this decay mode is energetically possible for more than 650 out of the 3435 known nuclei (19%). It is estimated that more than 4000 nuclei are still waiting to be discovered. The majority of them are on the neutron-rich side, and beta-delayed neutron emission will become their dominant decay mechanism. Unfortunately, an accurate theoretical description of this decay process is still lacking, especially in terms of competing de-excitation via gamma-rays and multi-neutron emission. This incomplete theoretical description creates an uncertainty in astrophysical simulations of the rapid neutron capture process (r-process) since the beta-delayed neutrons are predominantly emitted in the late stages of the r-process nucleosynthesis during the freeze-out phase. In this stage the emitted neutrons are recaptured by the material decaying back to stability and have a direct influence on the resulting r-process abundance distribution.

The new IAEA reference database contains two sub-databases. The "Macroscopic Database" for the reactor community contains compiled and evaluated total delayed neutron yields, composite delayed neutron spectra, and compiled and recommended 6- and 8-group parameters. The "Microscopic Database" contains compiled and evaluated experimental beta-decay half-lives and neutron-branching probabilities, as well as delayed neutron emission spectra for individual precursors. For every beta-delayed neutron emitter, a well-documented evaluation procedure was carried out and recommended values for the beta-decay half-life and the beta-delayed neutron emission probabilities are provided. These evaluations were published for Z=2-28 [2] and for Z>28 [3].

This evaluation effort was very timely. The Beta-Delayed Neutrons at RIKEN (BRIKEN) project is about to conclude its campaign this fall after 5 years of data taking and measuring half-lives and neutron-branching ratios of >250 new beta-delayed neutron emitters of relevance for r-process nucleosynthesis. The implantation and neutron detectors used in the BRIKEN campaign will return to their host institutions and be used in the next years to measure the most neutron-rich nuclei that can be produced at the new RIB facilities FAIR and FRIB.

This ongoing influx of new data will require an annual update of the database which will be carried out by JINA-CEE member and TRIUMF research associate Roger Caballero-Folch under guidance of evaluator Balraj Singh.

Further reading:

[1] P. Dimitriou, I. Dillmann, B. Singh et al., Nucl. Data Sheets 173 (2021) 144
[2] M. Birch et al., Nucl. Data Sheets 128 (2015) 131
[3] J. Liang et al., Nucl. Data Sheets 168 (2020) 1

Neutron Transfer Studies on ^{25}Mg and its Correlation to Neutron Radiative Capture Processes

Contributed by Michael Wiescher (Notre Dame University, USA)

Radiative neutron capture reactions play an important role in nuclear astrophysics. In some cases, direct neutron capture reaction studies are not possible and neutron transfer reactions have been suggested as a surrogate approach. A JINA-CEE led research team performed a detailed study of the ^{25}Mg(d,p)^{26}Mg reaction at a beam energy of 56 MeV, using the Grand Raiden spectrometer at RCNP (see Fig. 1) , as a surrogate reaction to the radiative neutron capture reaction ^{25}Mg(n,γ)^{26}Mg. A large number of neutron bound and unbound states between 10.6 and 12.1 MeV excitation energy in ^{26}Mg were observed. Angular distribution analysis provided information about the orbital momentum transfer populating these levels (see Fig. 2). The comparison with resonances observed in the ^{25}Mg(n,γ)^{26}Mg reaction indicate that different levels in ^{26}Mg are being populated through the two reaction mechanisms as demonstrated through an R-matrix calculation (see Fig. 3). This causes substantial discrepancies in the reaction-rate prediction. This result demonstrates that neutron transfer reaction studies may not necessarily lead to reliable predictions for neutron capture reaction rates.

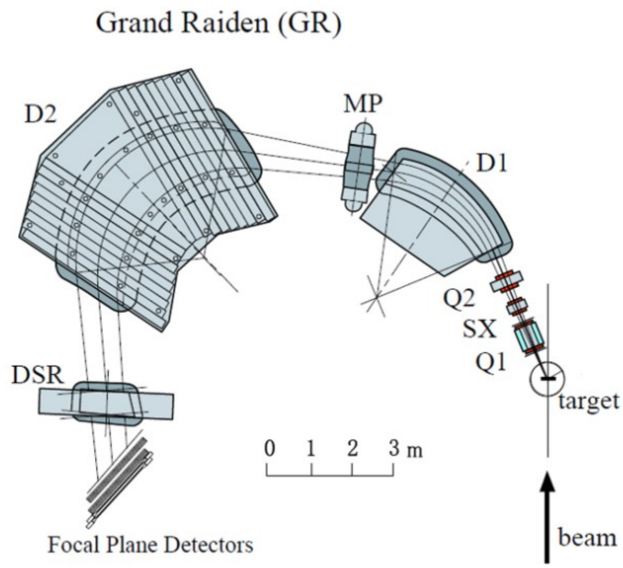

Figure 1. Schematic view of the Grand Raiden (GR) spectrometer at RCNP.

Further reading: Y. Chen et al. PRC 103, 035809 (2021)

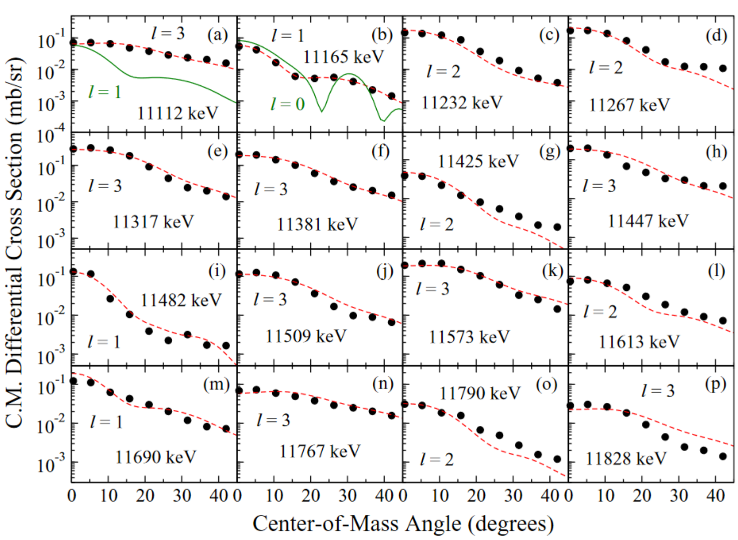

Figure 2. Measured angular distributions (data points) and `DWUCK4` calculations (solid and dashed lines) for excited states above the neutron threshold for the ^{25}Mg(d,p)^{26}Mg reaction at 56 MeV.

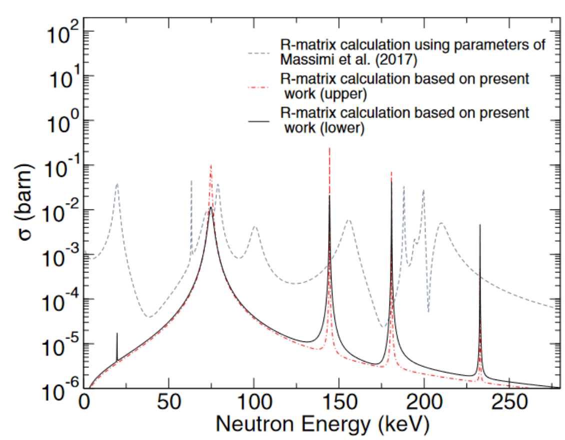

Figure 3. Comparison of the cross section for the ^{25}Mg(n,γ)^{26}Mg reaction calculated from the R-matrix parameters of Massimi et al. versus the upper and lower limits calculated using the level parameters of the present work. Calculations were performed using the code AZURE2.

Beta-delayed Neutron Emission of r-process Nuclei at the N=82 Shell Closure

Contributed by Alfredo Estrade (Central Michigan University, USA)

The BRIKEN collaboration recently published a measurement of Pn-values for 33 isotopes important to astrophysics models of nucleosynthesis via the rapid neutron capture process (r-process). Pn-values measure the probability that neutrons are emitted following the beta-decay of neutron-rich isotopes. It is one of the key pieces of nuclear data for r-process models, which is generally needed across all possible astrophysical scenarios. Delayed neutrons will affect the abundances of heavy elements produced by an r-process event as the unstable isotopes synthesized during the neutron-capture phase decay towards beta-stability.

The beta-delayed neutron at RIKEN (BRIKEN) collaboration was formed by several research groups in Asia, Europe and North America. The collaboration developed a high-efficiency neutron detector for Pn-value measurements based on ^{3}He counters [1]. The detector was specially designed for the properties of fast unstable isotopes beams at the Radioactive Isotope Beam Factory (RIBF) in RIKEN, Japan. Combining the high-efficiency of the BRIKEN detector and intense beams for neutron-rich isotopes produced at RIBF allowed BRIKEN to study a large number of r-process isotopes from the ^{78}Ni region [2] up to the region of the N=126 shell closure, with a campaign of experiments that began in 2017.

The latest BRIKEN results focused on the N=82 neutron-shell closure. They include isotopes from ^{116}Tc to ^{130}Cd, with 16 Pn-values measured for the first time. The measurement covers a mass range associated with r-process waiting-point isotopes at N=82 like ^{128}Pd, and is key to reduce the nuclear uncertainty for the formation of the A=130 r-process abundance peak. The results illustrate the impact of precise new experimental data. With the new data the authors evaluated the ratio for the abundance of A=127 and A=128 isotopes produced from the decay of the ^{127}Rh and ^{128}Pn waiting points with an uncertainty of only 14% due to the Pn-value data, and consistent with solar system abundances. The result shows good agreement with the latest calculation of Pn-values with the FRDM+QRPA model, yet diverges by up to a factor of 4 if compared with other theoretical models used in r-process calculations. The work was the Ph.D. project of Oscar Hall (University of Edinburgh) and the experiment was led in part by JINA-CEE members as spokespersons.

The first results from the BRIKEN collaboration demonstrate the potential of combining sensitive experimental equipment with the intense rare isotope beams at new generation facilities. More BRIKEN results are expected in the near future from data sets currently under analysis, which together with experiments planned at other laboratories like FRIB will make significant progress in the quest of providing accurate data to elucidate the nature of the r-process.

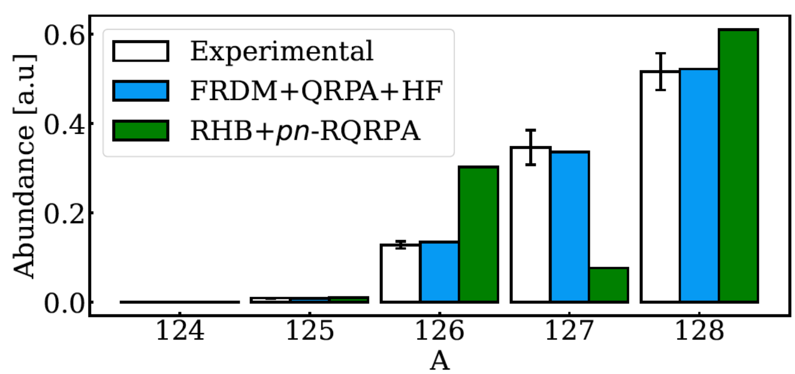

Figure 1: Resulting r-process abundance following an instantaneous freeze out starting with an initial abundance distribution of ^{128}Pd and ^{127}Rh weighted by their literature half-lives. The figures compares the results with the new experimental values of [3] and two theoretical models that predict decay properties across the nuclear chart.

Further reading:

[1] A. Tolosa-Delgado, et al. "Commissioning of the BRIKEN detector for the measurement of very exotic beta-delayed neutron emitters", Nucl. Instrum. Methods Phys. Res. A 925, 133 (2019).

[2] R. Yokoyama, et al., "Strong one-neutron emission from two-neutron unbound states in β decays of the r-process nuclei 86,87Ga" Phys. Rev. C 100, 031302(R) (2019).3] O. Hall et al, "Beta-delayed neutron emission of r-process nuclei at the N = 82 shell closure", Phys. Lett. B 816, 136266 (2021).

[3] O. Hall et al, "Beta-delayed neutron emission of r-process nuclei at the N = 82 shell closure", Phys. Lett. B 816, 136266 (2021).

JINA-CEE Continues Partnership with Minority Serving Institutions

As part of a collaboration initiated at the end of 2019, JINA-CEE is introducing students from seven Minority Serving Institutions (MSI) to the field of nuclear astrophysics. An introductory lecture series was launched online in the fall 2020 semester. Participating institutions are Alabama A&M University, Arkansas University At Pine Bluff, Dillard University, Howard University, Texas Southern University, University Of Texas Rio Grande Valley, Virginia Union University. The JINA lecture series highlighted cutting edge science in nuclear astrophysics, and provided information about graduate studies and REU opportunities at JINA-CEE participating institutions, and other career relevant information.

The lectures were embedded into the curriculum at the various institutions. 37 students attended the live lecture series via zoom, and many more watched the recorded videos on our YouTube channel. Participants expressed an increased interest in astronomy and nuclear physics after the lectures, and many found the information provided about grad schools useful. A website dedicated to the JINA-CEE lecture series for MSIs was created, which includes a short profile of each one of the instructors, and a variety of links to additional resources.

The program also includes internship opportunities at JINA-CEE institutions for selected students, following the lecture series. During Spring 2021, the first such internships were offered to undergraduate students enrolled at the participating institutions. Two students are currently working remotely with JINA-CEE faculty on nuclear astrophysics research:

Eboni Collins
Dillard University

Eboni Collins, from Dillard University, joined Remco Zegers' research group, where she contributes to the data analysis of charge exchange reaction experiments taken with the Low Energy Neutron Detector Array (LENDA). Eboni has been interested in physics since her senior year in high school, and has done summer research internships in the past at Fermilab, Tulane University and the U.S. Army. She will be starting her masters in engineering management at the University of New Orleans this fall. When asked about her impressions of her JINA internship she shared that "My research group has been extremely helpful and supportive. I really love working with Dr Zegers. His grad student Jacklyn, whom I work with closely, has been a great peer mentor. This experience changed my view of remote internships".

Kayleigh Johnson, from the University of Arkansas at Pine Bluff, is working with Ed Brown on research related to white dwarf stars accreting matter form a binary companion. Kayleigh has been involved in research experiences for undergrads for the last three summers at Princeton University, University of Arkansas, and Washington State University. She knew she wanted to go to graduate school, but thanks to her recent experience with JINA, she decided to apply to the nuclear graduate program at MSU. She was accepted and has recently relocated to East Lansing. She shared that "I did my research presentation at the end of my seminar class last fall based on the lecture by Dr Jinmi Yoon on galactic archaeology, and my whole class loved it. When I learned about the research internship I was very excited and applied immediately. Working with Dr Brown and his group has been an amazing experience, and it has given me the little push to know this is where I want to go."

Kayleigh Johnson
University of Arkansas at Pine Bluff

The second JINA-CEE lecture series in nuclear astrophysics for MSIs is planned for the upcoming fall semester, and more follow-up activities like summer schools are in the works for 2022.

JINA-CEE Faces:
Interview with Panos Gastis

Panos Gastis
Los Alamos National Laboratory

Panos Gastis is an experimental nuclear physicist who studies nuclear reactions that play key roles in various astrophysical processes. He is originally from Greece, and received his bachelors degree from the National Technical University of Athens at the School of Applied Mathematics and Physical Sciences. He graduated with his PhD from Central Michigan University in 2020, where he collaborated with Georgios Perdikakis, and he is currently working as a postdoctoral researcher at Los Alamos National Laboratory.

When did you decide to pursue a career in science?
-From an early age I always wanted to know how things worked, from electronic devices to the human body and the sun, and I also loved solving problems. When I was an undergrad I performed research at the Demokritos Laboratory in Athens, Greece, where I got involved in nuclear physics for the first time. I had the chance to work with the tandem accelerator there, which is a twin of the one at the Edwards Laboratory, located in Athens, Ohio. Quite a nice coincidence that as a grad student I got to work with the latter too!

How do you interact with JINA-CEE?
-Throughout grad school I collaborated mostly with JINA researchers, and to date I continue to work with several of them. I have also participated in various JINA summer schools and workshops. More recently I served as chair of the organizing committee of the IReNA online seminar, which gave me the opportunity to interact not only with the JINA community but also with colleagues from other networks.

What is the focus of your research?
-I am interested in the study of nuclear reactions associated with astrophysical phenomena, mainly stellar nucleosynthesis and supernovae. Recently, I started to focus also on the study of nuclear fission that plays a role in r-process nucleosynthesis. At LANL, I am part of the Nuclear and Particle Physics and Applications group, and I am working on fission experiments relevant to nuclear applications. These experiments could provide useful information for astrophysics as well.

What's your favorite part of your job?
-That what I do is like an art to me, it is not just something that I do and I leave behind after 5pm. It is a constant challenge where I have to come up with creative solutions every day. I have passion for what I do and that keeps things interesting. Science is not something you just end up doing by chance, you have to be intentional.

What do you consider has been your most important scientific finding so far?
-An experiment we did to characterize an instrument, initially, but that evolved into a contribution to the study of the feasibility of exoplanets to harbor life. It turns out that some key radionuclides, such as ^{40}K, are responsible for planetary radiogenic heating. By measuring the destruction rate of ^{40}K via the ^{40}K(n,p)^{40}Ar reaction, we provided valuable input data for calculation of stellar yields for ^{40}K, which we hope will in turn help to improve the accuracy of the radiogenic heating models currently used to identify exoplanets that could support life. This is a very complicated problem but we added a small piece of nuclear physics information that may be useful in a new research field.

What's your advice for junior researchers?
-When you are trying to solve a complicated problem, answers are often not straightforward, and you might think there's no point in trying harder. This is normal. Scientists have to deal with frustration and failure pretty often. If you're ever there, remember why you started in the first place, remember when you were little and had a curious mind. Keep in mind what inspires you to do science.

What do you do on your free time?
-I enjoy playing the guitar, and more recently swimming and hiking.

Michael Wiescher Receives British Royal Society Wolfson Fellowship

Michael Wiescher
University of Notre Dame

Michael Wiescher, Freimann Professor of Physics and director of the Institute for Structure and Nuclear Astrophysics (ISNAP) at the University of Notre Dame and founding director of JINA, received the prestigious Wolfson Fellowship of the British Royal Society. Wiescher will serve as a visiting professor at the University of Edinburgh to expand on a collaborative European research effort in nuclear astrophysics. This award will advance the role of the Notre Dame Nuclear Science Laboratory (NSL) by participating in the collaborative research efforts between the University of Edinburg and European research initiatives such as the INFN-MV accelerator at the Gran Sasso Underground Laboratory in Italy, the CryRing at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt Germany, as well as at the FRANZ neutron beam facility of the University of Frankfurt. These large scale international collaboration initiatives between US and European institutions have been developed through the NSF-funded International Research Network for Nuclear Astrophysics IReNA, with Wiescher as one of the Principal Investigators.

JINA-CEE Institutions

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

JINA-CEE Core Institutions:
Michigan State University
University of Notre Dame
Arizona State University
University of Washington

JINA-CEE Associated Institutions:
Alabama A&M University, Arkansas University At Pine Bluff, CCAPP Ohio State University, Central Michigan University, ChETEC, CNA Shanghai Jiao Tong University China, Dillard University, EMMI-GSI Helmholtz Gemeinschaft Germany, Florida State University, Howard University, INPP Ohio University, Los Alamos National Laboratory / LANSCE-3 / T2, Massachusetts Institute of Technology, McGill University Canada, MoCA Monash University Australia, National Astronomical Observatory of Japan, North Carolina State University, NUCLEI LANL, Argonne National Laboratory, Princeton University, Rutgers University, Texas Southern University, TRIUMF Canada, University of Amsterdam Netherlands, University of Chicago, University of Hull UK, University of Minnesota, University of Oslo Norway, University of Texas Rio Grande Valley, University of Victoria Canada, Virginia Union University, Western Michigan University.

For a full membership directory see the JINA-CEE website.

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