JINA-CEE
Center for the Evolution of the Elements

November 2017

A note from the Director, Hendrik Schatz

Dear Friends of JINA-CEE,

These are exciting times for nuclear astrophysics. The discovery of gravitational waves and a kilo nova from GW170817 by LIGO/VIGO in concert with many other telescopes is a major breakthrough for our field. It provides the long sought "smoking gun" signature of a possible site of the rapid neutron capture process, long thought to be responsible for the origin of much of the heavy elements in nature. The observations also indicate that neutron star mergers occur frequently enough and eject enough material to be major nucleosynthesis sites. It is now more important than ever to understand the underlying nuclear physics to connect merger models with the new observations, and to determine exactly which elements are produced in these events. The connection between chemical evolution models, nuclear physics, and the new gravitational wave data is discussed in a recent paper by JINA-CEE's Benoit Cote and co-workers that is presented in this newsletter.

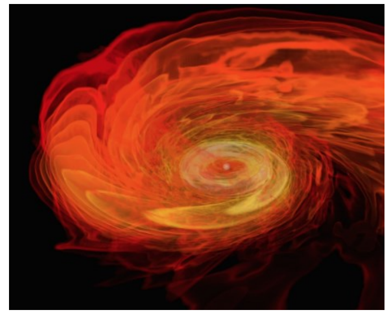
To discuss the impact of the GW170817 discovery on nuclear science and nuclear astrophysics JINA-CEE is organizing a live stream panel discussion on Friday, December 1, at 12:30 pm EST. You are invited to join via Zoom or YouTube, and submit questions by e-mail, YouTube Chat, or Twitter using #gwnuclear. More information at www.jinaweb.org/gwnuclear.

Nuclear astrophysics in the multi-messenger astronomy era requires multi-physics interpretations of observations and bringing together nuclear experimental data obtained with multiple techniques and accelerators, a range of nuclear theory approaches, advanced computational modeling, and a very broad range of theoretical astrophysics. This is what JINA-CEE is all about. You can again see this reflected in this newsletter with contributions on GW170817, the new CASPAR underground laboratory, as well as a broad range of JINA-CEE summer workshops that in many cases broke new ground in bringing together astronomers, theoretical astrophysicists, and nuclear scientists to discuss a diverse range of timely topics.

Inside this issue

The r Process in the Era of Gravitational Waves

Recently, the LIGO and Virgo collaborations have detected the gravitational wave coming from the merging of two neutron stars, now known as GW170817. Such neutron star collisions have long been suggested as possible sites for the creation of the heavy elements such as gold or europium in nature via a nuclear process called the rapid neutron capture process or r-process. With this detection one can for the first time infer an estimate of the frequency of such events in the local universe[1]. Moreover, concerted follow-up observations across the entire electromagnetic spectrum[2] enabled researchers to confirm the theory that merging neutron stars indeed produce and eject into space large amounts of heavy elements.



Neutron star merger simulation
Credit: NASA/AEI/ZIB/M. Koppitz and L. Rezzolla

We implemented the new data into models that track the chemical evolution of our Galaxy from its formation after the Big Bang with a simple composition of mostly hydrogen, helium, and lithium to today's complex mix of chemical elements that are the basis of life and the world as we know it. These chemical evolution models track formation and death of all kinds of stars, including the merging of neutron stars, and the elements they create and eject. In a previous paper[3] prior to the new discovery we reviewed and normalized a wide variety of such chemical evolution studies, including sophisticated cosmological hydrodynamic simulations. These models predicted the neutron star merger frequency required, for an assumed amount of elements ejected per event, in a galaxy evolution context to reproduce the r-process enrichment observed in our Galaxy, assuming neutron star mergers are the dominant astrophysical site of the r-process.

We can now test the possibility of neutron star mergers being the main source of r-process elements using the same models with the new data. Figure 1 shows that if GW170817 (pink shaded area) is a typical event, modern chemical evolution calculations (dark blue shaded area) confirm that neutron star mergers can produce enough r-process elements to explain the amount of europium observed in galaxies. Among other elements, we found that GW170817 ejected between 15 and 70 Earth masses of pure gold. This work implies that neutron star mergers are likely the dominant r-process site in the universe. In fact, there is an overlap between chemical evolution requirements (what is needed to explain the observed amount of elements), LIGO/Virgo (what is observed in terms of frequency and element production), and population synthesis models (the predicted event frequency). This work represents a massive collaborative effort that connects r-process nucleosynthesis, nuclear physics, multi-wavelength emissions, gravitational waves, binary population synthesis models, stellar abundances observations, and galactic chemical evolution simulations.

Nuclear physics related to rare isotopes is needed to understand which elements are being produced, how they are being made, and what the required conditions deep inside the neutron star collision region are. Our study is the first to directly include the impact of some of the large nuclear uncertainties (lighter blue shaded area) in a galaxy evolution context. These uncertainties will be addressed with experiments planned at future rare isotope facilities such as FRIB.

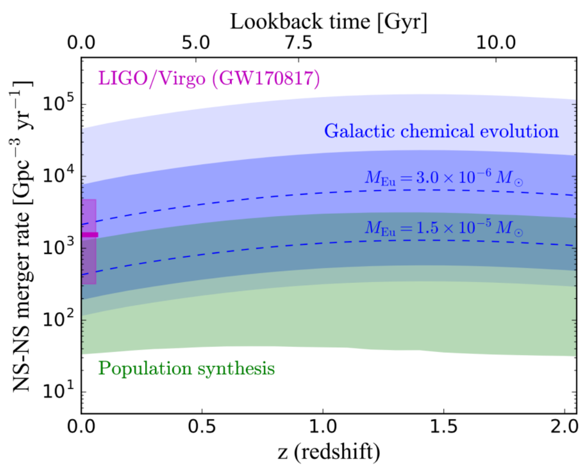


Figure 1.

Evolution of the neutron star merger rate density as a function of redshift. The pink thick horizontal line and shaded area (at low redshift) show the rate and uncertainty measured by LIGO/Virgo. The blue dashed lines show the rates needed in galactic chemical evolution (GCE) studies to reproduce the r-process enrichment observed in the Milky Way using neutron star mergers only. These two lines adopt two different europium ejecta masses per event, representing the lower and upper limits derived for GW170817, assuming a typical r-process abundance pattern. The dark blue shaded area surrounding these two lines represents GCE model uncertainties. When adopting theoretical r-process abundance patterns calculated from first principle, the mass of europium ejected becomes more uncertain due to nuclear physics uncertainties, which enlarges the uncertainty band associated with GCE (lighter blue shaded area). The green shaded area shows the neutron star merger rate densities predicted by population synthesis models that follow theoretically the evolution and interaction of binary stars and their remnants.

Researchers: B. Côté (Konkoly Observatory/MSU), C. L. Fryer (LANL), K. Belczynski (Copernicus Center), O. Korobkin (LANL), M. Chruslinska (Radbound U.), N. Vassh (U. Notre Dame), M. R. Mumpower (LANL), J. Lippuner (LANL), T. M. Sprouse (U. Notre Dame), R. Surman (U. Notre Dame), R. Wollaeger (LANL)

[1] LIGO Scientific Collaboration & Virgo Collaboration 2017, Physical Review Letters, 119, 161101
[2] LIGO Scientific Collaboration & Virgo Collaboration 2017, ApJL, 848, 12
[3] B. Côté et al. 2017, ApJ, 836, 230
[4] B. Côté et al. 2017, ApJL, submitted, arXiv:1710.05875

First Beam and Inauguration of CASPAR

The Compact Accelerator System for Performing Astrophysical Research (CASPAR) recently reached a huge milestone with the delivery of first beam to target. This marks a significant step in the creation and operation of the first US deep underground accelerator laboratory.

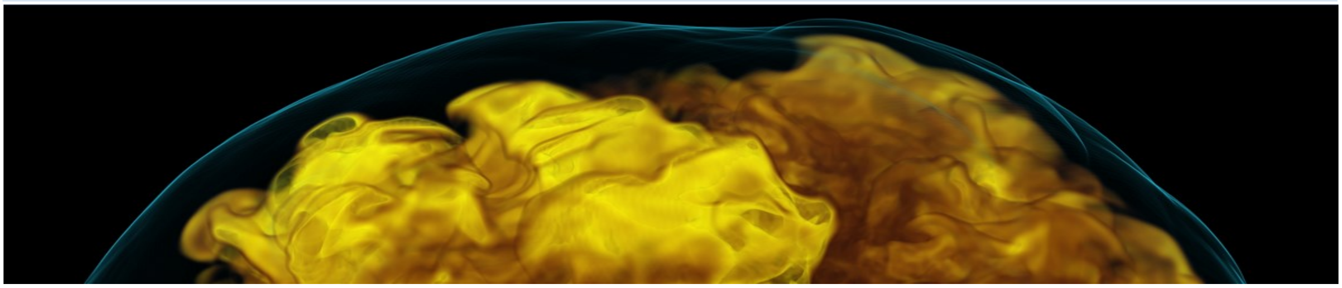
Located 4850 feet underground at the Sanford Underground Research Facility (SURF), CASPAR has entered its initial commissioning phase after two years of construction and installation. As a joint project by the University of Notre Dame, South Dakota School of Mines and Technology, and Colorado School of Mines, the CASPAR facility will soon see the beginning of "soft" operations with a focus on (α,n) and (p,γ) reactions of interest in stellar nucleosynthesis.

The team celebrated in July with an inauguration of the facility and ribbon cutting event. The ceremony at SURF was attended by CASPAR members, representatives of the associated institutions and members of the media, and is a defining moment as the facility is declared operational and unveiled to the community. With the system officially open, first measurements are projected for the fall.

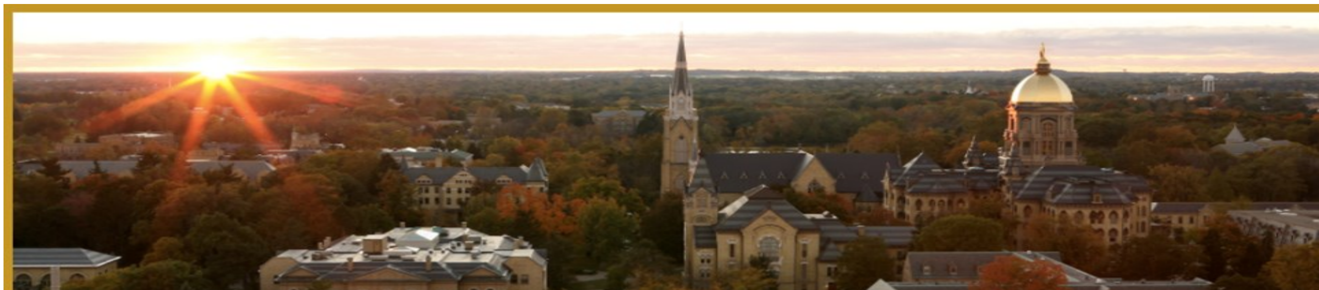
4850 feet underground at the Sanford Underground Research Facility in Lead, SD

From left: Dr. Manoel Couder and Dr. Michael Wiescher, UND; Dr. Jan Puszinski, SDSMT; Mike Headley, SDSTA; Dr. Dan Robertson and Dr. Mary Galvin, UND; Dr. Frank Strieder, SDSMT; Pat Lebrun and Casey Peterson, SDSTA; and Ron Everett, Lead. Photo by Matt Kapust, Sanford Underground Research Facility

MICRA 2017
Microphysics in Computational Relativistic Astrophysics



The fifth biannual Microphysics in Computational Relativistic Astrophysics (MICRA) workshop was hosted by JINA-CEE and held at the NSCL in East Lansing from July 17th through 21st. This interdisciplinary workshop aimed at fostering exchange between nuclear (astro-)physicists and computational modelers of relativistic astrophysical phenomena, such as the mergers of neutron stars and core-collapse supernovae. A major goal of the workshop series is to foster efforts to include increasingly realistic microphysics in simulations so that we can confidently interpret multi-messenger observations of high density environments. The talks and discussions at MICRA2017 focused on the impact of nuclear physics, neutrino transport, and magnetic fields on models of core collapse supernovae and neutron star mergers. Strategies for rigorous code-to-code comparison and verification between different groups and the microphysics needs of next generation simulations were



p-process Workshop 2017

University of Notre Dame, Notre Dame, IN, June 29 - July 1st, 2017

The sixth p-process Workshop was held at the University of Notre Dame, June 29 – July 1, 2017. This was a continuation of a series of workshops (Garching, Germany, 2009; Istambul, Turkey, 2011; Debrecen, Hungary, 2013; Limassol, Cyprus, 2015) dedicated to p-process nucleosynthesis that cover a wide range of topics related to the nucleosynthesis of heavy proton-rich nuclei. The topics range from the possible nucleosynthesis scenarios (g-process, rp-process, np-process, n-process), astrophysical sites, the nuclear physics contributions (nuclear structure, Hauser-Feshbach models, cross section measurements) to modeling of the nucleosynthesis processes (post-processing network calculations). The meeting gathers a wide spectrum of scientists from around the world working on all aspects of the p-process: from experimental and theoretical nuclear physics, through computational nuclear physics and observational astronomy.
This year, 35 participants from Europe and the U.S. gathered on the University of Notre Dame campus to talk about the recent progress in computational, experimental and theoretical efforts to understand the astrophysical p-process. Nearly half of the talks were given by students and postdocs, whose participation in the workshop was sponsored by JINA-CEE.
The next p-process Workshop will be held in Italy in 2019.

Forging Connections—From Nuclei to the Comic Web

The Forging Connections - From Nuclei to the Cosmic Web workshop, has been held on June 26-29th in East Lansing at the Kellogg Center. The primary goal of the meeting was to gather scientists from around the world to focus on the multidisciplinary challenge of using chemical elements as a tracer to understand how stars and galaxies evolve in the universe. Several key topics were covered by talks and posters: nuclear experiments, nuclear structure, nuclear reactions and nucleosynthesis, stellar evolution from low-mass to massive stars, supernova explosions, interstellar dust, chemical evolution, integrated-light spectroscopy, gamma-ray spectroscopy, large spectroscopic surveys, galactic archaeology, metal-poor stars, galaxy formation, interstellar inhomogeneities, gas flows inside and around galaxies, the circumgalactic medium, damped Lyman alpha systems, the high-redshift universe, and cosmology.

Two breakout sessions were scheduled to split participants into smaller groups in order to engage in detailed and focused discussion (e.g., dealing with uncertainties, formation of the Milky Way, origin of heavy elements, etc.). One of the great successes of the workshop has been to address chemical evolution at all epochs and at all scales, from the creation of the elements to the chemical signatures observed in the circumgalactic and intergalactic media. All participants made an effort to highlight the connections between the different fields of research, which allowed to draw a more coherent vision of the complex interplay between stars, galaxies, and their environments.

Photo by Chelsea Bonofiglio, FRIB

Upcoming JINA-CEE Events

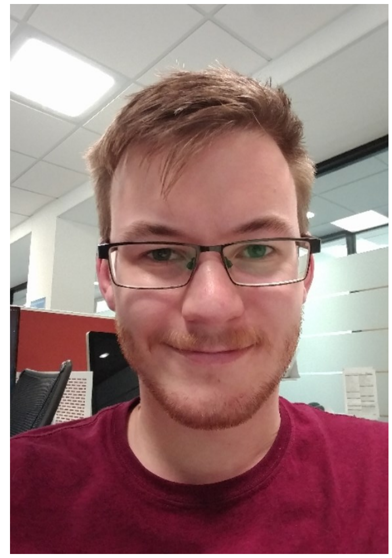
A Celebration of CEMP and Gala of GALAH
November 13 — 17 2017, Monash University, Australia

Titans of the Early Universe
November 20—24 2017, Monash Prato Centre, Prato, Italy

LIVESTREAM: Talks and Panel Discussion: The Impact of the LIGO/VIRGO Neutron Star Merger Discovery on Research in Nuclear Science and Nuclear Astrophysics
December 1, 2017

Joint EMMI / JINA-CEE workshop:
Nuclear Astrophysics at storage rings and recoil separators
March 13-15, 2018, GSI, Darmstadt, Germany

JINA-CEE faces: Interview with Grad Student Zac Johnston



Monash University and JINA-CEE
Grad Student Zac Johnston

Education:

I received my Bachelor of Science (Hons.) in mathematics and astrophysics at Monash University, Melbourne, Australia. I'm currently doing my PhD at Monash.

When you were young, what did you want to be when you grew up?

A filmmaker. I loved shooting and editing videos as a kid, and trying out different special effects.

When did you decide to pursue astrophysics/physics?

I wasn't interested in maths and science until my final year of high school, when I was suddenly captivated by the big questions of the universe and the maths underlying it all. I entered university wanting to study physics or pure maths, but by the end of my degree I'd realised computational astrophysics is what fascinates me the most.

What is your research focus?

I run computer simulations of X-ray bursts, which are thermonuclear explosions on the surface of neutron stars. Comparing these models to observations can teach us about nuclear physics and the nature of neutron stars, including their long-coveted equation of state.

With whom and where will you work within JINA-CEE?

My PhD supervisors at Monash are Alexander Heger and Duncan Galloway. I'm about to start a six-month visit to Michigan State University to meet and work with experts on neutron stars and X-ray bursts, including Hendrik Schatz, Ed Brown, and Adam Jacobs.

Where do you see yourself in 5 years?

I really enjoy doing research and solving new problems, so assuming I'm not completely sick of it by the end of my PhD I'd like to pursue academia. I'm also realistic, though, about the limited number of careers in academia, so I'm open-minded about entering the commercial world. Wherever I end up, I just hope it's somewhere I can still apply and improve my analytic and problem-solving skills.

And what about 20 years?

If my previous answer was vague then this one is practically undefined. I hope to have gained a deeper understanding and appreciation of the universe and the human experience within it, and perhaps even to have contributed in some small way. I also hope there are less bugs in my code.

Is there anything else you'd like to share?

I'd like to express my great appreciation for JINA-CEE. Thanks to their generous support, I was able to travel to the 2017 Frontiers meeting in Michigan and meet with the wider astrophysics community. Now they're helping me return for a longer visit to MSU, to further collaborate with international researchers.

Recent JINA-CEE Publications

K. S. S. Barrow et al., *First light: exploring the spectra of high-redshift galaxies in the Renaissance Simulations,* MNRAS 469, 4863 (2017)

M. R. Blanton et al., *Sloan Digital Sky Survey IV: Mapping the Milky Way, Nearby Galaxies, and the Distant Universe,* ApJ 154, 28 (2017)

R. Caballero-Folch, *β -decay half-lives and β -delayed neutron emission probabilities for several isotopes of Au, Hg, Tl, Pb, and Bi, beyond N =126*, Phys. Rev C 95, 064322 (2017)

T. Kajino and G. J. Mathews, *Impact of new data for neutron-rich heavy nuclei on theoretical models for r-process nucleosynthesis,* Rep. Prog. Phys. 80, 084901 (2017)

A. Kankainen et al., *Measurement of key resonance states for the ^{30}P (p , γ)^{31}S reaction rate, and the production of intermediate-mass elements in nova explosions,* Phys. Lett. B. 769, 549 (2017)

T. Kojima et al., *Evolution of N/O abundance ratios and ionization parameters from z~0 to 2 investigated by the direct temperature method*, Publ. Astron. Soc. Jpn 69, 44 (2017)

S. T. Linden *et al., Timing the Evolution of the Galactic Disk with NGC 6791: An Open Cluster with Peculiar High-alpha Chemistry as Seen by APOGEE,* ApJ 842, 49 (2017)

H. Martínez-Rodríguez, *Observational Evidence for High Neutronization in Supernova Remnants: Implications for Type Ia Supernova Progenitors*, ApJ 843, 35 (2017)

T. Matsuno et al., *High-resolution Spectroscopy of Extremely Metal-poor Stars from SDSS/SEGUE. III. Unevolved Stars with [Fe/H] <-3.5*, ApJ 154, 52 (2017)

T. Mishenina et al., *Observing the metal-poor solar neighbourhood: a comparison of galactic chemical evolution predictions,* MNRAS 469, 4378 (2017)

V.M. Placco et al., *RAVE J203843.2--002333: The First Highly R-process-enhanced Star Identified in the RAVE Survey,* ApJ 844, 18 (2011)

A. Simon et al., *Impact of the alpha optical model potential on the gamma-process nucleosynthesis,* J. Phys. G. 44, 064006 (2017)

Y. Y. Song et al., *An Expanded Chemo-dynamical Sample of Red Giants in the Bar of the Large Magellanic Cloud*, ApJ 153, 261 (2017)

A. Spindler and D. Wake, *The differing relationships between size, mass, metallicity and core velocity dispersion of central and satellite galaxies*, MNRAS 468, 333 (2017)

R. Tojeiro et al., *Galaxy and Mass Assembly (GAMA): halo formation times and halo assembly bias on the cosmic web*, MNRAS 470, 3720 (2017)

A. Yildirim et al., *The structural and dynamical properties of compact elliptical galaxies*, MNRAS 468, 4216 (2017)

JINA-CEE LIVESTREAM

FRIDAY, 1 DECEMBER 2017
12:30 PM US/EST

Talks and Panel Discussion:
The Impact of the LIGO/VIRGO Neutron Star Merger Discovery on Research in Nuclear Science and Nuclear Astrophysics

#GWNuclear
www.jinaweb.org/gwnuclear

JINA-CEE is supported by the National Science Foundation through the Physics Frontiers 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, CNA Shanghai Jiao Tong University Shanghai China, 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 Amsterdam, Netherlands, University of Chicago, University of Minnesota, University of Sao Paulo Brazil, University of Hull UK, 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, Stony Brook University, TU Darmstadt Germany, University of Illinois, University of Michigan, Wayne State University

For comments or questions about:	Contact:
Outreach and Education	Micha Kilburn: mkilburn@nd.edu
Newsletter and other JINA-CEE related issues	Dawn Welch: welch@nscl.msu.edu