Nuclear and astrophysics aspects for the rapid neutron capture process in the era of multimessenger observations

Report of Contributions

Contribution ID: **1** Type: **not specified**

Nuclear astrophysics in the era of multi-messenger observations at INFN-LNS

Tuesday 2 July 2019 14:30 (35 minutes)

Gravitational waves detection in neutron mergers and the parallel observations in the visual and IR spectrum have triggered a new era in astronomy, the so-called multi-messenger era, where information of astrophysical significance is carried by different messengers. The possibility to identify a source and follow its time evolution has opened a new window on exotic phenomena, allowing us to pinpoint a realistic site for the r-process.
Such more in-depth analysis of the astrophysical scenarios calls for a parallel comprehensive study of the nuclear processes powering them. In this contribution I will review the research activity that is presently carried out and it is under development at the INFN-Laboratori Nazionali del Sud (Italy). It can be broadly divided into three categories: (i) constraining the r-process through a better understanding of the s-process; (ii) the study of nuclear reactions involved in the r-process; (iii) studying the opacity of a plasma made up of lanthanides.
Understanding the s-process nucleosynthesis plays a pivotal role since abundances of r-nuclei are deduced by subtracting the calculated s-process yields from the galactic chemical abundances. Therefore, uncertainties on s-elements production directly reflects on the r-process yields. Now, while the 13C(a,n)16O neutron source is well constrained, the 22Ne(a,n)25Mg one, supplying a larger neutron flux than 13C(a,n)16O, is still affected by large uncertainties, calling for further studies to better constrain the s-process and so the r-process. Also, the investigation of neutron-capture cross sections, especially in the case of branch point nuclei, can help constraining the r-process nucleosynthesis. With this respect, the Trojan horse method (THM) is an indirect approach developed at LNS making it possible to study reactions of astrophysical importance (also neutron-induced) at the corresponding Gamow energies.
Such studies are important for point (ii) as well. In this case, other processes such as the study of the 12C+12C fusion reactions are very important. In fact, the cross section influences the rate of core collapse supernovae and, consequently, the neutron star birth rate. This is also independently determined from 26Al galactic abundance, so the reactions responsible from the production and destruction of 26Al plays an important role to cast light on the neutron star formation rate. With this respect, 26Al (n,p) and (n,a) reactions on the ground and isomeric state have a strong influence on the 26Al yield from core-collapse supernova explosion, and their study will be performed through the THM in the near future.
Also beta decay of r-nuclei has a great relevance in determining the abundance pattern deduced from the galactic material. In particular, beta-delayed neutron emission (βn) is a form of radioactive decay in which an electron, an anti-neutrino and one or more neutrons are emitted. The initial abundance distribution is shaped by the decay half-life T1/2, but the neutron emission affects the final abundances in two ways: on the one hand it shifts the decay path to lower masses and on the other hand it provides a source of neutrons for late captures that shift masses in the opposite way. Thus, a good knowledge of Pn and T1/2 values of the nuclei between the valley of stability and the r-process path is needed for a correct understanding of the observed abundances. The availability of FRIBS radioactive ion beams (and of the forthcoming separator FRAISE) and of the polycube neutron counter at LNS will make it possible to perform high accuracy studies of βn processes.
The third point is also extremely important, since along with a gravitational-wave signal and a short burst of γ-rays, neutron star mergers give rise to a transient optical–near-infrared (kilono-

vae). Unlike supernova absorption lines, the identification of kilonova atomic species is not secure. Therefore, the identification of r-nuclei in the ejecta is achieved by investigating the transient light curves, the maximum being directly connected with the optical thickness of the ejecta. The measured light curves suggest that the opacity is dominated by transitions from the lanthanides. However, predictions of the transient light curves and spectra suffer from the uncertain optical properties of heavy ions. At LNS we will have the unique opportunity to produce a controlled lanthanides plasma, with more accurate determination of temperature and density with respect to laser induced plasmas. The possibility to produce such stable and controlled plasmas is under study at LNS (Pandora project).

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Presenter: LA COGNATA, Marco (INFN-LNS)

Session Classification: Session

Contribution ID: **2** Type: **not specified**

Improving the nuclear energy density functionals: constraints from the ground state and collective excitations

Monday 1 July 2019 11:10 (35 minutes)

Over the past years the energy density functionals have been extensively used in nuclear physics and astrophysics research; there are more than 240 nonrelativistic Skyrme parametrizations and 260 relativistic-mean-field (RMF) models introduced so far. However, all of them are optimized mainly by the nuclear ground state data, often supplemented with pseudo-observables in order to set the nuclear matter (equation of state) properties. Recently a novel relativistic energy density functional has been constrained not only by the ground state properties of nuclei but also with the isoscalar giant monopole resonance energy and dipole transition strength in nuclei, i.e. dipole polarizability in 208Pb [1]. A unified framework of the relativistic Hartree-Bogoliubov model, random phase approximation, and χ^2 minimization protocol, based on the relativistic density-dependent point coupling interaction has been established in order to determine the DD-PCX parameterization [1]. The implementation of the experimental data on nuclear excitations allows improving the isovector channel of effective interaction as well as constraining the symmetry energy and nuclear matter incompresibility by using genuine observables on finite nuclei in the minimization protocol to constrain the effective interaction. The effective interaction DD-PCX accurately describes the nuclear ground state properties including the neutron-skin thickness, as well as the isoscalar giant monopole resonance excitation energies and dipole polarizabilities and open perspectives for further applications.

[1] E. Yuksel , T. Marketin, N. Paar, Phys. Rev. C 99, 034318 (2019)

Presenter: PAAR, Nils (Faculty of Science University of Zagreb)

Session Classification: Session

Contribution ID: **3** Type: **not specified**

Microscopic description of fission for the r-process in neutron-star mergers ejecta

Tuesday 2 July 2019 09:35 (35 minutes)

Nuclear fission is known to be of fundamental importance in many applications, for example for energy production applications, such as nuclear power reactors or nuclear waste recycling. In astrophysics, nuclear fission plays a significant role during the rapid neutron-capture process (r-process) of stellar nucleosynthesis by recycling the matter during the neutron irradiation occurring in a neutron star merger ejecta [1,2]. The recent observation of gravitational waves and its optical counterpart from a binary neutron-star merger proves that such events can provide a viable site for the production of heavy (and potentially super-heavy) nuclei by the r-process nucleosynthesis. During the r-process, heavy neutron-rich nuclei are produced and decay or fission. A reliable description of nuclear fission is needed to explain the fission of such heavy neutron-rich nuclei.

The description the nuclear fission is a theoretical challenge because the many-body problem has to be solved with an interaction between nucleons that is known in a phenomenologically way only. In addition of these static considerations there are dynamical effects which leads to the splitting of the nucleus. There are four major aspects that need to be described during the fission process, namely i) the fissioning nucleus formation, ii) the fission barrier penetration and transmission, iii) the fission fragment formation, and iv) the fission fragment de-excitation. Fissioning nucleus can be formed by neutron (neutron-induced fission), gamma capture (photofission), or beta decay (beta-delayed fission). The fission barrier can be crossed by tunnel effect like in spontaneous fission or be crossed over if the nucleus is sufficiently excited like in neutron/gamma-induced fission. When the barrier is crossed, nucleus can be splitted in many ways with different probabilities, called the fission yields. Finally fission fragments de-excite mainly by neutron and gamma evaporation.

All these aspects have to be properly and microscopically described for nucleosynthesis applications since they involve exotic neutron-rich nuclei that cannot be produced experimentally. The most recent theoretical and computational developments need to be considered for a reliable estimate. In the present paper, we will describe our effort to provide updated state-of-the-art models for the description of the fission process by exotic neutron-rich nuclei.
Concerning the fission path, new calculations have been performed, based on newly computed potential energy surfaces (PES) on the basis of Gogny HFB-calculations with beyond-mean-field corrections [3]. Results for all the 500 even-even nuclei from Th to Ds lying between the proton and the neutron drip lines will be compared with predictions obtained within the Skyrme-HFB or liquid-drop approaches. Moreover, through the determination of the inertia tensor at each point of the PES, the least action path can be determined and spontaneous fission half-lifes deduced and compared with available experimental data [4]. Based on these new non-trivial fission paths, all fission transmission coefficients have to be computed considering competition between fission and others possible channels to deduce fission cross sections. Recent results along those lines will be presented
Finally we will present the scission-point model, called SPY [5], developed to estimate yields and kinetic energies of the fission fragments. To improve the description of the fissioning system at the scission point, microscopic state densities, proton and neutron distributions as well as potential energy surfaces of each fragments are now considered within the mean-field approach. We will show that these new developments have a significant impact on the predictions of fission yields and fragment excitation energies. Implications for the r-process nucleosynthesis will be discussed.

[1] S. Goriely et al, Phys. Rev. Lett 111, 242502 (2013)
[2] S. Goriely, Eur. Phys. J. A 51, (2015)
[3] N. Dubray et al, Phys. Rev. C 77, 014310 (2008)
[4] J.-F. Lemaître et al, Phys. Rev. C 98, 024623 (2018)

[5] J.-F. Lemaître et al, Phys. Rev. C 99, 034612 (2019)

Author: Dr LEMAÎTRE, jean-françois (université libre de Bruxelles)

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Presenter: Dr LEMAÎTRE, jean-françois (université libre de Bruxelles)

Session Classification: Session

Contribution ID: **4** Type: **not specified**

Stellar Models for R-process Nuclear Astrophysics

Thursday 4 July 2019 17:05 (25 minutes)

Abstract: One of the primary mechanisms for guiding experimental research in nuclear astrophysics is the sensitivity study. In a broad sense, these studies involve a stellar model in which various quantities related to nuclear reactions are varied to examine the effects. These variables can include a single, or multiple, reaction rates, Q-values, nuclear masses, and others. Subsequently, various aspects of the model are examined, such as elemental abundances, thermodynamics, and astronomical observables and compared with theory and observations. This talk will examine the underlying stellar models, their strengths and limitations both broadly and as it applies to R-process, and discuss the findings of the most recent works, as well as improvements that must be made in the future in order to improve the accuracy of the results of the sensitivity study.

Author: LAUER, Amber (Triangle Universities Nuclear Laboratory)

Presenter: LAUER, Amber (Triangle Universities Nuclear Laboratory)

Session Classification: Session

Contribution ID: **5** Type: **not specified**

Pygmy Modes and Astrophysical Reaction Rates

Friday 5 July 2019 09:00 (25 minutes)

The new low-energy dipole and quadrupole modes in charge-asymmetric nuclei have been studied in a EFT-based approach by HFB and extended QRPA methods, accounting for anharmonicities by the coupling to up to 6 quasiparticle (QP) configurations. The spectroscopy of pygmy dipole (PDR) and quadrupole (PQR) states is discussed with focus on the region of N=50,82 isotones and the Z=50 Sn-isotopes. Multi-QP coupling is found to provides the proper energy shifts and fragmentation pattern of experimentally observed strength distributions. The spectroscopic results are used in calculations of astrophysical reaction rates. The pygmy modes lead to a significant enhancement of (n,g) capture rates, thus altering the nucleo-synthesis scenarios.

Author: LENSKE, Horst (U. Giessen)

Presenter: LENSKE, Horst (U. Giessen)

Session Classification: Session

Contribution ID: **6** Type: **not specified**

Mass ejection from neutron star mergers

Thursday 4 July 2019 09:35 (35 minutes)

The very first detection of gravitational waves from a neutron-star merger and accompanying electromagnetic emission has provided a wealth of information on astrophysics and nuclear physics. In particular, these observations have established that neutron star mergers play an important role for the Galactic enrichment by r-process elements. We will provide a general overview on neutron star mergers and will discuss the mass ejection from these events.

Author: BAUSWEIN, Andreas (GSI Darmstadt)

Presenter: BAUSWEIN, Andreas (GSI Darmstadt)

Session Classification: Session

Contribution ID: **7** Type: **not specified**

Mass measurements in the vicinity of the N=40 subshell closure

Wednesday 3 July 2019 16:30 (35 minutes)

Sensitivity studies have shown the predominant role of 67Fe and 69Co on the weak r-process abundance pattern [1]. The individual photodissociation rates in the r-process path depend exponentially on the reaction Q-values. The Q-value for 67Fe(n,ɣ)68Fe and 68Co(n,ɣ)69Co reactions are based directly on the masses of 67Fe and 69Co. The double Penning trap JYFLTRAP [2] at the University of Jyväskylä has been successfully used to measure masses of both 67Fe and 69Co influencing the astrophysical weak r-process. The long-living state of 70Co was also measured during the same experiment. The isotopes of interest were produced via proton-induced fission on a natural uranium target at the IGISOL facility [3]. The Time-of-flight Ion Cyclotron Resonance (TOF-ICR) technique [4] and the Ramsey's method of time-separated oscillatory field [5] were used for the mass measurements. The measured nuclei lie beyond the N=40 subshell closure, and provide information about the nuclear structure and mass surface in this region which is known for deformation and shape coexistence. In this talk, the experimental methods, the results and their impact on astrophysics and nuclear structure in the N=40 region will be discussed.

Author: CANETE, Laetitia (university of Jyväskylä)

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Presenter: CANETE, Laetitia (university of Jyväskylä)

Session Classification: Session

Contribution ID: **8** Type: **not specified**

Fission barriers of exotic nuclei

Fission barriers of exotic nuclei and the role of fission in the r-process are intimately connected with the density dependence of the symmetry energy at the sub-saturation densities attained in the neck region at the maximum of the fission barrier. In our talk we will discuss the future experiment to measure the fission cross sections using radioactive beams with the Active Target Time Projection Chamber detector at NSCL.

Author: CHAJECKI, Zbigniew (Western Michigan Univ./Physics)

Presenter: CHAJECKI, Zbigniew (Western Michigan Univ./Physics)

Contribution ID: **9** Type: **not specified**

Studying the structure of the A=98 decay products

Friday 5 July 2019 09:50 (25 minutes)

A series of experiments have been planned to study the neutron rich A=98 chain of decay products, starting from the decay of ^{98}Kr. Following systematic mass and charge radii studies of Rb, Sr and Y, the A=98 isotopes have displayed unique properties. These properties will be discussed and related to the motivation for the planned experiments to showcase a thorough study of the Kr,Rb, Sr and Y decay chain.

Author: RAJABALI, Mustafa (Tennessee Technological University)

Presenter: RAJABALI, Mustafa (Tennessee Technological University)

Session Classification: Session

Contribution ID: **10** Type: **not specified**

The solar r-process residual distribution

Thursday 4 July 2019 15:05 (35 minutes)

Theoretical r-process models still suffer for severe uncertainties, regarding in particular the physical conditions characterizing the hosting site and the adopted nuclear inputs.
For this reason, the contribution of the r-process to the solar distribution is commonly derived by subtracting the contribution coming from the slow neutron capture process (s-process), as r=1-s.
This curve provides, together with low metallicity stars heavy element distributions, the point of reference for r-process nucleosynthesis calculations. I will show the r-process residuals distribution we recently derived with a Galactic Chemical Evolution model including recent Asymptotic Giant Branch stars and rotating massive stars yields.

Author: Dr CRISTALLO, Sergio (INAF - Osservatorio Astronomico d'Abruzzo)

Co-authors: Prof. PRANTZOS, Nikos (Institut d'Astrophysique de Paris); Prof. ABIA, Carlos (Universidad de Granada); Dr LIMONGI, Marco (INAF - Osservatorio Astronomico di Roma); CHIEFFI, Alessandro (INAF - Istituto di Astrofisica e Planetologia Spaziali)

Presenter: Dr CRISTALLO, Sergio (INAF - Osservatorio Astronomico d'Abruzzo)

Session Classification: Session

Contribution ID: **11** Type: **not specified**

The nuclear physics of r-process abundance patterns

Thursday 4 July 2019 16:30 (35 minutes)

The properties of thousands of nuclear species far from stability set abundance patterns and other observables from r-process events. We will describe recent efforts to forge explicit links between the details of the r-process isotopic abundance pattern and specific nuclear properties, here focusing on masses and spallation cross sections. We will discuss future prospects given the anticipated capabilities of the next generation of radioactive beam facilities.

Presenter: SURMAN, Rebecca (University of Notre Dame)

Session Classification: Session

Contribution ID: **12** Type: **not specified**

New Approach for Determination of Stellar Nucleosynthesis Abundances

Tuesday 2 July 2019 17:05 (25 minutes)

The recent observation of neutron stars merger by the LIGO collaboration and the measurements of the event's electromagnetic spectrum as a function of time for different wavelengths, have altered profoundly our understanding of the r-process site, as well as considerably energized nuclear astrophysics research efforts. R-process abundances are a key element in r-process simulations, as a successful calculation must account for these abundances in the final debris of a stellar cataclysmic event. In this presentation, mankind's complete knowledge of neutron cross sections obtained in the last 80 years, as encapsulated in the latest release of the Evaluated Nuclear Data File (ENDF/B) library, is used to obtain solar r-process abundances in a novel way. ENDF/B cross sections has been successfully used for decades in nuclear power and defense applications and are now used to obtain r-process abundances in a fully traceable, documented and unbiased way.

Author: Dr PRITYCHENKO, Boris (Brookhaven National Laboratory)

Presenter: Dr PRITYCHENKO, Boris (Brookhaven National Laboratory)

Session Classification: Session

Contribution ID: **13** Type: **not specified**

r-Process Sites, their Ejecta Composition, and their Imprint in Galactic Chemical Evolution

Thursday 4 July 2019 09:00 (35 minutes)

From low metallicity stars and the presence of radioactive isotopes in deep-sea sediments we know that the main r-process, producing the heaviest elements, is a rare event. The question remains whether neutron star mergers, via GW170817 the only proven r-process site, are the only contributors or also (a rare class of) supernovae, hypernovae/collapsars, as well as neutron star - black hole mergers qualify as candidates. Early galactic evolution as well as variations in nucleosynthesis signatures, e.g. actinide boost stars, might indicate the need for such other sites. We discuss and present the possible options (a) with respect to possible differences in ejecta amount and composition, and (b) in terms of their timing (onset and frequency) during galactic evolution.

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Session Classification: Session

Contribution ID: **14** Type: **not specified**

How to deal with neutrinos in simulations of neutron-star mergers and core-collapse supernovae?

Monday 1 July 2019 11:45 (35 minutes)

Among the most difficult ingredients in models of neutron star mergers and core-collapse supernovae is the treatment of neutrinos. In this talk I will briefly summarize our understanding of the most important neutrino effects in the context of r-process nucleosynthesis and I will discuss a few recently proposed schemes and their pros and cons.

Author: JUST, Oliver (RIKEN Japan)

Presenter: JUST, Oliver (RIKEN Japan)

Session Classification: Session

Contribution ID: **15** Type: **not specified**

Mass ejection from neutron star mergers

The very first detection of gravitational waves from a neutron-star merger and accompanying electromagnetic emission has provided a wealth of information on astrophysics and nuclear physics. In particular, these observations have established that neutron star mergers play an important role for the Galactic enrichment by r-process elements. We will provide a general overview on neutron star mergers and will discuss the mass ejection from these events.

Author: Dr BAUSWEIN, Andreas (GSI Darmstadt)

Presenter: Dr BAUSWEIN, Andreas (GSI Darmstadt)

Contribution ID: **16** Type: **not specified**

Neutron capture elements in the Early Universe

Monday 1 July 2019 09:25 (35 minutes)

In the last years, the search for the oldest stars has started to investigate the central region of our Galaxy and its outskirts with ultra-faint galaxies.
Both Galactic bulge and ultra-faint galaxies host extremely old stars, with ages compatible with the ages of the oldest halo stars. The data coming from these recent observations present new signatures in neutron capture elements. Our study, based on stochastic chemical evolution models, shows how this new fundamental information can improve the constraints on the nature of the first sources of neutron
capture elements: the r-process events and the first massive stars.
Our findings support a scenario where at least a fraction of r-process events
has exploded in a very short timescale and where the first stellar generations have been fast rotators. We also predict the existence
of Eu-free stars due to the rarity of the r-process events.

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Presenter: CESCUTTI, Gabriele (Osservatorio Astronomico di Trieste, INAF)

Session Classification: Session

Contribution ID: **17** Type: **not specified**

The unknown site of actinide nucleosynthesis –clues from extraterrestrial Pu-244 in deep-sea archives

Thursday 4 July 2019 11:00 (35 minutes)

Half of the heavy elements are produced in r-process nucleosynthesis, which is exclusively responsible for actinide production. The abundance of long-lived actinides in today's interstellar medium (ISM) results from the interplay between production and decay. Their presence would establish that their production was recent.
The solar system moves through the ISM and collects ISM dust particles. Direct detection of freshly produced radionuclides 'live'on Earth, i.e. before decaying, provides thus direct insight into recent and nearby nucleosynthetic activity. In particular ^{244}Pu ($t_{1/2}$=81 Myr) can place strong constraints on r-process frequency and production yields over the last few 100 Myr [1,2]. In our work, we searched for such ISM radionuclides incorporated into terrestrial archives.
Detection of ISM-^{244}Pu in deep-sea archives complements the positive detection of interstellar and supernova-produced ^{60}Fe ($t_{1/2}$=2.6 Myr) [3-6]. However, the low concentrations measured previously suggest a low abundance of interstellar Pu [7]. It signals actinide r-process nucleosynthesis is rare, which is incompatible with the rate and expected yield of supernovae as the predominant actinide-producing sites, but compatible with high yield - low rate scenarios, such as e.g. neutron-star mergers.
Here we present new results for ^{244}Pu measured with a new facility at ANSTO (Sydney) with unprecedented sensitivity and background-free detection of Pu. We will report on the first time detection of a quantitative influx of the r-process nuclide ^{244}Pu onto Earth and link this to a concomitant influx of ^{60}Fe and supernova-activity. These data provide also new insights into their ISM concentrations [8].
[1] M. Paul et al. ApJL 558 (2001)
[2] C. Wallner et al. New Astr. Rev. 48 (2004)
[3] K. Knie et al., PRL 83 (1999); PRL 93 (2004)
[4] A. Wallner et al., Nature 532 (2016)
[5] L. Fimiani et al., PRL 116 (2016)
[6] P. Ludwig et al., PNAS 113 (2016)
[7] A. Wallner et al., Nature Comm. 6 '(2015)
[8] A. Wallner et al., submitted, in review (2019)

Presenters: WALLNER, Anton (The Australian National University); FROEHLICH, Michaela (ANU); KINOSHITA, Norikaru; HOTCHKIS, Michael; PAVETICH, Stefan; TIMS, Stephan

Session Classification: Session

Contribution ID: **18** Type: **not specified**

SHELL MODEL FAR FROM STABILITY: ISLANDS OF INVERSION MERGERS

Wednesday 3 July 2019 09:00 (35 minutes)

In this presentation, I will expose some of the last developments in microscopic nuclear structure calculations for exotic nuclei far from stabilitity in the vicinity of ^{78}Ni, in a key region needed for understanding nucleosynthesis paths of gold and some of the most heavy elements.

In a first part, I will expose recent study on the development of collectivity in neutron-rich nuclei around N=40, where recent experimental evidence suggest a rapid change from the spherical to rotational regime, in analogy to the island of inversion known at N=20 [1,2] and extension of the island of collectivity towards N=50 [3].
In a second part, our recent algebraic Nilsson SU3 self-consistent model [6] will be used to describe the intruder relative evolution in the vicinity of ^{78}Ni. The spectroscopy of the exotic nucleus ^{78} performed at the RIKEN-RIF laboratory in Japan has been recently published in Nature [1]. The results support the doubly magic character N=50, Z=28, of the heaviest nickel isotope, that is spherical in its ground state. In addition they have detected the presence at very low energy (2.5 MeV) of another facet of the same nucleus which is radically different, characterized by its spheroidal shape. This atypical phenomenon of coexistence, more germane to molecular systems, was predicted by the Configuration-Interaction (LSSM) calculations of the Strasbourg-Madrid collaboration in 2016 [6].
The model predicts as well the vanishing of the magic closure at N=50 for the
more exotic isotones of Chromium and Iron which should be deformed in
their ground states, leading to the idea of merging islands of collectivity from N=40 to N=50, as already observed from N=20 to N=28 [3]. Core excitations and their impact on moments in Cu and Zn isotopic chains will be discussed.
Finally, discussion of the underlying mecanism in terms of Spin-Tensor components will be exposed and compared to other neutron-rich regions of the nuclear chart.

[1] E. Caurier, F. Nowacki, A. Poves, Phys. Rev. C 90, 014302 (2014)
[2] S. Lenzi et al., Phys. Rev. C 82, 054301 (2010)
[3] C. Santamaria et al., Phys. Rev. Lett. C 115, 192501 (2015)
[4] A. P. Zuker et al., Phys. Rev. C 92, 024320 (2015)
[5] R. Tanushui et al., Nature 569, 53-58 (2019)
[6] F. Nowacki, A. Poves, Phys. Rev. Lett. {\bf 117}, 272501 (2016)

Authors: NOWACKI, Frederic (IPHC Strasbourg); Dr POVES, Alfredo (Universidad Autónoma de Madrid)

Presenter: NOWACKI, Frederic (IPHC Strasbourg)

Session Classification: Session

Contribution ID: **19** Type: **not specified**

Galactic Chemical Evolution of r-Process Elements

Monday 1 July 2019 10:00 (35 minutes)

Galactic chemical evolution simulations are powerful tools to reconstruct the evolution of the elements across cosmic time. In this talk, I will present how we can use these simulations to investigate the properties of r-process sites (e.g., frequency and mass ejected). Chemical evolution predictions should not be seen as the final answer, but rather as a complementary piece of puzzle that must be combined with the messages sent by other fields of research. In particular, I will present the connection made between galaxy simulations and the gravitational wave detection GW170817, I will highlight what can we learn about the delay time of neutron star mergers by looking at the chemical evolution trends of r-process elements in the disk of the Milky Way, and how we can use hydrodynamic simulations of the early Universe to address the chemical signatures left by r-process events on the surface of old metal-poor stars during the first billion years of galactic evolution.

Authors: CÔTÉ, Benoit; EICHLER, Marius; ARCONES, Almudena; FRYER, Chris L.; BELCZYNSKI, Krzysztof; VASSH, Nicole; MUMPOWER, Matthew R.; HANSEN, Camilla J.; O'SHEA, Brian W.; SMITH, Britton; KOROBKIN, Oleg; CHRUSLINSKA, Martyna; LIPPUNER, Jonas; SPROUSE, Trevor M.; SURMAN, Rebecca; WOLLAEGER, Ryan; SILVIA, Devin W.; WISE, John H.; SIMONETTI, Paolo; FREBEL, Anna; PIGNATARI, Marco; REICHERT, Moritz; MATTEUCCI, Francesca

Presenter: CÔTÉ, Benoit

Session Classification: Session

Contribution ID: **20** Type: **not specified**

The creation of the first r-process peak in neutron star mergers, impact of nuclear masses and beta decay rates.

Tuesday 2 July 2019 11:35 (35 minutes)

The observation of the electromagnetic counterpart of GW170817 gravitational wave hinted the production of r-process elements in the aftermath of neutron star mergers. The color of the electromagnetic counterpart suggests there are at least two different contributions of electron fraction (Y_e) distributions, one moderately high, reproducing the light r-process elements, and one < 0.25 reproducing heavier nuclei including the lanthanide elements. We present a study for the creation of the first r-process peak using astrophysical conditions matching the ones speculated for neutron star mergers. We identify the range of Y_e that can reproduce the first r-process peak and the effect of specific nuclear masses and beta decay rates on it.

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Co-authors: Prof. MARTINEZ-PINEDO, Gabriel (TU Darmstadt, GSI); Dr REITER, Moritz Pascal (University of Giessen, TRIUMF); Dr SIEVERDING, Andre (University of Minnesota); Dr WU, Meng-Ru (Academia Sinica)

Presenter: NIKAS, Stylianos (Techniche Universitat Darmstadt / GSI)

Session Classification: Session

Contribution ID: **21** Type: **not specified**

Beta-delayed neutron studies with the BRIKEN setup

Wednesday 3 July 2019 11:00 (35 minutes)

Beta-delayed neutron-emission will be the dominant decay mechanism for almost all new neutron-rich nuclei that are to be discovered in the next decades with the new generation of radioactive beam facilities. Despite that, the present status and understanding of beta-delayed neutron emitters is surprisingly poor. Since the first observation of this decay process 80 years ago (R. B. Roberts et al., Phys. Rev. 55, 664 (1939)) for only half of the identified 621 beta-delayed neutron emitters a measurement of the one-neutron branching ratio has been carried out, and many of these measurements are rather uncertain.

40 years ago beta-delayed two-neutron emission was detected in 11Li, closely followed by the detection of the three-neutron emission in the same nucleus (R. Azuma et al., Phys Rev. Lett. 43, 1652 (1979), R. Azuma et al., Phys. Lett. B 96, 31 (1980)). And in 1988 the only beta-delayed four-neutron emitter, 17B, was detected (J.P. Dufour et al., Phys. Lett. B 206, 195 (1988)).

Despite this long history, the competition between neutron emission and de-excitation via gamma-decay, and the emission of several neutrons is not yet fully understood and has - until recently- been neglected in theoretical models. This leads to large discrepancies for the calculation of even more neutron-rich nuclei and hampers the accuracy of r-process model calculations since beta-delayed neutrons modify the r-process abundance distribution at late phases when emitted during the freeze-out while material is decaying back to stability.

Since 2016 the BRIKEN project ("Beta-delayed neutron measurements at RIKEN for nuclear structure, astrophysics, and applications") focusses on the most exotic beta-delayed neutron-emitters which can presently be produced. The setup combines the most efficient neutron detection array in the world with a state-of-the-art implantation detector and two clover detectors. Several experiments have been carried carried out so far and covered >250 neutron-rich nuclei in the region between 64Cr and 170Gd. For many of these isotopes, the neutron-branching ratios have been measured for the first time, e.g. for the doubly-magic 78Ni. In addition also about 50 new beta-decay half-lives have been deduced. More experiments for A>150 and A<60 will be carried out in the upcoming 2 years.
Apart from the remeasurement of a large number of beta-delayed neutron-emitters, approximately 150 new emitters will be added to the list of ~300 known beta-delayed neutron emitters. Also the number of measured multi-neutron emitters will be largely expanded. The results from the BRIKEN campaigns will help to improve the theoretical understanding of this complex decay mechanism tremendously, and help towards a better reproduction of the r-process abundance distribution in astrophysical network calculations.

Author: DILLMANN, Iris (TRIUMF)

Presenter: DILLMANN, Iris (TRIUMF)

Session Classification: Session

Contribution ID: **22** Type: **not specified**

Towards a better understanding of dense matter with gravitational waves

Wednesday 3 July 2019 09:35 (35 minutes)

The observation of the tidal deformability extracted from GW170817 have been analyzed by many teams, leading to boundaries of the NS radius. In our analysis, we contrast continuous EoS with EoS with strong first order phase transitions showing that these two cases induce different constrain on global NS properties. We also explore the impact of low density neutron matter predictions from chiral EFT approach, and we show that our current nuclear physics knowledge is still a bit more constraining than GW170817 tidal deformability. We also analyze the required accuracy for the tidal deformability which can make it compete with nuclear knowledge and the one which could shed light on the presence of phase transition in the core of NS.

Presenter: MARGUERON, Jérôme (IPN Lyon)

Session Classification: Session

Contribution ID: **23** Type: **not specified**

Constraining neutron-capture reactions for the r process

Tuesday 2 July 2019 15:05 (35 minutes)

In this talk I will discuss experimental constraints to neutron-capture reactions far from stability. These reactions are a critical part of the r process, and to date are almost completely unconstrained experimentally. Measuring direct neutron-capture reactions on short-lived nuclei is extremely challenging, and therefore one has to rely on indirect constraints. I will discuss the β-Oslo method, which was developed for this purpose by a Michigan State University and University of Oslo collaboration. I will present resent results on neutron-rich nuclei around mass 70, and also future plans for expanding to heavier r-process nuclei.

Author: SPYROU, Artemis (Michigan State University)

Presenter: SPYROU, Artemis (Michigan State University)

Session Classification: Session

Contribution ID: **24** Type: **not specified**

Nucleosynthetic signatures of astrophysical r-process sites

Thursday 4 July 2019 11:35 (35 minutes)

The first observation of a kilonova (or macronova) in the aftermath of a gravitational wave signal has confirmed neutron star mergers (NSMs) as a major source of heavy r-process nuclei in the universe. However, some observational data of r-process elements in the galaxy seemingly cannot be explained if NSMs are assumed to be the only r-process site. Theoretical models show that the heaviest r-process nuclei can possibly be produced also in other astrophysical scenarios, such as magneto-rotationally driven supernovae (MRSNe) or disks forming around collapsars. Distinguishing these scenarios by means of their nucleosynthetic signatures proves extremely challenging, since the properties of the neutron-rich nuclei involved are unknown, in addition to the uncertainties in hydrodynamical conditions of the ejecta. Most models, however, agree that the ejecta from NSMs include components that are neutron-rich enough for fission cycling, while simulated outflows from MRSNe are generally less neutron-rich. This talk aims to outline possible differences in abundance patterns originating from this difference and to discuss uncertainties in nucleosynthesis calculations.

Author: EICHLER, Marius

Presenter: EICHLER, Marius

Session Classification: Session

Contribution ID: **25** Type: **not specified**

Towards a better understanding of dense matter with gravitational waves

- The observation of the tidal deformability extracted from GW170817 have been analyzed by many teams, leading to boundaries of the NS radius. In our analysis, we contrast continuous EoS with EoS with strong first order phase transitions showing that these two cases induce different constrain on global NS properties. We also explore the impact of low density neutron matter predictions from chiral EFT approach, and we show that our current nuclear physics knowledge is still a bit more constraining than GW170817 tidal deformability. We also analyze the required accuracy for the tidal deformability which can make it compete with nuclear knowledge and the one which could shed light on the presence of phase transition in the core of NS.

Author: MARGUERON, Jérôme (IPN Lyon)

Presenter: MARGUERON, Jérôme (IPN Lyon)

Contribution ID: **26** Type: **not specified**

Theoretical uncertainty of nuclear mass models

It's becoming increasingly important to understand the uncertainties and extrapolation power of nuclear mass model calculations when being extrapolated to driplines. In this contribution we evaluate the uncertainties of the parameters and model predictions of both the liquid drop model and three different Duflo-Zuker shell model mass formulas through a fractional sampling method. We optimize those nuclear mass models by fitting to large sets of randomly selected nuclei. Only a small fraction of data is chosen each time. We study the behaviour of the model predictions as a function of the size of the training data. It shows that one can construct an optimized model from a tiny portion of available data that can exhibit equal performance as those fitted to all data. However, the best trained model does not always lead to the best extrapolation. We determine the mean values and uncertainties of the model parameters and model predictions by fitting all calculated values to normal distributions. The parameter deviations increase as the complexity of the model increases which can deteriorate the extrapolation power of the model. The mean values of masses from all model predictions show a rather stable behaviour. However, the uncertainties can increase significantly as one goes towards the driplines. We hope that, within this framework, a minimal model with as few parameters as possible and good extrapolation power can be established for a given mass model or nuclear functional.

Author: Prof. QI, Chong

Presenter: Prof. QI, Chong

Session Classification: Session

Contribution ID: **27** Type: **not specified**

Neutron star mergers: neutrinos and r-process nucleosynthesis

Monday 1 July 2019 15:05 (35 minutes)

Presenter: MCLAUGHLIN, Gail (North Carolina State University)

Session Classification: Session

Contribution ID: **28** Type: **not specified**

Supernovae, neutron stars, and chemical evolution

Monday 1 July 2019 14:30 (35 minutes)

One of the open question of the r-process is whether neutron star mergers are the only site or whether there is an additional (rare) r-process site, possibly related to supernovae. In this talk, I will discuss neutron star and black hole distributions from core-collapse supernovae and how they may fit in with the notion of an additional rare r-process site.

Presenter: FROEHLICH, Carla (North Carolina State University)

Session Classification: Session

Contribution ID: **29** Type: **not specified**

Discussion

Monday 1 July 2019 16:30 (35 minutes)

Session Classification: Session

Contribution ID: **30** Type: **not specified**

r-process contributions from massive star explosions triggered by the hadron-quark phase transition

Tuesday 2 July 2019 09:00 (35 minutes)

Canonical core-collapse supernova explosions driven by the neutrino-heating mechanism are presently ruled out as nucleosynthesis site for the production of heavy r-process elements with A ~ 195 (third r-process peak). Detailed numerical studies, with accurate neutrino transport and a sophisticated treatment of weak processes included, have shown that the ejected material yields neither sufficiently high entropies nor large neutron excess [1] for the production of elements with atomic numbers greater than 32 < Z < 50 [2], known as light neutron-capture elements. Here, a review of this caveat will be presented. Based on new insights, a possibility will be revisited that a few rare supernova explosion events can account for a strong r-process, i.e. the production of elements up to mass numbers of A ~ 195. Therefore, it has been shown recently that the appearance of exotic phases of hot and dense matter, associated with a 1st-order phase transition from ordinary nuclear matter to the quark-gluon plasma at the supernova interior, can trigger the onset of energetic supernova explosions of massive stars with zero-age main sequence masses of 40–50 solar masses [3]. Surprisingly, these events yield a strong r process, details of which will be presented and discussed in this talk.

References

[1] G. Martnez-Pinedo, T. Fischer, A. Lohs, and L. Huther, "Charged-Current Weak Interaction Processes in Hot and Dense Matter and its Impact on the Spectra of Neutrinos Emitted from Protoneutron Star Cooling," Phys. Rev. Lett. 109, 251104, 2012.
[2] G. Martnez-Pinedo, T. Fischer, and L. Huther, "Supernova neutrinos and nucleosynthesis," J. Phys. G Nuc. Phys. 41, 044008, 2014.
[3] T. Fischer, N.-U. F. Bastian, M.-R. Wu, S. Typel, T. Klahn, and D. B. Blaschke, "Quark deconfinement as a supernova explosion engine for massive blue supergiant star", Nat. Astron. 2, 980

Presenter: FISCHER, Tobias (University of Wroclaw)

Session Classification: Session

Contribution ID: **31** Type: **not specified**

Nuclear reaction theory for the era of multi-messenger observations: capture cross sections from indirect measurements

Tuesday 2 July 2019 11:00 (35 minutes)

Obtaining cross sections for neutron-induced reactions on unstable isotopes is challenging, but critical for astrophysics simulations. Various indirect methods have been proposed to address this problem. The 'surrogate reaction method'[1] uses inelastic scattering or transfer ('surrogate') reactions to produce the compound nucleus of interest and measure its subsequent decay. When combined with a proper theoretical description of the surrogate reaction mechanism, this data provides constraints for the models describing the decay of the compound nucleus, which dominate the uncertainties of the cross section calculations. I will present applications of the method to recent measurements of the (p,d) and (d,p) transfer reaction in the Zr-Y-Mo region. The procedure for obtaining constraints for unknown capture cross sections is illustrated and results for both known (benchmark) and unknown capture reactions are presented [2,3]. The method makes no use of auxiliary constraining quantities, such as neutron resonance data, or average radiative widths, which are not available for short-lived isotopes; thus it can be applied to isotopes away from stability, including those of relevance to astrophysics simulations.

[1] Escher et al, Rev. Mod. Phys. 84, 353 (2012).
[2] Escher et al, PRL 121, 052501 (2018).
[3] Ratkiewicz et al, PRL 122, 052502 (2019).

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Presenter: ESCHER, Jutta

Session Classification: Session

Contribution ID: **32** Type: **not specified**

Nuclear fission for the r-process in the era of multi-messenger observations

Tuesday 2 July 2019 16:30 (35 minutes)

Presenter: MUMPOWER, Matthew

Session Classification: Session

Contribution ID: **33** Type: **not specified**

r-process studies at RIBF

Wednesday 3 July 2019 11:35 (35 minutes)

Presenter: NISHIMURA, Shunji (RIKEN Nishina Center)

Session Classification: Session

Contribution ID: **34** Type: **not specified**

Multimessenger area: Opportunities for future experiments at ISAC-II, TRIUMF

Wednesday 3 July 2019 14:30 (35 minutes)

The recent observation of neutron star mergers indicate the presence of the r-process in those events, but the precise elemental composition cannot be deduced from the multimessenger observations. Detailed information about the heavy, neutron-rich nuclei involved are needed in order to pin down the origin of heavy elements in the universe. The next-generation radioactive ion beam facility ARIEL at TRIUMF soon will start delivering intense and clean post-accelerated RIBs.

The new TI-STAR silicon tracker detector, under development in an international collaboration at the University of Guelph and TRIUMF, is designed for experiments with heavy, exotic beams at the future ARIEL facility. TI-STAR will contain a hydrogen, deuterium or helium gas target to gain a factor 20-100 in luminosity for direct reaction experiments compared to experiments using target foils. One major goal of TI-STAR is constraining neutron-capture rates of r-process nuclei in the key A=130 region around 132Sn. Calculations indicate that uncertainties of neutron capture rates are typically one order of magnitude, and can be responsible for current disagreements between predicted and measured abundance distributions. TI-STAR coupled to the TIGRESS array of HPGe detectors and the new EMMA recoil separator will offer populating the r-process nuclei via one-neutron transfer reactions. Reconstruction of excitation energies and gamma ray decay scheme will allow to determine the neutron capture rates via the Oslo method. I will present the status of our experimental program related to Oslo-type experiments at TRIUMF and will discuss the challenges and opportunities of the ARIEL and TI-STAR projects.

Presenter: MUECHER, Dennis (University of Guelph)

Session Classification: Session

Contribution ID: **35** Type: **not specified**

Bayesian extrapolation of nuclear observables towards the neutron drip line

Wednesday 3 July 2019 15:05 (35 minutes)

Quantifying the mass, or nuclear binding energy, of atomic nuclei is fundamental for understanding the origin of elements in the universe. The astrophysical processes responsible for the nucleosynthesis in stars often take place far from the valley of stability, where experimental masses are not known. Taking advantage of the information contained in mass model residuals, where the experimental information exists, we utilize Bayesian machine learning techniques to provide the missing nuclear information using extreme extrapolations of theoretical predictions.

Our methodology was developed on the two-neutron separation energies S2n of even-even nuclei, where we consider 10 global models. Quantified emulators of S2n residuals are constructed using Bayesian Gaussian Processes (GP) and Bayesian neural networks of which we assess respectively predictive power and honesty of credibility intervals with rms deviation and empirical coverage probability, using the AME2003 dataset for training and a testing dataset at its external boundary composed of all ulterior measurements. While both statistical models reduce the rms deviation from experiment significantly, GP offers a better and much more stable performance. After statistical corrections all models display similar rms deviations on the testing dataset.

This methodology is applied to the one- and two-neutron separations energies of the nuclei in the region of heavy calcium isotopes, which is at the frontier of experimental and theoretical nuclear structure research. The recent discovery of the extremely neutron-rich nuclei around 60Ca and the experimental determination of masses for 55-57Ca provide unique information about the binding energy surface in this region. To assess the impact of these recent discoveries on the nuclear landscape, we compute the posterior probability for nuclides between Si and Ti to be bound to neutron emission. We find that extrapolations for drip-line locations are consistent across the global mass models used, in spite of significant variations between their raw predictions. In particular we predict that 68Ca has an average posterior probability pex ≈ 76% to be bound to two-neutron emission while 70Ca is a threshold system with pex ≈ 57%; 61Ca is expected to decay by emitting a neutron (pex ≈ 46%). This analysis is finally extended to the full nuclear landscape.

Presenter: NEUFCOURT, Leo (Michigan State University)

Session Classification: Session

Contribution ID: **36** Type: **not specified**

Looking for what is not s process

Thursday 4 July 2019 14:30 (35 minutes)

Presenter: PIGNATARI, Marco

Session Classification: Session

Contribution ID: **37** Type: **not specified**

Electron capture on nuclei at finite temperature based on relativistic density functional

Friday 5 July 2019 09:25 (25 minutes)

Presenter: RAVLIC, Ante (University of Zagreb)

Session Classification: Session

Contribution ID: **38** Type: **not specified**

Session

Session Classification: Session

Contribution ID: **39** Type: **not specified**

TBA

Session Classification: Session

Contribution ID: **40** Type: **not specified**

R-process experiments with fast ion beams at the NSCL and FRIB

Friday 5 July 2019 11:00 (25 minutes)

Fragmentation beam facilities provide an efficient way to produce neutron-rich isotopes, and study the evolution of nuclear structure away from beta-stability. I will present recent work on time-of-flight mass measurement experiments at the National Superconducting Cyclotron Laboratory, aimed at extending the reach of this sensitive mass measurement technique to isotopes relevant to r-process nucleosynthesis models. I will also discuss the perspectives for r-process experiments at the future Facility for Rare Isotope Beams (FRIB).

Presenter: ESTRADE, Alfredo

Session Classification: Session

Contribution ID: **41** Type: **not specified**

Concluding remarks

Friday 5 July 2019 11:25 (35 minutes)

Session Classification: Session