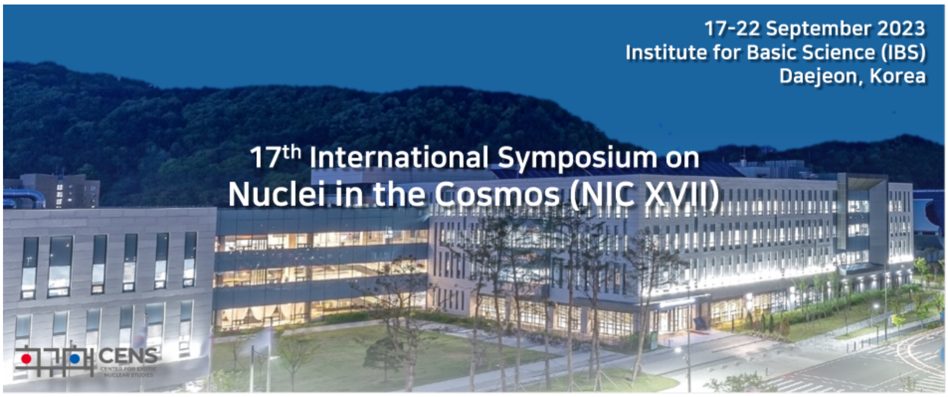
Nuclei in the Cosmos (NIC XVII)



Report of Contributions (Poster presentations)

https://indico.ibs.re.kr/e/NIC2023

Superheavy Elements in Kilonovae

With LIGO-Virgo-KAGRA in its fourth observing run, a new opportunity to search for electromagnetic counterparts of compact object mergers is also upon us. The light curves and spectra from the first “kilonova” associated with a binary neutron star binary (NSM) suggests that these sites are hosts of the rapid neutron capture (”*r*“) process. However, it is unknown just how robust elemental production can be in mergers. Identifying signposts of the production of particular nuclei is critical for fully understanding merger-driven heavy-element synthesis. This talk will explore the properties of very neutron rich nuclei for which superheavy elements ($Z \geq 104$) can be produced in NSMs and whether they can similarly imprint a unique signature on kilonova light-curve evolution. A superheavy-element signature in kilonovae represents a route to establishing a lower limit on heavy-element production in NSMs as well as possibly being the first evidence of superheavy element synthesis in nature.

Primary author: HOLMBECK, Erika (Observatories of the Carnegie Institution for Science)

Presenter: HOLMBECK, Erika (Observatories of the Carnegie Institution for Science)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Strong magnetic field impact on the neutrino process inside the SNe explosion

Strong magnetic fields such as MHD-Jet SNe could exist in the inner region of the explosive astrophysical site. The phase space of the electrons is quantized inside the magnetic field so that the weak interaction rates deviate from the field-free case. This talk focuses on the (anti)neutrinos absorption process. This process is essential since it determines the opacity of the neutrino and the position of the (anti) neutrino sphere. Moreover, we will show that the evolution of the electron fraction ⊠⊠ is also affected by the magnetic field since its value depends on the inverse reaction of the neutrino process. Such impact could leave an imprint on the ⊠-process nucleosynthesis yields.

Primary author: LUO, Yudong (Peking University)

Co-authors: KUSAKABE, Motohiko (Beihang University); KAJINO, Taka (National Astronomical Observatory of Japan, The University of Tokyo)

Presenter: LUO, Yudong (Peking University)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Galactic chemical Evolution with short lived radioactive isotopes

Studying the galactic chemical evolution with short lived radioisotopes (SLRs) has a significant advantage over using stable elements: Due to their radioactive decay, SLRs carry additional timing information on astrophysical nucleosynthesis sites.

We can use meteoritic abundance data in conjunction with a chemical evolution model to constrain the physical conditions in the last rapid neutron capture process event that polluted the early Solar system prior to its formation [1].

Further, with the help of detections of live SLRs of cosmic origin in the deep sea crust [2], we can use these data in a 3-dimensional chemical evolution code to explain why different classes of radioisotopes should often arrive conjointly on Earth, even if they were produced in different sites (e.g., neutron star mergers, core-collapse/thermonuclear supernovae) [3].

Finally, we included radioisotope production into a cosmological zoom-in simulation to create a map of Al-26 decay gamma-rays indicating areas of ongoing star formation in the Galaxy, consistent with the observations by the SPI/INTEGRAL instrument [4]. We provide predictions for future gamma-ray detection instruments.

[1] Côté et al., 2021 Science 371, 945
[2] Wallner et al., 2021 Science 372, 742W
[3] Wehmeyer et al., 2023 ApJ 944, 121
[4] Kretschmer et al., 2013 A&A 559, A99

Primary author: WEHMEYER, Benjamin (Konkoly Obs & Univ Hertfordshire)

Co-authors: Dr YAGÜE LÓPEZ, Andrés (LANL); Dr CÔTÉ, Benoit (University of Victoria); Prof. KOBAYASHI, Chiaki (University of Hertfordshire); Dr K. PETŐ, Maria; LUGARO, Maria (Konkoly Observatory, CSFK)

Presenter: WEHMEYER, Benjamin (Konkoly Obs & Univ Hertfordshire)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Multi-messenger Signals of Heavy Axionlike Particles in Core-collapse Supernovae

Axion-like particles (ALPs) are a class of hypothetical pseudoscalar particles which feebly interact with ordinary matter. The hot plasma in core-collapse supernovae is a possible laboratory to explore physics beyond the standard model including ALPs. Once produced in a supernova, a part of the ALPs can be absorbed by the supernova matter and affect energy transfer. We recently developed two-dimensional supernova models including the effects of the production and the absorption of ALPs that couple with photons. It is found that the additional heating induced by ALPs can enhance the explosion energy; for moderate ALP-photon coupling, we find explosion energies ~0.6*10^51 erg compared to our reference model without ALPs of ~0.4*10^51 erg. Our findings also indicate that when the coupling constant is sufficiently high, the neutrino luminosities and mean energies are decreased because of the additional cooling of the proto-neutron star. The gravitational wave strain is also reduced because the mass accretion on the proto-neutron star is suppressed.

Primary author: MORI, Kanji (National Astronomical Observatory of Japan)

Co-authors: Prof. TAKIWAKI, Tomoya (National Astronomical Observatory of Japan); HORIUCHI, Shunsaku (Virginia Tech); Prof. KOTAKE, Kei (Fukuoka University)

Presenter: MORI, Kanji (National Astronomical Observatory of Japan)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Atomic Structure Calculations of Neodymium and Uranium for Kilonova Emission Modeling

In 2017, the electromagnetic counterpart AT2017gfo to the binary neutron star merger GW170817 was observed by all major telescopes on Earth. While it was immediately clear that the transient following the merger event, is powered by the radioactive decay of r-process nuclei, only few tentative identifications of light r-process elements have been made so far. One of the major limitations for the identification of heavy nuclei based on light curves or spectral features is incomplete or missing atomic data which greatly affects the results of radiative transfer models. While progress has been made on lanthanide atomic data over the last few years, for actinides there has been less emphasis, with the firs set of opacity data only recently published.

This talk will present converged large-scale atomic structure calculations of lanthandies (focusing on neodymium, $(Z = 60)$) as well as actinides (focussing on uranium, $(Z = 92)$). Using two different codes (FAC and HFR) for the calculation of the atomic data, we investigate the accuracy of the calculated data (energy levels and electric dipole transitions) and their effect on kilonova opacities. I will show a comparison of bound-bound opacities as a function of included electron configurations, for both ab-initio and experimentally calibrated atomic structure calculations. Finally, I will present how optimization of the local central potential model in atomic structure calculations increases the accuracy of the obtained level energies, and, as a result, the opacities.

Primary author: Dr FLÖRS, Andreas (GSI Darmstadt)

Co-authors: FEREIRRA DA SILVA, Ricardo (LIP Lisbon); Dr DEPRINCE, Jerome (Université Libre de Bruxelles); CARVAJAL GALLEGO, Helena (Université de Mons); Dr SHINGLES, Luke (GSI Darmstadt); Prof. MARTÍNEZ-PINEDO, Gabriel (GSI Darmstadt); Prof. SAMPAIO, Jorge (LIP Lisbon); Prof. MARQUES, José (LIP Lisbon); Prof. QUINET, Pascal (Université de Mons); Prof. PALMERI, Patrick (Université de Mons); Prof. AMARO, Pedro (NOVA University Lisbon); Prof. GORIELY, Stephane (Université Libre de Bruxelles); Prof. GODEFROID, Michel (Université Libre de Bruxelles)

Presenter: Dr FLÖRS, Andreas (GSI Darmstadt)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

MeV Gamma Rays from Neutron Star Mergers: a Distinct Signature of r-Process Fission

Neutron star mergers (NSMs) are the first verified sites of rapid neutron capture (r-process) nucleosynthesis, and could emit gamma rays from the radioactive isotopes synthesized in the neutron-rich ejecta. These MeV gamma rays may provide a unique and direct probe of the NSM environment as well as insight into the nature of the r process, just as observed gammas from the 56Ni radioactive decay chain provide a window into supernova nucleosynthesis. Here we include the photons from fission processes for the first time in estimates of the MeV gamma-ray signal expected from an NSM event. We consider NSM ejecta compositions with a range of neutron richness and find a dramatic difference in the predicted signal depending on whether or not fissioning nuclei are produced. The difference is most striking at photon energies above ~3.5 MeV and at a relatively late time, several days after the merger event, when the ejecta is optically thin. We estimate that a nearby NSM could be detectable by a next generation MeV gamma-ray detector, up to ~10^4 days after the merger, if fissioning nuclei are robustly produced in the event. In addition, such MeV signal from NSM, if detected, can constrain the nuclear models for the heavy r-process nuclei that without experimental data.

Primary author: WANG, Xilu

Co-authors: VASSH, Nicole; SPROUSE, Trevor; MUMPOWER, Matthew; SURMAN, Rebecca

Presenter: WANG, Xilu

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

New Observable Signal of r-, i-, and s-process Nucleosynthesis in Collapsar Jet

In the era of multi-messenger astronomy, the afterglow of energetic photons emitted from the decay of long-lived neutron-rich actinides is an important observable signal for the rapid neutron-capture process (r-process) which occurred in the compact gravitational objects, i.e., binary neutron star merger (NSM), magneto-hydrodynamic jet supernova (MHDJ SN), and collapsar, which is an explosion of single massive star collapsing to a black hole. We calculated the collapsar nucleosynthesis including the fission of wide ranges of heavy nuclei for a long time (up to 10^17 seconds). We have recently found [1], for the first time, that the intermediate and slow neutron-capture processes (i- and s-processes) operate at a relatively later time in collapsar nucleosynthesis as secondary processes, when the primary r-process nuclei capture the neutrons produced by the fission of long-lived neutron-rich actinides. Here we show that the collapsar provides with another significant observable signal in the nucleosynthesis of heavy atomic nuclei.
In this article, we show the roles of neutron-capture reactions on unstable nuclei near the stability line in the i-process as well as those on extremely neutron-rich nuclei in the r-process. We also propose that the pronounced odd-even pattern in the mass-abundance relation near rare earth elements in metal-deficient halo stars could be a piece of observational evidence of the collapsar s- and -processes [1]. The s- and i-processes are believed to occur in asymptotic giant branch (AGB) stars to provide half of heavy atomic nuclei $90 \leq A$ in the Milky Way. Collapsar nucleosynthesis is one of the dominant sites for the production of heavy r-process nuclei over the entire history of Galactic chemical evolution until solar system formation [2]. Therefore, our finding [1] would motivate to improve an accepted standard interpretation that the solar r-abundance is the residual of the measured solar-system abundance subtracted by the s-abundance.

[1] Z. He, M. Kusakabe, T. Kajino, S.-G. Zhou, H. Koura, S. Chiba, submitted (2022).

[2] Y. Yamazaki, Z. He, T. Kajino, G. J. Mathews, M. A. Famiano, X.-D. Tang, J.-R. Shi, ApJ. 933 (2022), 112.

Primary authors: HE, Zhenyu (Beihang University); KUSAKABE, Motohiko (Beihang University); KAJINO, Toshitaka (Beihang Univ./NAOJ/Univ. of Tokyo); ZHOU, Shan-Gui (Institute of Theoretical Physics, Chinese Academy of Sciences); KOURA, Hiroyuki (Advanced Science Research Center, Japan Atomic Energy Agency); CHIBA, Satoshi (Tokyo Institute of Technology)

Presenter: HE, Zhenyu (Beihang University)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Constraining Supernova Nucleosynthesis from nu-Mass Hierarchy and the Roles of nu-Nucleus and Radioactive Nuclear Reactions

The origin of neutrino mass and mass hierarchy is one of the biggest unanswered questions in physics. In this article, we propose an astrophysical method so that the supernova (SN) ν-process nucleosynthesis, which is consistent with the mass hierarchy constrained from various ν-oscillation experiments, should provide independent observational signals of nucleosynthetic products in the specific nuclei such as ^{138}La, ^{98}Tc, ^{7}Li, ^{11}B and others (so-called ν-nuclei) through the ν-flavor oscillation due to the MSW matter effect and the effect of collective oscillation [1].
Core-collapse SNe emits a huge number of neutrinos which bring valuable observational information on how the neutrinos propagate through the high-density matter and change their flavors and how explosive nucleosynthesis occurs. We found that the still unknown mass hierarchy is imprinted in the nucleosynthetic products of ν-nuclei [1,2]. In this talk, we will discuss the mechanism of SN ν-process nucleosynthesis and try to constrain the mass hierarchy by comparing our theoretical prediction of nuclear abundances and observed values in the meteorites. Among the calculated results, the abundance ratios of ^{7}Li/^{11}B and ^{138}La/^{98}Tc provide exclusively sensitive probes to neutrino mass hierarchy [1]. These ratios are also influenced by the mass cut during the ejection phase of SN materials. These facts provide valuable quantitative tools to constrain the mass hierarchy through precise measurements of nuclear abundances of these ν-nuclei in SiC-X pre-solar grains and comprehensive studies of solar-system abundances. We also found the significance of removing the uncertainties associated with the ν-^{4}He,^{12}C,^{16}O, and ^{20}Ne reaction cross sections with all possible final particle-emission channels being taken into account and the radioactive nuclear reaction rates for $^{11}\mathrm{C}(\alpha, p)^{14}\mathrm{N}$ and many others for the production of these ν-nuclei. We will discuss these sensitivities and propose a list of ν-A and radioactive nuclear reactions to be studied experimentally and theoretically [3].

[1] Xingqun Yao, T. Kajino, M. Kusakabe et al., Paper-I (2023), to be submitted.

[2] Heamin Ko, D. Jang, M.-K. Cheoun, M. Kusakabe, H. Sasaki, X. Yao et al., ApJ 937 (2022), 2, id.116, 37pp.

[3] Xingqun Yao, T. Kajino, M. Kusakabe et al., Paper-II (2023), to be submitted.

Primary authors: KUSAKABE, Motohiko (Beihang University); KAJINO, Toshitaka (Beihang Univ./NAOJ/Univ. of Tokyo); YAO, Xingqun (Beihang Univ. & National Astronomical Observatory of Japan)

Presenter: YAO, Xingqun (Beihang Univ. & National Astronomical Observatory of Japan)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Follow-up of bright very metal-poor star candidates discovered by narrow-band survey

Chemical abundance of metal-poor stars is a clue to understand the chemical evolution of the early Universe. However, the metal-poor stars discovered by previous surveys are faint and it is difficult to measure their abundance of many elements with high precision. Therefore, we performed a photometric survey using the wide-field CMOS camera (Tomo-e Gozen Camera) on the Kiso Schmidt telescope with narrow-band filters sensitive to stellar metallicity to search for bright metal-poor stars. Very metal-poor star candidates with [Fe/H] < -2 were selected for follow-up medium-resolution spectroscopy with the Nayuta telescope. We establish a method for analyzing medium-dispersion spectra using 43 stars with metallicity measurements and determine the metallicity and abundance of alpha-elements of ~300 metal-poor star candidates that we have followed up so far. As a result, nine new very metal-poor stars and two low-alpha stars were discovered. In this talk, we present the results of the follow-up and the metal-poor star candidate selection methods.

Primary author: OKADA, Hiroko (University of Hyogo)

Co-authors: TOMINAGA, Nozomu (NAOJ); HONDA, Satoshi (University of Hyogo); AOKI, Wako (National Astronomical Observatory of Japan); FURUTSUKA, Kurumi (Univ. of Hyogo); MOROKUMA, Tomoki (Chiba Institute of Technology)

Presenter: OKADA, Hiroko (University of Hyogo)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Probing the origin of heavy isotopes in dwarf galaxies with a variable initial mass function

Astrophysical sources of r-process nucleosynthesis pose an ongoing enigma, with conflicting findings in the literature. We investigate three leading candidates—neutron star mergers, magneto-hydrodynamic jets, and collapsars—each associated with distinct stellar progenitor mass ranges. However, an overlooked bias in r-process studies arises from the influence of the initial mass function (IMF), which has been recently confirmed to vary with metallicity. This IMF variation affects the proportion of stars formed within specific mass ranges relative to metallicity, consequently impacting the rate of enrichment for potential r-process sites.

To address the influence of a variable IMF on r-process enrichment, we extend our open-source galactic chemical evolution model, GalCEM. GalCEM enables comprehensive calculations of the chemical evolution of all stable isotopes across galactic times. The code encompasses in synergy low-to-intermediate stars, massive stars, type Ia supernovae, and the aforementioned candidate processes. Our novel extension employs the integrated galaxy-wide IMF (IGIMF), a well-established and observationally validated theory. The IGIMF demonstrates remarkable consistency across diverse environments, including the Milky Way, high-redshift starburst galaxies, and local dwarf galaxies. We focus specifically on local dwarf galaxies and their low-metallicity stars, as they serve as self-contained nucleosynthetic laboratories, devoid of complex dynamic evolution.

Our study unveils the return rates of r-process nucleosynthesis candidates within the context of a variable IMF. This works provides fundamental constraints for future observational studies.

Primary authors: GJERGO, Eda (Nanjing University); Prof. ZHANG, Zhi-Yu (Nanjing University); Dr YAN, Zhiqiang (Nanjing University); KAJINO, Toshitaka (Beihang Univ./NAOJ/Univ. of Tokyo); KUSAKABE, Motohiko (Beihang University); Prof. KROUPA, Pavel (Bonn University); MATTEUCCI, Francesca (UNITS-INAF)

Presenter: GJERGO, Eda (Nanjing University)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

High-dispersion spectroscopic observations of r-process elements including thorium in solar metallicity and mildly-metal-poor stars

The origin of the r-process is unknown for many years, but in 2017, neutron-star merger (NSM) was observed by gravitational waves [1], it was found that NSM is the origin of the r-process by following photometric and spectroscopic observation. However, NSM is unable to explain the origin of the r-process alone. Observations of stellar abundances have found stars which have high [Th/Eu] value (Actinide-Boost stars). The origin of Actinide-Boost stars is unclear, the existence of such stars suggests that the r-process has more than one origin (e.g. [2, 3]). It is important to determine Th abundance in many stars to clarify the origin of the r-process. At present, there has been few observations of Th in [Fe/H] > -1.5 [4]. Therefore, we obtained a number of r-process abundances including Th, over ten objects in [Fe/H] > -1.5. We observed with Nayuta/MALLS and obtained Subaru/HDS archive data. We found the following two results. First, the value of [Th/Eu] is constant and independent of the metallicity. Second, there are not Actinide-boost stars in [Fe/H] > -1.5. These results are important to clarify the origin of Actinide-boost stars. Identifying the origins of Actinide-boost stars is to investigate the origins of the r-process.

[1] Abbott et al., PhRvL, 119, 16 (2017)
[2] Holmbeck et al., ApJ, 859, 2 (2018)
[3] Yong et al., Nature, 595, 7866 (2021)
[4] Mishenina et al., MNRAS, 516, 3 (2022)

Primary author: FURUTSUKA, Kurumi (University of Hyogo)

Co-author: HONDA, Satoshi (University of Hyogo)

Presenter: FURUTSUKA, Kurumi (University of Hyogo)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Bright metal-poor star survey with Tomo-e Gozen Camera

The first metal enrichment in the Universe was made by a supernova explosion of a population III star. Second-generation stars were formed from the mixture of the pristine gas and the supernova ejecta. Metal-poor stars were survivors of second-generation stars in the Galactic halo. Their abundance pattern records the metal abundance at their formation and tell us the chemical evolution in the early Universe. Therefore, large programs to survey metal-poor stars are performed and provide metal-poor star candidates and high-resolution spectroscopic follow-ups measure the metallicities and abundances of the metal-poor stars. These intensive observations constrain the chemical evolution and the nature of supernovae in the early Universe. To enhance this study, the discovery of bright metal-poor stars, for which the high-resolution spectroscopic follow-up is easy, is desired. Therefore, we plan to search for all bright metal-poor stars in the northern hemisphere using narrow-band CaHK filters and the Tomo-e Gozen Camera on the Kiso Schmidt Telescope at the University of Tokyo. We report the status of a pilot survey having been performed over 5000deg2 in 2022 and the survey plan.

Primary author: TOMINAGA, Nozomu (NAOJ)

Co-authors: AOKI, Wako (National Astronomical Observatory of Japan); HONDA, Satoshi (University of Hyogo); OKADA, Hiroko (University of Hyogo); MOROKUMA, Tomoki (Chiba Institute of Technology); Dr TAKAHASHI, Hidenori (The University of Tokyo); Dr SAKO, Shigeyuki (The University of Tokyo); Dr KANEKO, Keiko (NAOJ); Dr IWASHITA, Hikaru (NAOJ); Dr FUKUSHIMA, Mitsuhiro (NAOJ); Dr FUKUDA, Takeo (NAOJ); Dr KANZAWA, Tomio (NAOJ); Dr MITSUI, Kenji (NAOJ)

Presenter: TOMINAGA, Nozomu (NAOJ)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Kilonova Modelling: Nuclear Physics, Magnetic Fields, Neutrinos

The merging of two neutron stars can provide the conditions necessary for the production of the heaviest elements in the universe via the rapid neutron capture process (r-process). When this occurs, an abundance of material is produced lying far from nuclear stability, and the decays of these nuclei produce the electromagnetic signal: the kilonova. Modeling these kilonova signals remains subject to uncertainties stemming from both nuclear properties far from stability as well as from incomplete information regarding the evolution of the extreme astrophysical environment in which this occurs.

I will discuss current work aimed at approaching this problem from both an astrophysical perspective with magnetohydrodynamic simulations of the post-merger disk with neutrino transport, as well as from a nuclear perspective with detailed nucleosynthesis studies. I will highlight recent results in identifying key nuclei for the nuclear heating that powers the kilonova as well as the effect of nuclear uncertainties on cosmochronometry calculations for r-process enhanced metal-poor stars.

Primary author: LUND, Kelsey (North Carolina State University)

Presenter: LUND, Kelsey (North Carolina State University)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Supernova gravitational waves and asteroseismology

The supernova, which is the event at the last moment of the massive star's life, is the next promising candidate as the gravitational wave source. Up to now, gravitational waves from supernova explosions have been mainly discussed via numerical simulation. These results tell us the existence of the gravitational waves whose frequencies increase from a few hundred hertz up to kHz within a second. However, the physics behind this signal has been unclear. In this talk, we discuss the supernova gravitational waves from the approach with asteroseismology and we show the universal relation in the supernova gravitational waves. Using our relation, once one detects the gravitational waves from the supernova, one can estimate the evolution of the average density of the protoneutron star.

Primary author: Dr SOTANI, Hajime (RIKEN)

Presenter: Dr SOTANI, Hajime (RIKEN)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Systematic 3D simulations of core-collapse supernova and implications for explosive nucleosynthesis

Systematic studies of core-collapse supernovae (CCSNe) have been conducted based on hundreds of one-dimensional artificial models (O'Connor & Ott 2011,2013; Ugliano et al. 2013, Ertl et al. 2015) and two-dimensional self-consistent simulations (Nakamura et al. 2015;2019, Burrows & Vartanyan 2020). We have performed three-dimensional core-collapse simulations for 16 progenitor models covering ZAMS mass between 9 and 24 solar masses. Our CCSN models show a wide variety of shock evolution, explosion energy, and properties of the ejected material. Most of our models have proton-rich ejecta as usual in neutrino-driven explosions, but some of them involve neutron-rich (Ye<0.45) material. We will discuss the impacts of such a divergence of the ejecta properties on explosive nucleosynthesis.

Primary author: NAKAMURA, Ko

Co-authors: Prof. KOTAKE, Kei (Fukuoka University); Prof. TAKIWAKI, Tomoya (NAOJ)

Presenter: NAKAMURA, Ko

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Insight to the Explosion Mechanism of Core Collapse Supernovae Through γ-ray Spectroscopy of ^{46}Cr

Currently, the explanation behind the explosion mechanism of core collapse supernovae is yet to be fully understood. New insight to this phenomena may come through observations of ^{44}Ti cosmic γ rays; this technique compares the observed flux of cosmic ^{44}Ti γ rays to that predicted by state-of-the-art models of supernova explosions. In doing so, the mass cut point of the star can be found, a key hydrodynamic property of supernova that provides an understanding of the material that is either ejected from the explosion or bound to the residual neutron star or black hole. However, a road block in this procedure comes from a lack of precision in the nuclear reactions that destroy ^{44}Ti in supernovae, most notably the reactions $^{44}\mathrm{Ti}(\alpha,p)^{47}\mathrm{V}$ and $^{45}\mathrm{V}(p,\gamma)^{46}\mathrm{Cr}$. Therefore, this study aims to better understand the $^{45}\mathrm{V}(p,\gamma)^{46}\mathrm{Cr}$ reaction by performing γ-ray spectroscopy of ^{46}Cr with the aim of identifying proton-unbound resonant states.

The experiment was conducted at the ATLAS facility at Argonne National Laboratory, using the GRETINA+FMA setup. A beam of 120-MeV ^{36}Ar ions are impinged onto a ~200 μg·cm^{-2} thick ^{12}C target, producing ^{46}Cr via the fusion-evaporation reaction ^{12}C(^{36}Ar,2n). The cross section for producing ^{46}Cr, in this reaction, is estimated to be in the μb range. Nevertheless, with the power of the GRETINA+FMA setup, we show that it is possible to cleanly identify γ rays in ^{46}Cr. These include decays from previously unidentified states above the proton-emission threshold, corresponding to resonances in the ^{45}V + p system. This represents the state-of-the-art for in-beam γ ray studies for full spectroscopy up to the excitation energy region relevant for astrophysical burning.

Primary author: COUSINS, Christopher (University of Surrey)

Co-authors: Dr KENNINGTON, Adam (University of Surrey); REED, B.J. (University of Surrey); MULLER--GATERMANN, C. (Argonne National Laboratory); PAXMAN, C. (University of Surrey); Dr CAMPBELL, Chris (Lawrence Berkeley National Laboratory); O'SHEA, Connor (University of Surrey); SEWERYNIAK, D (Argonne National Laboratory); DOHERTY, Daniel (University of Surrey); WILSON, G.L. (Argonne National Laboratory, University of Massachusetts Lowell); LOTAY, Gavin (University of Surrey); HENDERSON, J. (University of Surrey); Dr LI, Jingang (Lawrence Berkeley National Laboratory); JOSE, Jordi (UPC Barcelona); CHIPPS, K.A. (Oak Ridge National Laboratory); CANETE, L. (University of Surrey); MOUKADDAM, M. (Universite de Strasbourg); SICILIANO, M. (Argonne National Laboratory); CARPENTER, M.P. (Argonne National Laboratory); REGAN, P.H. (University of Surrey); PAIN, S.D. (Oak Ridge National Laboratory); ZHU, Shaofei (Argonne National Laboratory); REVIOL, W. (Argonne National Laboratory); CATFORD, W.N. (University of Surrey)

Presenter: COUSINS, Christopher (University of Surrey)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Influence of key SN properties on Galactic Chemical Evolution

Galactic chemical evolution (“GCE”) is a great tool to probe the influence of various astrophysical sites on the observed abundances of stars. We use the high resolution ((20 pc)^3 /cell) inhomogeneous GCE tool “ICE”to estimate the impact of two main supernova (“SN”) properties on observed stellar abundances:

First, we will show that supernova yields need to be metallicity dependent in order to explain the observed alpha element abundances.

Second, we show that SN explosion energies have a significant impact on the mixing of the interstellar medium.

We further use pedicted SN explosion energies to constrain under which circumstances SNe “fail”, i.e., collapse to a black hole instead of leaving behind a neutron star. We then use these predictions to estimate if black hole –neutron star mergers might be a second, earlier acting rapid neutron capture (“r”) process production site.

Finally, we speculate whether a rare sub class of supernovae (“magnetorotationally driven supernovae”) can act as an additional and earlier r-process site and conclude that our simulations with an adequate combination of these two sites successfully reproduce the observed r-process elemental abundances in the Galactic halo.

Primary author: WEHMEYER, Benjamin (Konkoly Obs & Univ Hertfordshire)

Presenter: WEHMEYER, Benjamin (Konkoly Obs & Univ Hertfordshire)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Sensitivity of r-abundance to the intermediate mass nuclear reactions

We investigate the sensitivity of the r-process nucleosynthesis to intermediate-mass nuclear reactions. Many nuclear reactions with neutron-rich nuclei are still uncertain and the r-process sites are not fully understood. We use Meyer's code for the reaction network calculation and update some reaction rates. Then, we calculate the r-process nucleosynthesis in the core-collapsed supernovae for the magnetohydrodynamic (MHD) jet model. The sensitivity of the r-abundance to these reactions is estimated when there is an artificial increase in the thermonuclear reaction rates. We discuss reaction network flows under the various conditions and features of affection of intermediate-mass nuclear reactions to the r-process nucleosynthesis.

Primary authors: Dr KIM, Kyungil (Institute of Rare Isotope Science, Institute for Basic Science); KAJINO, Toshitaka (Beihang Univ./NAOJ/Univ. of Tokyo); CHOI, Yong-Beom (Pusan National University); KIM, Youngman (CENS, IBS)

Presenter: Dr KIM, Kyungil (Institute of Rare Isotope Science, Institute for Basic Science)

Session Classification: Poster session (Core-collapse supernovae, mergers and the r-process)

Track Classification: Core-collapse supernovae, mergers and the r-process

Neutrino and Anti-neutrino Emission from Neutron-Star Matter with Strong Magnetic Field in a Relativistic Quantum Approaches

Neutrino and antineutrino emissions are dominant for the cooling process of neutron-stars (NSs). Since neutrino emission rates depend on physical circumstances inside NSs, the study of NS cooling through neutrino emission gives important information for constraining internal NS structures. On the other hand, magnetic fields in NSs play important roles in the interpretation of many observed phenomena. In particular, magnetars, which are associated with super strong magnetic fields, have properties different from normal neutron stars (NSs). Thus, phenomena related magnetars can provide a lot of information about the physics of the strong magnetic field.
There are several kinds of the cooling processes such as the direct Urca (DU) process, the modified Urca process and the neutrino and anti-neutrino pair emission process through the Bremsstrahlung in NN scattering (NN-pair). In these processes the neutrino emission rates must be affected by the magnetic-field because these processes are restricted by the energy-momentum conservation, and a magnetic field provides additional momentum to the particles.
In this work, we study the NN-pair emission [1] and direct Urca [2] process under strong magnetic field in a relativistic quantum approach. We solve exact wave functions for protons and electrons in the states described with Landau levels and calculate neutrino (anti- neutrino) emissions from the transition between two different Landau levels, so that the NN-pair emission can be treated by one-body process.
Then we obtain the following results.
In 10^{15} G of the magnetic field, the energy loss of the NN-pair process is much larger than that of the modified Urca process. In addition, the neutrino emission increases as the magnetic field is weaker around $10^{14} - 10^{15}$ G. Therefore, the neutrino emissivity of the NN pair process must be very effective in relatively low density region. Even the direct Urca process can satisfy the kinematic constraints even in the density regions where this process could not normally occur in the absence of a magnetic field.
Thus, the strong magnetic field plays a very important role to increase the neutrino emissivity in NSs with strong magnetic fields.

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Primary author: MARUYAMA, Tomoyuki (Nihon university)

Co-authors: BALANTEKIN, Baha (University of Wisconsin, Madison); MATHEWS, Grant (University of Notre Dame); KUSAKABE, Motohiko (Beihang University); CHEOUN, Myung-Ki (Soongsil University); KAJINO, Taka (National Astronomical Observatory of Japan, The University of Tokyo)

Presenter: MARUYAMA, Tomoyuki (Nihon university)

Session Classification: Poster session (High-density matter)

Track Classification: High-density matter

Investigating the possible existence of hyper-heavy nuclei in a neutron-star environment

The synthesis of hyper-heavy elements is investigated under conditions simulating neutron star environment. The constrained molecular dynamics approach is used to simulate low energy collisions of extremely n-rich

nuclei. A new type of the fusion barrier due to a neutron wind is observed when the effect of neutron star environment (screening of Coulomb interaction) is introduced implicitly. When introducing also a background of surrounding nuclei, the nuclear fusion becomes possible down to temperatures of 10^8 K and synthesis of extremely heavy and n-rich nuclei appears feasible. A possible existence of hyper-heavy nuclei in a neutron star environment could provide a mechanism of extra coherent neutrino scattering or an additional mechanism, resulting in x-ray burst or a gravitational wave signal and, thus, becoming another crucial process adding new information to the suggested models on neutron star evolution.

Primary authors: Dr VESELSKY, Martin (Institute of Experimental and Applied Physics - Czech Technical University, 11000 Prague, Czechia); Dr PETOUSIS, Vlasios (Institute of Experimental and Applied Physics - Czech Technical University, 11000 Prague, Czechia)

Co-authors: Prof. MOUSTAKIDIS, Charalampos (Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece); Prof. SOULIOTIS, Georgios (Laboratory of Physical Chemistry, Department of Chemistry, National and Kapodistrian University of Athens, 15784 Athens, Greece); Dr BONASERA, Aldo (Cyclotron Institute, Texas A&M University, 77843 College Station, Texas, USA)

Presenter: Dr PETOUSIS, Vlasios (Institute of Experimental and Applied Physics - Czech Technical University, 11000 Prague, Czechia)

Session Classification: Poster session (High-density matter)

Track Classification: High-density matter

Density dependence of the nuclear symmetry energy: dilute and dense matter

The properties of neutron-rich nuclear systems are largely determined by the density dependence of the nuclear symmetry energy. Experiments aiming to measure the neutron skin thickness [1,2] and astronomical observations of neutron stars and gravitational waves [3,4] offer valuable information on the symmetry energy at sub- and supra-saturation densities, respectively.

The Korea-IBS-Daegu-SKKU (KIDS) theoretical framework for the nuclear eqution of state (EoS) and energy density functional (EDF) [5-7] offers the possibility to explore the symmetry-energy parameters such as J (value at saturation density), L (slope at saturation), K_{sym} (curvature at saturation), and so on, independently of each other and independently of assumptions about the in-medium effective mass. Within this versatile and physically motivated framework, any set of EoS parameters can be transposed into a corresponding EDF and readily tested in microscopic calculations of nuclear properties [6-8]. Related studies within KIDS of symmetry-energy parameters based on both astronomical observations and bulk nuclear properties [8,9] and a comprehensive Bayesian analysis of both isoscalar and isovector nuclear observables including giant resonances [10] were published recently.

In this talk, I plan to discuss the importance of high-order parameters such as K_{sym}, indications for a model decoupling of the nucleonic fluid from dense and dilute regimes, implications for the PREX-CREX puzzle, and first attempts to extend the framework to quarkionic matter [11].

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Primary author: PAPAKONSTANTINOU, Panagiota (IBS / RISP)

Presenter: PAPAKONSTANTINOU, Panagiota (IBS / RISP)

Session Classification: Poster session (High-density matter)

Track Classification: High-density matter

Non-equilibrium dynamics in the inner crust of a neutron star

We analyze the behavior of a nucleus as it moves through a superfluid neutron medium located in the inner crust of a neutron star. One important aspect of studying the behavior of nuclei in neutron stars immersed in superfluid neutrons is understanding how their effective mass is affected by interactions with the surrounding particles. To study it, we utilized the Time-Dependent Hartree-Fock-Bogoliubov framework, which allowed us to systematically extract an effective mass for different densities in the low-velocity limit. We use one of the latest nuclear energy-density functionals from the Brussels-Montreal family, developed specifically for applications to neutron superfluidity in neutron-star crusts.

Through investigating our system with no geometry restrictions, we identified several dissipation mechanisms: the production of phonons, the breaking of Cooper pairs, and the creation of vortex rings. The last channel is present only in some layers, which might have consequences for the details of glitch creation.

Primary author: Dr PĘCAK, Daniel (Warsaw University of Technology)

Presenter: Dr PĘCAK, Daniel (Warsaw University of Technology)

Session Classification: Poster session (High-density matter)

Track Classification: High-density matter

Beta-Decay of Mg-33 for Urca Cooling in Accreting Neutron Star Crusts

Low Mass X-ray Binaries that transiently accrete matter onto their neutron stars are excellent laboratories for studying dense matter physics. These systems go in and out of the quiescence phase over observational timescales of decades. Monitoring the surface temperatures of neutron stars in this phase reveals a great deal of information about their structure and composition. However, to infer these properties, it is necessary to have a complete understanding of different nuclear reactions that heat or cool the crust. Urca cooling is one such source of neutrino cooling in the crust that strongly depends on the ground-state to ground-state β-decay transition strengths. $A = 33$ mass chain, and specifically the ^{33}Mg - ^{33}Al transition is the strongest Urca cooling agent for crusts composed of X-ray burst ashes. This relies partly on the strong ground state branch measured in high resolution β-delayed γ-spectroscopy of ^{33}Mg. However, recent measurements of a negative parity ground state in ^{33}Mg makes this a first forbidden decay and the strong transition strength is questioned in the literature, citing Pandemonium effect as a possible reason. We try to resolve this anomaly using Total Absorption Spectroscopy that is mostly free of this Pandemonium effect. I will present the β-decay of ^{33}Mg experiment performed at the National Superconducting Cyclotron Laboratory (NSCL) with NERO/BCS/SuN detector system and discuss results from ongoing analysis. This measurement will also provide more information about the nuclear structure effects near the $N = 20$ island of inversion and how they manifest in astrophysical systems.

Primary author: JAIN, Rahul (MSU/FRIB)

Co-authors: SCHATZ, Hendrik (FRIB/MSU); ONG, Wei Jia (LLNL); Mr HERMANSEN, Kirby (MSU/FRIB); Dr RIJAL, Nabin (FRIB); BERG, Hannah (FRIB); DEYOUNG, Paul (Hope College); Mr FLYNN, Eric (MSU/FRIB); HARRIS, Caley (FRIB); Prof. LIDDICK, Sean (MSU/FRIB); LYONS, Stephanie (PNNL); Dr MISKOVICH, Sara; MONTES, Fernando (FRIB); Mr OGUNBEKU, Timilehin (FRIB); PALMISANO, Alicia (ORNL); RICHARD, Andrea (LLNL); Ms SMITH, Mackenzie (MSU/FRIB); Dr SMITH, Mallory (FRIB); SPYROU, Artemis (FRIB)

Presenter: JAIN, Rahul (MSU/FRIB)

Session Classification: Poster session (High-density matter)

Track Classification: High-density matter

Probing hadron-quark phase transition in inspiralling neutron stars

The discovery of GW170817 has significantly advanced our understanding of the high-density equation of state. In this talk, I will showcase our recent findings, which involve constraining the hadron-quark phase transition using both the existing GW170817 data and future GW observations. The discussion will encompass the constraints derived from both quasi-equilibrium tides and dynamic tides.

Primary author: MIAO, Zhiqiang (Xiamen University)

Co-authors: Prof. ANG, Li (Xiamen University); Dr ZHENYU, Zhu (TDLI); Dr SOPHIA, Han (TDLI); Prof. ENPING, Zhou (Huazhong University of Science and Technology); Prof. BING, Zhang (University of Nevada Las Vegas); Prof. ZI-GAO, Dai (University of Science and Technology of China)

Presenter: MIAO, Zhiqiang (Xiamen University)

Session Classification: Poster session (High-density matter)

Track Classification: High-density matter

Do Accreting Neutron Stars All Have Identical Crusts?

Accretion onto a neutron star induces nuclear reactions which heat the crust. By fitting crust models to the observed thermal evolution of the neutron star after accretion halts and the neutron star enters quiescence, we obtain constraints on the composition and heating of the neutron star crust, notably the crust impurity concentration and the amount of heat deposited per accreted nucleon. Heat deposition in the shallowest layers of the crust is required to fit the early-time cooling as well as to explain the observed recurrence time of superbursts, but the physical mechanism that causes this heating is unknown. It is also unknown whether this shallow heating is constant among different accretion outbursts and different neutron stars and whether different neutron stars have the same crust composition.

We model the thermal evolution of seven neutron stars in which crustal cooling has been observed using the crust cooling code dStar. We estimate the model parameters by performing Markov Chain Monte Carlo fits to the observational data. To test whether model parameters are constant across different outbursts and neutron stars, we perform our analysis first for each neutron star independently, then perform joint fits in which the heat deposition or crust impurity are shared among all neutron stars. We find that models in which the shallow heating is shared across neutron stars fit the data significantly more poorly than those in which it is not shared. This suggests that the shallow heating is indeed different for different neutron stars.

Primary author: GRACE, Justin (Michigan State University)

Co-author: BROWN, Ed (Michigan State University)

Presenter: GRACE, Justin (Michigan State University)

Session Classification: Poster session (High-density matter)

Track Classification: High-density matter

A novel approach to nuclear and astrophysical studies using a laboratory plasma: the PANDORA project

Theoretical predictions and past experiments on highly ionized atoms have shown that the β-decay lifetime can be modified even by several order of magnitudes relative to the value observed in neutral atoms due to the opening of a new decay channel called bound-state β-decay [1,2]. The effect of this variation is particularly relevant for those nuclei placed at the branching point of the s-process. A change in their lifetime would lead to a modification of the nucleosynthesis yield of elements produced accordingly to the competing beta-decay and neutron capture rates.
The PANDORA (Plasmas for Astrophysics Nuclear Decays Observation and Radiation for Archaeometry) project aims to measure, for the first time, possible variations of in-plasma β-decay lifetimes in selected isotopes of astrophysical interest as a function of the thermodynamical conditions of the in-laboratory controlled plasma environment.
The new experimental approach consists of creating and confining a plasma whose main features can mimic specific stellar-like conditions and mapping the evolution of the nuclear lifetime as a function of plasma density and temperature which affect the ions'charge state distribution [3]. To achieve this goal a dedicated plasma trap, based on a superconducting magnetic system where the radionuclides can be maintained in dynamical equilibrium for weeks, has been designed and is under construction at INFN –Laboratori Nazionali del Sud (Catania, Italy). The β-decay events will be tagged by detecting the γ-ray emitted by the daughter nuclei populated in the decay process using an array of 14 HPGe detectors placed around the trap. Plasma parameters will be monitored online and measured through an innovative non-invasive multi-diagnostic system which will work synergically with the γ-ray detection system and will allow to correlate plasma thermodynamic properties with the in-plasma β-decay lifetime [3].
Three physics cases were selected for the first PANDORA experimental campaign: 134Cs, 94Nb, and 176Lu. The sensitivity of the PANDORA setup to the expected variations of the nuclear lifetimes of the selected isotopes was evaluated through GEANT4 simulations. Results indicate that the designed setup is able to map the evolution of the nuclear lifetime variation as a function of the plasma parameters, with at least a 3σ level of significance, within a range of experimental run duration varying from a few days to about 3 months, depending on the initial value of the lifetime and the amount of relative variation observed.
The PANDORA plasma trap can be also employed for measuring opacity and optical properties of under-dense and low-temperature plasma relevant for kilonovae study. Preliminary results of the tests performed at the LNS using the compact Flexible Plasma Trap (FPT) will be presented [4].

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Primary authors: SANTONOCITO, domenico (INFN - LNS); Dr MASCALI, david (INFN - LNS); Prof. BUSSO, Maurizio (Univ. Pg and INFN - PG); Dr CELONA, Luigi (INFN - LNS); Dr GALATÀ, Alessio (INFN - LNL); Dr LA COGNATA, Marco (INFN - LNS); Dr MAURO, Giorgio (INFN - LNS); Dr MENGONI, Alberto (INFN - Bo and ENEA - Bo); Dr NASELLI, Eugenia (INFN - LNS); Dr ODORICI, Fabrizio (INFN - Bo); Dr PALMERINI, Sara (Univ. Pg and INFN - PG); Dr PIDATELLA, Angelo (INFN - LNS); Dr RÀCZ, Richard (ATOMKI); Dr TAIOLI, Simone (TIFPA-INFN and Fond. Bruno Kessler - Trento); Dr

TORRISI, Giuseppe (INFN - LNS)

Presenter: MISHRA, Bharat

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Others (new facilities, instruments, tools, etc)

Plasma Induced Variation of Bound State β-Decay Rates in PANDORA

PANDORA (Plasmas for Astrophysics, Nuclear Decay Observations and Radiation for Archaeometry) is an upcoming facility at INFN - LNS aiming to use an electron cyclotron resonance ion source (ECRIS) as a compact magnetoplasma to measure in-plasma β-decay lifetimes of radioisotopes. Decay rates are susceptible to changes in atomic configuration of the parent and daughter systems and are consequently modified inside plasmas due to the surrounding electron cloud, ion charge state distribution (CSD) and level population distribution (LPD). Since the CSD and LPD are strongly non-homogeneous in ECRIS, so are the decay rates, and calculating them is a complex process involving sequential simulations modelling space-resolved properties of electrons, ions and nuclei respectively. We present here a detailed study of the plasma induced nuclear lifetime variation, taking as a test case the orbital electron capture of ^{7}Be in a range of plasma density and temperatures. The results confirm the contribution of the atomic configuration to the decay rate and underline the importance of precisely calculating ion CSD/LPD. Using a Particle-in-Cell Monte Carlo (PIC-MC) code to model ECR dynamics, we extend the analysis to a realistic laboratory plasma and demonstrate expected spatial gradients of ^{7}Be decay rates in the plasma chamber.

Primary author: MISHRA, Bharat (INFN-LNS and University of Catania)

Presenter: MISHRA, Bharat (INFN-LNS and University of Catania)

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Nuclear reaction rates and stellar abundances

The 12C(p,g)13N reaction S-factor and Er = 422 keV resonance study at Felsenkeller facility.

The ^{12}C(p,γ)^{13}N is the kick off reaction of the CNO cycle, active in massive star core Hydrogen burning and RGB and AGB star H-shell burning, at typical temperatures between 0.02 and 0.1 GK. The ^{12}C(p,γ)^{13}N reaction plays a key role in many scenarios, being the ^{13}N decay one of the solar neutrino source and the main responsible for the ^{13}C pocket in AGB stars, crucial ingredient for s-process. Moreover the ^{12}C/^{13}C abundance ratio, observed in presolar grains, stellar atmosphere and in the interstellar medium, is a powerful tracer of mixing processes and of the Galactic chemical evolution.
Extrapolation of the ^{12}C(p,γ)^{13}N reaction S-factor down to astrophysical energies is dominated by the direct capture contribution and the tail of a broad resonance at E_r = 422 keV. Data below 400 keV are poorly constrained, with available data scattering in a 30\% band. Moreover a recent measurement performed at LUNA reported results in tension with literature data. Concerning the 422 keV resonance only few extensive studies are available in literature, resulting in poorly constrained resonance parameters, as radiative width and energy, which were proved to be crucial in determining the transition from CNO to Hot CNO cycle, active in explosive scenarios.
A new direct measurement was performed at the shallow underground Felsenkeller facility in the energy range E_{cm} = 320-620 keV, allowing to extensively study the 422 keV resonance and to overlap with LUNA range. The experiment was performed irradiating two evaporated carbon targets with 10 μA molecular beam. The γ-rays from ^{12}C(p,γ)^{13}N reaction were detected by mean of five HPGe detectors, located at different angles to check also the angular distribution.
In the talk details of the experimental setup, analysis and preliminary results will be described.

Primary author: PIATTI, Denise (Università degli Studi di Padova and INFN sezione di Padova)

Co-author: BOELTZIG, Axel (Helmholtz-Zentrum Dresden-Rossendorf)

Presenter: BOELTZIG, Axel (Helmholtz-Zentrum Dresden-Rossendorf)

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Underground nuclear astrophysics

Development of a low-background neutron detector array

^{13}C(α,n)^{16}O is the dominant neutron source of the s- and i-processes. The cross section of this reaction is extremely low at stellar energies(~10^{-14} Barn), which brings large errors of the measurements and makes it difficult to constrain the theoretical extrapolation.

To precisely measure the cross section of the ^{13}C(α,n)^{16}O reaction, we designed a detector array comprising 24 ^{3}He proportional counters. The counters were embedded in a polyethylene cube, which was shielded with 7% borated polyethylene layer. The neutron background measured at China Jinping Underground Laboratory(CJPL) was as low as 4.5(2) counts/h, 265 times lower than the result of the ground measurement.

The detection efficiency of the array for neutrons was determined in the range of 0.1MeV to 4.5 MeV, which was carried out with the 3 MV tandem accelerator at Sichuan University and Monte Carlo simulations. Future studies are expected to focus on further improvement of the efficiency and accuracy by measuring the angular distribution of the ^{13}C(α,n)^{16}O reaction.

Primary authors: Dr GAO, Bingshui (Institute of Modern Phuysics); JIAO, Taoyu (Institute of Modern Phuysics); Dr LIN, Weiping (Sichuan University); Dr TANG, Xiaodong (Institute of Modern Phuysics); Mr LI, Yutian (Institute of Modern Phuysics)

Presenter: JIAO, Taoyu (Institute of Modern Phuysics)

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Underground nuclear astrophysics

A new underground measurement of the ^{14}N(p,γ)^{15}O reaction at Bellotti Ion Beam Facility \\

An accurate understanding of the slowest reaction of the CNO cycle, the ^{14}N(p,γ)^{15}O, is crucial for estimating the lifetimes of massive stars and globular clusters, as well as determining the CNO neutrino flux from the Sun. Despite the efforts of many groups over the years, including pioneering underground measurements made by the LUNA collaboration, this reaction remains the predominant source of uncertainty when determining solar chemical composition.

The installation of a new 3.5 MV accelerator in the Bellotti Ion Beam Facility of the Gran Sasso National Laboratories (LNGS) will provide unprecedented opportunities for the nuclear astrophysics community. As a pilot project at this new facility, the LUNA collaboration is conducting a ^{14}N(p,γ)^{15}O experiment, focused on measuring the excitation function and angular distribution using improved solid targets, optimized to limit the beam-induced background contributions. The aim of this renewed measurement is to provide high-quality differential cross section data between 0.3 and 2.0 MeV, which may give new insights and strengthen the knowledge of this fundamental reaction.

Primary author: COMPAGNUCCI, Alessandro (Gran Sasso Science Institute)

Presenter: COMPAGNUCCI, Alessandro (Gran Sasso Science Institute)

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Underground nuclear astrophysics

ChETEC-INFRA: An EU-supported Starting Community of Research Infrastructures for Nuclear Astrophysics, 2021-2025

ChETEC-INFRA networks complementary types of research infrastructures to study the origin of the chemical elements in the cosmos: nuclear laboratories supply data on reactions of astrophysical interest, optical telescopes and accelerator mass spectrometers collect elemental and isotopic abundance data, and high-performance computing facilities perform stellar structure and nucleosynthesis calculations. The Transnational Access program of ChETEC-INFRA offers access to 13 European facilities, free of charge and open to scientific users worldwide. Joint Research Activities aim to improve usability and reduce barriers of access for efficient utilization of these facilities, and Networking Activities focus on strengthening networks within the scientific community using such facilities. An overview of the activities of ChETEC-INFRA, its transnational access program, activities and selected results will be presented. –Supported by the European Union (Horizon2020), grant agreement no. 101008324 (ChETEC-INFRA).

Primary authors: BOELTZIG, Axel (Helmholtz-Zentrum Dresden-Rossendorf (HZDR)); BEMMERER, Daniel (Helmholtz-Zentrum Dresden-Rossendorf (HZDR))

Presenter: BOELTZIG, Axel (Helmholtz-Zentrum Dresden-Rossendorf (HZDR))

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Others (new facilities, instruments, tools, etc)

A study of 14O via 10C+alpha elastic scattering: evidence of alpha clustering

We have studied the structure of the proton-rich 14O nucleus by performing the 10C + α elastic scattering measurement at the CRIB facility (CNS, the university of Tokyo). Recently, the cluster nature for some resonances was identified in the mirror nucleus 14C via the 10Be + α reaction (1). A preliminary Resonating Group Method (RGM) calculation has suggested that also the 10C + α system may present resonances with a large reduced width, an indication of clustering effects. The radioactive beam of 1OC was produced at CRIB using the 10B(p,n)10C reaction, using a 10B primary beam with energy 69.9 MeV (AVS cyclotron, RIKEN). The primary target was H2 at 400 Torr and 77K. The secondary beam 10C was produced at 36 MeV with a beam purity better than 97%. The gas chamber was filled with helium gas at 650 Torr and sealed with the Mylar window. Three DeltaE-E silicon detector telescopes were used in the gas chamber at different angles.
By measuring the protons and the α particles, a complex resonant structure for 14O was observed in the excitation energy region 13-18 MeV. By performing an R-matrix analysis of the elastic scattering data at several angles, some evidence of alpha clustering in 0+ and 2+ states has been observed, in fair agreement with the microscopic cluster model.
A better understanding of the nuclear structure of this nuclear mass region is relevant for future nuclear astrophysical studies.

(1) H. Yamaguchi et al., Physics Letters B 766, 11 (2017)

Primary authors: Prof. SFERRAZZA, Michele (Université Libre de Bruxelles); MA, N.R. (Center for Nuclear Study, the University of Tokyo, Wako branch, Wako, Japan and Department of Nuclear Physics, China Institute of Atomic Energy, Beijing, China); YAMAGUCHI, H. (Center for Nuclear Study, the University of Tokyo, Wako branch, Wako, Japan); DESCOUVEMONT, P. (Department of Physics, Université Libre de Bruxelles, Brussels, Belgium)

Co-authors: OKAMOTO, S. (Department of Physics, Kyoto University, Japan); CHERUBINI, S. (INFN-LNS and dipartimento di Fisica e Astronomia "E. Majorana", University of Catania, Italy); DOI, T. (Department of Physics, Kyoto University, Japan); FUJIKAWA, Y. (Department of Physics, Kyoto University, Japan); HAYAKAWA, H. (Center for Nuclear Study, the University of Tokyo, Wako branch, Wako, Japan); INABA, K. (Department of Physics, Kyoto University, Japan); KAWABATA, T. (Department of Physics, Osaka University, Japan); KOHDA, A. (Department of Physics, Osaka University, Japan); LA COGNATA, M. (INFN, Laboratori Nazionali del Sud, Catania, Italy); MANICO, G. (INFN, Laboratori Nazionali del Sud, Catania, Italy); PALMERINI, S. (INFN and University of Perugia, Perugia, Italy); PIZZONE, R.G. (INFN, Laboratori Nazionali del Sud, Catania, Italy); SAKAUE, A. (Department of Physics, Kyoto University, Japan); SAKANASHI, K. (Department of Physics, Osaka University, Japan); SHIZUMU, H. (Center for Nuclear Study, the University of Tokyo, Wako branch, Wako, Japan)

Presenter: Prof. SFERRAZZA, Michele (Université Libre de Bruxelles)

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Others (new facilities, instruments, tools, etc)

Development and Status of the In-Flight Fragment Separator at RAON

The Rare isotope Accelerator complex for ON-line experiments (RAON) is a heavy ion accelerator facility that provides both stable and rare isotope (RI) beams for basic and applied science research. The in-flight fragment (IF) separator of RAON, the main device for producing RI beams, is under development. In order to efficiently produce RI beams by using in-flight fission of uranium beams as well as projectile fragmentation reactions, the IF separator is designed to have angular acceptance and momentum resolution of ±40 mrad and ±3%, respectively. The IF separator consists of a target, beam dump, magnets, and detector systems. The high-power target and beam dump for the 80 kW primary beam were fabricated using graphite. The IF magnet system consists of a total of 8 dipole magnets, 15 sets of quadrupole magnet triplet, 2 sextupole magnets, and power supply systems. Fabrication of all IF magnets have been completed and on-site installation is in progress. In addition, detectors for particle identification (PID) and data acquisition (DAQ) systems were installed at the focal planes of the IF separator. The development status of IF separator is briefly introduced.

Primary author: Dr KIM, Do Gyun (Institute for Basic Science)

Co-authors: Dr YUN, Chong Cheoul (Institute for Basic Science); KIM, Eunhee (Institute for Basic Science); Dr JANG, Hyun Man (Institute for Basic Science); Dr KIM, Jang Youl (Institute for Basic Science); Dr CHOI, Sukjin (Institute for Basic Science); KIM, Yonghwan (RISP)

Presenter: Dr KIM, Do Gyun (Institute for Basic Science)

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Others (new facilities, instruments, tools, etc)

Studying the ^{12}C(^{12}C,α)^{20}Ne reaction at stellar energies using a novel technique

The ^{12}C+^{12}C fusion reaction plays an important role in various astrophysical models, such as type Ia supernova, superburst, and the evolution of massive star. The direct measurements are limited by backgrounds at energies above $E_{\mathrm{c.m.}}$=2.1 MeV. To overcome this limitation, we have developed a novel technique to study the ^{12}C(^{12}C,α)^{20}Ne reaction by using a time projection chamber. Preliminary results will be presented in this presentation.

Primary authors: ZHANG, Ningtao (Institute of Modern Physics, CAS); LU, Chengui (Institute of Modern Physics, CAS); LI, Yunzhen (Institute of Modern Physics, CAS); TANG, Xiaodong (Institute of Modern Physics, CAS)

Co-authors: CAI, Jiawei (Institute of Modern Physics, CAS); FANG, Xiao (Sino-French Institute of Nuclear Engineering and Technology, Sun Yat-sen University); FENG, Yucheng (Institute of Modern Physics, CAS); FANG, Xing (Institute of Modern Physics, CAS); HANG, Hao (Institute of Modern Physics, CAS); GAO, Bingshui (Institute of Modern Physics, CAS); JIAO, Taoyu (Institute of Modern Physics, CAS); LI, Kuoang (Institute of Modern Physics, CAS); LI, Libin (Institute of Modern Physics, CAS); LI, Xiaobin (Institute of Modern Physics, CAS); JING, Long (Institute of Modern Physics, CAS); LV, Bingfeng (Institute of Modern Physics, CAS); MA, Hongyi (Institute of Modern Physics, CAS); ONG, Hooi-Jin (Institute of Modern Physics, CAS); QI, Hui-Rong (Institute of High Energy Physics, CAS); RU, Longhui (Institute of Modern Physics, CAS); SHI, Fushuai (Institute of Modern Physics, CAS); SUN, Liangting (Institute of Modern Physics, CAS); TANG, Yu (Institute of Modern Physics, CAS); WANG, Xinyu (Institute of Modern Physics, CAS); WANG, Xin-Yu (Institute of Modern Physics, CAS); WANG, Bing (Institute of Modern Physics, CAS); XU, Xiaodong (Institute of Modern Physics, CAS); XU, Zhiguo (Institute of Modern Physics, CAS); YANG, Yao (Institute of Modern Physics, CAS); ZHAI, Yuhan (Institute of Modern Physics, CAS); ZHANG, Jinlong (Institute of Modern Physics, CAS); ZHANG, Bo (Institute of Modern Physics, CAS); ZHANG, Peng (Institute of Modern Physics, CAS); ZHANG, Wenhui (Institute of Modern Physics, CAS); ZHANG, Zhichao (Institute of Modern Physics, CAS); ZHAO, Hongwei (Institute of Modern Physics, CAS); FAN, Yihua (Institute of Modern Physics, CAS); WANG, Sicheng (State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China); ZHANG, Zhiyong (State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China)

Presenter: TANG, Xiaodong (Institute of Modern Physics, CAS)

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Others (new facilities, instruments, tools, etc)

Current status of KoBRA at RAON

A multi-purpose experimental instrument, called KoBRA (Korea Broad acceptance Recoil spectrometer and Apparatus), was constructed at the Institute for Rare Isotope Science (IRIS), as a part of the RAON facility in Korea. Stable or rare isotope (RI) beams can be produced using Electron Cyclotron Resonance (ECR) ion sources or the Isotope Separation On-Line (ISOL) system at RAON, and these beams can be delivered to KoBRA at energies of 1 – 40 MeV per nucleon via the Super-Conducting Linear
accelerator 3 (SCL3). Secondary RI beams can be produced by quasi-projectile fragmentation reaction, and KoBRA will be utilized to generate these RI beams for the studies of nuclear reaction, nuclear structure, and nuclear astrophysics.
KoBRA is currently under beam commissioning phase, and the first test with 40Ar stable ion beam was completed in June 2023. In this presentation, we report on the recent activities of KoBRA from its construction to beam commissioning, together with the detailed design of ion optics and detection system. Additionally, the results from the first beam test will be presented.

Primary author: Mr KIM, Dong Geon (Institute for Rare Isotope Science, Institute for Basic Science, Hanyang University)

Co-authors: Dr TSHOO, Kyoungho (Institute for Rare Isotope Science, Institute for Basic Science); Dr AHN, Deuk Soon (Center for Exotic Nuclear Studies, Institute for Basic Science); Dr AHN, Sung Hoon (Center for Exotic Nuclear Studies, Institute for Basic Science); Dr AKERS, Charles (Institute for Rare Isotope Science, Institute for Basic Science); Dr HAHN, Kevin Insik (Center for Exotic Nuclear Studies, Institute for Basic Science); Dr HAM, Cheolmin (Institute for Rare Isotope Science, Institute for Basic Science); Dr HONG, Seung-Woo (Institute for Rare Isotope Science, Institute for Basic Science); Dr HWANG, Jongwon (Center for Exotic Nuclear Studies, Institute for Basic Science); Dr KIM, Da Hee (Center for Exotic Nuclear Studies, Institute for Basic Science); Dr KIM, Jae Cheon (Institute for Rare Isotope Science, Institute for Basic Science); Dr KIM, Mijung (Institute for Rare Isotope Science, Institute for Basic Science); Prof. KIM, Yong Kyun (Hanyang University); Dr KWAG, Minsik (Institute for Rare Isotope Science, Institute for Basic Science); Dr LEE, Kwang-Bok (Institute for Rare Isotope Science, Institute for Basic Science); Dr LEE, Sangjin (Institute for Rare Isotope Science, Institute for Basic Science); Dr PYEUN, Seong Jae (Institute for Rare Isotope Science, Institute for Basic Science); Dr SHIN, Taeksu (Institute for Rare Isotope Science, Institute for Basic Science)

Presenter: Mr KIM, Dong Geon (Institute for Rare Isotope Science, Institute for Basic Science, Hanyang University)

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Others (new facilities, instruments, tools, etc)

Simulation Study of Neutron Production for NDPS at RAON

Nuclear Data Production System (NDPS) is one of the experimental systems at the Rare isotope Accelerator complex for ON-line experiments (RAON). It provides high-energy neutrons up to tens of MeV. The primary objective of NDPS is to accurately measure the neutron-induced nuclear cross sections, particularly for the neutron energy extending up to tens of MeV region. A beam commissioning of NDPS is scheduled for 2024. Ion beams, such as H, 2H, 16O, and 40Ar, are accelerated from SuperConducting Linac 3 (SCL3) and transported to the NDPS target room. High-energy neutrons will be produced by bombarding an ion beam into the neutron production target at the NDPS target room and delivered to users for the experiments.

For the preparation of forthcoming beam commissioning, simulation studies are performed to calculate neutron productions using the Monte Carlo particle transport codes, namely MCNPX, FLUKA and PHITS. By analyzing the simulation results of various combinations of the ion beams target materials and comparing with available benchmark measurements, an optimal pairing of ion beam and target is proposed for the beam commissioning.

Primary authors: KIM, Jaesung (Institute for Rare Isotope Science, Institute for Basic Science); HAM, Cheolmin (Institute for Rare Isotope Science, Institute for Basic Science); TSHOO, Kyoungho (Institute for Rare Isotope Science, Institute for Basic Science); LEE, Sangjin (Institute for Rare Isotope Science, Institute for Basic Science); PYEUN, Seong Jae (Institute for Rare Isotope Science, Institute for Basic Science); LEE, Kwangbok (Institute for Rare Isotope Science, Institute for Basic Science); AKERS, Charles (Institute for Rare Isotope Science, Institute for Basic Science); KIM, Mijung (Institute for Rare Isotope Science, Institute for Basic Science); KIM, Jae Cheon (Institute for Rare Isotope Science, Institute for Basic Science); KWAG, Minsik (Institute for Rare Isotope Science, Institute for Basic Science); KWAK, Donghyun (Institute for Rare Isotope Science, Institute for Basic Science); KIM, Dong Geon (Institute for Rare Isotope Science, Institute for Basic Science, Hanyang University); LEE, CheongSoo (Institute for Rare Isotope Science, Institute for Basic Science); LEE, Young-Ouk (Institute for Rare Isotope Science, Institute for Basic Science); SHIN, Taeksu (Institute for Rare Isotope Science, Institute for Basic Science); Mr SHIM, Hyungjin (Seoul National University)

Presenter: KIM, Jaesung (Institute for Rare Isotope Science, Institute for Basic Science)

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Others (new facilities, instruments, tools, etc)

Recent progress of Nuclear Data Production System at RAON

A fast neutron facility, called Nuclear Data Production System (NDPS), was constructed for nuclear science and applications at RAON (Rare Isotope Accelerator complex for ON-line experiments) in Korea. NDPS provides neutron beams not only for nuclear data measurements but also for other applications. NDPS is designed to provide both white and mono-energetic neutrons, using 98 MeV deuteron and 20 −83 MeV proton beams with a thick graphite and thin lithium targets, respectively. Neutron energy is determined by employing the time-of-flight (TOF) technique, along with a pulsed deuteron (or proton) beam with a repetition rate of less than 200 kHz. Fast neutrons are produced in the target room and are guided to the TOF room through a 4 m long neutron collimator consisting of iron and 5 % borated polyethylene. In the TOF room, a gas-filled Parallel Plate Avalanche Counter (PPAC) with a Th-232 layer and EJ-301 liquid scintillation detectors are installed to measure the neutron flux. The beam commissioning for NDPS is scheduled for 2024. The recent progress of NDPS will be reported, together with our plan.

Primary authors: HAM, Cheolmin (Institute for Rare Isotope Science, Institute for Basic Science); TSHOO, Kyoungho (Institute for Rare Isotope Science, Institute for Basic Science); LEE, Sangjin (Institute for Rare Isotope Science, Institute for Basic Science); PYEUN, Seong Jae (Institute for Rare Isotope Science, Institute for Basic Science); LEE, Kwangbok (Institute for Rare Isotope Science, Institute for Basic Science); AKERS, Charles (Institute for Rare Isotope Science, Institute for Basic Science); KIM, Mijung (Institute for Rare Isotope Science, Institute for Basic Science); KIM, Jae Cheon (Institute for Rare Isotope Science, Institute for Basic Science); KWAG, Minsik (Institute for Rare Isotope Science, Institute for Basic Science); KWAK, Donghyun (Institute for Rare Isotope Science, Institute for Basic Science); KIM, Dong Geon (Institute for Rare Isotope Science, Institute for Basic Science, Hanyang University); LEE, CheongSoo (Institute for Rare Isotope Science, Institute for Basic Science); KIM, Jaesung (Institute for Rare Isotope Science, Institute for Basic Science); Dr LEE, Young-Ouk (Korea Atomic Energy Research Institute); SHIN, Taeksu (Institute for Rare Isotope Science, Institute for Basic Science); HONG, Seung-Woo (Institute for Rare Isotope Science, Institute for Basic Science)

Presenter: HAM, Cheolmin (Institute for Rare Isotope Science, Institute for Basic Science)

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Others (new facilities, instruments, tools, etc)

Multi-reflection time-of-flight mass spectrometer (MRTOF-MS) at RAON

Nuclear mass is known as crucial information to determine the nuclear synthesis pathways occurring in specific stellar environments. These pathways significantly affect the isotopic abundance observed from astronomical observatories. In other words, the compiled mass database, provided through precise measurements, aids in the development of stellar evolution models and enables a deeper understanding of the evolution of stars.
A novel mass measurement device, the Multi-Reflection Time-of-Flight Mass Spectrometer (MRTOF-MS), is employed to study the nuclear mass of rare isotopes provided by RAON (Rare isotope Accelerator complex for ON-line experiments).
Currently installed in the ISOL beam line, the MRTOF-MS thermalizes the RI beams with low energy of less than 60 keV using a helium-buffer gas catcher. It minimizes the emittance of the ion bunches in the trap system and ultimately analyzes them after a few hundred reflections inside the MRTOF analyzer.
The entire system has been optimized using offline ion sources, and a high resolving power of around 100,000 has been achieved within less than 10 ms. The system is in the process of preparation for commissioning with an RI beam transported from the ISOL system.
In this presentation, the current status of the RAON MRTOF-MS, as well as future plans.

Primary authors: OH, G. (Institute for Rare Isotope Science (IRIS), Institute for Basic Science (IBS)); MOON, J. Y. (Institute for Rare Isotope Science (IRIS), Institute for Basic Science (IBS)); LEE, J. H. (Institute for Rare Isotope Science (IRIS), Institute for Basic Science (IBS)); TSHOO, K. (Institute for Rare Isotope Science (IRIS), Institute for Basic Science (IBS)); SHIN, T. (Institute for Rare Isotope Science (IRIS), Institute for Basic Science (IBS)); WADA, M. (Wako Nuclear Science Center (WNSC), Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK)); SCHURY, P. (Wako Nuclear Science Center (WNSC), Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK)); HASHIMOTO, T. (Institute for Rare Isotope Science (IRIS), Institute for Basic Science (IBS)); HIRAYAMA, Y. (Wako Nuclear Science Center (WNSC), Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK)); WATANABE, Y. X. (Wako Nuclear Science Center (WNSC), Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK)); ROSENBUSCH, M. (Wako Nuclear Science Center (WNSC), Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK)); ITO, Y. (Advanced Science Research Center, Japan Atomic Energy Agency); IIMURA, S. (RIKEN Nishina Center for Accelerator-Based Science, Osaka University); KIMURA, S. (RIKEN Nishina Center for Accelerator-Based Science); KORKULU, Z. (Center for Exotic Nuclear Studies (CENS), Institute for Basic Science (IBS)); MIYATAKE, H. (Wako Nuclear Science Center (WNSC), Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK)); NIWASE, T. (Wako Nuclear Science Center (WNSC), Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK)); TAKEMINE, A. (RIKEN Nishina Center for Accelerator-Based Science); WOLLNIK, H. (New Mexico State University)

Presenter: OH, G. (Institute for Rare Isotope Science (IRIS), Institute for Basic Science (IBS))

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Others (new facilities, instruments, tools, etc)

Capacitive pick-up monitor for the low-energy experimental system at RAON

The Rare Isotope Accelerator Complex for ON-line Experiments (RAON) provides both stable ion (SI) and rare isotope (RI) beams with wide energy ranges for nuclear physics research and other applications. Ion beams with energies up to a few tens of MeV/nucleon will be delivered to the low-energy experimental systems: the Korea Broad Acceptance Recoil Spectrometer and Apparatus (KoBRA) and the Nuclear Data Production System (NDPS). Due to the long beam transport line from the end of the Superconducting Linac3 (SCL3) to KoBRA, a re-bunching system was installed in the middle of the SCL3-KoBRA beam transport line for longitudinal focusing. Similarly, a Half Wave Resonator, in the middle of the SCL3-NDPS beam transport line, can be used as a re-buncher to provide a longitudinally compressed ion beam at the NDPS target room.

To verify the performance of the re-bunchers, the bunch length should be measured with and without the re-bunchers. Therefore, we optimized a capacitive pick-up monitor to measure the beam shape and arrival time at the target position without causing beam disruption. After finalizing the optimized design, we proceeded to manufacture and test the capacitive pick-up monitors. The beam test and installation are scheduled for the end of 2023.

Primary author: KWAK, Donghyun

Co-authors: HAM, Cheolmin (Institute of Basic Science); Dr KIM, Gidong (Institute of Basic Science); Dr WOO, Hyungjoo (Institute of Basic Science); TSHOO, Kyoungho (RISP/IBS); CHUNG, Moses (UNIST); SHIN, Taeksu

Presenter: KWAK, Donghyun

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Others (new facilities, instruments, tools, etc)

Development of Low-pressure Gas TPC for Stellar Nucleosynthesis Reactions

We develop an active-target Time Projection Chamber (aTPC) operated in a low-pressure, strong magnetic field. The aTPC comprises a cathode plane, four field-cage planes, a gating GEM (Gas Electron Multipliers) plane, a triple GEM structure, and a pad plane. The pad plane covers 10 x 10 cm2 with 1000 3x3 mm2 square pads. The construction of the detector is in progress, and the expected performance is verified using Geant4 and Garfield++ simulation. We will primarily focus on the cross-section measurement for oxygen production from the 12C(α,γ)16O reaction and potassium destruction through the reverse 37Cl(α,n)40K and 40Ar(p,n)40K reactions. This talk will present the current R&D status.

Primary author: LEE, Haein (Korea University)

Presenter: LEE, Haein (Korea University)

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Others (new facilities, instruments, tools, etc)

Development of a LaBr3(Ce) detector array for high-energy gamma-ray measurement

We have developed a LaBr3(Ce) detector array, the HANULball, for measuring high-energy gamma rays from nucleosynthesis reactions near 10 MeV. The HANULball prototype comprises eight LaBr3(Ce) detectors arranged on the surfaces of a truncated cuboctahedron structure. Each LaBr3 crystal has a diameter of 50 mm and a length of 75 mm. The prototype array uses 2-inch photomultiplier tubes to detect scintillation light. We tested the prototype performance using a 60Co radioactive source and proton capture gamma rays from the Al(p, gamma)Si reaction from Ep=2.030 to 2.080 MeV at the tandem ion accelerator, KIST. This talk will present the preliminary results of the LaBr3 detector performance over a wide range of gamma-ray energy.

Primary authors: Prof. AHN, Jung Keun (Korea Universty); LEE, Sungjune (Korea University)

Presenter: LEE, Sungjune (Korea University)

Session Classification: Poster session (New facilities, instruments and tools)

Track Classification: Others (new facilities, instruments, tools, etc)

Study of the $^{60}Ga(\beta^{+})^{60}Zn$ decay of for the Astrophysical rp process

One of the goals of nuclear astrophysics is to understand the various astrophysical events occurring in the cosmos.
The most common stellar explosions observed in our galaxy are Type I X-ray bursts (XRB1).
The isotopic abundances obtained from the astrophysical models of XRB1 depend strongly on a number of nuclear reaction rates, occurring both on the surface and inside the crust by the buried ashes.
The nuclear burning that creates these ashes is called the rapid proton (rp) capture process.
Investigating the rp process enhances our understanding of the dynamics of neutron stars and features of XRB1 spectra.
The nuclear reaction flow of the rp process is sensitive to the $\beta+$ decay properties of the nuclei involved, and the experimental study of such properties is of significant importance.
In this study, total absorption spectroscopy (TAS) analysis was performed for the $^{60}Ga(\beta+)^{60}Zn$ decay.
This experiment was performed at the National Superconducting Cyclotron Laboratory (NSCL).
In this presentation, the extracted beta feeding intensity will be discussed, along with a comparison to theoretical shell model and QRPA calculations.

Primary author: OWENS-FRYAR, Gerard (FRIB)

Co-authors: Dr CHESTER, Aaron (FRIB); Dr BROWN, Alex (FRIB); Dr PALMISANO, Alicia (ORNL); Dr RICHARD, Andrea (LLNL); Dr SPYROU, Artemis (FRIB); Ms TSANTIRI, Artemis (FRIB); Ms HARRIS, Caley (FRIB); Dr ROBIN, Caroline (GSI); Dr GOOD, Erin (FRIB); Dr MARTINEZ-PINEDO, Gabriel (GSI); Ms BERG, Hannah (FRIB); Dr BRANDENBURG, Katie (Ohio University); Dr CHILDERS, Katie (FRIB); Dr SAXENA, Mansi (Ohio University); Dr DEYOUNG, Paul (Hope College); Dr SUBEDI, Shiv (Ohio University); Dr LYONS, Stephanie (PNNL); Dr NEFF, Thomas (GSI); Dr MEISEL, Zach (Ohio University)

Presenter: OWENS-FRYAR, Gerard (FRIB)

Session Classification: Poster session (Novae and X-ray bursts, Type IA supernova and the p-process)

Track Classification: Novae and X-ray bursts

Evaluation of 19Ne nuclear structure with a Bayesian approach

The 15O(α, γ)19Ne and 18F(p, α)15O reaction rates at stellar temperatures have significant impacts on the dynamics in x-ray bursts, novae explosions, and heavy element synthesis. Due to its importance, the nuclear structure of the compound nucleus 19Ne, which determines the reaction rate, has been widely investigated. Collecting the available data from experimental measurements, Nesaraja et al. had previously evaluated the nuclear structure of 19Ne above the proton-threshold energy [Phys. Rev. C 75, 055809 (2007)], which provided useful information for reaction rate calculations. Because many new experiments have been performed since that evaluation, the nuclear structure properties of 19Ne needs to be updated. In this work, the results from the latest measurements are compiled and then evaluated employing a novel Bayesian approach to integrate the results from independent measurements. By demonstrating the statistical and physical meanings of the priors for resonance parameters and likelihoods for previous experimental results, the posterior (i.e., updated) distributions of the resonance parameters could be obtained. These posteriors will be presented and directly used as probability density functions for Monte Carlo reaction rate calculations.

Primary authors: KIM, Sohyun (Sungkyunkwan University); Prof. CHAE, Kyung-yuk (Sungkyunkwan University)

Co-author: Dr SMITH, Michael (Oak Ridge National Laboratory)

Presenter: KIM, Sohyun (Sungkyunkwan University)

Session Classification: Poster session (Novae and X-ray bursts, Type IA supernova and the p-process)

Track Classification: Novae and X-ray bursts

26Si(α, α)26Si measurement for the astrophysical 26Si(α,p)29P reaction rate

The study of the ^{26}Si(α,p)^{29}P reaction rate is essential for understanding X-ray burst phenomena. It is believed that the heavy elements up to the Sn-Sb-Te region can be synthesized during the burst. Since 26Si is considered to be a waiting point during the burst, the ^{26}Si(α,p)^{29}P reaction rate is believed to be one of the most significant reactions that affects nucleosynthesis. To study the ^{26}Si(α,p)^{29}P reaction rate, the properties of energy levels in the ^{30}S were studied through the ^{26}Si(α,α)^{26}Si reaction measurement. The radioactive 26Si beam was produced through the ^{3}He(^{24}Mg,n)^{26}Si reaction at the Center for the Nuclear Study Radioactive Ion Beam Separator (CRIB) of the University of Tokyo. By adopting the thick target method, the resonant states were observed over the wide energy range of E_x = 12 - 16 MeV for the first time. By comparing the empirical excitation function and theoretical calculation results with the SAMMY8 code, the properties of ^{30}S energy levels were constrained. The astrophysical ^{26}Si(α,p)^{29}P reaction rate was updated accordingly. The details of the results will be discussed.

Primary authors: KIM, Minju (Department of Physics, Sungkyunkwan University); CHAE, K. Y. (Department of Physics, Sungkyunkwan University)

Co-authors: OKAWA, K. (Center for Nuclear Study, University of Tokyo); HAYAKAWA, S. (Center for Nuclear Study, University of Tokyo); ADACHI, S. (Department of Physics, Osaka University); CHA, S. M. (Center for Exotic Nuclear Studies, Institute for Basic Science (IBS)); CHILLERY, T. (Center for Nuclear Study, University of Tokyo); DUY, N. N. (Department of Physics, Sungkyunkwan University); FURUNO, T. (Department of Physics, Osaka University); GU, G. M. (Department of Physics, Sungkyunkwan University); HANAI, S. (Center for Nuclear Study, University of Tokyo); IMAI, N. (Center for Nuclear Study, University of Tokyo); KAHL, D. (Extreme Light Infrastructure Nuclear Physics (ELI-NP)); KAWABATA, T. (Department of Physics, Osaka University); KIM, C. H. (Department of Physics, Sungkyunkwan University); KIM, D. (Center for Exotic Nuclear Studies, Institute for Basic Science (IBS)); KIM, S. H. (Department of Physics, Sungkyunkwan University); KUBONO, S. (RIKEN Nishina Center); KWAG, M. S. (Department of Physics, Sungkyunkwan University); LI, J. (Center for Nuclear Study, University of Tokyo); MA, N. R. (Center for Nuclear Study, University of Tokyo); MICHIMASA, S. (Center for Nuclear Study, University of Tokyo); SAKANASHI, K. (Department of Physics, Osaka University); SHIMIZU, H. (Center for Nuclear Study, University of Tokyo); SIRBU, O. (Extreme Light Infrastructure Nuclear Physics (ELI-NP)); UYEN, N. K. (Department of Physics, Sungkyunkwan University); YAMAGUCHI, H. (Center for Nuclear Study, University of Tokyo); YOKOYAMA, R. (Center for Nuclear Study, University of Tokyo); ZHANG, Q. (Center for Nuclear Study, University of Tokyo)

Presenter: KIM, Minju (Department of Physics, Sungkyunkwan University)

Session Classification: Poster session (Novae and X-ray bursts, Type IA supernova and the p-process)

Track Classification: Novae and X-ray bursts

Direct Measurement of the 14O(α,p)17F Cross Section

14O(α,p)17F is one of the important reactions that strongly affects the light curves of Type I X-ray burst models [1]. The reaction rate is known to determine the break-out path from the hot CNO cycle to the rp-process at sufficiently high temperatures (T9 > 0.5) [2]. However, its large uncertainty due to the lack of experimental measurements causes difficulties in the precise demonstration of astrophysical observables.

In order to constrain the reaction rate, a direct measurement of the 14O(α,p)17F cross section was performed at CNS RI beam separator (CRIB), RIKEN. A 14N beam with the energy of 8.40 MeV/u and H2 gas cell target were used to produce the 14O beam. As a reaction target and charged particle detector, the Texas Active Target Time Projection Chamber (TexAT) was used [3]. The detector was developed at Texas A&M University, and upgraded to TexAT_v2 at the Center for Exotic Nuclear Studies (CENS), Institute for Basic Science (IBS) to optimize the detection efficiency for the (α,p) cross section measurement. The energy and position resolution of detected charged particles from the reaction are enhanced thanks to the three-dimensional tracking of the particles. Along with segmented silicon and CsI(Tl) detectors around the field cage, the TexAT enables measuring more precise cross sections as a function of center-of-mass energy. In order to manage about 2500 channels from various detectors, the GET electronics is used with the GANIL data acquisition system [4].

Details of the experimental setup and the results of preliminary analysis of the experiment will be discussed.

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Primary authors: PARK, Chaeyeon (EWHA Womans University / CENS(IBS)); Dr AHN, Sunghoon(Tony) (Center for Exotic Nuclear Studies, Institute for Basic Science)

Co-authors: CHEN, Alan (Department of Physics and Astronomy, McMaster University, Hamilton, Ontario, Canada); KIM, Aram (Korea University); PSALTIS, Athanasios (Triangle Universities Nuclear Laboratory, Duke University, Durham, NC, USA); MOON, Byul (Center for Exotic Nuclear Studies, Institute for Basic Science); HONG, Byungsik (Korea University); KIM, Chanhee (Department of Physics, Sungkyunkwan University, Suwon, Republic of Korea); PARKER, Cody E (Cyclotron Institute, Texas A&M University, College Station, TX, USA); KIM, Dahee (Center for exotic nuclear studies, Institute Basic Science); BARDAYAN, Daniel W (Department of Physics & Astronomy, University of Notre Dame, Notre Dame, IN, USA); ROGACHEV, Grigory V (Cyclotron Institute, Texas A&M University, College Station, TX, USA); GU, Gyoungmo (Sungkyunkwan University); YAMAGUCHI, Hidetoshi (Center for Nuclear Study, University of Tokyo, Tokyo, Japan); LEE, Hyeji (Department of Physics, Tokyo Institute of Technology, Tokyo, Japan); HAHN, Insik (Center for Exotic Nuclear Studies, IBS); BISHOP, Jack (Cyclotron Institute, Texas A&M University, College Station, TX, USA); OKAWA, Kodai (Center for Nuclear Study, University of Tokyo, Tokyo, Japan); CHAE, Kyungyuk (Sungkyunkwan University); COGNATA, Marco La (INFN, Laboratori Nazionali del Sud, Catania, Italy); BARBUI, Marina (Cyclotron Institute, Texas A&M University, College Station, TX, USA); SASANO, Masaki (RIKEN Nishina Center, Wako, Saitama, Japan); AVILA, Melina L (Argonne National Laboratory, Argonne, IL, USA); ROOSA, Michael (Cyclotron Institute, Texas A&M University, College Station, TX, USA); SFERRAZZA, Michele (Département de Physique, Université Libre de Bruxelles, Bruxelles, Belgium); KIM, Minju (Sungkyunkwan university); IWASA, Naohito (Department of Physics, Tohoku University, Sendai, Miyagi, Japan); NGOC DUY, Nguyen (Institute of Postgraduate Program, Van Lang University, Ho Chi Minh City, Vietnam); IMAI, Nobuaki (Center for Nuclear Study, University of Tokyo, Tokyo, Japan); KITAMURA, Noritaka (Center for Nuclear Study, University of Tokyo, Tokyo, Japan); ZHANG, Qian (Center for Nuclear Study, University of Tokyo, Tokyo, Japan); HAYAKAWA, Seiya (Center for Nuclear Study, University of Tokyo, Tokyo, Japan); DO, Seungkyung (Department of Physics, Korea University, Seoul, Republic of Korea); KUBONO, Shigeru (RIKEN Nishina Center, Wako, Saitama, Japan); KIM, Sohyun (Sungkyunkwan University); CHA, Soomi (Center for Exotic Nuclear Studies); BAE, Sunghan (Center for Exotic Nuclear Studies, Institute for Basic Science); NAKAMURA, Takashi (Department of Physics, Tokyo Institute of Technology, Tokyo, Japan); CHILLERY, Thomas W (Center for Nuclear Study, University of Tokyo, Tokyo, Japan); KOSHCHIY, Yevgen (Cyclotron Institute, Texas A&M University, College Station, TX, USA); KIM, Yunghee (Center for Exotic Nuclear Studies, Institute for Basic Science, Daejeon, Republic of Korea)

Presenter: PARK, Chaeyeon (EWHA Womans University / CENS(IBS))

Session Classification: Poster session (Novae and X-ray bursts, Type IA supernova and the p-process)

Track Classification: Novae and X-ray bursts

Direct measurement of the ^{26}Si(α, p)^{29}P reaction at CRIB for the nucleosynthesis in the X-ray bursts

In the X-ray bursts, the ^{26}Si(α, p)^{29}P reaction rate is considered to have a great impact on the light curve. However, there were insufficient experimental data for this reaction because of technical difficulties. In order to measure the cross section of the reaction, a direct measurement was performed at the CNS RI beam separator (CRIB). CRIB produced a ^{26}Si beam with a typical intensity of 3.2×10^4 pps and a purity of 29%, which bombarded the ^{4}He gas target. The ^{26}Si(α, p)^{29}P reaction was measured up to the center-of-mass energy of about 7.5 MeV using the thick gas target method. This energy region corresponds to about T = 3 GK of the Gamow energy. In spite of the large number of background events and the large statistical error, an upper limit on the reaction cross section was obtained, which was 0.134 times that of the NON-SMOKER statistical model. This is the first experimental evaluation by direct measurement. Therefore, the result are useful to compare experimental and theoretical values at higher temperature and to constrain the ^{26}Si(α, p)^{29}P reaction rate and the X-ray burst light curve model.

The analysis method and the results will be discussed.

Primary authors: KIM, C. H. (Department of Physics, Sungkyunkwan University); KAHL, D. (Extreme Light Infrastructure Nuclear Physics (ELI-NP)); KIM, D. (Center for Exotic Nuclear Studies, Institute for Basic Science (IBS)); GU, G. M. (Department of Physics, Sungkyunkwan University); SHIMIZU, Hideki (Center for Nuclear Study, the University of Tokyo); YAMAGUCHI, Hidetoshi (Center for Nuclear Study, the University of Tokyo); LI, Jiatai (CNS, The university of Tokyo); SAKANASHI, K. (Department of Physics, Osaka University); OKAWA, Kodai (CNS, the University of Tokyo); CHAE, Kyungyuk (Sungkyunkwan University); KWAG, M. S. (Department of Physics, Sungkyunkwan University); KIM, Minju (Sungkyunkwan university); UYEN, N. K. (Department of Physics, Sungkyunkwan University); DUY, N. N. (Department of Physics, Sungkyunkwan University); MA, Nanru (CNS, The university of Tokyo); IMAI, Nobuaki (Center for Nuclear Studies, University of Tokyo, Tokyo, Japan); SIRBU, O. (Extreme Light Infrastructure Nuclear Physics (ELI-NP)); ZHANG, Qian (Center for Nuclear Study, the University of Tokyo); YOKOYAMA, R. (Center for Nuclear Study, University of Tokyo); ADACHI, S. (Department of Physics, Osaka University); KIM, S. H. (Department of Physics, Sungkyunkwan University); CHA, S. M. (Center for Exotic Nuclear Studies, Institute for Basic Science (IBS)); HAYAKAWA, Seiya (Center for Nulear Study, University of Tokyo); KUBONO, Shigeru (RIKEN Nishina Center); MICHIMASA, Shin'ichiro (Center for Nuclear Study, The University of Tokyo); HANAI, Shutaro (CNS, the University of Tokyo); FURUNO, T. (Department of Physics, Osaka University); KAWABATA, T. (Department of Physics, Osaka University); CHILLERY, Thomas

Presenter: OKAWA, Kodai (CNS, the University of Tokyo)

Session Classification: Poster session (Novae and X-ray bursts, Type IA supernova and the p-process)

Track Classification: Novae and X-ray bursts

Thermonuclear reaction rate sensitivity study for primordial nova nucleosynthesis

Classical novae are common cataclysmic events in the Galaxy involving a binary system. In the early Galaxy these explosions proceeded differently, mainly due to the accretion of sub-solar material onto the white dwarf. It has been proposed that these primordial novae explosions produce a different abundance pattern compared to their classical counterparts [1]. In particular, the nuclear flows extend up to the Cu-Zn region, compared to classical novae, which have an endpoint around Ca. To study the impact of the nuclear physics uncertainties in primordial novae nucleosynthesis we performed a sensitivity study, varying all the relevant reactions in the network within their uncertainty using a Monte Carlo approach [5]. We find nuclear reactions which uncertainties affect the production of intermediate mass nuclei under primordial novae conditions. These reactions need to be measured experimentally in stable and radioactive beam facilities to reduce their uncertainties.

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[4] C. Iliadis and A. Coc, Astrophys. J **901**, 127 (2020).
[5] A. Psaltis *et al.* (in preparation).

Primary author: PSALTIS, Thanassis (NCSU/TUNL)

Co-authors: ILIADIS, Christian (UNC/TUNL); JOSE, Jordi (UPC Barcelona); LONGLAND, Richard (North Carolina)

Presenter: PSALTIS, Thanassis (NCSU/TUNL)

Session Classification: Poster session (Novae and X-ray bursts, Type IA supernova and the p-process)

Track Classification: Novae and X-ray bursts

Igniting the Superburst on KS1731-260

Superbursts are rare, energetic explosions observed from accreting neutron stars in low-mass X-ray binaries. Associated with the unstable ignition of carbon, superbursts are challenging to model as their energetics are too low and recurrence times too short to be easily accommodated with theoretical models of the neutron star crust and the standard extrapolation of the C12+C12 cross-section to astrophysical energies. The quasi-persistent neutron star transient KS1731–260 is a particularly good site to probe these enigmatic bursts since its quiescent luminosity has been monitored over 20 years, which provides good constraints on the temperature of the neutron star's outer layers. In addition, it had one observed superburst while actively accreting in 1996. We explore the ignition of carbon on KS1731–260 using different C12+C12 cross-sections. We find tension between the burst depth in our models and the depth inferred from observations of the superburst indicating greater heating at shallow depths than expected. This discrepancy may be reconciled by either the lack of precision in the measured distance to KS1731–260 or an increase of the C12+C12 cross-section at ~1.5 MeV.

Primary authors: Prof. BROWN, Edward (Michigan State University); BRITT, Eric (Michigan State University); GRACE, Justin (Michigan State University); JAIN, Rahul (Michigan State University); ATHUKORALALAGE, Wasundara (Michigan State University)

Presenter: BRITT, Eric (Michigan State University)

Session Classification: Poster session (Novae and X-ray bursts, Type IA supernova and the p-process)

Track Classification: Novae and X-ray bursts

Lifetime measurement of the dominant 22Na (p, gamma) 23Mg resonance in novae

^{22}Na ($T_{1/2}$ = 2.6 y) is of high interest for space-based γ-ray astronomy because its direct observation could constrain classical nova models. Although the characteristic 1275 keV β-delayed γ decay radiation has not been observed yet, future γ-ray telescopes may detect the decay with high sensitivity. To link these observations with nova model predictions, nuclear data are needed. The ^{22}Na(p, γ) ^{23}Mg reaction destroys ^{22}Na produced during a nova. In the literature, there are discrepancies of one order of magnitude in the experimentally determined strength of the E_R=204 keV resonance important at nova temperatures. This affects predictions of the ejected yield substantially.
The resonance strength can be determined by measuring the proton branching ratio and the lifetime of the corresponding E_x=7.785 MeV excited state in ^{23}Mg.
With the Doppler-Shift Lifetime (DSL2) setup at TRIUMF-ISAC-II a new effort was started to measure the lifetime of this exited state. Excited states in ^{23}Mg are populated by the ^{24}Mg (^{3}He, α) ^{23}Mg reaction with a 75 MeV ^{24}Mg beam. Using the Doppler-Shift Attenuation Method (DSAM), deexcitation γ-rays are detected to perform line-shape analysis and infer the lifetime. This contribution will present the DSAM method and results from a preliminary measurement.

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Primary author: WAGNER, Louis (TRIUMF)

Co-authors: Dr DAVIDS, Barry (TRIUMF); Dr WREDE, Chris (FRIB); Ms WEGHORN, Lexanne (FRIB); Dr ESKER, Nicholas (SJSU)

Presenter: WAGNER, Louis (TRIUMF)

Session Classification: Poster session (Novae and X-ray bursts, Type IA supernova and the p-process)

Track Classification: Novae and X-ray bursts

Identifying the Origin of Presolar Grains: Gamma-Spectroscopy of 35Ar

Classical novae are the second most common explosive stellar phenomena in the Universe [1] and, as such, play an important role in the enrichment of the interstellar medium and chemical abundances we observe in the galaxy. One observable, which is key to understanding the processes that drive classical novae, is presolar grains. It is, therefore, important that we are able to characterise the origin of presolar grains based on their isotopic ratios. One issue that remains is being able to distinguish between grains of nova and supernova origin.

It has been suggested that the ^{34}S/^{32}S isotopic ratio could be used, in conjunction with the well-known ^{33}S/^{32}S ratio [2], in order to distinguish between solar and novae presolar grains [3,4]. The abundance of ^{34}S is dependent on the ^{34g,m}Cl(p,γ)^{35}Ar rp-process reaction rate. To determine this reaction rate, one has to know the energy, spin and parity of the contributing resonances in ^{35}Ar. The energies of all states above the proton threshold have been measured [3], however, almost all the spins and parities remain unknown.

Here, we report a gamma-spectroscopy measurement of ^{35}Ar with the aim of observing gamma decay from states above the proton-emission threshold. This experiment was conducted at Argonne National Laboratory's ATLAS facility. States in 35Ar were populated via the ^{9}Be(^{28}Si,2 n)^{35}Ar fusion-evaporation reaction. The excited states decay via the emission of gamma rays, which are detected using Gammasphere, in coincidence with the recoils at the focal plane of the Fragment Mass Analyzer (FMA).

This measurement represents the first observation of gamma-decays from states above the proton threshold in ^{35}Ar and led to more precise measurements of the resonance energies of the key states. The observed gamma-decay branches, along with mirror nuclei comparisons, enable restrictions to be placed on the spin-parity quantum numbers. This enables restrictions to be placed on the ^{34g,m}Cl(p,γ)^{35}Ar reaction rate and the ^{34}S/^{32}S isotopic ratio in novae.

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Primary author: REED, Ben (University of Surrey)

Co-authors: Dr DOHERTY, Daniel (University of Surrey); Dr SEWERYNIAK, Dariusz (Argonne National Laboratory); Prof. LOTAY, Gavin (University of Surrey); Dr ALBERS, Helena (GSI Helmholtz Centre for Heavy Ion Research); Dr CARPENTER, Michael (Argonne National Laboratory); Dr ILIEVA, Riley (University of Surrey); Prof. JANSSENS, Robert (University of North Carolina); Dr WILKINSON, Ryan (University of Surrey); Dr ZHU, Shaofei (Argonne National Laboratory); Dr LAURITSEN, Torben (Argonne National Laboratory)

Presenter: REED, Ben (University of Surrey)

Session Classification: Poster session (Novae and X-ray bursts, Type IA supernova and the p-process)

Track Classification: Novae and X-ray bursts

Direct measurement of the cross section for 102Pd(p,g)103Ag reaction in the p-process

The study of the p-process is of paramount importance in unraveling the origin of heavy elements in the universe. To describe the entire p-nuclei nucleosynthesis process, a comprehensive reaction network involving over ten thousand nuclear reactions is required, and accurate measurements of some key reaction cross sections are essential for determining reaction rates. 102Pd is one of the more than 30 p-nuclei, and the 102Pd(p,g)103Ag reaction is one of its significant destruction reactions. Experimental studies for the p-nucleus 102Pd indicate that the reaction rate for 102Pd(p,g)103Ag is significantly higher than HF predictions. There are significant discrepancies in the available data on the 102Pd(p,g)103Ag reaction cross section in the low-energy regime relevant to nuclear astrophysics. In light of these discrepancies, a direct measurement was carried out to determine the reaction cross section of 102Pd(p,g)103Ag within the energy range of 1.9-2.8 MeV. The measurement was conducted utilizing the 2*1.7 MV tandem accelerator at China Institute of Atomic Energy (CIAE). The latest cross section data were obtained using offline activation measurement technique based on the low background anti-muon and anti-Compton spectrometer in CIAE.

The latest results have extended the cross section of 102Pd(p,g)103Ag to the lowest energy range of proton down to 1.9 MeV. The newly measured cross section data provide valuable experimental references for the calculation of statistical models, particularly in the low-energy regime of interest in nuclear astrophysics. These results contribute to a better understanding of the p-process and its implications for the nucleosynthesis of heavy elements in the universe.

Primary authors: LIU, Fulong (Center for Nuclear Study, the University of Tokyo); Prof. GUO, Bing (China Institute of Atomic Energy); Prof. HE, Chuangye (China Institute of Atomic Energy); Ms CHENG, Hao (China Institute of Atomic Energy); Dr BO, Nan (China Institute of Atomic Energy)

Presenter: LIU, Fulong (Center for Nuclear Study, the University of Tokyo)

Session Classification: Poster session (Novae and X-ray bursts, Type IA supernova and the p-process)

Track Classification: Type Ia supernova and the p-process

Study of mirror resonant reactions by TTIK approach

Developments of the rare beam acceleration have opened new opportunities for study of mirror resonance reactions. Namely, comparison of the results of the mirror resonance reactions gives the opportunity to understand nuclear structure deeper.
Understanding the nuclear structure of ^{19}F and ^{19}Ne is crucial in comprehending the clustering structure around mass $A = 20$. Previously, experiment with $\alpha +^{15} N$ scattering was conducted only by Smotrich et al. [1] in 1960, covering broad angles and energy range. But the analysis of excitation functions with several channels and overlapping resonances has not been performed [1].
We present the results of R-matrix analysis on Smotrich data [1] and our recent data on $\alpha +^{15} N$ resonant interaction obtained by the Thick Target Inverse Kinematics (TTIK) [2,3] method at DC-60 cyclotron in Astana. New R-matrix parameters were obtained from analysis of ^{19}F and then used to fit the mirror 19Ne spectrum from [4] in the same energy range. R-matrix analysis of the excitation function for the mirror $\alpha +^{15} O$ elastic scattering was done based on new results for ^{19}F [5,6]; both experiments were performed using the TTIK method.
TTIK approach for data acquisition in mirror nuclear reactions allows to obtain new spectroscopic information.

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Primary author: SERIKBAYEVA, Gulfairuz (Nazarbayev University Research and Innovation System, Astana, Kazakhstan)

Co-authors: Ms NURMUKHANBETOVA, Aliya (Nazarbayev University Research and Innovation System, Energetic Cosmos Laboratory, Nazarbayev University, Astana, Kazakhstan); Mr GOLDBERG, Vlad (Cyclotron Institute, Texas A&M University, College Station, Texas, USA); Mr VOLYA, Alexander (Cyclotron Institute, Texas A&M University, College Station, Texas, USA; Department of Physics, Florida

State University, Tallahassee, Florida, USA); Mr NAURUZBAYEV, Dosbol (Nazarbayev University Research and Innovation System, Physics Department, School of Sciences and Humanities, Nazarbayev University, Astana, Kazakhstan); Mr ZHOLDYBAYEV, Timur (Institute of Nuclear Physics; Al-Farabi Kazakh National University, Almaty, Kazakhstan)

Presenter: SERIKBAYEVA, Gulfairuz (Nazarbayev University Research and Innovation System, Astana, Kazakhstan)

Session Classification: Poster session (Novae and X-ray bursts, Type IA supernova and the p-process)

Track Classification: Nuclear reaction rates and stellar abundances

Nuclear astrophysics study using SNACK at KoBRA

KoBRA (KOrea Broad acceptance Recoil spectrometer and Apparatus) [1] is a low energy nuclear physics facility at RAON (Rare isotope Accelerator complex for ON-line experiments) [2]. In its early phase of operation, KoBRA will produce RI beams with energies of 5 to 10 MeV/u from stable ion beams (10 ~ 40 MeV/u) delivered from the superconducting linear accelerator SLC3 of RAON. Transfer reaction measurements with RI beam are a powerful tool to extract spectroscopic information such as spins, parities, and spectroscopic factors. With this information, the thermonuclear reaction rates in explosive stellar environments such as novae, X-ray bursts, and supernovae can be studied. Therefore, the silicon detector system SNACK (Silicon detector array for Nuclear AstrophysiCs study at KoBRA) [3] has been developed by IRIS (Institute for Rare Isotope Science) for (*d,p*) transfer reaction measurements at KoBRA. By measuring protons produced in the reactions with SNACK and the trajectories of RI beams with upstream PPAC (Parallel Plate Avalanche Counter) detectors, excited energy levels can be reconstructed to extract spectroscopic information. In order to investigate the feasibility of the (*d,p*) reaction measurement using SNACK at KoBRA, the 18Ne(*d,p*)19Ne reaction measurement was simulated for study of the 18F + *p* system in nova explosions. In this presentation, details of the detector system development and results of the simulation will be presented.

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Primary author: Dr KWAG, Minsik (IRIS, IBS)

Co-authors: Dr AKERS, Charles (IRIS, IBS); Dr LEE, Kwangbok (IRIS, IBS); Dr SHIN, Taeksu (IRIS, IBS); Dr TSHOO, Kyoungho (IRIS, IBS)

Presenter: Dr KWAG, Minsik (IRIS, IBS)

Session Classification: Poster session (Novae and X-ray bursts, Type IA supernova and the p-process)

Track Classification: Novae and X-ray bursts

Extraction of Gamow-Teller Strength Using (d,2He) Reaction in Inverse Kinematics

Electron-capture (EC) rates play a key role in core-collapse and thermonuclear supernovae, the crust of accreting neutron stars in binary systems, and the final core evolution of intermediate mass stars. Charge-exchange reactions (CERs) at intermediate energies (~100 MeV) are crucial in extracting information for neutron-rich nuclei as the EC Q-values are positive for such nuclei. The differential cross-sections in CERs at zero momentum transfer are proportional to the Gamow-Teller strength, B(GT), from which the EC rates can be calculated. In a first of a kind experiment, the S800 spectrometer at National Superconducting Cyclotron Laboratory (NSCL) along with Active-Target Time Projection Chamber (AT-TPC) setup was used to run an experiment with (d,^{2}He) probe in inverse kinematics to study unstable nuclei. Data from the experiment for the ^{13}N(d,^{2}He)^{13}C reaction has been analyzed to extract the differential cross-section for ground and excited states to measure the B(GT).

Primary author: RAHMAN, Zarif (Michigan State University)

Co-authors: Dr ZAMORA, Juan (FRIB); Prof. ZEGERS, Remco (Michigan State University/FRIB); Dr GIRAUD, Simon (FRIB)

Presenter: RAHMAN, Zarif (Michigan State University)

Session Classification: Poster session (Nuclear properties for astrophysics)

Track Classification: Nuclear properties for astrophysics

QRPA calculations of weak-interaction rates in stellar conditions

Weak-interaction rates, including beta-decay and capture of electrons from the stellar plasma, are studied under various density and temperature conditions of astrophysical interest. The study focuses on different nuclear mass regions, such as neutron-deficient medium-mass waiting-point nuclei involved in the rp process, neutron-rich medium-mass isotopes involved in the r process, and pf-shell nuclei of special importance as constituents in pre-supernova formations.

The nuclear structure involved in the weak processes is described within a microscopic proton-neutron quasi-particle random-phase approximation with residual interactions in both particle-hole and particle-particle channels on top of a deformed Skyrme Hartree-Fock mean field with pairing correlations. This approach is found to reproduce reasonably well both the experimental beta-decay half-lives and the Gamow-Teller strength distributions measured under terrestrial conditions. Compared to terrestrial half-lives, the stellar ones receive contributions from thermally populated excited states in the decaying nucleus, as well as from electron captures in the stellar plasma. Both effects may modify substantially the weak-decay rates measured in the laboratory.

Primary author: SARRIGUREN, Pedro (Instituto de Estructura de la Materia, CSIC)

Presenter: SARRIGUREN, Pedro (Instituto de Estructura de la Materia, CSIC)

Session Classification: Poster session (Nuclear properties for astrophysics)

Track Classification: Nuclear properties for astrophysics

Understanding collective nuclear excitations within microscopic HFB+QRPA calculations

The study of nuclear excitations, particularly collective excitation modes such as the giant resonance (GR) and pygmy resonance (PR), can reveal important characteristics of the underlying nuclear structure. The PR is a fascinating excitation mode that is more prominent in nuclei with an excess of neutrons. This resonance is typically interpreted as a collective motion in which the neutron excess oscillates against a core. It is known to enhance the neutron capture rates, which are crucial for understanding the creation of elements in our universe. However, our knowledge of the low-lying collective excitations remains incomplete despite decades-long efforts to measure and describe collective phenomena. Our inability to include collective effects in reaction calculations affects a range of applications, from nuclear astrophysics to nuclear energy.

In this work, we investigate the low-lying collective excitations in selected Mo isotopes, focusing on the GR and PR modes. Our fully consistent calculations using the Quasi-particle Random Phase Approximation (QRPA) and Hartree-Fock-Bololiubov (HFB) provide valuable insights into the characteristics of these collective excitations. For representative nuclei, we present the electric transition strengths and transition densities, discuss the location of the PR, and investigate the relation between the PR and the neutron excess.

Primary author: IN, Eun Jin (Lawrence Livermore National Laboratory)

Co-authors: Dr CHIMANSKI, Emanuel V. (Brookhaven National Laboratory); Dr ESCHER, Jutta E. (Lawrence Livermore National Laboratory); Dr PÉRU, Sophie (CEA, DAM, DIF, France); Dr YOUNES, Walid (Lawrence Livermore National Laboratory)

Presenter: IN, Eun Jin (Lawrence Livermore National Laboratory)

Session Classification: Poster session (Nuclear properties for astrophysics)

Track Classification: Nuclear properties for astrophysics

Exploring Stealth Dark Matter on the Lattice

We conduct a numerical study of Stealth Dark Matter (SDM), a composite dark matter (DM) model in SU(4) gauge theory, using the method of lattice gauge theory. Utilizing the fastest supercomputers at Lawrence Livermore National Laboratory, we calculate the baryon-baryon scattering in SDM. In this talk, on behalf of the Lattice Strong Dynamics (LSD) collaboration, we discuss the recent progress and computational challenges in our project focused on SDM baryon scattering.

Primary authors: Dr MEYER, Aaron S. (Lawrence Livermore National Laboratory); Dr CULVER, Christopher (University of Liverpool); Ms CUSHMAN, Kimmy K. (Yale University); Dr VRANAS, Pavlos (Lawrence Livermore National Laboratory); PARK, Sungwoo (Lawrence Livermore National Laboratory)

Presenter: PARK, Sungwoo (Lawrence Livermore National Laboratory)

Session Classification: Poster session (Nuclear properties for astrophysics)

Track Classification: Nuclear properties for astrophysics

Bubble nuclei with shape coexistence and alpha-decay half-lives in deformed relativistic Hartree-Bogoliubov theory in continuum

After introducing the details of the deformed relativistic Hartree-Bogoliubov theory in continuum (DRHBc), we present our recent results on the bubble nuclei with shape coexistence in isotopes from Hf to Hg and alpha-decay half-lives of W to U. We predict several exotic isotopes that have both bubble configuration and shape coexistence. We also calculate alpha-decay half-lives in DRHBc and compare our results with them from relativistic continuum Hartree-Bogoliubov with spherical symmetry to discuss deformation effects in alpha-decay.

Primary author: Dr CHOI, Yong-Beom (Pusan National University)

Co-authors: Prof. LEE, Chang-Hwan (Pusan National University); Dr KIM, Youngman (Institute for Basic Science)

Presenter: Dr CHOI, Yong-Beom (Pusan National University)

Session Classification: Poster session (Nuclear properties for astrophysics)

Track Classification: Nuclear properties for astrophysics

Revisiting the Gamow Factor of Reactions on Light Nuclei

In this presentation, we provides an improved understanding of the penetration probabilities(PPs) in nuclear reactions for light nuclei by rectifying the assumptions utilized in the conventional Gamow factor. The Gamow factor effectively represents PP in nuclear reactions based on two assumptions: particle energy lower than the Coulomb barrier, and the disregard of nuclear interaction potential dependence. However, our findings reveal that these assumptions are invalid for light nuclei. Through calculations that exclude the aforementioned assumptions, we derived a PP that is dependent on the depth of nuclear interaction potential for light nuclei. With the potential depth fitted by experimental fusion cross-sections, we demonstrate that the PPs of light nuclei (D+D, D+T, D+3He, p+D, p+6Li, and p+7Li) exceed the conventional values near the Coulomb barrier. Additionally, we discuss the implications of this modified PP, such as alterations in the Gamow peak energy, which governs the measurement of the energy range of nuclear cross-sections in experiments, and the electron screening effect.

Primary author: HWANG, Eunseok (Soongsil University)

Co-authors: JANG, Dukjae (IBS); KO, Heamin (Soongsil University); HEO, Kyoungsu (Soongsil University); CHEOUN, Myung-Ki (Soongsil University)

Presenter: HWANG, Eunseok (Soongsil University)

Session Classification: Poster session (Nuclear properties for astrophysics)

Track Classification: Nuclear properties for astrophysics

Reaching for neutron rich nuclides near N=126 magicity below 208Pb

The neutron-rich unstable nuclei near neutron magic numbers are relatively well studied, far from the stability lineup to the neutron magic number N = 82. However, for the neutron-rich nuclei to the south of 208Pb, there is limited knowledge of the excited states of these nuclei. This arises from the difficulty in producing these nuclei using conventional methods. Even for the known nuclei, only limited information, mostly from decay spectroscopy, is known. The recent multi-nucleon transfer reaction showed promising results with several orders of magnitude larger cross-sections than those for fragmentation reactions.

A new experiment was carried out at GANIL to explore these isotopes of interest using 7MeV/u 136Xe beam and 198Pt target using multi-nucleon transfer reactions. Significant acceptance VAMOS++ magnetic spectrometer and AGATA Ge tracking array were used to measure excited states of nuclides of interest. And several new experimental techniques were implemented in this experiment. First, a second arm detector was newly installed, composed of a vacuum chamber and multi-wire proportional counter to measure the velocity vector of the target-like fragments. Second, four EXOGAM HPGe clover array was installed at the end of the second arm to measure the delayed gamma rays from the excited states of the produced nuclei. Finally, a new method to determine particle identification is under development using a machine learning algorithm, where energy and charge states are determined using supervised machine learning and atomic numbers are determined by the unsupervised learning method. The experiment's preliminary result, such as particle identification with the help of machine learning and gamma-ray spectroscopy neutron-rich nuclei, will be presented.

Primary author: KIM, Yung Hee (CENS)

Presenter: KIM, Yung Hee (CENS)

Session Classification: Poster session (Nuclear properties for astrophysics)

Track Classification: Nuclear properties for astrophysics

Identification of metastable isomeric states of Ac-228 with NaI(Tl) crystals

We report the identification of metastable isomeric states of Ac-228 at 6.28 keV, 6.67 keV, and 20.19 keV, with lifetimes of an order of 100 ns. These states were identified with NaI(Tl) crystal detectors of the COSINE-100 dark matter search experiment. The isomeric states are produced through the beta decay of Ra-228, a component of the Th-232 decay chain, with beta Q-values of 39.52 keV and 25.61 keV, respectively. The presence of these states has significant implications for low-energy background modeling in dark matter search experiments due to the low Q-value and the relative abundance of Th-232 and its progeny in low background experiments. In this presentation, we will describe methods and results with the COSINE-100 detectors as well as future prospects for a dedicated measurement of the Ac-228 isomeric states.

Primary author: KIM, Kyungwon (Center for Underground Physics, IBS)

Presenter: KIM, Kyungwon (Center for Underground Physics, IBS)

Session Classification: Poster session (Nuclear properties for astrophysics)

Track Classification: Nuclear properties for astrophysics

Mass measurements of neutron-rich nuclei along the r-process path using Bρ-TOF method

The sensitivity studies of r-process nucleosynthesis performed in recent years [1-3] have pointed out that nuclear masses are of fundamental importance in r-process modeling. The results indicate that independently of the mass models and astrophysical scenarios used, the most sensitive mass regions are along and near the r-process path, particularly around N=50 and N=82 closed shells. Consequently, in our approved experiment with 6.5-days of beam time, we plan to utilize the time-of-flight (TOF) technique at FRIB to measure the masses of 24 neutron-rich nuclei on and around the r-process path beyond the closed shell of N=50 for the first time. Furthermore, the precision of four mass values will be improved. New mass measurements of these neutron-rich nuclei will play a crucial role to understand better the first r-process abundance peak.

The experimental setup includes a 70-m flight path between the ARIS fragment separator and the S800 spectrograph. The TOF will be measured using fast-timing scintillators located at the focal planes of ARIS and S800. The relative measurement of magnetic rigidity, Bρ, will be obtained via position measurement using a microchannel plate detector (MCP) located at the target position of S800. Moreover, we developed a position-sensitive large-area MCP detector system that consists of two MCPs with 120 mm active diameter and delay-line anode [4]. This detector system has the potential to improve the resolution of the Bρ measurement, which is one of the factors currently limiting the mass resolution of the experimental setup.

In this talk, the physics motivation of our measurement, as well as an overview of the experimental setup will be presented. Additionally, we will report the properties and characteristics of the newly developed MCP detector system and future updates.

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Primary author: KORKULU, Zeren (Center for Exotic Nuclear Studies, Institute for Basic Science, Daejeon, Republic of Korea)

Co-authors: ESTRADE, Alfredo (Central Michigan University); AHN, Sunghoon (Institute for Basic Science); GADE, Alexandra (Facility for Rare Isotope Beams); ROGERS, Andrew (University of Massachusetts Lowell); KANKAINEN, Anu (University of Jyvaskyla); SHERRILL, Bradley (Michigan State University (MSU)); SULTANA, Chowdhury Irin (Central Michigan University); AHN, Deuk Soon (Institute for Basic Science); SOHLER, Dorottya Kunne (ATOMKI); KWAN, Elaine (Michigan State University (MSU)); RUBINO, Elizabeth (Lawrence Livermore National Laboratory); HOLMBECK, Erika (Carnegie Observatories); MONTES, Fernando (Facility for Rare Isotope Beams); SCHATZ, Hendrik (Michigan State University (MSU)); ARORA, Honey (Central Michigan University); PARK, Jason (Institute for Basic Science); PEREIRA, Jorge (Facility for Rare Isotope Beams); HAHN, Kevin (Institute for Basic); KIM, Kyungil (Institute for Basic Science); STUHL, László (Institute for Basic Science); MUMPOWER, Matthew (Los Alamos National Laboratory); PORTILLO, Mauricio (Facility for Rare Isotope Beams); TARASOV, Oleg (Michigan State University (MSU)); SURMAN, Rebecca (University of Notre Dame); ZEGERS, Remco (Michigan State University (MSU)); NOJI, Shumpei (Michigan State University (MSU)); CHA, Soomi (Institute for Basic Science); CHOI, Soonchul (Institute

for Basic Science); PAIN, Steven (Oak Ridge National Laboratory); KAJINO, Toshitaka (U. of Tokyo, Beihang U.); MITTIG, Wolfgang (Michigan State University (MSU)); KIM, Youngman (Institute for Basic Science); LITVINOV, Yury (Gesellschaft für Schwerionenforschung (GSI)); DOMBRÁDI, Zsolt (ATOMKI)

Presenter: KORKULU, Zeren (Center for Exotic Nuclear Studies, Institute for Basic Science, Daejeon, Republic of Korea)

Session Classification: Poster session (Nuclear properties for astrophysics)

Track Classification: Nuclear properties for astrophysics

Sensitivity Studies on Type Ia Supernova Observables

Although there is broad agreement that Type Ia Supernovae (SNe Ia) originate from thermonuclear explosions of carbon-oxygen white dwarf stars (WD), the details of the path towards explosion remain uncertain: the degeneracy of the binary system, mass, and chemical composition of the WD, and the explosion mechanism of the SNe Ia. Using the reaction rates in STARLIB [1] we probe the sensitivities of nuclear reactions responsible for the abundance of potential observables in hopes to shed light on some of these uncertainties. This is done by employing a Monte Carlo reaction network method [2] by varying all reaction rates simultaneously according to their rate probability densities in each simulation. The hydrodynamical trajectories were derived from a near-M$_{Ch}$ WD shell model with a 5 x 10^{-4} M He layer surrounding its carbon oxygen core [3]. To take advantage of future early time observations, we focus on both early-time (e.g. gamma ray emitters) and late-time observables (e.g. elemental abundances in ejecta, supernova remnants). Results will be discussed.

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Primary author: LEE, Minjoo (University of North Carolina Chapel Hill)

Co-authors: Mr ILIADIS, Christian (Triangle Universities Nuclear Laboratory (TUNL)); Mr WIEDENHOEVER, Ingo (Florida State University); Mr HÖFLICH, Peter (Florida State University)

Presenter: LEE, Minjoo (University of North Carolina Chapel Hill)

Session Classification: Poster session (Nuclear properties for astrophysics)

Track Classification: Nuclear properties for astrophysics

Recent theoretical activities in IRIS

In this Poster, we present a few examples of recent theoretical activities in IRIS.

Primary authors: SONG, Young-Ho (RISP, IBS); Dr SHIN, Ik Jae (IRIS, IBS); Dr KIM, Kyungil (IRIS, IBS); Dr PAPAKONSTANTINOU, Panagiota (IRIS, IBS)

Presenter: SONG, Young-Ho (RISP, IBS)

Session Classification: Poster session (Nuclear properties for astrophysics)

Track Classification: Nuclear properties for astrophysics

Comparison study for DJBUU and SQMD, microscopic models to describe Heavy ion collisions

Transport models are microscopic model to describe heavy ion collisions. they let us study nuclear matter properties, which are important to understand such as neutron star. transport models categorized two type, BUU-like and QMD-like model, we have each, DJBUU and SQMD, which are developed for RAON experiments. In this study, we compare the result of simulation using each model.

Primary author: KIM, Dae Ik (Pusan National University)

Co-authors: LEE, Chang-Hwan (Pusan National University); KIM, Kyungil (IRIS, IBS); Prof. JEON, Sangyong (McGill University); KIM, Youngman (CENS, IBS)

Presenter: KIM, Dae Ik (Pusan National University)

Session Classification: Poster session (Nuclear properties for astrophysics)

Track Classification: Nuclear properties for astrophysics

S matrices of elastic α-^{12}C scattering at low energies in cluster effective field theory

The elastic α-^{12}C scattering at low energies for $l = 0, 1, 2, 3, 4, 5, 6$ is studied in effective field theory. We discuss the construction of the S matrices of elastic α-^{12}C scattering in terms of the amplitudes of sub-threshold bound and resonant states of ^{16}O, which are calculated from the effective Lagrangian. The parameters appearing in the S matrices are fitted to the phase shift data below the p-^{15}N breakup threshold energy, and we find that the phase shifts are well described within the theory.

Primary author: ANDO, Shung-Ichi (Sunmoon University)

Presenter: ANDO, Shung-Ichi (Sunmoon University)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Analytic expression of triple-α reaction rates by a non-adiabatic three-body model

Triple-α reaction plays a significant role in nucleosynthesis heavier than ^{12}C and concomitant stellar evolution [1]. The reaction rates of this reaction at the helium-burning temperatures, $T_9 > 0.1$, are dominated by the sequential process via two narrow resonances: $\alpha + \alpha \rightarrow {}^{8}$Be($0_1^+$), ^{8}Be+$\alpha \rightarrow {}^{12}$C($0_2^+$: $E = 0.379$ MeV) [2,3], and they have been thought to decide a fate of massive stars up to their supernova explosion. T_9 is temperature in the unit of 10^9 K; E is the center-of-mass energy to the 3α threshold in ^{12}C.

In NACRE [2], ^{8}Be is assumed to be bound as a particle, and the reaction rates have been estimated by an improved model with the sequential process based on [4,5]. To determine the rates more accurately, the precise experimental decay studies of the 0_2^+ resonance have been performed recently (e.g. [6]). The theoretical models have also been being developed during decades. To take account of 3α continuum states distorted by the long-range Coulomb interaction, the methods with hyper-spherical coordinates are used in [7-10], and the Coulomb modified Faddeev method is also adopted in [11]. Whereas ^{8}Be continuum states are treated adiabatically in Refs. [9-11], the direct process from ternary continuum states, $\alpha + \alpha + \alpha \rightarrow {}^{12}$C, is calculated non-adiabatically in Refs. [7,8]. Although the theoretical models are consistent with each other at the helium-burning temperatures, they make the large difference in the rates below $T_9 = 0.07$. From the comparison between the calculations, Ref. [7] has found that the current reaction rates at $T_9 = 0.05$ can be reduced by about 10^{-4}, because of the assumed ^{8}Be.

In this presentation, I review the non-adiabatic approach to the triple-α reaction, and provide the derived rates. I use the Faddeev hyper-spherical harmonics and R-matrix (HHR*) expansion method [7,12,13], and I confirm that the photo-disintegration of ^{12}C(2_1^+($E = -2.835$ MeV) $\rightarrow 0^+$) for $0.15 < E < 0.35$ MeV is 10^{-15} – 10^{-3} pb order of cross sections. The resultant rates are shown to have the strong temperature dependence below $T_9 = 0.1$, as well as NACRE, and their numerical values are expressed in a simple analytic form [2,14].

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Primary author: KATSUMA, Masahiko

Presenter: KATSUMA, Masahiko

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

A new Multi-Channel and Monte Carlo R-Matrix analysis for the estimate of ^{17}O destruction rate in stars

When stars approach the red giant branch, a deep convective envelope develops and the products of the CNO cycle appear at the stellar surface. In particular, the ^{17}O is enhanced in RGB and AGB stars. Spectroscopic analyses of O isotopic ratios of these stars provide a powerful tool to investigate the efficiency of deep mixing processes, such as those powered by convective overshoot, rotation, thermohaline instability, gravity wave and magnetic field. However, this method requires a precise knowledge of the reaction rates that determine the ^{17}O abundance in a H-burning shell, among which the $^{17}\mathrm{O}(\mathrm{p},\gamma)^{18}\mathrm{F}$ and the $^{17}\mathrm{O}(\mathrm{p},\alpha)^{14}\mathrm{N}$ reactions are the more relevant. Since the last release of rates compilations (see the JINA reaclib database, https://reaclib.jinaweb.org/) a number of experiments have updated reaction rates, incorporating new low-energy cross section measurements. In order to provide up-to-date input to the astrophysics community we performed simultaneous multi-channel and Monte Carlo R-Matrix analyses of the two reactions including all newly available data, resulting in realistic uncertainty ranges for the rates.

We will give an overview of the input data, the methodology, present the updated reaction rates and give an outlook on planned evaluations of other CNO-cycle reactions using the same approach.

Primary authors: RAPAGNANI, David (University of Naples ”Federico II”); Prof. STRANIERO, Oscar (INAF)

Co-authors: Prof. BEST, Andreas (University of Naples ”Federico II”); Prof. DI LEVA, Antonino (University of Naples ”Federico II”); Prof. IMBRIANI, Gianluca (University of Naples ”Federico II”)

Presenter: Prof. BEST, Andreas (University of Naples ”Federico II”)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Measurement of the 27Al(p,alpha)24Mg fusion reaction at astrophysical energies via the Trojan Horse Method.

The abundance of 26Al carries a special role in astrophysics, since it probes active nucleosynthesis in the MilkyWay and constrains the Galactic core-collapse supernovae rate. It is estimated through the detection of the 1809 keV-line and from the superabundance of 26Mg in comparison with the most abundant Mg isotope (A=24) in meteorites. For this reason, high precision is necessary also in the investigation of the stable 27Al and 24Mg [1,2]. Moreover, these nuclei enter the so-called MgAl cycle playing an important role in the production of Al and Mg [3]. Recently, high-resolution stellar surveys have shown that the Mg-Al anti-correlation in red-giant stars in globular clusters may hide the existence of multiple stellar populations, and that the relative abundances of Mg isotopes may not be correlated with Al.
The common thread running through these astrophysical scenarios is the 27Al(p,alpha)24Mg fusion reaction, which is the main 27Al destruction channel and directly correlates its abundance with the 24Mg one. Since available spectroscopic data and tabulated reaction rates show large uncertainties owing to the vanishingly small cross section at astrophysical energies, we have applied the Trojan Horse Method (THM) to the three-body quasi-free reaction d(27Al,alpha 24Mg)n.This has allowed us to perform high precision spectroscopy on the compound nucleus 28Si, from which we extracted important information on the 27Al(p,alpha)24Mg fusion cross section in the energy region of interest
for astrophysics, not accessible to direct measurements. All details can be found in refs.[4,5]. In particular, the indirect measurement made it possible to assess the contribution of the 84 keV resonance and to lower upper limits on the strength of nearby resonances.
We have evaluated the effect of the THM recommended rate on
intermediate-mass asymptotic giant branch stars experiencing hot bottom burning. Here, a sizeable increase in surface aluminum abundance is observed at the lowest masses due to the modification on the fusion cross section, while 24Mg is essentially unaffected by the change we determined.

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Primary authors: LA COGNATA, Marco (INFN - LNS); PALMERINI, Sara (University of Perugia and INFN Perugia, Italy)

Co-authors: Dr OLIVA, Alessandro (INFN LNS); Dr DI PIETRO, Alessia (INFN LNS); Prof. TUMINO, Aurora (Kore University, Enna); Dr MAIOLINO, Concetta (INFN LNS); Dr LATTUADA, Dario (Kore University, Enna); HAMMACHE, Faïrouz (IJCLab-Orsay); Dr DELL'AGLI, Flavia (INAF, Observatory of Rome); GUARDO, Giovanni Luca (INFN LNS); RAPISARDA, Giuseppe Gabriele (University of Catania); Prof. LAMIA, Livio (University of Catania); SERGI, Maria Letizia (University of Catania); Prof. GULINO, Marisa (Kore University, Enna); VENTURA, Paolo (INAF, Observatory of Rome); Dr PRAJAPATI, Paresh M. (INFN LNS); Dr ADSLEY, Philip (Texas A&M University); Dr FIGUERA, Pierpaolo (INFN LNS); SPARTÀ, Roberta (Kore University, Enna); ALBA, Rosa (INFN LNS); Dr PIZZONE, Rosario

Gianluca (INFN LNS); Prof. CHERUBINI, Silvio (University of Catania); Prof. ROMANO, Stefano (University of Catania); SANTONOCITO, domenico (INFN - LNS)

Presenter: PALMERINI, Sara (University of Perugia and INFN Perugia, Italy)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Production of solar abundances for nuclei beyond Sr: do we need better nuclear physics input?

It is widely accepted that the slow (s-process) and rapid (r-process) scenarios of neutron captures contribute to the solar abundances of trans-Fe nuclei.
The yields of up-to-date and totally independent models for s- and r-process show a general good and complementary agreement in reproducing the Solar System abundances. However, some local discrepancies do occur and this fact could hint to a contribution by another nucleosynthesis mechanisms (e.g. the i-process) as well as the need for more precise nuclear physics inputs to be used for the nucleosynthesis calculations. In particular in last years the need for new (theoretical and hopefully experimental) estimates for the beta decay rates in stellar plasma conditions of some key isotopes has been highlighted. We present an analysis of the s-process contributions to Sr–Pr region from recent models of
asymptotic giant branch stars, for which uncertainties are known to be dominated by nuclear effects.
In particular, we will focus on for four nuclei (98Mo, 106Pd, 118Sn, and 135Ba) whose predicted abundances are in clear disagreement with observed ones and whose s-process yields will be crucially modified if the half-lives of some isotopes (i.e. 113,115Cd, 115In, and 134,135Cs) would be different in ionized plasma environments.

Primary authors: BUSSO, Maurizio (Univ. Pg and INFN - PG); PALMERINI, Sara (University of Perugia and INFN Perugia, Italy)

Presenter: PALMERINI, Sara (University of Perugia and INFN Perugia, Italy)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Measurement of the 159Tb(n, γ) cross section at the CSNS Back-n facility

The stellar (n, γ) cross section data for the mass numbers around A ≈ 160 are of key importance to nucleosynthesis in the main component of the slow neutron capture process, which occurs in the thermally pulsing asymptotic giant branch (TP–AGB). The new measurement of (n, γ) cross sections for 159Tb was performed using the C6D6 detector system at the back streaming white neutron beam line (Back-n) of the China spallation neutron source (CSNS) with neutron energies ranging from 1 eV to 1 MeV. Experimental resonance capture kernels are reported up to 1.2 keV neutron energy with this capture measurement. Maxwellian-averaged cross sections (MACS) are derived from the measured 159Tb (n, γ) cross sections at kT = 5 ~100 keV and are in good agreement with the recommended data of KADoNiS-v0.3 and JEFF-3.3, while KADoNiS-v1.0 and ENDF-VIII.0 significantly overestimate the present MACS up to 40% and 20%, respectively. A sensitive test of the s-process nucleosynthesis is also performed with the stellar evolution code MESA. Significant changes in abundances around A ≈ 160 are observed between the ENDF/B-VIII.0 and present measured rate of 159Tb(n, γ) 160Tb in the MESA simulation.

Primary authors: Mr WANG, Dexin (Inner Mongolia Minzu University); LI, Guo (Inner Mongolia Minzu University); Ms HUANG, Meirong (Inner Mongolia Minzu University); Prof. ZHANG, Suyalatu (Inner Mongolia Minzu University)

Presenter: Prof. ZHANG, Suyalatu (Inner Mongolia Minzu University)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Understanding the S- and C-type Giant Stars in the Milky Way

Asymptotic giant branch (AGB) stars are a key site of element synthesis in galaxies. As low-mass AGB stars evolve, they undergo internal helium-burning shell flashes, or thermal pulses. These thermal pulses temporarily extinguish the hydrogen-burning shell, allowing the convective envelope of the star to move into the intershell region, mixing products of helium-burning to the surface, including carbon. This is known as third dredge-up (TDU). The envelopes of the majority of AGB stars are oxygen-rich, and are classified as M-type. After enough mixing episodes, the star may eventually become "carbon-rich", meaning the surface carbon-to-oxygen ratio (C/O) exceeds unity. These stars also show signs of s-process element enhancement, such as technetium. Generally, it is thought that the carbon enrichment follows a sequence from M-type to C-type (carbon-rich), moving through S-type (C/O = 0.5-0.99) before becoming C-type (C/O > 1). These intermediate S-type stars are of particular interest because they have likely only recently commenced episodes of TDU. A significant uncertainty in stellar modelling is the minimum stellar mass for TDU, as well as its efficiency as a function of stellar mass; therefore, accurately determining the masses of these S-stars can help us address these uncertainties.

The third data release of the Gaia survey has improved the luminosity determination of S-stars. However, constraining their current and initial masses remains complicated and requires stellar modelling, as AGB stars show long-period variability from radial pulsations, as well as longer term variability from thermal pulses. In this poster, we use radial pulsations to improve upon stellar mass estimates for Galactic S-stars. These will allow us to better constrain the minimum mass required for TDU in stellar models, and ultimately address uncertainties in the stellar yields of AGB stars and the chemical enrichment of the Milky Way galaxy.

Primary author: MORI, Yoshiya (Monash University)

Presenter: MORI, Yoshiya (Monash University)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Astrophysical S factor of $^{15}\mathrm{N}(p,\gamma)^{16}\mathrm{O}$ in the cluster effective field theory

The radiative proton capture reaction of $^{15}\mathrm{N}(p,\gamma)^{16}\mathrm{O}$ is one of the thermonuclear reactions in the carbon-nitrogen-oxygen (CNO) cycle. This process provides a link between the type-I (CN) cycle and type-II (NO) cycle so that the $^{16}\mathrm{O}$ nucleus can be produced and the further types of the cycle start. We investigated the $^{15}\mathrm{N}(p,\gamma)^{16}\mathrm{O}$ reaction in the effective field theoretical approach. The effective Lagrangian which is appropriate for this reaction in a stellar environment is introduced, and the capture amplitude and the corresponding S factor are calculated. In this work, we included two resonances due to the excited states of $^{16}\mathrm{O}$ as di-field propagators. By fitting our theoretical result to the empirical data of the S factor we determined the model parameters such as the low-energy constants and the S factor values of $S(0) = 29.8 - 34.1~\mathrm{keV~b}$ from the recent data sets are estimated. These results are compared to the estimations from several approaches such as the R-matrix and the potential models.

Primary author: SON, Sangyeong (Kyungpook National University)

Co-authors: ANDO, Shung-Ichi (Sunmoon University); Prof. OH, Yongseok (Kyungpook National University)

Presenter: SON, Sangyeong (Kyungpook National University)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

The first direct measurement of the $65\,keV$ resonance strength of the $^{17}\mathrm{O}(p,\gamma)^{18}\mathrm{F}$ reaction at LUNA

The $^{17}\mathrm{O}(p,\gamma)^{18}\mathrm{F}$ reaction plays a crucial role in Hydrogen burning via CNO cycle. In particular at temperatures of interest for HBB in AGB stars ($20\,\mathrm{MK} < \mathrm{T} < 80\,\mathrm{MK}$) the main contribution to the astrophysical reaction rate comes from the poorly constrained $E_R = 65\,\mathrm{keV}$ resonance. The strength of this resonance has only been determined through indirect measurements. The LUNA (Laboratory for Underground Nuclear Astrophysics) developed a new high sensitivity setup to measure this resonance directly.

The new setup is located at LNGS, where the cosmic ray background is reduced by several orders of magnitude. The residual background was further reduced by installing a devoted shielding made of 10 cm lead and 4 cm borated polyethylene. A 4π BGO detector was coupled with a target chamber and target holder of Aluminum, to increase the efficiency. The beam induced background contribution was precisely determined by collecting more than $300\,\mathrm{C}$ on $\mathrm{Ta}_2(^{18}\mathrm{O})_5$ targets.

With more than $400\,\mathrm{C}$ accumulated on $\mathrm{Ta}_2(^{17}\mathrm{O})_5$ targets the LUNA collaboration has performed the first direct measurement of the $65\,\mathrm{keV}$ resonance strength: this is the weakest resonance ever directly measured. In this contribution the improved experimental setup, the analysis procedure and preliminary results will be presented.

Primary author: GESUÈ, Riccardo Maria (Gran Sasso Science Institute)

Co-author: LUNA COLLABORATION

Presenter: GESUÈ, Riccardo Maria (Gran Sasso Science Institute)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

First study of the ^{139}Ba(n,γ)^{140}Ba reaction to constrain the conditions for the astrophysical i process

In recent years the plethora of new astronomical observations has shown that the synthesis of heavy elements cannot be explained just by the three traditional processes (s, r, and p). For this reason, new processes have been proposed that are able to explain these new observations. The "intermediate" or i process (see e.g. [1]) is one such process and corresponds to neutron densities and time scales intermediate between the slow (s) and the rapid (r) neutron-capture processes. It involves nuclei that are roughly 5 neutrons away from the last stable isotope and as such the majority of their nuclear properties are experimentally known. The only missing piece of information from the nuclear physics side is the neutron-capture reaction rates.

In the present work we investigate the production of La. La is one of the elements for which a large number of stellar observation data is available. La/Eu has been used traditionally to distinguish between the s and r processes, while enhanced Ba/La has been observed in metal-poor stars beyond s and r process values. At the considered neutron density of the i process, the uncertainties are dominated by the reaction ^{139}Ba(n,γ)^{140}Ba.

In a collaboration between Michigan State University (MSU), the University of Cologne, the University of Guelph, the University of Oslo, iThemba LABS and Lawrence Livermore National Lab we have experimentally constrained the neutron capture rate for the ^{139}Ba(n,γ)^{140}Ba reaction rate, for the first time [2]. The measurement of the relevant reaction took place at the CARIBU facility at Argonne National Lab. A combination of the β-Oslo method and the newly developed "Shape method" [3] were used to extract the nuclear level density and the γ ray strength function, which were used to constrain the neutron capture reaction rate on ^{139}Ba. The resulting rate is used in astrophysical i-process calculations which show that the uncertainty in the predictions for the double abundance ratio of [La/Eu] and [Ba/La] is greatly reduced and is now comparable to the uncertainties from astronomical observations. With this result we have been able to narrow down the group of stars out of the JINAbase that most likely have experienced neutron densities associated with rapidly accreting white dwarf simulations, which will be a stepping stone for further investigations of this astrophysical site.

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Primary authors: MUECHER, Dennis (University of Cologne); SPYROU, Artemis (FRIB)

Presenter: MUECHER, Dennis (University of Cologne)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Estimation of fission from proton-induced uranium-238 using the Langevin method

RAON aims to produce rare isotope beams through proton-induced fission of uranium-238. In this study, we utilize the Langevin method to predict the mass distribution by plotting trajectories based on the potential surface of compound nuclei, integrating the Liquid Drop Model (LDM) and the Shell model (SM). To enhance the shell effect at high excitation energy, we employ a multi-chance fission (MCF) approach. Our predictions provide valuable insights and bridge the gaps in experimental data, contributing to our understanding of isotope production.

Primary authors: Mr SONG, Chang-hoon (Pusan National University); SHIN, Ik Jae (RISP/IBS); Mr TAKAGI, Shinya (Kindai University, Japan); ARITOMO, Yoshihiro (Kindai University, Japan); KIM, Youngman (Institute for Basic Science); LEE, Chang-Hwan (Pusan National University)

Presenter: Mr SONG, Chang-hoon (Pusan National University)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Constraining neutron-capture cross section for the i-process for the 151–153Nd(n,γ)152–154Nd reaction via the β Oslo

Nucleosynthesis of heavy elements has been traditionally attributed to two neutron-capture processes, namely the *s* and *r* processes. Recent astronomical observations have revealed stars where the abundance distributions cannot be described by the aforementioned processes and for this reason the astrophysical *i* process was introduced (*i* for intermediate between *s* and *r*). While we know neutron densities are between the *s* and *r* process, the stellar site where it can occur has not yet been clearly identified and that is largely because of the nuclear uncertainties. The *i* process flow involves isotopes only a few steps from stability, and in this region the main nuclear physics uncertainty comes from neutron-capture reaction rates. Specifically neutron-capture reactions on Nd isotopes have been identified as important for the production of Eu and Sm. With this goal in mind, an experiment was run at the ATLAS facility using the low-energy beams delivered from CARIBU to constrain neutron-capture reactions of importance for the *i* process. β-decays and their corresponding γ-rays were identified using the SuN detector and the SuNTAN moving tape system. The β-decay of $^{152-154}$Pr into $^{152-154}$Nd was measured and the β-Oslo method was used to extract the nuclear level density and γ-ray strength function of $^{152-154}$Nd; preliminary results from this experiment will be presented here. From these statistical properties, $^{151-153}$Nd(n,γ)$^{152-154}$Nd reaction cross sections and reaction rates will be constrained and their significance to the *i* process will be presented.

Primary author: BERG, Hannah (Michigan State University)

Presenter: BERG, Hannah (Michigan State University)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Experimental integral cross-sections of photonuclear reactions on proton-rich ^{113}In and ^{114}Sn nuclei for cosmic nucleosynthesis modelling

(10 minutes)

Photonuclear reactions play an essential role in nucleosynthesis taking place in all sites, e.g., stars, novae, and interstellar gas media. Especially important these reactions are for formation of isotopes heavier than iron. The proton-rich p-nuclei, such as ^{114}Sn, and ^{113}In, can be created only via a complex sequence of radiative processes, involving both emission and capture of γ-rays [1]. Correct modelling of cosmic nucleosynthesis processes requires a wealth of confident experimental data both about nuclear reactions, and nuclear structure of involved nuclei.
Presented work is a continuation of our earlier studies of photonuclear reactions involving p-nuclei [2]. Yields of the $^{114}Sn(\gamma,n)^{113}Sn$ photonuclear reaction were measured in the bremsstrahlung energy range from 11.5 to 14 MeV with a step of 0.5 MeV using Linear Electron Accelerator of the National Science Centre "Kharkiv Institute of Physics and Technology" (Ukraine). For $^{113}In(\gamma,\gamma')^{113}In$ and $^{113}In(\gamma,n)^{112}In$ photonuclear reactions in the bremsstrahlung energy range from 7 to 23 MeV with a step of 2 MeV, the experiment was carried out using Microtron M-25 of the Institute of Nuclear Physics (Czech Republic). High-resolution gamma spectrometers based on HPGe detectors were used to measure induced activities in both experiments.
The results of experimental measurements are compared with the data available in the literature and with the nuclear reaction statistical model calculations obtained using TALYS 1.95 [3] computer codes.

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Primary authors: Mrs CHEKHOVSKA, Anastasiia (Institute of Solid State Physics, University of Latvia); Dr KRASTA, Tamara (Institute of Solid State Physics, University of Latvia); Dr RIEKSTIŅA, Daina (Institute of Solid State Physics, University of Latvia); Dr SKAKUN, Yevgen (National Science Center "Kharkiv Institute of Physics and Technology"); Mr SEMISALOV, Igor (National Science Center "Kharkiv Institute of Physics and Technology"); Dr CHVÁTIL, David (Nuclear Physics Institute, Czech Academy of Sciences)

Presenter: Mrs CHEKHOVSKA, Anastasiia (Institute of Solid State Physics, University of Latvia)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

The impact of systematic and statistical nuclear uncertainties on the i-process nucleosynthesis

The observed surface abundance distribution of Carbon-enhanced metal-poor (CEMP) r/s-stars suggests that these stars have been polluted by an intermediate neutron-capture process (the so-called i-process) occurring at intermediate neutron densities between the r- and s-processes. Triggered by the ingestion of protons inside a convective He-burning zone, the i-process could be hosted in several sites, a promising one being the early AGB phase of low-mass low-metallicity stars. The i-process remains however affected by many uncertainties including those of nuclear origin since it involves hundreds of nuclei for which reaction rates have not yet been determined experimentally.

We investigate both the systematic and statistical uncertainties associated with theoretical nuclear reaction rates of relevance during the i-process and explore their impact on the i-process elemental production, and subsequently on the surface enrichment, for low-mass low-metallicity stars during the early AGB phase.
We use the TALYS reaction code (Koning et al. 2023) to estimate both the model and parameter uncertainties affecting the photon strength function and the nuclear level densities, hence the radiative neutron capture rates. The impact of correlated systematic uncertainties is estimated by considering different nuclear models, as detailed in Goriely et al. (2022). In contrast, the uncorrelated uncertainties associated with local variation of model parameters are estimated using a variant of the backward-forward Monte Carlo method to constrain the parameter changes to experimentally known cross sections before propagating them consistently to the neutron capture rates of nuclei of i-process interest.
On such a basis, the STAREVOL code (Siess et al. 2006) is used to determine the impact of nuclear uncertainties on the i-process nucleosynthesis in a 1 $M_\odot$ [Fe/H] = - 2.5 model star during the proton ingestion event in the early AGB phase. A large nuclear network of 1160 species coherently coupled to the transport processes is solved to follow the i-process nucleosynthesis.

We show the importance of both statistical and systematic uncertainties with respect to the surface abundances in AGB stars and we identify and provide a list of reaction rates that would need to be better constrained in the future in order to improve our understanding of the i-process.

Primary author: MARTINET, Sébastien (Université Libre de Bruxelles)

Co-authors: CHOPLIN, Arthur (ULB); GORIELY, Stephane (Université Libre de Bruxelles); SIESS, Lionel (Université Libre de Bruxelles)

Presenter: MARTINET, Sébastien (Université Libre de Bruxelles)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Impact of the excited- and bound-state β-decays of ^{63}Ni on weak s-process nucleosynthesis [1]

Although about 90$\%$ and 50$\%$ of the solar-system Cu and Zn abundances are presumed to originate from the slow neutron-capture process (weak *s*-process) during core He and shell C burning in massive stars, their stellar conditions are still poor known. This is because ^{63}Ni ($t_{1/2}$=101.2±1.5yr) takes the key as a bottleneck for the synthesis of these nuclei in the *s*-process branching: At high temperature, the β-decays from the excited states make a remarkable contribution. On the other hand, at low temperature and high density, the bound-state β-decays are important for highly ionized atoms when the transition energy is small. For these reasons many shell model calculations using different Hamiltonians were devoted to calculate excited-state β-decays, and both excited- and bound-state β-decay effects were studied in gross theory [2]. The calculated half-lives are unfortunately different from one another. In order to assess the significance of these effects, we carry out, for the first time, the *s*-process nucleosynthesis calculations using all nuclear models of β-decays in a $25M_{\odot}$ star with solar metallicity [1].
Firstly, we study the competition between ^{63}Ni($\beta^- \bar{v}$)^{63}Cu vs. ^{63}Ni(n,γ)^{64}Ni by taking account of the both effects to clarify the main nuclear flow paths [1]. We find that ^{63}Cu and ^{64}Ni change by 7$\%$ in abundance, ^{64}Zn changes by more than 20$\%$, ^{65}Cu and $^{66-68}$Zn change by 6$\%$, and all the other stable nuclei A = 69 –90 change systematically by 5$\%$ at the mass coordinate $M_r = 2M_{\odot}$ before the onset of the core Si burning, which depends strongly on the nuclear models [2]. We, secondly, confirm that although the β-decay half-life of ^{63}Ni^{28+} changes by more than 35$\%$ at T = 0.3 GK due to the effect of bound-state β-decay, abundance change of stable nuclei proves to be less than 3$\%$ [1]. These new quantitative results show the significance of future experimental measurement of the excited-state β-decays, in particular of ^{63}Ni, and the microscopic nuclear model calculations of both excited-state and bound-state β-decays.

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Primary author: Mr WANG, Xinxu (Beihang University, China)

Co-authors: Prof. SUN, Baohua (Beihang Univ.); Prof. FANG, Dongliang (Institute of Modern Physics, Chinese Academy of sciences); Prof. KUSAKABE, Motohiko (Beihang University); Prof. KAJINO, Toshitaka (Beihang Univ./NAOJ/Univ. of Tokyo); Mr HE, Zhenyu (Beihang University); Prof. NIU, Zhongming (Anhui University, China)

Presenter: Mr WANG, Xinxu (Beihang University, China)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Neutron capture and total cross-section measurements on 94,95,96Mo at n_TOF and GELINA

Cross-sections for neutron-induced interactions with molybdenum, in particular for the neutron capture reaction, play a significant role in various fields ranging from nuclear astrophysics to safety assessment of conventional nuclear power plants and the development of innovative technologies. Molybdenum is found in pre-solar silicon carbide (SiC) grains and an accurate knowledge of its neutron capture cross section has a crucial role in stellar nucleosynthesis models, in particular in Asymptotic Giant Branch (AGB) stars. From the work of Liu et al. [1], a deviation on the model predictions has been observed when using Mo cross section data from the two main KADoNiS versions [2][3], with KADoNiS 1.0 providing the better agreement with the grains data. This deviation is particularly evident when extrapolating the data to lower energies. A new measurement of the capture cross section of the molybdenum isotopes is therefore needed to confirm this trend at low thermal energy. In addition to its astrophysical role, molybdenum isotopes can be found as a fission product in fission power plants and the use of this material is under study for future improved reactors [4][5]. This shows the importance of an accurate knowledge of the total and capture cross-section for molybdenum isotopes.

Experimental data in the literature for the capture cross-section of Mo isotopes suffer from large uncertainties. This is also reflected in the large uncertainties of the cross-sections recommended in the ENDF/B-VIII.0 library [6]. Below 1 eV the relative uncertainty of the capture cross-section is above 18% for ^{94}Mo and around 40% for ^{96}Mo, while above 2 keV the uncertainties are in the order of 10-20% for ^{94,95,96}Mo. The uncertainty on the capture cross section data in the libraires is also reflected in the uncertainty of the MACS (Maxwellian Averaged Cross Section) found in the latest version of KADoNiS [3], which presents uncertainties on the level of 10% in the MACS at 30 keV for all the molybdenum isotopes. One of the reasons for these large uncertainties is related to the absence of transmission data for enriched samples.

In this contribution the first transmission and radiative capture measurements results obtained at n_TOF (CERN, Switzerland) and GELINA (EC-JRC Geel, Belgium) will be presented. Moreover, the updated values of the MACS for ^{94,95,96}Mo will be shown. The effect of these new preliminary values of the cross section in stellar nucleosynthesis calculations for AGB stars will be presented.

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Primary author: MUCCIOLA, Riccardo (University and INFN Torino)

Co-authors: CRISTALLO, Sergio (INAF); Prof. MASSIMI, Cristian (Univeristy and INFN Bologna); MENGONI, Alberto (INFN - Bo and ENEA - Bo); KOPECKY, Stefan (European Commission, Joint Research Centre (JRC)); MANNA, Alice (Univeristy and INFN Bologna); MOENS, Andre (European Commission, Joint Research Centre (JRC)); PARADELA, Carlos (European Commission, Joint Research Centre (JRC)); SCHILLEBEECKX, Peter (European Commission, Joint Research Centre (JRC)); SIBBENS,

Goedele (European Commission, Joint Research Centre (JRC)); THE N_TOF COLLABORATION

Presenter: MUCCIOLA, Riccardo (University and INFN Torino)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Massive star models with the updated 12C+12C reaction rate

The reaction rate of the carbon fusion reaction is one of the basic inputs in the stellar model to understand the final stages of the massive star evolution. However, this reaction rate is yet uncertain because it depends on the extrapolation methods. The cross-section measurement for this reaction is challenging because the energy range relevant to the stellar evolution is much below the Coulomb barrier, i.e., the Gamow window is only 1.5-2.5 MeV. In this study, we update the carbon fusion reaction rate by obtaining new extrapolation results based on the measurement data available in the literature to date. By adopting our new reaction rate, we calculate massive star models with the 1D stellar evolution code, MESA (Modules for Experiments for Stellar Astrophysics). We find that our updated nuclear reaction rate is about a half of the previous one (Caughlan and Fowler 1988), resulting in almost negligible changes in the HR-diagram of the massive star models in consideration. However, the updated rate has a significant impact on the temperature change in the core and thus on the neutrino cooling during the carbon burning stage. We find that our updated reaction rate reduces the lifetime of the carbon burning stage by a factor of ~ 0.7.

Primary authors: SEONG, Gwangeon (UNIST); Ms KIM, Yubin (Ewha Womans University); Prof. KIM, Chunglee (Ewha Womans University)

Co-authors: Prof. KWAK, Kyujin (UNIST); Dr AHN, Sunghoon (Center for Exotic Nuclear Studies (CENS)); Ms PARK, Chaeyeon (Ewha Womans University, Center for Exotic Nuclear Studies (CENS)); HAHN, Kevin (Center for Exotic Nuclear Studies (CENS))

Presenter: SEONG, Gwangeon (UNIST)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

The COREA experiment: measurement of 12C(α,γ)16O reactions with an active-target TPC

The COREA (Carbon Oxygen Reaction Experiment with Active-target TPC) is an experiment to measure the precise cross-section of the 12C(α,γ)16O reaction in stellar nucleosynthesis. The reaction rate of 12C(α,γ)16O determines the 12C/16O abundance ratio in the universe and the entire scenario of the stellar nucleosynthesis after the helium burning up to the Fe core in the last years of stellar life. We are developing a novel detector system consisting of an active-target time projection chamber in a conduction-cooled superconducting magnet of the magnetic field up to 3 T and a LaBr3 gamma detector array. In this talk, we will present the status of the experiment and the development of the unique COREA detector system.

Primary author: KIM, Shin Hyung (Korea University)

Co-author: Prof. AHN, Jung Keun (Korea University)

Presenter: KIM, Shin Hyung (Korea University)

Session Classification: Poster session (Nuclear reaction rates and stellar abundances)

Track Classification: Nuclear reaction rates and stellar abundances

Full 3D Fluid Simulations of the Convective Urca Process in a Simmering White Dwarf Star

Type Ia supernovae are extremely bright thermonuclear events and have been very well studied by numerous observations. However, there remain many open questions about the progenitor system for these explosive events. In the single-degenerate progenitor model, in which a white dwarf accretes mass from a stellar companion, a phase of simmering occurs where carbon burning drives core convection prior to the thermonuclear explosion. A poorly understood aspect of this simmering phase is the convective Urca process, a linking of convection and weak nuclear reactions. We present full 3D fluid simulations of the A=23 convective Urca process in a simmering white dwarf using the MAESTROeX low-Mach hydrodynamic software. This enables us to model both the slow moving convection and weak nuclear reactions. We characterize the extent of mixing across the Urca shell, the convective velocity, and the energy losses due to neutrino emissions. These results can inform 1D stellar evolution models which track the longer timescale evolution of the carbon simmering phase. This research was supported in part by the US Department of Energy (DOE) under grant DE-FG02-87ER40317.

Primary author: BOYD, Brendan (Stony Brook University)

Co-authors: Prof. CALDER, Alan (Stony Brook University); Prof. TOWNSLEY, Dean (Univeristy of Alabama); Prof. ZINGALE, Michael (Stony Brook University)

Presenter: BOYD, Brendan (Stony Brook University)

Session Classification: Poster session (Stellar modelling)

Track Classification: Stellar modelling

Searching for a cosmological variation of the gravitational constant using strong gravitational fields

Searching for varying dimensionless physical constants presents a meaningful characteristic in experimental and observational studies. One of the most valuable explorations of these variations could depend on the evolution of white dwarf stars. Applying the spectrum of white dwarf star: G191-B2B, we derive a robust limit on the cosmological variation of the gravitational constant G˙/G=(0.238±2.959)×10−15yr−1. This limit proposes a potential test of the framework of modern unification theories.

Primary author: LE, Duc Thong (Institute for Computational Science)

Presenter: LE, Duc Thong (Institute for Computational Science)

Session Classification: Poster session (The early Universe, galactic evolution)

Track Classification: Galactic evolution

Heavy Element Nucleosynthesis and Galactic Chemical Evolution

The origin and evolution of heavy elements in nature are not yet fully understood. THis talk will overview the current status of models for both the formation of both r-process and nu-p-process elements. We summarize recent state-of the art developments of supernova and binary neutron star evolution in the context of both the r-process and p-process nucleosynthesis. In particular, we highlight two recent recent works detailing the emerging evidence for the important role of hypernovae (energetic supernovae) and collapsars (jets from the collapse of massive stars to a black hole). These studies illuminate how such events may play a key role in the origin and early evolution of explosive heavy-element nucleosynthesis.

Primary author: MATHEWS, Grant (University of Notre Dame)

Co-authors: Dr SASAKI, Hirokazu (NAOH); KAJINO, Toshitaka (Beihang Univ./NAOJ/Univ. of Tokyo); Dr YAMAZAKI, Yuta (NAOJ)

Presenter: MATHEWS, Grant (University of Notre Dame)

Session Classification: Poster session (The early Universe, galactic evolution)

Track Classification: Galactic evolution

Chemical Abundance Patterns of Very Metal-Poor Stars Dynamically Associated with Substructures in the Milky Way

We present a detailed chemical abundance analysis for about 40 Very Metal-Poor (VMP; [Fe/H] < -2.0), selected from Sloan Digital Sky Survey (SDSS) and Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) surveys. Their high-resolution (R ~ 45,000) spectra were obtained with GEMINI/GRACES, and their atmospheric stellar parameters and various chemical abundance ratios were derived. Because most of them are associated with the well-known Milky Way (MW) substructures, such as the Gaia-Sausage-Enceladus, Thamnos, and others, we investigate their dynamical characteristics and chemical abundance patterns to characterize their progenitor dwarf galaxies. Their chemodynamical properties will provide valuable clues to infer their accretion history as well as the assembly history of the MW.

Primary author: JEONG, MIJI (Chungnam National University)

Co-authors: Dr KIM, Young Kwang (Chungnam National University); LEE, Young Sun (Chungnam National University)

Presenter: JEONG, MIJI (Chungnam National University)

Session Classification: Poster session (The early Universe, galactic evolution)

Track Classification: Galactic evolution

An exact solution of the higher-order gravity in standard radiation-dominated era

We report that the standard evolution of radiation-dominated era (RDE) universe $a \propto t^{1/2}$ is a sufficient condition for solving a sixth order gravitational field equation derived from the Lagrangian containing $BR^{ab}R_{ab} + CRR^{;c}{}_{c}$ as well as a polynomial $f(R)$ for a spatially flat radiation FLRW universe. By virtue of the similarity between $R^{ab}R_{ab}$ and R^2 models up to the background order and of the vanishing property of $R^{;c}{}_{c}$ for $H = 1/(2t)$, the analytical solution can be obtained from a special case to general one. This proves that the standard cosmic evolution is valid even within modified gravitational theory involving higher-order terms. An application of this background solution to the tensor-type perturbation reduces the complicated equation to the standard second order equation of gravitational wave. We discuss the possible ways to discriminate the modified gravity model on the observations such as the gravitational wave from the disturbed universe and primordial abundances.

Primary author: YUN, Chae-min (Soongsil University)

Co-authors: PARK, Jubin (Soongsil University); CHEOUN, Myung-Ki (Soongsil University); JANG, Dukjae (IBS)

Presenter: YUN, Chae-min (Soongsil University)

Session Classification: Poster session (The early Universe, galactic evolution)

Track Classification: The early Universe

New targets for relic antineutrino capture

^{163}Ho has been considered as a suitable candidate for the capture of relic antineutrinos. However, the detection of the relic antineutrino using ^{163}Ho is extremely challenging with current techniques. Therefore, we have searched for new targets for relic antineutrino detections through the resonant capture on nuclides undergoing electron capture. We have investigated nuclear and atomic properties of all nuclides. And we finally propose ^{131}Ba, ^{159}Dy, ^{175}Hf, ^{195}Au, and ^{243}Cm as new candidates for the relic antineutrino detection, and call for high precise experiments of Q_{EC}-values and intensities of EC decays for these new candidates.

Primary author: Dr LEE, Jeong-Yeon (Soongsil University)

Co-authors: KIM, Yeongduk (IBS); Prof. CHIBA, Satoshi (Tokyo Institute of Technology)

Presenter: Dr LEE, Jeong-Yeon (Soongsil University)

Session Classification: Poster session (The early Universe, galactic evolution)

Track Classification: The early Universe

Big Bang Nucleosynthesis in the Extended Starobinsky Model and Early Universe Chemistry

(10 minutes)

Our study links cosmic evolutions in the extended Starobinsky model (eSM), Big Bang Nucleosynthesis (BBN), and early universe chemistry. We demonstrate standard and oscillating cosmic evolutions and discuss BBN constraints. By connecting BBN abundances to the early universe chemistry, we identify the formation of intriguing and critical molecular structures. These findings underscore the pivotal role that early universe chemistry plays in shaping our understanding of cosmological phenomena.

Primary authors: YUN, Chae-min (Soongsil University); JANG, Dukjae (IBS); PARK, Jubin (Soongsil University and OMEG institute); CHEOUN, Myung-Ki (Soongsil University)

Presenter: PARK, Jubin (Soongsil University and OMEG institute)

Session Classification: Poster session (The early Universe, galactic evolution)

Track Classification: The early Universe

Astrophysically relevant Neutron induced reactions studied via THM

Neutron induced reactions on unstable nuclei play a significant role in the nucleosynthesis of the elements in the cosmos. Their interest range from the primordial processes occurred during the Big Bang Nucleosynthesis up to the "stellar cauldrons"where neutron capture reactions build up heavy elements. In the last years, several efforts have been made to investigate the possibility of applying the Trojan Horse Method (THM) to neutron induced reactions mostly by using deuteron as "TH-nucleus". Here, the main advantages of using THM will be given together with a more focused discussion on the 7Be(n,alpha)4He "study case"and the 14N(n,p)14C reaction. The former reaction was studied via the THM application to the quasi-free 2H(7Be,aa)p reaction and it represents the extension of the method to neutron-induced reactions in which an unstable beam is present. The 14N(n,p)14C reaction was studied via the 2H(14N,p14C)p experiment performed at INFN-LNS via a 50 MeV 14N beam provided by the INFN-LNS TANDEM accelerator. Preliminary results shows the population of intermediate 15N excited states at astrophysical energies. These applications open new frontiers in the application of the method (i.e. the study of 7Be+d or 11C+alpha reactions) extending its range of applicability for contributing to astrophysically relevant problems.

Primary author: Dr LAMIA, LIVIO (UniCT & INFN-LNS)

Presenter: Dr LAMIA, LIVIO (UniCT & INFN-LNS)

Session Classification: Poster session (The early Universe, galactic evolution)

Track Classification: The early Universe

Measurement and evaluation of the 7Be + n reactions approaching the cosmological lithium problem

The cosmological lithium problem has been known as the outstanding discrepancy of primordial lithium abundances between observations and theoretical predictions. We have measured key nuclear reactions which act to reduce ^{7}Li during the big bang nucleosynthesis (BBN), namely, ^{7}Be$(n,p)^{7}$Li and ^{7}Be$(n,)^{4}$He, by means of the Trojan Horse method [1].

We also performed R-matrix fits to data sets including both the previous and present cross sections of the (n,p_0), (n,p_1) and (n,α) reaction channels based on the resonances at known excited levels. This analysis resulted in an improved uncertainty evaluation of the (n,p_0) cross section, and the first-ever quantification of the (n,p_1) contribution in the BBN energy region.

We implemented the revised total reaction rate summing both the (n,p_0) and (n,p_1) contributions in one of the state-of-the-art BBN codes PRIMAT. It results in a reduction of the predicted ^{7}Li abundance by about one tenth, which would offer less nuclear physics uncertainty to further theoretical works on the cosmological lithium problem.

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Primary author: HAYAKAWA, Seiya (Center for Nulear Study, University of Tokyo)

Co-authors: LA COGNATA, M. (INFN, Laboratori Nazionali del Sud, Catania, Italy); LAMIA, LIVIO (UniCT & INFN-LNS); YAMAGUCHI, Hidetoshi (Center for Nuclear Study, the University of Tokyo); KAHL, D. (Extreme Light Infrastructure Nuclear Physics (ELI-NP)); ABE, K. (Center for Nuclear Study, The University of Tokyo); SHIMIZU, H. (Center for Nuclear Study, University of Tokyo); YANG, L. (Center for Nuclear Study, The University of Tokyo); BELIUSKINA, O. (Center for Nuclear Study, University of Tokyo); CHA, S. M. (Center for Exotic Nuclear Studies, Institute for Basic Science (IBS)); CHAE, Kyungyuk (Sungkyunkwan University); CHERUBINI, S. (INFN-LNS and dipartimento di Fisica e Astronomia "E. Majorana", University of Catania, Italy); FIGUERA, Pierpaolo (INFN LNS); GE, Z. (University of Jyv¨askyl¨a); GULINO, Marisa (Kore University, Enna); HU, Jun (Institute of Modern Physics, Chinese Academy of Science); INOUE, Azusa (RCNP, Osaka University); IWASA, N. (Department of Physics, University of Tohoku); KIM, Aram (Korea University); KIM, Dahee (Center for exotic nuclear studies, Institute Basic Science); KISS, Gabor (RIKEN Nishina Center); KUBONO, Shigeru (RIKEN Nishina Center); LA COMMARA, Marco (INFN - Naples); LATTUADA, Marcello (INFN LNS Catania, Italy); EUNJI, Lee (Department of Physics, Sungkyunkwan University); MOON, J.Y. (Rare Isotope Science Project, Institute for Basic Science); PALMERINI, Sara (University of Perugia and INFN Perugia, Italy); PARASCANDOLO, Concettina (INFN - Naples); PARK, S. Y. (Center for Underground Physics (CUP), Institute for Basic Science (IBS)); PHONG, V.H. (RIKEN Nishina Center); PIERROUTSAKOU, Dimitra (INFN - Naples); PIZZONE, R.G. (INFN, Laboratori Nazionali del Sud, Catania, Italy); RAPISARDA, Giuseppe Gabriele (University of Catania); ROMANO, Stefano (INFN LNS Catania, Italy); SPITALERI, Claudio (INFN-LNS); TANG, Xiaodong (Institute of Modern Physics, CAS); TRIPPELLA, Oscar (INFN-Perugia); TUMINO, Aurora (INFN LNS Catania, Italy); ZHANG, Ningtao (Institute of Modern Physics, CAS)

Presenter: HAYAKAWA, Seiya (Center for Nulear Study, University of Tokyo)

Session Classification: Poster session (The early Universe, galactic evolution)

Track Classification: The early Universe

Nuclear reactions of astrophysical interest on neon isotopes at LUNA

A group of reactions involving neon isotopes have been studied at the Laboratory for Underground Nuclear Astrophysics (LUNA) using the intense proton beam delivered by the LUNA 400 kV accelerator and a windowless differential-pumping gas target.
For years the $^{22}\mathrm{Ne}(\mathrm{p},\gamma)^{23}\mathrm{Na}$ reaction was the most uncertain reaction in the NeNa cycle of hydrogen burning. LUNA was able to discover three new low-energy resonances in this reaction and to measure the nonresonant capture to unprecedently small energy. LUNA has significantly reduced the uncertainty surrounding this reaction and the NeNa cycle, but there is now a need for new, precise data on other reactions in the NeNa cycle.
The $^{20}\mathrm{Ne}(\mathrm{p},\gamma)^{21}\mathrm{Na}$ reaction is the slowest in the NeNa cycle and determines the overall rate at which the entire cycle proceeds. Within the temperature range of 0.1 GK to 1 GK, the rate of the reaction is primarily influenced by the 366 keV resonance and the direct capture component. These factors play a crucial role in determining the quantity of $^{22}\mathrm{Na}$ produced, which is a key observable in gamma-ray astronomy. LUNA reduced the uncertainty on the 366 keV resonance strength from 18% to 7% and for the first time measured the direct capture below 370 keV.
New measurements of low energy resonances in the $^{21}\mathrm{Ne}(\mathrm{p},\mathrm{g})^{22}\mathrm{Na}$, the second reaction in the NeNa cycle, are ongoing.
Furthermore, new studies are dedicated to $^{22}\mathrm{Ne}$, an important neutron source in the weak s-process via the $^{22}\mathrm{Ne}(\alpha,\mathrm{n})^{25}\mathrm{Mg}$ reaction.
The $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ reaction, which competes with the $^{22}\mathrm{Ne}(\alpha,\mathrm{n})^{25}\mathrm{Mg}$ reaction has been recently studied. At temperatures T < 300 MK the (α,γ) channel becomes dominant and the rate of the $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ reaction is influenced by multiple resonances that have been solely investigated using indirect techniques thus far. The new upper limits determined by LUNA cause the intershell $^{25}\mathrm{Mg}/^{26}\mathrm{Mg}$ ratio to decrease by a factor of 15 in 5 $M_{\odot}$ AGB stars.
Recent results will be presented and discussed, together with future perspectives for the study of the $^{22}\mathrm{Ne}(\alpha,\mathrm{n})^{25}\mathrm{Mg}$ reaction.

Primary author: FERRARO, Federico (INFN - LNGS)

Co-author: PIATTI, Denise (Università degli Studi di Padova and INFN sezione di Padova)

Presenter: FERRARO, Federico (INFN - LNGS)

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