NIC-XIV School 2016

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Niigata University (Ikarashi Campus)

Book of Abstracts

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Welcome

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Detection of Gravitational Waves and Astrophysics with Gravitational Waves

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The gravitational-wave signal GW150914 from merging black holes was observed on 14 September 2015 by the Advanced LIGO. It is not only the first detection of gravitational waves predicted by Albert Einstein just a century ago, but also the first observational evidence for the existence of binary black holes and relatively heavy, stellar-mass black holes larger than 25 solar masses. It has also inaugurated a new era of gravitational-wave astrophysics. I will explain what is gravitational waves and how we observe them. The gravitational-wave signals from various types of astronomical sources are generally buried in the noise of the detector and thus various tools of data analysis are indispensable to extract the signal from the noise. I will describe gravitational-wave data analysis. Finally, collaboration of multiple detectors is essential to realize gravitational-wave astrophysics. I will thus introduce the Japanese project KAGRA.
Welcome to the field of gravitational-wave astrophysics.

Paar / 9

Nuclear density functional theory for astrophysics

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In this lecture an overview will be given on the relativistic nuclear energy density functional, and its applications in modeling nuclear properties and weak interaction processes involving nuclei of relevance for astrophysics. In the first step, the formalism of the theory framework will be introduced, and the strategies to constrain the functional will be discussed. In the second part the applications in modeling nuclear ground state properties, collective excitations, beta decay and electron capture rates, and neutrino-nucleus reactions will be addressed. Astrophysically relevant properties of nuclear matter will be introduced, including strategies to constrain the nuclear symmetry energy from experimental data on finite nuclei, and relations to the neutron star properties.

Nagataki / 39

Death of Massive Stars: Supernovae and Gamma-Ray Bursts with Explosive Nucleosynthesis

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Massive Stars explode as supernovae, and very special supernovae explode as gamma-ray bursts. The explosion mechanism of supernovae is "almost" understood now, while the explosion mechanism of gamma-ray bursts is hardly known. In supernovae/gamma-ray bursts, lots of heavy nuclei are produced by explosive nucleosynthesis. Even r-process nucleosynthesis may happen in special supernovae including gamma-ray bursts. In this lecture, I would like to introduce the current understanding for the explosion mechanisms of supernovae & gamma-ray bursts. Then I would like to introduce explosive nucleosynthesis in supernovae. Finally, the possibility of r-process nucleosynthesis in special supernovae such as jet-induced supernovae & gamma-ray bursts is introduced, as well as another possibility of r-process nucleosynthesis in binary neutron star mergers.

Beers / **29**

The Chemistry of the First Stars and the Origin of the Astrophysical r-Process

Author: Timothy Beers[1]

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[1st Lecture]
The very metal-poor (VMP; [Fe/H] < −2.0) and extremely metal-poor (EMP; [Fe/H] < −3.0) stars provide a direct view of Galactic chemical and dynamical evolution; detailed spectroscopic studies of these objects are the best way to identify and distinguish between various scenarios for the enrichment of early star-forming gas clouds soon after the Big Bang. It has been recognized that a large fraction of VMP (15-20%) and EMP stars (30-40%) possess significant over-abundances of carbon relative to iron, [C/Fe] > +0.7. Recent studies show that the majority of CEMP stars with [Fe/H]< −3.0 belong to the CEMP-no sub-class, characterized by the lack of strong enhancements in the neutron-capture elements ([Ba/Fe] < 0.0). The brightest EMP star in the sky, BD+44:493, with [Fe/H] = −3.8 and V = 9.1, is a CEMP-no star. It shares a common elemental-abundance signature with the recently discovered CEMP-no star having [Fe/H] < −7.8. The distinctive CEMP-no pattern has also been identified in high-z damped Lyman-alpha systems, and is common among stars in the ultra-faint dwarf spheroidal galaxies, such as SEGUE-1. These observations suggest that CEMP-no stars exhibit the nucleosynthesis products of the VERY first generation of stars. We discuss the lines of evidence that support this hypothesis, and describe current efforts to identify the nature of the massive stellar progenitors that produced these signatures.

[2nd Lecture]
There are presently some 25 highly r-process-element-enhanced metal-poor (r-II) stars known in the Galactic halo, roughly twenty years after their first recognition. These stars exhibit enhancements of their r-process-element to iron ratios, relative to Solar ratios, by a factor of 10 to 100+ ([r-element/Fe] > +1.0). Despite their very low metallicities ([Fe/H] < −2.0), these stars exhibit an apparently universal [r-element/Fe] pattern that is very well-matched to the Solar r-process pattern. As such, they have long been thought to provide fundamental information on the likely astrophysical site of the r-process. We describe a comparison of the observed properties of halo r-II stars with the remarkable recent detection of a large sample of r-II stars identified in the Ultra Faint Dwarf (UFD) galaxy Reticulum-II, and suggest that the UFD environment is the natural birthplace of essentially all r-II stars - due to their relative rarity, the clear overlap in metallicity of the field r-II stars with that of UFDs, and the observed range in the absolute abundances of r-process elements in such stars. Other recent observational constraints, including the demonstration that the formation of r-II stars does not rely on the presence of a binary companion, will be discussed.

Navratil / **28**

Ab initio calculations of nuclear reactions important for astrophysics

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The description of nuclei starting from the constituent nucleons and the fundamental interactions among them has been a long-standing goal in nuclear physics. In addition to the complex nature of nuclear forces with two-nucleon, three-nucleon and possibly even four-nucleon components, one faces the quantum-mechanical many-nucleon problem governed by an interplay between bound and continuum states. In recent years, significant progress has been made in ab initio nuclear structure and reaction calculations based on input from QCD employing Hamiltonians constructed within chiral effective field theory. Among the newly developed methods is the No-Core Shell Model with continuum (NCSMC) capable to describe simultaneously bound and unbound states of light nuclei. I will present NCSMC results for reactions important for astrophysics that are difficult to measure at relevant low energies energies, such as 7Be(p,γ)8B, 3He(α,γ)7Be and 3H(α,γ)7Li radiative capture, and the 3H(d,n)4He and 3He(d,p)4He fusion. I will also highlight our recent studies of p-shell exotic nuclei and address prospects of calculations of 11C(p,γ)12N, 2H(α,γ)6Li and 4He(nn,γ)6He capture reactions.

Takechi / **31**

Study of the properties of atomic nuclei with RI beam

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The study and measurements on stable nuclei have been extensively performed since the discovery of atomic nucleus in early 20th century. Their physics properties such as mass, life-time, saturation density property, radii, and their stability have been researched and the knowledge obtained in those studies made the basis of understanding about nuclear structures, strong interaction of nucleons in nuclei, and behaviour of nuclear matter.

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In these a few tens of years, the study of nuclear physics is not limited on the stable or sub-stabl
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In this lecture, the current advanced radio active beam facilities and the method to produce short-l
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Kotake / **5**

The explosion mechanisms of core-collapse supernovae: how to blow up massive stars

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In this lecture, we mainly focus on the explosion mechanisms of core-collapse supernovae. After we briefly review the standard scenario, we talk about a recent status of numerical models where three-dimensional general-relativistic hydrodynamics code including both detailed weak interactions and nuclear equations of state is now meeting with sophisticated neutrino transport scheme. We then discuss the multi-messenger signatures of gravitational waves, neutrinos, and electromagnetic waves expected from these self-consistent models, which should be important to unveil the mystery of the central engine hidden deep under the thick veils of massive stars.

Students1 / 4

Relevant cross section measurements to the astrophysical p-process nuclei

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For an accurate description of the p-process nucleosynthesis a large reaction
database involving several hundreds to thousands of reaction rates is necessary. Unfortunately, there is a considerably lack of experimental data on the relevant cross sections in the p-process energy range, due to the fact that most γ-induced reactions are very difficult to measure directly [1]. To overcome this difficulty, the charged particle induced reaction cross sections are measured and their inverse photodisintegration reaction cross section are calculated. Alpha particle induced reactions play a significant role in the study of nuclear structure, nuclear reactions and astrophysics. Reaction rate estimates within the framework of the Hauser-Feshbach statistical model must be further tested in order to validate the existing alpha-nucleus optical model potentials, especially at low energies, far bellow the Coulomb barrier. Experimental data for these reactions in the astrophysical relevant energy range, near the Gamow window, have been measured for different p-nuclei.
The cross sections were measured by means of the activation method using an alpha beam delivered by the Bucharest IFIN-HH Tandem 9MV accelerator. The induced activities were measured in close-to-detection geometry using two large volume HPGe detectors in a low background passive shielding. The experimental results were compared with theoretical predictions obtained in the framework of the statistical model. Extended experimental cross sectiondata on p-nuclei give a higherreliability in using global optical model potential parametrization [2].

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[2] M. Avrigeanu et al., Phys. Rev. C 91, 064611 (2115).

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How to make a supernova associated with a Gamma-Ray Burst in the collapsar model ?

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Gamma Ray Bursts (GRBs) are among the most energetic events in the universe. GRBs are divided by the duration time into long GRBs and short GRBs. A popular model of the central engine of long GRBs involves a hyper accreting black hole (BH), created by a core collapse of a massive star (the collapsar model) [1].
Indeed, supernovae (SNe) have been observed to be associated with some GRBs since 1998. For example, SN1998bw was connected to GRB980425, and this SN was a very energetic core collapse SN [2].
In the collapsar model, it has been suggested that there could be strong outflow from the hyper accreting disk around the BH, with a kinetic energy of about 10^52 erg [3, 4]. This wind could induce an energetic SN associated with a GRB.
However, what condition is needed for the wind to produce a core collapse SN has not been clarified. Also, a possible relation between features of GRBs and those of associated SNe with in this scenario is not clarified either.
So, we explore what kind of a progenitor star could explode a GRB and an SN, and investigate mutual relations between the GRB and SN expected within a context of the collapsar model. We develop a simple model to describe a system consisting of a BH, disk and infaling surrounding envelope as a result of a core collapse of a massive star, adopting a range of progenitor structures (e.g., angular momentum). We evolve the system by calculating the mass and angular momentum transfer between these three components, largely following prescriptions given by Kumar et al. 2008 [5]. Furthermore, we include the effect of the ram pressure of the infalling materials to evaluate a capability of the wind to induce an SN explosion, and estimate nucleosynthesis properties, following methods by Maeda and Tominaga 2009 [6].
We found that some relations are expected between properties of GRBs and those of SNe in the collapsar context. Some models result in the wind kinetic energy exceeding 10^51 erg, associated with a GRB jet kinetic energy of 10^53 erg. However, we also found that it is generally difficult for the wind to explode an SN because of the high ram pressure of the infalling materials. Using these results, we further discuss what is required for the properties of the wind and the central engine to simultaneously produce a GRB and an SN.

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[6] Maeda K., Tominaga N., MNRAS, 394, 1317 (2009)

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Pairing dynamics in Richardson model

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Nuclei show a variety of collective phenomena. Especially, excited 0^+ states in even-even nuclei show puzzling properties. Recent experiments reveal anomalous properties of the low-lying 0^+ states. We presume that the pairing dynamics plays a significant role in these low-lying excited 0^+ states. For instance, the 0_2^+ states in ^{152}Sm and ^{154}Gd, which were interpreted as the β vibrations, are strongly populated by two-neutron transfer reaction [1,2].
Our goal is to construct a new framework to elucidate pairing dynamics in nuclei.
As a first step, we treat simple systems with the two-body pairing interaction, known as the exactly solvable Richardson model [3]. We have found new properties about collective excited 0^+ states. The strength of two-particle transfer reaction to the excited 0^+ states strongly depends on the strength of pair correlation. In the strong pairing regime, these excited 0^+ states form a pair-rotational band, in addition to the "ground" pair-rotational band.
We have studied properties of these 0^+ states, employing the time-dependent Hartree-Fock-Bogoliubov (TDHFB) theory and requantizing the pairing dynamics. As a result of the quantization of the TDHFB, looking at the classical trajectories in the intrinsic gauge space, we are able to classify these collective excited 0^+ states into two types of states. Similar to the classification of the ground state, they are identified as either normal states or pair-condensed states. The pair-condensed excited states have properties analogous to the pair-condensed ground states.
In this contribution, we will present our recent results in two topics. (1) Requantization of collective coordinates in Richardson model; the application of Sommerfeld quantization and canonical quantization. (2) Applying the Richardson model to nuclei. We will show the strength of two-neutron transfer reaction in Sn isotope, discussing anomalous pairing vibration states discussed in Ref. [4].

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β-decay studies of r-process nuclei using the Advanced Implantation Detector Array (AIDA)

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The origin of the heavy elements is one of the most fundamental open questions in modern astrophysics, with a notable difficulty being the lack of a complete description of the rapid neutron-capture process (r-process) [1]. Two key quantities used in r-process calculations are β-decay half-lives and β-delayed neutron emission probabilities. The half-lives determine the timescale for the flow of matter to heavy isotopes. Isotopes near neutron shell closures, which are closer to stability and have longer half-lives, act as waiting points resulting in the observed r-process abundance peaks. As r-process nuclei then β-decay towards stability, β-delayed neutron emission shapes the final abundance curve.
The Advanced Implantation Detector Array (AIDA) represents the latest generation of silicon implantation detectors for use in β-decay half-life and β-delayed neutron emission measurements at fragmentation beam facilities. Thanks to the large yields of neutron-rich isotopes available at the Radioactive Ion Beam Factory (RIBF), AIDA will soon be used to conduct studies of r-process nuclei in the mass region of uranium fission fragments. These studies will utilise both the BRIKEN neutron detector and the EURICA γ-ray spectrometer at RIBF, RIKEN.
We present data from commissioning experiments and discuss plans for future measurements.
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Students1 / **22**

Evolution of the magnetar-powered supernovae

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Magnetars are neutron stars with strong magnetic fields(B~10^14-10^15G). The mechanism to make such a strong magnetic field and what kind of supernova generates a magnetar have not been well understood. Recent observations of supernova remnants associated with magnetars indicate that magnetar progenitors are massive stars and the typical explosion energy is 10^51 erg (e.g. Kumar et al., 2014, Vink & Kuiper, 2006).
We perform 1D hydrodynamical simulations of magnetar-powered supernovae to test a scenario of magnetar-powered supernovae. The explosion of a massive star triggered by the energy supply from the rotation energy of a magnetar due to the magnetic dipole radiation. If the initial spin period of a magnetar is very short(P0~1 ms), the rotation energy becomes up to 10^52 erg. A half of the energy is used to climb up the gravitational potential well of a massive star and the resultant supernova remnant possesses the rest of the energy. Our simulation results reproduce the expansion velocity, the size, and the luminosity observed for CTB109, which is one of supernova remnants associated with magnetars.

Students1 / **25**

Searching for the origin of galactic Al-26 with an experiment using isomeric Al-26 beam

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We will present an experimental plan to measure proton resonant elastic scattering with a thick target in inverse kinematics with a novel beam of isomeric Al-26 to be produced with CRIB at RIBF of RIKEN Nishina Center. The steady-state galactic abundance of the Al-26 radionuclide provides a unique window to the ongoing nucleosynthesis in the MIlky Way, as its decay along the galactic plane has been directry observed by astronomical telescopes. Despite a lot of efforts over the past four decades, the precise site of galactic Al-26 is poorly figured out. The experiment aims to search for strong proton resonances with low spin-parity in Si-27 using an isomeric beam of isomeric Al-26.

Students2 / **26**

Insights on the first stars from CEMP-no stars

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The CEMP-no stars (Carbon-Enhanced Metal-poor stars with no sign or weak signs for the presence of s- or r-elements) are long-lived small mass stars presenting a very low iron content and overabundances of carbon. Their chemically peculiar abundance pattern could be inherited from a previous massive star (the source star) that has lost mass through winds or at the time of the supernova. Because of the rotational mixing at work in a rotating source star, the chemicals species can be mixed efficiently between the different burning regions (e.g. H- and He-burning). It leads to a varied and rich nucleosynthesis. Such an internal mixing tends also to boosts the weak s-process. The observed abundances of the CEMP-no stars can give interesting clues on the behavior (rotation, nucleosynthesis…) of their progenitor.

Students2 / **30**

Single-particle energies of oxygen isotopes in the unitary-model-operator approach

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Owing to the recent computational progress, the medium-mass nuclei have been investigated recently by the ab initio methods such as the coupled-cluster method, in-medium similarity renormalization group approach, and self-consistent Green's function method. Similarly to these methods, the unitary-model-operator approach (UMOA) can also be applied to the medium-mass nuclei. So far, we calculated the ground-state energies and radii of the closed sub-shell nuclei in the UMOA. The single-particle energies of nuclei are important ingredients to understand more deeply the nuclear structure. In this presentation, we will show the calculation results of the single-particle energies for the oxygen isotopes in the UMOA.

Students2 / **33**

Impact of rotation and convective boundary mixing in low mass AGB stars

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After the central He burning in exhausted, stars with an initial mass of 1.5-3 solar masses start the AGB phase. In this phase, the s-process takes place, which is producing about half of all elements heavier than iron. Our non-rotating AGB stellar models calculated with MESA (see Battino et al., submitted) include a treatment of convective
boundary mixing based on the results of hydrodynamic simulations and on the theory of mixing due to gravity waves in the vicinity of convective boundaries. We show examples of how the models compare with spectroscopic abundance observations and presolar grains measurements. In particular, our models reproduce the highest observed values of the s-process index [hs/ls]. On the other hand, the full range of the observed [hs/ls] as well as the laboratory measurement of Zr isotopic-ratios were not properly reproduced. A spread of initial rotational velocity in AGB stars might help to improve this. We are calculating stellar evolution models including both rotation and the above described ingredients, enabling us to analyse their interplay and the impact on s-process efficiencies.

Students2 / **36**

Lfitetime measurements to constrain the 30P(p,g)31S rate at classical nova temperatures

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In classical novae, the 30P(p,g)31S reaction potentially acts as a bottleneck in nucleosynthesis flow to higher masses. Knowledge of this reaction rate is necessary for the modeling of elemental and isotopic ratios in classical novae, which affect proposed nova thermometers and presolar grain identification, respectively. While most of the resonance energies are known experimentally, the corresponding resonance strengths are not yet known. As a step towards determining experimental resonance strengths, an experiment to measure the lifetimes of these resonances, using the Doppler Shift Lifetime (DSL) setup at TRIUMF, is scheduled in late May. A measurement of the lifetimes of these states will provide the total widths of these resonances, and can be used along with the spins and proton branching ratios to determine resonance strengths.

Students2 / **37**

Development of high time resolution detector for RI beam using Cherenkov light

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In order to improve the resolution of particle identification for radioactive beams, it is important to develop the high time resolution detector to measure TOF. We have developed the high time resolution TOF detector which detects the Cherenkov light emitted when RI beam passes through the high refractive index radiator. Generally, the plastic scintillation counter has been commonly used as a fast TOF detector. The fast scintillation light of an organic scintillator could be emitted with the decay time of the order of a few ns. On the other hand, Cherenkov light could be instantly emitted without de-excitation process. Therefore, it is advantageous to use Cherenkov radiation instead of scintillation to obtain the high time resolution.

Experiments were performed at HIMAC (Heavy Ion Medical Accelerator in Chiba), NIRS. 58Ni, 82Kr and 132Xe beams of which beam energies are from 200 to 500 MeV/nucleon have been used for the test of Cherenkov detector. The methods to couple radiator and PMTs optically have been studied through the experiment and also simulation by Geant4. The time resolution of 5 ps has been achieved with 132Xe beam of 420A MeV. It has been found that the time resolution depends on the number of Cherenkov photons detected by a TOF detector. In the short talk, the experimental results will be reported and discussed.

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Overview of the BRIKEN Project

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Stellar nucleosynthesis of about half of elements heavier than iron is predicted to be proceed via the rapid neutron capture mechanism (r-process). As the astrophysical environment of the process and the relevant nuclear physics data far from stability are still questioned; more efforts for the astrophysical observation, simulation and radioactive beam experiment are needed. Among the nuclear physics data for r-process, beta-decay half-life determines the speed of the process, while beta-delayed neutron emission affects the late stage neutron recapture and detours the beta-decay

chain back to stability. The BRIKEN project, an experimental program at the Radioactive Isotope Beam Factory (RIBF), will survey those decay parameters for the most neutron-rich nuclei which are responsible for the formation of the r-process abundance pattern. Within the project, a high and flat efficiency neutron counter array and highly segmented implantation detector are employed to take advantage of the intense RI beam produced by RIBF.
In this report, an overview of the BRIKEN project will be presented. The impact of the specific beta-delayed neutron emitters, which are proposed to be measured, will be also clarified.

Posters - Board: 22 / **60**

Determination of charge form factors of nuclei by the elastic electron scattering

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Differential cross sections for elastic electron scattering reflect on charge distribution of nuclei because they are given by products of the Mott cross section and charge form factors. Charge distribution of nuclei is obtained from the Fourier transform of the charge form factors.

We conducted an experiment of electron scattering to study the relations between the cross section and the charge distribution. This experiment was carried out at KURRI-LINAC (Kyoto University) on January 31 and February 7, 2016. An electron beam at 46 MeV was collided with C, Al, Cu and Au targets, and the scattered electrons were detected at 78, 86 and 94 degrees using plastic scintillators.

We determined the charge form factors of the target nuclei by measuring the cross section for the elastic electron scattering. The obtained charge form factors were compared with theoretical form factors calculated under the assumption that each nucleus is a uniformly charged sphere. We also examined the mass dependence of the charge form factors.

We found that momentum transfer dependence of the form factors agrees with the theoretical expectation, and relative amplitude of the charge form factors is also reasonable, however the amplitude is 3 times larger than the theoretical expectation at the maximum. This discrepancy in the amplitude might be due to uncertainty of the beam intensity and backgrounds from inelastic electron scattering. We should improve the experimental setup to solve the discrepancy. It is also necessary to increase the number of the measurement angles for the precise determination of the charge form factor.

Posters - Board: 7 / **20**

ASTROPHYSICAL NEUTRINOS FLAVOR EVOLUTION WITH SELF INTERACTION

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The neutrinos that emerge in the core collapse supernovas play an important role in the cooling mechanism of the proto-neutron star (PNS). The luminosity of the neutrinos that emerge in the explosion is estimated to be 10^{52} erg/s [1]. Although the neutrinos' interaction cross-section is relatively very small, such a dense medium makes it possible for the neutrinos to engage in self-interaction [2]. In this study interactions of neutrino-matter are added to the calculations indirectly [3]. Neutrino-neutrino interactions are described by two kinds of scattering diagrams: the forward scattering diagram and the scattering diagram with exchanged momentum. When the self-interacting neutrinos are emitted from the PNS and traverse approximately 300km of range, they undergo a spectral split in their energy spectrums [4]. The spectral split which is dependent on the initial conditions such as the variety of distributions and temperature is important because it can give us important clues in evaluating or interpreting a neutrino signal of a supernova explosion that is anticipated to be observed in the near future. In this study, spectral splits for various energy spectrums, mixing angles and temperatures that are employed in the supernova models in the literature are obtained. Thus when the neutrinos, which are assessed to be coming from a supernova explosion, are detected, we can understand that which supernova model is more realistic and compatible with the experimental data.

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Posters - Board: 8 / **21**

The 23Na(a,p)26Mg Reaction Rate and its Astrophysical Reaction Rate

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Within the C/Ne convective shell of a massive star the 23Na(α,p)26Mg reaction is an important source of protons for 26Al production[1]. This shell is also the main source of Na ejected by core-collapse supernovae. A new experimentally determined reaction rate has been calculated across the relevant temperature range based on 3 new cross-section measurements [2-4] and angular distributions measured at the Aarhus University 5 MV Van de Graaff.

A recent measurement by Almaraz-Calderon et al. [2] found cross-sections 40 times greater than statistical-model cross-sections. Two additional experiments were performed by Howard et al. [3] and Tomlinson et al. [4], who both found results more consistent with statistical cross-sections. A follow up study by Almaraz-Calderon et al. identified a scaling problem in their original data, and after correcting this [5], it is more consistent with the others.

Combining these data, a full reaction rate study incorporating newly measured angular distributions has been performed. Experimental data is particularly important for this reaction, as the statistical models are not expected to have good predictive power because of the low density of states [1]. The data from [3] include measured angular distributions which have been extended and are used to reduce the systematic uncertainties in [4] and [5]. A combined reaction rate is calculated to a low uncertainty, improving the reliability of theoretical predictions of 23Na and 26Al in massive stars.

Posters - Board: 19 / **46**

Twist3 mechanism to hyperon polarization in unpolarized proton-proton collision

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We study the transverse polarization of hyperons produced in the high-energy unpolarized proton-proton collision in the framework of the collinear factorization. To understand this phenomenon is one of the big challenges in high-energy hadron physics because it can't occur in the conventional framework for high-energy inclusive reactions: parton model and perturbative QCD. However, using the collinear factorization, it has been known that this phenomenon is caused as a twist3 effect which reflects quark-gluon correlations in hadrons. These effects can be classified into two types of contributions: the twist-3 distribution function in the unpolarized nucleon and the twist3 fragmentation function for the hyperon. In this work, we focus on the former contribution and derive the complete LO cross-section. The cross-section is obtained from two types of pole contributions, the soft-fermion-pole and the soft-gluon-pole which arise from internal propagators in the hard part.
For the soft-gluon-pole term, we develop the "Master formula" which simplify the procedure of the calculation and show explicitly that only the derivative term contributes. Moreover, we calculate the soft-fermion-pole contribution for the first time and show that it vanishes. These results provide a useful tool to explain the mechanism of the hyperon polarization.

Posters - Board: 17 / **44**

PUSHING CORE-COLLAPSE SUPERNOVAE TO EXPLOSIONS IN SPHERICAL SYMMETRY: NUCLEOSYNTHESIS YIELDS

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Core-collapse supernovae are the extremely energetic deaths of massive stars. As such, they play a vital role in the synthesis and dissemination of many heavy elements in the universe. In the past, core-collapse supernova nucleosynthesis calculations have relied on artificial explosion methods that do not adequately capture the physics of the innermost layers of the star. The PUSH method, calibrated against SN1987A, utilizes the energy of heavy-flavor neutrinos emitted by the proto-neutron star (PNS) to trigger parametrized explosions. This makes it possible to follow the consistent evolution of the PNS and to ensure a more accurate treatment of the electron fraction of the ejecta, both of which are critical for nucleosynthesis calculations. Being robust and computationally affordable, this method is an ideal tool for performing extended progenitor studies. Here, nucleosynthesis results for core-collapse supernovae, exploded with PUSH, will be presented for a wide range of progenitor masses. Multiple interesting trends of ejected alpha elements with respect to progenitor compactness, explosion energies and neutron-star remnant masses are found. Comparisons of the calculated yields to observational metal-poor star data will also be presented. These complete nucleosynthesis yield predictions will be immensely useful as an input to galactic chemical evolution models.

Posters - Board: 18 / **45**

MIXING OF NI-56 IN MULTIDIMENSIONAL PAIR-INSTABILITY SUPERNOVA SIMULATIONS

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The new highly diverse class of supernovae, Super Luminous Supernovae (SLSNe), along with observations of Very Massive Stars (VMS) in the Local Universe have helped to revive interest in Pair-Instability Supernovae (PISNe; originally postulated in 1967) over the last decade. While PISN models have had no trouble explaining the enormous amount of light that defines a SLSN, they have heretofore been unable to reproduce the light curve shape and spectral evolution seen in such events. The majority of SLSNe evolve too fast and/or are too blue in color to be matched with existing PISN model predictions. However, our work indicates that certain slowly-evolving hydrogen-poor SLSNe, such as PTF12dam (one of many recent events with similar properties), might be explained by the PISN of a stripped carbon-oxygen core with considerable mixing of radioactive nickel in the ejecta. Here we present 1D, 2D, and 3D hydrodynamical simulations of PISNe computed with FLASH in order to study the effects of natural mixing of nickel on the light curve shape. We use as inputs stellar models of VMS evolved with the GENEVA code. The light curves are calculated with radiation-hydrodynamics code STELLA and comparisons are made to observations of SLSNe.

Posters - Board: 15 / **42**

Measurement of interaction cross section for 90Sr

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We have studied nuclear reactions for Long-Lived-Fission-Products (LLFP) 90Sr for the purpose of nuclear transmutation. The nuclear data of proton and deuteron beam for LLFP target is one of the essential dataset for the study of transmutation. However, the nuclear data for those LLFP are insufficient and the accumulation of precise nuclear data is required. The interaction cross sections (σ_I) for 90Sr on C, CH_2, and CD_2 targets were measured in inverse kinematics using secondary beam of 90Sr of which beam energy was 190 MeV/nucleon at Radioactive Isotope Beam Factory (RIBF), RIKEN [1]. The cross sections of 90Sr on proton and deuteron have been obtained for the first time by this work. The transmission method was employed to measure σ_I. In order to determine σ_I for 90Sr on proton / deuteron, reaction on C target have been subtracted from reaction on CH_2 / CD_2 target. The preliminary experimental results will be shown with the comparison to the Glauber model [2]. The experimental setup, analysis method, and the result of comparison will be also introduced.

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Posters - Board: 16 / **43**

Pair correlation and deformation in neutron-rich Ne isotopes

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In couple of decades, thanks to the development of the radioactive isotope beam technology, the study for neutron-rich light nuclei has become possible. The nuclei in this region often have the exotic properties, such as the neutron halo, disappearance of the canonical magic numbers, and appearance of the new magic numbers.
Recently, in the experimental study of the neutron-rich nuclei[1], the enhanced interaction cross section of 31Ne was observed. Around the neutron number N=20, the pronounced quadrupole collectivity and emergence of quadrupole deformation have been suggested experimentally and theoretically. Thus, the enhanced interaction cross section measured in 31Ne could be associated with the deformed halo structure that has been never observed.
We investigate the ground states for the Ne isotopes by solving the Skyrme-Hartree-Fock-Bogoliubov (Skyrme-HFB) equation that takes into account the pair correlation based on density functional theory. In order to describe the quadrupole deformation, we impose the axially symmetry. Also in order to describe the nuclear density extending spatially in neutron-rich nuclei, we solve the HFB equation using the THO basis. The Harmonic-Oscillator (HO) basis is not suitable for describing the density expanding spatially because its density artificially drops at large distance. But the THO basis that is obtained by transforming the variables of the HO basis has the property that its density exponentially damps at large distance, so the THO basis is reasonable for describing the neutron-rich nuclei.

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Posters - Board: 14 / **40**

PAIRING CORRELATION EFFECTS ON WIDTH OF QUASI-PARTICLE RESONANCE IN NEUTRON DRIP-LINE NUCLEI

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Low-lying (less than 1 MeV) resonances in neutron-rich nuclei has important role in neutron capture phenomena like the r-process. We focus on a new type resonance in superfluid nuclei. That is called quasi-particle resonance [1,2]. Many nuclei with open-shell configuration have superfluidity generated by pairing correlation. The pairing correlation causes continuum coupling in weakly bound nuclei like neutron drip-line nuclei. The Hartree-Fock-Bogoliubov theory in coordinate space can describe such weakly bound superfluid system [3,4]. It is a mean-field theory including pair condensate field. The theory predict the quasi-particle resonance in a single-particle scattering problem on a superfluid nucleus. An unbound particle couples a Cooper pair and a hole orbit, then forms the quasi-particle resonance. We have investigated the effects of pairing correlation on the width of low-lying p wave quasi-particle resonance. Through this investigation, we have discovered that the pairing correlation has the effect of reducing the resonance width [5].

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Posters - Board: 1 / **8**

A Bright r-II Star Detected by High-Resolution Follow-Up of the RAVE Survey

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Metal-poor stars in the Galactic halo have been studied for the past half century in order to understand the chemical evolution of the Galaxy, extending back to the first generations of stars born in the Universe. However, only within the last twenty years have very metal-poor, highly r-process-element-enhanced (r-II) stars begun to shed light on the cosmic origin of the r-process elements. Herein we present the first r-II star found within the RAVE survey (RAVE J2038-0023; a bright, non-carbon-enhanced star with V = 12), following medium- and high-resolution spectroscopic follow-up with the KPNO/Mayall and Magellan Telescopes, respectively. An initial analysis indicates that this star, with [Fe/H] = −2.8, lies within the metallicity range typical of r-II stars, and that it is strongly enhanced in neutron-capture elements (Eu/Fe] = +1.85). High-resolution follow-up has confirmed the presence of the actinides Th and U (this star is only the fourth very metal-poor star known with clearly detected U). We will present a full chemical abundance analysis for this star, as well as a comparison with current theoretical yields for the r-process. Ongoing efforts to identify additional r-II halo field stars, described here as well, will provide critical constraints on the astrophysical site of the r-process.

Posters - Board: 21 / **13**

Relativistic Brueckner-Hartree-Fock Theory for Finite Nuclei

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Nuclear structure information serves as important inputs for the study of nuclear astrophysics, for example, the equation of state for neutron star, and the nuclear masses and decay rates for nucleosynthesis . Nowadays ab initio methods have been paid more and more attention since they study nuclear structure from the realistic nucleon-nucleon (NN) interaction, which can be obtained either from high precision NN scattering data or eventually from the first principle QCD. As the only ab initio method available in the relativistic scheme, the relativistic Brueckner-Hartree-Fock (RBHF) theory has been raised in the 80s and shows many advantages in the study of nuclear matter such as saturation mechanism. In this work, we extend the RBHF theory to finite nuclei and study the ground state properties of double magic nuclei as a first step. The binding energy and charge radius are close to experiment. By strictly taking the relativistic effect into account, the present study reproduce the spin-orbit splitting from the bare NN interaction in a self-consistent way. Furthermore, the present self-consistent RBHF calculation provides a solid benchmark for various studies using local density approximation.

Posters - Board: 5 / **15**

Impact of New GT Strengths on Explosive SN Ia Nucleosynthesis

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Recent experimental results have confirmed a possible reduction in the GT+ strengths of pf-shell nuclei. These proton-rich nuclei are of relevance in the deflagration and delayed-detonation and explosive burning phases of Type Ia supernovae (SNe Ia). While prior GT strengths result in nucleosynthesis predictions with a higher-than-expected neutron-excess isotopes for the elements Cr-Mn-Fe-Co-Ni even in a best SN Ia model W7 [1], a reduction in the GT+ strength can result in a

reduced abundance of these neutron-rich nuclei. A new generation of shell model parametrization [2] has been developed which more closely matches experimental GT strengths [3]. The resultant electron-capture rates are used in nucleosynthesis calculations for carbon deflagration and delayed-detonation explosion phases of Type Ia supernovae, and the final mass-fractions are compared to those obtained using more commonly-used rates [4].

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K. Iwamoto and K. Nomoto in preparation.

Posters - Board: 3 / **11**

Determination of neutrino-mass hierarchy by matter oscillations

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We study neutrino oscillations of atomospheric neutrinos when they go through the earth, which has a dense core and a mantle with less density. Survival probabilities of atomospheric muon neutrinos are calculated within the three-flavor mixing model. Dependence of the probability at the exit surface of the earth on the neutrino energy and zenith angle is investigated. The survival probability is shown to depend sensitively on both the neutrino energy and the zenith angle. We show that the MSW matter enhancement effects are seen in case of normal hierarchy while it is not in case of inverted hierarchy. The effects of finite CP-phase on the matter oscillations are also investigated, and their effects are found to be rather small. It is suggested that the mass hierarchy can be distinguished from the difference of the survaival probabilities at the surface of the earth.

Posters - Board: 2 / **10**

Determination of Neutrino-Mass Hierarchy and CP-phase by Reactor Neutrino Oscillations

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We study neutrino oscillations of reactor neutrinos, anti-electron neutrinos, both in the short- and medium- to long-baseline cases. THe survival and generation probabilities of the neutrinos are calculated within the three-flavor mixing model, and the dependence of the probabilities on the mass hierarchy and CP-phase is investigated. We find that the hierarchy can be determined from the different oscillation phases of electron anti-neutrinos in the medium-baseline region where the suvival probability is aroun 50%. The CP-phase, on the other hand, can be determind from the oscillation patterns of muon and tau anti-neutrinos generated.

Posters - Board: 13 / **38**

Latent heat and pressure gap at the first order transition point of SU(3) gauge theory

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We calculate the energy gap (latent heat) and pressure gap between the hot and cold phases of the SU(3) gauge theory at the first order deconfining phase transition point. We perform simulations around the phase transition point with the lattice size in the temporal direction Nt = 6; 8 and 12 and extrapolate the
results to the continuum limit. We also investigate the spatial volume dependence. The energy density andpressure are evaluated by the derivative method with non-perturabative anisotropy coefficients. We adopt a multi-point reweighting method to determine the anisotropy coefficients. We confirm that the anisotropy coefficients approach the perturbative values as Nt increases. We find that the pressure gap vanishes at all values of Nt when the non-perturbative anisotropy coefficients are used. The spatial volume dependence in the latent heat is found to be small on large lattices. Performing extrapolation to the continuum limit, we obtain Δε/T^4=0.825±0.116 and Δ(ε-3p)/T^4=0.664±0.052.

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Critical line in finite temperature and density lattice QCD by O(4) scaling analysis

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We study scaling behavior of a chiral order parameter in the low density region, performing a simulation of two-flavor lattice QCD with improved Wilson quarks. It have been confirmed that the scaling behavior of the chiral order parameter defined by a Ward-Takahashi identity agrees with the scaling function of the three-dimensional O(4) spin model at zero chemical potential. We discuss the scaling properties of the chiral phase transition at finite density, applying the reweighting method and calculating derivatives of the chiral order parameter with respect to the chemical potential. In the comparison between the scaling functions of the O(4) spin model and QCD at low density, there is a fit parameter which can be interpreted as the curvature of the chiral phase transition curve in the QCD phase diagram with respect to temperature and chemical potential. We determine the curvature of the phase boundary by the fitting. The physical scale is set by the gradient flow.

Posters - Board: 4 / **14**

Measurements of the elastic scattering cross sections of 13C ions on 12C nuclei at the near Coulomb barrier energy

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In elastic scattering in the system 12C + 13C the neutron transfer mechanism 12C(13C,12C)13C can manifest at backward angles. In this context, study of the cross sections in this area is of great interest for astrophysics since it allows us to estimate cross sections of the possible radiation capture 12C(n,) 13C reaction and its role in the evolution of the Universe immediately after the Big-Bang. Because of the Coulomb repulsion the reaction near the Coulomb barrier, the process of the neutron transfer is peripheral.
Previously elastic scattering 12C + 13C at an energy close to our, was investigated in limited range of angles up to 600 [1]. In the resent study which done by Chua and Gobbi [2, 3] have been investigated the 12C + 13C system in the energy range of Elab=20 to 35.5 MeV. They have been obtained reasonable description of the experimental data for these energies. However, they could not give a satisfactory agreement between the theoretical calculations and experimental behavior angular distribution which is the rise cross section at backward hemisphere at Elab=32 MeV. In present work the angular range extended substantially (up 1200 in the center mass system). Differential cross sections for elastic scattering of 13C ions on the 12C nuclei were measured using beam extracted from the Cyclotron K = 160 HIL (Warsaw University) at the energy 2.5 MeV/nucleon.
Experimental data on elastic scattering were analyzed within the framework of the optical model (OM) and the Coupled Reaction Channels (CRC) method with code FRESCO [4] taking into account the neutron transfer mechanism. Analysis showed that, OM does not provide cross sections enhancement in backward direction. Only taking into account the neutron transfer mechanism gives rise to cross sections at large angles. The set of the optimal parameters of the potential was V0=73.1MeV, r0=1.03fm, a0=0.699fm, W=35.22MeV, rw=1.19fm aw=0.211fm.
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Posters - Board: 10 / **32**

Experimental Study on Symmetry Energy of Nuclear Matter with SπRIT-TPC

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The nuclear equation of state (EoS) is one of the most fundamental expressions that describe the basic relationship between energy, pressure, density, temperature, and isospin asymmetry δ=(ρ_n-ρ_p)/(ρ_n+ρ_p) for a nuclear system. For a neutron star, which has extreme asymmetry of its isospin, the symmetry energy term of the EoS is considered to play an important role in determining physical property, for example, its mass-radius relation. As of now, at a nuclear saturation density or less, symmetry energy is well constrained by several experiments and observations. In contrast, there remains large uncertainty of the theoretical predictions on symmetry energy at supra-saturation densities because of lack of the experimental constraints[1]. To give constraints to symmetry energy at high density region, we plan to observe the ratio of positive and negative pion or light ion fragments from several types of heavy-ion collisions. Radio Isotope Beam Factory (RIBF) at RIKEN has a capability of providing an isotope beam with wide range mass number so that we can measure the effect of symmetry energy for different isospin-asymmetric systems. We designed large acceptance TPC using with SAMURAI dipole magnet at 0.5T for particle identification (SAMURAI Pion Reconstruction and Ion-Tracker, SπRIT-TPC[2]). In the Spring 2016, the first physics run will be held. In this poster presentation, I would like to show the analytical status of physics run of SπRIT-TPC.

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Posters - Board: 12 / **35**

MEASUREMENT OF THE 7Be(d, p) REACTION FOR THE STUDTY OF THE PRIMORDIAL 7LI PRODUCTION IN THE BIG-BANG NUCLEOSYNTHESIS

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The overestimation of primordial 7Li abundance in the standard Big-Bang Nucleosynthesis (BBN) is one of the known and unresolved problems in nuclear astrophysics. The latest theoretical prediction of the primordial 7Li abundance is still a factor of 2 to 3 times higher than the recent precise observation [1]. A key to solve this discrepancy is the destruction of 7Be, for which the 7Be(d, p)8Be and 7Be(n, α)4He are the two promising processes, and it is suggested that a contribution from 7Be(d, p)8Be reaction is bigger than 7Be(n, α)4He reaction [2]. As for this experiment, we are focusing on 7Be(d, p) reaction. Although the reaction cross sections have been measured in normal and inverse kinematics conditions [3] [4], the former result was not reached critical energy region and the accuracy of the later one was not enough.
In this study we plan to improve the accuracy of the cross section, by performing the measurement with normal kinematics using a novel method, which we call it as an "activated target". We produced 7Be using 7Li solid target via 7Li(p, n) reaction and perform the 7Be(d, p) reaction experiment at Van de Graaff facility, Osaka University. As a result, we could measure the 7Be(d, p) reaction using the activated target. We are also developing a method of implantation target. We will implant 7Be ions to a gold plate target and perform a measurement experiment of 7Be(d, p) reaction. We are measuring the 7Be(d, p) reaction in various methods. We will report the results, future prospects and the

progress of the development of the implantation method.

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Posters - Board: 11 / **34**

PHASE-IMAGING MASS MEASUREMENTS WITH THE CANADIAN PENNING TRAP MASS SPECTROMETER

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The astrophysical rapid neutron capture process (r process) of nucleosynthesis is thought to be responsible for the production of roughly half of the elements heavier than iron. Despite its large influence in explaining the observed abundance of heavy elements, much of the r process is still poorly understood. A more thorough library of nuclear data, including masses, of neutron-rich nuclei is needed to improve the accuracy and progression of r-process calculations. The Canadian Penning trap mass spectrometer (CPT) is located in the CARIBU facility at Argonne National Laboratory where intense radioactive beams of neutron-rich nuclei are produced from the spontaneous fission of 252Cf. The scope of the CPT experiment at CARIBU is to perform direct mass measurements of isotopes which play a role in the r process. Since moving to CARIBU in 2010, the CPT has successfully measured the masses of more than 110 isotopes to a typical precision of 15 keV/c2 by measuring the cyclotron frequency of ions through a time-of-flight (TOF) technique. An upgrade to a position-sensitive microchannel plate detector at the CPT has facilitated a novel phase-imaging technique, and a multi-reflection time-of-flight mass separator (MR-TOF) has been commissioned at CARIBU which provides fast isobar separation with mass resolving power surpassing 100,000. These two upgrades allow for the CPT to probe shorter- lived nuclei further from stability than has previously been achievable at CARIBU. To illustrate the advantages of phase-imaging over the more commonly used TOF technique, the mass measurement of three previously unresolved nuclear isomers will be discussed.

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Cross-section measurements via the activation technique at the Cologne Clover Counting Setup

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The activation technique is a widely used method for the determination of cross- section values for charged-particle induced reactions at astrophysically relevant energies. Since network calculations of nucleosynthesis processes often depend on reaction rates calculated in the scope of the Hauser-Feshbach-statistical model, these cross-sections can be used to improve the nuclear-physics input-parameters like optical-model potentials (OMP), γ-ray strength functions, and nuclear level densities. In order to extend the available experimental database, the 108Cd(α,n)111Sn reaction cross section was investigated at ten energies between 10.2 MeV and 13.5 MeV. As this reaction is almost only sensitive on the α-decay width, the results were compared to statistical model calculations using different models for the α-OMP. The irradiation as well as the consecutive γ-ray counting were

performed at the Institute for Nuclear Physics of the University of Cologne using the 10 MV FN-Tandem accelerator and the Cologne Clover Counting Setup [1]. This setup consists of two clover-type high purity germanium (HPGe) detectors in a close face-to-face geometry to cover a solid angle of almost 4π.
In this contribution the experimental setup, the results of the cross-section measurement for the 108Cd(α,n) reaction, as well as the results from the statistical model calculations will be presented.
Supported by the DFG under the contracts ZI 510/8-1 and INST 216/544-1 and the ULDETIS project within the UoC Excellence Initiative institutional strategy.
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Pizzone / **24**

Trojan Horse Method: a powerful tool to study nuclear reactions at astrophysical energies

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The low energy behavior of reactions of astrophysical interest is one of the most important input to calculate the
reaction rates of astrophysical importance and therefore to evaluate their impact on astrophysical environments. Astrophysical energy range are so low that only in few cases direct measurements in those energy ranges were possible. This is even truer for reactions induced by radioactive ion beams.
Besides, direct measurements in the last decades have highlighted a new problem
related to the lowering of the Coulomb barrier between the interacting nuclei due to the
presence of the ''electron screening" in the laboratory measurements. It was systematically
observed that the presence of the electronic cloud around the interacting ions in
measurements of nuclear reactions cross sections at astrophysical energies gives rise to an enhancement of the astrophysical S(E)-factor as lower and lower energies are explored [1].
Moreover, at present such an effect is not well understood as the value of the potential for
screening extracted from these measurements is higher than the upper limit of theoretical
predictions (adiabatic limit).
On the other hand, the electron screening potential in laboratory measurement is different
from that occurring in stellar plasmas thus the quantity of interest in astrophysics
is the so-called "bare nucleus cross section". This quantity can only be extrapolated in direct measurements.
These are the reasons that led to a considerable growth on interest in indirect measurement
techniques and in particular the Trojan Horse Method (THM). An overview of direct and indirect methods will be given. Attention will be focused to the THM, to its prescriptions and assumptions as well as the application to some problems of big astrophysical relevance. Besides a step-by-step introduction to the experimental features of the method will be given as well as comparison to other direct and indirect methods.

Results concerning the bare nucleus cross sections measurements will be shown in those cases.

Lugaro / **27**

Asymptotic giant branch stars as drivers of cosmic chemistry

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All stars born with mass between roughly 1 and 10 solar masses evolve through the asymptotic giant branch (AGB) phase before disappearing from sight as white dwarfs. On the AGB they synthetise elements in their deep, hot layers, mix them to the surface, and shed them into their surrounding by stellar winds. Through this series of processes(nucleosynthesis, mixing, and winds) AGB stars contribute to the chemical evolution of stellar groups and galaxies. Specifically, they significantly produce a number of light elements (from C and N up to Na), as well as roughly half of the cosmic abundances of the elements from Sr to Bi. I will explain the nucleosynthesis inside AGB stars focusing on the understanding of the complex interplay between H burning, He burning, and mixing, which makes this stellar evolutionary phase so unique. I will describe the operation of the neutron source reactions and the neutron-capture path during the slow (s) and intermediate (i) neutron-capture processes that produce the elements heavier than iron in these stars. Finally, I will present a selection of issue of current interest in the modelling and observables related to AGB stars, from stardust grains to globular clusters, and which nuclear input is required to better address them.

Ejiri / 41

Phase structure of QCD at high temperature and high density by numerical simulations of lattice QCD

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I will talk about the phase transition of quantum chromodynamics (QCD) at high temperature and high density. The color confinement and the chiral symmetry breaking are the most important properties of the strong interaction and these properties vary depending on temperature and density. The numerical simulation of lattice QCD is a powerful tool to study the strong interaction. In this lecture, I will explain the basic formulation of lattice QCD and review recent progress of lattice QCD.

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Closing remarks

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