# RECENT TRENDS IN NUCLEAR STRUCTURE AND ITS IMPLICATION TO NUCLEAR ASTROPHYSICS

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# Infinite nuclear matter model and mass formulae for nuclei

**L. Satpathy**
*IOP, Bhubaneswar*

The matter composed of the nucleus is a quantum-mechanical interacting many-fermionic system. However, the shell and classical liquid drop have been taken as the two main features of nuclear dynamics, which have guided the evolution of nuclear physics. These two features can be considered as the macroscopic manifestation of the microscopic dynamics of the nucleons at fundamental level. Various mass formulae have been developed based on either of these features over the years,resulting in many ambiguities and uncertainties posing many challenges in this field. Keeping this in view, Infinite Nuclear Matter (INM) model has been developed during last couple of decades with a many-body theoretical foundation employing the celebrated Hugenholtz-Van Hove theorem, quite appropriate for the interacting quantum-mechanical nuclear system. A mass formula called INM mass formula based on this model yields rms deviation of 342 keV being the lowest in literature. Some of the highlights of its result includes its determination of INM density in agreement with the electron scattering data leading to the resolution of the long standing '$r_0$-paradox' it predicts new magic numbers giving rise to new island of stability in the drip-line regions. This is the manifestation of a new phenomenon where shell -effect over comes the repulsive component of nucleon-nucleon force resulting in the broadening of the stability peninsula. Shell quenching in N= 82,and N= 126 shells, and several islands of inversion have been predicted. The model determines the **empirical value** of the nuclear compression modulus, using high precission 4500 data comprising nuclear masses, neutron and proton separation energies.

The talk will give a critical review of the field of mass formula and our understanding of nuclear dynamics as a whole.

## Towards Superheavies: Excitations built on the highest neutron orbital

**Partha Chowdhury**
*UML*

Excitations of very heavy high-Z nuclei, whose fragility stems from enhanced Coulomb repulsion and whose stability stems from quantum shell effects, are currently our best indicators for superheavy nuclear structure. The heaviest nuclei where such spectroscopy is possible is near Z ~100, where the nuclei exhibit surprisingly robust fission barriers up to high angular momenta. These studies provide critical input for constraining theoretical models that attempt to describe the physics of superheavy nuclei, which include single-particle energies, shell-gaps and pairing. We have concentrated on excitations built on the highest neutron orbitals with 150 ? N ? 154 in Z < 100 nuclei, where inelastic and transfer reactions are possible with radioactive targets. We have populated high angular momentum states in a range of Pu (Z=94), Cm (Z=96) and Cf (Z=98) nuclei with beams of ^207,208 Pb and ^209 Bi from the ATLAS accelerator facility at Argonne, with gamma rays detected by the Gammasphere array. The most recent results and analysis will be presented and discussed within the context of the emerging physics.

# Modern Nuclear Structure Models : Chiral Symmetry, Wobbling Motion and γ-Bands

**Javid Sheikh**
*KU, Kashmir*

The major challenge in nuclear theory is to provide a microscopic description of the three basic excitation modes of rotational, vibrational and single-particle motion in a unified manner. In recent years, the microscopic tool of triaxial projected shell model (TPSM) approach has been demonstrated to provide an excellent description of the three modes observed in transitional nuclei [1, 2]. In this approach, the three-dimensional angular momentum projection is performed to project out the good angular momentum states from the triaxially deformed intrinsic configuration. The simplified pairing plus quadrupole-quadrupole interaction employed in this approach allows one to undertake a systematic investigation of series of nuclei in a reasonable time frame. The TPSM model has provided new insights into the nature of various outstanding phenomena which are related to triaxiality in atomic nuclei [3-9]. Recently, it has been demonstrated that TPSM describes the unique transition from longitudinal to transverse wobbling motion observed in La and Pr isotopes [10].

In the present talk, some applications of TPSM approach related to the triaxial properties of atomic nuclei shall be presented. In particular, it shall be shown that γ-bands are built on each configuration and some observables that have remained unexplained for quite sometime could be explained by considering γ-bands built on two-quasiparticle configurations. Further, recently it has become possible to perform the yrast spectroscopic studies using the state-of-the-art Skyrme density functional approach [11]. This work shall form a substantial part of the presentation.

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# Studies in Nuclear Structure relevant to Astrophysics: theoretical and experimental efforts

**Maitreyee Saha Sarkar**
*SINP, Kolkata*

Experimental and theoretical investigations in the region around doubly magic neutron rich $^{132}$Sn nucleus have recently revealed many intriguing issues concerning some newer aspects of nuclear structure in such exotic environments [1–3]. These nuclei lie on or close to the path of the astrophysical r-process flow. A glimpse of the implication of these studies on the r-process nucleosynthesis will be discussed [4].

Presently, the Nuclear Physics group in Saha Institute of Nuclear Physics is working for installation of a high-current, low energy Accelerator as the primary component of the Facility for Research in low Energy Nuclear Astrophysics (FRENA), a national facility, at Kolkata. Planning for future experiments has been undertaken for successful utilization of this facility.

Implantation technique has been found to be one of the most effective methods to produce isotopically pure targets. We have prepared a few isotopically pure targets using this technique [5].

Being the slowest process of the CNO cycle, study of the $^{14}$N(p, γ) $^{15}$O (Q = 7297 keV) capture reaction is of high astrophysical interest. From an experiment utilizing one of the newly prepared 14N implanted targets, a preliminary estimate of the lifetime of 6792 keV state in $^{15}$O has been obtained, using Doppler shift attenuation method (DSAM). The sensitivity of the results with respect to the uncertainties in various input quantities has been tested. This endeavour will be helpful to design a better experiment to extract more precise lifetime for this important state.

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# Recent studies on Hoyle state decay

**Chandana Bhattacharya**
*VECC, Kolkata*

In nuclear physics, clustering plays an important role in determining the structure of light nuclei. Moreover the study of these nuclei is crucial for various astrophysical scenarios. The study of alpha cluster emission is one of the most important methods to investigate the structure of N = Z nuclei. In recent years, there has been lot of interest in the study of cluster states using resonance particle spectroscopy with special emphasis on the structure of second 0+ excited state of $^{12C}$ at 7.65 MeV, the famous Hoyle state, which is believed to play a key role in the synthesis of $^{12}C$ and the other heavy elements in the Universe. Though a few attempts have been made in the past to understand the nature of this Hoyle state, the study of structure of this state is still a subject of great interest. From nuclear structure point of view too, the Hoyle state presents many unique features which are yet to be understood properly. A high precision, high statistics experiment on the decay of Hoyle state have been performed at the Variable Energy Cyclotron Centre, to quantify the contributions of various direct 3 alpha decay mechanisms of the Hoyle state, the results of which will be presented .

# Reactions involving weakly bound stable projectiles

**S. Santra**
*BARC, Mumbai*

The cross sections of radtiative capture of alpha by deuteron or triton at low energies producing weakly bound nuclei $^{6}Li$ or $^{7}Li$ provides the value of the astrophysical "S" factor, a very important quantity in the field of nuclear astrophysics, to understand the abundance of the above nuclei. These cross sections can be obtained from the measurement of Coulomb dissociation cross sections of $^{6,7}Li$ projectiles (into alpha and deuteron/triton) in the field of heavier target nuclei using inverse kinematics. Breakup of these projectiles proceeds via direct as well as several sequential processes. Several exclusive measurements of these processes have been made and their effects on various other channels (e.g., elastic, fusion, fission, etc.) have been investigated. Results of these studies will be reviewed and their implications on nuclear astrophysics will be discussed.

## Radiative capture in medium mass region: Astrophysical importance

**Gautam Gangopadhyay**
*CU, Kokata*

Nucleon capture reactions in medium and heavy mass regions play important parts in astrophysical processes such as the r-, s- and pprocesses. Relativistic mean field calculations have been performed to obtain nuclear density profile in medium mass region. Microscopic nucleon-nucleon interactions have been folded with the calculated densities of finite nuclei to obtain semi-microscopic optical potentials. Low energy proton and neutron capture reactions have been studied using the potential in this mass region. Details of some simplified network calculations will be discussed.

# Quasi-bound low energy tail of resonances

**Gheorghe Iulian Stefan**
*IPN Orsay*

It is well known that the ground state of particle-unbound nuclei can be observed as a resonance and that shorter the lifetime of the state, broader in energy the resonance. The Briet-Wigner formalism describes very well the shape of a resonance when the energy dependence of the partial widths is taken into account. This energy dependence is caused by the Coulomb and the centrifugal barriers and by the relative velocity of the system forming the resonance. For the resonances near charged particles emission threshold, the capture probability of the charged particle in the low energy tail of the state is drastically reduced by the coulomb barrier. Similarly, the charged particle decay of the unbound state from the low energy tail is strongly hindered, meaning also that the decay is strongly delayed. In this contribution examples and possible consequences of those features are discussed in the astrophysical context. An example is the $^{15}O$ case. $^{15}O$ is a well known waiting point in the CNO cycle, caused by the fact that $^{16}F$ is an unbound nucleus, making this unbound nucleus a barrier for the proton capture by $^{15}O$. An innovative way to bypass $^{15}O$ waiting point is proposed using the mechanism described above and applying it to the capture reactions $^{15}O(p,\gamma\beta)$ and $^{15}O(p,\gamma)(p,\gamma)$ .

This contribution will conclude with an overview of recent results obtained at IPN Orsay local facility and future projects at GANIL.

# Structure effects in low energy radiative capture reactions

**Rajdeep Chatterjee**
*IIT Roorkee*

Radiative capture reactions play an important role in stellar nucleosynthesis. At temperatures relevant to these events the corresponding relative energies between the participating nuclei are mainly in the sub-MeV scale. This talk will focus on an indirect method, the Coulomb dissociation method, to calculate these cross sections at low energies incorporating proper structure effects of the participating nuclei. In particular, recent results on $^{15}N(n,\gamma)^{16}N$, $^{14}C(n,\gamma)^{15}C$ and $^{8}Li(n,\gamma)^{9}Li$ capture will be discussed. We shall also show how to incorporate projectile deformation in the fully quantum mechanical theory of Coulomb dissociation, thereby opening up the possibility of calculating radiative capture cross sections involving deformed projectiles.

# Nuclear structure studies with INGA at IUAC and future possibilities

**R. P. Singh***
*IUAC, New Delhi*

Study of nuclear structure exhibits a wide variety of modes of nuclear excitations. The various modes of excitations reflect different underlying structures nuclei adopt to for a given situation of spin, iso-spin and excitation energy. Trying to understand and reconcile these large variety of underlying structures (and symmetries) in a finite quantal system, like nuclei, is of great interest to physicists.

The gamma ray spectrometer called Indian National Gamma detector Array (INGA) (a national collaboration) /1/ has given further impetus to these studies due to enhanced photo-peak detection efficiency for gamma rays. In recent years our group in collaboration with universities and institutes have probed the various dynamical symmetries like chirality, shears and gamma bands built over excited configurations. I would discus some of the recent results from these studies.

Further, at IUAC we are working on combining the INGA spectrometer with our hybrid gas-filled mass analyser HYRA /2/ for study of heavy nuclei in the forthcoming INGA-HYRA campaign. Some of these developments would also be discussed.

I would like to acknowledge the great effort by our collaborators from different universities, IITs and research institutions in various experimental campaigns at IUAC.

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* e-mail : rps@iuac.res.in

# Nuclear structure effects in Ag isotopes

**Sukalyan Chattopadhyay**
*SINP, Kolkata*

The Ag isotopes demonstrate a rich diversity of structure phenomena. These can be linked to the single particle configurations and the collective rotation of a tri-axial core. The presentation will cover the experimental evidences which have been established using the heavy ion beams from the Pelletron accelerators at Mumbai and Delhi and comparisons with different nuclear structure models.

# Practicing DSAM in Aberrant Domain: Motivation, Method & Measurements

**S. S. Ghugre**

*UGC-DAE CSR, Kolkata Center*

Measurement of nuclear level lifetime constitute an indispensable probe into the microscopic structure of the states and is thus of much significance in nuclear structure research. Of the several methods of lifetime measurement, the Doppler Shift Attenuation Method (DSAM) is the one adopted for measuring lifetimes typically in the range of few tens of fs to few ps. One of the crucial components of the related analysis is the simulation of the stopping process, of the residues of interest, in the target and the backing media. This requires calculation of the corresponding stopping powers and the same has been identified as one of the principal uncertainties on the measured lifetime in DSAM. The problem is further compounded in case of a molecular target, acting as the stopping medium, that might be required for certain nuclear structure pursuits. For instance, the $^{18}O$ target, extensively used for spectroscopic studies in sdpf nuclei, often comes in the form of metallic oxides such as $Ta_2O_5$ or $V_2O_5$ and, depending on the method of fabrication, may assume thickness sufficient to act both as the target and the backing. Such a setup presents an atypical scenario in the DSAM practice and the corresponding stopping simulations are beyond the purview of the widely used conventional analysis packages, such as the LINESHAPE [Wells et al. (1991)].

The proposed presentation shall discuss the developments pertaining to the application of updated experimentally benchmarked stopping powers and state-of-the-art stopping simulations in lifetime analysis along with the associated modifications in the codes to handle thick target acting as the target and the backing. The stopping powers have been calculated using the SRIM code while the simulations have been carried out using the TRIM program and the results have been successfully implemented in the lifetime analysis following appropriate incorporation of the nuances of nuclear reaction, with inputs from the contemporary statistical model calculations, through an extensive developmental exercise. The related algorithms, and their application to lifetime measurements in the sdpf nuclei, shall be elaborated in the presentation.

The aforesaid developments, though primarily conceived in the context of unconventional DSAM practices, are expected to aid in restricting the uncertainties even for typical setups. In conjunction, they are envisaged to extend the applicability of DSAM to a wider choice of targets that might be essential for specific nuclear structure studies.

# Simulation of TIFR-INGA array: present and future possibilities

**Sudipta Saha,** R. Palit , J. Sethi , S. Biswas , and P. Singh
*TIFR, Mumbai*

Discrete γ-ray spectroscopy using large array of high purity germanium detectors continue to provide new insights to the structure of an atomic nucleus and its dynamics. The Indian National Gamma Array (INGA) [1, 2] at Tata Institute of Fundamental Research (TIFR) is a powerful spectrometer with a provision of placing 24 Compton suppressed clovers, mounted at different angles with respect to the beam line. A Geant4 [3] based code has been developed to study various features of the array which are of general interest in γ-ray spectroscopy study. Response of the clover detectors have been tested up to 4.8 keV. For the first time geometrical correction factor required in angular distribution, angular correlation measurements have been extracted. The efficiency and addback factor of clover detectors have been successfully reproduced in the simulation. Good agreement has been obtained in simulated and experimental spectrum providing very accurate background estimation even at low energies. Simulations have also been carried out to introduce the concept of a multiplicity filter within the scope of present INGA assembly. In this context some relevant experimental measurements where there can be potential scope of using the simulation results will be discussed.

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# Structure of Pt isotopes along the line of stability

**Sujit Tandel**
*UM-DAE Centre for Excellence in Basic Sciences, Mumbai – 400098, India*

Excited states in stable Pt isotopes have been investigated through multi-nucleon transfer reactions. The isotopes studied range from $^{192}$Pt which is formed solely through the s process up to the most neutron-rich $^{198}$Pt which is produced in the r process. The evolution of structure with increasing neutron number has been mapped in these isotopes. New isomeric states are identified and rotational structures with underlying oblate deformation established. A striking contrast is visible between the gradual decrease in collectivity near the ground state with increasing neutron number, and its abrupt quenching at high spin around N=120. The role of high-j valence nucleons in determining the shape and extent of collectivity has been explored.

# Nuclear shape from fission fragment spectroscopy

**D.C. Biswas**
*BARC, Mumbai*

The shape of the fissioning nucleus evolves in the multidimensional space of relative separation, neck opening, mass asymmetry and deformation of the fragments. Various types of nuclear shape deformation have been observed from the fission fragment spectroscopy studies, which provide crucial information in the understanding of the dynamics of the fission process. Several nuclear models have been put forward to describe the fission fragment mass distribution as well as shape deformation of the fragments.

Nuclear fission process also offers an opportunity to study the interplay of the structure and dynamics in the fission process. Recently, the accelerator-based experiments are performed to populate the high-spin states for studying the mass distribution from the spectroscopy measurements to understand the signature of the reaction mechanism. Fine structure dips have been observed in the fragment mass distribution, corresponding to fragment shell closures at Z=50 and N=82 in $^{208}$Pb,$^{238}$U($^{18}$O,f) reactions, indicating the evidence for a new feature of "shape inhibition" of closed shell nuclei at the scission point. The role of nuclear shell structure as well as importance of shape deformations in the fission fragment mass distribution will be discussed.

# Signature inversion: precursor to the back bending in $^{126}$I

**Pragya Das**
*IIT Bombay*

The yrast band in $^{126}$I was found to have signature splitting and signature inversion in our earlier work [1]. We explained the cause of signature inversion to be the change in the axis of rotation from the shortest axis to intermediate axis of the triaxial nucleus. We utilized the theoretical frame work of particle rotor model and cranking model. The triaxial shape parameters were determined from these calculations. We are now trying to determine the shape parameters from the experimental values of the quadrupole moment derived from the analysis of lifetimes using the Doppler Shift Attenuation Method (DSAM) [2]. Furthermore, we are trying to understand the phenomenon of back bending which occurred at the angular momentum just above the signature inversion. Our investigation will throw some light if the occurrence of back bending at a certain rotational frequency was influenced by the change in the axis of rotation at the signature inversion.

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## Nuclear structure studies with low-energy light ions: Fundamental & Applied

**I. Mazumdar**
*TIFR, Mumbai*

Studies in low and medium energy nuclear physics have been dominated by heavy-ion induced reactions for last five decades. Heavy-ion induced nuclear reactions have enriched our knowledge of the structural evolutions and intricacies of reaction dynamics of the nuclear many-body systems. However, the emergence and rise of heavy-ion physics have seen a general decline in studies with low- and medium-energy light-ion beams. The harsh reality of dwindling number of low-energy light ion facilities adversely affect research in nuclear physics. Very low-energy and high current light-ion facilities immediately conjures up in our minds the studies in nuclear astrophysics. Measurements of light-ion capture cross sections and astrophysical S factors are the major themes of research at most of the light-ion facilities. However, the importance low energy light-ion beams is multifarious. A variety of measurements providing vital support and inputs to heavy-ion research can only be carried out at the low-energy, light-ion facilities. Light-ion beams are also useful for generation of mono-energetic neutron beams. In this talk I will draw from some of our recent measurements to show the importance of light-ion beams in nuclear astrophysics and also in applied nuclear physics.

# New challenges in nuclear structure and nuclear astrophysics using gamma-ray tracking technique

**C. Michelagnoli**
*GANIL CEA/DSM-CNRS/IN2P3, Caen, France*

The understanding of astrophysical phenomena claims for an accurate measurement of Nuclear Physics observables, fundamental inputs for theoretical calculations and model validation. In particular, the determination of stellar burning rates, essential for the comprehension of stellar evolution, relies on the position and width of resonances in the process of proton capture. These quantities can be precisely determined via gamma–ray spectroscopy techniques, since they correspond to bound nuclear states in the compound nucleus.

Doppler shift techniques constitute a powerful tool for the determination of the lifetime of nuclear states (and thus of their width), that developed along with the availability and progress of array of HPGe detectors. The Doppler Shift Attenuation Method has been recently pushed to the limit of its applicability by using the sensitivity and position resolution of the Advanced–GAmma–Tracking– Array (AGATA), used for the first time for the detection of high–energy gamma rays of astrophysical interest, in a sub–femtosecond lifetime measurement of the 6.79 MeV state in $^{15}$O (Legnaro National Laboratories). The width of this nuclear excited level is a crucial input for the determination of the $^{14}$N(p,γ) reaction at stellar energies, bottle–neck of the CNO–cycle. A precise determination of this reaction rate at Gamow energies is necessary for resolving many astrophysical puzzles, as the one of the *solar composition problem*. With the sub–femtosecond upper limit measured with AGATA for the lifetime of the 6.79 MeV state in $^{15}$O, a direct lower limit is set for the first time on the astrophysical S-factor at zero energy for the $^{14}$N(p,γ) reaction.

After a general introduction on gamma–ray spectroscopy measurements of interest in Nuclear Astrophysics, the experimental setup and results of the above–mentioned experiment will be reported. The new technique used for the measurement of fs lifetimes with a position–sensitive Ge array will be described, after a general introduction on the principles at the basis of the AGATA array. The new physics opportunities both in Nuclear Structure and Astrophysics offered by the utilization of this innovative device will be thus outlined, included a lifetime measurement with AGATA at GANIL aimed at the comprehension of classical novae evolution and explosion.

# Magnetic and Anti-magnetic rotation in nuclei

**S. Muralithar**
*IUAC, New Delhi*

The most interesting aspect of nuclear structure studies is to understand various modes of excitations and shapes of nucleus as a function of angular momentum and excitation energy. Users across country have studied various phenomena like breaking of current symmetry (magnetic-rotation and anti-magnetic rotation), triaxilaity from moderate to high spins, shape co-existance, study of neutron-rich species through fission reaction and octupole correlation by gamma ray spectroscopy method.

Some of the tools namely Gamma detector array, HIRA-GDA, INGA-HIRA, and Indian national gamma array at IUAC were used in past for studying above nuclear phenomena.
Magnetic rotational bands, found in nearly spherical nuclei, arise from anisotropic current distribution in nucleus instead of the collective rotational motion due to anisotropic charge density distribution (a rotational top). The magnetic rotation and anti-magnetic rotation studies carried out will be presented with examples.

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e-mail : murali.iuac@gmail.com , murali@iuac.res.in
http://www.iuac.res.in/research/np/inga/inga_main.htm

# Open Up the Heavens: Nuclear Astrophysics with Gamma-ray Beams

**Rajarshi Raut**
*UGC-DAE CSR, Kolkata Center*

The High Intensity -ray Source (HIS) at the Triangle Universities Nuclear Laboratory (TUNL) in Durham, USA, is the most intense source of monoenergetic -ray beam in the world, characterized by high beam flux and small energy spread. It presents diverse experimental prospects in a multitude of domains ranging from few body physics, nuclear astrophysics, nuclear structure studies, and photoactivation measurements.

In the proposed presentation couple of measurements, with relevance in the domain of nuclear astrophysics, carried out at the HIS facility shall be discussed. One of them, for instance, is the 86Kr(,n) cross-section measurement to investigate the s-process branching point at 85Kr [R. Raut, A.P. Tonchev et al. Phys., Rev. Lett. 111, 112501(2013)]. The branching points cater for a testing ground of the nucleosynthesis models and are much pursued in nuclear astrophysics measurements. However, one of the prerequisites of such application is an accurate knowledge of the neutron capture cross section on the branching point nucleus. The same for 85Kr has been extracted using the aforesaid inverse photodisintegration measurement and shall be discussed. Another set of measurements carried out with the facility is the 4He(,p)3H [R. Raut, W. Tornow et al. Phys. Rev. Lett. 108, 042502(2012)] and the 4He(,n)3He [W. Tornow, J.H. Kelley, R. Raut et al. Phys. Rev. C85, 061001R(2012)] cross section studies. The photodisintegration cross section measurements on 4He have consequences in the understanding of the neutrino induced reactions following the core collapse supernova explosion as well as in the production of elements in Big-Bang Nucleosynthesis. The measurements and the results shall be elaborated in the presentation.

These studies have been carried out under the guidance of Prof. W. Tornow and Prof. A.P. Tonchev and with active collaboration from Prof. C. Iliadis, Dr. M. Lugaro, Dr. S. Goriely, Dr. R. Schwengner, Dr. N. Tsoneva, Dr. A. Banu, Dr. G. Rusev, Prof. J.H. Kelley, Prof. M.W. Ahmed, Dr. A.S. Crowell, Dr. S.C. Stave and Dr. J. Buntain.

# Charged particle detectors in nuclear structure studies

**Akhil Jhingan**
*IUAC, New Delhi*

Studies of heavy ion induced nuclear reactions around the Coulomb barrier has provided a wealth of information for understanding important aspects of nuclear structure and reactions, and its implications to nuclear astrophysics. To probe the nuclear structure and related phenomena more deeply, there has been a significant progress and new facilities with multi-detector arrays have been constructed at various facilities around the world. New accelerator facilities are coming up, which will provide high intensity beams of stable and exotic nuclei. In addition to them, the instrumentation required to carry out these studies include particle detectors such as position sensitive proportional counters and silicon detectors, ionization chambers, scintillation detectors etc., along with their front-end electronics are being developed. Detectors with good timing and spatial resolution as well as detectors with large granularity, good energy, timing and spatial resolution with the state of the art high density electronics are now easily available. For the experimental facilities such as INGA [1], HYRA [2] and NAND [3] exploiting the new superconducting LINAC at IUAC, and future facilities at FAIR and SPIRAL2, new detector systems are being planned and developed with the idea of improving the efficiency, timing, position and energy resolutions, and the large solid angle coverage. Ancillary detector system like charged particle arrays based on CsI for light charged particle detection are being developed for both INGA and NAND. Particle identification with silicon detector systems are being planned for nuclear spectroscopic studies using transfer and deep-inelastic collision, and decay spectroscopy at focal plane of the recoil spectrometer HYRA. Proportional counters have been developed for Coulex, recoil and isomer decay tagging experiments. New detectors are also being developed for beam characterization for future RIB facilities. An overview of these detector developments at the detector development laboratory of IUAC will be presented.

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**Unified equation of state for neutron stars on a microscopic basis**

**X. Vinyas**
*Universitat de Barcelona, Spain*

# Nuclear Incompressibility and "Fluffiness" of Open-Shell Nuclei

**U. Garg**
*Department of Physics, University of Notre Dame, Notre Dame, IN 46556, USA*

The current status of the research on direct experimental determination of nuclear incompressibility from the isoscalar giant monopole resonances (ISGMR) will be reviewed. In particular, it has been observed that the energy of the ISGMR in the Cd and Sn isotopes is significantly lower than theoretical predictions using the interactions that correctly reproduce the ISGMR energies in the closed-shell nuclei, leading to the question: Why are the off-shell nuclei so "fluffy"? Possible shell-structure effects in ISGMR in the A~90 region reported recently will also be discussed.

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# Sensitivity of symmetry energy content of nuclear matter to the properties of neutron rich systems

**Bijay Agrawal**
*SINP, Kolkata*

# Collective excitation in relativistic thomas fermi formalism

**S. K. Biswal**
*IOP, Bhubaneswar*

Study of collective excitation like giant monopole and dipole resonances remain a fateful procedure to understand the nuclear structure. It has parallel contribution to both finite nuclei and infinite nuclear matter. Excition energy of isoscalar giant monopole (ISGMR) resonance define infinite nuclear matter compressibility, which is an indispensable parameter in determining the equation of state (EOS) of neutron star. EOS is the sole ingredient of stellar structure equation (TOV), whose output is the mass-radius profile of neutron star. Isovector giant dipole resonance (IVGDR) is related with the vibration of the proton and neutrons with opposite phase to each other. IVGDR has a vital role in constrain the symmetry energy (J) of the infinite nuclear matter.

In the present context we used scaling method to calculate excitation energy of giant isoscalar monopole and isovector dipole resonance. We have used the relativistic Thomas-Fermi formalism (RTF) for the nuclonic interaction. Semi classical method like Thomas-Fermi formalism remains a crucial method to study collective excitation. Collective properties varie very smoothly over the nuclear mass number, so Semi classical method can give reasonable results for collective properties. I will discuss both monopole and dipole resonance in our model.

Key words: Giant monopole resonance, Relativistic Thomas-Fermi, Excitation energy

## New parametrization with iso-vector channel

**S. K. Singh**
*IOP Bhubaneswar*

We have fitted new parameter sets for finite and infinite nuclear system within the relativistic mean field theory (RMF). The contributions of isospin vector channel are incorporated on top of the non-linear Walecka and effective mean field motivated extended Lagrangian. This fitting is taken care within the minimization of $\chi^2$ by using simulated annealing method (SAM). We discussed some more properties of finite and infinite nuclear system with these newly obtained parameters and compared with the well established effective mean field like NL3 and G2 interactions.

# Angular momentum distributions and nuclear structure studies tagged by Hybrid Recoil mass Analyzer (HYRA) at IUAC

**N. Madhavan**
*IUAC, New Delhi*

Angular momentum distributions of heavy Evaporation Residues (ERs) help in probing the pre-saddle region, in understanding the limits of survival of ERs, in probing nuclear viscosity effects and, possibly, in deducing the onset of quasi-fission processes. This, however, requires the efficient selection of ERs and the measurement of correlated discrete gamma ray multiplicity with high efficiency. On the other hand, high spin studies in heavy nuclei and search for microsecond isomers around Z = 82 proton shell closure or N=126 neutron shell closure can be best studied if the background from the overwhelming fission processes are eliminated and the ERs are detected in a time-correlated manner. The first stage of dual mode, dual stage separator/spectrometer HYbrid Recoil mass Analyzer (HYRA), operated in gas-filled mode, efficiently selects the heavy ERs from beam-like particles, target-like recoils and fission fragments, and, transports the selected ERs to the background-free focal plane to enable such studies along with a spin spectrometer or a clover Germanium detector array. The gas-filled mode of HYRA has been used in several ER excitation function measurements as a stand-alone device, in ER angular momentum distributions in conjunction with the TIFR 4π spin spectrometer, in the search for micro-second isomers in conjunction with a single clover germanium detector and is ready to be used with the Indian National Gamma Array (INGA) for ER tagged high spin studies in heavy nuclei. In this talk, experimental results obtained in reaction dynamics and nuclear structure studies using HYRA and plans for the immediate future will be elaborated.

Email: madhavan.nsc@gmail.com

# GDR study in 28Si+124Sn reaction at low temperature

**Chandan Ghosh[1],** G. Mishra[2], N. Dokania[3], M. S. Pose[1], V. Nanal[1], R. G. Pillay[1], Suresh Kumar[2], P. C. Rout[2], Sandeep Joshi[2]

[1]*Department of Nuclear and Atomic Physics, Tata Institute of Fundamental Research, Mumbai, India.*
[2]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai, India.*
[3]*India-based Neutrino Observatory, Tata Institute of Fundamental Research, Mumbai, India.*

Giant Dipole Resonance (GDR) is a powerful tool for studying the average nuclear shape at high temperature (T) and angular momentum (J) [1]. In particular the variation of the GDR width ($\Gamma_D$) as a function of T and J, still remains a challenge. Although the Thermal Shape Fluctuation Model (TSFM), based on inhomogeneous damping is successfully able to describe the variation of GDR width with T and J in medium mass region, some discrepancies have been observed in A ~ 150 mass region [2]. It has been reported in ref. [3] that in addition to inhomogeneous damping, the contributions from intrinsic damping needs to be included to describe the observed T- and J-dependence of the GDR width in 28Si +124Sn system at 149 MeV and 185 MeV. The intrinsic damping process is expected to have a steep T dependence. Therefore, study of the GDR in the same compound nucleus 152Gd at lower excitation energy will provide insight into the T- dependence of the GDR damping mechanism. With this motivation, the experiment was carried out using 135 MeV pulsed 28Si beam from PLF at Mumbai, bombarding an enriched 2.0 mg/cm2 thick 124Sn target producing 152Gd at E* ~ 71 MeV and <J> ~ $24\hbar$. The experimental setup for detecting high energy $\gamma$-rays in coincidence with low energy $\gamma$-multiplicity will be discussed. Combining the extracted GDR parameters using statistical model analysis from the present data with earlier measurement [3], the disentanglement of temperature and angular momentum effect on GDR width will be presented.
The observed GDR widths at lower temperature will be compared with the TSFM calculation performed recently [4]. The different behaviour of GDR width as a function of temperature in 152Gd from other nuclei in same mass region will be discussed.

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# Giant Resonances built on Excited States of Nuclei

**Rhine Kumar**
*TIFR, Mumbai*

Nuclear models representing the nature of ever-intriguing nuclear force can be robust if they render applicability over various domains, including the extremes of temperature (*T*), spin (*I*), isospin and density. Hence, extending the nuclear models to study nuclei at these extremes also gains significance, especially in the light of recent developments in the experimental facilities with which these nuclear states are becoming more accessible. Another important task in this regard is to identify the relevant phenomena for which the observables can be calculated reliably in all the considered domains. Giant resonance (GR) in nuclei is one such fundamental mode of excitation which can be built on any nuclear state. In a simplistic view, the GR are due to collective oscillations of protons and neutrons under the influence of the electromagnetic field induced by the emitted/absorbed photons, which results in a large peak in the emission/absorption spectrum of γ-rays. Among the various possible modes of the GR, the most dominant mode is the isovector giant dipole resonance which is commonly termed as GDR. Constructing a theoretical framework to study the GDR built on various nuclear states so as to unravel the underlying nuclear structure, is the broad aim of my work.

At very low temperatures there is a strong interplay between the shell (quantal fluctuations), statistical (thermal fluctuations), and residual pairing effects. At high-*I*, the pairing collapses but still the other two effects are strong and so is their interplay. In these cases, conclusive experimental results are scarce. We have constructed a theoretical framework to study the GDR with proper treatment of pairing and its fluctuations along with the thermal shape fluctuations. Our study reveals that the observed quenching of GDR width at low temperature in the nuclei $^{97}$Tc, $^{120}$Sn, and $^{179}$Au can be understood in terms of simple shape effects caused by the pairing correlations. For a precise match with the experimental data, the consideration of pairing fluctuations is crucial. My thesis work is an attempt to understand such warm nuclei both in the rotating and nonrotating cases, by studying the GDR observables.

# FRENA: An upcoming facility for Nuclear Astrophysics; Capabilities and Potentials

**Asimananda Goswami**
*SINP, Kolkata*

In this presentation a brief description of the FRENA machine will be presented. The possibilities of different types of experiment using this machine, which are astrophysically important, along with some future planning will be discussed.

# Neutron-Induced Reaction Cross-Section Measurements for Nuclear Astrophysics using 3 MV Particle Accelerator

**T. Trivedi**

*National Centre for Accelerator based Research, Department of Pure & Applied Physics, Guru Ghasidas Vishwavidyalaya, Bilaspur-495009.*

Investigation of neutron-induced activation cross-sections is gaining considerable interest due to their potential applications in nuclear technology, nuclear astrophysics, dosimetry, nuclear medicine, industry apart from the Nuclear Physics. These reaction cross-section measurements are extremely impotent to understand the nuclear astrophysical physical process which requires improved nuclear data and higher precision reaction cross-sections. The advances in accelerator technology coupled with state-of-the-art detection systems have provided scope of studying neutron induced reaction cross-sections, neutron activation analysis and low energy nuclear astrophysics. The 3 MV Pelletron Accelerator (9SDH-4, NEC) has been established at GGV, Bilaspur for providing accelerator based research tools in interdisciplinary research areas using ion beams and an attempt is initiated for the expansion of facility for neutron related activities. For this purpose accelerator has includes a high current TORVIS and SNICS-II ion sources. The TORVIS source provides negative ions of hydrogen and helium whereas SNICS-II is used for heavy elements producing negative ions. The unique feature of the accelerator is a TORVIS ion source which can deliver proton beam up to 6 MeV at intensities of 50 microamperes on target. Due to availability of high current proton beam the accelerator facility can be used for generating high neutron flux and hence a dedicated facility for neutron based research at the Centre is planned. This facility will be dedicated for neutron activation analysis and neutron induced cross-section measurements especially for astrophysically important reactions cross sections relevant to Nucleosynthesis and stellar evolution model. The salient features of this newly installed low energy high current Pelletron accelerator along with extension of facility for neutron generation shall be presented in the talk so as to enable the scientists and researchers to deliberate upon the kind of new experiments which can be designed using this new machine.

# Nustar - DEGAS and Indian Participation

**S. Mandal**
*DU, New Delhi*

# On the road to FAIR: a few snapshots from PreSPEC experiments

**Pushpendra P. Singh**
*IIT Ropar*

# Measuring electromagnetic moments in nano second isomers

**S.N. Mishra**
*TIFR, Mumbai*

# Beautiful phase of Nuclear Rotation in Transitional Nuclei: a competition between special coupled few nucleons and collective system

**Suresh Kumar**
*Department of Physics and Astrophysics, University of Delhi, Delhi-07, INDIA*

The transition nuclei in the nuclear landscape provide a situation where single particle and collective mode co-exist. In some cases, the rotation due to special coupled few nucleons system is much more dominate than the single and collective system. Thus, the spectroscopy of these transition nuclei provide information which will help to understand the bridge between the single particle excitation and collective degree of freedom.

In this talk, I will discuss a schematic model base on semi classical (SC) approach to explain MR band-crossing. The MR band-crossing occurs due to the alignment of a pair of valence nucleon and the shear blades re-open to built up a new shear band. Apart from this, the results on the transition probability in the transitional Sr isotopes will be discussed to understand the role of nucleons in the rotation of special coupled few nucleons system. In addition it, I will explain the critical point phase transition specially E(5) in these transition nuclei. In future plan, the lifetime measurements and g-factor for isomeric state of these nuclei will be the important focus of our study.

# Investigation of High Spin Structure of N ~ 28 Nuclei with PHF model

**Z. Naik**
*Sambalpur University*

Nucleus in 50 Mass shows verity of High Spin Phenomena. Some of them are K-Isomer, Band termination, States Beyond Band termination, Spuerdeformed Structure, Shape co-existence and many more. I will address some of these phenomena with Projected Hartree-Fock (PHF) model and discuss the microscopic structure associate with them.

# Structure of first excited 2+ states of Tin Isotopes in Relativistic QRPA

**Ahmad Ansari**

# Neutron rich nuclei around 132Sn

**Sarmishtha Bhattacharya**
*VECC, Kolkata*

The neutron rich nuclei with few particles or holes in 132Sn have various experimental and theoretical interest to understand the evolution of nuclear structure around the doubly magic shell closure Z=50 and N=82. Some of the exotic neutron rich nuclei in this mass region are situated near waiting points in the r-process path and are of special astrophysical interest. Neutron rich nuclei near 132Sn have been studied using fission fragment spectroscopy. The lifetime of low lying isomeric states have been precisely measured and the beta decay from the ground and isomeric states have been characterized using gamma-ray spectroscopy.

# Structure of 132Te: The Two-Particle and Two-Hole Spectrum of 132Sn

**Sayani Biswas**
*TIFR, Mumbai*

High-spin spectroscopy of neutron-rich nuclei near $^{132}$Sn is a subject of current interest in nuclear structure [1, 2]. Such studies allow us to compare the experimental data with the predictions of large scale shell model calculations using modern effective interactions [3, 4]. The motivation behind such comparison is to derive a more reliable effective nucleon-nucleon interaction which is necessary to understand the evolution of shell gaps with changing isospin [5]. The other important aspect is the understanding of the p-n correlations [6] as function of spin and isospin in addition to the better studied n-n and p-p correlations. At higher spins, the protons and neutrons align simultaneously and thus the p-n interaction can be probed by studying such states. One of the basic building blocks for studying the different types of correlations is a pair of protons and neutrons interacting with each other. In this regard, $^{132}$Te that contains of a pair of proton particles and neutron holes is an ideal candidate. In the present work, the states above the previously identified $10^+$ isomer (with $T_{1/2}$=3.70(9)μs) in $^{132}$Te [7], have been studied. The level scheme has been extended up to $J^\pi$= $(17^+)$. This identification was made possible from two complementary experiments. The first experiment was carried out in the Indian National Gamma Array (INGA) [8] using $^{232}$Th($^7$Li, f) at 5.4 MeV/u with a self-supporting target of thickness ~ 12 mg/cm$^2$. The prompt-delayed coincidence technique and angular correlation analysis were performed and the states till $J^\pi$ = $14^+$ were identified. The higher spin states were identified using the second experiment with the $^9$Be($^{238}$U, f) at 6.2 MeV/u and EXOGAM-array coupled with the VAMOS++ spectrometer [9, 10]. Alignment of the particles in the high-j orbitals, $\pi g^2_{7/2}$ and $\nu h^{-2}_{11/2}$, simultaneously are responsible for the generation of the observed high-spin states. Large scale shell model calculations using the jj55pna interaction [11] and the code NuShellX [12] have been carried out to be compared with the experimental level energies. It has been seen that a reduction in the p-n interaction strength gives a better agreement with the measurements up to $J^\pi$= $15^+$. Furthermore, a comparison of the differences between the experimental and calculated level energies for the N= 76; 78 isotones of Te and Sn shows an increasing disagreement as a function of spin. The magnitude of disagreement is larger in Te than in Sn pointing to the fact that there could be deficiencies in the p-n correlations, in addition to the n-n correlations in Sn. The other building blocks made up of two proton particles/holes coupled to the neutron particle/hole states can be investigated further by looking into the high-spin states in Te and Cd at N < 82 and N > 82.

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# Generalized seniority and Shell model calculations in n-deficient to n-rich Sn isotopes

**B. Maheswari**
*IIT Roorkee*

# The time-dependent nuclear mean-field and its astrophysical applications

**P. Stevenson**
*University of Surrey , UK*

# Pasta in QMC

**P. K. Panda**

# Study of proton capture reactions for astrophysically important $p$ nuclei with different *NN* potentials in A~100-120 region.

**C. Lahiri**
*IOP, Bhubaneswar*

Microscopic optical potentials for low energy proton reactions have been obtained by folding density dependent M3Y interaction derived from nuclear matter calculation with densities from mean field approach to study astrophysically important proton rich nuclei in mass 100-120 region. Again we choose some nonlinear R3Y interactions from RMF calculation and folded them with corresponding RMF densities to reproduce experimental S factor values in this mass region. Our main intension is to discuss the effects of nonlinearity on our results.

# Comparison between experiment and theory for nuclear structure phenomena at extremes

**S. Roy**
*TIFR, Mumbai*

Occam's razor can often be applied to various phenomena in nuclear physics to describe complex physics in a simple picture. In a nucleus various excitation modes are possible, which can be broadly classified into single or collective. Though these modes are interlinked, these are separable in the Hamiltonian. This is the primary reason; nuclear excitations can be treated in the semi classical approximation. In the semi classical picture, often there are only a few independent variables, which are sufficient to describe the experimental observation. In these cases, it is always important to consider the total picture and fix the free parameters according to the physics of the problem. Under this topic, I will be discussing two extreme scenarios of nuclear deformation, which are of current interest to the community.

# A new model for spontaneous fission mass and charge distribution and its applicability to nuclear astrophysics

**Jhilam Sadhukhan**
*VECC, Kolkata*

Information on spontaneous fission rates and fission fragment distributions are key ingredients of reaction network calculations aiming at simulating the formation of elements in the universe through nucleosynthesis processes. In this talk a methodology to calculate microscopically mass and charge distributions of spontaneous fission yields is outlined. We combine the multi-dimensional minimization of collective action for fission with stochastic Langevin dynamics to track the relevant fission paths from the ground state configuration up to scission. The nuclear potential energy and collective inertia governing the tunneling motion are obtained with nuclear density functional theory in the collective space of shape deformations and pairing. We obtain a quantitative agreement with experimental data and find that both the charge and mass distributions in the spontaneous fission of 240Pu are sensitive both to the dissipation in collective motion and to adiabatic characteristics.

# Study of shape evolution in neutron-rich A ≈ 150 nuclei and CAGRA project at RCNP

**Eiji Ideguchi**

*Research Center for Nuclear Physics (RCNP), Osaka University*

In my talk, I would like to present two topics.

One is a study of high-K isomers and shape evolution in neutron-rich A ≈ 150 nuclei. The neutron-rich A~150 region contains a wide variety of shape phenomena, including shape coexistence and possible static octupole and hexadecapole deformations. By the systematic studies of neutron-rich A ≈ 150 nuclei, onset of shape transition from near spherical to prolate deformation was found in Nd and heavier isotopes at N=90 or 92[1]. Beyond these neutron numbers, nucleus shows a strong quadrupole deformation and the high-K isomers were found [2]. The results indicate increasing quarupole collectivities with neutron numbers, but such studies were so far limited to N □96 due to the experimental difficulties. In order to study neutron-rich A ≈ 150 nuclei, we have performed isomer and β-γ spectroscopy experiments in the neutron-rich A=150□160 Nd, Ce, Ba nuclei using a high-efficient gamma spectrometer, EURICA[4] at the RIBF facility in RIKEN. The latest experimental studies of A ≈ 150 nuclei will be presented.

The other is the CAGRA project now on-going at RCNP cyclotron facility. Based on the U.S.-Japan-China collaboration, this project has constructed a Compton suppressed Germanium clover array (CAGRA) consisted of 16 Ge Clover detectors with BGO anti-Compton shields. It will provide many physics opportunities and strongly enhance the scientific output from the experimental program at RCNP. Three experimental sites are foreseen: at the EN beam line, where beams of rare isotopes are available; the Grand Raiden Spectrometer, where high-precision coincidence experiments utilizing light-ion reactions can be performed; and the muon beam facility (MuSIC) at RCNP. A wide variety of important scientific questions will be addressed, such as the detailed nature of pygmy dipole and Gamow-Teller resonances, the shell-evolution across the chart of nuclei, searches for superdeformed states, as well as astrophysical applications. Recently, CAGRA campaign experiments were successfully performed at RCNP EN beam line. An overview of EN CAGRA campaign and future prospect of CAGRA project will be presented.

# Importance of high-j orbitals in the high-spin structure of nuclei around the stability line

**Gopal Mukherjee**
*VECC, Kolkata*

The high-j proton and neutron orbitals play important roles in breaking the spherical symmetry in nuclei and driving a nucleus towards prolate or oblate shape. The high-spin nuclear structure in the A = 130 and A = 195 region sensitively depend on the position of the proton and neutron Fermi levels with respect to the high-j $h_{11/2}$, $h_{9/2}$ and $i_{13/2}$ orbitals. The high-j orbitals are also responsible for the isomeric states in the nuclei in these regions. Our experimental results on the excited states including high-spin isomers in nuclei in these two astrophysical important regions around neutron and proton magic numbers at N = 82 and Z = 82 will be discussed.

# Study of the level structure of $^{66}$Cu

**Purnima Singh**
*TIFR, Mumbai*

In recent years, the structure of neutron-rich nuclei in the vicinity of $^{68}$Ni has been the subject of considerable interest. Several experimental and theoretical efforts have been made to investigate the magicity of $^{68}$Ni and to understand the existence of multiple coexisting shapes in this region, however, a satisfactory description of nuclear structure is still lacking. Further experimental information on these nuclei is an important step towards providing a firmer understanding of their properties through comparisons with modern theoretical models. In this talk, I will present our recent work on investigation of the nature of yrast excitations up to moderate spin in the neutron-rich Cu isotope, $^{66}$Cu, using the INGA array.

# First total-absorption spectroscopy measurement on the neutron-rich Cu isotopes

**Naqvi Farheen**
*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*
*&*
*Joint Institute for Nuclear Astrophysics, Michigan State University, East Lansing, Michigan 48824, USA*

The first beta-decay studies of 74Cu isotope using the Total Absorption Spectroscopy (TAS) will be reported. The Cu isotopes have one proton outside the Z = 28 shell and hence are good candidates to probe the single-particle structure in the region. Theories predict weakening of the Z = 28 shell gap due to the tensor interaction between the valence pn single-particle orbitals. Comparing the beta-decay strength distributions in the daughter Zn isotopes to the theoretical calculations will provide a stringent test of the predictions. The experiment was performed at the National Superconducting Cyclotron Laboratory (NSCL) employing the TAS technique with the Summing NaI(Tl) detector, while beta electrons were measured in the NSCL beta-counting system. The experimentally obtained total absorption spectra for the neutron-rich Cu isotopes will be presented and the implications of the extracted beta- feeding intensities will be discussed.

# Neutrinoless Double Beta Decay

**Vandana Nanal**
*TIFR, Mumbai*

The mass and nature of neutrinos play an important role in theories beyond the standard model. The nuclear β decay and double beta decay can provide the information on absolute effective mass of the neutrinos. At present, neutrinoless double beta decay (NDBD) is perhaps the only experiment that can tell us whether the neutrino is a Dirac or a Majorana particle. Given the significance of the NDBD, there is a widespread interest worldwide employing a variety of novel techniques. This talk will present a brief report of ongoing and proposed NDBD experiments and will highlight Indian efforts to search for $0\nu\beta\beta$ in $^{124}Sn$ ($Q_{\beta\beta}$=2.28 MeV, 5.8% abundance) at the upcoming underground facility of India based Neutrino Observatory (INO).

# Nuclear Transition Matrix Elements and Neutrino Mas


***P. K. Rath***

*Department of Physics, University of Lucknow, Lucknow-226007, India*



Presently, the observation of neutrinoless double beta $(\beta\beta)_{0\nu}$ decay is the most pragmatic approach to establish the Majorana nature of neutrinos. In addition, a number of issues related to neutrinos, namely the origin of neutrino mass, absolute scale of neutrino mass, neutrino mass hierarchy, CP violation in the leptonic sector and the role of various mechanisms in different gauge theoretical models beyond the standard model of electroweak unification would also be clarified. In this endeavour, there is a need to calculate the model dependent nuclear transition matrix elements, as accurately as possible. The main objective of the talk will be to deal with the uncertainties in nuclear transition matrix elements for the $(\beta\beta)_{0\nu}$ decay.

# Title

**P.K. Raina**
*IIT Ropar*

# The surface properties of drip-line nuclei at N=50

*M. Bhuyan*

# Structure of Neutron Stars in a Modified Quark-Meson Coupling Model

**R. N. Mishra**
*Ravenshaw University, Cuttack*

# Microscopic description of proton emitters relevant to astrophysics

**P. Arumugam**
*IIT Roorkee*