Report from the Nuclear Structure Working Group at the ATLAS Users Workshop 2014

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Nuclear structure studies remain a broad research topic at ATLAS judging by the strong interest in the session devoted to unique stable and radioactive beams, new equipment initiatives, and the existing infrastructure at ATLAS (e.g. Target Lab). One of the recurring themes was taking advantage of the intense stable beams (i.e. ATLAS upgrade) and associated equipment (e.g. AGFA). Another frequently discussed theme was the use of CARIBU re-accelerated beams. There is also a large overlap and common interest between the nuclear structure and single-particle structure and reaction sessions both in terms of physics questions and the equipment presented in the preceding plenary session.

ATLAS is home to some of the most powerful detector systems for nuclear structure studies (including Gammasphere, FMA, HELIOS, and a suite of auxiliary systems). The facility also operates and hosts the gamma-ray tracking array GRETINA for dedicated campaigns. Access to state-of-the-art instrumentation and detectors that match facility capabilities is essential to maintaining a vibrant and forward moving research program. Higher beam intensities will require continued detector/electronic and target development. In-flight measurements with re-accelerated CARIBU beams require, among other instrumentation improvements, high efficiency gamma-ray detection with excellent Doppler correction. The ATLAS research community is continuing to add new instrumentation and pursuing a number of upgrades to meet these demands.

Looking ahead, a future 4π gamma-ray tracking detector array GRETA, which could be available towards the end of this planning period, would provide a powerful new capability for the ATLAS research community. In the mid-term, 3-5 years, a 2π “GRETINA/GRETA” would greatly extend the science reach for reaccelerated RIB experiments with CARIBU and provide increased efficiency for experiments with the FMA.

The following list contains the topics discussed in our session, which can be grouped in 7 categories. These are related, in part, to the limits in mass (cat. 1), spin (cat. 2), isospin (cat. 3, 4), and temperature (cat. 5).

1. Spectroscopy in the trans-actinide region

Detailed spectroscopy of No-Rf-Sg nuclei: Following recent studies of K isomers in ^{252}No, at RITU, and ^{254}Rf, at the FMA and the BGS, further studies in the region are envisioned that will help to shed light on the single-particle structure of superheavy nuclei. In a related endeavor, it is planned to study the yrast structure of ^{256}Rf, ^{254}Rf, and of even higher-Z nuclei, as well as the ground-state decay properties of nuclei in the region. At ATLAS, one is perfectly prepared for this type of studies by combining, in particular, the following equipment: Digital Gammasphere or GRETINA with FMA or AGFA, each with the Digital Implantation Station at the focal plane of the separator. These studies can be complemented by deep-inelastic and transfer-reaction experiments, with suitable equipment, which cover a considerable part of the trans-uranium region.

Atomic spectroscopy in the No region: It has been shown, e.g. at SHIP, that the atomic structure of Fm or No is accessible by dedicated experiments using resonance ionization spectroscopy. The required element selectivity can be provided by α-decay tagging. This creates new opportunities to study atomic levels in the heaviest elements and test theoretical predictions. AT ATLAS, a Paul trap will be incorporated in a setup with AGFA, the latter providing separation of the fusion-reaction products of interest. Like the nuclear-spectroscopy projects, these experiments take advantage of the intense ATLAS beams.

2. Spectroscopy at ultra-high spin

Discrete spectroscopy at ultra-high spin (UHS), near the fission limit, is actively pursued by a number of groups. Here, the center of interest is refining our picture of stable triaxial deformation. The key nuclei are ^{158}Er and ^{161}Lu. The former hosts the highest-spin structure ever observed. The latter appears to be an ideal laboratory for such studies; it has a wobbling band and is a candidate for an UHS structure. The objective is measuring relative transition quadrupole moments of UHS and wobbling band in the same nucleus, in order to understand the underlying structure of the UHS sequence in ^{158}Er. These types of studies will be enhanced utilizing Digital Gammasphere, which should allow for larger data sets to be accumulated in order to search for even weaker populated structures as well as decay gamma-rays connecting these exotic bands with states of known spin and parity. Longer term, the future 4π tracking array GRETA will enable these studies to take advantage of higher fold gamma-coincidence data and significantly increase the sensitivity to study exotic weakly populated structures at the limits of spin and deformation.

3. Shape coexistence and shell evolution in neutron-rich nuclei

The region of neutron-rich mass-100 nuclei that coincides with the light-mass peak of ^{252}Cf SF is well known for rapid shape changes and gamma softness. The CARIBU beams provide a great opportunity for experimental tests of the predicted shape coexistence effects, especially oblate and stable triaxial shapes at low to medium spin. Cases for such tests are the neutron rich Zr to Ru nuclei, for which comprehensive studies are to be performed by measuring energy levels, B(E2) transition probabilities and lifetimes. The in-beam work with traditional methods should probably be complemented by studies of isomeric beams such as ^{96m,98m}Y. Other complementary approaches are β-decay and fission-source experiments; the latter are using the state-of-the-art equipment and the infrastructure at ATLAS.

For the in-beam work, Coulex and transfer reactions are the primary sources of information and can be studied with CHICO or Phoswich Wall in conjunction with Gammasphere or GRETINA and, if needed, with the Yale Plunger. For the decay work, both a setup with a thick target and a moving-tape collector is conceivable.

While studies using CARIBU in the region of the heavy-mass peak of ^{252}Cf were not explicitly discussed, there is a strong interest in this region among the members of our working group, as expressed during the workshop. Here the topics include aspects of octupole collectivity and of shell evolution particularly for proton states. Specifically, Coulomb excitation experiments using

GRETINA and CHICO have already started using a ^{144}Ba CARIBU beam with the goal of measuring B(E3) matrix elements associated with the lowest lying octupole band.

Re-accelerated CARIBU beams pose an added complication due to their low intensities. In order for the physics program to extend as far as possible, CARIBU beam intensities and purity should be maximized. In addition, a GRETINA/GRETA array with equal or greater gamma-ray efficiency as Gammasphere would provide a unique device for Coulomb excitation measurements by providing the highest gamma-ray efficiency and energy resolution available in the world. Finally, the proposed multi-user capability for ATLAS would enhance the physics reach for re-accelerated CARIBU beams by allowing experiments to run longer with beam on target without significantly impacting the stable beam program.

An active program involving a number of groups have studied neutron-rich nuclei utilizing deep inelastic reactions with neutron-rich stable beams. Recent investigations have examined single-particle shell structure, shape co-existence and K-isomers in the N=40, N=126 and A~180 regions. These studies will continue and the physics reach extended using Digital Gammasphere in conjunction with $LaBr_3$ detectors.

Opportunities also exist in the study of neutron-rich nuclei using the low energy beam line for CARIBU to study both ground-state, excited state and decay properties of these neutron-rich isotopes with the long range goal to extend these measurements to the most neutron-rich isotopes delivered by CARIBU. Much of the planned experiment program can be accomplished utilizing the laser facility, the X-array decay station and the ORNL detectors MTAS, VANDLE and 3HEN. In addition, similar decay studies could be performed with the proposed N=126 Factory to study the ground and excited state decay properties for neutron-rich nuclides “south” of ^{208}Pb.

4. Nuclear-structure aspects of proton-rich nuclei

Nuclei near the proton dripline exhibit a large variety of nuclear-structure effects. Among the prominent cases are $N \approx Z$ nuclei, where the effects of isospin symmetry (i.e. interplay of $T = 0$ and $T = 1$ states), n-p pairing correlations, and shape coexistence can be studied. An additional aspect for studies in the ^{100}Sn region is superallowed α decay. With the improved instrumentation, a new round of highly selective studies in the ^{100}Sn region is planned, initially focusing on the cases ^{101}Sn and ^{105}Te to determine the order of the neutron $g_{7/2}$ and $d_{5/2}$ states; these are relevant for the composition of the 2^+ state in ^{100}Sn.

For the new studies, the recoil-β-tagging technique is crucial. The experimental programs in this region will take advantage of the GRETINA + FMA combination and the upgraded Implantation Station. A enhanced GRETINA/GRETA detector with equivalent or greater gamma-ray efficiency as compared to Gammasphere would provide an extended physics reach over Gammasphere due to the fact that the target could be located 3 times closer to the FMA’s first quadrupole, and thus resulting in significantly larger FMA residue efficiencies for reactions producing large recoil cones.

5. Studies of phase transitions

Projects of studying shape/phase transitions, in different energy domains though, have been presented in our working group. The "low-energy" project addresses the transition between dynamic symmetries. The cases to be studied are light rare-earth nuclei; methods of discrete γ-ray spectroscopy are used. The "high-energy" project is a level-density study in the 15 – 30 MeV excitation-energy range. The purpose of the study is testing the predicted rise and fade-out of the collective enhancement of the level density with temperature. The cases to be studied are in the isotopic chain of Nd or Sm nuclei; evaporation neutrons will be measured, mass selected by the FMA.

6. Studies of light nuclei

Two projects of studying certain properties of light nuclei (A < 10) have been discussed. First, continuing the very successful program of laser spectroscopy of neutron-rich nuclei in light atoms a comparable study of ^{8}B has been proposed. A structure in this nucleus is viewed as a proton halo. Secondly, the equally successful program of precision lifetime measurements, to test ab-initio calculations, will be continued. The focus will be on measuring M1 strengths in nuclei like ^{7,8}Li.

7. Nuclear-astrophysics aspects of proton-rich nuclei

Spectroscopic studies with the Gammasphere + FMA combination relevant for the rp process and similar issues have been initiated a few years ago. Continuing studies in more exotic nuclei will include studies of ^{26}Al and the ^{34}Ar/^{34}Cl mirror system. Some of these will take advantage of the GRETINA + FMA combination.

APPENDIX

INVITED PRESENTATIONS

1. Nuclear Moments and Radii with Laser Spectroscopy (Peter Mueller)
2. Heavy Element Studies (Darek Seweryniak)
3. Studies of Exotic Proton Rich Nuclei (Helena David)
4. Nuclear Structure using Deep Inelastic Reactions (Partha Chowdhury)
5. Exploring Exotic Nuclear Shapes at ATLAS (Daryl Hartley)
6. Isomeric beams at CARIBU (Ching-Yen Wu)
7. Shape evolution in neutron-rich nuclei around A=100 (Wolfram Korten)
8. Decay spectroscopy techniques to study neutron-rich fission fragments at ATLAS. (Carl Gross)

CONTRIBUTED PRESENTATIONS

1. The Yale Plunger at Gammasphere and GRETINA (Walter Reviol)

2. LaBr Array (Stefan Lalkovski)
3. Deep Inelastic Studies on the neutron-rich side of Pb (Alejandro Sogzoni)
4. Tests of Ab-Initio calculations (Libby McCutchen)
5. Level Density with FMA and neutron detectors (Lee Soboka)