LaTeX Reactions of Nuclear Astrophysics interest using radioactive ion beams at TRIUMF

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The advent of radioactive ion beam (RIB) facilities has opened the way to a new era in nuclear astrophysics research, where experimental data conducted at nuclear physics laboratories world-wide can be directly related to observational data, and aid the development of precise stellar models and nucleosynthesis yields aiming at understanding the interplay of nuclear reactions in stellar interiors. The TRIUMF ISAC (**I**sotope **S**eparator and **AC**celerator [1]) facility in Vancouver, BC, Canada is one of the facilities dedicated to the production and delivery of RIBs, and employs the worlds largest cyclotron to generate a high intensity, 75μA, 500 MeV proton beam for the bombardment of thick high-power production targets. With different combinations of ion sources and target materials a large variety of exotic nuclei can be produced and delivered to the local experiments.

A major expansion of TRIUMF's RIB program, the **A**dvanced **R**are **I**sotop**E** **L**aboratory (ARIEL) nears its completion [2]. Once the ARIEL facility becomes operational, it will triple TRIUMF's RIB capacity. ARIEL evolves around a 500 kW, 50 MeV electron accelerator (e-linac) for isotope production via photon-production and photo-fission, as well as a second proton beam line from the cyclotron allowing for isotope production via proton-induced spallation, fragmentation and fission. Unprecedented rare isotope beam intensities for neutron-rich nuclei are expected to become available for delivery to TRIUMF's nuclear astrophysics experiments, allowing for instance direct studies of reactions involved in potential r-process sites.

The DRAGON (**D**etector of **R**ecoils **A**nd **G**ammas **O**f **N**uclear reactions) recoil separator was built to recreate nuclear fusion reactions in the laboratory, in particular radiative capture reactions on protons and alpha particles [3]. The reactions require to be studied in inverse kinematics in order to take advantage of the radioactive beams delivered by ISAC, which are in most cases too short-lived to be used as target material for normal kinematics measurements.

DRAGON holds the record for radioactive beam measurements of radiative capture, as over the last one and a half decades 8 out of 10 radioactive beam measurements of radiative capture were performed at this facility. By the end of this year we intend to have completed the 9^{th} RIB measurement with the study of the ^{15}O(α,γ) reaction, leaving number 10 in tantalizing reach. The study of the ^{15}O(α,γ) reaction will further mark a milestone in the history of this facility, as DRAGON has specifically been designed for a measurement of this particular reaction. To date studies utilizing RIBs at DRAGON have included astrophysical measurements of importance to the production of isotopic nova observables (^{21}Na(p,γ)^{22}Mg [4, 5], ^{26g}Al(p,γ)^{27}Si [6], ^{18}F(p, γ)^{19}Ne [7], ^{38}K(p,γ)^{39}Ca [8], ^{19}Ne(p, γ)^{20}Na [9]), to nucleosynthesis pathways in novae (^{23}Mg(p,γ)^{24}Al [10]), or of relevance for the ν-p-process (^{7}Be(α,γ)^{11}C).

Further, active nuclear astrophysics research is conducted using the **T**RIUMF **U**K **D**etector **A**rray (TUDA) facility at TRIUMF-ISAC. TUDA is a multipurpose, large solid angle and high granularity silicon detector array, detection chamber and instrumentation apparatus designed for charged particle detection. The LEDA-type detectors are p-n junction type, reversed biased strip detectors, arranged in a radially symmetric

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configuration of 16 annular strips in each of a total of eight azimuthal segments. The energy resolution for detected light particles is exceptional with these detectors, as is the differential and integral linearity of the associated custom-designed analogue electronics, leading to very precise determinations of particle energy/angle. Similar to the DRAGON facility, the experimental program at TUDA covers a wide range of astrophysical scenarios, thereby investigating explosive as well as a non-explosive nucleosynthesis environments. For instance RIBs have been used to target reactions influencing the abundance of nova observables (^{21}Na(p,p)^{21}Na [11], ^{18}F(p,α)^{15}O [12], ^{18}F(p,p)^{18}F [13]), reactions relevant for the breakout from the hot CNO cycle leading to the rp-process in X-ray bursts (^{18}Ne(α,p)^{21}Na [14], ^{20}Na(p,p)^{20}Na [15]), reactions, which are essential to gain insight into AGB star nucleosynthesis (^{18}F(α, p)^{21}Ne), as well as reactions of importance for ^{44}Ti production in core-collapse supernovae (^{21}Na(α, p)^{24}Mg).

In the near future, the scientific program at TUDA will not only address urgent questions regarding nucleosynthesis in stellar environments, but also nuclear structure aspects by combining experimental nuclear astrophysics research with recent efforts in ab-initio theory at TRIUMF [16, 17].

The latest and highly anticipated addition to the nuclear astrophysics program is the Electro-Magnetic Mass Analyzer (EMMA), which has successfully been commissioned most recently [18]. EMMA has been designed for efficiency, as well as for selectivity, and possesses large acceptance in angle, mass and energy while maintaining high beam suppression and resolving power. Thus, the facility is ideally suited to detect recoils from fusion-evaporation reactions. Additionally, the EMMA is intended to be used for the detection of projectile-like recoils from transfer reactions in inverse kinematics.

In my presentation I will outline the achievements of the well established nuclear astrophysics program at TRIUMF and elaborate the challenges of a selection of already realized and planned radioactive beam experiments, as well as the advantages and versatility of the employed facilities. Finally, in view of the upcoming experimental possibilities, I will present an outlook of possible science cases that will come within reach in the future.

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