Proposal for TRIUMF Commitment (5YP 2015-2020)

Date: 26th September 2012

PROJECT/COMMITMENT TITLE: Nuclear Astrophysics at ISAC: DRAGON and TUDA

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PROJECT DESCRIPTION:

The TRIUMF Nuclear Astrophysics Program consists of a wide variety of experiments aimed at determining important thermonuclear reaction rates for a variety of astrophysical scenarios, such as main-sequence stars, classical novae, core-collapse supernovae or type I X-ray bursts. Mainly, this is done through the use of 2 core facilities: the DRAGON facility and the TUDA facility. Currently these facilities receive operating funds for their scientific programs from NSERC, and a set of TRIUMF operating resources for their ongoing maintenance and operation within the laboratory. These ongoing needs will continue into the next 5-year plan, with the addition of some specific upgrades design to expand the abilities of the facilities, such as the expansion of the angular acceptance of DRAGON, and a new lanthanum-bromide array for DRAGON. Ongoing commitments and upgrades will be discussed separately.

Ongoing Commitments

DRAGON

The DRAGON Recoil Spectrometer at the ISAC Facility remains the world's most advanced facility for making direct measurements of the cross sections of *radiative capture* reactions using radioactive ion beams. These reactions are the most common type of fusion reaction in stars, and are of critical importance in quiescent and exotic stellar scenarios, such as main sequence and red giant stars, classical novae, supernovae, and type I X-ray bursts. The combination of ISAC's high-intensity radioactive beams, low-energy accelerator, and the DRAGON instrument, is unique; no other facility can successfully perform the difficult measurements enabled by DRAGON's access to these beams and its versatility and capabilities in sensitivity and background rejection. Since its inception, the DRAGON program has directly measured many of the reactions of importance for nuclear processes in novae and supernovae, that affect the astronomical observables, which are currently targets of interest for gamma-ray astronomy. DRAGON has already directly measured two of these proton-capture reactions for the first time using radioactive beams: ^{21}Na+p → ^{22}Mg+γ and ^{23}Mg+p → ^{24}Al+γ. DRAGON has also measured for the first time the ^{26g}Al+p → ^{27}Si+γ reaction in inverse kinematics using the most intense accelerated ^{26g}Al beam in the world, and also more recently the first ever measurement of radiative capture on a nuclear isomer, namely ^{26m}Al+p → ^{27}Si+γ.

With a series of new ion sources having recently been commissioned at TRIUMF, as well as some near-future developments such as the laser ion source RFQ up ahead, the ability to produce the most intense short-lived radioactive beams at astrophysical energies will been greatly enhanced. Over the years ahead we

anticipate delivery of a wider variety of radioactive and stable beams enabling many direct measurements that were hitherto impossible. These will allow the continuation of our program in making measurements of reactions affecting nucleosynthesis in hydrogen and helium-burning scenarios, such as novae, core-collapse supernovae and type 1 X-ray bursts.

DRAGON operates its scientific program via an NSERC Subatomic Physics Project grant, on the order of $200,000 per annum. In addition, TRIUMF resources of around $15,000 per annum are required. Projected resource requirements for regular operation in the 5 year plan period 2015-2020 are:

- Design Office: 1.5 FTE-week/year (minor upgrade items)
- Controls: 2 FTE-week/year (regular controls maintenance issues)
- Machine shop: 2 FTE-week/year (minor items)
- DAQ Group: 2 FTE-week/year (regular DAQ maintenance issues)
- ISAC Technician 3 FTE-week/year

Major upgrades to the DRAGON facility are considered elsewhere in this document.

TUDA

TUDA (TRIUMF-UK Detector Array) is a general-purpose charged-particle scattering array based on a large number of high-resolution analogue electronic channels, allowing the instrumentation of a variety of highly segmented, large solid-angle silicon detectors.

The TUDA facility has been used in conjunction with gas and solid targets to perform direct reaction studies, indirect charged-particle reaction spectroscopy studies, and elastic scattering studies, for important astrophysical nuclear reactions. This is done both at ISAC I energies and at ISAC II energies, and the facility has been designed to be able to switch between the two beam lines with a minimum of effort.

The TUDA facility is operated mainly by the local collaborating scientists (Buchmann, Davids and Ruiz), along with the external collaborating groups from the UK (Universities of Edinburgh and York). As such, TUDA does not require as many TRIUMF resources as DRAGON for its maintenance and operation, but a modest budget of $4,000 per annum is requested, as well as 2 FTE-week/year of an ISAC technician, in order to move the facility between ISAC I and II, and to perform routine maintenance of vacuum equipment and power supplies. In addition, 0.8 FTE-weeks of Controls work is requested per year.

Future Upgrade Commitments

Upgrade of the acceptance of DRAGON

Despite being the recoil separator with the highest beam suppression anywhere in the world, DRAGON suffers from a smaller angular acceptance than some recoil separators, making measurements of some important astrophysical reactions difficult due to the drop in efficiency at low energies and the need for complex simulations to recover the cross-sections. An increase in the solid angle acceptance by a factor of 2 would permit the measurement of some reactions without transmission losses, and allow the facility to push to very low energies in others, exploiting the capability of the Supernanogan ion source to deliver very high intensity stable beams and thus make small cross-sections measurable at DRAGON.

Increasing the acceptance of DRAGON would be a major disruption to the ongoing program, in that elements of the separator would need to be disassembled and replaced. However, it is deemed feasible on a 2-year timescale. Firstly, ion optical studies would need to be performed to determine the correct size and

type of new quadrupole replacements for the very upstream and downstream parts of the separator. New gas target pumping calculations would need to be done by an appropriately qualified physicist in order to determine what modifications are required to the windowless gas target pumping system. Finite element calculations of gas flow would be needed. This would be followed by a period of design, for replacement

pumping stages, increase of beam-pipe bores and stand positioning. The application for an NSERC equipment grant on the order of $250,000 would follow, once the relevant parameters were determined. With award of this grant, equipment could be purchased and work could began on the modification, staring with the ion-optics and pumping stages. During this time the following resources would be required from TRIUMF:

- Gas target physicist: 13 FTE-weeks
- Beam Optics Physicist: 13 FTE-weeks
- Designer: 20 FTE-weeks
- ISAC technician: 20 FTE-weeks
- Machinist: 13 FTE-weeks
- Controls 2 FTE-weeks

Upgrade of DRAGON gamma-array

The BGO detector array is at the heart of DRAGON's success. With its extremely high detection efficiency for reaction gamma rays (40-80%), it allows efficient background rejection for reactions with small cross sections, giving DRAGON its superior total beam suppression factor, and enabling further background rejection through measurement of the separator time-of-flight. The BGO array has been operating successfully for 12 years now, but it is beginning to show signs of deterioration. In recent years new scintillation materials and other detection media have become available that mimic the high efficiency of BGO but with superior energy resolution and timing properties. One such material is lanthanum-bromide ($LaBr_3$). We propose to apply for funds from NSERC in the next few years for a test detector then a full array of DRAGON-spec LaBr3 detectors. Such a grant would be on the order of $200,000. However, this will require a small amount of TRIUMF resources to be put into action in 2015, namely:

- Designer: 4 FTE-weeks
- ISAC Technician: 4 FTE-weeks
- Machine Shop: 1 FTE-weeks

$5,000 material costs, in order to design and build the support structure for the new array.

SCIENTIFIC JUSTIFICATION:

The study of nuclear astrophysical reactions using direct and indirect methods using radioactive beams is considered one of the cutting edge topics in experimental physics today. The question of the origin of the chemical elements is considered one of the largest scientific questions of our time, and the field of study to understand exotic stellar environments, and their role in the evolution of the universe and their prospective uses for diagnostics in cosmology, remains current and urgent.
The combination of low-energy radioactive beams at TRIUMF and the DRAGON facility is unique in the world, making TRIUMF the only place where some of the important nuclear reactions can be studied.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY:

With a large and diverse astronomy, astrophysics and experimental nuclear physics community, Canada is a hotbed of activity in the field of nuclear astrophysics, with strong connections to JINA in the USA, and European organizations such as EuroGENESIS. Close ties between the astrophysics group at the University of Victoria and the TRIUMF nuclear astrophysics group present the prospect of future collaborative work in the area of astrophysical modeling and reaction rate sensitivity studies, intimately connected to the experiments at TRIUMF, making Canada be in one of the strongest positions in the world for a laboratory

able to do both the experiments and the simulation required to best exploit the beams and facilities to make advances in the field.

BROADER IMPACTS:

Advances in the field of nuclear astrophysics; origin of the chemical elements; link to gamma-ray astronomy missions; link to cutting edge of astrophysical modeling field.

MAJOR MILESTONES:

Description	Date
Equipment grant for LaBr3 array – installation of array	2015
Ion optical, gas and vacuum studies for DRAGON upgrade	2015-2016
Equipment grant for DRAGON upgrade	2016
Installation and Commissioning of DRAGON upgrade	2016-2017

RESOURCE REQUIRMENTS:

CASH FLOW REQUIREMENTS						
\YEAR SOURCE \	ONE	TWO	THREE	FOUR	FIVE	TOTAL
TRIUMF	24,000	19,000	19,000	19,000	19,000	100,000
EXTERNAL	400,000	450,000	200,000	200,000	200,000	1,450,000
TOTAL	424,000	469,000	219,000	219,000	219,000	1,550,000
TRIUMF NON-CASH RESOURCES (FTE-weeks)						
\YEAR RESOURCE\	ONE	TWO	THREE	FOUR	FIVE	TOTAL
Nuclear Physicist	63	63	63	63	63	315
Gas Target Physicist	13					13
Beam Optics Physicist	13					13
Designer	25.5	1.5	1.5	1.5	1.5	31.5
Machinist	16	2	2	2	2	24
DAQ	2	2	2	2	2	10
ISAC Tech.	9	25	5	5	5	49
Controls	2.8	4.8	2.8	2.8	2.8	16

EXTERNAL FUNDING INFORMATION:
DRAGON Operating grant, NSERC (expected ~$200,000/year). DRAGON Equipment grant 1, NSERC ($250,000). DRAGON Equipment grant 2 ($200,000).

ONGOING OPERATIONAL REQUIREMENTS:
DRAGON and TUDA maintenance (power supplies, cooling, controls, gas, vacuum, DAQ).

DECOMMISSIONING REQUIREMENT:

Accepted:	Date: