TRIUMF - RESEARCH PROPOSAL	**Experiment no.** 1106	**Sheet** 1 **of** 15

Title of proposed experiment

Nova observables – ^{18}F abundance and the ^{17}O(p,α)^{14}N reaction

Name of group
TUDRAGON

Spokesperson for group
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Members of group (name, institution, status)
(For each member, include percentage of research time to be devoted to this experiment over the time frame of the experiment)

R. Lewis	University of York	PDRA	40 %
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A. M. Laird	University of York	Lecturer	20 %
A. Murphy	University of Edinburgh	Lecturer	10 %
M. Aliotta	University of Edinburgh	Lecturer	10%
L. Buchmann	TRIUMF	Senior Research Scientist	10%
B. Davids	TRIUMF	Research Scientist	5%
S. Fox	University of York	Scientific Officer	10%
B. Fulton	University of York	Full Professor	10%
C. Ruiz	TRIUMF	Research Assistant	10 %
A. Shotter	TRIUMF	Full Professor	5%
K. Vaughan	University of York		
P. Walden	TRIUMF	Research Scientist	10%

Date for start of preparations: Fall 2006

Date ready: Spring 2007

Completion date: Spring 2008

Beam time requested:

12-hr shifts	**Beam line/channel**	**Polarized primary beam?**
28	ISAC	No

SUMMARY	**Sheet** 2 **of** 15

Do not exceed one page.

The observation of gamma rays from nova outbursts will provide theorists with a unique opportunity to test the predictions of current models. Assuming that the nuclear reaction rates are sufficiently well known, such observational data would allow the underlying hydrodynamics of these models to be put to the test. The launch of the INTEGRAL satellite (aimed at making these observations) emphasises the current need for improved information on the relevant nuclear reaction rates.

The decay of ^{18}F is the major source of gamma rays of 511 keV (and below) from novae. Consequently, it is important to know the final abundance of ^{18}F synthesized during such an event in order to constrain nova models. Moreover, the distance from which these gamma rays could be detected, and thus the expected number of novae that could be observed in this fashion, also relies on such information.

The final abundance of both ^{18}F and the rarest stable oxygen isotope ^{17}O depend strongly on the ratio between the (p,α) and (p,γ) reactions on ^{17}O, since the (p,α) reaction competes with the (p,γ) reaction, thereby reducing the rate of ^{18}F production. Improved information on this ratio at nova temperatures will allow for better estimates of the limiting distance over which we would expect to observe these gamma emissions.

This proposal describes our intention to measure the $^{17}O(p,\alpha)^{14}N$ reaction in the region of the astrophysically important 183 keV resonance. Silicon strip detectors will be used in the DRAGON windowless gas target to measure, in coincidence, the reaction products from an ^{17}O beam impinging on a hydrogen gas target. This measurement is complementary to the accepted DRAGON proposal E1076 which will measure radiative proton capture on ^{17}O.

BEAM and SUPPORT REQUIREMENTS

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Experimental area

ISAC1 – HE, DRAGON

Primary beam and target (energy, energy spread, intensity, pulse characteristics, emittance)

^{17}O, 197keV/u
Intensity at the DRAGON of 5×10^{10} pps.

Secondary channel

None

Secondary beam (particle type, momentum range, momentum bite, solid angle, spot size, emittance, intensity, beam purity, target, special characteristics)

None

TRIUMF SUPPORT:
Summarize all equipment and technical support to be provided by TRIUMF. If new equipment is required, provide cost estimates.

NOTE: Technical Review Forms must also be provided before allocation of beam time.

^{17}O bunched beam production.
Operational support of DRAGON gas target
Support from DAQ and controls groups

NON-TRIUMF SUPPORT:
Summarize the expected sources of funding for the experiment.
Identify major capital items and their costs that will be provided from these funds.

DRAGON

TUDA electronics and detectors, as well as some manpower, will be provided by the Universities of York and Edinburgh.

Support of Canadian participants by NSERC project grants

SAFETY	**Sheet** 4 **of** 15

Summarize possible hazards associated with the experimental apparatus, precautions to be taken, and other matters that should be brought to the notice of the Safety Officer. Details must be provided separately in a safety report to be prepared by the spokesperson under the guidance of the Safety Report Guide available from the Science Division Office.

This experiment does not introduce any additional safety hazards beyond those covered under normal operation of the DRAGON and TUDA facilities. Safety procedures for the operation of the DRAGON and TUDA facilities have been developed and approved.

1 Astrophysical motivation

In addition to the generation of significant amounts of energy, nova outbursts are responsible for the synthesis of many proton-rich nuclides. In order to model the contribution to the interstellar medium of such outbursts, accurate information is needed on the reaction rates that play a role in these events. Direct tests of such models can be provided by the observation of gamma rays originating from nova ejecta. Measured gamma fluxes would provide observational constraints on the final abundances of certain nuclides and thus on the underlying models, assuming that the relevant reaction rates are sufficiently well known. The observation of ^{22}Na, which, via its decay to an excited state in ^{22}Ne, is responsible for a characteristic gamma ray of 1.275 MeV, could be used in this context. Several successful studies have been performed at TRIUMF using the DRAGON [1] and TUDA [2] facilities to gain much needed data on the reactions determining the final abundance of ^{22}Na.

Another important nuclide in this context is ^{18}F. This nuclide is thought to be the most significant source of gamma rays at energies of 511 keV and below [3]. These gamma rays dominate the gamma flux during the first few hours after an outburst. ^{18}F is considered the main contributor since it is produced in relatively high abundances and its half life (109.8 min) is such that the decay positrons are emitted after the expanding envelope becomes transparent to gamma rays.

The distance from which these gammas can be observed is determined by the amount of ^{18}F synthesised during the outburst. In turn, the final abundance of ^{18}F depends upon the relative rates of the processes that produce and destroy it. In novae, ^{18}F is produced mainly by the decay of ^{18}Ne or by the ^{17}O(p,γ)^{18}F reaction while its destruction is via the ^{18}F(p,α)^{15}O and ^{18}F(p,γ) ^{19}Ne reactions. The influence of these two reactions has been investigated by Coc *et al.* [3] who concluded that in the relevant temperature regime the rates of these reactions remain uncertain, emphasising the need for additional experimental information on both these reactions as well as on the ^{17}O(p,α)^{14}N /^{17}O(p,γ)^{18}F ratio. A recent sensitivity study by Iliadis et al. [4] showed that the amount of ^{18}F can vary significantly, depending on the relative rates of the ^{17}O(p,α)^{14}N and ^{17}O(p,γ)^{18}F reactions.

The ^{18}F(p,α)^{15}O and ^{17}O(p,γ)^{18}F reactions are already the focus of accepted ISAC proposals and so the current proposal focuses on the ^{17}O(p,α)^{14}N reaction.

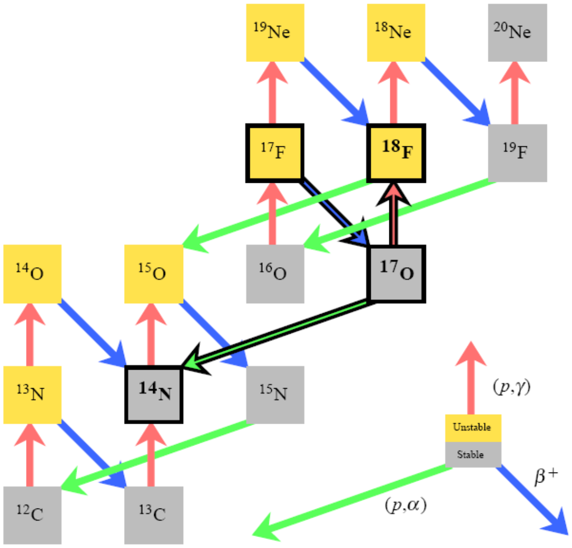

Figure 1: The HCNO cycle. The production and destruction reactions of ^{17}O are highlighted in bold.

2 Current status

The measurement of a previously unknown resonance in the ^{17}O(p,α)^{14}N reaction has recently been reported by Chafa et al. [5]. The location of the new resonance is shown in Figure 2. This new resonance at 183 keV lies in the energy region relevant to novae and significantly changes the ^{17}O(p,α)^{14}N /^{17}O(p,γ)^{18}F reaction rate ratio as shown in Figure 3. The astrophysical implications of the new ratio were found to be as follows: a reduction in the final ^{17}O abundance by a factor of 2.4, and a corresponding reduction in the ^{18}F abundance by a factor of 2.9. This results in a reduction of the detectability distance of novae by a factor of 1.7, with respect to values reported in [6].

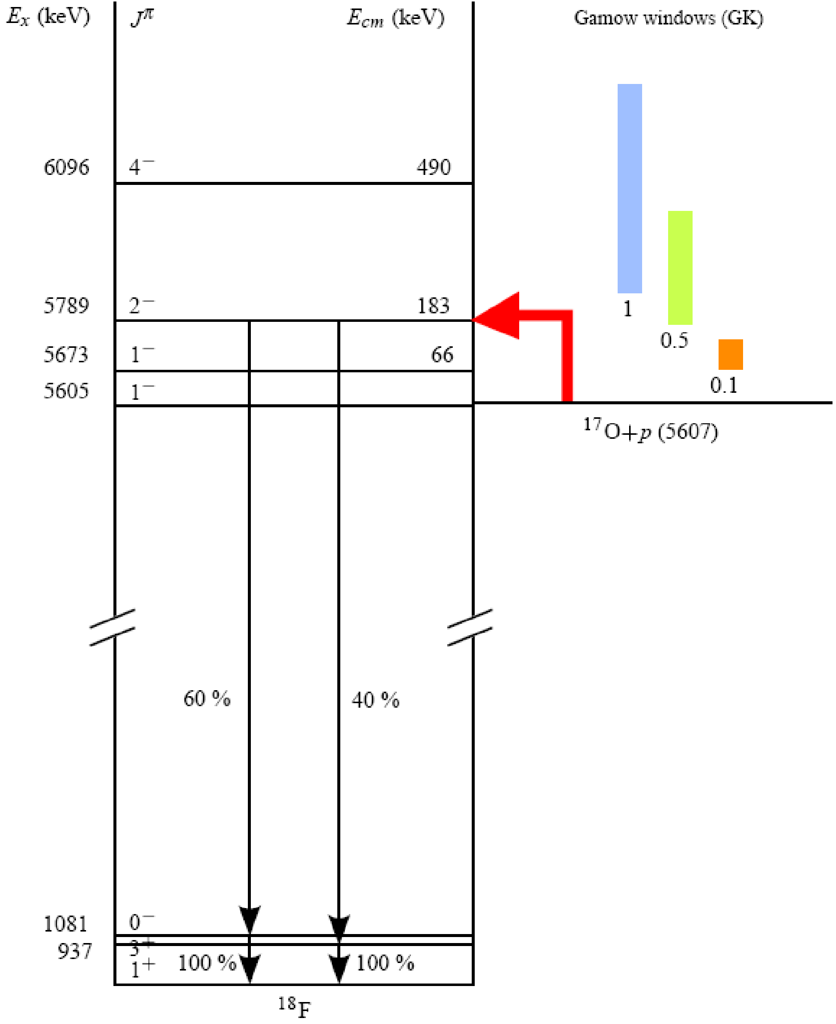

Figure 2: Energy level diagram for ^{18}F. Gamow window is shown for three different temperatures. Figure from Jonty.

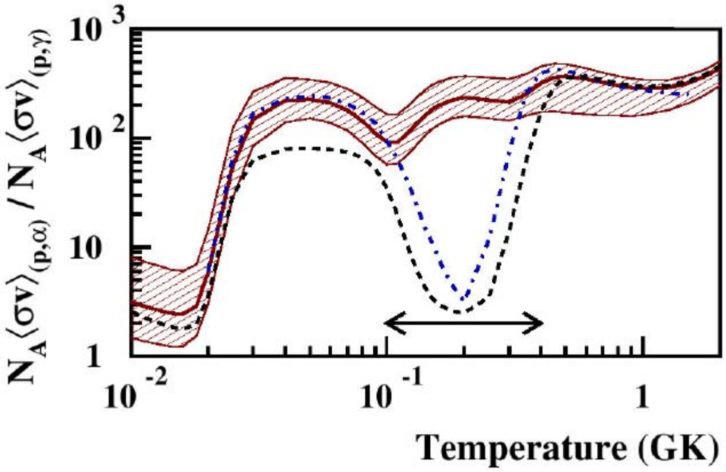

Figure 3: The ratio of the $^{17}O(p,\alpha)^{14}N$ and $^{17}O(p,\gamma)^{18}F$ reaction rates, taken from Chafa [5]. This shows the ratio from Chafa [5] (solid line), Angulo [6] (dashed line) and Fox [7] (dot-dashed line).

Chafa et al. [5] used a proton beam of 60–90 μA and a water-cooled target to investigate the strength of the 183 keV resonance. Targets were made from 0.3 mm thick Ta sheets which were ion implanted with ^{17}O and ^{18}O beams. Reaction products were detected in four silicon detectors with active areas of 3 cm^2 at 105, 120, 135 and 150 degrees, at a distance of 14 cm from the target. A 2-mm aluminized Mylar foil was placed in front of the detectors to protect them from an intense flux of elastically-scattered protons. The resonance strength was found to be $\omega\gamma_{p\alpha} = 1.6 \pm 0.2$ meV.

It is proposed that an independent measurement of this resonance is timely for several reasons. Firstly, Figure 3 shows that the ^{17}O(p,α)^{14}N /^{17}O(p,γ)^{18}F reaction rate ratio is strongly affected by the new resonance and thus an independent measurement is extremely desirable. The proposed technique is in inverse rather than direct kinematics and uses a gas rather than a solid target. Secondly, because it is planned to measure the ^{17}O(p,γ)^{18}F rate at DRAGON in inverse kinematics, a measurement of the ^{17}O(p,α)^{14}N using a similar technique will minimise the effect of possible systematic errors, since uncertainities due to target thickness or beam current can be factored out when determining the reaction rate ratio. Previous measurements of the (p,α) and (p,γ) rates have been independent, and are therefore more difficult to compare, so performing these experiments at the same facility represents a new opportunity.

3 The experimental technique

We propose to measure the 183 keV resonance strength of the 17O(p,a) reaction in inverse kinematics using an 17O beam. The experimental setup will use a combination of the DRAGON gas target together with the TUDA detectors and electronics.

This measurement requires the development of a high intensity ^{17}O beam, as detailed in the DRAGON E1076 proposal. The beam will be delivered to the DRAGON windowless gas target, and its intensity and position will be monitored using the existing Faraday cups and profile monitors. A new gas target box will be constructed to accommodate silicon barrel and annular detectors as well as the required vacuum feedthroughs for signals from the silicon detectors. The BGO array will not be required for this measurement and so can be pulled away from the target box on their cradles, thereby allowing sufficient space for the new target box. The forward annular detectors will cover 8-23 degrees in the laboratory (measured from the centre of the target), measuring 75% of the emitted ^{14}N assuming an isotropic distribution in the centre of mass. (The elastically scattered ^{17}O have a maximum angle of 3.4 degrees and so will not be detected.) The barrel detectors will cover 25-100 degrees in the laboratory to measure the alphas. The recoiling protons have sufficiently different energies in the barrel detector for them to be cleanly distinguished from the alphas. There is some overlap in energy between the ^{14}N and alphas in the annular detector but these can be separated by using time of flight with respect to the pulsed beam. The overall efficiency for detection of both ^{14}N and alphas is approximately 60%. The angular range of the proposed detector configuration is indicated in figure 4.

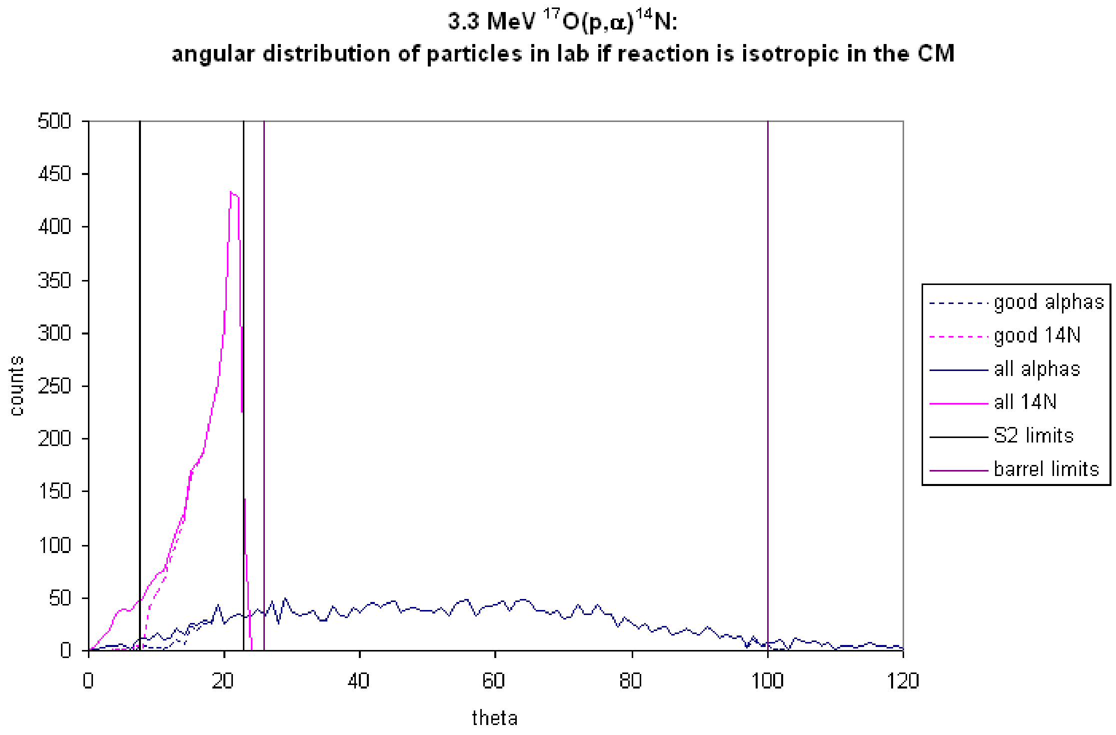

Figure 4: The angular distribution of 14N and alphas in the lab. The proposed angular limits of the silicon detectors are indicated.

From the thick target yield, Y, the resonance strength, $\omega\gamma_{p\alpha}$, can be obtained. The two quantities are related in the following way:

$$Y = \frac{\lambda^2}{2\varepsilon}\frac{m_{17}+m_p}{m_p}\omega\gamma_{p\alpha}$$

In this equation, λ is the de Broglie wavelength and m_{17} the mass of the projectile ^{17}O, m_p the mass of the target proton and ε the stopping power of the projectile in the target in the laboratory system. Therefore, with a measurement of the thick target yield, and knowledge of the stopping power of the projectile in the target (which can be measured in the experiment), the resonance strength can be found, which in turn is directly proportional to the stellar reaction rate.

The proposed experimental configuration covers approximately 80% of the angular range of the emitted particles. To determine the contribution from the rest of the angular range, an angular distribution will be calculated from the coincidence data and a Legendre polynomial will be fitted. The corrected yield will then be used to determine the resonance strength.

The main uncertainties are expected to come from the target thickness, beam intensity and the actual detector efficiency. As the required parameter is the ratio of the (p,α)/(p,γ) reaction rates, the effects of uncertainties in the target thickness and beam current should largely be factored out due to the similarities between this experiment and the (p,γ) reaction experiment.

The proposed experiment uses a technique that is significantly different from that of the previous measurement [5] in several ways, thereby providing a sufficiently independent determination of the strength of the 183 keV resonance. The previous measurement used direct kinematics, whereas we will use inverse kinematics and will therefore have a very narrow forward cone of scattered beam, permitting us to put detectors at a wide range of angles forward and backward, whereas they use only four detectors at backward angles. In addition, they used a solid target implanted with the desired species, and therefore subject to large backgrounds from reactions on the target substrate, as well as energy loss through the target, whereas we use a high-purity windowless gas target, and will therefore have fewer background reactions to separate from the desired reaction products.

4 Beam request

This request is based on the calculation of the expected yield based on the following assumptions: a beam intensity of 5×10^{10} pps; target pressure of 4.5 Torr; cross-sections based on the results of Chafa [5]; total detection efficiency of 60%. Two shifts are requested for testing detectors in the Dragon gas target, weeks or months before beginning the experiment proper. In addition, measurements with two beam energies near the resonance energy (shifting the location of the resonance through the target chamber) will be made, in order to test the systematic uncertainties of the experiment.

Requested beam time:

	Shifts
Detector testing (to be scheduled before the experiment)	2
Resonance measurement 1	8
Resonance measurement 2	8
Off resonance measurement	8
Beam energy changes and contingency	2
Total	28

5 Readiness

The proposed experimental setup requires the manufacturing of a new target box for the DRAGON facility. This can begin at once if this proposal is accepted and is estimated to take 6 months. In addition the silicon barrel detectors will need to be purchased. Funds exist for this and the estimated delivery time is 6 months.

Bearing these factors in mind, it is expected that the set up will be ready shortly after the new OLIS ECR is installed and tested.

6 Future directions

The current proposal is similar in aims to the previously accepted ^{18}F(p,α)^{15}O TUDA proposal, which is awaiting the development of the radioactive ^{18}F beam. Therefore a measurement of the (p,α) reaction on ^{17}O should provide useful information on this technique and highlight possible benefits or drawbacks of the current experimental configuration compared to that proposed for the ^{18}F(p,α)^{15}O measurement.

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