Title of proposed experiment:

Astrophysical Studies Using ^{26}Al ground-state and isomeric beams

Name of group: DRAGON

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Members of the group (name, institution, status, per cent of time devoted to experiment)

Name	Institution	Status	Time
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R. E. Azuma	University of Toronto	Professor	
L. Buchmann	TRIUMF	Research Scientist	
J. Caggiano	TRIUMF	Research Scientist	
A. Chen	McMaster University	Lecturer	
J.M. D'Auria	Simon Fraser University	Professor	50%
B. Davids	TRIUMF	Research Scientist	
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A.M. Laird	University of York	Lecturer	
A.S. Murphy	University of Edinburgh	Lecturer	
A. Olin	TRIUMF	Research Scientist	15%
P. Parker	Yale University	Professor	
J. Rogers	TRIUMF	Research Scientist	
A. Shotter	TRIUMF/University of Alberta	Professor	
TUDA names to be added:			
M. Aliotta	University of Edinburgh	Lecturer	
T. Davinson	University of Edinburgh	Research Associate	
P. Walden	TRIUMF	Research Scientist	
P.J. Woods	University of Edinburgh	Professor	
More names to come...?			

Start of preparations:

Date ready:

Completion date:

Beam time requested:

12-hr shifts Beam line/channel Polarized primary beam?

The synthesis of ^{26}Al is one of the unique cases in Nuclear Astrophysics where we are provided with a direct observational signature enabling comparison with theoretical stellar models. This is seen with the decay of ^{26}Al with a characteristic γ-ray. The contribution of various astrophysical sources to the observed ^{26}Al/^{27}Al ratio seen in the solar system in, for example, Carbonaceous Chondrite Chondrules, can be gauged via an understanding of observational spectra and stellar models. The relevant nuclear reaction rates to the formation of ^{26}Al are vital model parameters which need to be measured experimentally. Of increasing importance in recent years is the need to understand the extent of ^{26}Al formation in novae and supernovae.

The ^{26}Al(p,γ)^{27}Si reaction plays an important role in the formation of ^{26}Al since besides β-decay, it is the only direct ^{26}Al destruction process. This reaction rate is known to within a factor four, rather than the 20% accuracy required for consistent astrophysical modeling. Matters are complicated due to the existence of a low-spin, low-energy isomeric state of ^{26}Al which will be populated at the peak temperatures relevant to nova and supernova scenarios. The ^{26m}Al(p,γ)^{27}Si reaction has previously been included in reaction-rate compilations using theoretical estimates, and no direct experimental information for it exists. Any significant resonance contribution in this reaction rate could directly affect the final ^{26}Al/^{27}Al ratio synthesised in high temperature astrophysical scenarios.

The possibility of the existence of previously unobserved s-, p-, and d-wave resonances in ^{26m}Al+p and the prospect of a mixed ground-state/isomeric ^{26}Al beam at ISAC allows for the first time a direct experimental determination of these reaction rates using the DRAGON facility.

We propose to measure astrophysically relevant resonance strengths in the ^{26g}Al(p,γ)^{27}Si and ^{26m}Al(p,γ)^{27}Si reactions, at energies ranging between 190 keV/u and 1600 keV/u.

Experimental area

DRAGON and TUDA facilities in the ISAC experimental hall

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

500 MeV proton beam from TRIUMF cyclotron

Secondary channel ISAC - HE

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

^{26}Al (mixed ground state and isomer) with intensities $> 10^9$ ions/sec. Energies ranging from 150 to 1600 keV/u. Stable ^{28}Si will be used for charge-state studies at DRAGON.

TRIUMF SUPPORT:

Continued infrastructure support from TRIUMF for DRAGON at ISAC, including assigned personnel.

NON-TRIUMF SUPPORT

NSERC DRAGON Project Grant (J. M. D'auria et al.), approved by NSERC in 2001 for 3-year support.

The ground state of ^{26}Al has a half-life of 717,000 years. Assuming beam intensities of the order 10^9 ions/sec, approximately 50 Bq of activity would be generated if this were distributed in one place over a period of three weeks. DRAGON will ensure that removable liners, slits and collimators will be used in sections of the separator where beam is deposited. Active radiation monitoring of affected areas and consequent relevant courses of action will be undertaken.

The metastable state of ^{26}Al has a half-life of 6.35 seconds. Normal DRAGON procedures when running short-lived radioactive beam will be observed.

Standard DRAGON procedures for use of the Hydrogen-filled windowless gas target will be observed.

1 Scientific Justification

1.1 Galactic Production of ^{26}Al and ^{26}Al/^{27}Al Abundance Ratios

Measurements of ^{26}Mg excesses in meteorites such as the Allende, suggest that it is formed via the beta-decay of ^{26}Al, which has a half-life of 0.7 million years. The initial abundances of ^{26}Al can be estimated. Similar studies on the Galactic production of ^{26}Al allow a more detailed understanding of nucleosynthesis in the cosmos. ^{26g}Al (J^{π}=5^{+})[1], beta-decays to the first excited state of ^{26}Mg, which decays with a characteristic gamma-ray of energy 1.809 MeV. Space based observatories such as INTEGRAL will possibly be able to measure gamma-ray fluxes from astrophysical sources such as novae, allowing a diagnostic observation of the production rate of ^{26g}Al in these scenarios. ^{26}Al is formed in the MgAl cycle, within the sequence:

$$^{24}\mathrm{Mg}(\mathrm{p},\gamma)^{25}\mathrm{Al}(\beta^{+})^{25}\mathrm{Mg}(\mathrm{p},\gamma)^{26}\mathrm{Al}$$

The ^{25}Al(p,γ)^{26}Si reaction rate is of importance to the formation of ^{26}Al since the ^{26}Si decays only to the isomeric state (0^{+}) of ^{26}Al at 228 keV, which then completely bypasses the ground state via beta-decay to the ^{26}Mg ground state with a half-life of 6.35 seconds. Thus the stronger the ^{25}Al(p,γ)^{26}Si rate is, the less ^{26}Al is formed. This rate is the subject of an accepted experiment proposal here at TRIUMF-ISAC using the DRAGON recoil separator [Che01], and requires the development of a ^{25}Al beam.

Also of major importance to the ^{26}Al production rate is the ^{26}Al(p,γ)^{27}Si reaction itself, since besides beta-decay it is the only direct ^{26g}Al destruction process. The stronger this rate is, the less ^{26g}Al is formed. This rate is extremely sensitive to the properties of resonances corresponding to states in ^{27}Si.

The short lived isomeric state, ^{26m}Al, is formed via the ^{25}Mg(p,γ) reaction, as well as the beta-decay of ^{26}Si. Because of the large spin difference between this isomeric state and the ground state, no direct communication exists between them (although some communication occurs via higher lying states) [Run01]. Thus the ^{26m}Al(p,γ)^{27}Si reaction is not directly important for the destruction of ^{26g}Al, and ^{26m}Al is not detected via gamma-ray flux measurements anyway since no characteristic γ-ray results from its decay. However, a better understanding of the role of the ^{26m}Al(p,γ)^{27}Si reaction could be an important aspect of Nucleosynthesis studies since abundance ratios in the Al-Si range may be affected by this rate, and in supernova scenarios rather than novae, this reaction may play a more important role in the formation of ^{26}Al. The correct consideration of the role of the isomeric state in high temperature scenarios such as supernovae type II requires accurate experimental information on all the isomeric state creation and destruction processes, of which ^{26m}Al(p,γ)^{27}Si is the most uncertain, being based solely theoretical calculations. S. Woosley, an expert experienced in supernova type II (SNII) nucleosynthesis studies, believes that SNII are responsible for the majority of ^{26}Al formed in the Galaxy, and that hydrogen burning in the Ne shell of the SNII precursor is the dominant contributing process, although some burning may also take place in the H-layer. The role of the

[1] From hereon the suffixes g and m denote the ground- and isomeric-state of Aluminium-26 respectively. When no suffix is present, this indicates that the present context refers to Aluminium-26 in general.

^{26}Al isomeric state is included in calculations using the Hauser-Feschbach estimates and assuming a temperature-dependent half-life for ^{26}Al to take into account possible thermal mixing processes. Woosley has expressed desire to know the isomeric state rates accurately to improve existing calculations [Woo03].

Both the ^{26g}Al(p,γ)^{27}Si and ^{26m}Al(p,γ)^{27}Si reactions depend strongly on the properties of resonances corresponding to excited states in ^{27}Si. Therefore a proper understanding of the spectroscopy of ^{27}Si is required in addition to direct measurements of the rates themselves.

The existing data on the isomeric state reaction rate is soleley based on Hauser-Feschbach calculations, and no direct measurement of this rate exists. The ground state reaction rate is dominated by a few specific resonances at low temperatures, which have been measured indirectly[2] with large uncertainties.

1.2 Spectroscopy of ^{27}Si

The current NACRE compilation [Ang99] contains adopted ^{26}Al+p resonance parameters corresponding to fifteen states in the compound nucleus ^{27}Si. Out of the fifteen observed resonances, only five were included in the adopted ^{26}Al(p,γ)^{27}Si reaction rates in this compilation, all below 370 keV centre-of-mass energy. The remaining ten resonances were considered to provide a negligible contribution to the reaction rate over the tabulated temperature range between $0.018 \leq T_9 \leq 10$. Above $T_9 = 0.9$, Hauser-Feshbach calculations were used for the reaction rate evaluation. Figure 1 shows a level diagram of ^{27}Si and the analogue nucleus ^{27}Al. The Q-value for ^{26g}Al+p is 7464 keV, while the isomeric state at 228.305 keV makes a higher threshold with a Q-value of 7692 keV. Table 1 lists the ^{27}Si excitation energies with their corresponding resonance energies, adopted resonance strengths, spin-parity assignments and widths in the ^{26g}Al+p system, for those states included in the NACRE compilation. The right-hand column indicates whether the adopted resonance strengths were taken from shell-model (SM) calculations or experimental (EX) measurements, and the relevant reference is listed also. The earliest experimental work performed relevant to the ^{26}Al(p,γ)^{27}Si reaction was by Buchmann et al. [Buc84], directly measuring ^{26}Al+p resonances from the 276 keV resonance upwards. With the exception of the resonance at 328 keV, this measurement remains the source for the adopted resonance strengths at these higher energies. Later experimental work includes that of Schmalbrock et al. [Sch86], which probed states in ^{27}Si using the ^{28}Si(^{3}He,α)^{27}Si reaction. This study confirmed the existence of the Buchmann states, as well as identifying several more states in the energy region of interest, including what are now adopted as the 68 keV, 128 keV, 188 keV and 238 keV resonances.

Later spectroscopy by Wang et al. [Wan89] using the ^{27}Al(^{3}He,t)^{27}Si reaction identified seven resonances below the lowest Buchmann resonance at 276 keV, including the 68 keV, 128 keV, 188 keV and 238 keV resonances seen by Schmalbrock et al. A new resonance was discovered at 4 keV, while tentative identifications were made of resonances at 93 keV and 226 keV. This study attempted to estimate the possible capture ℓ-value for each resonance from comparisons with the mirror nucleus ^{27}Al. It concluded that only

[2] One measurement of the strengths of these resonances exists, although the data have never been published [Vog89].

E_x (^{27}Si) (keV)	E_R (keV)	adopted $\omega\gamma$ (meV)	J^π	Γ (keV)	source
7468	4	1.5 x 10^{-75}			SM Cha93
7532	68	2.2 x 10^{-11}			SM Cha93
7557	93	5.3 x 10^{-9}			SM Cha93
7592	128	5.9 x 10^{-7}			EX Vog96
7652	188	0.064			EX Vog96
7690?	226	?			EX Wan89
7702	238	4.7 x 10^{-3}			SM Cha93
7741	276	3.8 ± 1.0	(9/2,11/2)+	< 0.3	EX Buc84
7792	328	0.2 +0.02-0.01			SM Cha93
7828	363	65 ± 18	(9/2,11/2)+	< 1.0	EX Buc84
8157	693	51 ± 27		< 0.5	EX Buc84
8165	701	16 ± 6		< 0.5	EX Buc84
8226	762	36 ± 13		< 0.5	EX Buc84
8289	825	41 ± 16		< 1.0	EX Buc94
8358	894	67 ± 28		< 0.5	EX Buc94

Table 1 Excitation energies in ^{27}Si and the corresponding ^{26g}Al+p centre-of-mass resonance energies, adopted resonance strengths and assigned spin-parities and/or total widths; as tabulated in the NACRE compilation [Ang99] (Excitation energies from [End90]).

one s-wave resonance would exist below 276 keV, probably being the 128 keV resonance. All other resonances below this energy were concluded to have a minimum d-wave capture. The Wang study also identified seven ^{27}Si states in the region between the 363 keV resonance and the 693 keV resonance, at excitation energies of 7893 keV, 7911 keV, 7972 keV, 8036 keV, 8074 keV, and 8140 keV [End90].

An investigation of ^{27}Si states by Vogelaar et al. [Vog96] measured spectroscopic factors for the 125 keV, 188 keV and 276 keV resonances using the ^{26}Al(^{3}He,d)^{27}Si reaction. Unique ℓ-transfer assignments could not be made, and so estimates of the resonance strengths assuming a range of pure ℓ-transfers were obtained.

Theoretical work on the states in ^{27}Si consists of shell-model calculations by Champagne et al. [Cha93] and Coc et al. [Coc95]. The Champagne paper uses a single particle shell model to predict level shifts between ^{27}Al and ^{27}Si. Suggested analogue assignments between these mirror nuclei were made, and the maximum level shift was found to be of the order 650 keV.

The current updated knowledge of states in ^{27}Si is represented in figure 1. Shown are the Gamow windows for peak temperatures of T_9=0.05, 0.1, 0.2, 0.3 and 0.9, for both ground state and isomeric state capture. It can be seen from a comparison of figure 1 and table 1 that there are several states known in ^{27}Si in the region corresponding to low- and medium-temperature burning of ^{26m}Al for which spin-parities and resonance strengths are unknown. The 5^+ ground state of ^{26}Al forms states in ^{27}Si with comparatively large angular momenta: s-wave resonances will form states with J^π=$9/2^+$,$11/2^+$. However the 0^+ isomeric state will form states of much lower angular momentum, and indeed can only form states with J^π=$1/2^+$ via s-wave capture. Thus the presence of a state with low angular momentum in the region between 7828 keV < E_x < 8158 keV could facilitate the

^{26m}Al(p,γ)^{27}Si reaction via s-, p- or d-wave capture.

Looking at the analogue states in ^{27}Al in the region around 8 MeV, it can be seen that there are several candidates with low angular momentum which could correspond to some of the unassigned states in ^{27}Si. Most striking is the $1/2^+$ state at 8130 keV, which, following the trends in level shifts proposed by Champagne et al., could correspond to one of the five states between 7828 keV and 8158 keV in ^{27}Si and therefore provide a strong s-wave resonance in ^{26m}Al+p. Also present are the $3/2^-$ state at 8182 keV, which could correspond to an ℓ=1 resonance, and the 5/2 states at 8097 keV and 8136 keV which could correspond to ℓ=2 resonances.

2 Resonance Strengths in ^{26g}Al+p

The dominating resonance in ^{26g}Al+p for novae is that at E_{cm}=188 keV [Ang99]. A change in the strength of this resonance by 1/6th of its adopted value would result in a large change in the final abundance of ^{26}Al [Jos03]. It is then essential that the strength of this resonance be measured to a high precision. The current adopted strength of the resonance is 0.064 meV, where the upper and lower limits are 0.29 meV and 9.9×10^{-6} meV respectively. This resonance strength had been measured previously with a strength of $55 \pm 9\mu$eV [Vog89] but the results were never published in a peer-reviewed journal and therefore were not included in the recent reaction rate evaluations of Angulo et al. and Iliadis et al. [Ang99],[Ili01]. Since extreme importance is attached to this reaction rate, we believe it is important that an independent measurement be made of this resonance strength using the DRAGON facility.

The state corresponding to a resonance at 226 keV, observed in only one experimental study and not included in the NACRE evaluation, could have interesting implications for the final ^{26}Al(p,γ)^{27}Si rate.

A direct measurement of these resonance strengths is proposed, using the DRAGON recoil separator. Experimental details are given in section 3.

2.1 Resonance Strengths in ^{26m}Al+p

The possible existence of s-, p- or d-wave resonances in ^{26m}Al+p introduces the need for the experimental determination of the resonance strengths in order to determine the contribution to the ^{26m}Al(p,γ) reaction rate, and the subsequent astrophysical consequences. In order to determine the feasibility of measurement of these resonance strengths, and estimate the possible magnitude of their influence, one can derive similar upper limits on resonance strengths as considered for ^{26g}Al+p in previous work, using the following method. The resonance strength is defined as

$$\omega\gamma = \frac{(2J+1)}{(2I_1+1)(2I_2+1)} \times \frac{\Gamma_\gamma \Gamma_p}{\Gamma_\gamma + \Gamma_p} \qquad (1)$$

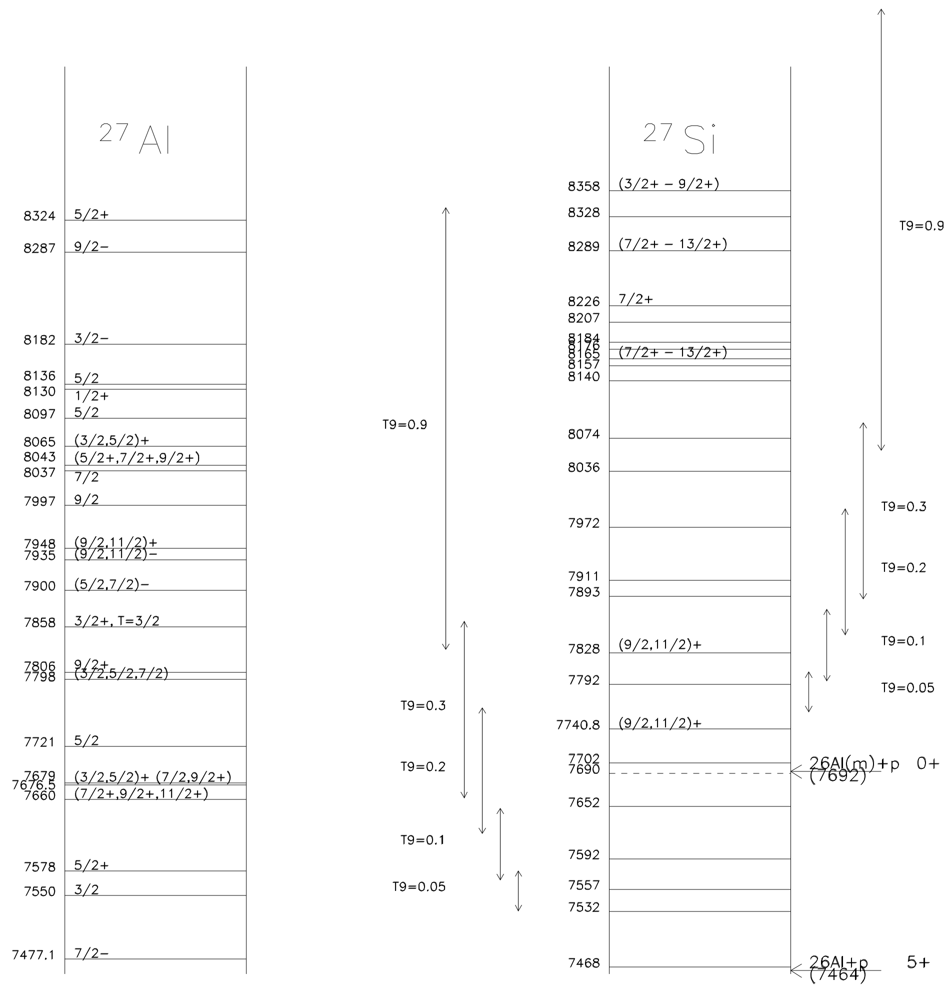

Fig. 1 Comparison of known states in the A=27 analogue system. Marked are the proton-capture thresholds for both ^{26g}Al and ^{26m}Al. Also marked are the Gamow windows for a range of peak temperatures corresponding to both these captures. The ranges from T_9=0.05-0.3 correspond to nova temperatures, while T_9=0.9 corresponds to a typical supernova type II temperature. Data taken from [Ang99] and [End90].

which for $\Gamma_p \ll \Gamma_\gamma$ leads to the approximation $\omega\gamma \approx \omega\Gamma_p$. The upper limit of the resonance strength for different possible ℓ-values can then be calculated by setting the dimensionless proton width, θ_p to unity:

$$\omega\gamma = \omega\frac{3\hbar^2}{\mu r^2}P_\ell(E)\theta_p^2 \tag{2}$$

The above method is good for estimating resonance strengths when $\Gamma_p \ll \Gamma_\gamma$. However, as the energy of the system increases, the proton widths of the states tend to increase also. Thus at higher energies when $\Gamma_\gamma \ll \Gamma_p$, the equivalent argument would imply $\omega\gamma \approx \omega\Gamma_\gamma$. The analogue assignments made in the work of Wang et al. [Wan89] show that level shifts between states in ^{27}Al and ^{27}Si are of the order 100 keV. This would imply that states in ^{27}Si with resonance energies in the ^{26m}Al+p system above 400 keV would correspond to analogue states in ^{27}Al above around 8192 keV. States in this region are likely to have γ-ray widths of the order 1 eV and above[3], and so reasonable estimates of the maximum possible resonance strengths in ^{26m}Al+p can be made by combining this information with calculated single particle proton-widths.

Table 2.1 shows the resulting maximum[4] proton widths and resonance strengths for the ^{27}Si states at 7893 keV and above, up to the 8451 keV state. States with known large ^{26g}Al+p resonance strengths or known high spin values have been omitted.

Figure 2.1 shows the maximum possible ^{26m}Al(p,γ)^{27}Si reaction rate assuming s-wave capture, using the resonance strengths from table 2.1. The black bold curve shows the maximum total rate, while the coloured curves show the contributions for individual resonances. The bold red curves joining the diamond and circular data points are the adopted reactions ratres for the metastable state and ground state respectively. The figure gives an idea of how the actual reaction rate might differ from the adopted rate if strong resonances exist in the ^{26m}Al+p system. It can be seen that at supernova temperatures, ie, 0.9 GK, the rate could differ by two orders of magnitude. Of course nothing is really experimentally known about resonances in the ^{26m}Al+p system, and the rate could even turn out to be less than the adopted rate at supernova temperatures. Recent nova calculations [Jos03] have shown that changing the adopted ^{26m}Al(p,γ)^{27}Si rate by a factor 500 does not have a significant effect on the production of ^{26}Al, and only changes final abundances of nuclei which are fairly abundant anyway, such as ^{26}Mg. However, there is as yet no information on how this rate might affect nucleosynthesis in supernova, the most recent calculations being made using the Hauser-Feschbach based adopted rates [Tim]. It should be noted that in the higher taemperature scenarios of supernova type II, the ground state and isomer are mixed in quasi-thermal equilibrium. It is then desirable to the modelers that experimental nuclear physics information on all of the creation and destruction processes of the isomeric state be provided in order to correctly investigate the consequences for synthesis of the Magnesium to Silicon group of isotopes and production of ^{26}Al [Woo03].

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[3] The 8442 keV state is known to have a lifetime of 0.5 femtoseconds, corresponding to a width of 1.3 eV, and the 8597 keV state is known to have a width of 0.56 eV.

[4] The largest possible angular momentum for the compound state has been assumed for each capture ℓ-value.

E_x (keV)	E_R^m (keV)	Γ_p^{sp} (keV)	$\omega\gamma$ ℓ=0,1,2 (eV)
7893	201	2.4e-5	0.023
		5.1e-6	0.010
		2.9e-7	0.001
7911	219	7.7e-5	0.071
		1.7e-5	0.033
		9.7e-7	0.003
7972	280	1.7e-3	0.628
		3.7e-4	0.545
		2.3e-5	0.068
8036	344	1.7e-2	0.944
		3.8e-3	1.587
		2.5e-4	0.603
8074	382	5.0e-2	0.980
		1.1e-2	1.840
		7.8e-4	1.312
8140	448	2.3e-1	0.996
		5.4e-2	1.964
		3.9e-3	2.386
8176	484	4.6e-1	0.998
		1.1e-1	1.982
		8.1e-3	2.671
8184	492	5.3e-1	0.998
		1.3e-1	1.984
		9.5e-3	2.714
8207	515	7.8e-1	0.999
		1.9e-1	1.990
		1.4e-2	2.806
8328	636	4.2	1.0
		1.1	2.0
		0.09	3.0
8451	759	14.9	1.0
		4.0	2.0
		0.4	3.0

Table 2 Maximum strengths calculated for possible resonances in ^{26m}Al+p for ℓ=0,1,2 using a dimensionless proton width equal to unity.

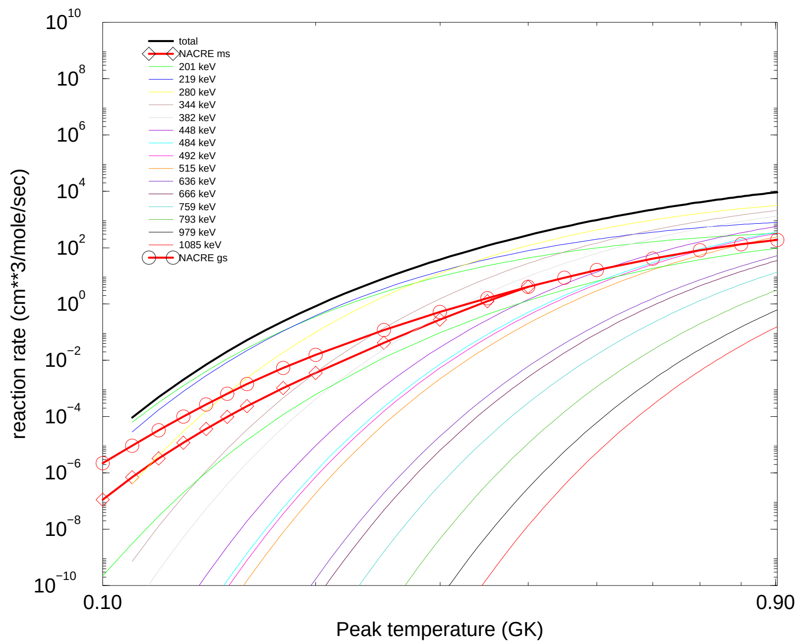

Fig. 2 Maximum ^{26m}Al(p,γ)^{27}Si reaction rate contributions compared with the adopted ^{26}Al(p,γ)^{27}Si rates. The contributions were calculated using upper limits on $\omega\gamma$ assuming s-wave capture.

In order to ascertain the existence of resonances in the ^{26m}Al+p system, it is proposed that a resonant elastic scattering experiment be perfomed at TUDA using a mixed isomer/ground-state beam. Any significant resonances can then be targeted using DRAGON, with the aim of directly measuring their strengths. The methodology and details of these experiments will be described in the next section.

3 Description of the Experiment

3.1 Phase I: ^{26g}Al(p,γ)^{27}Si resonance strengths

The ^{26g}Al(p,γ)^{27}Si reaction will be measured in inverse kinematics using the DRAGON recoil separator. The thick target yield function is given by

$$Y = \frac{\lambda^2}{2\epsilon}\frac{M+m}{M}(\omega\gamma) \tag{3}$$

which applies since the target thickness is greater than the width of the proposed resonances. The parameter ϵ is the stopping power in units of eV/atom/cm^2 in a uniform density target. Thus an experimental measurement of the ^{27}Si yield per incoming ^{26}Al ion results in determination of $\omega\gamma$, the important astrophysical parameter.

The ^{26}Al beam will be produced using the SiC solid target and the resonant laser ionisation source on-line. Isobaric contamination of ^{26}Na, ^{26}Mg, and ^{26}Si (ΔM/M 1/4763, 1/6044 and 1/5004 respectively) should be removed by the selectivity of the ISAC mass separator (ΔM/M = 1/10000). ^{26}Si and ^{26}Na contamination are the more problematic, they decay however, with half-livese of 2.234 seconds and 1.072 seconds respectively. The ^{26m}Al component of the beam ($t_{1/2}$ = 6.35 s) can be controlled by allowing the proton beam to stay on target for a certain period of time, then stopping the beam, during which time the target temparature will be raised. This allows fast diffusion of the required ^{26}Al ground state, while the shorter lived isomeric state will have mostly decayed. This way the ratio of ^{26m}Al/^{26g}Al can be controlled. Further Z-discrimination will be provided using the ion-chamber at the DRAGON focal plane, ensuring any contamination in the recoil spectrum from other isobars is removed.

The amount of ^{26m}Al present in the beam can be monitored by stopping the beam on a cup next to a scintillator and counting the betas. Besides this, normalisation can be performed using the elastic monitor at the DRAGON gas target. In the low-energy region, proton widths are small and therefore elastic cross-sections are very close to Rutherford.

^{26m}Al beams have already been measured at the ISAC yield station with intensities of the order 10^7 ions/sec using the SiC target and the surface ionisation source. Comparisons between Faraday cup measurements and γ-yields imply that two orders of magnitude more ground state was present in the beam. Further testing to optimise ^{26}Al output from the targets, as well as the hoped for ionisation enhancement from the resonant laser ioisation source offer the prospect of intense ^{26}Al beams in the near future [Mar03].

The DRAGON windowless gas target will have an H_2 areal density of approximately 3×10^{18} atoms/cm^2 at an operating pressure of 4 Torr. Using calculated stopping power

E_x (keV)	E_r (keV)	$E_{r,lab}$ (keV)	$E_{r,beam}$ (keV/u)	$\Delta\theta$ (mrad)	Yield (per ion)
7652 ± 3	188 ± 3	5036	194	15.5	0.4×10^{-12}
7690 ± 3	226 ± 3	6053	233	14.2	0.3×10^{-13}

Table 3 Yields for the proposed measurements of two resonances in ^{26g}Al(p,γ)^{27}Si, with a target pressure of 4 Torr and adopted values of the resonance strengths (a value of 1/10th that of the 188 keV resonance was used for the 226 keV resonance).

values, estimates of the yield per incoming ion can be made using the current adopted values of the resonance strengths. These yield estimates for the two proposed ^{26g}Al+p resonances are displayed in table 3.

Using estimated values of 40% each for the efficiency due to the charge state distribution of the recoils and the BGO array, the yields listed in table 3 gives rise to count rates of 0.23 counts/per hour and 0.02 counts/per hour with a beam intensity of 10^9 ions/sec for the 188 keV resonance and 226 keV resonance respectively[5].

3.2 Phase II: ^{26m}Al(p,p)^{26m}Al resonant elastic scattering

At TUDA, resonant elastic scattering can be used to identify strong resonances in nuclear systems. Such work has already successfully been completed using radioactive ^{21}Na and ^{20}Na beams at ISAC [Rui02][Mur03]. However, the ground state of ^{26}Al, with its high spin of 5^+, can only form high spin states in the compound nucleus. However, resonances in the ^{26m}Al+p system would correspond to lower spin states which could be observed using resonant elastic scattering on the isomeric state. Sub-keV resonances have already been observed in resonant elastic scattering using TUDA [Rui03], and it is then probable that resonances of the order 1 keV would be observed at higher centre-of-mass energies using scattering of the isomeric state. It is proposed that a mixed isomer/ground-state beam be used to scatter off thick polyethylene foils in the TUDA chamber. Recoil protons will be detected using highly segmented large solid-angle LEDA detectors, and the resonant data used to identify strong resonances in the ^{26m}Al+p system, much as in the previous work of Ruiz et al [Rui01][Rui03]. Background runs with the isomeric component of the beam reduced[6] can be made to ensure definite removal of the effects of scattering from the ground state.

In summary, it is proposed that resonant elastic scattering be performed using a mixed isomer/ground-state beam, using thick polyethylene targets, at centre-of-mass energies ranging from 500 keV to 1600 keV. Background runs will be performed with the isomeric component of the beam substantially reduced.

In order to see keV-width level variations in the cross-section, spectra with good statistics (thousands of counts per channel) need to be acquired. It is the experience of previous TUDA runs that each thick target run, spanning around 150-200 keV in the centre-of-mass, can acquire such statistics in 48 hours with beam currents of around 5×10^7 ions/sec. The data rate in previous experiments was limited by the acquisition system. The new VME-based acquisition system is designed to handle rates of around 10 kHz,

[5] The strength of the 226 keV resonance was set to 1/10th that of the 188 keV resonance.
[6] Refer to Phase I of the proposal for a description of the reduction process.

compared to an acceptible 1 kHz with the CAMAC system. This will enable a factor ten increase in beam intensity (taking care to renew the polyethylene targets as required). Given the fact that around 10 thick target runs will be required to span the energy range of interest. It is a conservative estimate that around 10 days will be required per thick target scan. See last section of this proposal for beamtime requirements.

3.3 Phase III: Resonance strengths in the ^{26m}Al(p,γ)^{27}Si reaction

Any resonances observed in the elastic scattering experiment will be measured directly using DRAGON with similar methodology as detailed in Phase I of this proposal. Since the amount and strength of any prospective resonances are unknown, reliable estimates of the time required are difficult. However, in section 3, we ask for an initial amount of beamtime in order to facilitate the measurement of any or some of the resonances identified during the running of TUDA in phase II of this proposal.

4 Beam Time required

PHASE I

Measurement	Shifts Required
• Charge state distributions	
^{28}Si	3
• Resonance Strengths of the ^{26g}Al(p,γ)^{27}Si reaction	
On 188 keV resonance	20
Off 188 keV resonance (1 energy)	10
On 188 keV resonance with reduced isomer component	20
On 226 keV resonance	10
On 226 keV resonance with reduced isomer component	10
TOTAL	73

PHASE II

Measurement	Shifts Required
• Thick target resonant elastic scattering of ^{26m}Al	
500 keV - 1500 keV scan	20
500 keV - 1500 keV scan with reduced isomeric component	20
• Calibration resonance	

PHASE III

Measurement	Shifts Required
• Resonance Strengths of the ^{26g}Al(p,γ)^{27}Si reaction	
Resonance strength measurements	10

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