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Letter

Identification of γ-decaying resonant states in ^{26}Mg and their importance for the astrophysical s process

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Abstract. The ^{22}Ne(α, n) reaction is expected to provide the dominant neutron source for the weak s process in massive stars and intermediate-mass (IM) Asymptotic Giant Branch (AGB) stars. However, the production of neutrons in such environments is hindered by the competing ^{22}Ne$(\alpha,\gamma)^{26}$Mg reaction. Here, the ^{11}B(^{16}O,p) fusion-evaporation reaction was used to identify γ-decay transitions from ^{22}Ne$\,+\,\alpha$ resonant states in ^{26}Mg. Spin-parity restrictions have been placed on a number of α-unbound excited states in ^{26}Mg and their role in the ^{22}Ne$(\alpha,\gamma)^{26}$Mg reaction has been investigated. In particular, a suspected natural-parity resonance at $E_{c.m.} = 557(3)$ keV, that lies above the neutron threshold in ^{26}Mg, and is known to exhibit a strong α-cluster character, was observed to γ decay. Furthermore, a known resonance at $E_{c.m.} = 466(4)$ keV has been definitively assigned 2^+ spin and parity. Consequently, uncertainties in the ^{22}Ne(α,γ) stellar reaction rate have been reduced by a factor of ~ 20 for temperatures ~ 0.2 GK.

Nearly half of all the elements in our Galaxy heavier than iron were formed by the astrophysical s process. This process involves a series of neutron captures on nuclei lying at or near stability and, as such, represents one of the most experimentally well-studied astrophysical processes to date —cross sections for almost all (n,γ) reactions involved have been constrained to a precision of $\sim 20\%$ or better [1]. However, significant difficulties remain in successfully modelling the astrophysical s process, due to large uncertainties in the nuclear reactions responsible for the production of neutrons in stellar environments. Furthermore, in order to accurately classify unique signatures of s-process nucleosynthesis in presolar grains [2], a number of specific reaction cross sections need to be obtained with even greater precision.

A detailed examination of solar abundances reveals that the astrophysical s process comprises two key components: i) a "main" one that is responsible for the synthesis of elements of mass $A > 90$, and ii) a "weak" component responsible for the synthesis of elements of mass, $A \sim 60$–90 [3]. The weak s process arises during the He burning phase of massive stars ($\geq 8\,M_{\odot}$) in which the core temperature is high enough (~ 0.2–0.3 GK), such that the ^{22}Ne$(\alpha,n)^{25}$Mg reaction is expected to represent the dominant source of neutrons [3]. This reaction is also thought to govern the production of neutrons in intermediate-mass ($\geq 4\,M_{\odot}$) Asymptotic Giant Branch (IM-AGB) stars and its rate in such environments could explain the observed enhancement of ^{87}Rb that has been reported recently [4]. Specifically, at low neutron densities, the β decay of ^{85}Kr ($t_{1/2} \sim 11$ yr) dominates over the neutron-capture rate, and the s-process path runs from ^{85}Kr to ^{85}Rb and ^{86}Sr,

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while at high neutron densities, the neutron-capture chain continues to ^{86}Kr and ^{87}Rb. Unfortunately, in both massive stars and AGB stars, the production of neutrons is strongly influenced by the competing $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ reaction, which, due to its positive Q-value, can activate at lower temperatures than the $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ reaction, thereby depleting the overall amount of ^{22}Ne. Furthermore, the $^{22}\mathrm{Ne}(\alpha,\gamma)$ reaction plays a key role in determining the amount of ^{26}Mg produced in IM-AGB stars. This isotope can now be measured with very high precision in presolar grains and magnesium represents one of the few elements for which individual isotopic ratios can be derived from stellar spectra [5,6]. In this regard, stellar model predictions for ^{26}Mg can vary by up to $\sim 30\%$ due to uncertainties in the $^{22}\mathrm{Ne}+\alpha$ reaction rates [7].

During the high-temperature convective carbon-shell burning phase ($T \sim 1\,\mathrm{GK}$) of massive stars, the cosmic γ-ray emitting nucleus ^{60}Fe [8] is predominantly produced via s-process neutron capture on ^{59}Fe [9]. In these scenarios, the $^{22}\mathrm{Ne}(\alpha,n)$ reaction is expected to be the primary source of neutrons and, although the $^{22}\mathrm{Ne}(\alpha,\gamma)$ reaction is unlikely to compete with this process at $\sim 1\,\mathrm{GK}$, its rate at lower temperatures may significantly reduce the level of ^{22}Ne fuel available. Thus, in order to accurately compare stellar models with the observed abundance of ^{60}Fe in our Galaxy, a detailed knowledge of the $^{22}\mathrm{Ne}(\alpha,\gamma)/^{22}\mathrm{Ne}(\alpha,n)$ ratio is essential.

The $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ reaction is expected to be dominated by resonant capture to natural-parity excited states above the α-emission threshold energy of 10614.738(35) keV in ^{26}Mg [10]. In particular, resonances that correspond to states with large spectroscopic factors and lie within the Gamow energy window of He burning in massive stars, $E_{c.m.} \sim 360$–750 keV, are likely to have the largest impact on the rate. Over the past few decades, considerable experimental efforts have been devoted to reducing uncertainties in the $^{22}\mathrm{Ne}(\alpha,\gamma)$ reaction [7,11–18], including a direct measurement [14]. However, the direct measurement was limited to energies $E_{c.m.} \geq 700$ keV [14] and more constraints need to be placed on the spin-parity assignments of lower energy resonances.

Recently, two high-resolution $^{26}\mathrm{Mg}(\alpha,\alpha')^{26}\mathrm{Mg}$ scattering experiments have been performed, which report a number of potential natural-parity states in ^{26}Mg above the α-emission threshold with $E_{c.m.} < 700$ keV [17, 18]. In most cases, spin-parity assignments were not uniquely determined and, thus, resonance strengths remain largely unconstrained. That being said, Talwar *et al.* also performed a complementary $^{22}\mathrm{Ne}(^{6}\mathrm{Li},d)$ transfer reaction measurement at the same time as the α-scattering study, which allowed for an investigation of α clustering in ^{26}Mg [17]. In that study, two excited states at 11167(8) and 11317(18) keV, corresponding to resonances at $E_{c.m.} = 552(8)$ and 702(18) keV were identified as exhibiting especially strong α-cluster structures. In particular, it was concluded that the 552 keV resonance increased the $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ stellar reaction rate by up to 2 orders of magnitude above the previously reported rate of Longland *et al.* [13]. However, it is important to note that this 552 keV resonance is located above the neutron threshold at 11093.034(96) keV in ^{26}Mg [8] and, as such, its relative contribution to the $^{22}\mathrm{Ne}(\alpha,\gamma)$ and $^{22}\mathrm{Ne}(\alpha,n)$ reactions depends crucially on the magnitude of its γ- and neutron-decay partial widths, Γ_γ and Γ_n. This issue was not addressed in the study of ref. [17] and could dramatically affect the strength of the 552 keV resonance for the $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ reaction. It is expected that this 552 keV resonance observed in the $^{22}\mathrm{Ne}(^{6}\mathrm{Li},d)$ study of Talwar *et al.* [17] corresponds to a recently reported $^{25}\mathrm{Mg}+n$ state at 11171.02(1) keV in ^{26}Mg [15,16]. Taking a combination of the R-matrix fit results of refs. [15,16], a range of values for the γ- and neutron-decay widths of the 552 keV resonance is indicated. In particular, $\Gamma_\gamma = 1$–6 eV and $\Gamma_n = 0.1$–30 eV. Consequently, by adjusting the decay widths within their associated uncertainties leads to a factor 30 variation in the 552 keV resonance strength in the $^{22}\mathrm{Ne}(\alpha,\gamma)$ reaction.

Here, a 5 pnA, 19 MeV beam of ^{16}O ions, produced by the Argonne ATLAS accelerator, was used to bombard a $\sim 300\,\mu\mathrm{g/cm}^2$ thick target of ^{11}B for ~ 100 hrs to produce ^{26}Mg nuclei via the one-proton evaporation channel. At this low energy, the $1p$, $1p1n$, $1n$ and 1α evaporation channels, leading to ^{26}Mg, ^{25}Mg, ^{26}Al and ^{23}Na, respectively, are produced most abundantly. The resulting γ decays were detected using the Gammasphere array [19, 20], which in this instance was used in standalone mode and consisted of 99 Compton-suppressed HPGe detectors. Data were sorted off-line into γ-γ coincidence matrices and γ-γ-γ cubes. Examples of the γ-γ gated spectra used in the analysis of excited states above the α threshold in ^{26}Mg are displayed in fig. 1. Energy and efficiency calibrations were obtained using standard ^{152}Eu and ^{56}Co sources and a high-energy 6.129 MeV γ-ray in ^{16}O. For strong transitions, an angular distribution analysis was performed by fitting γ-ray intensities as a function of detection angle with respect to the beam axis with the function $W(\theta) = A_0[1 + a_2P_2(\cos\theta) + a_4P_4(\cos\theta)]$. Values of a_2/a_4 coefficients of $0.13(3)/0.03(3)$ and $-0.16(2)/-0.03(3)$ were obtained for the known $4_1^+ \to 2_1^+$ and $3_1^+ \to 2_2^+$ transitions in ^{26}Mg [21], respectively. Due to the nature of the reaction used in the experiment, no $J = 0$ or 1 levels were strongly populated. Only $E1$, $M1$ and $E2$ multipolarities were considered for the observed γ-ray transitions.

Table 1 presents a summary of the properties of excited states above the α-emission threshold in ^{26}Mg from the present work, together with a comparison to the previous full evaluation [21]. The excitation energies obtained are in good agreement with previous studies and the observed γ-decay branches for the 10650.7(4) and 10943.0(40) keV excited states in ^{26}Mg are comparable with earlier work [23]. An angular distribution analysis of the 1482.6(1) keV γ-ray to the 6_1^-, 9167.9(2) keV state revealed a_2/a_4 coefficients consistent with a $\Delta J = \pm 1$ transition, restricting the possible spin of the 10651 keV state to $J = 5$ or 7. An additional 2698.5(3) keV γ-decay branch to the 5_1^- level, with a_2/a_4 coefficients consistent with a $\Delta J = \pm 2$ transition, was also observed from the 10651 keV state. Consequently, we assign the 10651 keV excited level in ^{26}Mg to have a spin-parity of 7^-. The 7^-, 10651 and $(5^-, 6^+, 7^-)$,

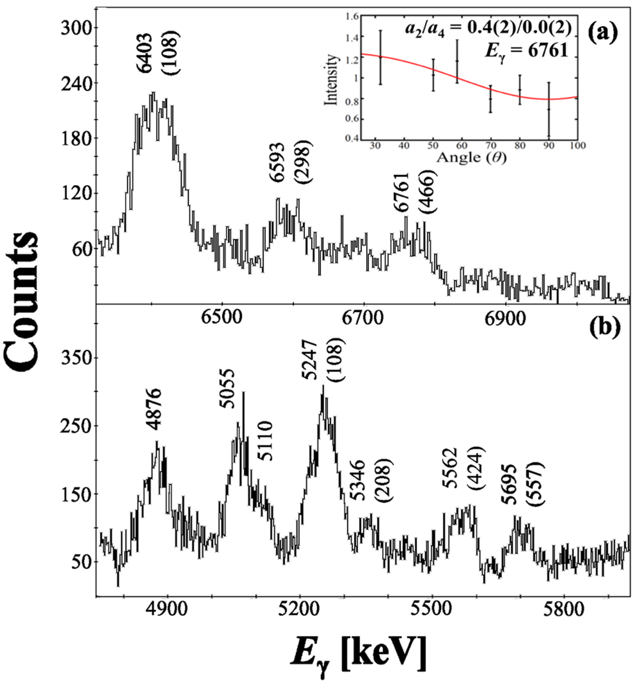

Fig. 1. Representative ^{26}Mg coincidence spectra, (a) γ-γ coincidence spectrum with a gate placed on the 2510 keV, $4^+_1 \rightarrow 2^+_1$ transition. The inset displays the measured $\Delta J = 2$ angular distribution of the observed 6761 keV transition. (b) γ-γ coincidence spectrum with a gate placed on the 1157 keV, $4^+_3 \rightarrow 4^+_1$ transition. Peaks are labelled with γ-ray energy and, in parentheses, resonance energy.

10943 keV states, corresponding to resonances in the ^{22}Ne + α system at 36.0(4) and 328.3(40) keV, respectively, are both of natural parity. However, due to their high spin, they are expected to have a negligible effect on the ^{22}Ne(α,γ)^{26}Mg stellar reaction rate. In fact, based on the spin-parity restrictions of the current study, all resonances with $E_r < 190$ keV are expected to make little contribution to the overall rate. Consequently, the following discussion concentrates only on astrophysically important natural-parity resonances with $E_r > 190$ keV.

In investigating the nature of the key $(1^-, 2^+)$, 11167(8) keV neutron-unbound, strong α-cluster state, recently identified by Talwar *et al.* [17], we observe a 5695(3) keV γ decay to the 4^+_3 level, as shown in fig. 1(b), indicating a well-matched excited state in ^{26}Mg at 11171.7(30) keV. The presently observed decay for the 11172 keV level, corresponding to a ^{22}Ne(α,γ) resonance at 557.0(30) keV, rules out a 1^- assignment and, consequently, a 2^+, 11172 keV excited state in ^{26}Mg is adopted in table 1. The observation of γ decay from this state is consistent with two previous ^{25}Mg(n,γ) studies by Massimi *et al.* [15,16], which highlight an excited level at 11171.02(1) keV in ^{26}Mg as potentially having a significant γ-decay width in comparison to its neutron decay width (conversely we do not observe an excited state at 11289 keV, which is known to have a neutron width that is greater than its γ-decay width [16]). Given its significant γ-decay branch and expected strong α-cluster structure [17], it is expected that the 557 keV resonance will make a significant contribution to the ^{22}Ne(α,γ) stellar reaction rate. No γ-decay transitions were observed, in the present study, from any known excited state in ^{26}Mg above E_x = 11182 keV [15,16], which is consistent with neutron emission becoming the dominant decay mode.

Considering fig. 1(a), a high-energy coincidence relationship with the 4^+_1, 4318.9(2) keV excited state in ^{26}Mg is observed at 6761(4) keV, indicating an α-unbound level at 11080.9(40) keV, in good agreement with previously reported values [21]. This 11081 keV state, which corresponds to a resonance in the ^{22}Ne + α system at 466.2(40) keV, was also observed in the α-scattering experiment of Talwar *et al.* and given an assignment of $(2^+, 3^-)$ [17]. Here, an angular distribution analysis of the 6761 keV γ-ray reveals an a_2/a_4 coefficient of 0.4(2)/0.0(2), ruling out a pure dipole transition, and eliminates a 3^- possibility for the 11081 keV excited level. In fact, the shape of the 6761 keV γ-ray angular distribution, also shown in fig. 1(a), is characteristic of a $\Delta J = \pm 2$ transition and, therefore, we conclude that the 11081 keV excited state has a spin-parity assignment of 2^+. This has important implications for the astrophysical ^{22}Ne(α,γ) reaction: although the 11081 keV level was not observed in the complementary (^{6}Li$, d$) study of ref. [17], it was noted that the upper limit of 0.06 for the spectroscopic factor of a 2^+ state could still contribute considerably to the rate.

A further three likely natural-parity resonances with $E_r > 190$ keV were identified for the first time by their γ decays in the present work. However, these states are expected to be far less critical for a determination of the ^{22}Ne(α,γ) stellar reaction rate and, as such, we simply present a brief overview of their properties here. Recently, Adsley *et al.* [18] identified two natural-parity excited states in ^{26}Mg at 10822(10) and 10890(10) keV, with spins of $J = 0$ and > 1, respectively. Here, a 5346(3) keV γ-ray transition to the 4^+_3 level in ^{26}Mg is observed, as illustrated in fig. 1(b), indicating an excited state at 10822.6(30) keV. The level energy is in good agreement with that of ref. [18]. However, the current spin restriction of J = 2–6 is incompatible with the angular distribution measurements of Adsley *et al.* [18]. Consequently, the presently observed 10823 keV state is expected to represent a separate level in ^{26}Mg. In this regard, an earlier (e, e′) study by Lees *et al.* [22] observed a 2^+ excited state in ^{26}Mg at 10838(24) keV and, thus, we tentatively assign the current 10823 keV level as a 2^+ state. The previously reported 10890 keV excited state in ^{26}Mg was observed in the present study at 10897.6(47) keV with γ-decay branches to the 3^+_2, 5^+_2 and 3^+_1 levels, indicating possible spin-parity assignments of 3^+, $4^{+/-}$ and 5^+. Given the good agreement in excitation energy with ref. [18], we propose a tentative natural-parity assignment of 4^+ for the presently observed 10898 keV state in ^{26}Mg, corresponding to a ^{22}Ne + α resonance at 282.9(47) keV. Interestingly, a state at $\sim$ 10.9 MeV can clearly be seen in the (^{6}Li$, d$) spectrum of ref. [17]. No further information is provided for this level in ref. [17], but its population is consistent with a relatively high spectroscopic factor.

Table 1. Properties of excited states in ^{26}Mg above the α-emission threshold from the present and earlier works. Level energies have been corrected for the recoil of the compound nucleus.

E_x (keV) Present	E_x (keV) Ref. [21]	E_r (keV)	E_γ (keV)	E_{final} (keV)	J^π_{final}	a_2/a_4	J^π adopted
	10646(2)	31.3(20)					1^+
10650.7(4)	10650(2)	36.0(4)	1482.6(1)	9167.9(2)	6^-_1	−0.54(4)/0.14(5)	7^-
			2698.5(3)	7952.0(1)	5^-_1	0.4(1)/0.2(2)	
	10681.9(3)	67.2(3)					
10696.3(4)	10693(3)	81.6(4)	3300.2(4)	7395.9(2)	5^+_2		4^+
10703.7(22)	10702(3)	89.0(22)	4987(1)	5716.0(2)	4^+_4		$(2^+, 4)$
			6353(2)	4350.0(1)	3^+_2	−0.26(8)/0.04(11)	
10708.9(22)	10709(2)	94.2(22)	2756(2)	7952.0(2)	5^-_1		(3–6)
			5808(1)	4900.9(1)	4^+_2		
	10715(3)[(a)]	100.3(30)					$(1^-, 2^+)$
10722.7(22)	10726(3)	108.0(22)	5247(1)	5476.0(2)	4^+_3	0.06(9)/0.03(9)	(3^+)
			6403(2)	4318.9(1)	4^+_1	−0.14(8)/ − 0.07(10)	
10741.7(30)	10744(3)	127.0(30)	7802(3)	2938.4(1)	2^+_2	0.17(7)/0.17(8)	3^+
10765.1(30)	10766(3)	150.4(30)	3369(3)	7395.9(2)	5^+_2		(3–7)
	10805.9(4)[(a),(b)]	191.2(4)					1^-
10822.6(30)	10838(24)[(c)]	207.9(30)	5346(3)	5476.0(2)	4^+_3		(2^+)
	10824(3)[(b)]	209.3(30)					0^+
	10881(3)	266.3(30)					
10897.6(47)	10893(3)[(a)]	282.9(47)	3501(2)	7395.9(2)	5^+_2		(4^+)
			6546(3)	4350.0(1)	3^+_2		
			6956(3)	3941.7(1)	3^+_1		
10912.8(30)	10915(3)	298.1(30)	6593(3)	4318.9(1)	4^+_1	0.4(2)/0.3(2)	$(2^+, 6^+)$
	10927(3)	312.3(30)					
10943.0(40)	10945(3)[(a),(b)]	328.3(40)	1775(4)	9167.9(2)	6^-_1		$(5^-, 6^+, 7^-)$
	10949.1(8)[(a),(b)]	334.4(8)					1^-
	10978(3)	363.3(30)					
10999.0(50)	10998(3)	384.3(50)	3603(3)	7395.9(2)	5^+_2		$(3^+, 4^+)$
			8059(4)	2938.4(1)	2^+_2		
11017.3(36)	11012(3)	402.6(36)	6666(2)	4350.0(1)	3^+_2		(2–5)
			7075(3)	3941.7(1)	3^+_1		
11038.6(30)	*new state*	423.9(30)	5562(3)	5476.0(2)	4^+_3		(2–6)
	11048(3)	433.3(30)					
11080.9(40)	11084(3)[(b)]	466.2(40)	6761(4)	4318.9(1)	4^+_1	0.4(2)/0.0(2)	2^+
	11114(3)	499.3(30)					2^+
	11142(6)	527.3(60)					
	11153.5(10)	538.8(10)					1^+
	11162.93(7)	548.2(1)					2^+
	11169.30(7)	554.6(1)					3^-
11171.7(30)	11171(3)[(a),(b)]	557.0(30)	5695(3)	5476.0(2)	4^+_3		(2^+)[(d)]
11181.8(20)	11183.06(6)	567.1(20)	5465(2)	5716.0(2)	4^+_4		(2–6)

(a) Observed in (^{6}Li, d) [11,12,17].
(b) Observed in (α, α') [17,18].
(c) Observed in (e, e') [22].
(d) Adopted value based on presently observed decay and previous assignment of ref. [17].

Table 2. A comparison of the ^{22}Ne(α,γ)^{26}Mg resonance parameters available from previous studies to those used for the evaluation of the stellar reaction rate in the present work (see text for details). In determining the previous upper and lower limits of resonance strengths, we have utilised the full range of spectroscopic factors and spin-parity assignments obtained in refs. [11–13,17,18]. For states in which only a spectroscopic factor upper limit is available, we have chosen to adopt a value of $S_\alpha/10$ for the lower limit. Furthermore, for the resonance at 283 keV, for which no previous spectroscopic factor information exists, we have adopted a value of 0.1. Partial decay widths calculated from spectroscopic factors are assumed to carry a factor of 2 uncertainty.

	Previous studies [11–14,17,18]						Present		
	Upper limit			Lower limit			recommended		
E_r (keV)	J^π	S_α	$\omega\gamma$ (eV)	J^π	S_α	$\omega\gamma$ (eV)	J^π	S_α	$\omega\gamma$ (eV)
191	1^-	0.06 [17]	1.23×10^{-22}	1^-	0.048 [13]	9.87×10^{-23}	1^-	$0.054^{(a)}$	1.11×10^{-22}
209	0^+	0.06 [17]	3.18×10^{-21}	2^+	0.006 [17]	1.56×10^{-22}	0^+	0.06	3.18×10^{-21}
283	2^+	0.10	2.23×10^{-16}	6^+	0.10	3.01×10^{-20}	4^+	0.10	3.53×10^{-18}
328	5^-	0.15 [17]	3.68×10^{-17}	7^-	0.007 [13]	2.34×10^{-20}	5^-	$0.07^{(b)}$	1.72×10^{-17}
334	1^-	0.15 [17]	1.86×10^{-13}	1^-	0.007 [13]	8.69×10^{-15}	1^-	$0.07^{(b)}$	8.69×10^{-14}
466	2^+	0.06 [17]	4.56×10^{-10}	3^-	0.007 [17]	7.42×10^{-12}	2^+	0.06	4.56×10^{-10}
557	2^+	0.99 [17]	$6.30\times10^{-7(c)}$	1^-	0.36 [17]	$1.86\times10^{-8(d)}$	2^+	0.99	5.07×10^{-7}
702	1^-		$4.00\times10^{-5(e)}$	1^-		$3.20\times10^{-5(e)}$	1^-		$3.60\times10^{-5(e)}$

(a) Average of previous values [11,13,17].
(b) Average of previous values [11–13,17].
(c) Determined by adopting $\Gamma_\gamma = 6$ eV [16] and $\Gamma_n = 1$ eV [15].
(d) Determined by adopting $\Gamma_\gamma = 1$ eV [15] and $\Gamma_n = 30$ eV [16].
(e) Direct measurement [14].

Finally, a 6593(3) keV γ-decay transition to the 4_1^+ level from an excited state at 10912.8(30) keV in ^{26}Mg is observed, as shown in fig. 1(a). An angular distribution of this γ-ray reveals a_2/a_4 coefficients consistent with a $\Delta J = \pm2$ transition, indicating possible assignments of $(2^+, 6^+)$ for the 10913 keV state. Such a state, representing a ^{22}Ne(α,γ) resonance at 298.1(30) keV, has not been observed in any previous α-scattering study [17,18] or (^{6}Li, d) experiment [12,11,17]. Consequently, it is expected that the newly reported 298 keV resonance most likely has a low spectroscopic factor or is of high spin.

In evaluating the astrophysical ^{22}Ne(α,γ)^{26}Mg reaction rate, the present resonance energy measurements and spin-parity assignments are used, and only those states that have also been previously observed in direct measurements [14], (^{6}Li, d) transfer reaction studies [11,12,17] and α-scattering experiments [17,18] are considered. Spectroscopic factors adopted for the determination of α partial widths are listed in table 2. It is difficult to determine whether previous studies [11,12,17] populate the 328 or 334 keV resonance. Consequently, $S_\alpha = 0.07$ is assumed for both. For a determination of the 557 keV resonance strength, we have adopted $\Gamma_\gamma = 3$ eV and $\Gamma_n = 0.8$ eV from ref. [15] for its recommended value, while we assume $\Gamma_\gamma = 6$ eV and $\Gamma_n = 0.1$ eV for the upper limit and $\Gamma_\gamma = \Gamma_n$ for the lower limit. A dominant neutron branch can be ruled out, as the state would not have been observed in the present study. We also explored if there was a depletion in the intensity of the 5695 keV γ-ray from the 557 keV resonance, in comparison to transitions from lower-lying, bound 2^+ states in ^{26}Mg at ~ 10 MeV excitation, and found no evidence for such a depletion.

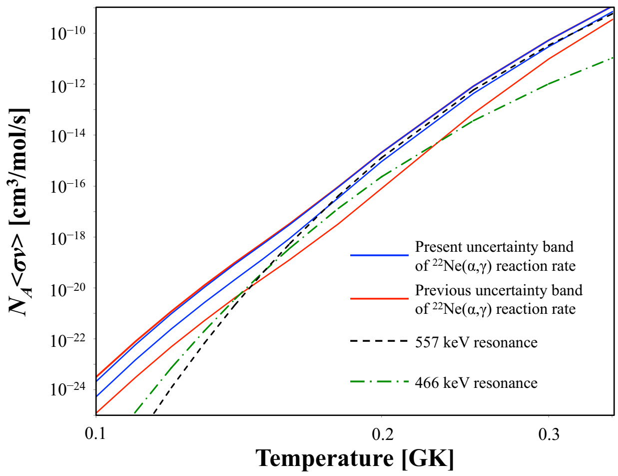

Fig. 2. (Colour online) Comparison of previous uncertainties in the ^{22}Ne(α,γ)^{26}Mg stellar reaction rate, as given in table 2 (red lines) to those deduced from the present work (blue lines) over the temperature range relevant for helium burning in massive stars and IM-AGB stars. Also shown are the contributions of the 466 and 557 keV resonances.

A comparison of current uncertainties associated with the ^{22}Ne(α,γ)^{26}Mg reaction to those from previous work is displayed in fig. 2. Based on the present results, uncertainties in the rate have been reduced by a factor ~ 10 for $T = 0.16$–0.20 GK. Furthermore, from 0.16–0.30 GK, the ^{22}Ne(α,γ) reaction is expected to dominate over the ^{22}Ne(α,n) reaction [13], significantly reducing *s*-process overabundances in massive stars and IM-AGB stars, in agreement with ref. [17]. This is largely due to the presently observed γ-decay branch and adopted 2^+ assignment of the 557 keV resonance, which now support the earlier work of Massimi *et al.* [15], as well as the definitive 2^+ assignment for the 466 keV resonance. Specifically, the large range of possible neutron decay widths dominated previous uncertainties in the strength of the 557 keV resonance, while present restrictions have reduced these by a factor ~ 17. That being said, present uncertainties in the ^{22}Ne$(\alpha,\gamma)^{26}$Mg reaction do not account for uncertainties in the spectroscopic factor of the 557 keV resonance, which governs the rate for almost the entire temperature range of helium burning in massive stars and IM-AGB stars. In particular, it should be noted that, in the study of Talwar *et al.*, the extracted spectroscopic factor for the 557 keV resonance is based off a single data point at 0 degrees [17] and, therefore, may carry a significant uncertainty. The predicted strength of $\sim 5 \times 10^{-7}$ eV for the 557 keV resonance would indicate that a direct measurement may be feasible and such a study is encouraged. However, should this 557 keV resonance be significantly weaker than expected, the importance would shift to the 466 keV resonance. Consequently, further $(^6\mathrm{Li}, d)$ transfer reaction studies are also desirable to reduce uncertainties in the spectroscopic factors of the two states.

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