The impact of $^{17}$O+$\alpha$ reaction rate uncertainties on the s-process in rotating massive stars

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Half of the elements heavier than iron were produced in the s-process. Neutrons are produced from source reactions, more importantly $^{13}$C($\alpha$,n) and $^{22}$Ne($\alpha$,n) and captured on seed nuclei. The neutron-capture rate is rather slower than the beta-decay rate and thus the nuclei produced during this process are close to the line of stability. In reality, “the” s-process is something of a misnomer since various different slow neutron-capture processes take place in different astrophysical locations caused by different reactions and with different characters.

A number of factors influence the elemental abundances of the elements created in the s-process. These include the amount of s-process neutron seed material ($^{13}$C and $^{22}$Ne) available, the metallicity of the star, and the rates of various nuclear reactions both in producing the neutrons for the s-process and the capture rate for those neutrons. One important set of reactions are neutron sinks: $^{16}$O captures neutrons to make $^{17}$O. The $^{17}$O($\alpha$,γ) reaction locks the captured neutron away, preventing additional nucleosynthesis. The $^{17}$O($\alpha$,n) reaction recycles the neutrons causing additional neutron-capture reactions to take place. The $^{17}$O+$\alpha$ reactions depend on the properties of excited states in the compound nucleus, $^{21}$Ne. To investigate the spectroscopic properties of these states, we used the $^{20}$Ne(d,p)$^{21}$Ne reaction with the TUNL Split-Pole (Enge) spectrograph. A focal-plane spectrum showing excited states in $^{21}$Ne is shown in Fig. 1. Using this reaction, we measured excitation energies and assigned spins and parities, and neutron widths to excited states in $^{21}$Ne and recomputed the $^{17}$O+$\alpha$ reaction rates. We found that the neutron recycling of the $^{17}$O+$\alpha$ reactions is stronger than predicted by previous rate estimates, and that the s-process in rotating metal-poor stars can potentially make elements up to at least barium (Z=56). This work has been published in Monthly Notices of the Royal Astronomical Society1. Another paper is in preparation reporting on states in $^{21}$Ne below the $\alpha$-particle threshold which may be interesting for nuclear structure.

1 J. Frost-Schenk et al. MNRAS 514 2650 (2022)
An additional experiment studying the $^{20}$Ne(d,p)$^{21}$Ne reaction using the HELIOS spectrometer at Argonne National Laboratory was performed in inverse kinematics. The resulting data will be published in another forthcoming paper.

![Excitation energy spectrum](image)

**Fig. 1.** The focal-plane excitation-energy spectrum for the $^{20}$Ne(d,p)$^{21}$Ne reaction. The black spectrum shows the results from the neon-implanted carbon target and the red spectrum is that for only the carbon backing.