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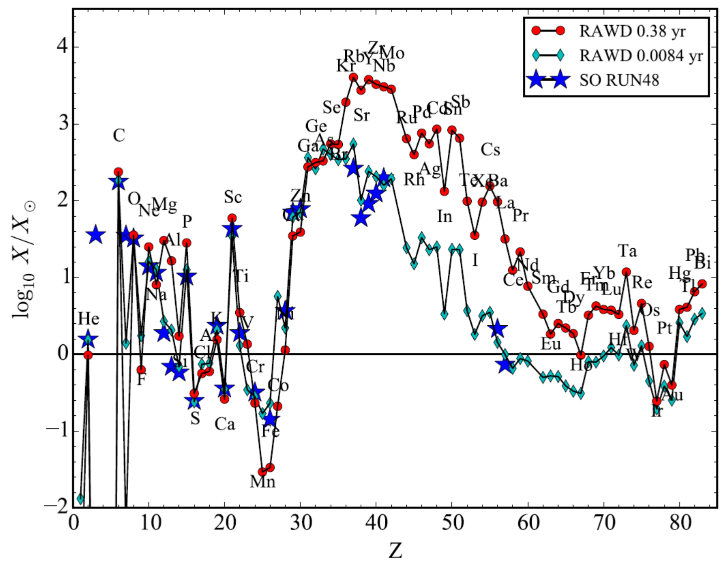
i-process Nucleosynthesis and Mass Retention Efficiency in He-shell Flash Evolution of Rapidly Accreting White Dwarfs

Most of the heavy elements beyond Fe are the products of neutron captures by iron and other seed nuclei. Nearly half of them have been synthesized in the rapid (r-) process that requires neutron densities $N_n>10^{20}/cm^3$, while the other half has been made in the slow (s-) process with $N_n<10^{11}/cm^3$. The most likely events in the lives of stars with the corresponding neutron densities are, respectively, neutron star mergers and He-shell flashes in asymptotic giant branch (AGB) stars.

Surprisingly, a spectroscopic analysis of the post-AGB star Sakurai's object has revealed a heavy-element abundance distribution [1] that can only be explained by an intermediate (i-) neutron-capture process with N_n~10^{13}-$10^{15}/cm^3$ [2]. As originally proposed by Cowan & Rose [3], the i-process requires that protons from an adjacent H-rich layer are ingested by convection driven by He-shell flashes.



Abundance distributions in the RAWD model A from [5], after the second He flash, with M_{WD}= 0.65 $M_\odot$ and T_{WD} = 21MK, for the long (0.38 yr) and short (0.0084 yr) timescales of H ingestion (red circles and teal diamonds, solid lines), and for comparison the model RUN48 (blue stars) from [2] that matches the observed abundances of Sakurai's object.

Other stars that undergo He-shell flashes are rapidly accreting white dwarfs (RAWDs) in close binary systems, which have been considered as possible progenitors of type Ia supernovae. For that to happen, the white dwarf has to accrete H-rich material, donated by its companion, rapidly enough for the accreted H to burn into He. Furthermore, thermal flashes in the accumulated He shells should not lead to a significant mass loss, otherwise RAWDs' masses would never reach the Chandrasekhar limit to explode in a supernova.

We have used the MESA stellar evolution code [4] to compute, for the first time, multiple cycles of stationary H burning intermittent with He shell flashes on RAWDs [5]. Our results show that the RAWDs have a very low mass retention efficiency, that can even become negative in some cases, meaning that the white dwarf mass either increases very slowly or it decreases with time. This makes RAWDs very unlikely candidates for type Ia supernova progenitors. On the other hand, the He-shell flash convection in our RAWD models ingests H from the accreted H-rich envelopes, which triggers the i-process in the convective zone. Post-processing nucleosynthesis simulations of the i-process in the RAWD models with solar-composition envelopes yield high overabundances of the first peak s-process elements, such as Rb, Sr, and Y, similar to what is observed in Sakurai's object and its model (Figure). Simple estimates predict that this can be important for the galactic chemical evolution.

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Further Reading:

[1] Asplund M., et al., 1999, A&A, 343, 507
[2] Herwig, F., et al., 2011, ApJ, 727, 89
[3] Cowan, J. J., & Rose, W. K., 1977, ApJ, 212, 149
[4] Paxton B., et al., 2011, ApJS, 192, 3
[5] Denissenkov, P., et al., 2017, ApJ, 834, L10