Super-AGB stars: A nuclear astrophysics site for the i-process

Elements heavier than iron are mainly formed by neutron-capture processes, though the respective astrophysical sites and conditions are still rather uncertain. Recent observations as well as new models and simulations have suggested that, in addition to the well-known slow- and rapid neutron capture processes, there may be an intermediate mode of neutron capture nucleosynthesis, the so-called i process. This process is defined by a neutron flux larger than those found in the well established slow neutron capture or s process, yet smaller than the extreme conditions of the rapid or r process. A possible signature of the i process [1] could be the simultaneous enhancement of Eu, usually considered an r-process element, and La, usually considered an s-process element, in some carbon enhanced metal-poor stars that have been classified as CEMP-r/s stars [2]. Also pre-solar grains and post-AGB stars have been discussed earlier as a possible nucleosynthesis site for the i process, however, there are still discrepancies and open questions.

In a new study by Jones, Ritter, Herwig and collaborators [3], super-AGB stars are identified as another possible astrophysical site for the i process. In their new computational models of these very heavy AGB stars mixing at convective boundaries is taken into account according to a parameterized model. These new stellar evolution models suggest that proton-rich material could be convectively mixed into He-shell burning (Figure 1), leading to conditions suitable for the i process.

Interestingly, it could be shown that i-process conditions are more prominently found in models with lower metal content, indicating that the i process could have been more important in the early universe. In their paper the authors emphasize that 1D stellar evolution models can only identify possible sites for i-process nucleosynthesis, but that the H-ingestion flashes are likely associated with substantial nuclear energy release, reaching maybe the level of the local binding energy of the He-burning shell. Such enormous energy input would launch an inherently 3D hydrodynamic global response that cannot be realistically described with 1D simulations [4]. 3D stellar hydrodynamics simulations are needed to understand these nuclear astrophysics events fully and provide the appropriate context for further nuclear astrophysics investigations.

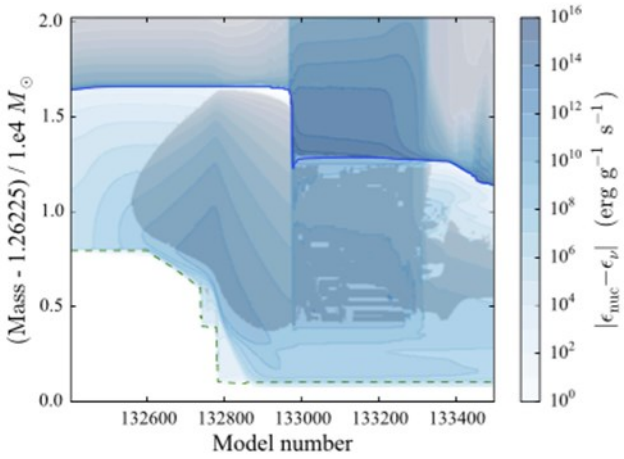

Figure 1: Evolution of convective regions (grey) and energy generation (blue shades) during a He-shell flash with H-ingestion in a 7Msun, Z=0.0001 ([Fe/H] = -2.3) stellar model with convective boundary mixing.

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