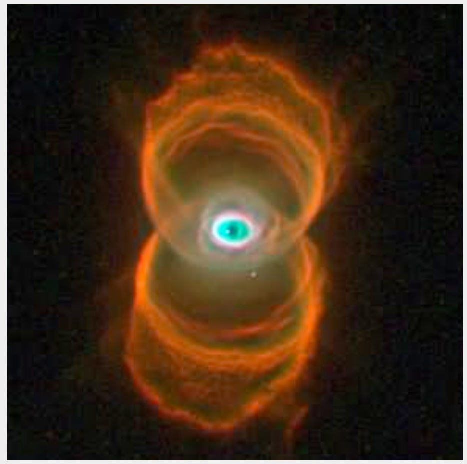
AGB Stars Nuclear Rates and Carbon

The Hourglass Nebula, the remnant of a star that has gone through advanced stages of evolution. During the Asymptotic Giant Branch phase we describe here such a star blows much of its carbon enriched envelop into the interstellar medium, leaving behind a white dwarf and the nebula we see here.



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Early in their lives, stars with masses a few times that of the sun burn the hydrogen in their cores to make helium, become red giant stars, and then burn that helium to make carbon and oxygen. Subsequently, in the Asymptotic Giant Branch (AGB) phase, hydrogen and helium continue to burn, now in shells that surround the carbon-oxygen core. We know that flashes occur in the helium shell and that the carbon they produce is eventually dredged up into the envelop of the star and then to the stellar surface. As the giant star continues to grow in size it eventually enters a superwind phase that leads to the ejection of the star's envelop to form a planetary nebula, leaving behind a white dwarf.

While we are certain that this picture is qualitatively correct we can not account quantitatively for important observables related to the nuclear production inside these giants. The standard model of the process leads to stars with a dominantly oxygen envelop. Yet many AGB stars observed in nature have carbon rich envelopes. The standard models involve approximations to the hydrodynamics and turbulence of convection that might explain the discrepancy. There have, however, been no evaluations of the sensitivity of the AGB process to uncertainties in the important nuclear reaction rates that govern the process. We have undertaken such sensitivity studies using detailed calculations based first on the standard nuclear reaction rates and then on rates changed within their uncertainties. We find that production of carbon in AGB stars is insensitive to the ^{12}C + alpha → $^{16}O + \gamma$ reaction, but that changes in the $^{14}N + p$ → $^{15}O + \gamma$ or the 3α → ^{12}C (triple alpha) reaction can increase the carbon abundance by a factor of two, leading to a carbon rich surface.

The increased production of carbon reflects the increased efficiency of transporting nuclear processed material from the interior of the star to its surface. This will also enhance the production of all elements that are efficiently produced in AGB stars, among them the heavy elements made in the slow-neutron capture process (s-process). This result shows clearly that better measurements of the reaction rates are imperative if we wish to obtain accurate nuclear production models to confront the latest astrophysical observations. New measurements of these reactions are in various stages and will in the next few years tell us whether we have truly found the solution to the problem.

It is important for several reasons that we do find a solution. ABG stars are the source of a substantial carbon and affect our understanding of galactic chemical evolution. They also serve as diagnostics for extragalactic populations, so it is important to know the conditions for the oxygen rich to carbon rich transition—carbon rich giants are the brightest infrared population in extragalactic systems. And finally, the envelopment enrichment of AGB stars with the s-process elements is intimately related to the dredge up properties of these models.

Investigators
Falk Herwig, LANL
Sam M. Austin, NSCL
John C. Lattanzio, Monash University

Contacts:
Herwig: fherwig@lanl.gov 505-667-0452
Austin: austin@nscl.msu.edu 517-333-6311

Papers:
F. Herwig and Sam M. Austin, Astrophysical Journal Letters 613:L73-L76 (2004)
F. Herwig, Sam M. Austin, and John C. Lattanzio, astro-ph/0511386

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