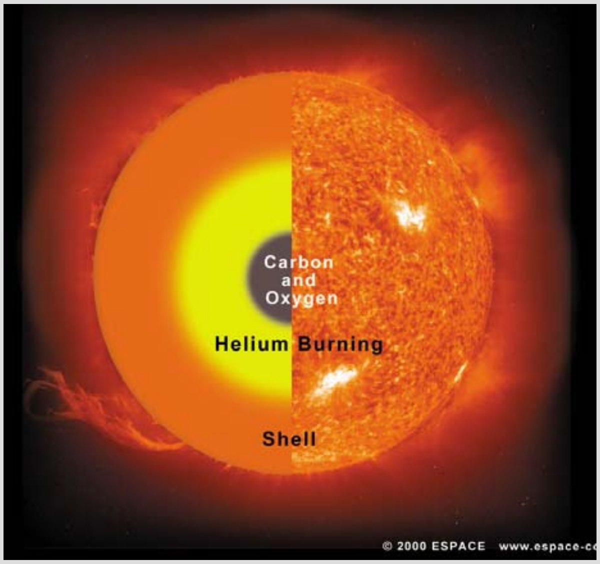
The Hoyle State and Carbon in Stars

The properties of the Hoyle State in ^{12}C determine the ratio of carbon to oxygen formed in the stellar helium burning process shown here. This ratio strongly affects the future evolution of the star. A new experiment should greatly improve our description of the Hoyle state.

Credits



Stars that have exhausted the hydrogen fuel in their cores by converting it to helium, then convert that helium to carbon and oxygen by a sequence of two reactions. The triple alpha reaction first fuses three alpha particles to form carbon. This is followed, sometimes, by the capture of an alpha particle to form oxygen. The relative strength of the two reactions determines the ratio of carbon to oxygen at the completion of helium burning. We are undertaking experiments to determine better the strength of the triple alpha reaction.

Hoyle showed long ago that the observed amount of carbon in the cosmos could be made in stars *only* if there was an excited state in carbon with a particular spin and parity, 0^+, and a particular energy, about 7.6 MeV. That state was soon found experimentally. Recent experiments at CERN and Jyväskylä have shown that only the properties of the Hoyle state are necessary to describe the triple alpha reaction in the cosmos. But we need to know these properties better than at present to predict accurately how stars evolve after the completion of helium burning. For example, the present accuracy does not allow astrophysicists to predict with sufficient precision either the sizes of the iron cores of massive stars that collapse and power supernovae or the ensuing nucleosynthesis following the supernova explosion. At least 10% accuracy in the ratio is required; at present neither of the individual rates is known that well. Similar accuracy is needed to describe the carbon production in stars with masses a few times that of the sun: AGB stars that burn hydrogen and helium is shells surrounding a carbon-oxygen core.

Predicting the triple alpha rate is complex; it is given by the product of four experimentally determined quantities. The major source of uncertainty is in one of these quantities, the so-called pair-branch, the fraction of the time the Hoyle State, once formed, decays to the ground state of carbon by simultaneously emitting a positron and an electron. We have undertaken an experiment to determine this branch and thereby to determine the triple alpha rate to within 6%.

We form the Hoyle state by scattering protons, produced by the Tandem accelerator at Western Michigan University, from a carbon target at an energy and angle that maximizes its formation. Detection of the scattered proton tells us that the state has been formed. We determine whether the state emits a positron-electron pair that we detect in a plastic scintillator array. The detector is now being built and we hope to have results in about six months. The experiment is difficult because this process is so improbable, occurring only about seven times in a million chances. But it appears that the measurement can be made with the desired accuracy.

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Papers:
"Making Carbon in Stars", S. M. Austin, Nucl. Phys.A**758**, 375c (2005).
"Nuclear Reaction Rates and Carbon Star Formation", Falk Herwig and Sam M. Austin, Ap. J. Lett., **613**, L73 (2004), and references therein.