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Stellar Evolution Constraints on the Triple-Alpha Reaction Rate

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(Submitted on 25 Jul 2011)

We investigate the quantitative constraint on the triple-alpha reaction rate based on stellar evolution theory, motivated by the recent significant revision of the rate proposed by nuclear physics calculations. Targeted stellar models were computed in order to investigate the impact of that rate in the mass range of 0.8 < M / Msun < 25 and in the metallicity range between Z = 0 and Z = 0.02. The revised rate has a significant impact on the evolution of low- and intermediate-mass stars, while its influence on the evolution of massive stars (M >~ 10 Msun) is minimal. We find that employing the revised rate suppresses helium shell flashes on AGB phase for stars in the initial mass range 0.8 < M / Msun < 6, which is contradictory to what is observed. The absence of helium shell flashes is due to the weak temperature dependence of the revised triple-alpha reaction cross section at the temperature involved. In our models, it is suggested that the temperature dependence of the cross section should have at least nu > 10 at T = 1 - 1.2 x 10^8 K where the cross section is proportional to T^{nu}. We also derive the helium ignition curve to estimate the maximum cross section to retain the low-mass first red giants. The semi-analytically derived ignition curves suggest that the reaction rate should be less than ~ 10^{-29} cm^6 s^{-1} mole^{-2} at ~ 10^{7.8} K, which corresponds to about three orders of magnitude larger than that of the NACRE compilation. In an effort to compromise with the revised rates, we calculate and analyze models with enhanced CNO cycle reaction rates to increase the maximum luminosity of the first giant branch. However, it is impossible to reach the typical RGB tip luminosity even if all the reaction rates related to CNO cycles are enhanced by more than ten orders of magnitude.

Comments:	14 pages, 8 figures, accepted by the ApJ
Subjects:	**Solar and Stellar Astrophysics (astro-ph.SR)**; Nuclear Experiment (nucl-ex)
Cite as:	**arXiv:1107.4984 [astro-ph.SR]**
	(or **arXiv:1107.4984v1 [astro-ph.SR]** for this version)

Submission history

From: Takuma Suda [view email]
[v1] Mon, 25 Jul 2011 15:54:02 GMT (597kb)