Carbon-enhanced Metal-poor Stars and Thermohaline Mixing

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Abstract

One possible scenario for the formation of carbon-rich metal poor stars is the accretion of carbon-rich material from a binary companion that may no longer be visible. It is generally assumed that the accreted material remains on the surface of the star and does not mix with the interior. However, this picture neglects the process of thermohaline mixing which should cause the accreted matter to mix with the original stellar material.

We investigate the effect that thermohaline mixing has on the surface abundances by modelling a binary system of metallicity $Z=10^{-4}$ with a $2M_{solar}$ primary and a $0.74M_{solar}$ secondary in an initial orbit of 4000 days. Accretion of material from the primary forms a carbon-rich secondary, with the accreted material mixing with about 90% of the star. This has important consequences for the surface abundances, particularly after the occurrence of 1st dredge-up.

Introduction

Carbon-rich metal-poor stars are defined as stars with [C/Fe]>1.0 (Beers & Christlieb 2005). A possible formation mechanism scenario for these stars is the accretion of carbon-rich material from a companion. It is commonly assumed (e.g. Cayrel et al. 2004) that this accreted material sits unmixed on the surface of the star up to the point at which the star undergoes first dredge-up. At this point, it is thought that the accreted material becomes mixed with the part of the interior of the star in the deep convective envelope that developes.

However, this picture neglects an important physical process – that of thermohaline mixing. This could have important consequences for the surface abundances of such stars.

Thermohaline mixing

This processes occurs when the mean molecular weight of the stellar gas increases towards the surface. A gas element, displaced downwards and compressed, will be hotter than its surroundings. It will therefore lose heat, increase in density and continue to sink. This results in mixing on a thermal timescale until the molecular weight difference has disappeared.

We expect thermohaline mixing to occur in a star that has accreted material from a carbon rich companion as this material will have a greater mean molecular weight than that of the unevolved star.

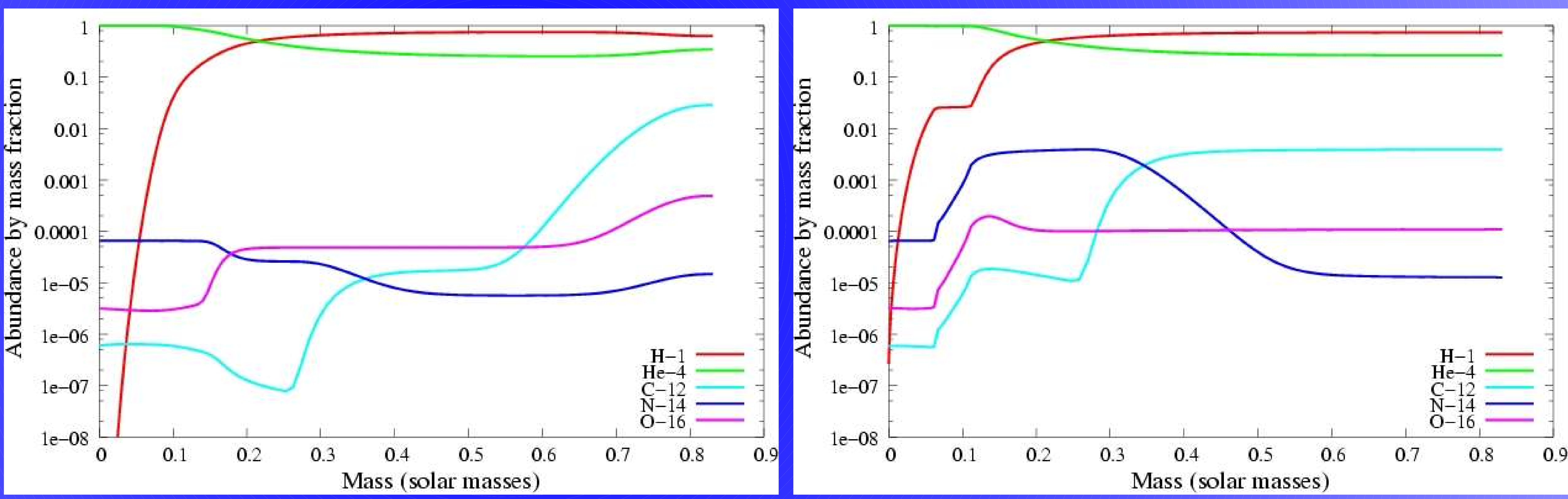
The aim of this work is to determine the effect that thermohaline mixing has on the surface abundances of such an object.

Figure 1.

Left-hand panel: The abundance profile of the model without thermohaline mixing at the end of core H-burning.

Right-hand panel: The abundance profile of the model with thermohaline mixing. Note that the accreted material has mixed deep in to the interior of the star and some of the carbon has been converted in to nitrogen.

The plateau in the H-abundance is due to there being a gradient in the CNO abundance in the burning regions, with the outer regions burning more rapidly.



The Model

We use the synthetic evolution code BSE (Izzard et al. 2006) to model the evolution of a binary system consisting of a $2M_{solar}$ primary and $0.74M_{solar}$ secondary initially in a 4000 day orbit. We find that $0.09M_{solar}$ of material is transferred during the AGB superwind phase and we record the average composition of this material.

We then create a detailed model of the secondary using the stellar evolution code STARS (Eggleton 1971), and accrete the requisite amount of material of the composition predicted by BSE on to this star. We then evolve two model sequences, one without thermohaline mixing and the other including it.

Results

Figure 1. shows the difference in the abundance profiles of the models towards the end of core H-burning. Thermohaline mixing leads to C-rich material being mixed through around 90% of the star. Some of this material is converted in to nitrogen by the CNO cycle. Without thermohaline mixing, the material remains on the stellar surface.

The evolution of [C/Fe] and [N/Fe] as a function of luminosity is shown for both models in Figure 2. Without thermohaline mixing, both C and N abundances drop at 1st dredge-up as the accreted material is diluted in the deepening envelope. In the case with thermohaline mixing, N becomes strongly enhanced at 1st dredge-up as the accreted material that was CNO-processed in the interior is brought to the surface.

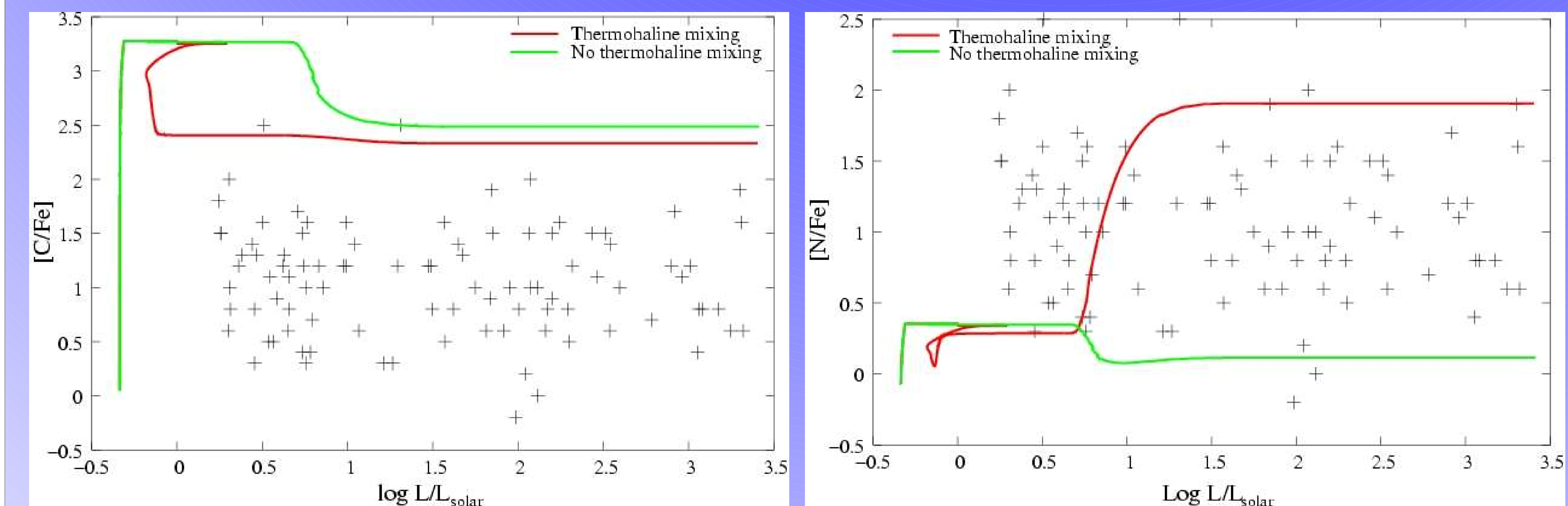


Figure 2.
Left-hand panel: The evolution of [C/Fe] as a function of luminosity.
Right-hand panel: The evolution of [N/Fe] as a function of luminosity.

In both panels, the sudden change in abundance at log L/L_{solar} of around 0.7 corresponds to the onset of 1st dredge-up.

Crosses are from the observations of Lucatello et al. (2006). The spread in abundances could be reproduced by variations in the composition of the accreted material.

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