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Gone with the wind: The elusive origin of Carbon-Enhanced Metal-Poor stars

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Abstract. Among the very metal-poor stars observed in the Galactic halo many stars show a great enhancement in the abundance of carbon. These stars are called carbon-enhanced metal-poor (CEMP) stars. One explanation of the observed enhancements is that in the past CEMP stars have undergone wind mass-transfer from an AGB binary companion. The accretion of stellar wind is considered an inefficient mechanism to transfer mass in binary stars; however, recent hydrodynamical simulations suggest a wind-accretion model applicable in the case of slow and dense AGB winds, called wind Roche-lobe overflow (WRLOF), that predicts accretion efficiencies much higher than the canonical predictions. We present results of binary population simulations in which we explore the consequences of the WRLOF model for the population of CEMP stars.

1. Carbon-Enhanced Metal-Poor stars and wind mass transfer

In the halo of the Galaxy we observe a population of old stars characterised by low mass and metallicity, almost unevolved, the relics of the early stages of star formation in the Milky Way. Among these very metal-poor (VMP) stars, defined by the iron abundance [Fe/H] $\lesssim -2.0$, we observe a substantial fraction of carbon-enhanced metal-poor stars ([C/Fe] $\geq +1.0$; CEMP stars). The observed CEMP/VMP fraction varies from 9% (Frebel et al. 2006) to 25% (Marsteller et al. 2005), rapidly increasing for decreasing iron content and for increasing distance from the Galactic plane (Carollo et al. 2012). About 80% of all observed CEMP stars show enhancement in the abundance of heavy elements produced by slow neutron-capture processes, like barium, and are called CEMP-*s* stars (Aoki et al. 2007).

The analysis of the spectra of CEMP-s stars reveals that most of them (likely all) have a binary companion (Lucatello et al. 2005). This evidence suggests that CEMP-s stars are formed in binary systems. In the binary scenario, the primary star becomes a TPAGB star, produces carbon and *s*-elements in its interior, brings them to the surface by third dredge up and expells them by the wind. A fraction of the ejected material is accreted to the companion star. The TPAGB star then evolves into a white dwarf and today we are able to observe only the chemically-enriched secondary star. However, binary population synthesis models fail to reproduce the observed CEMP/VMP fraction by almost a factor 10 (Izzard et al. 2009).

Many uncertainties in the models may cause this discrepancy. In this work we investigate the wind mass-transfer process. The canonical description of wind mass transfer is the Bondi-Hoyle-Lyttleton (BHL) prescription, which predicts low accretion efficiencies (maximum ≈ 10% and typically much less). The BHL prescription is accurate when the wind velocity is much larger than the orbital velocity of the accreting star (Bondi & Hoyle 1944). However AGB winds are observed in the range $5 - 30\ \mathrm{km\,s^{-1}}$, in many cases slow or comparable to the orbital velocity.

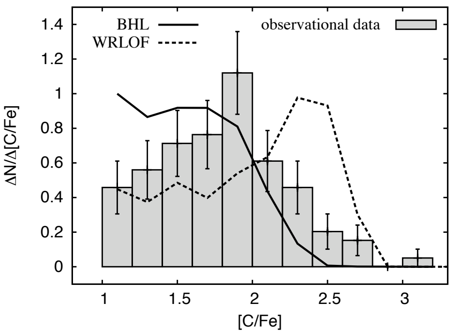

Figure 1. Distribution of [C/Fe] in the CEMP population.The plot is normalised such that the area under the graph is the same and BHL model peaks at 1.

Recent hydrodynamical simulations suggest a new mode of mass transfer called "wind Roche-lobe overflow" (WRLOF) applicable in the case of the slow AGB winds. WRLOF occurs in systems where the radius of the wind acceleration zone, i.e. the region where the wind is accelerated beyond the escape velocity, is larger than, or is a significant fraction of, the Roche-lobe radius of the wind-losing star. When this condition is full-filled the wind is gravitationally confined to the Roche lobe of the donor star and it is focused through the inner Lagrangian point L_1 towards the secondary and is accreted with high efficiency (up to 50%) in a wide range of separations. Because AGB winds are thought to be dust-driven, for AGB stars the radius of the wind acceleration zone is by definition the dust-formation radius, which depends on the stellar radius, on the effective temperature of the AGB star and on the condensation temperature of the dust (during most of the AGB phase the dust formation radius is proportional to the stellar radius and for carbon-rich dust $R_{\rm d}/R_* \approx 3$). We refer to Mohamed & Podsiadlowski (2007) for a complete description of the WRLOF process.

In this work we implement in our population synthesis code a model of the WRLOF process and we present its effects on a population of CEMP stars.

2. Results

Our population synthesis simulations consist of N^3 binary stars in $\ln M_1 - \ln M_2 - \ln a$ parameter space, where $M_{1,2}$ are the initial masses of the primary and the secondary star, a is the initial separation and we choose $N = 128$. M_1 , M_2 and a vary respectively in the range [0.8, 8.0] $\mathrm{M}_\odot$, and [0.1, 0.9]$\mathrm{M}_\odot$ and [3, 10^5] $\mathrm{R}_\odot$. Metallicity is $Z = 10^{-4}$. For a complete discussion of our model we refer to the work of Izzard et al. (2009).

With our model of the WRLOF process we calculate a CEMP/VMP ratio of 4.06%, an increase by a factor 1.8 compared to prior studies but low compared to the observed ratio. In Fig. 1 we show the distribution of the carbon abundance calculated with the BHL (solid line) and the WRLOF (dashed line) prescriptions compared with the observations (histograms with Poisson errors). The WRLOF model shows qualitatively the same trend as the data, but peaks at a carbon abundance higher than the observations. This is a consequence of the high accretion efficiency in our model, that allows very low mass secondaries to become CEMP stars. A small star needs to accrete a large amount of mass that is only weakly diluted in the envelope, therefore the large carbon-enhancement.

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