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Production and Recycling of Carbon in the Early Galactic Halo

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Abstract. A large fraction of extremely metal-poor halo stars are strongly enriched in carbon (CEMP stars). The standard scenario for their origin is mass transfer in binary systems, but this assumes that they *are* binaries. If not, the C must have been implanted in their natal clouds from a distant production site(s) in the preceding - possibly first - generation of stars. The binary population of CEMP subgroups can shed light on these processes.

Keywords. Galaxy: halo – Stars: carbon – binaries: spectroscopic – ISM: structure

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1. Why are carbon-enhanced extremely metal-poor stars interesting?

Carbon-enhanced extremely metal-poor (CEMP) stars ([Fe/H] < -3.0; [C/Fe] $> +0.7$) are assuming central importance in the study of the earliest stages of the Galactic halo – see the recent comprehensive review by Frebel & Norris (2015). CEMP stars are of two main types: CEMP-*s* stars exhibit large excesses of *s*-process elements and dominate the inner halo, while the CEMP-no stars do not, and are mostly found in the outer halo and at the lowest metallicities as measured by [Fe/H].

In the conventional scenario for the origin of CEMP-*s* stars, the excess elements were synthesized in an initially more massive AGB binary companion, which transferred the processed material to the surviving star by Roche-lobe overflow and/or a stellar wind. Previous fragmentary data suggested that most CEMP-*s* stars were indeed long-period binaries, but there was little firm evidence on the binary population among CEMP-no stars. We set out to provide this evidence; details are in Hansen *et al.* (2015abc).

2. Observing programme

Our observational strategy was simple: ∼Monthly, long-term radial velocity monitoring of 22 CEMP-*s* and 24 CEMP-no stars with the stable, bench mounted, fibre-fed échelle spectrograph FIES at the 2.5m Nordic Optical Telescope (NOT). Spectra of high resolution ($R \sim 45,000$) and low S/N ratio are cross-correlated to yield radial velocities with errors of ∼100 m s^{-1} and identify the single stars and binaries.

3. Results and implications

Our results were also simple, but rather surprising: The frequency and orbital properties of binaries among CEMP-no stars are *completely normal* at ∼17% (see Fig. 1); conversely, among the CEMP-*s* stars ∼80% are binaries, while ∼20% are in fact single.

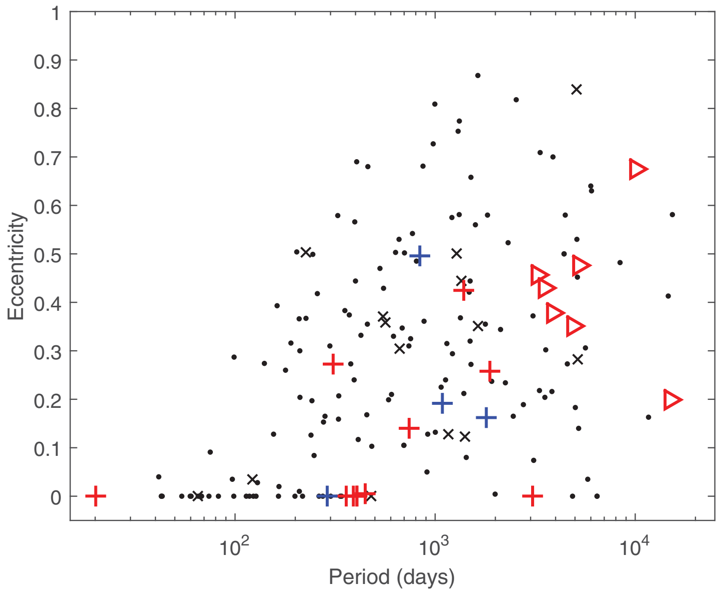

Figure 1. Period−eccentricity diagram for the binaries found here. Red and blue crosses: CEMP-*s* and CEMP-no stars, respectively (systems with $P > 3,000$ days are shown as right–pointing triangles; their true periods may be even longer). Black dots and small crosses: Comparison samples of giant binaries in Population I clusters: Mermilliod *et al.* (2007), Mathieu *et al.* (1990) and in Population II: (Carney *et al.* (2003).

So the binary mass-transfer scenario can account for the excess C in many CEMP stars, but by far not for all: The carbon in the single stars must have been produced elsewhere and transported across interstellar distances in the ISM to enrich the natal clouds of the second-generation CEMP stars, as seen in some high-redshift DLA systems by Cooke *et al.* (2012). "Spinstars" or 'faint' SNe II are among the prime suspects – see Frebel & Norris (2015) and discussion in Hansen *et al.* (2015abc).

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