Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
Proceedings IAU Symposium No. 343, 2019
F. Kerschbaum, M. Groenewegen & H. Olofsson, eds.

doi:10.1017/S1743921318003812

The Evolutionary State of CEMP Stars

Johannes Andersen[1,2] **and Birgitta Nordström**[1,2]

[1]Dark Cosmology Centre, The Niels Bohr Institute, University of Copenhagen, Juliane Maries Vej 30, DK-2100 Copenhagen, Denmark.

[2]Stellar Astrophysics Centre, Aarhus University, Aarhus, Denmark. DK−2100 Copenhagen, Denmark

emails: ja@nbi.ku.dk, birgitta@nbi.ku.dk

Abstract. The standard scenario for the production of carbon-enhanced extremely metal-poor (CEMP) stars requires a more massive binary companion, which has evolved through the AGB stage and transferred carbon-rich material to the surface of the surviving, likewise extremely metal-poor (EMP) star. Evidently, the binary companion plays a key role in this process.

In order to characterise the polluting star, if any, the stage of evolution of the observed star (whether RGB or AGB), and whether pulsations exist, must be known. The Gaia DR2 parallaxes and photometry should contain the answer.

Keywords. Galaxy: halo, stars: Population II, stars: AGB and post-AGB, stars: carbon, stars: distances, stars: evolution.

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1. Introduction

In 2015–2016, systematic long-term radial-velocity monitoring with high precision ($\sim$100 m s $^{-1}$) had surprisingly shown (Hansen *et al.* 2015, 2016a,b) that extremely metal-poor (EMP) stars are basically all single (i.e. have a Pop I normal binary fraction). Stars strongly enhanced in *r*-process elements, or in carbon without a similarly strong enhancement in *s*-process elements, all showed this. In stark contrast, EMP stars strongly enhanced in both carbon and *s*-process elements were nearly all binaries, interspersed with a small sprinkling of certified single stars. But no evidence was then available whether they were RGB or AGB stars. The second release of data from ESA's astrometric satellite Gaia has now changed that situation, providing individual distances for a subset of the brightest of those stars.

2. Previous Observations

The first step was a survey of the detailed composition of a sample of EMP stars. This requires an 8-metre-class telescope with an efficient high-resolution spectrograph, and we used the ESO VLT and UVES to identify stars in which a pronounced excess of carbon and/or of elements produced by neutron-capture processes might exist.

In contrast, precise and consistent binary identification by repeated determination of radial velocities over several years requires much less light for the individual observation by cross-correlation of low-S/N spectra, but a stable and repeatable instrumental setup over several years is essential. For this, we consequently used the 2.5-metre Nordic Optical Telescope (NOT) and its bench-mounted echelle spectrograph FIES in a separate, temperature-controlled underground vault.

Finally, determination of small stellar parallaxes with micro-arcsecond precision is only feasible in a space environment, free of atmospheric turbulence. For this, Gaia without competition–even in DR2, which is based on only two years of data.

3. Results of the Gaia Data

The Gaia DR2 trigonometric parallaxes and resulting distances for the 64 brightest stars show unambiguously that these stars are “normal” bright giants (although still EMP stars, with [Fe/H] ~ -2.5). They have $M_V \sim 0.5$ mag and are thus not true AGB stars ($M_V \sim -5$ mag). The ‘standard’ scenario for the origin of these stars thus basically still holds; they are intrinsically EMP giants. However, whereas the chemical anomalies in the single stars were imprinted on the material from which they formed (i.e., from birth), the binary CEMP-*s* stars acquired theirs by mass transfer from the companion to the surface layers of the star we see today. Thus, the mystery remains: How did the CEMP-no and the single CEMP-*s* stars acquire their marked carbon excesses in the absence of any AGB or other massive binary companions? Standard (local) chemical evolution models seem not to include this form of mass transfer across interstellar distances.

The Gaia DR2 data do include G, blue, and red photometry of micro-magnitude precision, but the DR2 time basis is still too short to allow conclusions on the possible presence and period of any pulsations in these stars (Hansen *et al.* 2016a,b).

References

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