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25. Differences in chemical enrichment of metal-poor Milky Way stars

T. Mishenina(1), M. Pignatari(2,3,4), I.Usenko(1),C. Soubiran(5), F.-K. Thielemann(6,7), A.Yu. Kniazev(8), S.A.Korotin(9), T.Gorbaneva(1)

(1) Astronomical Observatory, Odesa National University, 1b, Marazlievska str., 65014, Odesa, Ukraine
(2) Konkoly Observatory, HUN-REN, Konkoly Thege Miklos ut 15-17, H-1121 Budapest, Hungary
(3) MTA Centre of Excellence, Budapest, Konkoly Thege Miklos ut 15-17, H-1121, Hungary
(4) E.A. Milne Centre for Astrophysics, University of Hull, Hull HU6 7RX, UK
(5) Laboratoire d'Astrophysique de Bordeaux, Univ. Bordeaux, CNRS, B18N, allee Geoffroy Saint-Hilaire, 33615, Pessac, France
(6) Department of Physics, University of Basel, Klingelbergstrabe 82, CH-4056 Basel, Switzerland
(7) GSI Helmholtzzentrum fur Schwerionenforschung, Planckstrasse 1, D-64291 Darmstadt, Germany
(8) Southern African Large Telescope Foundation, South African Astronomical Observatory, P.O. box 9, 7935 Observatory, Cape Town, South Africa
(9) Crimean Astrophysical Observatory, Nauchny 298409, Crimea

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Abstract

The relative variations of the chemical compositions between metal-poor stars ([Fe/H] < -1) reveal the pure signature of different nucleosynthesis processes. In this work we present the atmospheric parameters, the dynamic properties and the abundances of four metal-poor stars: HE 1523 -– 0901 ([Fe/H]=–2.91±0.15), HD 6268 ([Fe/H]=–2.55±0.19), HD 121135 ([Fe/H]=–1.63±0.14), and HD 195636 ([Fe/H]=–2.79±0.04). We compare our results with theoretical stellar models and with other stars. HE 1523 – 0901, HD 6268 and HD 195636 show anomalies that are better explained by supernova models from fast-rotating stellar progenitors. If we consider the elements beyond Fe, HE 1523-0901 can be classified as an r-II star, HD 6268 an r-I candidate, and HD 195636 and HD 121135 show a borderline r-process enrichment between limited-r and r-I star. We discuss those in the context of the r-process nucleosynthesis.

Observations and methods

The spectra: HRS echelle spectrograph at the Southern African Large Telescope (SALT, e.g. Buckley et al. 2006), a resolving power of R ~ 40 000, the wavelengths 3700—5500 and 5500--8900 ÅÅ + blue region of the spectra UVES/VLT archive.
The atmospheric parameters: LTE, IE, photometry (SIMBAD).
Elemental abundance: under LTE and NLTE approximations ,
with Ews: Ca, Ti, Cr, Fe, and Ni,
sythesis: C, N, O, Na, Mg, Al, Si, K, Sc, Mn, Co, Cu, Zn, Sr, Y, Zr, Mo, Ru, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Hf, Os, Ir, and Th.
Atmospheric models by Castelli&Kurucz (2004), the new version software package (Tsymbal, 1996) and the new version of the VALD atomic data (Kupka et al. 1999).
NLTE corrections: O, Na, Mg, Al, K, Cu, Sr, Ba.

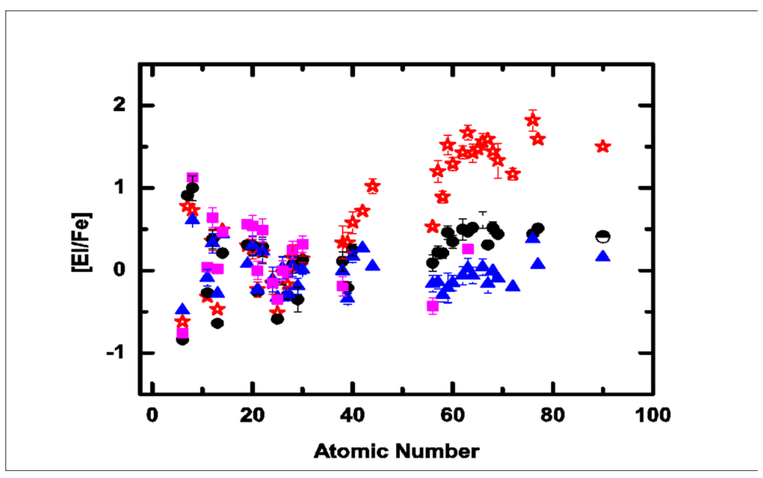


Figure 1. Abundance distribution of [El/Fe] with respect to atomic number for HE 1523–0901 (red empty asterisks), HD 6268 (black full circles), HD 121135 (blue full triangles) and HD 195636 (purple full squares). The Th abundance for HD 6268 are from Roederer et al. 2014 (black semicircle).

Based on their kinematical properties, **HE 1523–0901** and **HD 195636** are halo stars with typical high velocities; **HD 121135** has a peculiar kinematics making unclear if it is a halo or an accreted star; and **HD 6268 probably** is a rare prototype of very metal-poor thick disk stars.

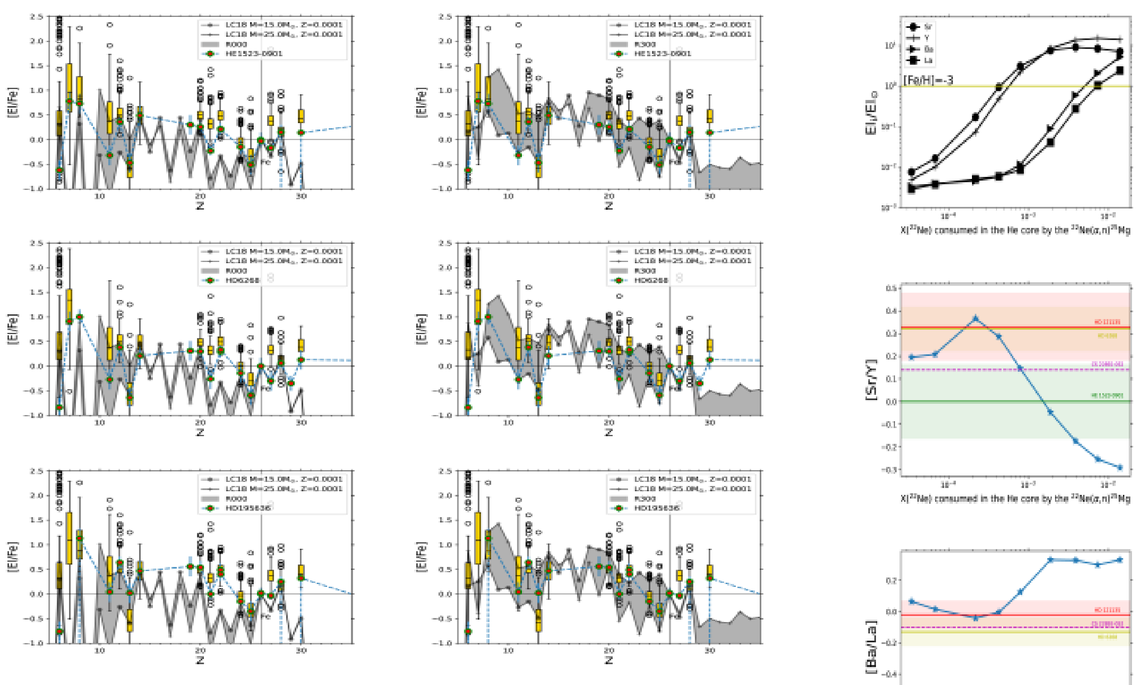


Fig. 12. Abundance distribution up to Zn of HE 1523–0901 (upper panels), HD 6268 (central panels) and HD 195636 (lower panels) are compared to other stars with similar [Fe/H] (within 0.5 dex) by Frebel (2010) and to stellar model predictions for CCSNe of initial mass 15 M⊙ and 25 M⊙ and metallicity Z = 0.0001, non rotating (left panels) and with initial rotation equal to 300 Km per second (right panels), by Limongi & Chieffi (2018).

Fig. 14. Upper Panel: the production of Sr, Y, Ba and La is shown for nucleosynthesis models of fast-rotating massive stars for different amounts of 22Ne consumed by the 22Ne(α,n)25Mg reaction rate. The trends of [Sr/Y] (central panel) and [Ba/La] (lower panel) are shown with the stars observed in this work with current error ranges if available, in comparison with the r-process star CS22892-052 (Sneden et al. 2003, 2009).

HD 121135

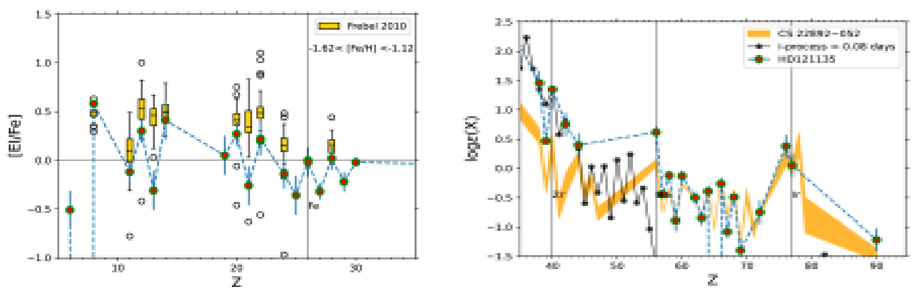


Fig. 11. Observed abundances of HD 121135 are shown in comparison with the abundance distribution of stars with analogous metallicity (-1.62 < [Fe/H] < -1.12) by Frebel (2010). The rectangle boxes cover the observed values between 25% and 75% of all the data points, for elements with more than 15 observed stars. The median values of the models are also shown in the boxes. The error bars cover 1.5 times the range of the box plot. Any points outside the error bars (outliers) are shown as open circles.

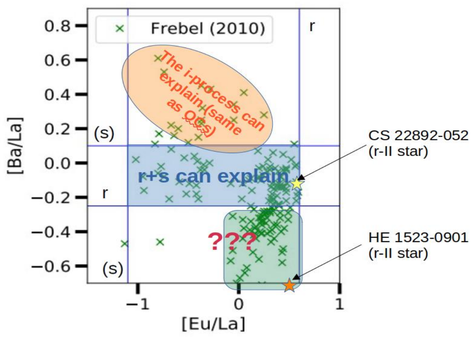
Fig. 15. The heavy element abundance distributions of HD 121135 are compared to the abundance pattern of the r-process star CS22892-052, and to the i-process abundances normalized to Zr.

r process

Based on [Eu/Fe] and other criteria : HD 121135 is a limited-r candidate; HD 6268 qualifies as an r-I candidate; HD 195636 shows as a borderline case between limited-r and r-I stars; **HE 1523–0901 is an r-II stars, but with an anomalous low [Ba/La] compared to r-process simulations or the r-II star CS22892-052**.
The studied stars support a scenario where the solar r-process pattern it is not a universal product of r-process sites in nature. The source of such a variation could be explained by a unique astrophysical site but with varying conditions from event to event, or more likely by a number of r-process sites contributing to the chemical evolution (e.g., Farouqi et al. 2022).

For instance, the magneto-rotational SNe could be responsible for the limited-r stars, and Compact Binary Mergers and Collapsars could be the source of the abundances observed in r-I and r-II stars.

The problem of Ba deficiency in metal-poor stars:



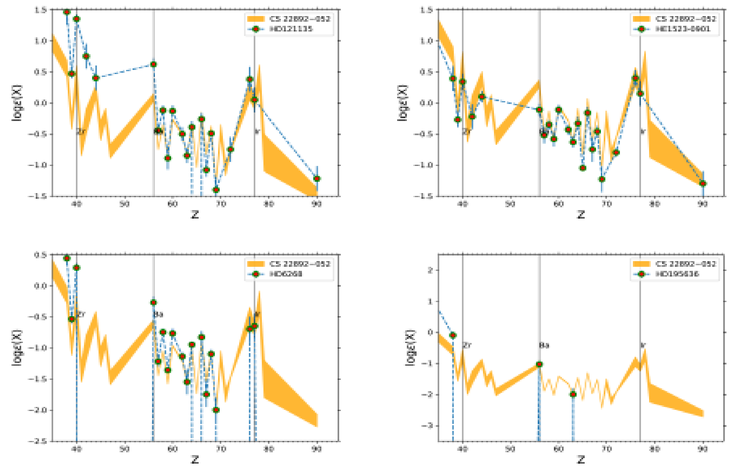


Fig. 13. Heavy element abundance distributions of HD1211135, (upper left) HE1523-0901 (upper right), HD6268 (lower left) and HD195636 (lower right) are compared to the abundance pattern of the r-process star CS22892-052 (Sneden et al. 2003, 2009).

Results & highlights

-- HD 121135 is Al-poor and Sc-poor compared to stars observed in the same metallicity range (-1.62 > [Fe/H] >-1.12). The most metal-poor stars in our sample, HE 1523 - 0901, HD 6268 and HD 195636, show anomalies that are better explained by supernova models from fast-rotating stellar progenitors for elements up to the Fe group. Compared to other stars in the same metallicity range, their common biggest anomaly is the low Sc abundances. If we consider the elements beyond Zn, HE 1523-0901 can be classified as an r-II star, HD 6268 an r-I candidate, and HD 195636 and HD 121135 show a borderline r-process enrichment between limited-r and r-I star. Significant relative differences are observed between the r-process signatures in these stars.

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