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Draco 119: A Giant Lacking Neutron-Capture Elements

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Abstract

We report the abundance analysis of high S/N spectra of the most metal-poor ([Fe/H] = –2.85) star known to be a member of a dwarf galaxy, the Draco dSph red giant D119. No absorption lines for elements heavier than Ni are detected in two Keck HIRES spectra covering the $\lambda\lambda$ 3850–6655 Å wavelength range. We present upper limits for several heavy element abundances. The most stringent limits, based on the non-detection of the Sr II λ4407 Å and Ba II λ4554 Å lines, suggest that the total s- and r-process enrichment of D119 is at least 100 times smaller than normal Galactic stars of similar metallicity.

1.1 Introduction

The elements heavier than the iron group are believed to be produced primarily by neutron-capture processes. The "slow" and "rapid" processes (also known as the "s-" and "r-processes") are named due to the rate of neutron captures with respect to the beta-decay times of the resulting nuclei (Burbidge et al. 1957).

The exact astrophysical sites of these processes has been the basis of much research. Sneden & Cowan (2003) and Truran et al. (2002) review the current understanding of the origin of the neutron-capture elements. The s-process is generally accepted to occur in two sites: the He-burning cores of massive stars and the thermally pulsing He shells of AGB stars. However, the specific site of the r-process is unknown, but it is strongly suspected that Type II supernovae play an important role. Truran et al. (2002) point out four possible sites, three of which occur in Type II supernovae explosions.

The abundances of elements other than the neutron-capture elements may be a potential diagnostic in determining the site(s) of the r-process. In this case, we analyze a star that does not show any enrichment of neutron-capture elements. If the origin of the other elements can be discerned, it may be possible to eliminate some of the potential r-process sites.

In this contribution, however, we will limit our discussion to the properties of the neutron-capture element poor star Draco 119 (D119; identification by Stetson (1979). D119 is presently the most metal-poor giant in the Draco (or any other) dSph galaxy for which a detailed abundance analysis has been performed. The overall abundance in D119 is far below that of any Galactic globular cluster and is near the realm of the ultra metal-poor stars (McWilliam et al. 1995; Ryan et al. 1996; Johnson 2002). Fulbright et al. (2004) compares the abundances of D119 to various nucleosynthesis theories.

1.2 Observations

Draco 119 was observed using the HIRES spectrograph on Keck I on the nights of 6 July 2000 and 29 June 2001. The July 2000 observations consisted of a total exposure than 15000 s covering the $\lambda\lambda$ 3850–6280 Å wavelength range. The June 2001 observations covered the $\lambda\lambda$ 4225–6655 Å wavelength range with a total exposure of 21000 s. Both sets of observations were made at a resolution of 45000. The data were reduced with the MAKEE package developed by Tom Barlow. The S/N is about 5 per pixel in the far blue, about 35 per pixel around the Ba II 4554 Å and about 60 per pixel in the red.

HD 88609 is a "normal" local halo red giant with stellar parameters very similar to those of D119. We will therefore use it as a comparison object and analyze it in a similar fashion. Jennfier Johnson has kindly provided us with high-S/N HIRES blue spectra of this star used in Johnson (2002) and Johnson & Bolte (2002). The red spectrum of this star taken by Fulbright (2000) was also used in the reanalysis of this star. The 4554 Å Ba II and 4703 Å Mg I lines of the two stars are compared in Figure 1.

1.3 Abundance Analysis

The abundance analysis of the two stars was conducted using the LTE code MOOG (Sneden 1973) and Kurucz model atmospheres. The line list was composed of lines used in the Johnson (2002) and Fulbright (2000) abundance surveys. Hyperfine splitting analysis was included where the line data was available. The carbon abundance was deduced from the CH features of G-band using the line list of Brown et al. (1987).

The $T_{\rm eff}$ value of the two stars were set using the photometric $T_{\rm eff}$ calibration of Alonso (1999). The value of log(g) was set by adopting a mass (0.8 $M_\odot$), distance (82 kpc for D119 and 910 pc for HD 88609), bolometric corrections (Alonso 1999), and $T_{\rm eff}$ value. The microturbulent velocity was determined using Fe I lines.

The stellar parameters values ($T_{\rm eff}$, log(g), [m/H], v_t) adopted for D119 are 4440 K, 1.12, -2.60, and 2.05 km/s and 4600 K, 1.58, -2.60, and 2.10 km/s for HD 88609. D119 was previously observed by Shetrone et al. (1998), at lower S/N ($\sim$25 per pixel) using 4370 K, 0.15, -2.80, and 2.8 km/s as the parameters. The difference in adopted parameters only slightly affects the final abundance results.

For many elements in D119 we were not able to accurately measure a single line. In order to place upper limits for the abundance of these elements, we studied the observational limit of the many Fe lines in the spectrum as a function of S/N and wavelength. It was found that the measurement limit was approximately twice the value given by the EW error formula of Cayrel (1988). We therefore used this value to help estimate the upper abundance limit of several elements. A comparison of the [X/Fe] ratios of both stars and field halo stars for the neutron-capture elements is shown in Figure 2.

1.4 Abundance Results

The limits on [Sr/Fe] and [Ba/Fe] suggest the material that formed D119 was not enriched by n-capture processes. We will assume that D119 formed before enough time had elapsed for AGB stars to enrich Draco with s-process material. The 15 Gyr age assigned to D119 by Tolstoy et al. (2003) supports this assumption. Burris et al. (2000) finds that there may be some s-process enrichment in the Galaxy at [Fe/H] ≈ -2.75, but the main s-process only begins to dominate at [Fe/H] ≈ -2.2. Therefore, any implications derived from the the lack of neutron-capture elements in D119 will only affect theories of the r-process.

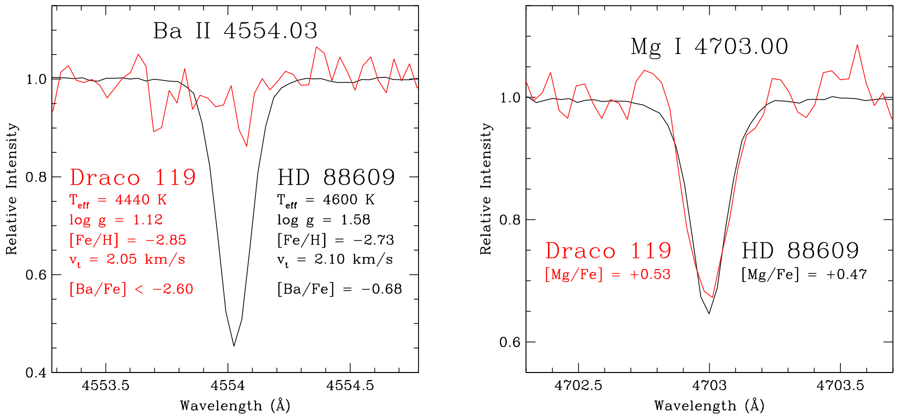

Fig. 1.1. Comparison of the 4554 Å Ba II line (left) and the 4703 Å Mg I line (right) between Draco 119 (red) and HD 88609 (black). Both stars have very similar parameters and Mg line strengths, but the Ba line is not detected in Draco 119.

The [X/Fe] ratios of Ca, Ti, Cr, Mn, and several neutron-capture elements are lower in D119 than in HD 88609. The strongest limits on the neutron-capture enrichment of D119 are given by the normally-strong Sr II 4077 Å and Ba II 4554 Å lines, neither of which were detected in D119. The resulting limits for these elements are [Sr/Fe] < -2.2 and [Ba/Fe] < -2.6.

Conversely, the [C/Fe], [Mg/Ca] and [Mg/Ti] ratios are higher in D119. Shetrone et al. (1998) find that all observed Draco dSph giants show high [Mg/Ca] and [Mg/Ti] ratios. As shown in Figure 2, the Draco dSph giants also show lower [Y/Fe] ratios than field halos stars. The more metal-rich Draco giants show similar [Ba/Fe] ratios to the halo field, but the star Draco 24 might have a significantly lower [Ba/Fe] ratio. Understanding the context of Draco 119 within the Draco system will be necessary to determine which abundance anomalies are related to the lack of neutron-capture elements in D119.

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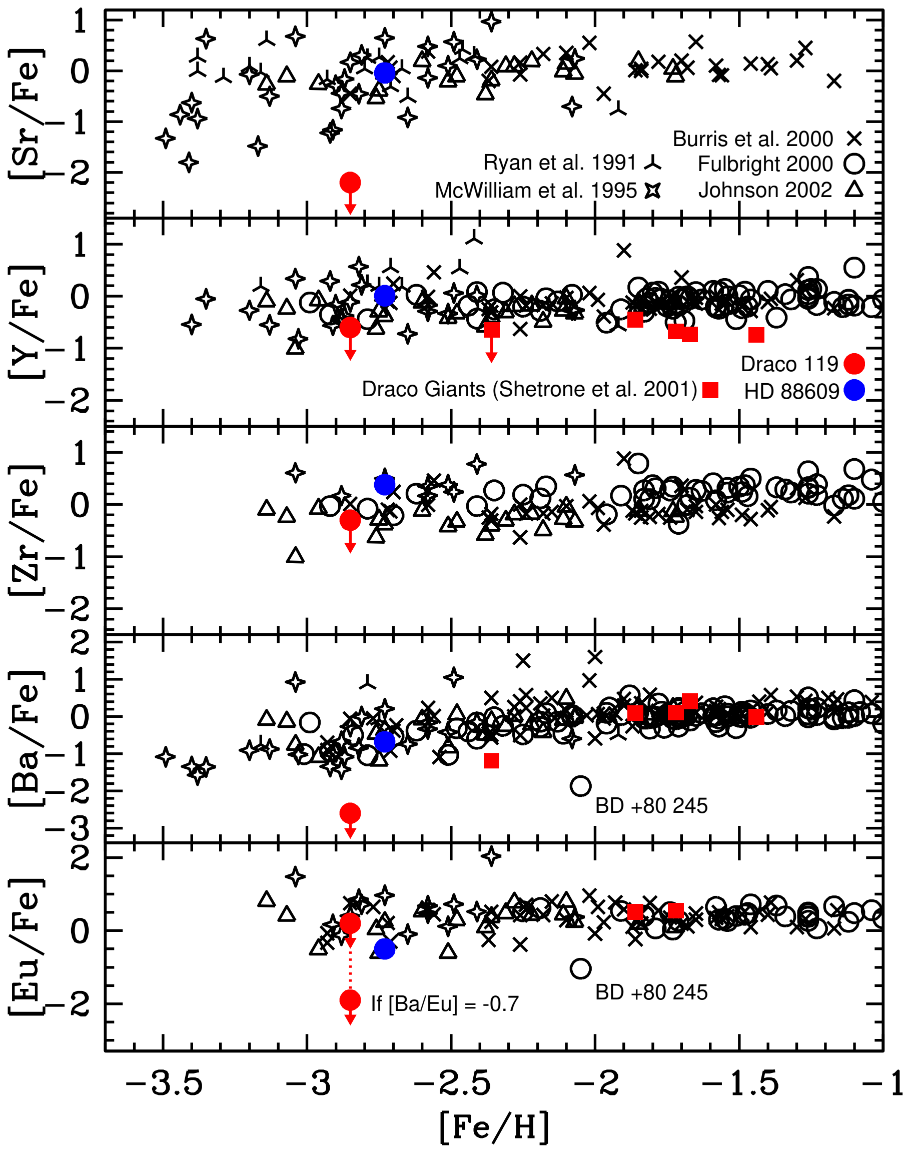

Fig. 1.2. Comparison of the neutron-capture [element/Fe] ratios as a function of [Fe/H] for Draco dSph giants (red) and field halo stars (green and black). Draco 119 is the red circle, while the red squares denote the stars from Shetrone et al. (2001). Our comparison star, HD 88609, is representative of the halo field population. The Draco dSph giants have lower [Y/Fe] ratios at all metallicities, but the [Ba/Fe] ratios are similar to the field halo population (with the exception of Draco 119). In the bottom panel, a much lower value for upper limit for [Eu/Fe] is implied if the "pure" r-process [Ba/Eu] ratio of -0.7 is assumed.