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The Rise of the *s*–process in the Galaxy

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Abstract

Throughout the history of the Galaxy, the production of neutron-capture elements (those with Z>30) has been dictated mainly by two nucleosynthetic processes: the *s*–process and the *r*–process. Elements generated by the *s*(low)-process are believed to be formed in the He-burning regions of low to intermediate mass stars, while *r*(apid)-process elements likely originate in massive star supernovae. In the most metal-poor stars, those elements with large *s*-process components are deficient with respect to those with large *r*-process components. This is consistent with the expected nucleosynthetic output from the massive stars that probably dominated the element forming processes early on in the Galaxy. Typically, the measurement of the $s-/r$–process has been carried out with the elements Ba and Eu, since the former is produced almost entirely in the *s*-process and the latter in the *r*-process. Here, instead of Ba, we measure the *s*–process element La, since new and highly accurate atomic data have become available for La and Eu, making the results much more precise than they have been.

1.1 Data and Results

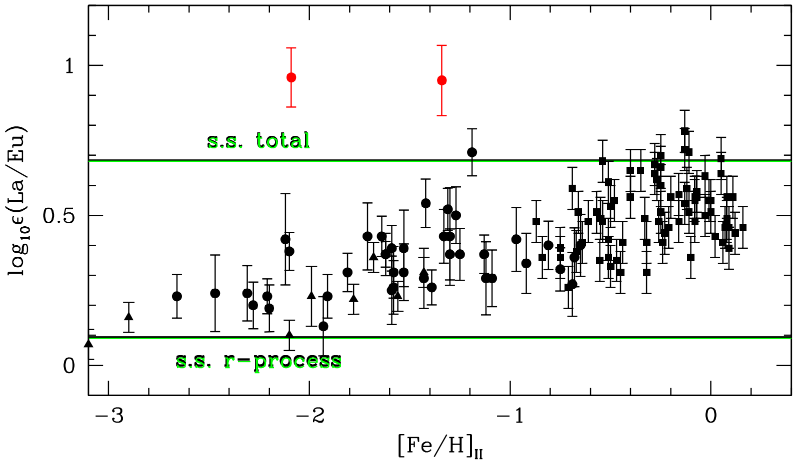
Our sample includes $\sim$100 stars observed on the McDonald Observatory 2.7m telescope with the cross-dispersed echelle spectrograph at R$\sim$60,000. Signal-to-noise is typically 100 at 4100Å. Stars were selected to have $-2.5 \geq$[Fe/H]≥ -1 and were taken from Bond (1980) and Carney et al. (1994). Most of our stars near [Fe/H]$=-1$ are dwarfs taken from the Carney et al. (1994) high proper-motion survey, which may be expected to yield a disproportionate number of thick-disk stars in this range. Our sample has been supplemented with higher-metallicity data from Woolf et al. (1995).

Stellar parameters were fixed in a self-consistent manner, with T_{eff} from infrared colors calibrations and stellar surface gravity from the relation

$$logg = log(M/M_{sun}) + 4 * log(T/T_{sun}) + 0.4 * (M_V - 4.75) + 4.45$$

. Note that this may result in significant differences between [Fe I/H] and [Fe II/H]. The quantity logϵ(La/Eu) is highly insensitive to uncertainties in stellar atmospheric parameters (i.e., log g and T_{eff}), and the pictured error bars will represent the standard deviation of the mean La/Eu.

1.1.1 Figures



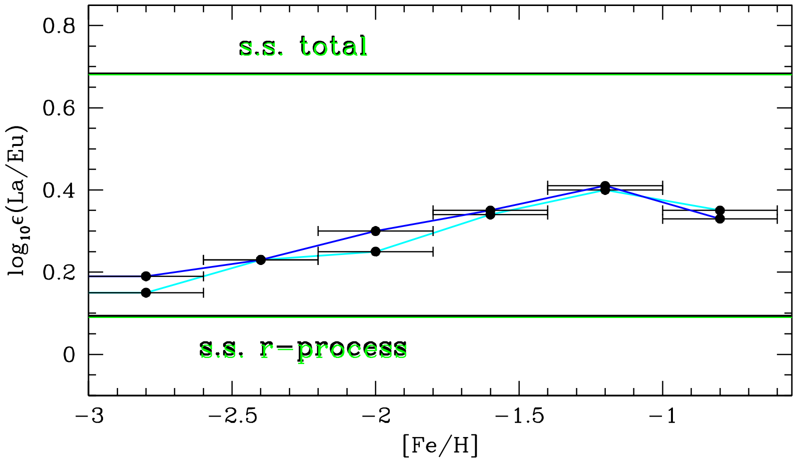
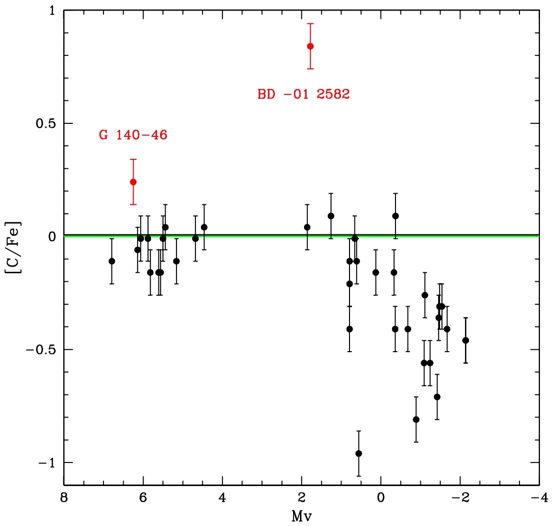


Fig. 1.1. TOP:The abundance ratio log ϵ(La/Eu) for our sample (circles) as a function of stellar metallicity (measured by Fe II). Stars from the Woolf sample (squares) and values gathered from other reliable sources (triangles) are also shown. There is no evidence of appreciable offset between data sets. The upper green bar represents the total (meteoritic) abundance of La/Eu measured in the solar system and the lower green bar is the solar system La/Eu with the *s*–process contribution removed. At low metallicity ([Fe/H]< -2), contributions from the *s*–process appear to be largely absent, though an upward trend begins near [Fe/H]$=-1.8$. It should be noted that the downturn at [Fe/H]~ -1 may be due to the aforementioned selection effects in our sample. Even so, most stars fall well below the solar value, even at solar metallicity.

Fig. 1.2. BOTTOM:Average log ϵ(La/Eu) in 0.4 dex [Fe/H] bins (centered on the black points). The dark blue line follows the trend in [Fe/H]$_{avg}$; the light blue line follows [Fe II/H]. There is very little difference in the overall shape (despite the large discrepancy in [Fe I/H] and [Fe II/H] at low metallicity).



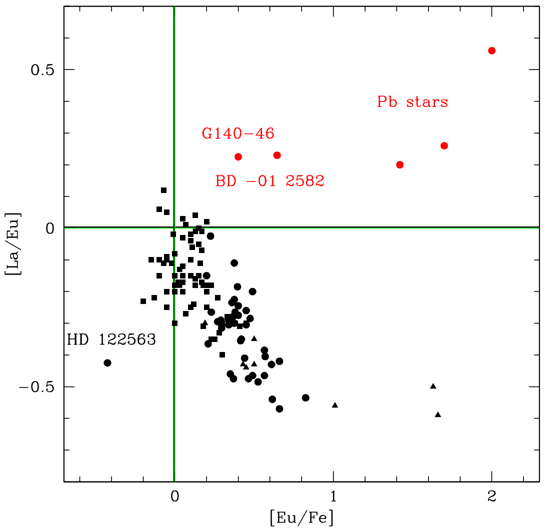
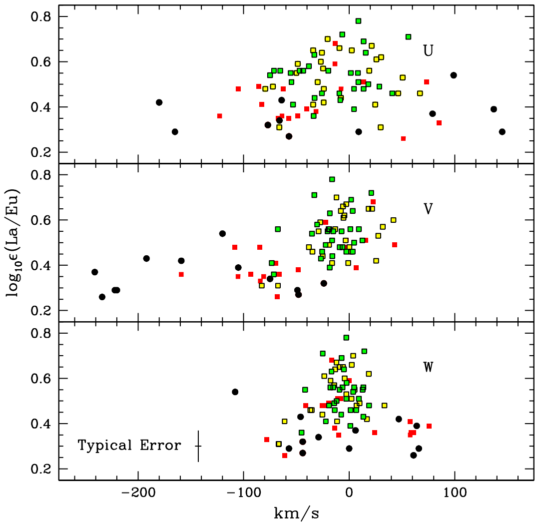


Fig. 1.3. TOP:Two stars with extremely large La abundances (shown here in red) have been removed from consideration as part of the Galactic trend. Closer examination has revealed that both G140-46 and BD-01°2582 have anomalously high carbon abundances, which may be indicative of unique chemical histories. Tomkin and Lambert (1999) have identified G140-46 as a CH star.

Fig. 1.4. BOTTOM:The transition to increasing *s*–process abundance is considerably smoothed out when the overall Eu abundance is taken into account. Here we plot results from out data (circles) and the Woolf data set (squares). The correlation is quite compact, with the notable exception of HD 122563, which appears to be remarkably Eu-poor and the two *s*–process rich stars shown in red, as above. The other three red points are stars with large Pb and *s*–process abundances (see references). The triangles represent selected literature data–most notably CS22892-052 and CS31082-001, stars known to have *r*–process enhancements.



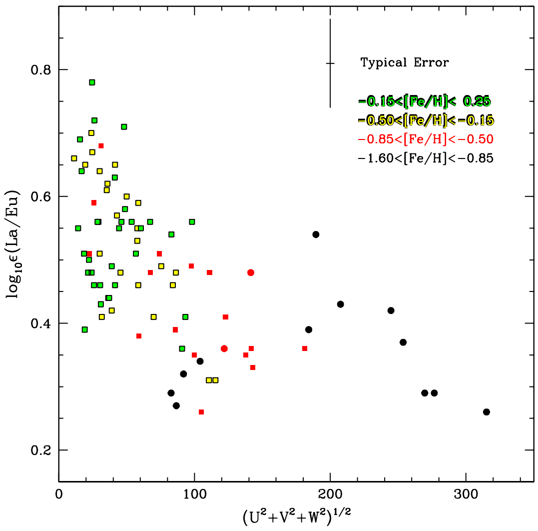


Fig. 1.5. TOP:We find a correlation between the total space velocity V and La/Eu, such that stars with solar $s-/r$–process ratios have low velocity, independent of [Fe/H]. Indeed, [Fe/H] shows no real connection to kinematics in this metallicity range. Only dwarfs have been included (as giants are typically too distant to have reliable proper motion or parallax measurements). Woolf stars are shown with squares, our stars with circles.

Fig. 1.6. BOTTOM:Velocity components for those dwarf stars shown above (calculated according to Johnson and Soderblom, 1987). The color and symbol coding is the same. The Woolf star velocities were calculated with HIPPARCOS data while our more metal-poor dwarfs are shown with the velocities given by Carney et al (1994). There may be a minor systematic difference between the velocities due to a small offset between Carney et al. and HIPPARCOS distances.

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