Clues to the Isotopic Evolution of the Solar System from Er and Yb in Allende CAIs

An inaugural isotopic study of heavy rare earth elements

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Calcium-aluminum-rich inclusions (CAIs), the first solids to condense in the protoplanetary disk, provide insights into the formation and evolution of our Solar System. Previous work has suggested that normal CAIs formed in an isotopically homogenous reservoir that was different from later formed objects in the Solar System [1-6]. This study examines the Er and Yb isotopic composition of Allende CAIs in order to further characterize the CAI reservoir and investigate why isotopic differences exist within various Solar System materials.

Background

Differences in the isotopic compositions of CAIs and other bulk Solar System materials can possibly be explained by excesses and depletions in isotopes produced by nucleosynthetic processes (*p*-, *s*-, and *r*-process). Therefore, elements that have multiple stable isotopes produced by these processes (e.g., Er and Yb) are desirable for study. In this work, we present isotopic data on four large coarse-grained CAIs that had previously been analyzed for Mg, Ti, Cr, Sr, Zr, Mo, Te, Ba, Nd, Sm, Gd, Dy, and U isotopic compositions [1, 5, 7-9]. Large CAIs were chosen so enough material was available for isotopic measurements by both MC-ICPMS and TIMS.

Chemical Separation

In order to precisely measure Er and Yb isotopes, the first step is to separate the rare earth elements (REEs) from the CAI matrix. The second step is to isolate and purify Er and Yb in order to remove isobaric interferences such as Dy and Lu. To achieve this, a new chemical separation procedure (Fig. 1) was developed utilizing LN-Spec resin and various volumes of 1.25N, 2.15N, and 3.5N HCl. This procedure was tested using rock standards and column yields were >90% for both Er and Yb. Two passes through LN-Spec chemistry is necessary to sufficiently isolate the elements of interest for isotopic measurement.

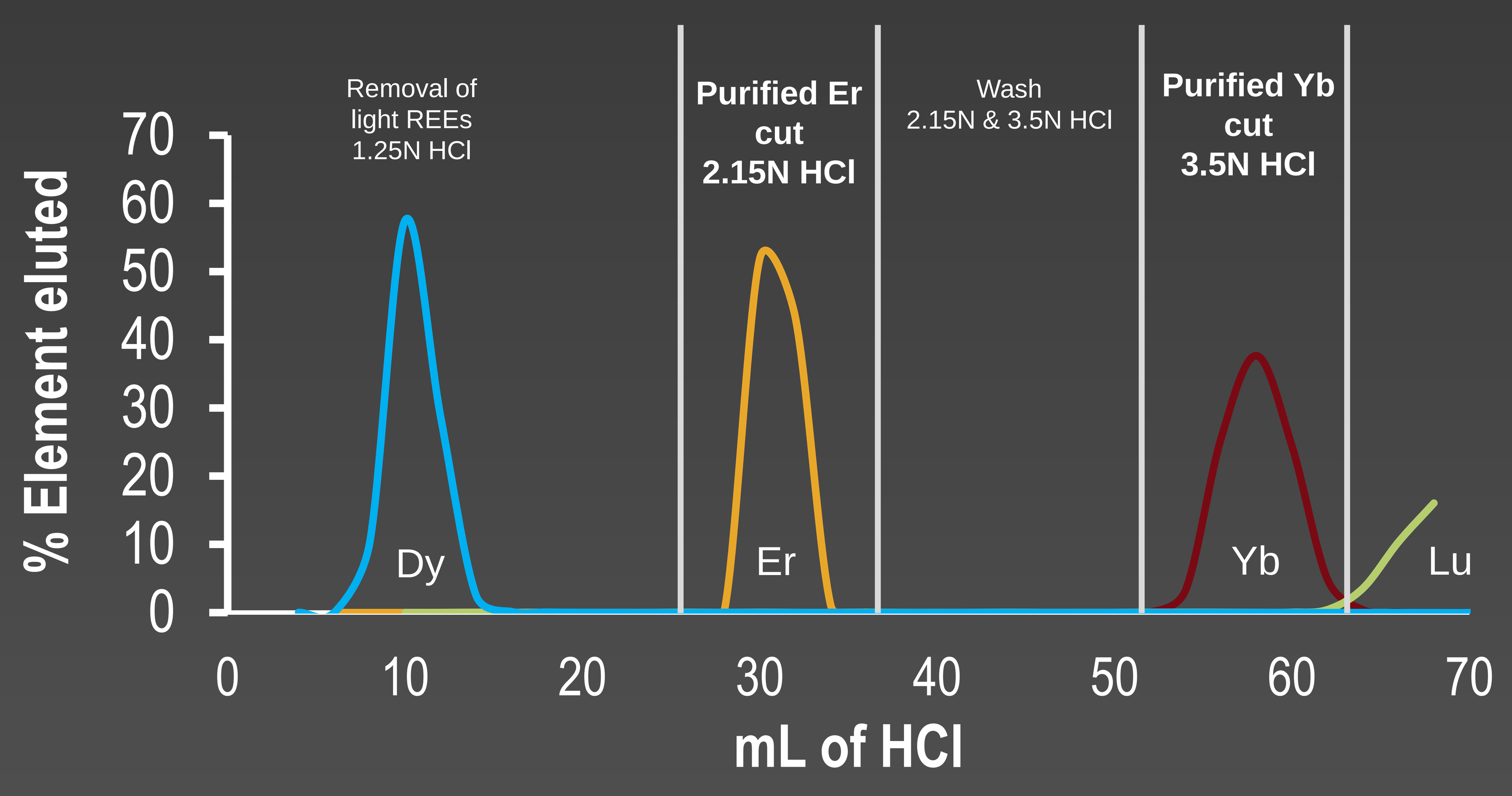

Fig. 1. Chemical separation of the heavy REEs. The x-axis shows the mL of HCl added to the column and the y-axis is the percent of the element eluted from the column.

Results

The Er and Yb isotopic compositions of Allende CAIs analyzed in this study along with *r*-process abundance models are presented in Figs. 2 and 3. All of the CAIs for both elements and measurement techniques yield consistent values. As such, only the average CAI data is given. Values are presented in parts per million (ppm) deviation from the standard. The uncertainties presented for the terrestrial standards represent the 2SD of the long-term reproducibility of that standard over the measurement campaign. Internal normalization was used to correct for instrumental mass bias using $^{166}Er/^{168}Er = 1.2414$ and $^{174}Yb/^{172}Yb = 1.4772$.

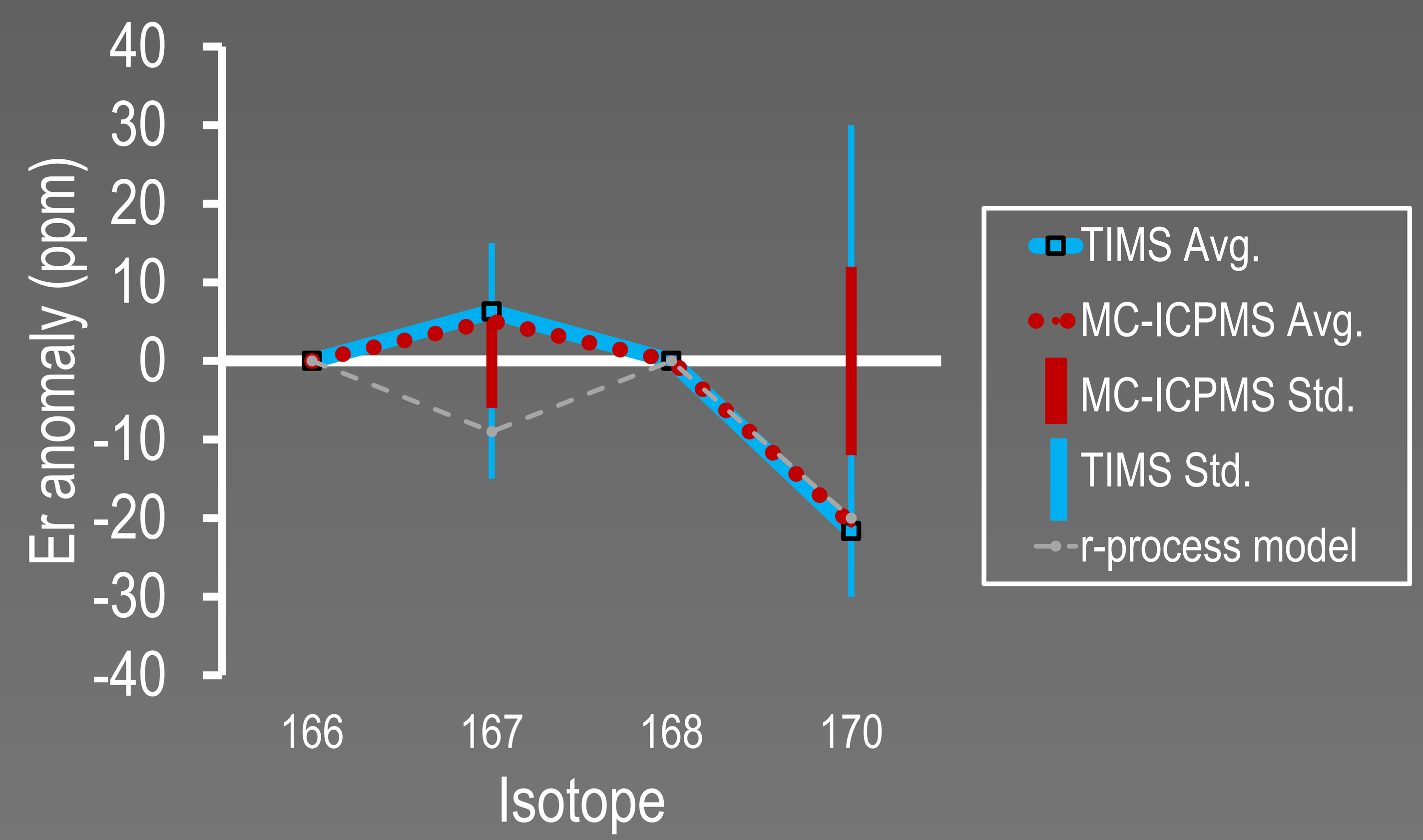

Fig. 2. The TIMS and MC-ICPMS average Er isotopic compositions of CAIs normalized to terrestrial standards. The x-axis contains the isotopes of Er and the y-axis shows the deviation from the terrestrial standard in ppm. The dashed gray line is the "best fit" *r*-process deficit model based on *r*-process abundances from [10].

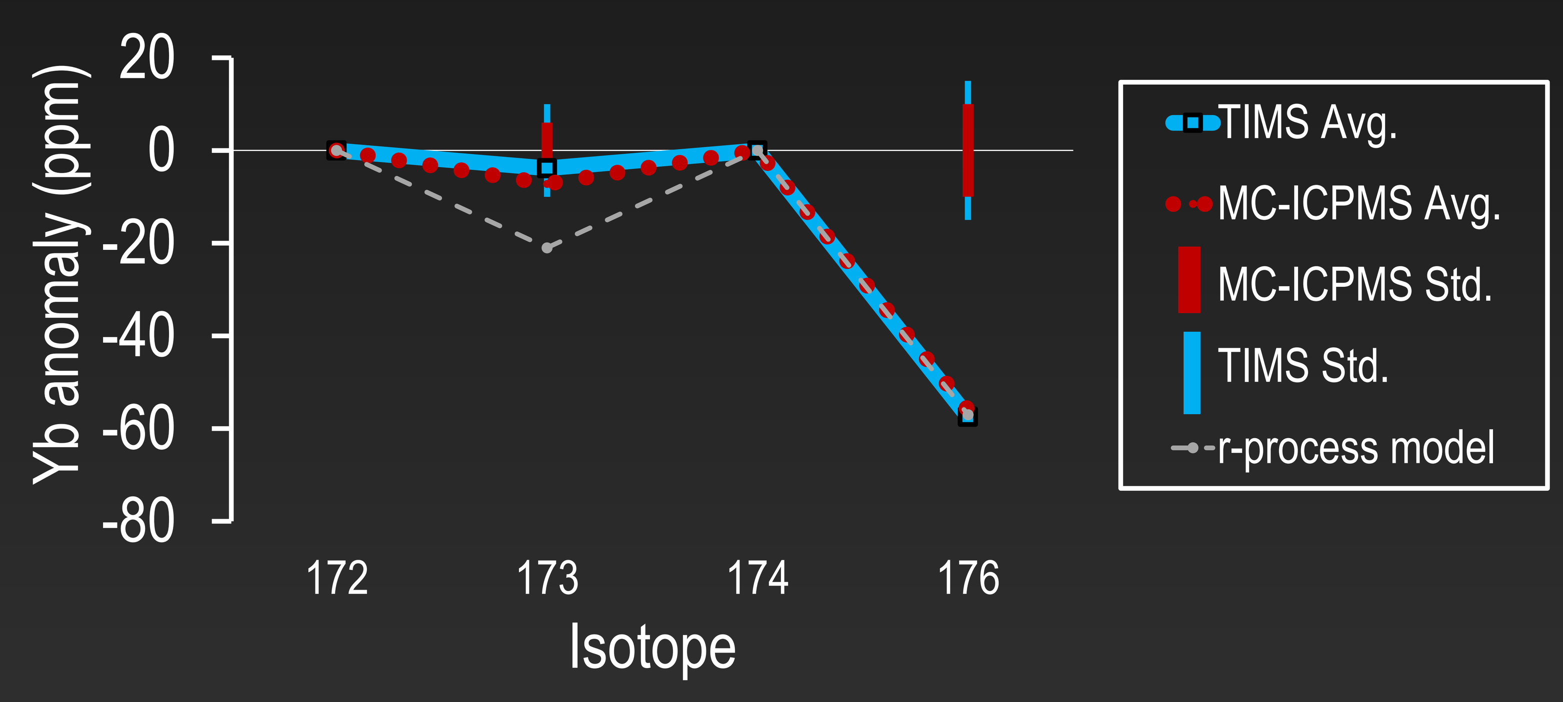

Fig. 3. The TIMS and MC-ICPMS average Yb isotopic compositions of CAIs normalized to terrestrial standards. The x-axis contains the isotopes of Yb and the y-axis shows the deviation from the terrestrial standard in ppm. The dashed gray line is the "best fit" *r*-process deficit model based on *r*-process abundances from [10].
Note TIMS data only averages three Allende CAIs because one CAI did not have enough material for MC-ICPMS and TIMS measurement.

Discussion

The CAIs analyzed using both MC-ICPMS and TIMS are indistinguishable from one another for both Er and Yb. These data agree with previous results from other elements that Allende CAIs contain uniform, yet distinct nucleosynthetic anomalies [1-5]. Furthermore, both elements studied have a depletion in *r*-process derived material compared to terrestrial rocks (Fig. 4) consistent with other REEs examined [1,5]. Whereas the Er isotopics reveal a slightly lower than expected *r*-process depletion based on the previously established systemic trend from mass ~80-160, this disturbance could simply be a lack of understanding in the processes creating these isotopes and/or the uncertainties related to the nucleosynthetic model and isotopic measurements generating Fig. 4. Overall, the systematic trend is still intact but further assessment is necessary to investigate the significance of this trend.

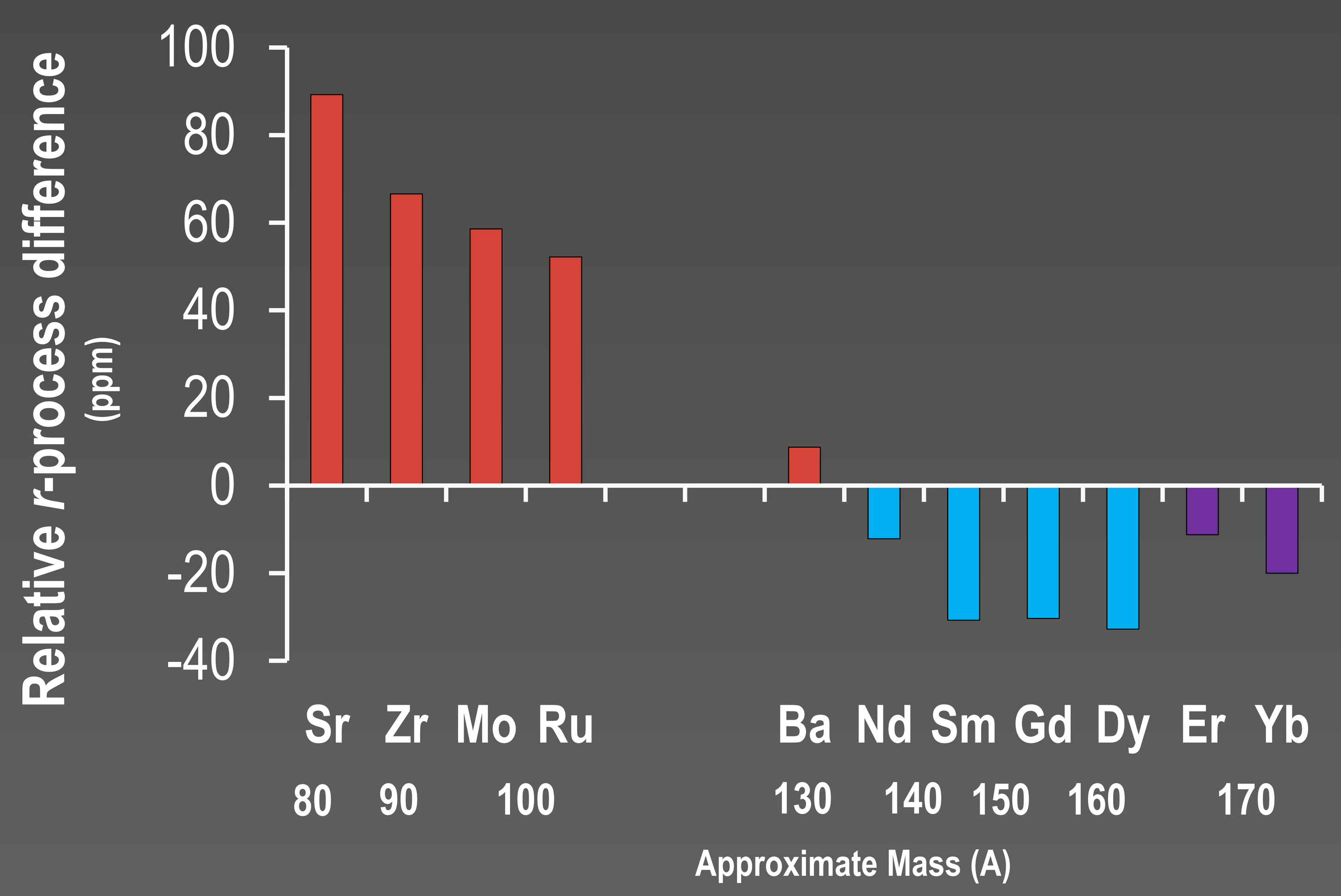

Fig. 4. The relative *r*-process difference between CAIs and terrestrial standards (in ppm) on the y-axis plotted against elements of increasing mass. The terrestrial composition is defined as zero for each element and the difference is calculated by how much *r*-process material is needed to be added or subtracted to match the data obtained from CAIs. Figure modified from [1, 5] with the addition of Er and Yb (in purple) from this study.

Conclusion

The stable isotope compositions of almost all elements studied in normal CAIs from a variety of meteorites, including new isotopic data from Er and Yb, strongly support an isotopically homogeneous CAI reservoir [1, 3-6]. The isotopic character of this reservoir is clearly defined by *r*-process excesses and depletions of varying magnitudes in different elements. It is still unknown why such isotopic differences exist between CAIs and other bulk Solar System objects, however it is possible that admixing of supernova derived material after condensation of CAIs could explain the difference, as suggested in [1].

Works Cited

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Acknowledgements

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Document LLNL-POST-668382.