2MASS J00101758-1735387: A Star's Journey Across the Cosmos from an R-processed Ultra Faint Dwarf Galaxy to the Milky Way Halo

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Abstract

While the lighter elements (Z<30) are known to be forged during the lifetime of stars, the elements heavier than Strontium are thought to be forged by events following their deaths. Metal-poor stars enhanced with the rapid-neutron-capture (or r-) process provide the perfect opportunity to constrain the astrophysical site of the r-process. We present a detailed abundance analysis of a metal-poor r-process enhanced star, 2MASS J00101758-1735387, with [Fe/H]= -2.4 dex. We detect Thorium from which we estimate a preliminary age of 12.5 Gyrs, from [Th/Eu]= -0.507 using nucleo-cosmo chronometry. Early analysis of this halo star's chemical abundances shows that the traces of its α-elements are systematically lower than what would be expected of stars in the Milky Way Halo. Its [Mg/Eu] ratio, is however consistent with the Ultra Faint Dwarf Galaxy Reticulum II, which is an old and less chemically evolved system than the Milky Way. Further comparisons to other UFDs can help elucidate into the accretion origin of J0010-1735. Moreover, the age of J0010-1735 itself allows us to age the system in which it was born, which may present a unique opportunity to place a preliminary age for the oldest galaxies in the universe.

Introduction

When the universe was first created, stars were formed in the pristine gas that consisted of mostly Hydrogen and Helium. As these stars went through their life cycle, they produced the light elements (H to Fe) via nuclear fusion. Upon their violent deaths, the astrophysical environment creates the opportunity for the elements ranging from Strontium to Uranium to be forged via the rapid-neutron-capture process. This process requires an extremely high flux of neutrons which can only be produced in explosive events such as Neutron Star Mergers. The elements that the star has accumulated are then ejected into the medium around them, enriching the gas with these elements. The oldest stars are the least chemically evolved bodies, due to them being formed from under-enhanced gases. Metals (any element heavier than Hydrogen or Helium, according to astronomers) characterize the level of chemical evolution in stars. This is delineated by the abundance of Iron relative to Hydrogen [Fe/H], otherwise known as the metallicity.

The galactic chemical history can be studied by analyzing metal-poor stars. We look towards the halo of the Milky Way, which is less chemically involved than the heavy star formation of the bulge. We can also look towards Ultra Faint Dwarf Galaxies (UFDs) which are some of the oldest and least chemically evolved systems in the universe. Halo and UFD stars have chemically encoded the environment that was present at their birth. Older metal-poor stars that are enriched in the r-process could indicate that only one progenitor event occurred that enriched its surroundings with the r-process, providing the perfect opportunity to constrain its sites and attributes.

Our star J0010-1735 is an older, metal-poor, r-process enhanced star in the Milky Way Halo. By studying it, we can attempt to learn about the conditions at the time of its creation as well as learning more about the r-process.

Methodology

J0010-1735 was first observed using the Magellan Inamori Kyocera Echelle (MIKE) spectrograph on the 6.5 m Magellan Clay telescope at Las Campanas Observatory in Chile. After the observation, we conducted an in-depth spectroscopic analysis to determine its stellar parameters and chemical abundances. Spectroscopy Made Hard (SMH), a Python code was used to determine the temperature, metallicity, surface gravity, and micro-turbulent velocity of this star. To determine these properties, the star's spectra was analyzed and the Fe absorption lines were determined using the equivalent width (EW) measurements by fitting Gaussian line profiles to the spectral absorption features. The initial temperature was determined by reducing trends in the Fe I abundances with respect to excitation potential. The surface gravity was determined by ensuring equilibrium between the Fe I and Fe II lines. The micro-turbulent velocity was deduced from removing trends in the Fe I abundances with respect to the equivalent widths. Finally, the metallicity was found by using the average abundances of both Fe I and Fe II lines. After the initial temperature was found, we applied the corrective equation (1) determined by Frebel et al. to obtain the true corrected temperature. The abundances of all of the elements detected in this star were interpreted the same way, by determining equivalent width measurements at the wavelengths were the elemental lines were known to be. Nuclear cosmo-chronometry was used to age the star utilizing Thorium's radioactive decay on a cosmological timescale. We first input our measured ratio of Thorium relative to Europium into an equation determined by Schatz et al. (2), then input a production ratio determined by Hill et al. to obtain a preliminary age for J0010-1735.

$$T_{\mathrm{eff}}(\mathrm{FR13\ corr.}) = T_{\mathrm{eff}}(\mathrm{LTE}) - 0.1 \times_{\mathrm{eff}} (\mathrm{LTE}) + 670 \quad (1)$$

$$\tau = 46.7\mathrm{Gyr} * [\log(\mathrm{Th/X})o - \log(\mathrm{Th/X})*] \quad (2)$$

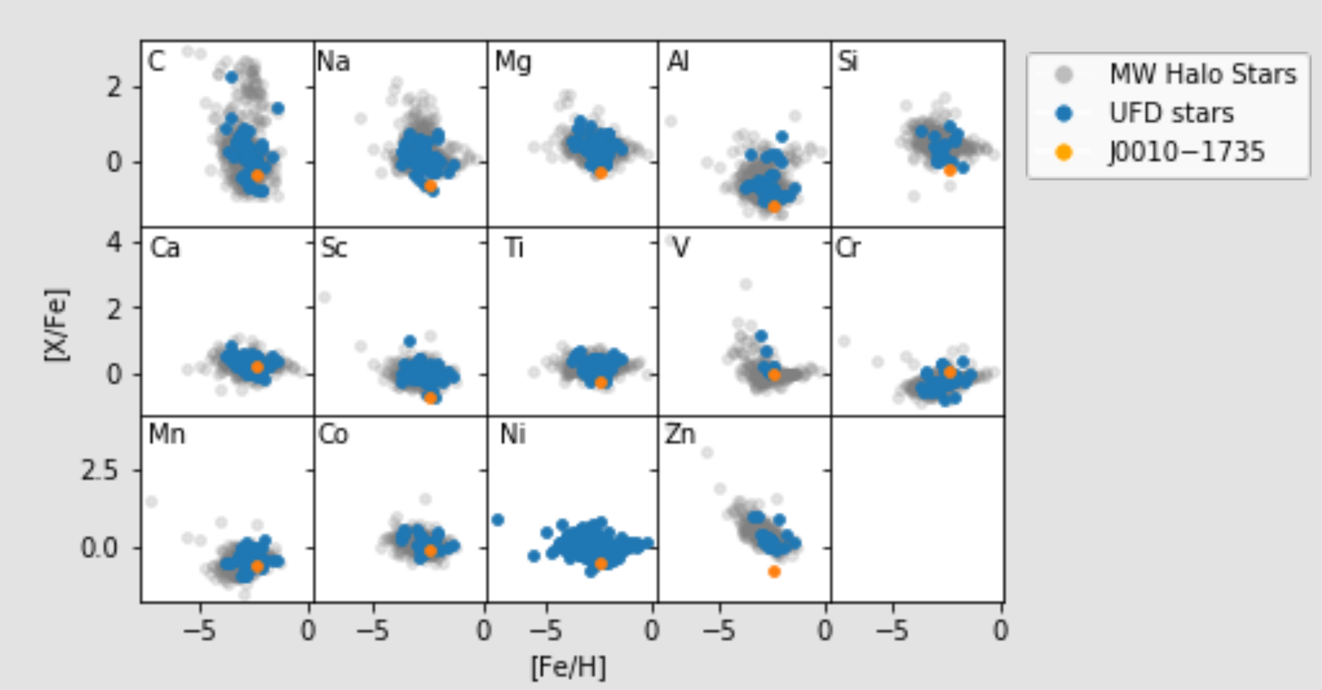
Results

- The determined values of J0010-1735 can be found in the first table, including both the initial parameters and the parameters after they were corrected by Frebel's equation.
- In the first plot (right), we showcase that the abundances of elements in our star J0010-1735 are systematically lower than the stars both in the Milky Way Halo and in multiple UFDs.
- In the second plot (left), we see that [Eu/Mg] for J0010-1735 aligns very nicely with the values of the r-processed Ultra Faint Dwarf Galaxy Reticulum II. This is significant because Eu is an element indicative of the r-process, and Mg is formed more slowly in UFDs. Thus, stars of similar origins and ages would lie in similar sections on the plot.
- The age determination for J0010-1735 by [Th/Eu] = -0.507 yielded 12.47 Gyrs.
  - log(Th)=-1.105
  - log(Eu)=-0.598

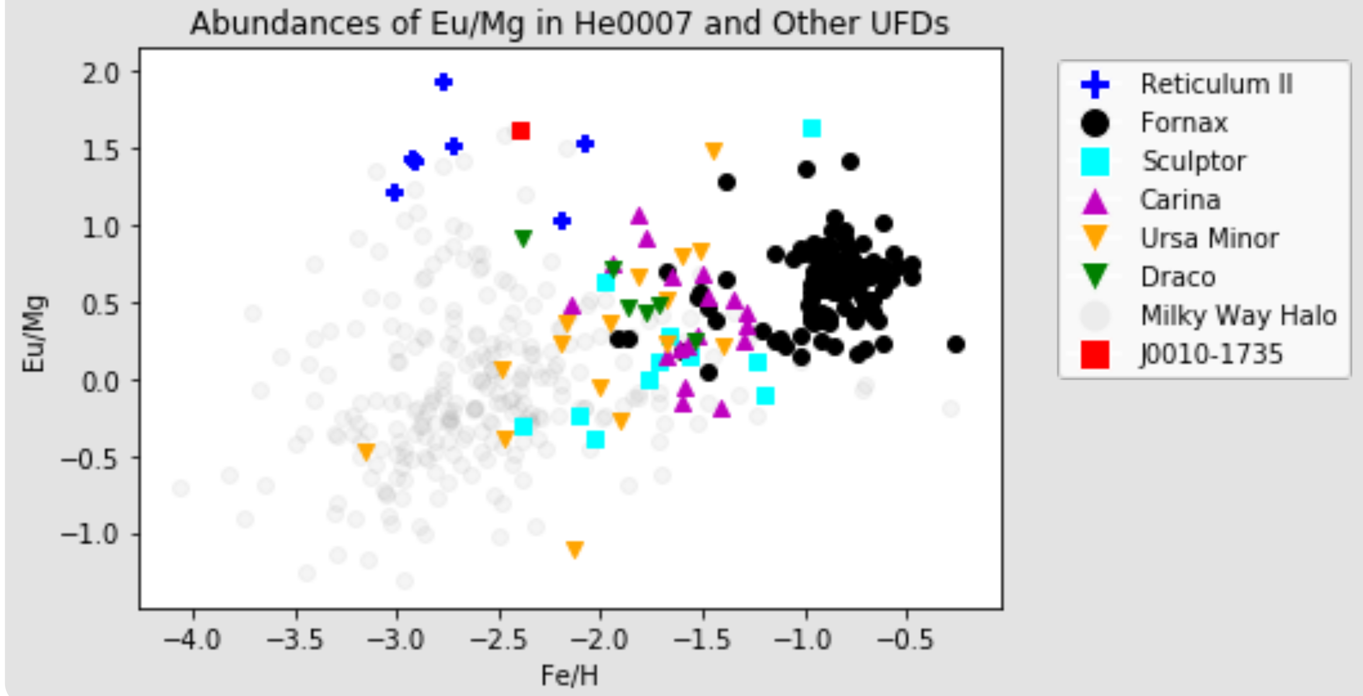
Stellar Parameters of J0010-1735

	LTE	Photometrically Corrected
Temperature	5050 K	5125 K
Surface Gravity	2.15	2.58
[Fe/H]	-2.4	-2.4
Micro-turbulent Velocity	1.37 km/s	1.25 km/s

Abundances compared to MW Halo Giants and UFD Stars



Abundances of Eu/Mg in He0007 and Other UFDs



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Conclusion

J0010-1735 is a metal-poor r-processed enhanced star that has a preliminary age estimation of 12.47 Gyrs. This star has a temperature of 5125 K, and a metallicity of -2.4 dex. While this star is r-process enhanced, it is simultaneously under-enhanced in its lighter elements, Carbon through Zinc. The under-enhancement of these elements lead us to believe that J0010-1735 did not originate from the Milky Way Halo, where it is currently located. Instead, we look outwards to Ultra Faint Dwarf galaxies which are the least chemically evolved systems. Our star has lower abundances of elements compared to most UFD stars, which means our star must be older than most. The [Eu/Mg] abundance matches with Reticulum II, a UFD, suggesting that our star comes from a very similar system. Nuclear cosmo-chronometry was used to obtain this star's age estimation, which yields an age close to the age of the universe. Putting an age on J0010-1735 which was formed in a near-pristine environment enables us to attempt to put an age on one of the oldest systems in the universe.

Recommendations

A complete work-up of J0010-1735's stellar kinematics, would be essential for the next step in this project. This would help determine the exact Ultra Faint Dwarf Galaxy that J0010-1735 accreted from, as well as providing insight into the process by which it accreted. To do this, galactic simulations would be the best way to predict the journey of J0010-1735, as well as taking into account the eccentricity of its orbit through the Milky Way Halo. The hierarchal formation of the Milky Way Halo could be better understood by linking dwarf galaxy system masses and their r-process productions. By using different simulations that factor in these characteristics, we could attempt to put constraints on the exact progenitor event that created J0010-1735, specifically the system's mass. More broadly, studying other older, metal-poor and r-process enhanced stars can help us definitively determine the astrophysical site of the r-process, and allow us to truly understand how the heavy elements on the periodic table are produced.

References

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