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CTA Proposal: SEGUE-1: An Unevolved Fossil Galaxy from the Early Universe

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1. TOPIC BACKGROUND

When studying the early universe scientists commonly seek out stars that were formed early on in the universe. Locked inside these stars are clues about the physical and chemical conditions that led to the formation of the star. With this information scientists can better understand physical and chemical conditions in the early universe as a whole. One way to identify these ancient stars is by their relatively low heavy metal ($Z \geq 24$) content compared to lighter elements, such as α-process elements and hydrogen.

Lighter α-elements are synthesized within massive stars and are released into the interstellar medium (ISM) once these massive stars undergo core-collapse supernova upon running out of helium. The lifetime of these massive stars, from their nucleosynthesis to their core collapse supernova event takes place in a very short time frame, often less than 10^6 yrs. Heavier elements, the paper specifically measures iron (FeI and FeII), strontium, and barium abundance, are synthesized and released later in the universe timeline. Iron is mainly synthesized during Type Ia supernovae events. These events occur when a white dwarf in a binary star system reaches the critical Chandrasekhar limit and explodes into a supernova event. These white dwarf systems have much longer lifetimes of around 10^8 yrs. Strontium and Barium, unlike the α-elements and iron do not form via normal fusion but only during neutron capture nucleosynthesis. Neutron capture nucleosynthesis happens during r-process supernovae and during the nucleosynthesis of population III supermassive stars. During each of these neutron capture nucleosynthesis events approximately $10^{-4} M_{\odot}$ of neutron capture elements are released into the ISM.

The low metallicity of early stars, specifically stars with high [α/Fe] and low [Fe/H] values, indicate that their nucleosynthesis occurred during a period after the first round of core-collapse supernovae but before large numbers of Type Ia supernovae events. For decades scientists looked early stars in the halo of the Milky Way to study the early universe. These Milky Way halo stars have [Fe/H] values of < -1.0.

In the past decade efforts such as the Sloan Digital Sky Survey (SDSS) have uncovered a plethora of very dim dwarf spheroidal (dSph) galaxies and ultra faint dwarfs. These dSph and ultra faint dwarfs have total luminosities in the range of $10^5 L_{\odot} \lesssim L \lesssim 10^7 L_{\odot}$ and $L \lesssim 10^5 L_{\odot}$, respectively, which contain stars with [Fe/H] values of ~ -2.5. With the use of medium resolution spectroscopy scientists recently uncovered a moderate population of super low metal stars with [Fe/H] values < -3.0 within ultra fain dwarfs. Within the same systems scientists did not find any stars with [Fe/H] > -1.0. In this population one galaxy, SEGUE-1, stood out from the rest. SEGUE-1's population of stars show increasing metallicity, in the form of α-elements, but do not exhibit decreasing [α/Fe] ratios. This would indicate that the star formation phase in SEGUE-1 occurred before most, if not all, Type Ia supernovae events. This also indicates that there was likely only one star formation phase within the galaxy.

2. NOVELTY AND METHODS

The authors of this paper made new spectrography measurements of six stars within SEGUE-1 using the Magellan/MIKE and Keck/HIRES spectrographs focusing on the chemical enrichment process to better understand star formation in the very early universe. The six stars that were chosen were the brightest stars in SEGUE-1 which allowed for high resolution spectrography. Using the spectrographs the authors collected data on the abundance of iron (Fe I and Fe II), carbon, α-elements, and neutron-capture elements. The authors then compared this data to

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stars found in classical dSph galaxies and the Milky Way halo. The parameters for the measurements of each of the stars are listed in table 1. Due to the dim nature of the six starts the signal to noise ratio (S/N) was only moderate with values between 20 and 50

3. RESULTS, DISCUSSION, AND FUTURE WORK

With the high resolution spectrograph data the authors were able to extrapolate the abundances of the various elements inside the stars. In figure 1 the authors plotted the spectra of the 6 stars compared to two other known stars, the ultra low metal $CD - 38°245$ and the very bright, and much younger, Arcturus. The plots are listed in ascending order of metallicity from top to bottom.

In the three lowest metallicity stars (The top 3 blue lines) the abundance of iron (both Fe I and Fe II) is mostly indistinguishable from the noise in the measurements. In the 3 stars with observable amounts of iron there was no correlation between increasing iron abundance and increasing metallicity, indicated by the appearance of more spectral lines as the metallicity increases. This indicated that there was at most one or maybe two Type Ia supernova that enriched SEGUE-1's birth cloud. This contrasts the trend found in younger galaxies where there would be a clear trend in increasing metallicity and increasing iron abundance in the stellar population as they evolve alongside energetic supernovae events.

Another indication of SEGUE-1's age is the enhanced [α/Fe] values found in all the measured stars that are consistent with each other and the initial birth cloud. Figure 3 shows enrichment behavior plots, [Fe/H] vs. [α/Fe], for MW Halo stars, classical dSph galaxy stars, and SEGUE-1 stars. The top plot in fig. 3 shows the general trend of how classical dSph galaxies and MW Halo stars will appear on the enrichment behavior plot. The middle plot shows the spread of MW Halo stars which have a plateau in the [α/Fe] until [Fe/H] ≈ -1 at which point the [α/Fe] approaches 0 where [Fe/H] is almost at 0. The bottom plot of fig. 3 shows the enrichment behavior plot for dSph galaxy stars (small black circles), the measured stars from SEGUE-1 (large red filled in circles from this article, and red crosshair from previous papers), and some other candidate stars (blue square, green circles, and magenta circles). In this bottom plot we can see that the classical dSph stars and some of the other candidate stars have a plateau but do slope down towards the [α/Fe] = 0 line. On the other hand, the 6 measured stars from SEGUE-1 all reside around the [α/Fe] = 0.5 line, even past the point where MW Halo starts to slope down on the [Fe/H] axis. The consistent [α/Fe] values in SEGUE-1 stars suggest that after the initial enrichment of the birth cloud there were no other enrichment events, such as type Ia supernovae, in SEGUE-1.

The final indicator of SEGUE-1's old age is the low abundance of neutron-capture elements in SEGUE's non-binary system stars, which total to less than $\sim 10^{-7} M_\odot$ for each element, indicate that there were no neutron-capture element producing process, which produce $\sim 10^{-4} M_\odot$ of neutron-capture elements per event, that occurred during the star formation phase.

Future research points to observing a larger portion of SEGUE 1 stars. The six stars that were observed in this paper were deemed to be the brightest in the ultra faint dwarf galaxy and only allowed for a moderate S/N values between 20 and 46. In order to observe the other, dimmer, stars in SEGUE 1 we would require better telescopes to overcome the noise.

REFERENCES

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