The Metallicity Distribution Function of the Ultra-Faint Dwarf Galaxy Segue 1

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Segue 1: A Primitive Galaxy

Introduction: Ultra-faint dwarf galaxies (UFDs) are low-luminosity dwarf spheroidal galaxies, mostly discovered around the Milky Way. UFDs are exemplary probes of the earliest stars and galaxies, having formed all of their stars in the first ~1 Gyr of the universe and being quenched by reionization at z~6. Within this class of extreme dwarfs, Segue 1 is among the lowest mass (~5.8 x 10^5 $M_\odot$), lowest luminosity, most dark matter-dominated, and most metal-poor galaxies we know of [1]. Thus, **Segue 1 serves as a nearly pristine relic of the first stars and earliest galaxies.**

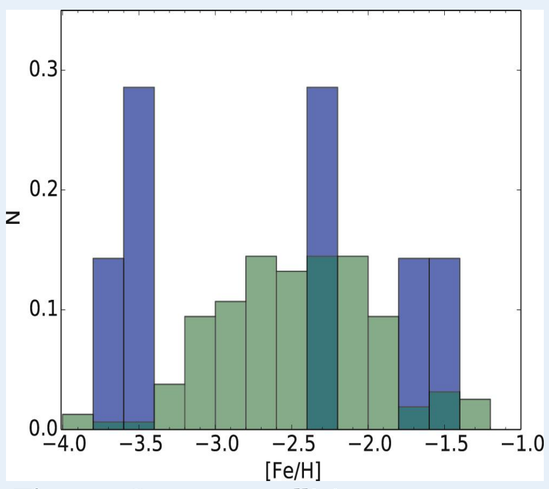

Figure: *Segue 1 metallicity distribution (purple) for the 7 RGB stars from high spectral resolution studies compared with total metallicity distributions (green) for a sample of other UFDs [3]. Figure from Webster et al. 2016.*

Previous work (N = 7 stars) find an average [Fe/H] ≈ -2.7 with three distinct peaks [2]. This trimodality could be explained by clustered star formation, which would be evidence of the earliest star clusters [3].

Segue 1 has only 7 published metallicities, and Keck/LRIS is the only facility capable of measuring additional metallicities. To get a larger sample of stars in Segue 1, we must **observe fainter main-sequence turnoff stars (MSTO)**.

Observations and Data

These fainter MSTO stars are observed with lower spectral resolution, as their magnitudes are $g < 20.5$. Low-Resolution Imaging Spectrometer (LRIS) observations allow us to measure the equivalent width of the CaK line at 3933 Å to obtain stellar metallicities for 32 main-sequence turnoff stars [4]. The figure below highlights this fainter MSTO regime in yellow, and the previously measured RGB metallicities in red.

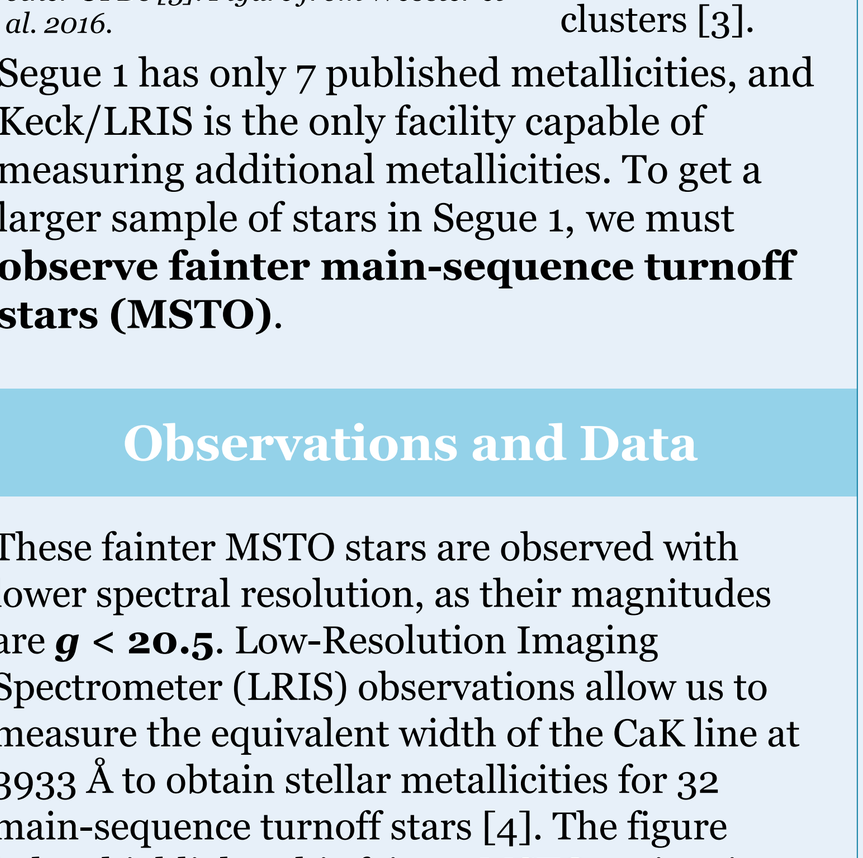

Figure: *Color-magnitude diagram of Segue 1 from Simon+2011 [1]. Pink highlighted region indicates the 7 RGB stars with published metallicities. Yellow highlighted region indicates this work with MSTO stars.*

Stellar Metallicity Calculations

The stellar metallicities were each calculated using their CaK equivalent width and their B-V color, as described for the calibration in Beers et al. 1999 [4]. The B-V colors were derived from Sloan Digital Sky Survey (SDSS) photometry for each of the stars in this sample.

The following spectroscopic analysis was done for all ~32 MSTO stars in this LRIS sample. Analysis of the spectroscopic CaK equivalent widths for this sample of MSTO stars results in the metallicity distribution function (MDF) seen in the figure on the right.

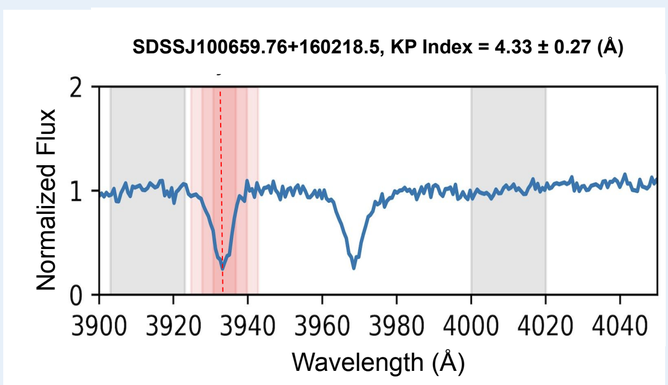

Figure: *Example LRIS spectrum for a star in Segue 1 with KP Index and corresponding K6, K12, and K18 indices (shown in red) centered around the CaK line at 3933 Å, as described in Beers et al. 1999 [4] . The grey regions indicate the sections of the spectrum used to fit the continuum.*

Additionally, the figure below presents the colors (B-V) and equivalent widths associated with each star in this sample, showing a range of equivalent widths for a given color.

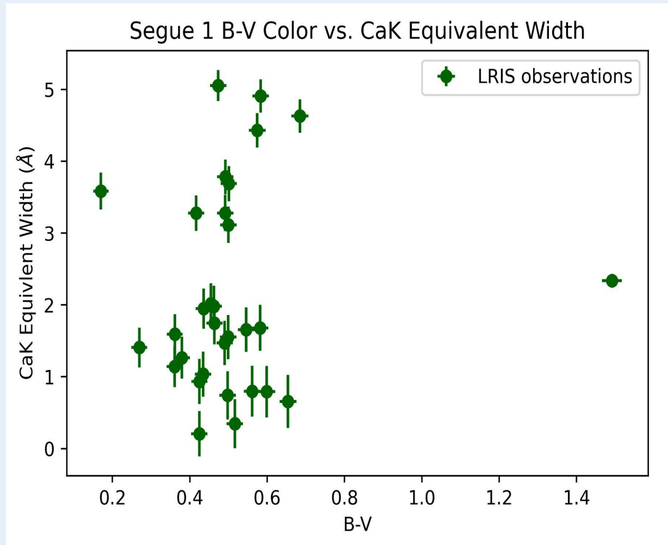

Figure: *B magnitude and V magnitude values were taken from SDSS photometry. CaK equivalent widths were calculated from LRIS spectroscopy.*

References

[1] Simon, J. D., Geha, M., Minor, Q. E., et al. 2011, ApJ, 733,463 46, doi: 10.1088/0004-637X/733/1/46464.

[2] Frebel, A., Simon, J. D., & Kirby, E. N. 2014, ApJ, 786, 74,452 doi: 10.1088/0004-637X/786/1/74453.

[3] Webster, D., Frebel, A., & Bland-Hawthorn, J. 2016, The467 Astrophysical Journal, 818, 80,468 doi: 10.3847/0004-637x/818/1/80469.

[4] Beers, T. C., Rossi, S., Norris, J. E., Ryan, S. G., & Shefler,442 T. 1999, AJ, 117, 981, doi: 10.1086/300727443.

The Metallicity Distribution Function

LRIS observations of MSTO stars have an average metallicity of [Fe/H] ≈ - 2.8 without distinct peaks. The range of metallicities is a maximum of [Fe/H] ~ -1.4 and a minimum of [Fe/H] ~ -4.2.

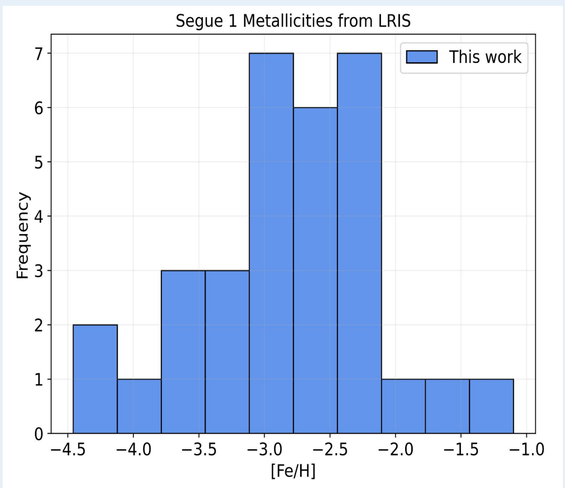

Figure: *Segue 1 metallicity distribution function including the 32 MSTO from LRIS observations.*

This MDF represents a fivefold increase in the total number of stars (N_{tot} = 39 stars). A figure of the MDF of Segue 1 with this LRIS data as well as the seven published metallicities is included below.

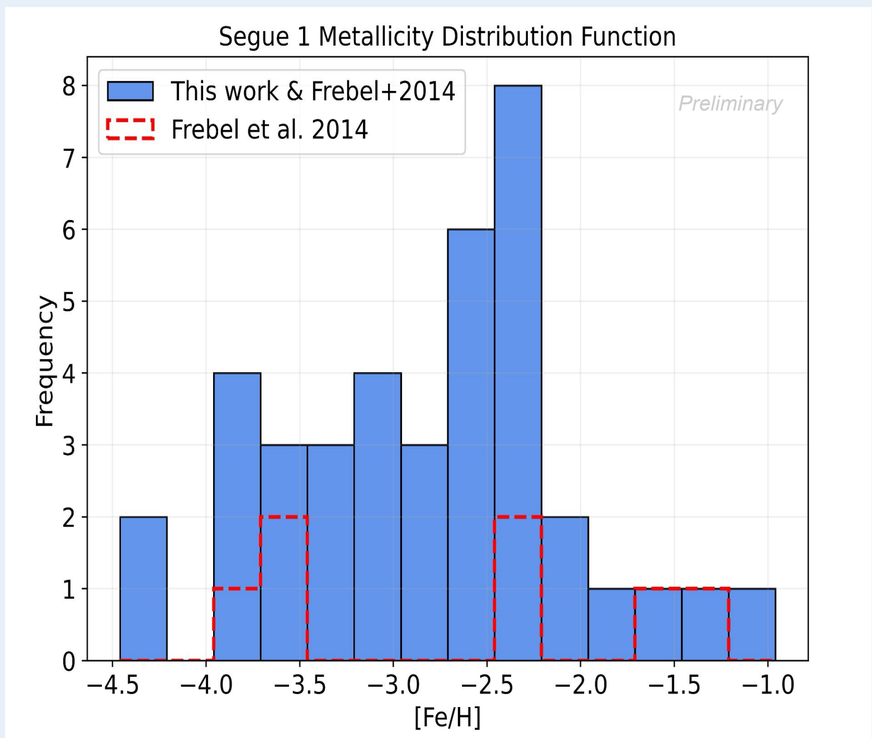

Figure: *The MDF plot includes data from 32 MSTO stars, plotted in blue, and the 7 stellar metallicities described in Frebel 2014, plotted as the red dotted overlay [2].*

When combined with the published stellar metallicities, the overall MDF of Segue 1 does not appear to have distinct peaks. *This observed distribution, without the three modes previously seen in the MDF, would suggest that Segue 1 formed from continuous star formation.*

Conclusion

Measuring metallicities allows us to distinguish between a single- or a multi-peaked metallicity distribution and therefore, different galaxy formation scenarios for Segue 1. With a **5x greater sample size** compared to previous published metallicities, this **observed single-peaked MDF supports the idea that Segue 1 may not have formed as three distinct star clusters, but instead from a gradual star formation process.** As one of the most primitive galaxies known, these results will have important consequences for studies of dwarf galaxies.