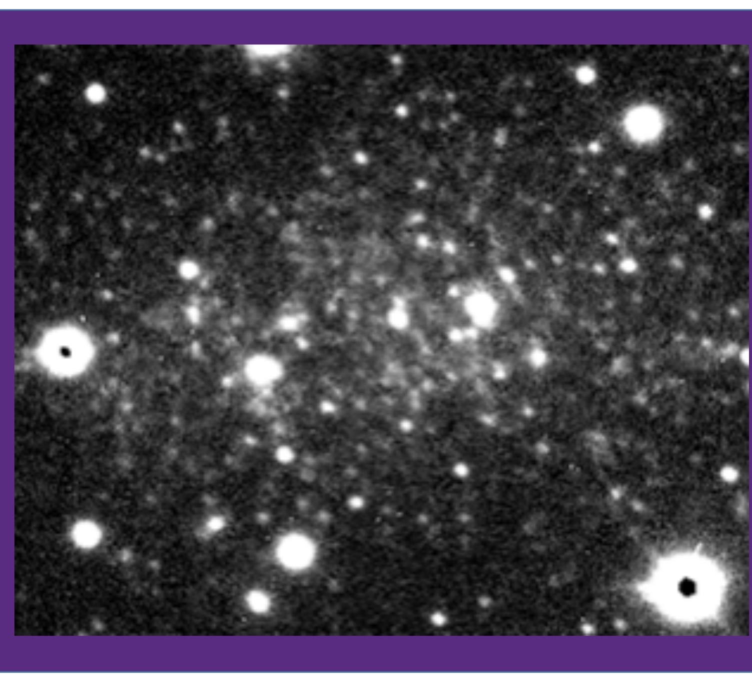
Using *The Cannon* to study the chemistry of the Sagittarius dwarf galaxy

Matthew Melendez, *Peter M. Frinchaboy, John Donor, Amy Ray*

Texas Christian University



Abstract: Sagittarius (Sgr), a dwarf spheroidal galaxy and satellite to the Milky Way, is in the process of being tidally torn apart. To study the chemical distribution of Sgr we have taken spectra for thousands of stars in the large area of the galaxy. The membership of stars in Sgr has been previously constrained based on radial velocity, which also allowed for the study of galaxy dynamics. We have analyzed the stellar component of Sgr by using *The Cannon*, a data-driven method for determining stellar parameters (temperature, surface gravity, [M/H], [α/M], and elemental abundances) from stellar spectra. A subset of our stars have previously been observed as part of SDSS/APOGEE survey, at higher resolution and signal-to-noise, which allows us to use these spectra to train *The Cannon*, and obtain accurate abundances for the 1,185 Sgr member stars. This study will allow us to identify chemical sub-groups within the galaxy, confidently study the history and evolution of Sgr, and place its chemical properties within the context of other dwarf galaxies.

Motivation:

The Sagittarius (Sgr) dwarf spheroidal galaxy provides an excellent laboratory to explore chemical and dynamical trends in a clearly disrupting Milky Way satellite. Due to being tidally disrupted over a long period of time, Sgr has an elongated core and two arms that wrap around the Milky Way. By studying the chemical properties of the Sgr core we can place Sgr in the context of other dwarf spheroidal galaxies. Previous studies analyzing the chemistry of Sgr have either only targeted a small portion of the core or tail, or have too few stars to analyze the global chemical properties the dwarf galaxy. This project aims to significantly increase the number of stars with at least [Fe/H] and [α/Fe] across the entire face of Sgr to get a more complete sample of the stellar population, but exploring chemical trends in elliptical radii across the core of Sgr (Figure 1).

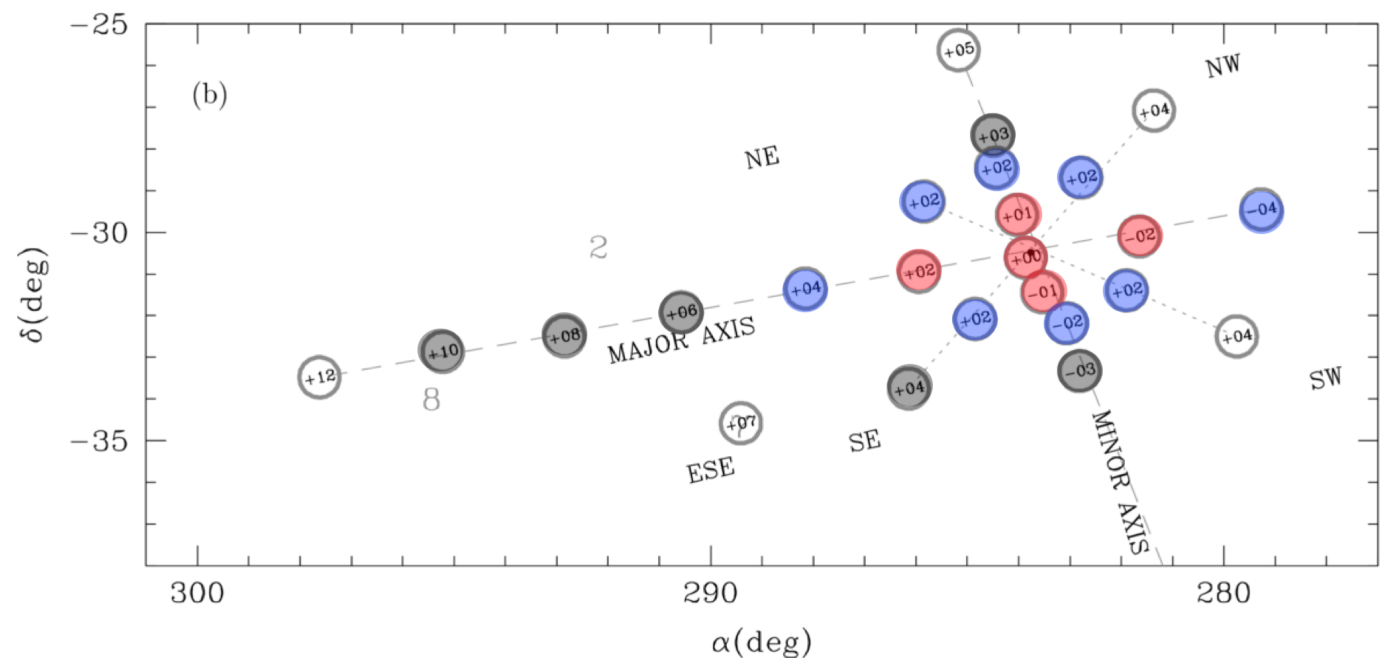


Figure 2 (Above): CTIO/Hydra fields observed in this study, using data from the RV-based study Frinchaboy & Majewski (2008). The inner core region is shown in red, the middle core region in blue, and the outer core region in black/grey as in Figure 1.

Data:

The data used in this study was taken by the CTIO/Hydra spectrograph with medium-resolution (R~15,000), as fully explained in Frinchaboy & Majewski (2008). While the original study was to explore dynamics, with new techniques that allow abundance analysis from lower signal-to-noise data (e.g., *The Cannon*). We are able to analyze nearly 1200 Sgr member stars determined from previous work to derive abundances for 7 elements in this study. The spectra cover the well utilized Calcium Triplet region (Figure 3.)

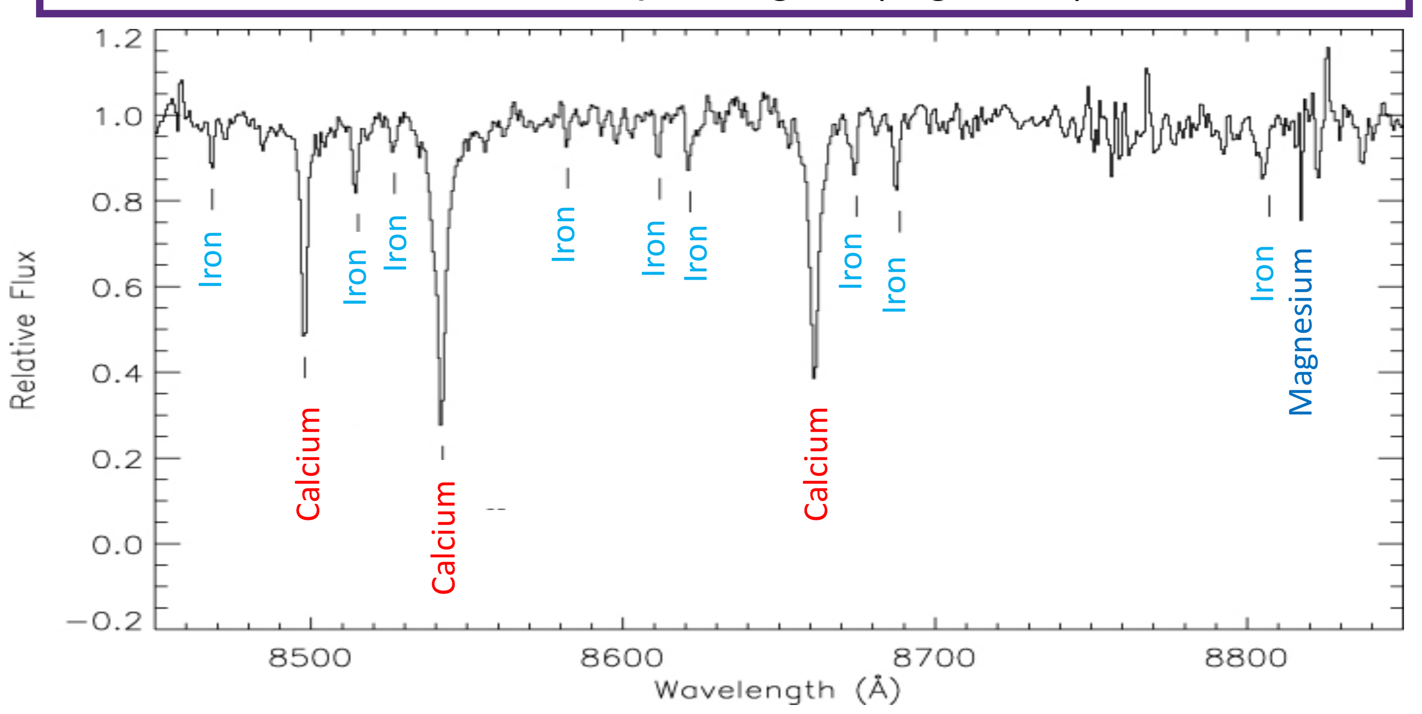


Figure 3 (Above): An example stellar spectrum covering the region near the Calcium Triplet used in this study.

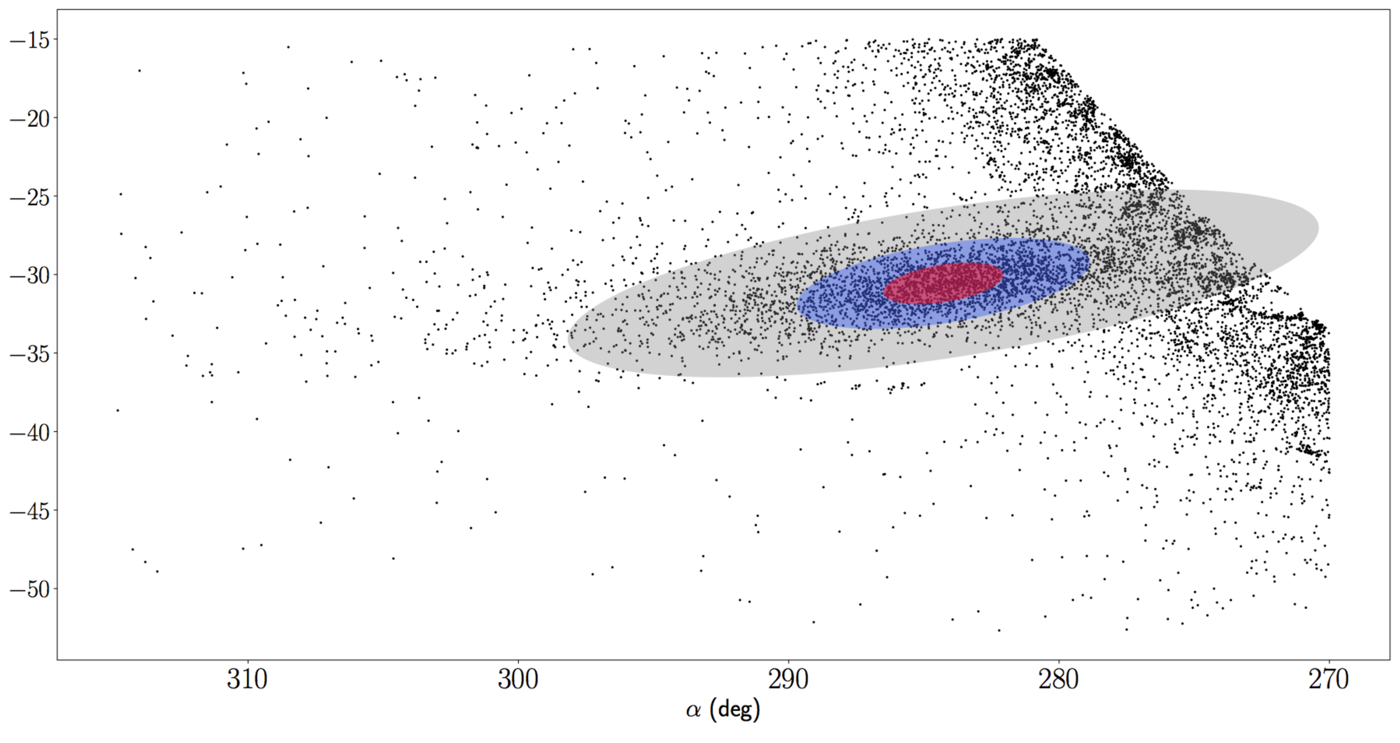


Figure 1 (Above): Stellar component of Sagittarius as seen on the sky. The Milky Way can be seen on the right side of the image and the core of the galaxy is highlighted above and, for the purpose of this research, is divided into three "slices." The inner core region is shown in red, the middle core region in blue, and the outer core region in black/grey.

Methods:

The Cannon (Ness et. al 2015, Ho et. al 2016), a machine-learning method for determining stellar labels, is a solution for the challenge of modeling hundreds of thousands of stars for large-scale surveys. The program is trained using high-resolution spectra with known stellar parameters to create a model to fit the spectroscopic data to. The Cannon has been proven to work even at lower signal-to-noise.

The parameters used in this study are taken from SDSS/APOGEE DR14 and include: T_{eff}, log g, [M/H], [α/M], [Fe/H], Mg, Ca, Ti, Si, and Ni. The APOGEE data used in this training set, and analyzed independently by Hasselquist et al (2017), were targeted by APOGEE using the membership analysis that this work is based on (Frinchaboy & Majewski 2008), allowing a significant overlap between APOGEE and this dataset for targets in Sgr. The overlapping data comes from the northern fields (Major+00, Major-02, Major -04, Minor +01, Minor +02, & NM+02). The training set comparison is shown below in Figure 4.

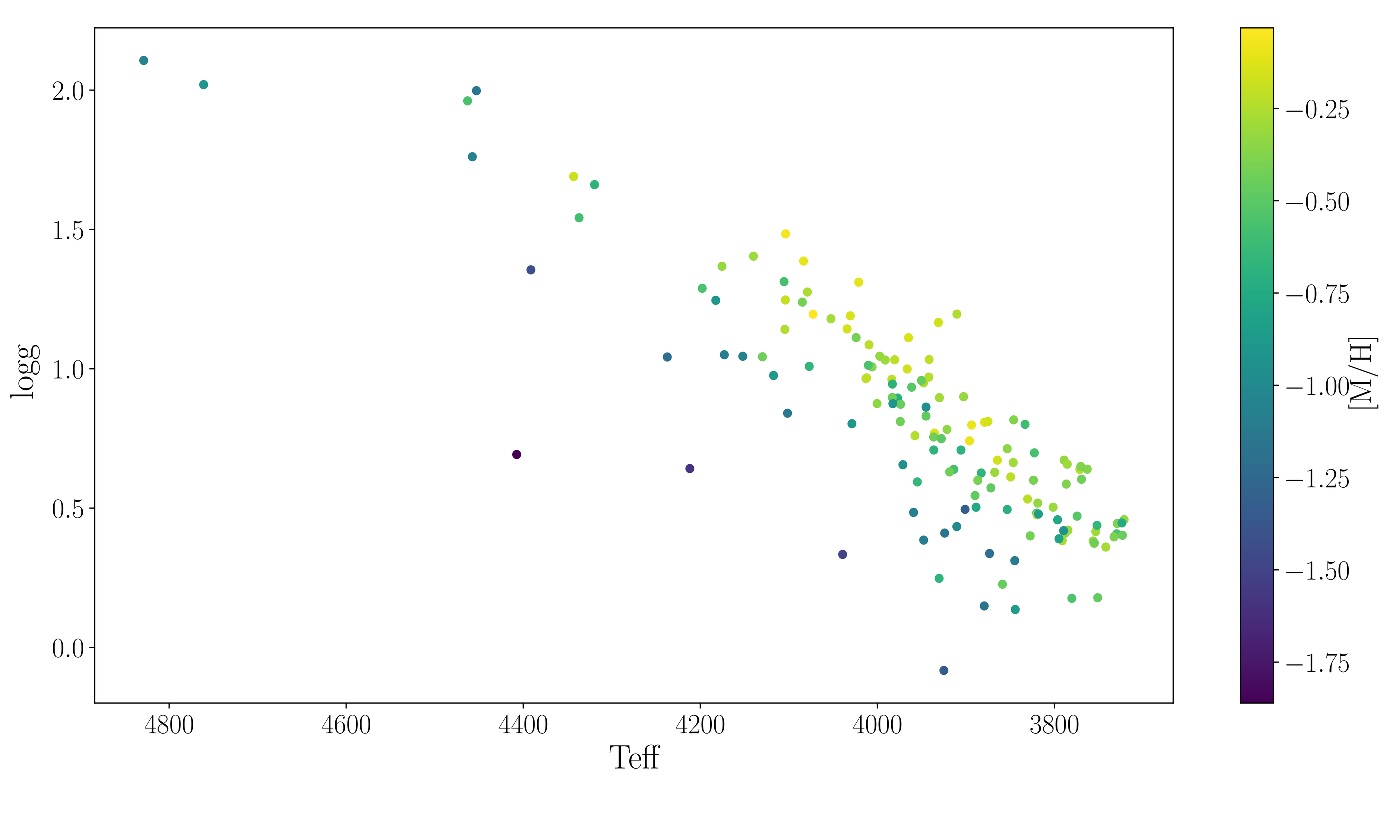


Figure 4 (Above): Parameter space for T_{eff}, log g, and [M/H] that was used to train *The Cannon*, showing the range of values for each parameter. A similar range of values are seen in all other elemental parameters.

Results:

To study the chemical distribution and history of the Sagittarius dwarf galaxy we studied the spectral properties of the stellar component of Sgr across the large area of the dwarf spheroidal galaxy. In order to analyze our large data set we used many stellar parameters from SDSS/APOGEE DR14 to train The Cannon in our spectral region. Our results show a decreasing metallicity trend as a function of radius, with a larger spread in metallicity in the core relative to the outer regions (Figure 5), similar to other study of dSph galaxies. More interestingly, we find evidence for the first time for two distinct populations in alpha abundances as a function of metallicity as seen in Figure 6. These two populations are seen using [α/M] as well using individual element analysis [Mg/Fe], [Ti/Fe], and [Si/Fe]. While, we work to improve our uncertainties, our current results show that with large area coverage we see that these two populations are well mixed across the galaxy and only with large numbers of stars and area coverage is this discovery possible.

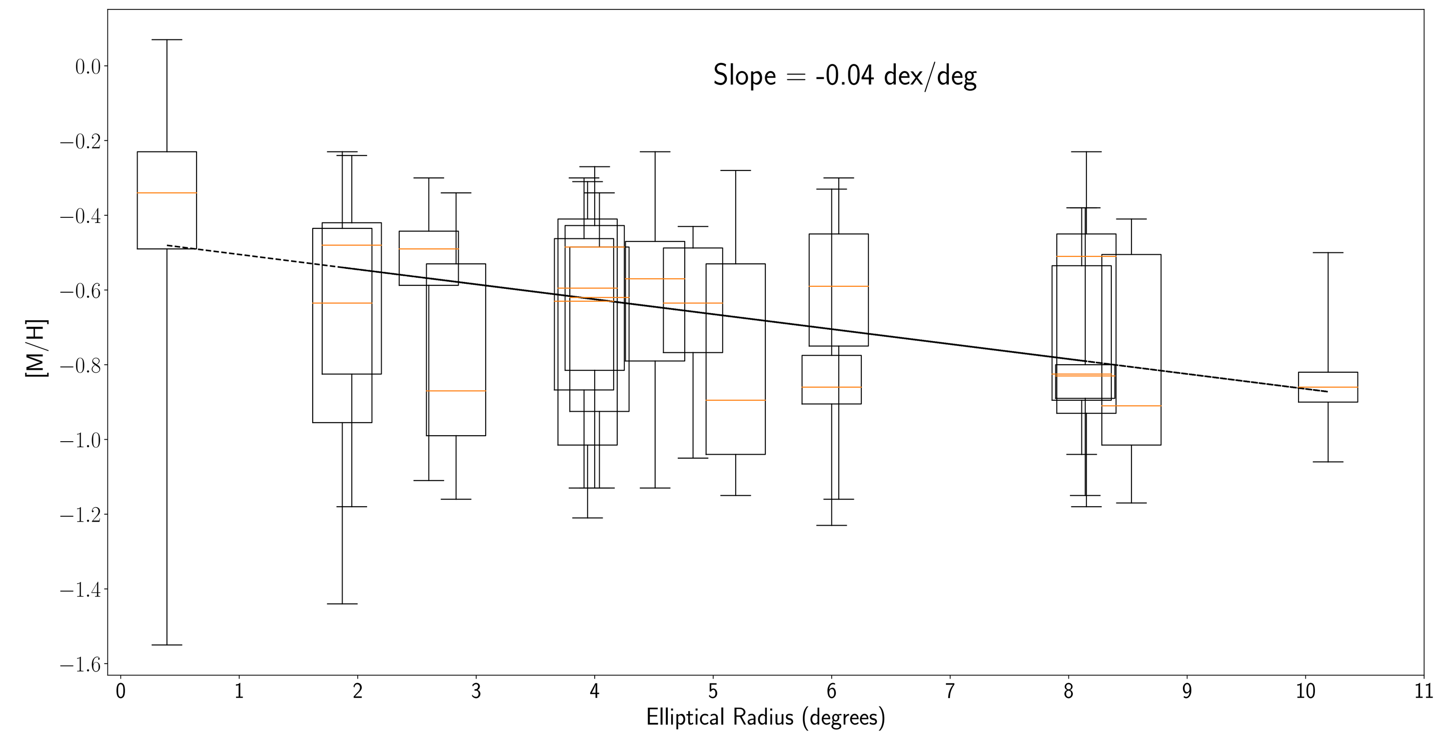


Figure 5 (Above): Box Plot of the overall metallicity as a function of elliptical radius along with the slope of the metallicity. Data for each box comes from multiple stars taken in one of 18 fields across the core of Sgr.

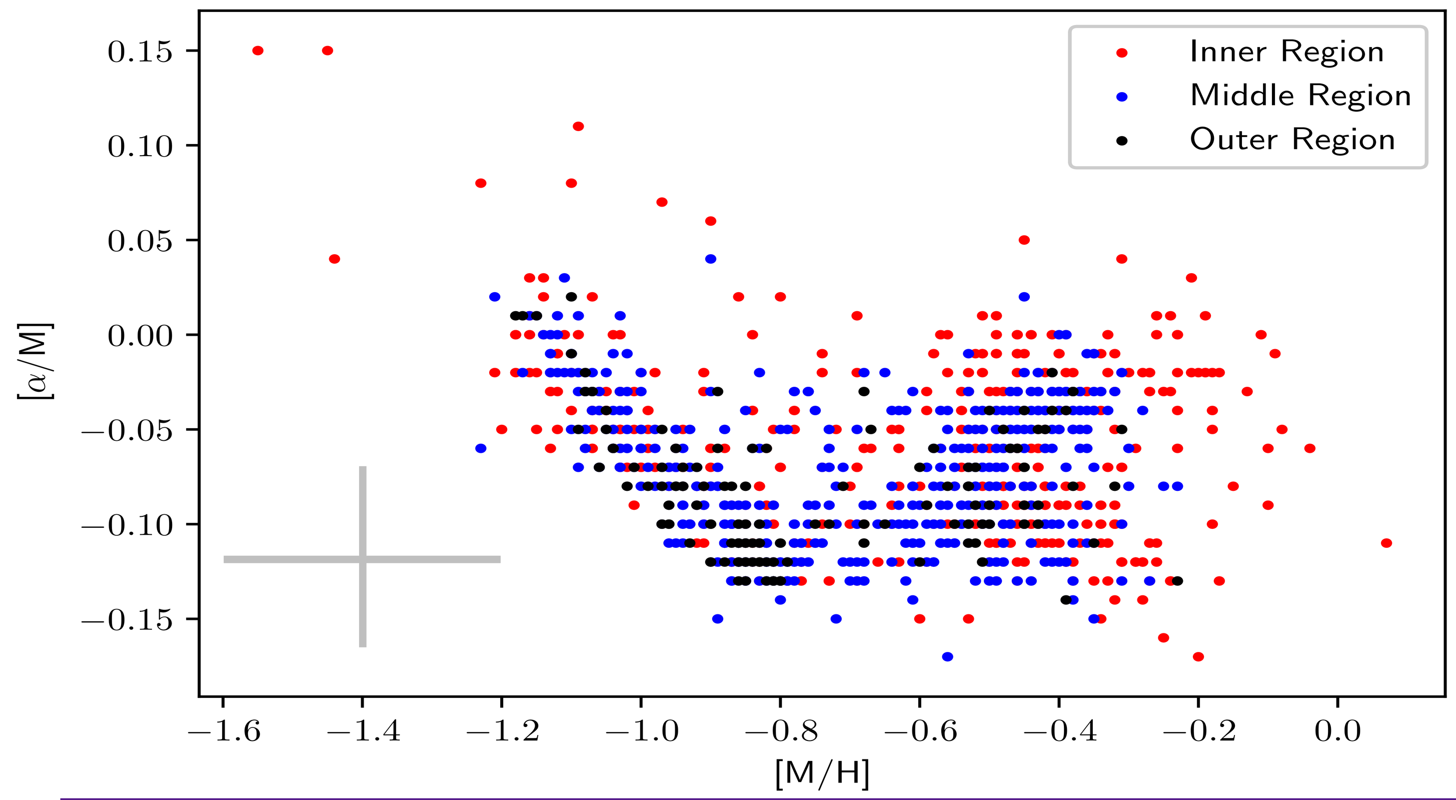


Figure 6 (Above): [α/M] versus [M/H] is plotted above (overall alpha abundance and overall metallicity, respectively. The colors correspond to the regions shown in the plot above. Every star has an error of ± 0.22 dex in [M/H] and ±0.05 dex in [α/M]. The results show two distinct populations in this parameter space.

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