Painting a Portrait of a Young Milky Way using Globular Clusters

Natalie Myers[1], Peter M. Frinchaboy[1], John Donor[1], Taylor Spoo[1],
Adrian M. Price Whelan[2]

(1) Texas Christian University, (2) Flatiron Institute

Star Clusters – A Brief Intro

Star clusters are gravitationally bound groups of stars which were all formed from the same gas cloud. This means all stars within a cluster have the same chemistry, age and they all move in the same direction. Star Cluster is also an umbrella term which contains two distinct subcategories open and globular. Open clusters, in short, are loosely-bound young clusters (ranging from "currently forming" to 8-9 billion years old) that are primarily located within the disk of our home Galaxy, the Milky Way. Globular clusters, on the other hand, have way fewer heavy metals, are significantly older (ranging from 10 billion years old to the age of the universe: 13.7 billion years old), and tend to be way more massive.

Data

We create a sample of globular clusters that has data from only two sources: (1) the SDSS/APOGEE survey (Abdurro'uf et al. 2022), which is a high-resolution, infrared, spectroscopic survey that provides chemical abundances for over 16 elements and Doppler velocities for more than 657,000 stars in the Milky Way and (2) The Gaia Space Telescope (Gaia Collaboration et al. 2021), which provides astrometric data for the clusters (velocities, locations, and distances for nearly two billion stars).

Cluster Members and Orbit Calculations

A large part of this work was to identify what stars were members of the cluster. For that we utilize the Harris Catalog (Harris 1996) and the Baumgardt et al. (2019) catalog for initial-guesses of the clusters' up-to-date properties. (including the position and motion of the cluster). Of the 157 globular clusters within the Harris catalog, we find APOGEE data for 72 of them, including nearly 5000 different stars in total. We further cut this sample into "high-quality" and "low-quality" samples, largely determined by the number of stars available, which leaves us with a sample of 43 high-quality clusters.

We also explore the orbital distribution of these clusters by adopting the results of Bajkova et al. 2020, which compares the orbital parameters and location of each globular cluster to determine whether it is a bulge, disk, or halo globular. Specifically, clusters small radii are designated as bulge, clusters with high eccentricity are halo, and those with circular orbits are disk.

Space Chemistry

Since we are unable to travel to the things we study, we rely heavily on the light they produce. One powerful, but costly, tool is spectroscopy. While it takes a longer period of time to glean the necessary data from a star, a spectrum can tell us the entire chemical composition of a star as well as other fundamental stellar parameters, like the temperature, which are needed to properly categorize the star.

Stars are constantly fusing light elements (like hydrogen and helium) into heavier elements (like carbon, silicon, sodium, iron, etc…). As stars die, they fling these elements into their surroundings, contaminating the gas with their chemical "signature". Additionally, if their death is sufficiently dramatic, they can create even heavier elements as well (think lanthanides and actinides). Therefore, the location and time that a star is born into can potentially provide a unique, traceable, chimical signature. This is why we need large surveys, which take large amounts of spectroscopic data for hundreds of thousands of stars.

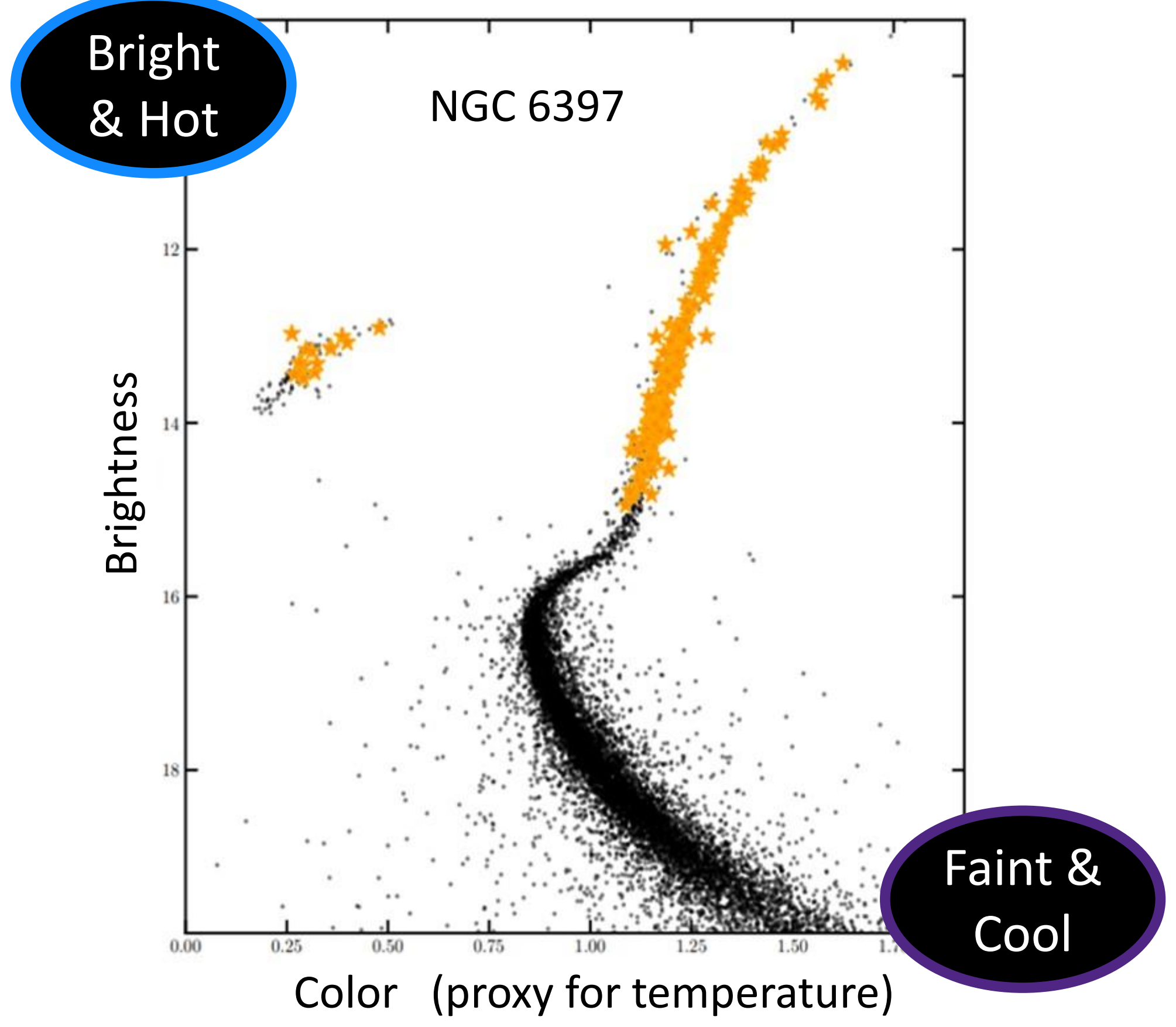
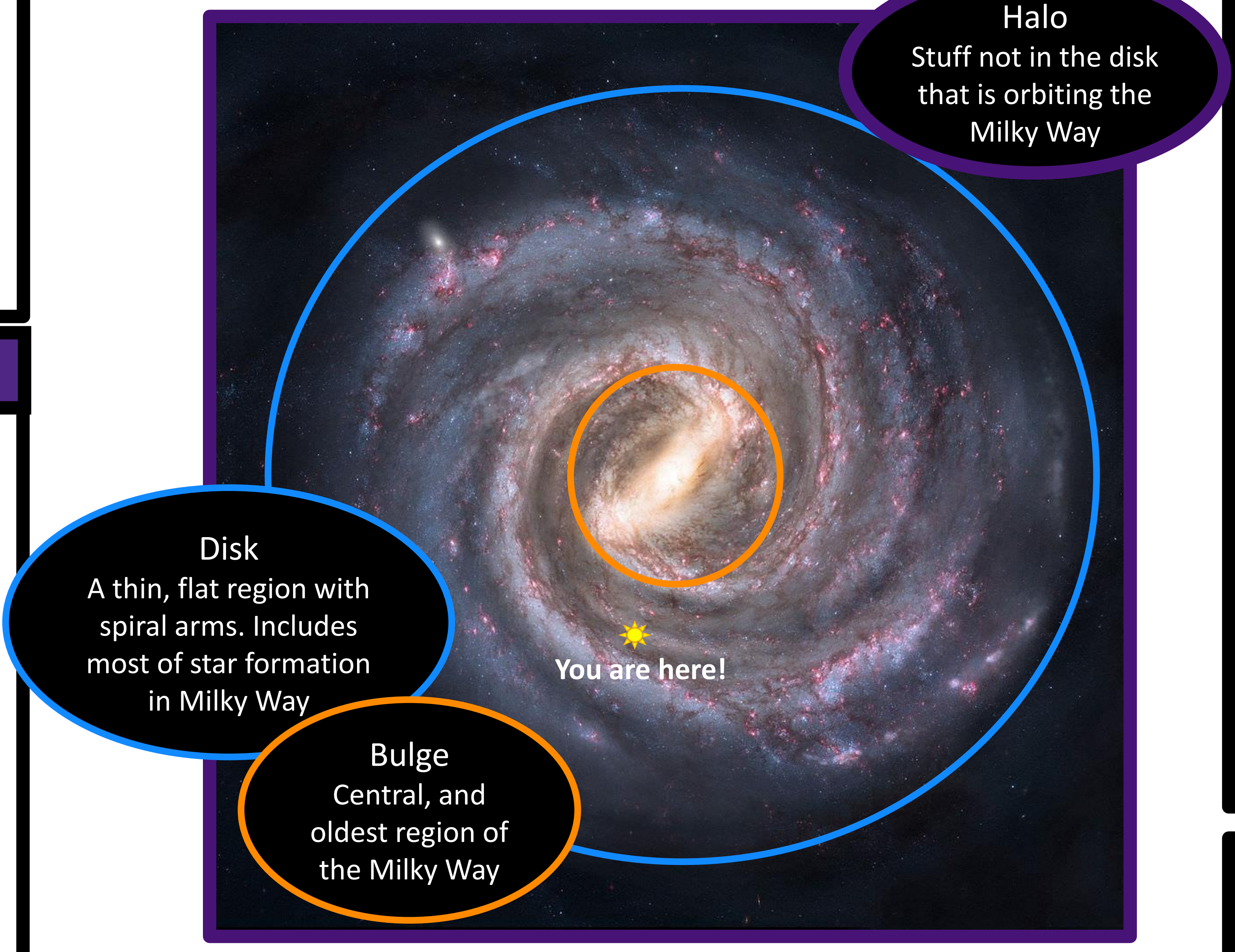


Figure 1 (above): Color-Magnitude Diagram of NGC 6397. The orange stars are data that have chemistry from APOGEE. The black stars are other stars from *Gaia* that are members of the cluster.



Halo
Stuff not in the disk that is orbiting the Milky Way

Disk
A thin, flat region with spiral arms. Includes most of star formation in Milky Way

Bulge
Central, and oldest region of the Milky Way

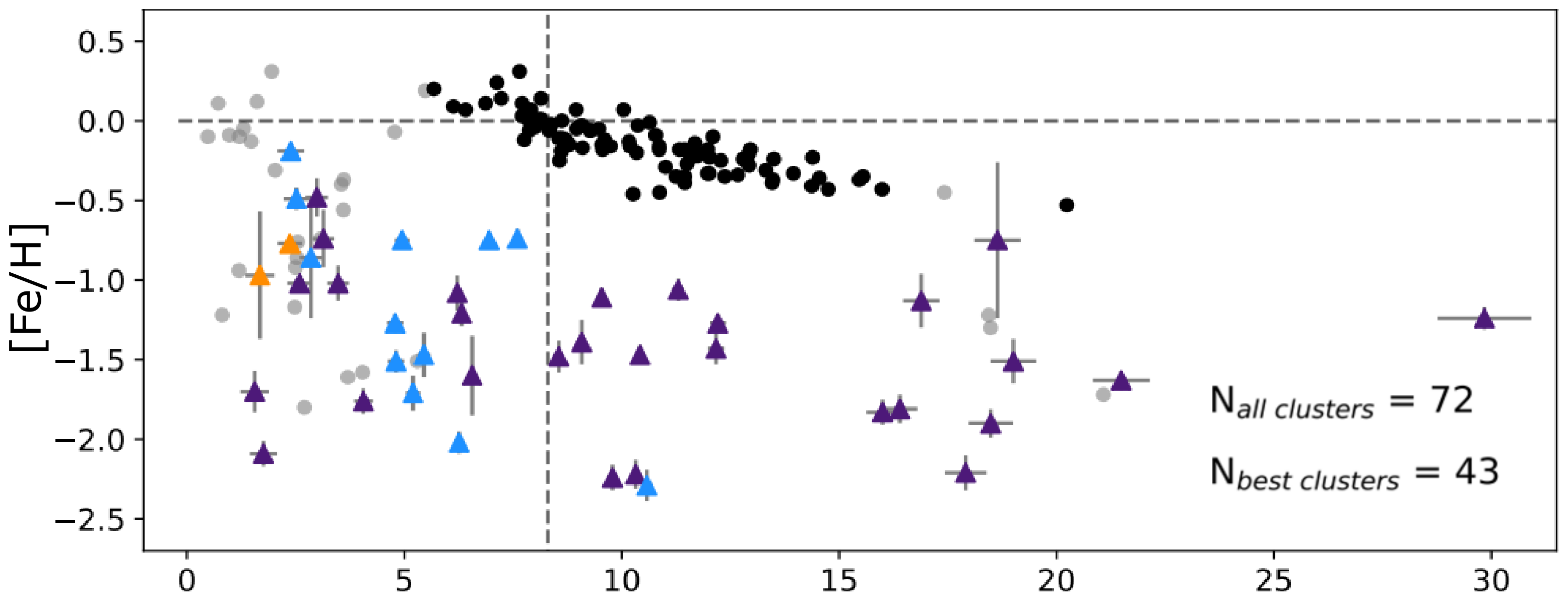


Figure 2 (above): Iron contant / Hydrogen content relative to the Sun [Fe/H] as a function of radius for all globular clusters in the sample. The triangles represent the high-quality globular cluster sample (4+ stars), light grey dots are the other globular clusters within the sample, and the black dots show the open cluster sample from the OCCAM survey. All globular clusters are colored by their orbital classification.

Preliminary Results (Figure 2)

The [Fe/H] of a star (or group of stars) is used to determine how chemically enriched it is. High [Fe/H] is often correlated with younger objects (more time for enrichment to happen) and whereas low [Fe/H] tends to correlate with old objects. In Figure 2, the open clusters (black dots) are shown to have a significant, decreasing, trend with radius, whereas the globular clusters don't. There is also no clear distinction between the "halo"-, "disk"-, and "bulge"-type orbits. This figure also shows that the majority of the clusters were formed at a time when the Milky Way was much younger and much smaller than it is currently. The more distant clusters are potentially accreted systems.

Preliminary Results (Figure 3)

From Figure 3 – Abundances

We look at clusters from three different elemental groups: alpha elements (silicon), odd-z elements (aluminum), and iron-peak (nickel). Alpha elements are elements with even atomic number between roughly oxygen and titanium and are primarily enriched into their surroundings by Type II supernova. Odd-z elements are elements with odd atomic number between the same range as the alpha elements. Iron-peak elements are those that are found around iron, ranging from roughly vanadium to zirconium. Type Ia supernova are the main enrichment process corresponding these elements. The globular clusters associated with the disk, halo, bulge populations appear to be well mixed in all element families.

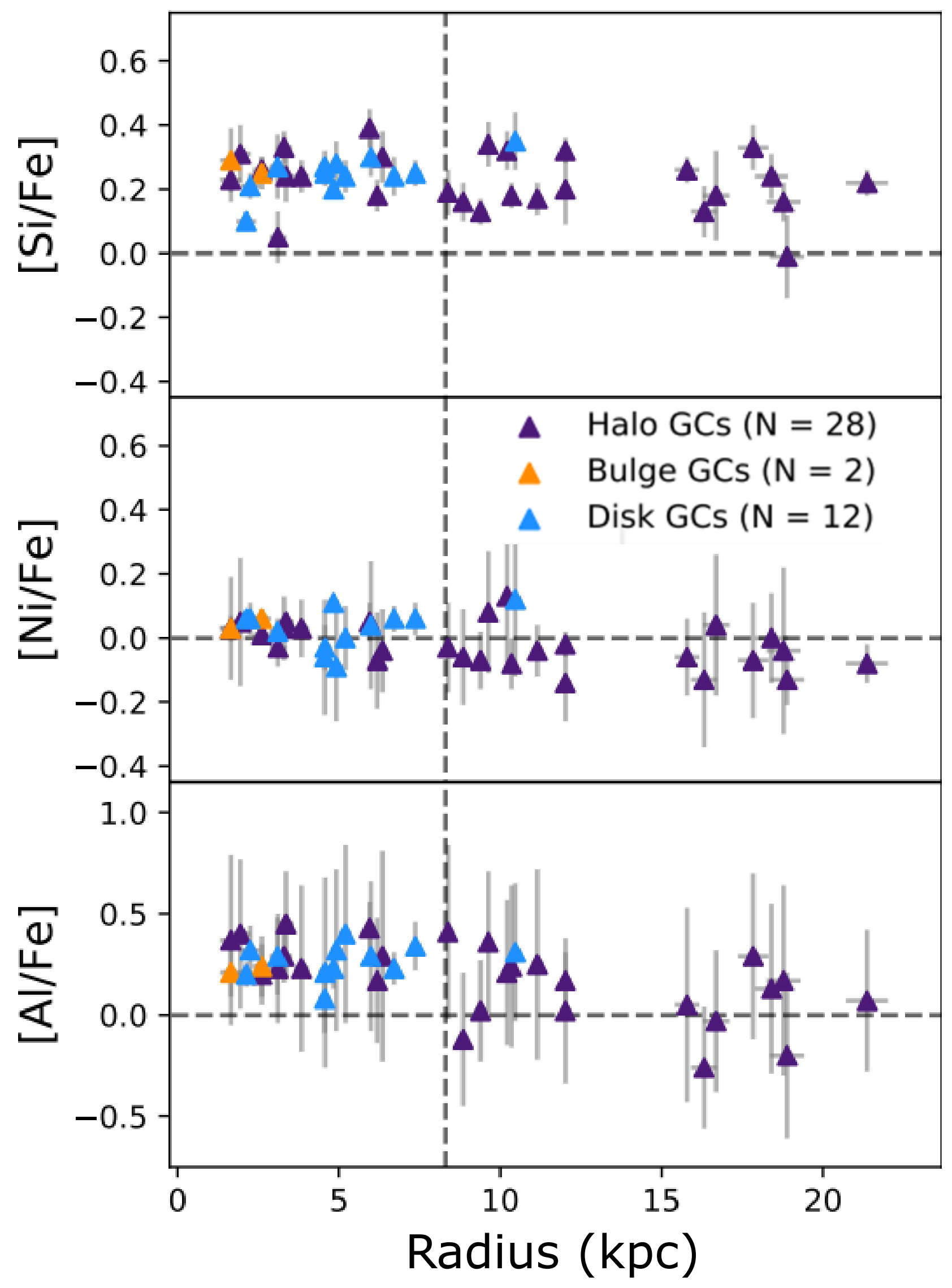


Figure 3 (below): Silicon, nickel and aluminum as a function of both Galactocentric radius and the guiding center radius for the high-quality globular cluster sample. Each cluster is color-coded by its orbit classification (halo, disk, or bulge globular cluster).

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Star clusters have long been used as chemical and dynamical tracers for our home galaxy, the Milky Way. Many of these clusters are the old, metal poor, and massive objects known as globular clusters. These globular clusters are ideal test-beds for studying stellar evolution, stellar dynamics, and Galactic evolution since all the included stars are born from the same gas cloud. In this work, we combine the positions and motions of stars on the sky, provided by the European Space Agency's Gaia space telescope, with the high-resolution chemical abundances from the Apache Point Galactic Evolution Experiment (APOGEE) to create a catalog of globular clusters. By only using data from two sources this sample of clusters is less susceptible to systematic offsets induced by combining multiple literature datasets. Overall, our catalog includes nearly half of all known Milky Way globular clusters, and a total of 5000 likely stellar members with APOGEE chemical abundances. We use these data to explore the internal properties of globular clusters as well as the population of the clusters as a whole to paint a picture of what the Milky Way looked like when it was first forming.

Future Work

These are just preliminary results, much more work will be needed to further expand this analysis and explore the clusters within.

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