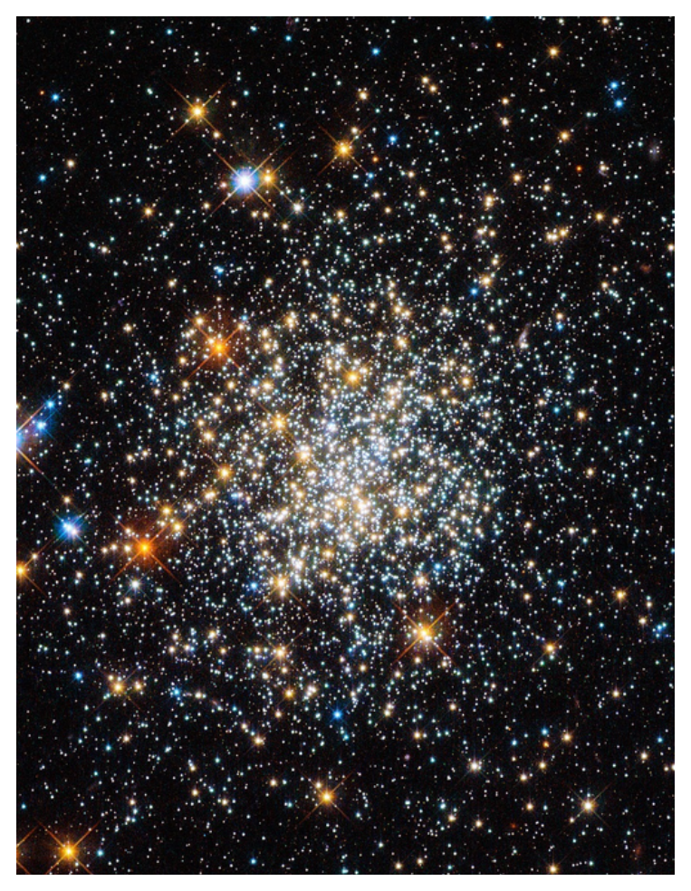

Atomic Buoyancy in Star Clusters - Can We Assume Chemical Homogeneity?

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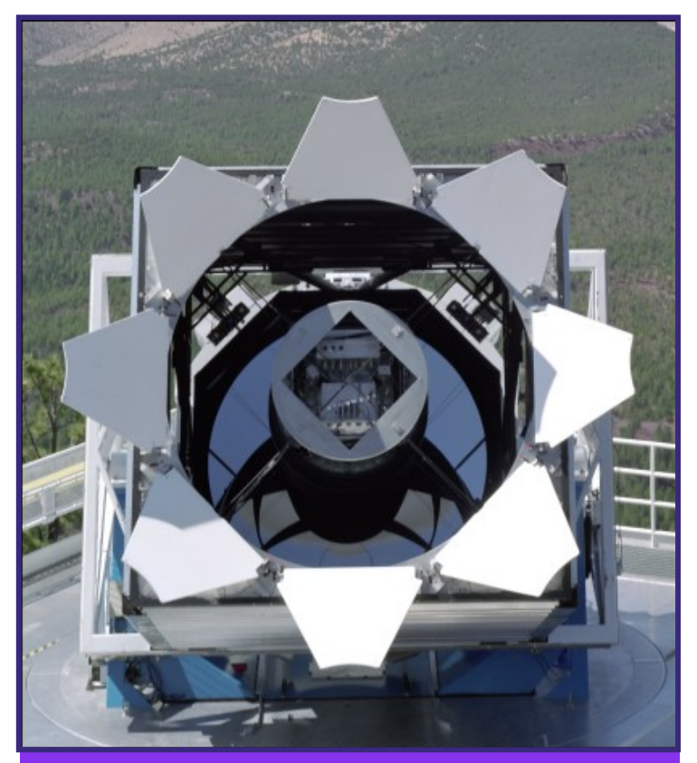


OCCAM

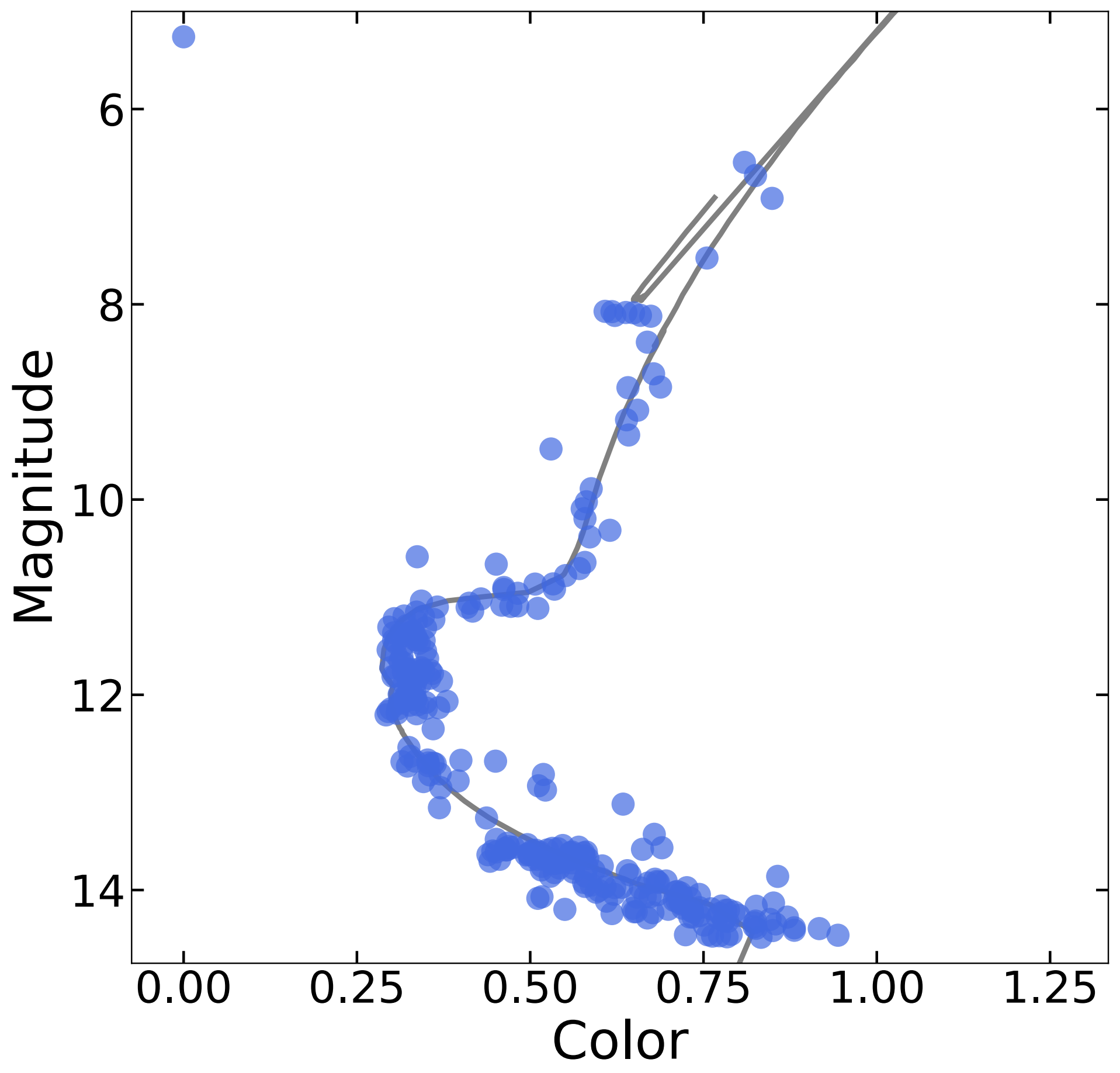
Open Cluster Chemical Abundance and Mapping

Abstract:

Astronomers determine chemical abundances of stars through spectroscopy, which provides clues as to where the stars were formed. We use the chemical composition of stars to infer their relative ages due to past enrichment. However, the surface abundance of stars is not always constant during its life and will change as the star evolves due to its internal processes. As a result, if we assume the chemical makeup of stars is constant within a star cluster, it can cause systematic errors when inferring stellar parameters. For example, in previous investigations (Souto et al. 2018, 2019), the star cluster M67 has been observed to have signatures of atomic diffusion: the combined effect of gravity pulling elements deeper into the star and radiation preventing elements from floating to the surface locks elements below the observable surface of a star which cannot be unlocked until the star evolves further, changing the measured abundance. When the star evolves, convection reaches into the interior of the star and carries these elements back to the surface where they can now be observed once again. This process can explain the elemental abundance variation found in main-sequence stars, like our Sun, and also evolving stars, which can also affect what apparent age we determine. Stars within a cluster tend to form from the same gas cloud at the same time, giving them the same age and initial chemical composition. Therefore, star clusters are ideal test-beds for investigating elemental abundance and the resulting apparent age variations. Data from the Apache Point Galactic Evolution Experiment (APOGEE) survey provides the opportunity to investigate how abundance variation/diffusion is affected by age.

Star Clusters:

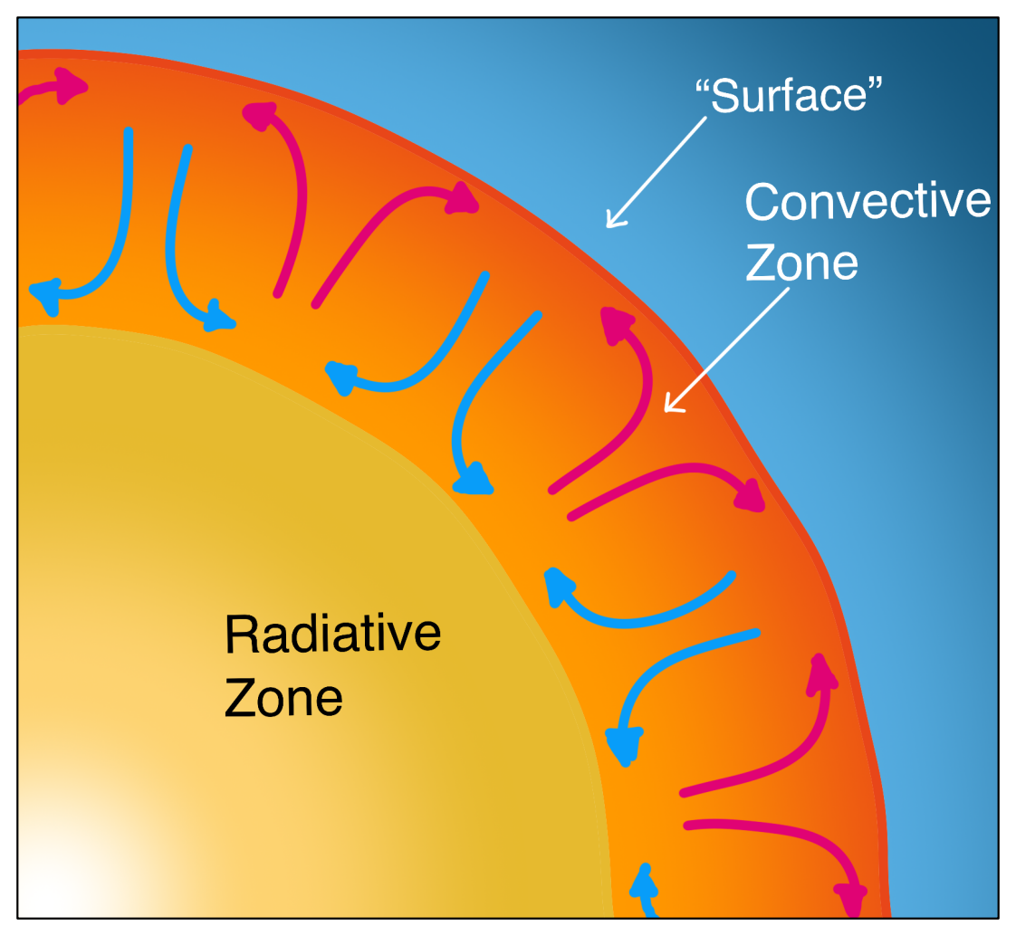
A star cluster is a gravitationally bound group of stars all formed form the same giant gas cloud and have similar: chemical abundances, kinematic properties, distance, and age. Observers can create a color-magnitude diagram (CMD; see below). From CMDs, stellar evolution is derived from cluster sequences and used to calibrate stellar models. These models (isochrones) are represented by a curve connecting positions of evolved stars with various masses that have the same age and same composition as the cluster. As a cluster evolves the main-sequence turn-off will move down, and then we can estimate an age of the cluster and hence, the stars within it.



(1) ABOVE: An example of CMD for a star cluster with an isochrone.

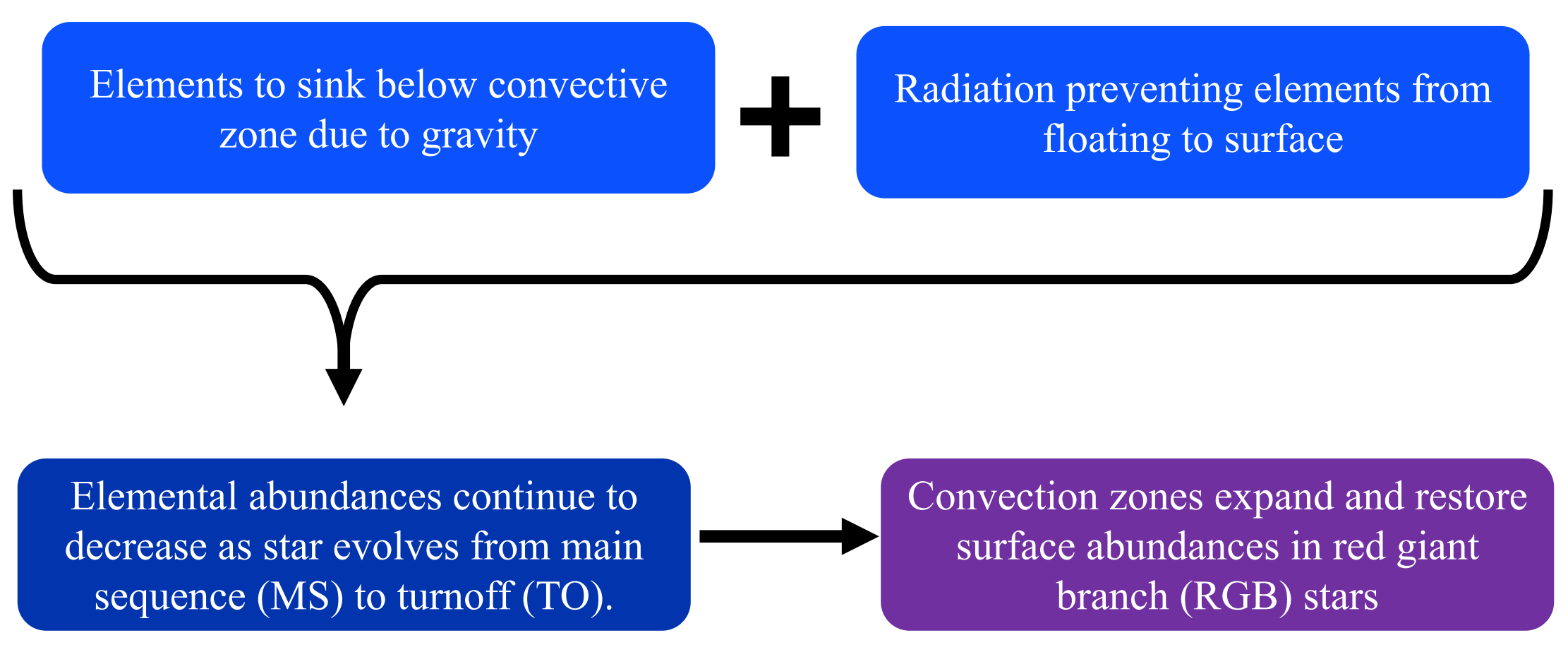
Stellar Chemistry:

- Astronomers can only spectroscopically observe abundances from the star's surface
- Surface elemental abundances characterize the star.
- Assumption is abundance is constant, **but surface variances do occur** due to internal processes.
- Elemental information can be locked below the surface in deeper regions of the stellar interior.



(2) ABOVE-RIGHT: A labeled diagram of the structure of a star, similar to our Sun, highlighting the surface, convective zone, and radiative zone.

Atomic Diffusion:



Elements to sink below convective zone due to gravity

+

Radiation preventing elements from floating to the surface

Elemental abundances continue to decrease as star evolves from main sequence (MS) to turnoff (TO).

Convection zones expand and restore surface abundances in red giant branch (RGB) stars

Survey Data:

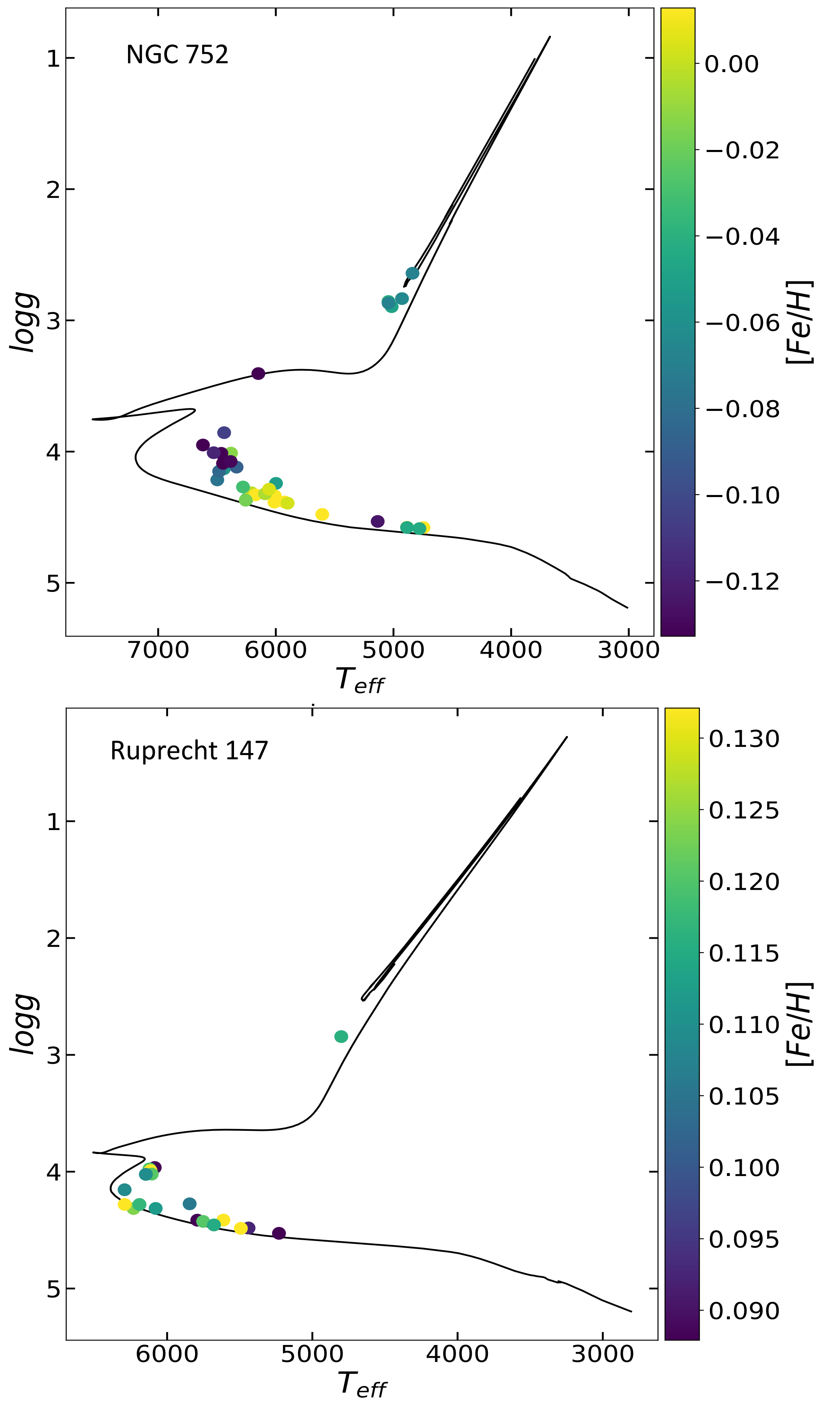
In this study, we used:

- 17th data release of APOGEE (Abdurro'uf et al. 2022)
  - High-resolution, infrared, spectroscopic survey
  - Over 650,000 stars
  - 16+ elemental abundances

- Membership was determined by the OCCAM survey (Donor et al. 2018, 2020; Myers et al. 2022)
  - Sample contains 150 open cluster, 94 clusters determined to be "high quality"
  - Provides membership probabilities in stellar apparent sky motion, Doppler velocity, as well as Fe-abundance ([Fe/H]).
  - [Fe/H] probability was not used as it excludes stars that are affected by atomic diffusion.

Cluster Sample:

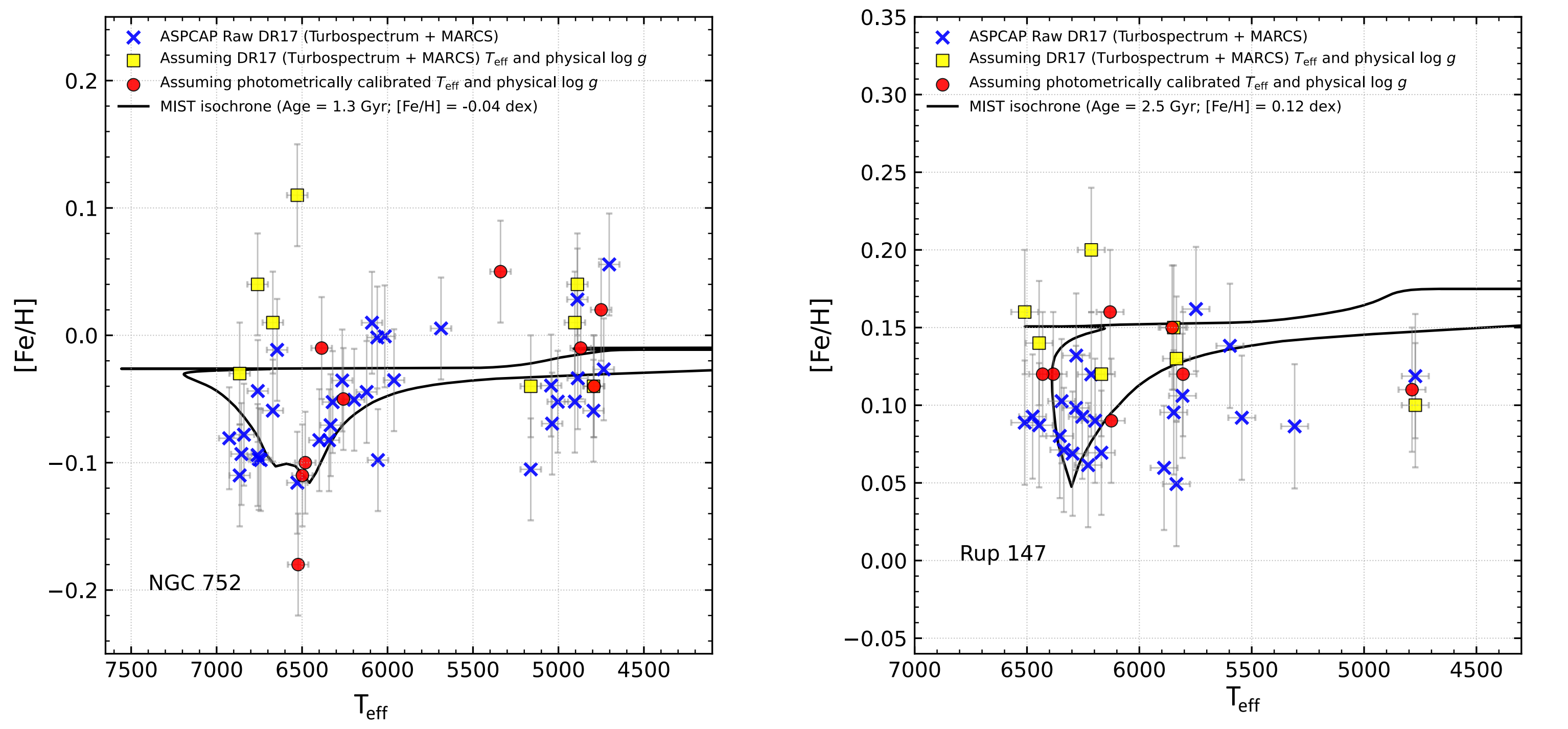
After standard quality cuts and membership selection, our sample is comprised of two open clusters: NGC 752 (35 stars) and Ruprecht 147 (23 stars). These clusters have stars in MS, TO, and RGB evolutionary stages that make them suitable to probe the effects atomic diffusion has on elemental abundances.



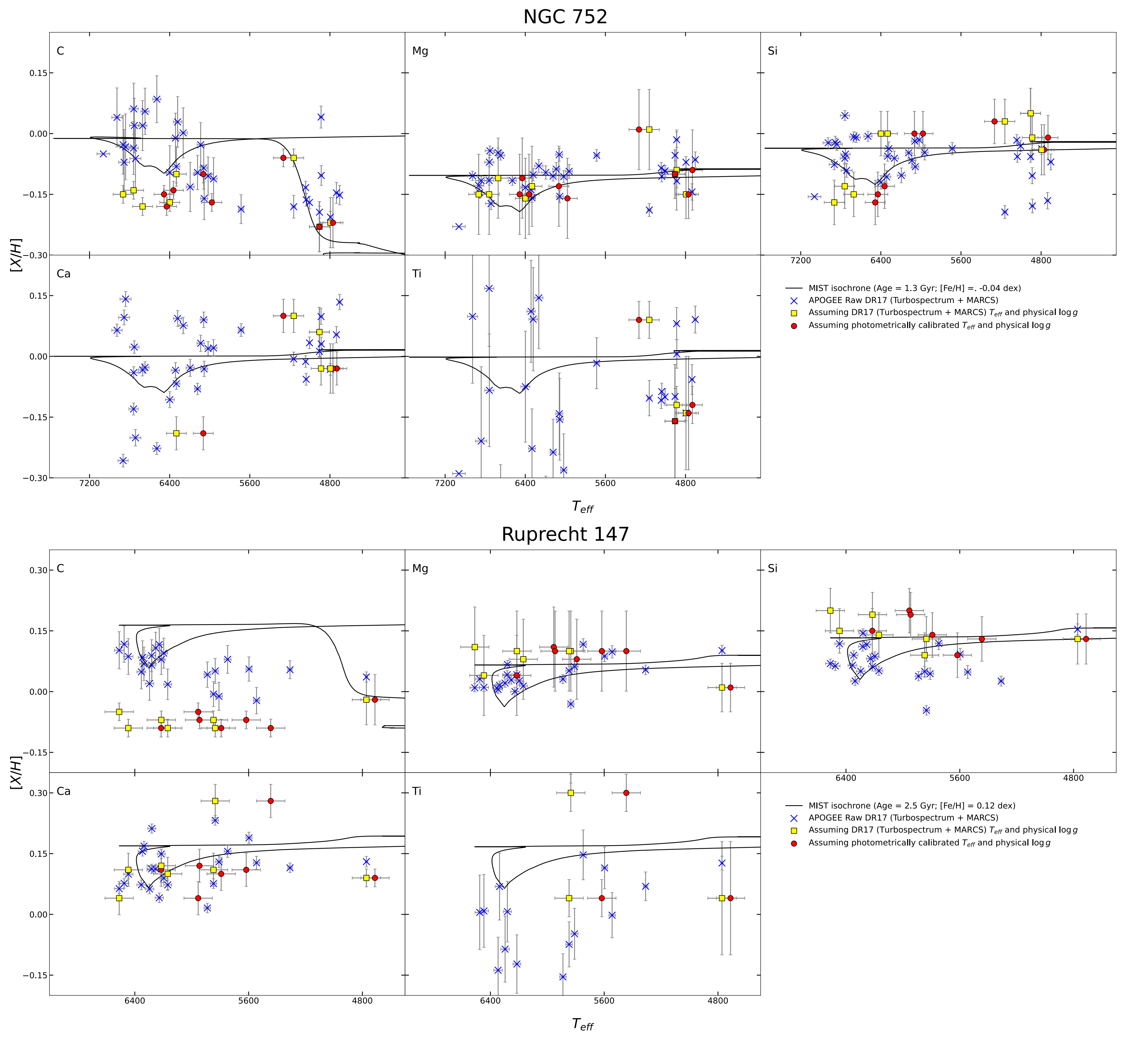
(3) ABOVE: Surface density (logg) vs. temperature (T_{eff}) plot for open clusters NGC 752 (*top*) and Ruprecht 147 (*bottom*) with isochrone colored by [Fe/H].

Results:

We show the abundances of Fe, C, Mg, Si, Ca, and Ti for stars within NGC 752 and Ruprecht 147 derived from the APOGEE pipeline and from a by-hand analysis done in Souto et al. 2018, 2019. These abundances were then compared MIST model for the respective cluster. These assessments show signatures for atomic diffusion in the turn-off stars using the reported abundances values from APOGEE DR17 and the by-hand analysis, similar to those found previously for M67. The atomic diffusion signature in NGC 752 is significant for most of the elements, while in Ruprecht 147, which is older and more metal poor, has only very weak signature for Fe and no signatures for the other five elemnts.



(4) ABOVE: [Fe/H] vs. temperature (T_{eff}) for open clusters NGC 752 (*left*) and Ruprecht 147 (*right*) with the MIST model shown with a solid black line.



(5) ABOVE: Elemental abundance ([X/H]) vs. temperature (T_{eff}) for open clusters NGC 752 (*top*) and Ruprecht 147 (*bottom*) with the MIST model shown with a solid black line.

Future Work:

This work explores the internal process of atomic diffusion to explain abundance variation in the surface. The next step would be to compare to other models, especially with MESA stellar models which gives freedom to include more internal processes (i.e., mass loss, rotational mixing, etc.) as well as control the amount of influence these processes have.

In astronomy, determining stellar ages is a difficult process. The chemical make-up of stars is a key constraint to precisely calibrate stellar ages. Observed stellar chemistry is not always constant during the lifetime of a star but is not always the case. In this work, we investigated the effects of an internal process called atomic diffusion in two star clusters to understand observed elemental abundance variation. For five elements, we found one cluster possessed significant atomic diffusion signatures. This information will aid in better understanding stellar chemistry which will improve our understanding and determining of stellar age.

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