Sifting through the Milky Way's Star Clusters: Real or Imposter?

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What is a Star Cluster?

The exact definition of what a star cluster is depends on who you ask, with definitions involving mass density ratios, velocity dispersions and dynamic crossing times. In general, we can define a star cluster as a group of 12 or more stars that has an average density that is at least 4 times as dense as it's surrounding environment, that is moving together in a particular region of space and was born in the same gas cloud at the same time. There are two kinds of star clusters, open star clusters and globular clusters. Our team is primarily interested in open clusters which tend to be less than 5,000 solar masses and younger than 10 billion years old. A major focus of our lab is determining whether a specific group of stars that appear to be moving together is a real open star cluster or just a group of stars moving through space together.

Real or Imposter?

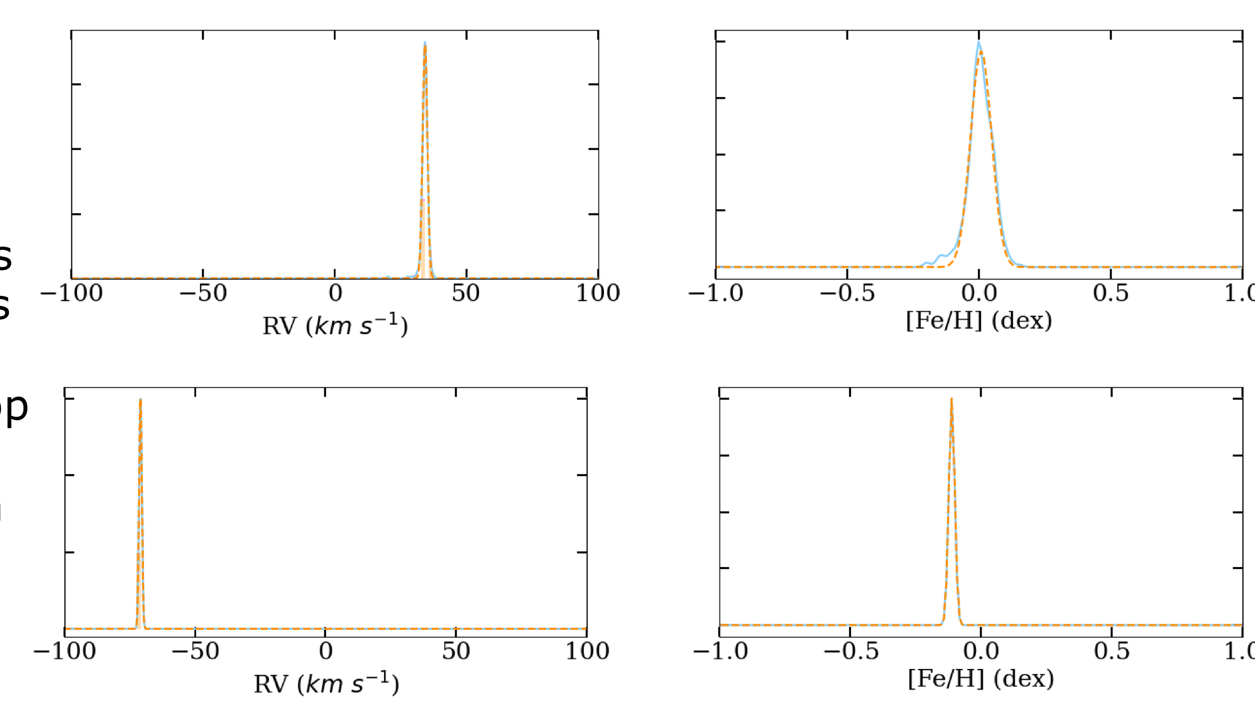
The key to determining if a particular group of stars is a real star cluster or not lies in the fact that member stars were born at the same time out of the same gas cloud. This means that they should all have the same chemical composition and be the same age. Our group does this by utilizing open cluster membership catalogs produced using position, distance and apparent motion data from the *Gaia* satellite. Then we supplement these lists with radial velocity and chemical abundance information to determine additional membership probabilities for individual stars that are potential cluster members. This ensures that groups of stars that are close by and moving together also have similar chemistry and are moving towards or away from us at the same rate, allowing for a stricter determination over which stars are or are not a part of the cluster. The diagnostic plots that we generate are shown to the right in Figure 2 for the two potential clusters pictured in Figure 1.
The final test is to make a color-magnitude diagram (CMD) each cluster. What an open cluster should look like in color and magnitude space is well understood. We do a by eye test to see if the stars that are determined to be cluster members come together to form a cohesive CMD. The CMDs for our two potential clusters are shown in Figure 3. Can you pick out the real one?

Why do we need open cluster membership?

Open clusters are a key building block of the Milky Way. They are crucial in the effort to understand how our Galaxy formed and evolved over time. They are excellent tracers of chemistry due to all member stars forming out of the same gas cloud, as well of age since all members stars formed at the same time. Including stars that are not real members into open cluster catalogs can lead the community astray by skewing any potential trends in either of these spaces. As the number of observed stars in our Galaxy surpasses 1 billion accurate membership lists are more important now than ever before.

Figure 1: SDSS imaging of two potential Milky Way open clusters identified using data from the *Gaia* mission. FSR 0394 is on the left-hand side, while NGC 2682 is on the right-hand side.

Figure 2: Gaussian fits of the RV and [Fe/H] distributions for the two clusters pictured above. NGC 2682 is the top panel, and FSR 0394 is the bottom panel.



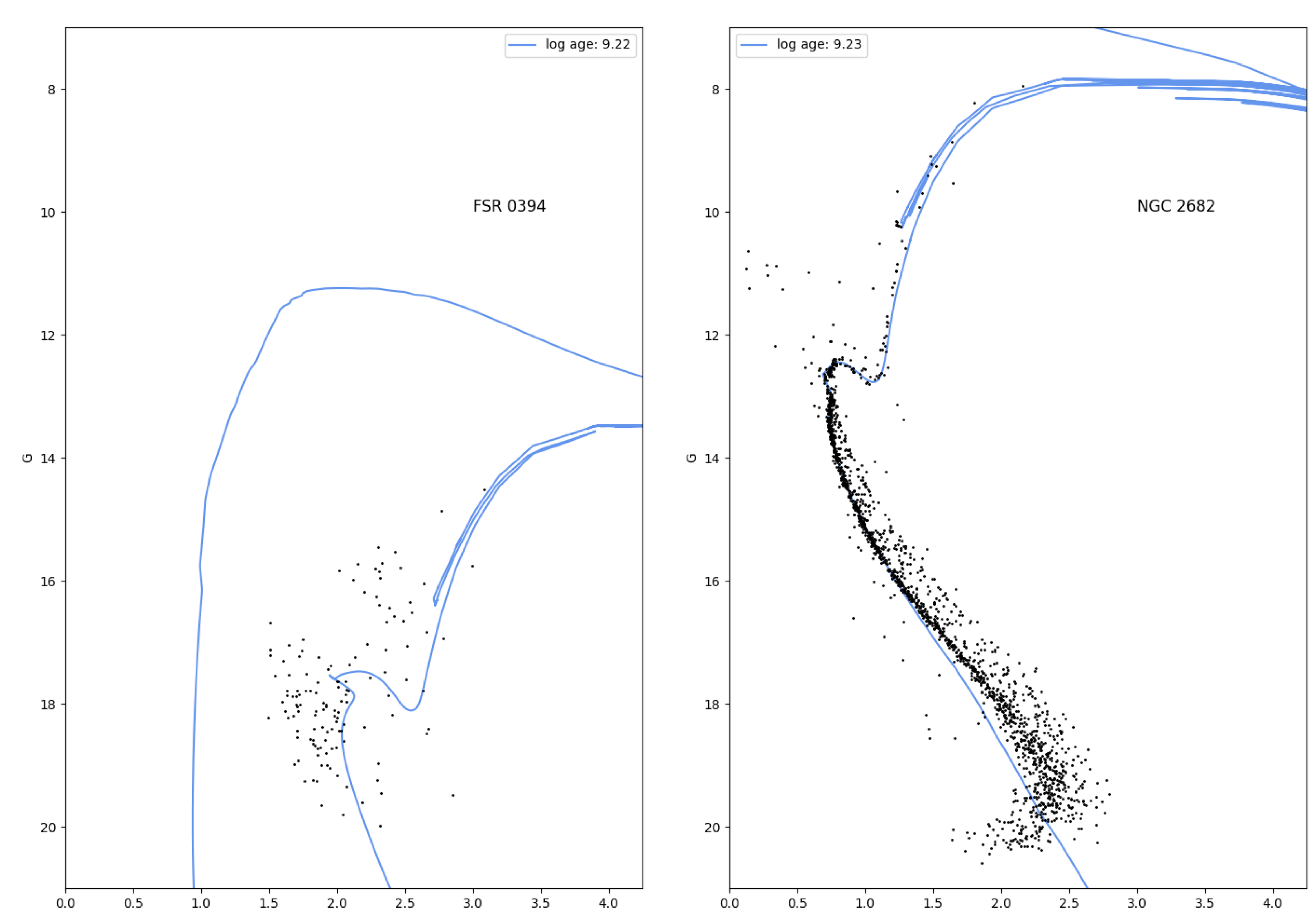


Figure 3: A CMD of our two clusters. The black dots are individual members of the cluster as determined by their kinematics. The blue line is the path a cluster of its age should follow.

Galactic Chemical Gradients

One application of open clusters is to investigate how the chemistry of the Milky Way changes as you move farther and farther from the center. Two different radii are used for this task. The first is the Galactocentric radius, or how far it is from the center of the Milky Way at present day. The other is the guiding center radius which uses some clever math to find the radius the cluster would be at if it had a completely circular orbit with the same amount of energy. This accounts for any potential migration of the cluster from its birth radius to its current radius.
We can further exploit the power of open clusters by breaking down the overall chemical gradient, seen in Figure 4 below, into different age brackets. This allows for a careful investigation of what the Milky Way's chemistry looked like at different points in the past. Helping to achieve the goal of increasing our understanding of how the Milky Way formed and evolved through time.

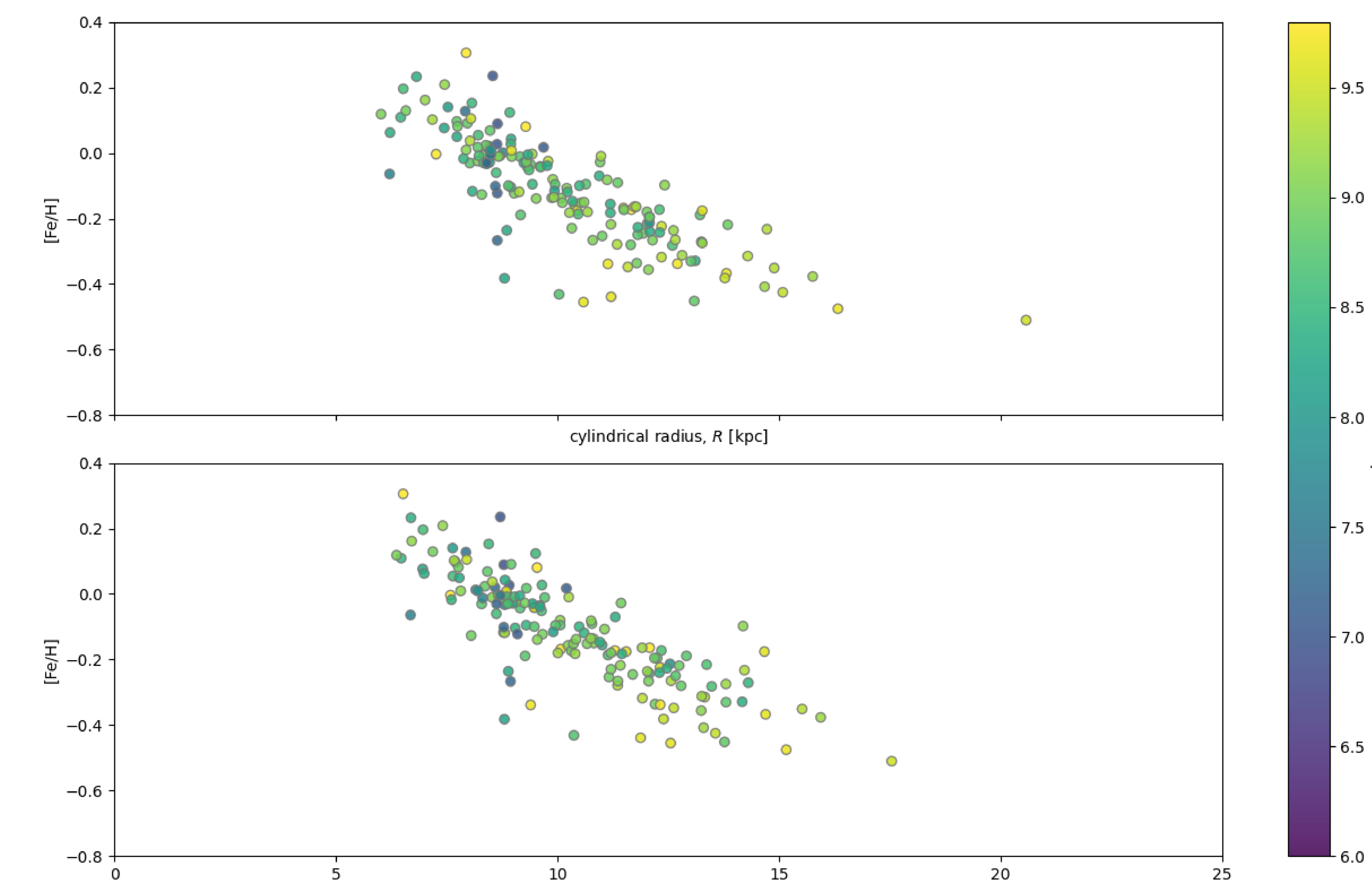


Figure 4: A plot of the whole open cluster sample with radius on the x axis and iron abundance on the y axis. The top plot uses the current Galactocentric radius, the bottom the guiding center radius.

Add same plot as above but in different age bins