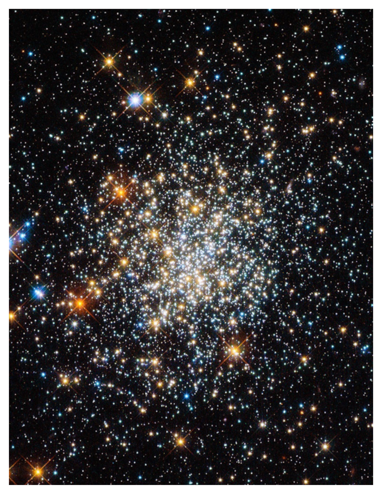

Tik Tok on the Chemical Clocks! Calibrating the Age to Chemistry Link

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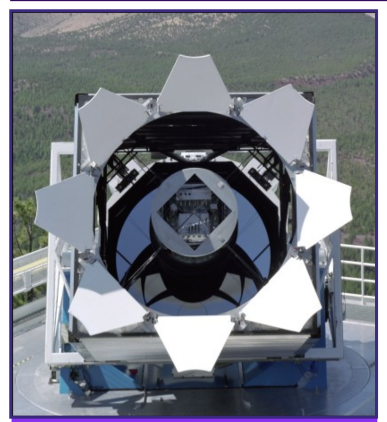


OCCAM

Open Cluster Chemical Abundance and Mapping

Science Question:

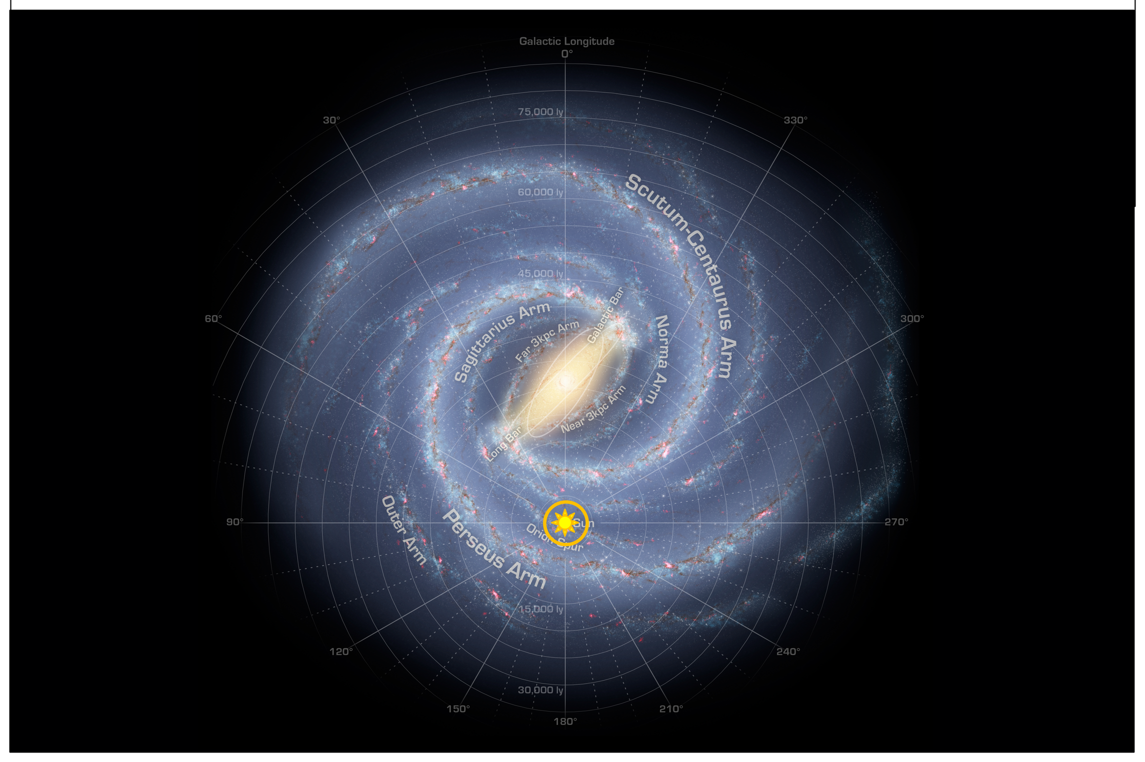
Is there a reliable age indicator that can be applied to a significant number of stars to allow us to measure the large-scale evolution of the Milky Way?

Abstract:

Through the use of large-scale surveys, astronomers are able to investigate Milky Way galaxy evolution, both dynamically and chemically; however, determining reliable stellar ages has been elusive. Star clusters are the most reliable way to measure ages of stars, and new surveys are measuring detailed chemistry for cluster stars that may be able to be correlated with age. For our study, we are using carbon and nitrogen abundances within red giant stars as age indicators. Using the Open Cluster Chemical Abundances and Mapping (OCCAM) survey, we utilized stellar parameters and abundances, and created a uniform empirical relationship between stellar ages and carbon-to-nitrogen abundances using star clusters. This new calibration will allow us to determine reliable ages for over 100,000 stars across the Milky Way galaxy, allowing us to measure the chemical evolution of the Galaxy.

Motivation:

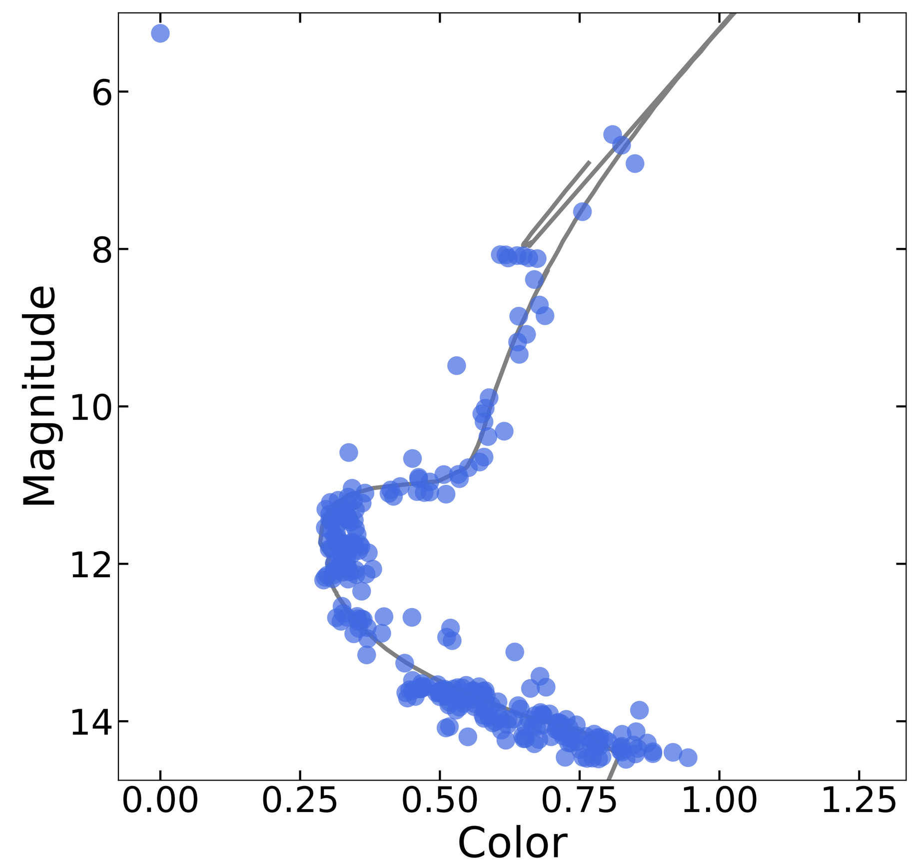
To understand the present-day structures of our Galaxy, we need to learn how the Milky Way formed and evolved over time. To do this we need to determine the age of stars, however obtaining stellar ages is an elusive process and of the field stars determine so far, all of them have been from the solar neighborhood.



(1) ABOVE: Artist interpretation of the Milky Way. Credit: NASA

Star Clusters:

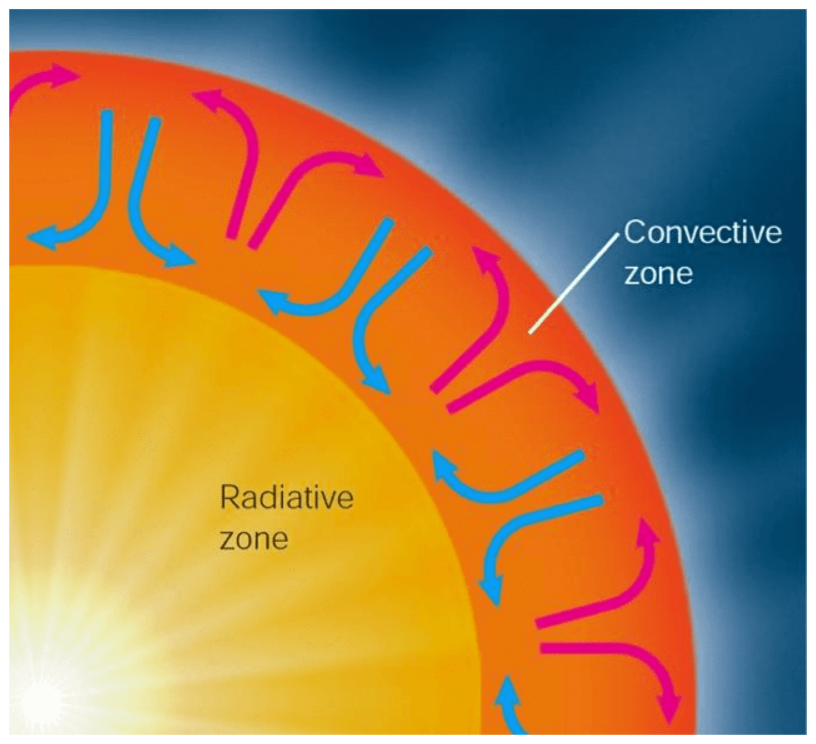
A star cluster is a gravitationally bound groups of stars all formed form the same giant gas cloud and have similar: chemical abundances, kinematic properties, distance, and **AGE**. Observers can create a color-magnitude diagram (CMD; see below). From CMDs, stellar evolution is derived from cluster 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.



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

Chemical Clock [C/N]:

For most of a star's life, hydrogen is fused into helium in the core through two processes: proton-proton chains and carbon-nitrogen-oxygen (CNO) cycle. During the CNO-cycle carbon, nitrogen, and oxygen are used as catalysts, both consumed and reproduced throughout the process, to fuse H to He in the stellar interior. As the star evolves from it's H-burning phase to it's He-burning phase, convective envelopes carry carbon and nitrogen to the surface, where they can now be observed. When these convective envelopes reach maximum penetration depth into the core, this is called the first dredge up (FDU). The amount of carbon and nitrogen in the stellar surface is dependent on the penetration depth of the convective envelope which is dependent on the stellar mass and hence related to stellar age. This implies that [C/N] can be used as a chemical clock. (Chemical clocks are elemental abundance ratios that have been observed to track with stellar age.) **Although to use this chemical clock, the clock needs to be calibrated.**



(3) ABOVE: Stellar interior structure diagram highlighting the convective and radiative zones of the star.

Data Selection:

Data:

In this study, we used:

- APOGEE DR17
  - Most reliable C and N abundances
  - ~734,000 stars
  - ~310,000 evolved stars
  - OCCAM survey (Donor et al. 2018, 2020; Myers et al. *submitted*)
    - 96 "highly reliable" clusters
- Cantat-Gaudin et al (2020) catalog
  - Estimated ages for ~230,000 stars n 2017 star clusters

Selection Criteria:

Source	Parameter	Selection
	APOGEE Data Quality Cuts	
APOGEE/DR17	STARFLAG - Stellar Parameters	$!= 16$
APOGEE/DR17	ASPCAP C Flag	$!= 21$
APOGEE/DR17	ASPCAP N Flag	$!= 22$
APOGEE/DR17	ASPCAP Flag - Chemistry	$!= 23$
APOGEE/DR17	VSCATTER (km s^{-1})	< 1
APOGEE/DR17	SNREV	> 70
	Cluster Membership Cuts	
(Myers et al., *submitted*)	RV_PROB	> 0.3
(Myers et al., *submitted*)	FEH_PROB	> 0.3
(Myers et al., *submitted*)	PM_PROB	> 0.3
(Cantat-Gaudin et al. 2020)	$\sqrt{((l_* - l_{CG})\cos(b_{CG}))^2 + (b_* - b_{CG})^2}$	$< 2\times$ r50
	Stellar Evolutionary Cuts	
APOGEE/DR17	LOGG	< 3.3

→ This resulted in a **uniform** sample of 75 clusters with 577 stars

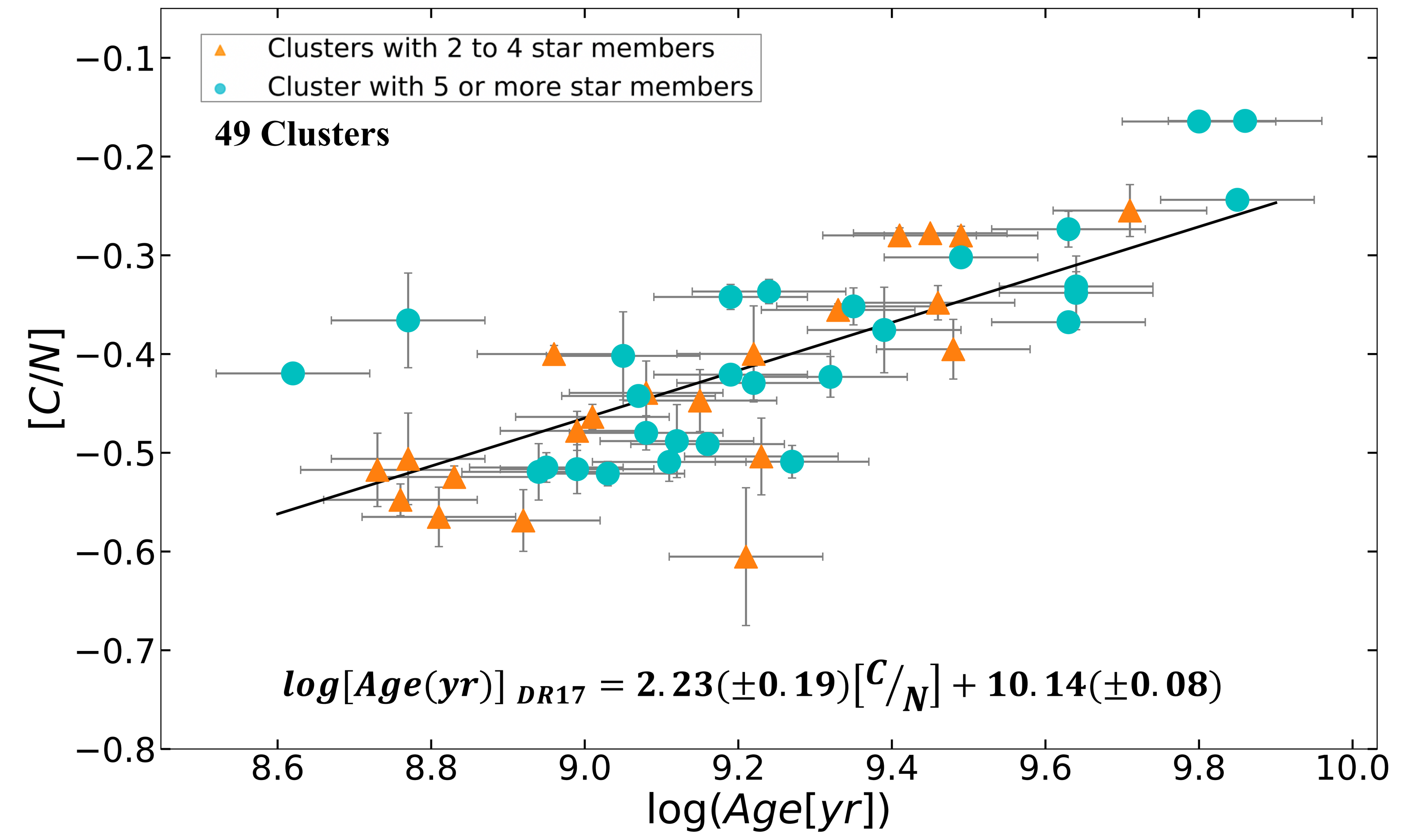
Final Cluster Sample:

To ensure a reliable calibration, we exclude clusters that have one member after applying the selection criteria. Additionally, clusters younger than $\log(Age[yr]) < 8.5$ were excluded because they do not follow the trend in [C/N] due to evolutionary effects (although encourage more careful studies of stars in this regime in the future).

→ This finalizes our calibration sample to be **49 clusters** (530 stars), with an age range of $\mathbf{8.62 \leq \log(Age[yr]) \leq 9.82}$ and a metallicity range of $\mathbf{-0.53 \leq [Fe/H] \leq 0.31}$.

Results:

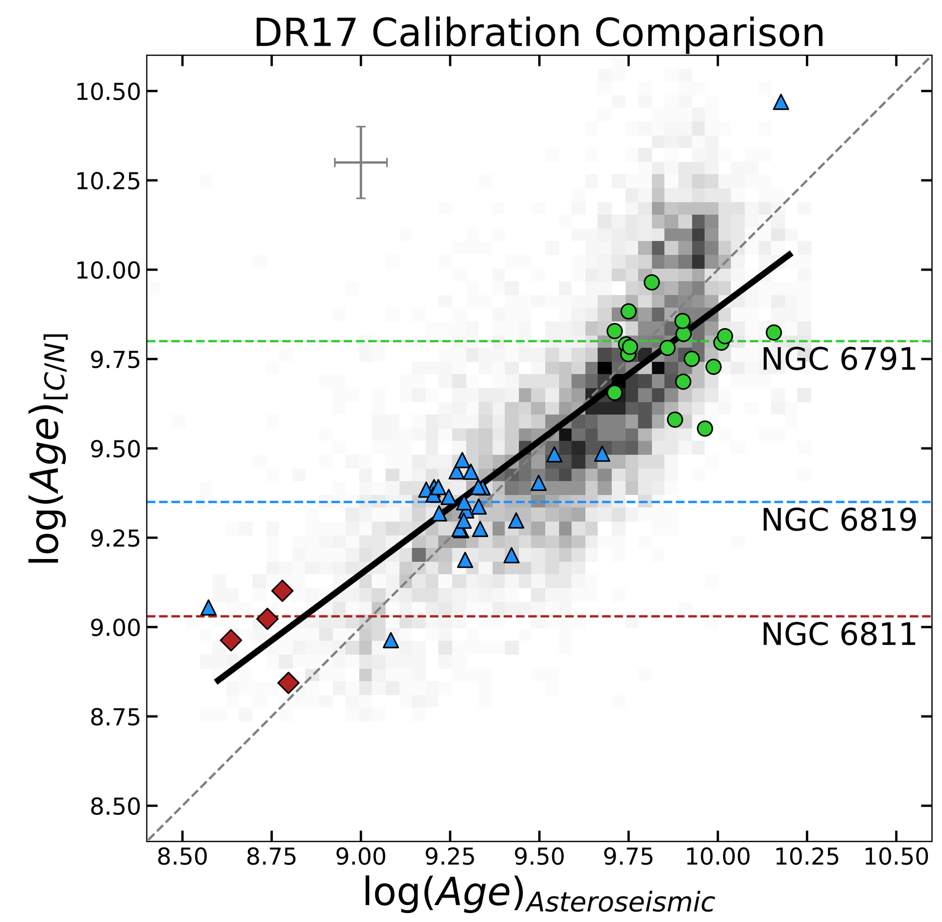
After data quality cuts and selecting evolved stars that have experienced the FDU, our sample is comprised of 49 clusters. Following, a Monte Carlo based linear fit was used to calibrate [C/N] abundances with stellar age.



(4) ABOVE: [C/N] vs log(Age[yr]) for the final sample common to the OCCAM Survey and Cantat-Gaudin sample.

Comparison to Previous Work:

- Asterosiemic determined ages using high quality photometry to measure oscillations in the star to obtain core mass and hence stellar age. APOGEE and Kepler Asteroseismology Science Consortium (APOKASC, Pinsonneault et al. 2018) survey is available to compare with.
- Comparison with asteroseismic results suggests that [C/N] based ages can be trusted to 10% for 99.79% of giants.
- Opening an exciting future for the estimation of precise and accurate ages for hundred of thousands of evolved stars across the Milky Way galaxy.

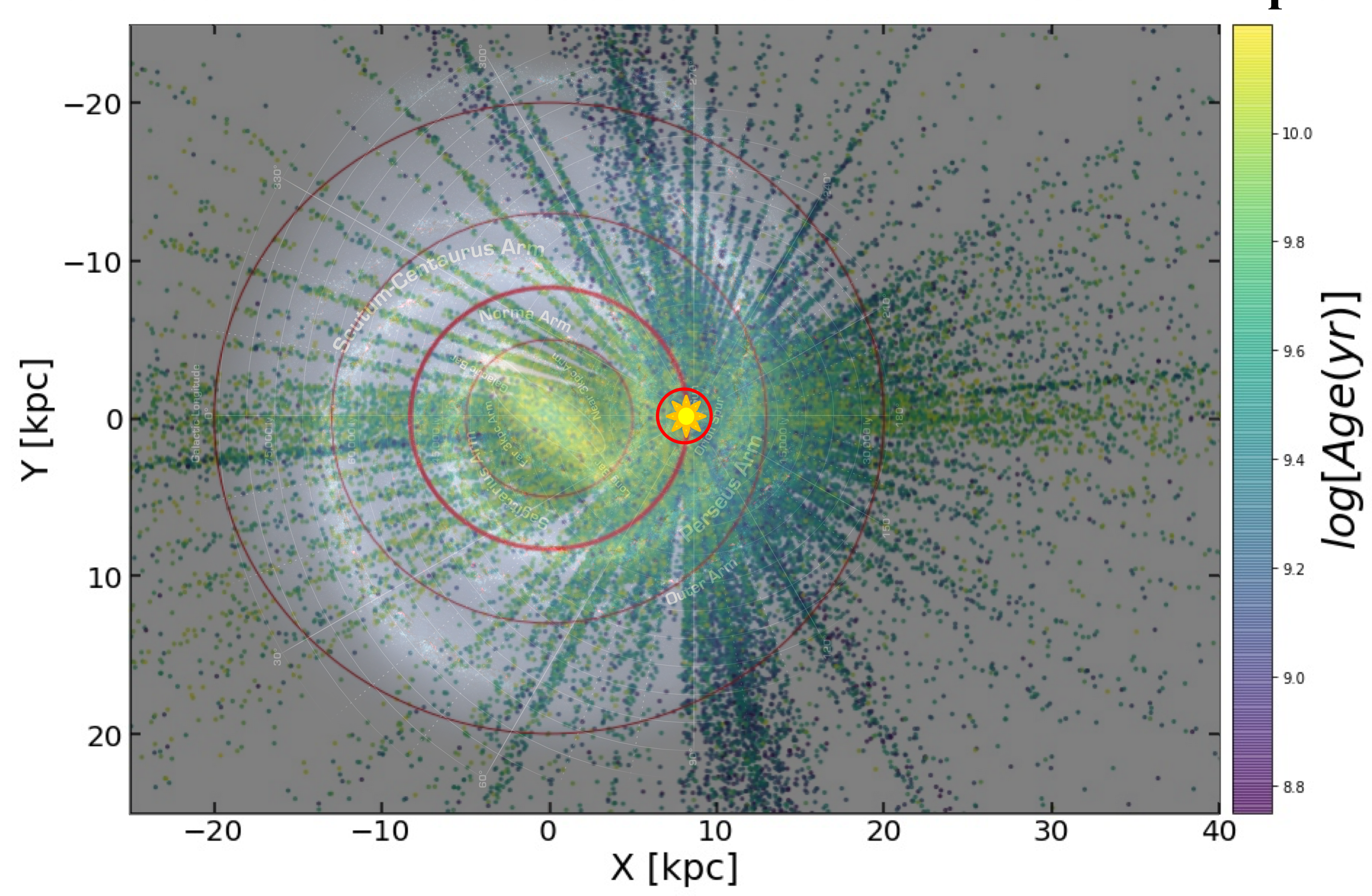


(5) ABOVE-RIGHT: A comparison between our DR17-based age calibration to asteroseismically determined ages from APOKASC. The grey-gradient shaded regions represent bins of field stars. The colored shapes represent cluster member stars common to both samples and corresponding-colored dashed lines are Cantat-Gaudin determined ages for each cluster. The diagonal dashed grey line represents the one-to-one relationship. The solid black line is the linear fit to the main trend of the field stars. Mean representative error bars are shown in each panel.

Future Work:

We will be able to apply this work to a large portion of the Milky Way galaxy

This method can be used on 37% to 42% of the APOGEE sample.



(6) ABOVE: Plot highlighting potential stars in the Milky Way that this method can be applied to.

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Link to the paper. Scan QR code.