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INVESTIGATING THE AGE, METALICITY AND RADIAL ACTIONS OF MAIN SEQUENCE AND RED GIANT STARS IN THE GALAH SURVEY

Anastasios Tzanidakis[1] and Bridget L. Ratcliffe[1]

[1] *Department of Astronomy, Columbia University, Manhattan New York*

ABSTRACT

Radial Migration in the Milky Way indicates a global evolutionary model of how galaxies form from the inside-out model. Utilizing and cross-matching the APOGEE, Gaia DR2 and GALAH Catalogues, we obtain a crossmatched catalogue of stars that include position, ages and metallicity of stars in the local solar neighborhood. Exploring the correlations between age, metalicity and radial action (J_r) we search for preliminary signatures of radial migration between Main Sequence stars (selected as log(g)>3.5 dex) and Red Giant Stars (selected as log(g)<3.5) in a local distance volume that spans roughly 5 kpc in diameter. Our preliminary analysis suggests that despite there being spatial correlations between age and metallicity for both samples, using Jr as a tracer for radial migration does not seem to fully justify the process of radial migration. Instead, we suspect that the combination (J_z) alongside with (J_r) alongside with the age and chemistry of stars to better understand radial migration.

Keywords: editorials, notices — miscellaneous — catalogs — surveys

1. INTRODUCTION

Radial migration, or stars migrating to different orbital radii over time due to changes in angular momentum, has an extensive effect on the evolution of disk galaxies and even helped develop the theory that the Milky Way formed in an inside-out fashion (1). It has also been proposed that radial migration could explain the chemical differences between the thin and thick disks of the Milky Way (2). Thus, by studying radial migration we can determine much about the formation and structure of disk galaxies. It is still uncertain which variables reveal the most about radial migration. Sellwood & Binney (2002) claim that galaxies with no radial migration have a perfect correlation between a star's age and metallicity (3), and Edvardsson et al. (1993) did not find an assured relationship between the two in the solar neighborhood (4). One topic that seems not to have been explored thoroughly is if radial action can be an indicator of radial migration.

In this report we investigate the correlation between orbital eccentricity, stellar age, and metallicity in order to determine if Red Giants and Main Sequence stars are radially perturbed over time. The structure of this report is as follows: in Section 2 we introduce the data used. Methods and Results are given in Section 3 and conclusions are laid out in Section 4.

2. DATA

For our analysis we only use stars that are in all three catalogues: APOGEE DR14, Gaia DR2, and GALAH.

APOGEE DR14 samples all major components of the Milky Way and contains elemental abundances for over 263,000 stars (5). From this catalogue we use [Fe/H] and its associated error. [Fe/H], commonly known as iron abundance, is the $\log_{10}$ ratio of a star's iron to hydrogen content to that of the Sun's and is an indicator for metallicity. Namely, [Fe/H] $= \log_{10}(N_{Fe}/N_H)_* - \log_{10}(N_{Fe}/N_H)_\odot$. In particular, stars with [Fe/H] = 1 have 10^1 times the metallicity of the Sun while those with a value of 1 have 10^{-1} times the metallicity of the Sun.

Gaia DR2 provides parallaxes for about 1.3 billion Milky Way stars (6), but we use the catalogue from Sanders and Das which presents parallaxes, $\log_{10}$ ages, radial actions, and errors for about 3 million stars (7). These variables tell us the star's location, log base 10 age in Gyr, and orbital eccentricity respectively. A radial action, given as

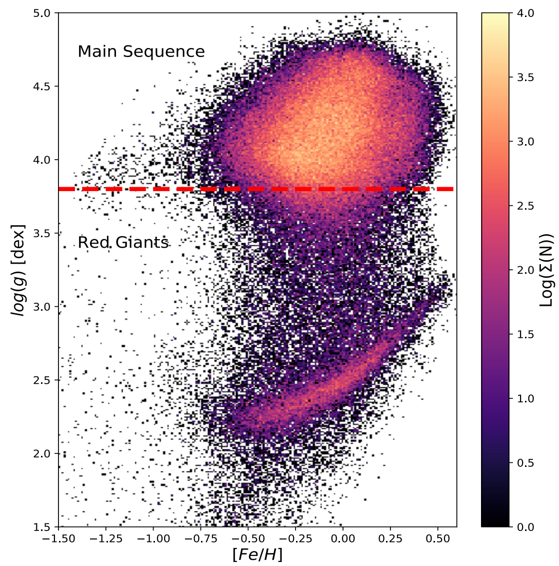

Figure 1: 2D Log Density of Log g as a function of Metallicity. The red dashed line represents a log g cut of 3.8 dex, the typical cutoff for Main Sequence versus Red Giant stars. We propose a log g cut of 3.5 dex in order to minimize the misclassification between the two stellar populations.

the variable J_R, near 0 means the star has a near circular orbit while a larger value corresponds to a more elliptical orbit.

Finally GALAH yields the star's surface gravity (log g) in cm/s^2 and accompanying error for 342,682 stars (8). We use surface gravity to divide the stars into two separate populations: Red Giants and Main Sequence stars. These two populations correspond to two different times in a star's life and hence we believe they deserve to be examined separately.

After crossmatching the catalogues using the stars' 2MASS IDs our dataset consists of just under 350,000 stars. We begin our quality cuts by removing NA and the impossible 999 values. We also decide to only look at stars with [Fe/H] between -2 and 0.5 as this includes the majority of stars with no extreme values. Similarly we only consider stars with -1 cm/s^2 $<$ log g $<$ 6 cm/s^2. In order to achieve a high fidelity set of measurables we take radial action errors $<$ 10%. Our last quality cut is to remove values that differ from the mean value by 2 standard deviations for variables J_R, [Fe/H], and age. This cut ensures our conclusions are not influenced by outliers. We finally split this dataset into the Red Giant and Main Sequence populations by doing a log g cut of $<$ 3.5 cm/s^2 and $>$ 3.5 cm/s^2 respectively. As is apparent in Figure 1, log g = 3.5 splits the two high density regions with little overlap and hence gives us the cleanest cut for the two groups. The resulting Red Giant dataset consists of 1,630 stars while the Main Sequence dataset contains 1,089 stars.

3. RESULTS

In Figure 2a we demonstrate through a 2D binned histogram the split between the Main Sequence and Red Giant stars selected in our crossmatched catalogues. Figure (2a), demonstrated that for the MS sample that the radial action is primarily Jr 0 for a distribution of metallicities that range from metal poor to metal ritch, while the ages and metallicities do not show steep gradients. The unclear correlation between age and metalicity, alongside with Jr is perhaps a confirmation that in the local solar neighborhood, that there is indeed not a clear correlation that confirms Edvardsson et al. (1993) results, and thereby suggesting a first order approximation of radial migration signatures.

On the hand, Figure 2b which shows the same parameters for the RG sample, has distinct correlation between metallicity Age and Jr. In comparison to the MS sample, the RG has a concentration of high metallicity stars with a

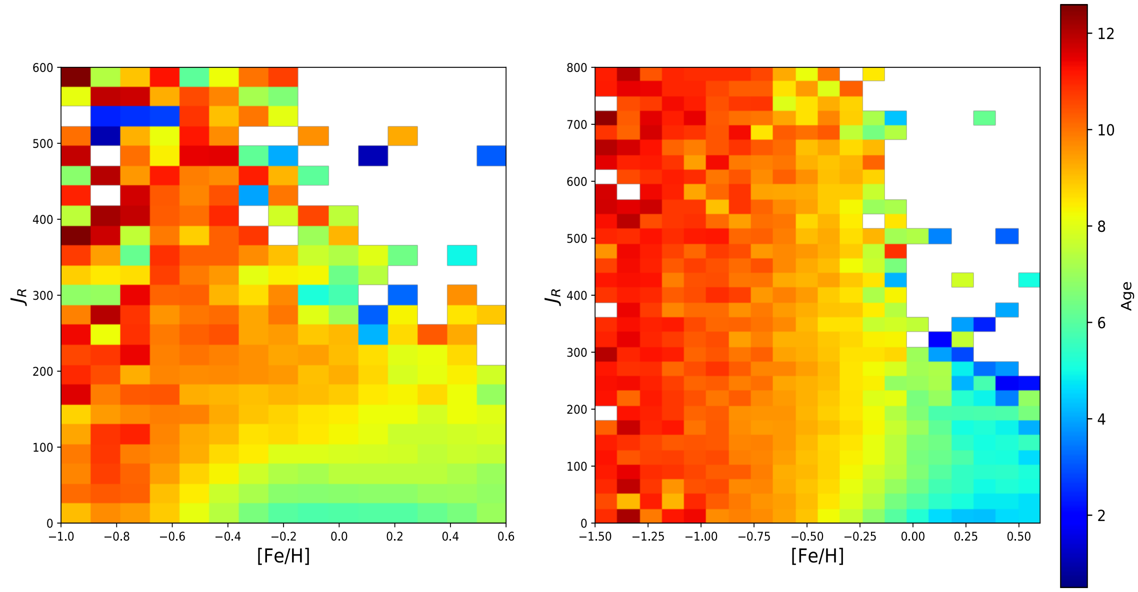

Figure 2: Figure 2a (left) and Figure 2b (right) are the binned 2D histograms of the median age for the Main Sequence and Red Giant star samples respectively. The Main Sequence sample demonstrated

range of relatively small radial actions that are young. Such selection effect is from the continuity of the MS sample size. The RG sample effectively stars from closer distances (¡2kpc) however, most of the RG sample resides beyond a scale heigh ¡Z¿ 2kpc suggesting that most of these stars are inhibited in the Halo. It is also noted, that the gradient in age as a function of metallicity for the RG stars is a clear signature of disk-halo age and metalicity separation.

In Figure 3, we project out RG and MS samples into their physical coordinates (X,Y,Z) and plot their 2D histograms color-coded by their associated Age, [Fe/H] and Jr. We perform such spatial analysis to see if the data demonstrates any correlation with physical positions. The RG sample (3a), seems to show a distinct age separation for higher scale heights, the age increases, conversely, the radial actions also increase with scale height while the relationship is reversed for metallicity as expected. While the MS sample (3b) seems to also demonstrate gradients with age and Jr, we note the bizarre inverse behaviour of age as a function of scale height (Z). It is not expected that for larger radii to see younger stars. We suspect that while crossmatching GALAH to APOGEE and Gaia DR2, that some complex selection function that has inverse the relationship and thus has created a bias that is beyond the scope of this project.

Finally, we additionally separate our samples by an age cut of young and old stars. We assume that young are stars with ages less than 6 Gyr while older stars are older than 6 Gyr. We proceed to model these subsamples as an exponential model, $x \sim \lambda e^{-\lambda x}$, as the density curves looked exponential. In order to fit this model we use the Maximum Likelihood Estimator for λ, which is $\frac{1}{\bar{x}}$. Doing so we achieve the fitted estimated densities given in Figure 5. For both Main Sequence stars and Red Giant stars we see that younger stars (in red) have a higher standard deviation than older stars (in black). Precisely, the variances are 0.002 and 0.001 for Main Sequence young and old stars and 0.001 and 0.0005 for Red Giant young and old stars. Given that there is essentially no difference in J_r dispersion between young and old stars for both Red Giants and the Main Sequence we determine that J_r is not a good tracer for radial migration.

4. CONCLUSIONS

In this analysis we investigate the signatures of radial migration in the GALAH fields that have been crossmatched with Gaia DR2 and APOGEE. We investigate the correlations between age, metallicity and radial action for stars identified as Main Sequence and Red Giants, given a 3.5 dex log(g) cut. We conclude that for the MS sample that our data, that 2D binned histograms suggest a low correlation between the three variables that may be speculated to be due to radial migration theories. This may also be confirmed in spatial coordinates, where we find that the MS sample is at low scale heights. Conversely, for the RG sample, we find a much higher correlation between the three variables, however, notice that in the spatial projections that since we are looking at greater distances, and perhaps a separation between disk and halo stars that such correlation might be due to different stellar populations. Finally, the

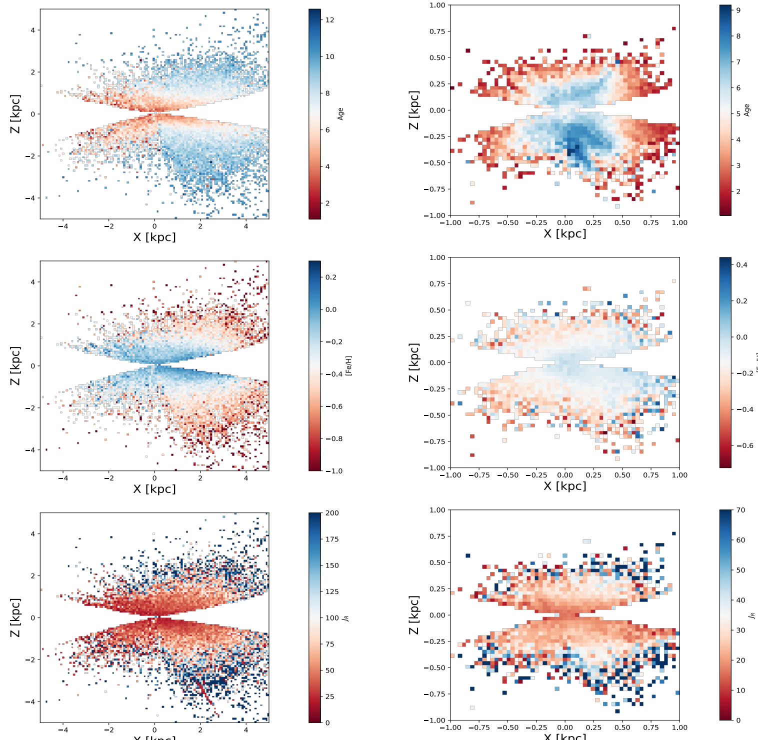

Figure 3: Spatial projections of both RG(right panel), MS(left panel) in the X,Z planes. We explore in each panel the spatial correlation between the age, metallicity and J_r with 2D binned histograms color-coded by their associated physical parameter.

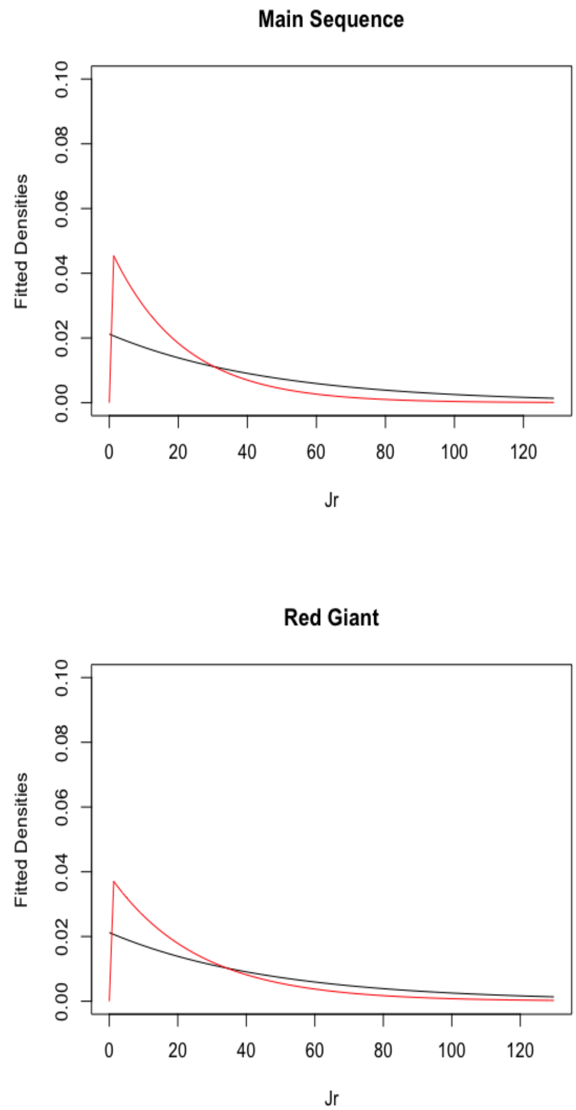

Figure 5: The estimated J_r densities for Main Sequence stars (left) and Red Giant stars (right). The red line corresponds to young stars (age $<$ 6 Gyr) while the black line corresponds to old stars (age $>$ 6 Gyr). The J_r distribution for young and old stars are very similar, with younger stars having a slightly larger variance.