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Estimating the Birthplaces and Metallicities of Samples of Nearby Main-Sequence Stars in the Milky Way

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Abstract

Knowing the birth environments with the signatures of the chemical compositions of main-sequence stars in our nearby galactic vicinity plays an important role in understanding the beginning evolution of the Milky Way. We are carefully studying the selected objects of 67 ($\sim 0.8 - 1.8 M_{\odot}$) nearby main-sequence stars to know their ages, metallicities, and mostly the birth radii at the galactic disk. We analyze the stellar properties in comparison with the galactic chemical gradients with respect to cosmic time by integrating current isochrone models with the metallicity spectroscopic calculations and rotational data. Our findings confirm the existence of inverse correlation between stellar age and metallicity, as well as between mass and evolutionary phase, which suggests that the time resolution of the chemical enrichment structure in the interstellar medium. Considerably, the reassembled of birth radii shows that a significant number of stars, currently orbiting in the solar circle, were most likely born supplementary inward, thus correlations give important evidence of radial migration. The results support the argument of the dynamic activity of the Milky Way, in which the stellar kinematics and the chemical evolution are highly correlated.

Keywords: Main Sequence Stars; Stellar age; Birthplace; Milky Way.

تقدير الولادة الاولى والمعدنية لعينة من النجوم القريبة الواقعة على التسلسل الرئيسي في مجرة درب التبانة

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الخلاصة

ان معرفة بيئات الولادة مع بصمات التركيبات الكيميائية لنجوم التسلسل الرئيسي في جوار مجرتنا القريبة لها دور مهم في فهم التطور الاولي لمجرة درب التبانة. نحن ندرس بعناية الاجسام المختارة من 67 نجماً قريباً من التسلسل الرئيسي (حوالي $0.8 - 1.8$ مليون كتلة شمسية) لمعرفة أعمارها ومعادنها ومعظم أقطار الولادة في القرص المجري. نقوم بتحليل الخصائص النجمية بالمقارنة مع التدرجات الكيميائية المجرية فيما يتعلق بالوقت

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الكوني من خلال دمج نماذج الزمن المتساوي الحالية مع الحسابات الطيفية المعدنية وبيانات الدوران. تؤكد نتائجنا وجود علاقة عكسية بين عمر النجم ومعدنه، وكذلك بين الكتلة والمرحلة التطورية، مما يشير إلى أن الوقت قد حل لبنية الإثراء الكيميائي في الوسط بين النجوم. يُظهر تجميع أنصاف أقطار الولادة أن عددًا كبيرًا من النجوم التي تدور حاليًا في الدائرة الشمسية وُلدت على الأرجح مُكَمَّلَةً للداخل، وبالتالي تُعطي هذه الارتباطات دليلًا مهمًا على الهجرة الشعاعية. تدعم هذه النتائج حجة النشاط الديناميكي لمجرة درب التبانة، حيث ترتبط حركية النجوم والتطور الكيميائي ارتباطًا وثيقًا.

1- Introduction

The abundances of Stellar surfaces can role as fossils, as it is shown that most of the composition elements of low-mass stars are controlled by minimal changes over the lifetime of stars [1]. By combining the age of stars and the chemical abundances, we can have insight into the formation and evolution of the Milky Way, as well as the nucleosynthetic track of the chemical richness [2]. The Sun offers a surprising instance, which shows higher metallicity than nearby stars of comparable age, proposing that it formed near the center of the Milky Way. The most recent estimates model of the Sun's birth radius, taken from inverse modeling and the metallicity gradient of the galactic disk 4.6 Gyr ago, assumes formation mostly around 6.6 kpc. These measurements propose that the Sun was born from an active region in the MW. The migration to the present-day position, located around 8.2 kpc from the center of the Milky Way, assumes the essential impact of the galactic bar and the spiral arms [3, 4, 5].

Additionally, there are other techniques to calculate the distance $R_{i,\odot}$ of the Sun from the galaxy center at the time of formation, where (i) represents the initial position of (R) at the Sun's birthplace. These techniques need to apply the following steps: (1) calculate the mean metallicity of star that was initially created at the same instant time and shows important reliance at the distance of galactic center R_i ; (2) the distribution of initial metallicity of the born stars at typical time (t), as well as the typical galactic center R_i is small; (3) the metallicity of stars and its age must be known, for example, the Sun [6, 7].

The study of nearby stars of the main-sequence gives us important details of the formation and the evolution of the MW. These objects, which represent a huge part of the stellar population in our galaxy, hold important information about birthplaces, in addition to the information about the chemical compositions and stellar dynamical history. By studying their metallicities, ages, and kinematic properties, one can have a view of the chemical enrichment processes of the galaxy. As well as the dynamical mechanisms that have formed the Milky Way over the past ~ 10 billion years.

One of the important relations in the field of astrophysics is the relationship between the age of stars and their metallicity. Usually, the older stars show lower metallicities, and that means the gradual production of the interstellar medium, related to heavy elements that are produced across multiple generations of stellar evolution [8]. This correlation is the initial foundation of galactic trace, allowing us to understand the timeline of the chemical evolution in the Milky Way [9]. Furthermore, the mass-age correlation clarifies how the stellar evolution is contributing by mass, with higher stellar mass stars evolving more rapidly and forming younger stellar populations [10].

The relation between rotational velocity ($V_{\text{sin}i}$) and the effective temperature (T_{eff}), as well as metallicity, trace the distribution of the angular momentum in relation to the stellar dynamical inner. Hot stars (e.g., O/B-types) show mainly higher ($V_{\text{sin}i}$), because of their relation to the radiative region and heat-transferring [11]. Furthermore, the spatial distribution of stars as a function of age gives us a view into the kinematic heat techniques and the stages

of radial migration, which are important keys to understanding the dynamics of galactic disk evolution [12,13,14].

The Hertzsprung-Russell (H-R) diagram is considered to be one of the most important techniques for classifying stars, as well as understanding the path of stellar evolution. By studying temperature, luminosity, absolute magnitude, and other physical properties of stars, we can distinguish between main-sequence stars, red giants, and white dwarfs, each one of these objects representing a different stage of stellar evolution [15]. The spectral properties of stars give us further strength about the mass versus age relationship, with early-type stars (O/B/A) connected with younger populations, while late-type stars (G/K/M) control older stars' populations [16].

Recently, Haywood et al. (2024) suggest that the initial structure that connects the beginning of the Milky Way bar formation with a prolonged period of radial redistribution. This suggests that such non-axisymmetric structures have not only participated, but may have fundamentally restructured the chimerical dynamical parts of the galactic disk. On the other hand, Imig (2023) used APOGEE's data release to produce an empirically detailed graphic of the disk, which carefully maps the dispersion of the metallicity and elemental abundance piecemeal in both thin and thick disk populations. This spatially determines the chemical mapping, reveals acquired indications of stellar diffusion, and the extent of radial mixing grows with stellar age, in line with long-term processes.

The aim of this study is to find key relationships by focusing on a sample of nearby main-sequence objects, concentrating on their metallicities, ages, and spatial distributions. The results exhibited in this manuscript increase our knowledge of the dynamics and chemical evolution of the MW.

The paper is organized as follows: the data sources and sample selection criteria are presented in Section 2. Section 3 describes the methodology used to determine the parameters and estimate stellar birth radii. Section 4 presents the results, which include trends in mass, temperature, metallicity, and inferred birth radii. We discuss the implications for galactic dynamics and chemical evolution in Section 5. Finally, Section 6 summarizes our conclusions.

2- The sample and data set

In this work, we examined the link between metallicity, age, and birth radii of main-sequence stars using a sample of 67 nearby stellar objects. Only stars that have been proven to be on the main sequence make up the sample; these stars were chosen to reduce evolutionary biases and guarantee consistent comparisons across age and chemical composition. The observational parameters were integrated from various studies. The cross-calibrated catalogs of [17] were used to compute the stellar effective temperatures (T_{eff}), metallicities ($[Fe/H]$), and projected rotational velocities (V_{sini}). Age estimates were updated using isochrone fitting based on consistent input parameters to reconcile theoretical models with known star properties (see Appendix A) [18].

3- Determining parameters

To resolve the stellar birth radii (R_i), we compared the estimated stellar ages with their associated metallicities. This analysis is based on the assumption that the radial metallicity gradient and sequential chemical enrichment within the galactic disk. By fitting the observed stellar metallicities and ages to predictive chemical evolution models at various galactocentric radii, we identified the most probable birth radii for the stellar samples analyzed in this study.

All of the stellar identifications, including magnitudes, classifications, and coordinates, were obtained via the SIMBAD astronomical database.

4- Results and discussion

4.1 Stellar mass and Age

Many observational studies that focus on star clusters, particularly the mass-age relation, show a dominance of the low-mass stars because of their advanced ages [19]. In the present study, the relationship between stellar mass and the logarithmic age of stellar objects is illustrated in Figure 1. The data reveal the expected trend for higher-mass stars to evolve off the MS more rapidly than lower-mass stars. Specifically, intermediate-mass stars (with masses approximately $> 1.2 M_{\odot}$) have shorter lifetimes and are therefore absent from the older age bins in our sample. In contrast, low-mass stars (with masses $\lesssim 1.2 M_{\odot}$) have lifetimes longer than the age of the galactic disk and thus dominate the older stellar populations observed here [20]. This mass–radius dichotomy is echoed in more complex astrophysical systems, such as globular clusters, where structural correlations have been similarly explored [21, 22, 23].

To quantify mass–age correlation, we applied a stellar mass estimation formula based on photometric color indices (B–V) and metallicity [17]:

$$\log \frac{M}{M_{\odot}} = 0.269 - 0.368 (B - V) + 0.121 \left[\frac{Fe}{H} \right] \quad \dots\dots\dots (1)$$

Which is valid for $-0.4 \leq [Fe/H] \leq 0.4$ and $0.4 \leq B - V \leq 1.2$

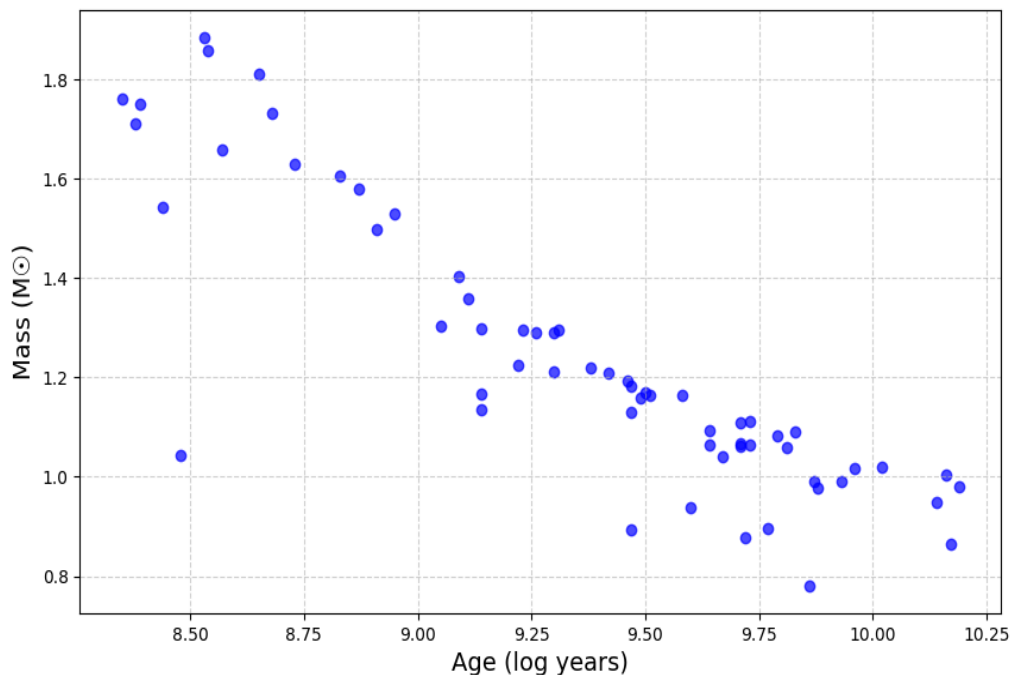


Figure 1: The stellar mass versus logarithmic age for a sample of stellar objects using observational data from [17].

4.2 Stellar Age and Temperature

Fig. 2 shows the link between a star's age (as measured logarithmically) and its effective temperature, which displays a strong anti-correlation. Wherein older stars (log age ≈ 9.75 – 10.0) exhibit low temperatures (6000–7000 K), while younger stars (log age ≈ 8.5 – 9.0) show higher

temperatures (7000–9000 K). The Main-sequence stars progressively emit energy, which causes their outer layers to expand and cool over time. This pattern aligns with recognized stellar physics [17]. Remarkably, the switch at $\log \text{age} \approx 9.5$ may signal the beginning of post-main-sequence cooling and is compatible with anticipated stellar development stages. To compute the M_v of Main-Sequence (MS) stars with regard to the metallicity and age, we use the following equation [18]:

$$M_v = 0.147 \left[\frac{F_e}{H} \right] + 0.62 \log T_9 + 0.173 \quad \dots\dots\dots (2)$$

Here, (T_9) denotes the age in units of 10^9 yr. The final formula may be used to stars with ages between ($10.0 < \log T < 10.2$) years and metallicities between (0.0004) and (0.008).

In general, the following formula is used to determine the luminosity L_λ in the V-band ($M_{v,\odot} = 4.82$ mag) [24].

$$L_{(V \text{ band})} = 10^{-0.4(M_v - M_{v,\odot})} \times L_{v,\odot} \quad \dots\dots\dots (3)$$

The regression line described by the Stefan-Boltzmann equation, which connects the radius (R) with the effective temperature (T_{eff}) of stars:

$$L = 4\pi R^2 \sigma T_{eff}^4 \quad \dots\dots\dots (4)$$

Where (σ) the Stefan-Boltzmann constant [25].

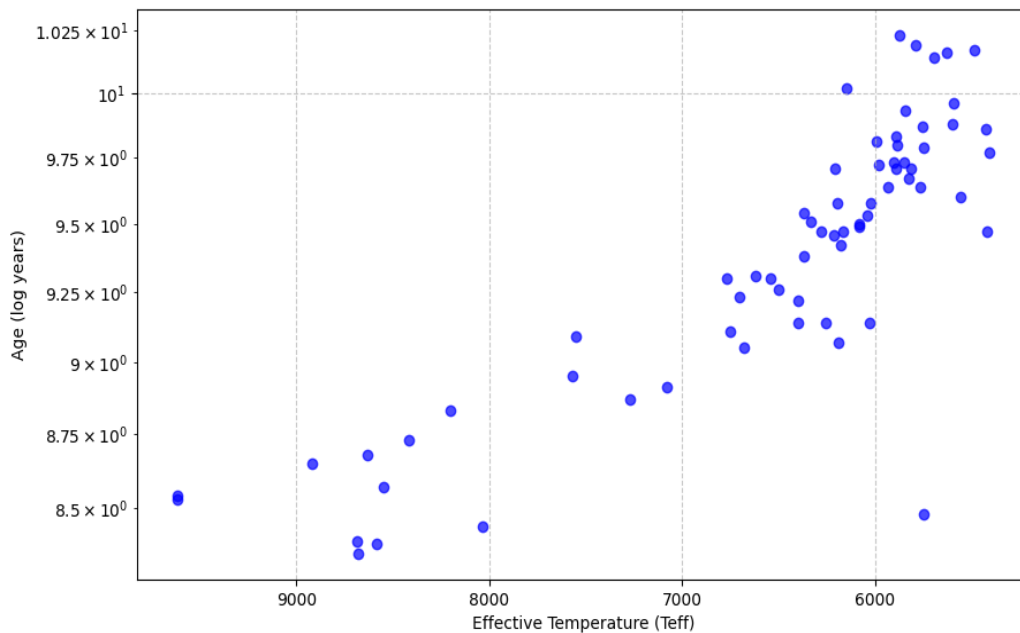


Figure 2: Thermal Evolution of Stars: Inverse Relationship Between Logarithmic Age and Effective Temperature

4.3 Metallicity and Stellar Age

The important correlation between stellar metallicity ($[Fe/H]$) and age gives us significant information about galactic chemical evolution and the star formation history. We used linear regression to determine the metallicity-age relationship:

$$[Fe/H] = \alpha \times \log(T) + \beta \quad \dots\dots\dots (5)$$

The empirical coefficients (α , β) indicate the slope and intercept of the connection, which is connected with the metallicity enrichment rate and the original metallicity baseline. This

association trend is consistent with assumptions from galactic chemical evolution models (e.g., [26]).

As illustrated in Figure 3, the calculated regression,

$$[\text{Fe}/\text{H}] = -0.20 \times \log(\text{Age}) + 1.77, \quad \dots\dots\dots (6)$$

This shows an inverse linear association between logarithmic age and stellar metallicity ($[\text{Fe}/\text{H}]$) for nearby main-sequence stars. According to this model, older stars (e.g., $\log(\text{Age}/\text{yr}) \approx 10.1$) are much more metal-poor, whereas younger stars ($\log(\text{Age}/\text{yr}) \approx 8.5$) tend to be more metal-rich. With each new generation of stars developing from progressively enriched gas, this pattern illustrates the interstellar medium's gradual chemical enrichment across cosmic time.

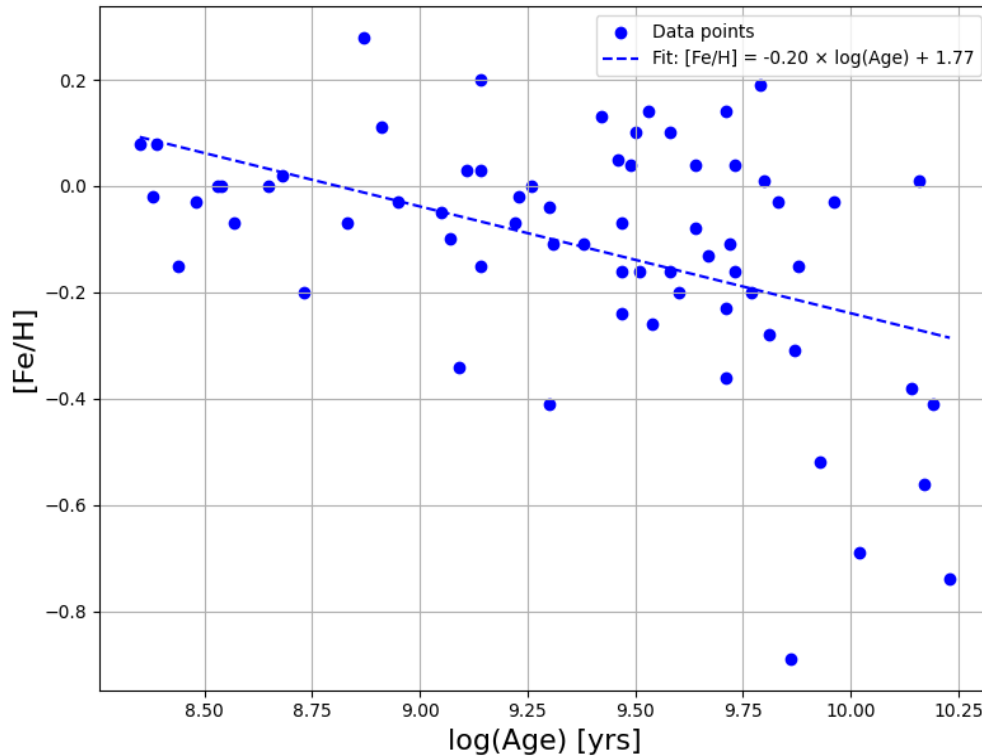
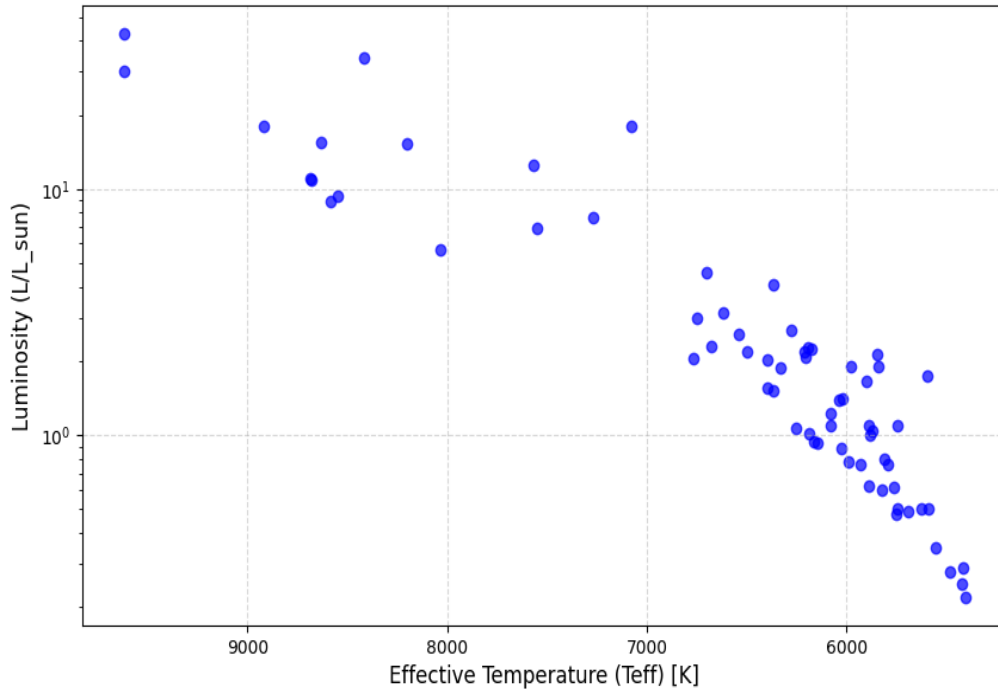


Figure 3: The star metallicity ($[\text{Fe}/\text{H}]$) versus the logarithmic age ($\log(\text{Age})$). The dotted blue line illustrates the best-fit linear regression, which represents the inverse metallicity-age relation across the stellar population.

4.4 Luminosity and Effective Temperature.

Figure 4 illustrates the direct correlation between effective temperature and stellar brightness for main-sequence stars. The lack of red giant branch stars indicates that main-sequence stars make up the majority of the sample, which is in line with the isochrones of young to intermediate-age populations reported in [18]. The temperature-luminosity distribution may encode information about star birthplaces, notably through metallicity-dependent variations in the main sequence. These effects are particularly noticeable in the 6000–7000 K region, where changes in metal concentration have a major impact on atmospheric opacity and, as a result, change where the stars are located in the Hertzsprung-Russell diagram. Figure 4 shows the distribution of luminosity vs effective temperature for main-sequence stars, highlighting the metallicity-dependent characteristics and depicting their evolutionary phases.



4.5

Birthplaces of Nearby Main-Sequence Stars in the Milky Way

Figure (5) gives crucial insights into the evolutionary history of the MW, displaying a well-defined ($[\text{Fe}/\text{H}]$ vs. Age) relation. Also, the highlighted lines of constant initial galactic central distance (R_i) = 4.5 to 12.5 kpc.

In agreement with the isochrone models presented by [19], the metallicity drop from $[\text{Fe}/\text{H}] \approx 0.0$ at 2 Gyr to $[\text{Fe}/\text{H}] \approx -1.0$ at 12 Gyr verifies the increasing chemical enrichment of the MW.

The link between star age, metallicity, and birth radius is quantified using the following empirical formula [19]:

$$[\text{Fe}/\text{H}] = +0.05 \text{ dex} - 0.09 \text{ dex} \left(\frac{R_i - R_0}{\text{kpc}} \right) - 0.048 \text{ dex} \left(\frac{\tau}{10^9 \text{ year}} \right) \dots \dots \dots (7)$$

From where the initial value of the galactic center radius (R_i) at the birthplace can be derived using [2]:

$$\frac{R_i - R_0}{\text{kpc}} = -11[\text{Fe}/\text{H}] - 0.53 \left(\frac{\tau}{10^9 \text{ year}} \right) + 0.6 \dots \dots \dots (8)$$

The Sun's metallicity anomaly (+0.17 dex above the mean trend) strongly suggests outward migration from a birth radius of approximately $R_{i,\odot} \approx 6.6$ kpc to its present location at ~ 8.5 kpc (see [27]), which corresponds to an outward drift of 1.9 kpc that matches orbital diffusion model predictions.

The evaluation of stellar migration history and Galactic chemical evolution is often conducted through analysis of the radial metallicity gradient, typically measured at approximately -0.09 dex/kpc. The radial mixing processes are empirically supported by the increasing metallicity dispersion with age (especially after 8 Gyr), where older stars show more scatter in $[\text{Fe}/\text{H}]$ because they have been exposed to dynamical perturbations in the disk for a longer period of time [28, 29].

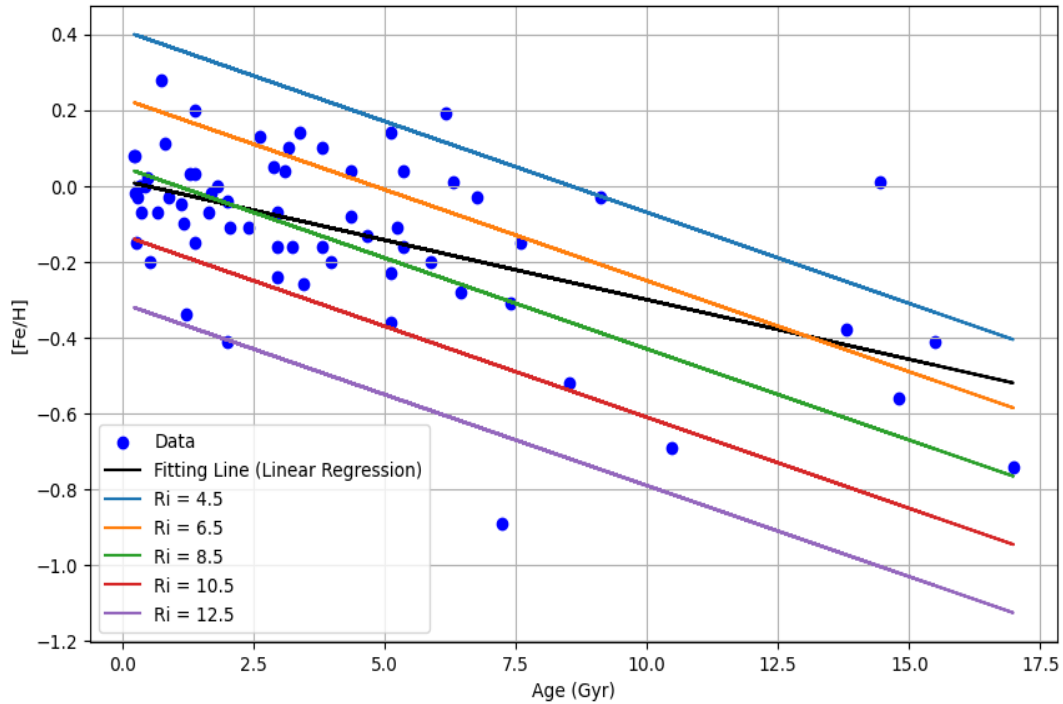


Figure 5: Age–metallicity relation for nearby main-sequence stars, annotated with birth-radius contours ($R_i = 4.5$ – 12.5 kpc). Each contour represents the inferred initial galactocentric distance at stellar formation based on metallicity and age.

By comparing observed stellar metallicity and age to model-predicted values along curves of constant galactocentric radius (R_i), the birth radius of individual stars can be estimated. Figure 6 displays these theoretical isochrone predictions as solid lines, with color-coded by R_i values ranging from 4.5 to 12.5 kpc. Each color marks the expected metallicity for a star of a given age that formed at a specific R_i , based on the adopted radial metallicity gradient and age-metallicity relation.

This approach gives an empirical technique of tracking stellar origins, enabling the reconstruction of plausible formation radii by comparing the observed metallicities of stars with the model predictions. The models at $R_i = 6.5$ kpc and 8.5 kpc show the closest match to the observed data across the entire age range. A histogram (Figure 7) of the best-fitting R_i values reveals that most stars likely originated near the solar circle, with a pronounced peak between 8.5 and 10.5 kpc. In contrast, models at 4.5 and 6.5 kpc account for fewer stars, and no stars are well-matched at $R_i = 12.5$ kpc.

Figure 8 presents the spatial trajectories of the stars, showing their birth (blue) and current (red) locations, connected by green lines indicating their motion. The results suggest that although moderate radial migration has occurred, the majority of stars remain close to their original formation sites [30].

Furthermore, we note that the abundances of α -elements ($[\alpha/\text{Fe}]$) were not available for all objects in the data set. As the stars are primarily nearby, thin-disk main-sequence stars $[\text{Fe}/\text{H}]$ give us a sufficient path of the chemical radial evolution.

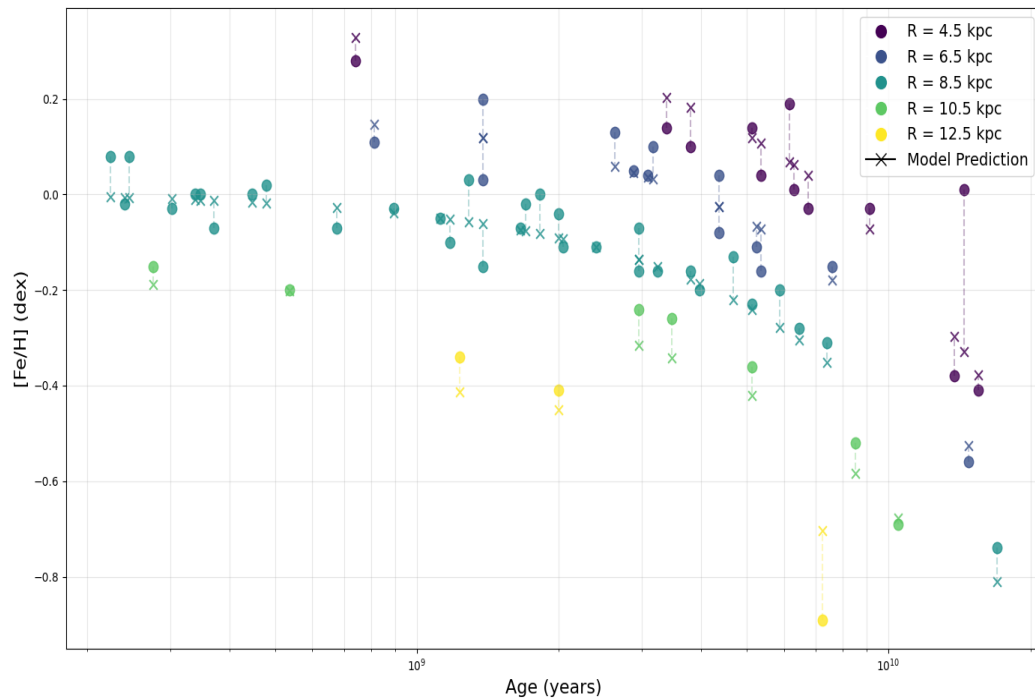


Figure 6: Empirical reconstruction of stellar birth radii and corresponding metallicity evolution, compared against theoretical model predictions of chemical enrichment and radial migration.

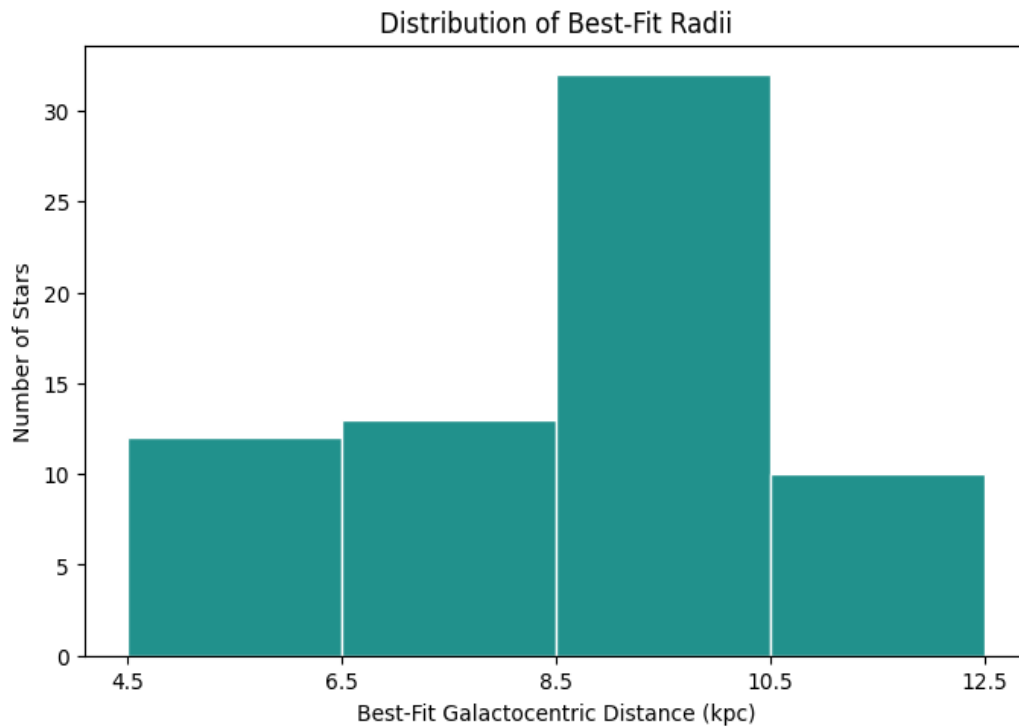


Figure 7: Histogram showing the distribution of inferred best-fit initial galactocentric radii (R_i) for a sample of nearby main-sequence stars, based on their present-day metallicity and age.

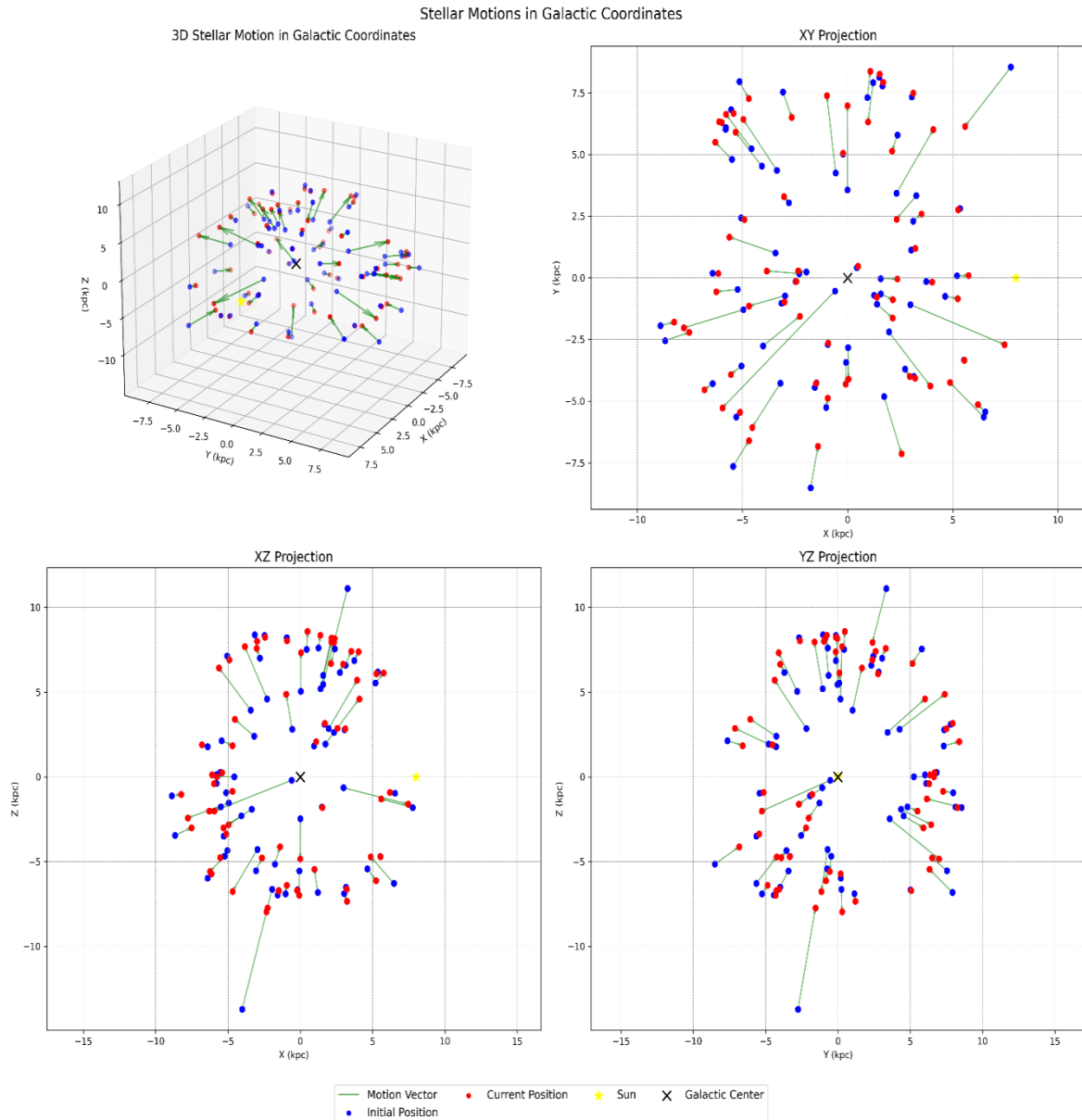


Figure 8: Spatial distribution and radial migration paths of MS stars in the Milky Way, highlighting the difference between current locations and inferred birth radii.

Conclusion:

This work offers a comprehensive investigation of the chemo-dynamics of MW formation in addition to the origins, chemical compositions, and evolution of neighboring main-sequence stars. Using a dataset containing the stellar ages, metallicities, rotational velocities, and spatial distributions, we computed the most likely birth radii for individual stars. These computations demonstrate complex yet substantial patterns of star emigration and metallicity dispersion over cosmic duration.

Our findings demonstrate an ongoing chemical richness of the galactic disk and support the accepted inverse relationship between star age and metallicity. The concept that the Sun originated in a more metal-rich region of the inner disk and then migrated outward is supported by the Sun's greater metallicity in comparison to older stars. The observational data correspond

well with hypothetical equilibrium states and metallicity levels, agreeing with assumptions from recent models of radial collisions and dynamical dispersion.

Significantly, the distribution of metallicity among older star populations offers strong empirical support for radial motion throughout the disk and represents the overall impact of long-term evolutionary dynamical processes. The majority of the stars in the sample started close to the present-day solar circle, suffering only mild orbital motion, as indicated by the prominent peak in reconstructed origin galactocentric radii approximately 8.5 and 10.5 kpc. These results have important implications for recreating the Milky Way's evolutionary history and chemical navigation.

In comparison with the recent studies, our findings provide additional information. For APOGEE red giants, we calculate an age-metallicity relation of $[\text{Fe}/\text{H}] = -0.20 \times \log(\text{Age}) + 1.77$, which is steeper than the connection reported by [28]. Correspondingly, our radial metallicity data indicate that the slope of $-0.09 \text{ dex kpc}^{-1}$ is steeper than the $-0.06 \text{ dex kpc}^{-1}$ obtained by [28]. Additionally, our results demonstrate a more constrained birth-radius range with a distinct peak between 8.5 and 10.5 kpc, indicating that the neighborhood solar radial motion is moderate in accordance with the expected bar-driven models. Whereas [27] confirms the wide radial dispersal caused by the decrease in speed of the galaxy's bar. These discrepancies explain our contribution using nearby main-sequence stars as an appropriate data set to tighten restrictions on galactic chemical evolution and our understanding of its dynamics.

References

- [1] P. D. López, C. Scannapieco, S. A. Cora, and I. D. Gargiulo, "Unveiling the origins of galactic bars: insights from barred and unbarred galaxies," *Mon. Not. R. Astron. Soc.*, vol. 529, no. 2, pp. 979–998, 2024. doi: 10.1093/mnras/stae576.
- [2] M. Elvis and T. Milligan, "How much of the Solar System should we leave as Wilderness?" *Mon. Not. R. Astron. Soc.*, vol. 535, no. 1, pp. 392–396, 2024. doi: 10.1093/mnras/stad3092.
- [3] J. Baba, T. Tsujimoto, and T. R. Saitoh, "Solar System Migration Points to a Renewed Concept: Galactic Habitable Orbits," *Astron. J.*, vol. 976, L29, 2024. doi: 10.3847/2041-8213/ad9260.
- [4] L. Y. S. AL-Mashhadani and A. H. Abdullah, "A Cosmological View for the Time-Variation of the Fundamental Constants of Nature," *NeuroQuantology*, vol. 18, no. 12, pp. 18–29, Dec. 2020. doi: 10.14704/nq.2020.18.12.NQ20233.
- [5] R. Wielen, B. Fuchs, and C. Dettbarn, "On the birth-place of the Sun and the places of formation of other nearby stars," *Astron. Astrophys.*, vol. 314, pp. 438–447, 1996.
- [6] J. G. Fernández-Trincado *et al.*, "Aluminum Enhanced Metal-Poor Stars buried in the Inner Galaxy," *Astronomy & Astrophysics* 643, 2020.
- [7] S. A. A. Al, M. N. A. H., and H. Huda, "Measurement of the distance to the central stars of Nebulae by using Expansion methods with Alladin Sky Atlas," *1st Int. Conf. Phys. Sci. Adv. Mater.*, IOP Conf. Ser., vol. 757, 2020. doi: 10.1088/1757-899X/757/1/012043.
- [8] B. Chen *et al.*, "Chemical evolution with radial mixing redux: a detailed model for formation and evolution of the Milky Way," *Mon. Not. R. Astron. Soc.*, vol. 523, no. 3, pp. 3791–3811, 2023. doi: 10.1093/mnras/stad1568.
- [9] A. Bragaglia, "The Gaia-ESO Survey: Target selection of open cluster stars," *Astron. Astrophys.*, vol. 659, Art. no. A200, 2022. doi: 10.1051/0004-6361/202142674.
- [10] G. Costa, "Evolutionary tracks, ejecta, and ionizing photons from intermediate-mass to very massive stars with PARSEC," *Astron. Astrophys.*, vol. 694, Art. no. A193, 2025. doi: 10.1051/0004-6361/202452573.
- [11] J. Zorec and F. Royer, "Rotational velocities of A-type stars. IV. Evolution of rotational velocities," *Astron. Astrophys.*, vol. 537, A120, 2022. doi: 10.1051/0004-6361/201117691.
- [12] S. Sharma, M. R. Hayden, and J. Bland-Hawthorn, "Chemical enrichment and radial migration in the Galactic disc – the origin of the $[\alpha\text{Fe}]$ double sequence," *Mon. Not. R. Astron. Soc.*, vol. 507, no. 4, pp. 5882–5901, 2021. doi: 10.1093/mnras/stab2015.

- [13] G. Chabrier, I. Baraffe, M. Phillips, and F. Debras, "Impact of a new H/He equation of state on the evolution of massive brown dwarfs. New determination of the hydrogen burning limit," *Astron. Astrophys.*, vol. 671, Art. no. A119, 2023. doi: 10.1051/0004-6361/202243832.
- [14] D. Katz *et al.*, "Radial structure and formation of the Milky Way disc," *Astron. Astrophys.*, vol. 655, A35, Nov. 2021. doi: 10.1051/0004-6361/202140453.
- [15] J. Lian *et al.*, "Quantifying radial migration in the Milky Way: inefficient over short time-scales but essential to the very outer disc beyond ~ 15 kpc," *Mon. Not. R. Astron. Soc.*, vol. 511, no. 4, pp. 5639–5655, Apr. 2022. doi: 10.1093/mnras/stac479.
- [16] M. J. Pecaut and E. E. Mamajek, "Intrinsic colors, temperatures, and bolometric corrections of pre-main-sequence stars," *Astrophys. J. Suppl. Ser.*, vol. 208, no. 1, p. 9, 2023. doi: 10.1088/0067-0049/208/1/9.
- [17] R. Lachaume, C. Dominik, T. Lanz, and H. J. Habing, "Age determinations of main-sequence stars: Combining different methods," *Astron. Astrophys.*, vol. 348, pp. 897–909, 1999.
- [18] G. Bertelli, A. Bressan, C. Chiosi, F. Fagotto, and E. Nasi, "Theoretical isochrones from models with new radiative opacities," *Astron. Astrophys. Suppl. Ser.*, vol. 106, pp. 275–302, 1994.
- [19] S. M. Fall and Q. Zhang, "Dynamical Evolution of the Mass Function of Globular Star Clusters," *Astrophys. J.*, vol. 561, no. 2, 2022. doi: 10.1086/323358.
- [20] E. Villaver, A. Manchado, and G. García-Segura, "The Dynamical Evolution of the Circumstellar Gas around Low- and Intermediate-Mass Stars. II. The Planetary Nebula Formation," *Astrophys. J.*, vol. 581, no. 2, pp. 1204–1213, 2002. doi: 10.1086/344250.
- [21] A. K. Ahmed, G. B. Ali, and M. Y. Amin, "Detailed surface photometry of the spiral galaxies NGC 7339, NGC 7537, and NGC 7541," *Int. J. Adv. Res.*, vol. 2, no. 1, Jan. 2014.
- [22] G. Kordopatis *et al.*, "Stellar ages, masses, extinctions, and orbital parameters based on spectroscopic parameters of Gaia DR3," *Astron. Astrophys.*, vol. 669, Art. no. A104, 2023. doi: 10.1051/0004-6361/202244283.
- [23] A. Eckart *et al.*, "The infrared K-band identification of the DSO/G2 source from VLT and Keck data," *Proc. Int. Astron. Union*, published online, May 22, 2014. doi: 10.1017/S1743921314000726.
- [24] R. H. Ibrahim, "Determining the optimum reference orbits using Lagrange's series for geocentric satellite in low earth orbit," in *AIP Conf. Proc.*, vol. 3282, no. 1, Apr. 2025, Art. no. 050013, pp. 1–8, doi: 10.1063/5.0225676.
- [25] B. W. Carroll and D. A. Ostlie, *An Introduction to Modern Astrophysics*, 2nd ed., Pearson Education, 2013.
- [26] C. Kobayashi and P. Taylor, "Chemo-dynamical Evolution of Galaxies," in *Handbook of Nuclear Physics*, I. Tanihata, H. Toki, and T. Kajino, Eds. Singapore: Springer, 2023. doi: 10.1007/978-981-19-6345-2_106.
- [27] M. Haywood *et al.*, "Timing the Milky Way bar formation and the accompanying radial migration episode," *Astron. Astrophys.*, vol. 690, Art. no. A147, 2024. doi: 10.1051/0004-6361/202348767.
- [28] J. Imig, "A Tale of Two Disks: Mapping the Milky Way with the Final Data Release of APOGEE," *Astrophys. J.*, vol. 954, no. 2, Art. no. 124, 2023. doi: 10.3847/1538-4357/ace9b8.
- [29] M. N. Al Nam, A. H. A, and Y. E. Rashed, "Estimating the evolution and the content fractions of baryonic gas for Luminous Infrared Galaxies," *Mon. Not. R. Astron. Soc.*, vol. 537, no. 2, pp. 1597–1607, 2025. doi: 10.1093/mnras/staf023.
- [30] H. Zhang, "Observational Constraints of Radial Migration in the Galactic Disk Driven by the Slowing Bar," *Astrophys. J.*, vol. 983, no. 1, Art. no. L10, 2025. doi: 10.3847/2041-8213/adc261.

Appendix A: Full Stellar Sample and Derived Parameters

	HD	T _{eff} [K]	[Fe/H]	M _v [mag]	B-V	Ages (yr)	Mass M _⊙
1	693	6206	-0.36	3.504	0.490000248	5.13E+09	1.109481101
2	1581	5991	-0.28	4.563	0.570000172	6.46E+09	1.060131983
3	4813	6254	-0.15	4.219	0.5	1.38E+09	1.166406685
4	7570	6078	0.1	4.065	0.579999924	3.16E+09	1.168584248
5	9826	6212	0.05	3.454	0.539999962	2.88E+09	1.192147559
6	10700	5483	-0.56	5.683	0.71999979	1.48E+10	0.863535264
7	10780	5417	-0.16	5.637	0.809999943	2.95E+09	0.894458141
8	12311	7077	0.11	1.153	0.2900002	8.13E+08	1.498269457
9	13709	9615	0	0.219	-0.0170002	3.39E+08	1.884760073
10	14412 C	5421	-0.89	5.809	0.730000019	7.24E+09	0.781034095
11	14802	5848	-0.16	3.472	0.604000092	5.37E+09	1.065045021
12	15008	8918	0	0.979	0.029999733	4.47E+08	1.81117368
13	17051	6081	0.04	4.201	0.569999695	3.09E+09	1.15899113
14	19373	6040	0.14	3.94	0.704000082	3.39E+09	1.891117367
15	20630 R&C	5747	-0.03	5.053	0.670000076	3.02E+08	1.044263196
16	20766	5751	-0.31	5.092	0.639999866	7.41E+09	0.990763615
17	20807	5889	-0.23	4.814	0.585999966	5.13E+09	1.060527691
18	22001	6621	-0.11	3.054	0.390000343	2.04E+09	1.294702163
19	22484	5981	-0.11	3.602	0.849999905	5.25E+09	0.87677879
20	30495	5824	-0.13	4.857	0.639999866	4.68E+09	1.041717714
21	33262	6164	-0.24	4.361	0.506999969	2.95E+09	1.130795343
22	34411	5889	-0.03	4.194	0.619999886	6.76E+09	1.089456871
23	38393	6398	-0.07	3.825	0.470000267	1.66E+09	1.223404016
24	38678	8546	-0.07	1.875	0.111999989	3.72E+08	1.656967554
25	39060	8035	-0.15	2.418	0.170000315	2.75E+08	1.542729855
26	61421	6704	-0.02	2.65	0.420000017	1.70E+09	1.294255424
27	69897	6365	-0.26	3.845	-	3.47E+09	-
28	76151	5763	0.04	4.84	0.670000076	4.37E+09	1.064829249
29	84737	5899	0.04	3.759	0.619999886	5.37E+09	1.110912983
30	90839	6191	-0.1	4.289	-	1.17E+09	-
31	95128	5882	0.01	4.298	-	6.31E+09	-
32	97603	8199	-0.07	1.337	0.150000095	6.76E+08	1.604463955
33	101501	5554	-0.2	5.421	0.739999771	3.98E+09	0.938598994
34	102365	5692	-0.38	5.064	0.670000076	1.38E+10	0.947239875
35	102647	8582	-0.02	1.91	0.089999914	2.40E+08	1.711827629
36	102870	6176	0.13	3.41	0.550000191	2.63E+09	1.20873175
37	106591	8630	0.02	1.318	0.090000153	4.79E+08	1.731011463
38	112758 A	5408	-0.2	5.945	0.796000004	5.89E+09	0.89510091
39	114710	6029	0.03	4.438	0.590000153	1.38E+09	1.136344316
40	114762	5871	-0.74	4.259	0.6	1.70E+10	1.181233267

41	115383	6021	0.1	3.931	0.8	3.80E+09	1.741265951
42	115617	5590	-0.03	5.079	0.700000286	9.12E+09	1.018051844
43	117176	5596	-0.15	3.681	0.710000038	7.59E+09	0.976270094
44	120136	6398	0.2	3.522	0.490000248	1.38E+09	1.296820624
45	126660	6280	-0.07	3.228	0.509999752	2.95E+09	1.182633267
46	128167	6767	-0.41	3.514	0.370000362	2.00E+09	1.211239058
47	134083	6500	0	3.452	0.430000305	1.82E+09	1.290505583
48	135379	8686	0.08	1.698	0.095999718	2.45E+08	1.751265951
49	139664	6676	-0.05	3.415	0.402999878	1.12E+09	1.302105115
50	142373	5843	-0.52	3.612	0.570000172	8.51E+09	0.991562142
51	142860	6333	-0.16	3.613	0.500000238	3.24E+09	1.163161215
52	157214	5791	-0.41	4.595	0.620000362	1.55E+10	0.980008554
53	157792	7267	0.28	2.089	0.28399992	7.41E+08	1.578948734
54	160691	5746	0.19	4.194	0.699999809	6.17E+09	1.082405699
55	172167	9616	0	0.612	0	3.47E+08	1.857804455
56	173667	6369	-0.11	2.78	0.460000038	2.40E+09	1.220140902
57	185395	6747	0.03	3.129	0.380000114	1.29E+09	1.357656671
58	187642	7548	-0.34	2.221	0.220000029	1.23E+09	1.402490698
59	197692	6543	-0.04	3.289	0.415999889	2.00E+09	1.291433479
60	203280	7567	-0.03	1.582	0.220000029	8.91E+08	1.529008816
61	203608	6146	-0.69	4.394	0.480000019	1.05E+10	1.020633909
62	207129	5933	-0.08	4.592	0.599999905	4.37E+09	1.092748037
63	215789	8415	-0.2	0.478	0.089999914	5.37E+08	1.628096084
64	216956	8681	0.08	1.724	0.090000033	2.24E+08	1.760191777
65	217014	5812	0.14	4.522	0.699999809	5.13E+09	1.067431636
66	222368	6192	-0.16	3.42	0.5	3.80E+09	1.16316145
67	43834	5626	0.01	5.057	0.729000092	1.45E+10	1.004472303