Galaktik Astronomi Çalıştayı Bildiriler Kitabı
Galactic Astronomy Workshop Proceedings Book

İSTANBUL UNIVERSITY PRESS

DOI: 10.26650/PB/PS01.2021.001.005

Galactic CanDy

Özgecan ÖNAL TAŞ[1]

[1]İstanbul University, Science Faculty, Department of Astronomy and Space Sciences, İstanbul, Turkey

ORCID: Ö.Ö.T. 0000-0003-0864-1921

ABSTRACT
Galactic CanDy is an upcoming study that is devoted to investigate the chemo-dynamic structure of the Solar vicinity with the newly developed techniques in population, age and distances estimation and observational data of up-to-date astrometric and spectroscopic surveys. This project is relying on the findings that took decades of Galactic archeaology studies in the literature.

1. Introduction

How galaxies formed in general and how our Galaxy is formed specifically ia an unsolved problem in astrophysics. Understanding the formation mechanisms, test models and put constraints on simulations, the Galactic archaeology relies on chemo-dynamical information of various tracer objects with different ages and chemical compositions in the Galaxy.

Galaxies are dynamically active ensembles of gas, dust and stars that take aeons to change their shapes in a recognizable sense. Likewise our galaxy, the Milky Way, is exposed to various effects that cause drastic changes, such as inner and outer perturbation sources. The Galaxy is generally considered to have distinct components, i.e. bulge, disc and halo, and each have different characteristics in age, kinematics and chemistry. Regardless of the status of the transition between these Galactic components, they are formed from each other as a combination of gas either in clouds or in dark matter halos inside the same gravitational potential (Bland-Hawthorn & Gerhard, 2016). These components are shaped by an on-going collapse into a plane of the gas material, or by part of stellar evolution of its subjects and or by merger events with the surrounding environment (Binney & Tremaine, 2008). Meanwhile, the gas content governs this formation period in two ways (i) by its amount and how it varied over time, (ii) by the chemical enrichment of the gas via on-going stellar evolution of the stars (Chiappini et al., 1997). It is known that stars have the same chemical structure as the molecular cloud in

Submitted/Başvuru: 27.09.2019 **Accepted/Kabul:** 31.01.2020

Corresponding author/Sorumlu yazar: Özgecan Önal Taş (Dr.), İstanbul University, Science Faculty, Department of Astronomy and Space Sciences, İstanbul, Turkey. E-mail: ozgecan.onal@istanbul.edu.tr

Citation/Atıf: Önal Taş, Ö. 2021, in: Galactic CanDy, eds. S. Ak & S. Bilir, *Galactic Astronomy Workshop Proceedings Book*, 45. https://doi.org/10.26650/PB/PS01.2021.001.005

which they were born until the dredge-up and/or stellar wind processes take over. Moreover, as a natural extension of the stellar evolution, most of the synthesized elements do return to the interstellar medium (ISM), where new stars are formed, either through supernova explosions of shortlived massive stars and/or binary stars or expanding shells of long-lived low mass stars. These processes enrich the ISM with various elements in the periodic table on different time-scales and abundances. This is known with different names such as chemical tagging (Freeman & Bland-Hawthorn 2002), the cosmic clock approach (Minchev et al., 2013). Principally, this helps to uncover the time dependent chemical structure of any chosen, observable Galactic region, and also helps to put constraints on Galactic formation scenarios. The other important aspect of the Galactic evolution helps to establish the necessary environment to test the existing findings regarding the Galactic formation, which is called as the inside-out formation of the Galaxy disc (Chiappini et al., 1997, and references therein). According to the two infall model (Chiappini et al., 1997; Chiappini, 2001) the thin disc is evolved by the infall of high-angular momentum gas from inside-out, from the central regions like bulge to the outer regions of the disc radius, for the last 7-8 Gyrs.

Various effects of these interactions are shown by studying the chemistry, kinematics and orbital dynamics of the Solar neighbourhood objects. According to Eggen et al. (1962), stellar orbits vary from circular to elongated eccentric as the vertical distance from the Galactic plane increase. Also, Wielen (1977) showed that the natural encounters with massive objects like giant molecular clouds during a lifetime of a star do alter the shape of the stellar orbit. Moreover, the Galactic bar causes resonance regions that affect the gravitational field which are known as inner and outer Lindblad (ILR and OLR) and co-rotation resonance (CR) regions.

Metallicity gradients are one way of looking into the chemo-dynamic structure of the Solar neighbourhood, which probe the change in metallicity trends during Galaxies ongoing evolution, especially if various metallicity indicators are derived from the mid- or high-resolution spectroscopy (HRS) of large star samples that reach out great distances. Yet it is very hard to reveal the complexities that govern the time evolution of the Milky Way, only by looking into the metallicity gradients. It is important to have accurate spectroscopic observations and trigonometric parallaxes for insightful metallicity gradient results.

This review is focused on the background studies that lead us to develope an advanced chemo-dynamical study based on the state-of-the-art astrometric and mid- or high-resolution spectroscopic data and the newly arisen problems of the *Gaia* era.

2. Metallicity Gradients

In Önal Taş et al. (2016), static and dynamic state of the metallicity gradients of the red clump (RC) stars were investigated using Radial Velocity Experiment's Fourth Data Release (Kordopatis et al., 2013). The largest RC sampled that is compiled at the time. Also in the study metallicity gradient studies between 2000 to 2015 were presented and these studies were grouped based on the selected distance indicator such as current Galactocentric distance (static state), guiding radius of the stellar orbit (dynamic state) and mean Galactocentric distance (dynamic state) of the stellar orbit. RC stars are low/intermediate mass, stable core helium burning, metal rich horizontal branch stars and these are one of the most prominent features of the HR diagram (Girardi, 2016). This clump structure is formed due to the evolutinarty state of these objects that cause a narrow change in their luminosity. So that an average value of an absolute magnitude could be assigned to represent whole population to determine distances as a "standard candle".

RC stars were selected by constraining the effective temperature and logarithmic surface gravity, i.e. $4000 < T_{eff}$ (K) < 5400 and $1 < \log g$ (cgs) < 3. Equatorial coordinates, radial velocities and atmosphere model parameters were selected from RAVE DR4; proper motions were crossmatched with UCAC-4 (Zacharias et al., 2013); interstellar extinction and reddening values in the direction of the sample stars were retrieved from Schlafly & Finkbeiner (2011). Stellar distances were calculated using photometric parallax method (see Bilir et al., 2012) by assuming a constant absolute magnitude in 2MASS K_s band (Groenewegen, 2008) due to the standard candle status of RC stars. Using this parameters space defined by astrometric, photometric and spectroscopic properties of the sample stars secondary parameters such as space velocity components and axisymmetrical orbit properties are calculated from Johnson & Soderblom's (1987) matrices and algorithm and *MW2014Potential* function of the *galpy* potential library of Bovy (2015), respectively.

Metallicity gradients are calculated for the distances radially increasing from the Galactic centre and for the distances vertically increasing from the Galactic plane. In this study the radial metallicity gradients were considered to probe the chemo-dynamic structure within the 2 kpc radius of the Solar vicinity. Here we deliberate on the results of the radial metallicity gradients obtained in the literature and this study. In Önal Taş et al. (2016), the radial metallicity gradients were calculated for the current (static) and mean (dynamic) Galactocentric distances.

Calculations for the current coordinates were showed that the resulting radial gradient for the thin disc ($0 < |Z| < 0.5$ kpc) were too shallow with respect to the literature values, but the trends of the gradients are the same, i.e. a negative gradient in thin disc and becoming zero or positive with the increasing distance perpendicular to the Galactic plane. When the current positions of the objects were considered it should be noticed that samples that are closer to the Galactic plane are contaminated by the thick disc (6%) and halo (0.1%) stars (Bilir et al., 2008). To this end, the dynamic state of the RC sample is considered using orbit parameters such as z_{max}, e_p, e_v, R_m, R_{apo}, R_{per}, calculated under an axisymmetrical potential conditions. RC sample were separated into rough Galactic populations using z_{max} interval, so called maximum vertical distance of the stellar orbit from the Galactic plane, i.e. $0 < z_{max} < 0.5$ kpc, so on. Radial metallicity gradients for these samples were found still shallow even shallower than the static state and the trends were as it is expected and seen in the literature for the other Galactic populations. What would cause this problem even the samples that are uncontaminated by the neighbouring Galactic components?

Distribution of e_p and e_v (vertical and planar eccentricty, respectively) for four z_{max} intervals that represent thin disc ($0 < z_{max} < 0.5$ kpc), transition between thin adnd thick disc ($0.5 < z_{max} < 1$ kpc), thick disc $1 < z_{max} < 2$ kpc and beyond thick disc ($z_{max} > 2$ kpc). According to these distribution, vertical eccentricities do change from circular to eccentric orbits as the sub-samples evolve from thin disc to thick disc. However, planar eccentricities do not follow any trend, instead the values were found in almost every value. This lead us to constrain planar eccentricities in each z_{max} interval, i.e. $e_p < 0.05$, 0,07, 0.10, 0.20. Calculated radial gradients with e_p and z_{max} limits were showed that the metallicity gradients are very steep for the lowest e_p sub-sample in thin disc interval and radial gradient values for increasing e_p subsamples were becoming flatter, but still steep with respect to previous thin disc sub-samples. Comparison with the literature were showed that the gradient values are accordance with the studies of Plevne et al.'s (2015) F-G main sequence thin disc sample and Nordström et al.'s (2004) F-G main sequence with age limited ($4 < \tau < 11$ Gyr) sample. However, still no consensus is found on the radial metallicity gradient value for the various subsamples that represent different Galactic components or or properties such as age, spectral type, kinematics etc.

The possible cause of these planar eccentricity distribution is further investigated in another study of Önal Taş et al. (2018).

3. Galactic Disc

In Önal Taş et al. (2018), using a new set of RC stars were selected from RAVE DR4 to investigate the possible effects of Galactic perturbation sources on the orbits of the stars. The RC sample differs from Önal Taş et al.'s (2016) sample by adding extra constraints on spectral algorithm convolution and spectral morphology flags. Proper motions were cross-matched with UCAC-4 catalogue and distance and space velocity components are calculated with the same methods as in Önal Taş et al. (2016). Stellar orbits in this study were calculated for axisymmetric (MW) and non-axisymmetric (MWBS) potentials. Milky Way's disc hosts large scale perturbers such as Galactic long bar, spiral arms and giant molecular clouds. To add the effects of these sources additional term included in axisymmetrical potential function that represent the Galactic bar and transient spiral arms. In this study, the possible effect of molecular clouds were ignored. To see the effects on stellar orbits and chemo-dynamics the radial metallicity gradients were calculated using the constraints that are determined in the previous study.

Based on the calculations of the Galactic orbits, RC subsamples were generated for aforementioned cumulatively increasing e_p and discrete z_{max} intervals to see the contamination effects on the radial metallicity gradients from the inclusion of the eccentric stellar orbits. More detailed analyzes were obtained once the discretely increasing e_p subsamples considered, and peri-Galactic distances which were given the radial extent of the RC samples that are affected from the well-known resonance regions (CR and OLR). As the number of stars with eccentric orbits increases in the e_p subsamples, the radial metallicity gradients become positive in the $0 < z_{max} \leq 0.5$ and $0.5 < z_{max} \leq 1$ kpc distance intervals for both the MW and MWBS potential models. It can be deduced as the peri-Galactic distances of the sample stars increase, so as their planar eccentricities. Thus as a consequence RC orbits become perturbed by various phenomena from the inner Galactic regions.

In order to investigate these perturbation effects, this time RC subsamples were generated for discretely increasing e_p and z_{max} intervals up to $e_p = 0.5$. Output parameters such as the median values of eccentricity, peri- and apo-galactic distances, metallicity, age, the number of RC stars and the radial metallicity gradients are re-calculated for both of the potential models. By doing so, the planar eccentricity limits that coincide with the Galactocentric radii where the positions of the OLR and CR. Radial metallicity gradients were shown a general trend of flattening with increasing planar eccentricity and become positive with increasing z_{max}. This trend has been found for both of the potential models. Based on the results, RC stars under the influence of an axisymmetrical potential were reached down to 3 kpc distance from the Galactic centre, whereas for the MWBS potential model the peri-galactic distances were increased by ~ 0.3 kpc (R_p =

3.3 kpc). This was another demonstration of the effects on the RC stellar orbits when major perturbers are considered in potential calculations. Thus, the sub-samples that were originated from slightly inner Galactic radii are excluded, the radial metallicity gradients become more authentic for the Solar neighbourhood.

4. Galactic CanDy

CanDy is a sub-project of KMAP project, which has been supported by Türkiye Scientific and Technological Research Council as of March 2019. KMAP project aims to study extensively the kinematic structure of the Solar vicinity. As a sub-project, CanDy aims to study the chemistry and dynamics of the Solar vicinity from an observational point of view using the most precise astrometric data from *Gaia* DR2 (Gaia Collaboration, 2018), and upcoming mid-resolution spectroscopic data of southern sky from RAVE DR6 (Guiglion et al., 2018) and high-resolution spectroscopic data of both hemispheres from APOGEE-2S and APOGEE-2N (Aguado et al., 2018) surveys. This project is built-on the experience of Önal Taş et al. (2016; 2018) papers by complimenting the distances directly from the precise trigonometric parallaxes, equatorial coordinates and proper motion components instead of methods that rely on various assumptions and arithmetical approaches. By doing so, samples with different spectral types and luminosity classes observed from both hemispheres will be able to be examined within a large parameter space with more precision than before.

Even though the trigonometric parallaxes are obtained precisely for billions of objects, transforming these data into an acceptable and realistic distances is a challange. The literature was used to rely on inverse parallax calculation as a good approximation when the samples constrained within the Solar neighbourhood (up to 2 kpc from the Sun). However, as the *Gaia* DR2 contains 1.7 billion objects with accurate 5-parameter astrometric solution, it is inferred that a new method of distance estimation that depends on Bayes statistics with prior and a joint posterior distribution for individual stars is required in the literature (Bailer-Jones, 2015; Querioz et al., 2017; Bailer-Jones et al., 2018). So, which method to trust? This is the most important question that needs an answer to pursue studies in our current reality of Galactic archeaology.

References

Aguado, D.S., Ahumada, R., Almeida, A. et al., 2018, ApJS, 240, 2
Bailer-Jones, C.A.L., 2015, PASP, 127, 994
Bailer-Jones, C.A.L, Rybizki, J., Fouesneau, M. et al., 2018, AJ, 156, 58
Bilir, S., Cabrera-Lavers, A., Karaali, S., Ak, S., Yaz, E., López-Corredoira, M., 2008, PASA, 25, 69
Bilir, S., Karaali, S., Ak, S., Önal, Ö., Dağtekin, N.D., Yontan, T., Gilmore, G., Seabroke, G.M., 2012, MNRAS, 421, 3362
Binney, J., Tremaine, S., 2008, Galactic Dynamics Second Edition (Princeton University Press)
Bland-Hawthorn, J., Gerhard, O., 2016, ARA&A, 54, 529
Bovy, J., 2015, ApJS, 216, 2
Chiappini, C., Matteucci, F., Gratton, R., 1997, ApJ, 477, 765
Chiappini, C., 2001, AmSci, 89, 506
Eggen, O.J., Lynden-Bell, D., Sandage, A.R., 1962, ApJ, 136, 748
Freeman, H., Bland-Hawthorn, J., 2002, ARA&A, 40, 487
Gaia Collaboration, Brown, A.G.A., Vallenari, A. et al., 2018, A&A, 616, A2
Girardi, L., 2016, ARA&A, 54, 95
Groenewegen, M.A.T., 2008, A&A, 488, 25

Guiglion, G. et al., 2018, IAUS, 334, 302
Johnson, D.R.H., Soderblom, D., 1987, AJ, 93, 864
Kordopatis, G., Gilmore, G., Steinmetz, M. et al., 2013, AJ, 146, 134
Minchev, I., Chiappini, C., Martig, M., 2013, A&A, 558, 9
Nordström, B., Mayor, M., Andersen, J., Holmberg, J., Pont, F., Jørgensen, B.R., Olsen, E. H., Udry, S., Mowlavi, N., 2004, A&A, 418, 989
Önal Taş, Ö., Bilir, S., Seabroke, G.M., Karaali, S., Ak, S., Ak, T., Bostancı, Z. F., 2016, PASA, 33, E044
Önal Taş, Ö., Bilir, S., Plevne, O., 2018, Ap&SS, 363, 35
Plevne, O., Ak, T., Karaali, S., Bilir, S., Ak, S., Bostancı, Z.F., 2015, PASA, 32, 43
Queiroz, A.B.A., Anders F., Santiago B.X. et al., 2017, MNRAS, 476, 2
Schlafly, E.F., Finkbeiner, D.P., 2011, ApJ, 737, 103
Wielen, R., 1977, A&A, 60, 263
Zacharias, N., Finch, C.T., Girard, T.M. et al., 2013, AJ, 145, 44