Setting the scene for Gaia and LAMOST
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Moving Groups in the Galactic Disc

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Abstract. We present results of chemical abundance study of a few representative stellar streams of Galactic thick and thin discs. Arcturus stream, which was proposed to have an extragalactic origin, and a recently detected stream called AF06 were studied. Results show a range of metallicity, age and abundance pattern that are consistent with those of Galactic thick disc component. We found similar results for AF06. The abundance and age results unambiguously rule out the possibility that the member stars are vestiges of open clusters. Abundance results of a sample of stars of Sirius and Hercules streams combined with the kinematics show that both the streams belong to the thin disc component. Also, results rule out these are remnants of open clusters. It is likely these streams formed insitu due to perturbations caused by non-axisymmetric components such as bar or spirals.

Keywords. Galaxy: abundances, Galaxy: disc, Galaxy: kinematics and dynamics, Galaxy: evolution, stars: abundances

1. Introduction

Apart from the two main components namely the thick disc and the thin disc, there exist many substructures or overdensities in the velocity field of disc stars in the solar neighbourhood. These kinematically coherent groups are called in the literature as stellar streams or moving groups. Many such moving groups are known to exist in the solar neighborhood (Eggen 1996 and reference therein). The origin of the stellar streams is an important ingredient to Galaxy modelling to understand its chronological formation and evolution. Though the concept of the moving groups has been there for decades, still there is no consensus on the phenomenon that creates these kinematic groups in the Galaxy. In the recent literature related to moving groups one may find a many pronged strategy such as chemical tagging and sophisticated statistical approaches (see e.g; Bensby *et al.* 2007, Pakhomov *et al.* 2011, de Silva *et al.* 2011, Pompéia *et al.* 2011, Williams *et al.* 2009). There are three principal scenarios that were put forward by various studies to explain the existence of moving groups: a) disruption of open clusters (Eggen 1996)., b) dynamical perturbations due to non-axisymmetric components such as bar and/or spiral arms (Kalnajs 1991, Fux 2001, Dehnen 2000, De Simone *et al.* 2004, Quillen *et al.* 2005)., c) dynamical perturbations due to merging satellite galaxies (Minchev *et al.* 2009) or vestiges of accreted galaxies themselves (Navarro *et al.* 2004). Some of these scenarios may explain some particular moving groups with some particular characteristics, but the common theory for their existence is still elusive.

In this article, we discuss the abundance patterns of a few representative streams which are being studied for my thesis work. The selected streams are Arcturus and a new stream identified by Arifyanto & Fuch (2006) is also called as AF06. Both belong to thick disc component. We also discuss the preliminary results of two other streams from the thin disc component namely Hercules and Sirius streams. The discussion is based on elemental abundance results obtained from high resolution spectra.

2. Arcturus and AF06

Abundances were obtained for 18 member stars of Arcturus and 26 of AF06. Sample data was drawn from the study of Arifyanto & Fuch (2006) who identified these as overdensities based on statistical analysis of a large number of F and G dwarfs in the phase space. The mean kinematics of Arcturus and AF06, respectively are $V = -125$ km s^{-1} and $\sqrt{U^2 + 2V^2} = 185$ km s^{-1} and at $V = -80$ km s^{-1} and $\sqrt{U^2 + 2V^2} = 130$ km s^{-1}.

For the entire sample stars, in both the streams, abundance analysis was performed. Abundance trends of a few key elements against metallicity ([Fe/H]) are shown in Fig 1. Also, shown are the corresponding elemental abundances of the thin and thick disc stars adopted from Reddy *et al.* (2003, 2006). In both the cases, one may note that the α-element abundance trends are very similar to those of the thick disc abundance trends. Within the metallicity range of the respective streams, the α-abundance ratios are indistinguishable from that of larger thick disc component. The derived ages, based on

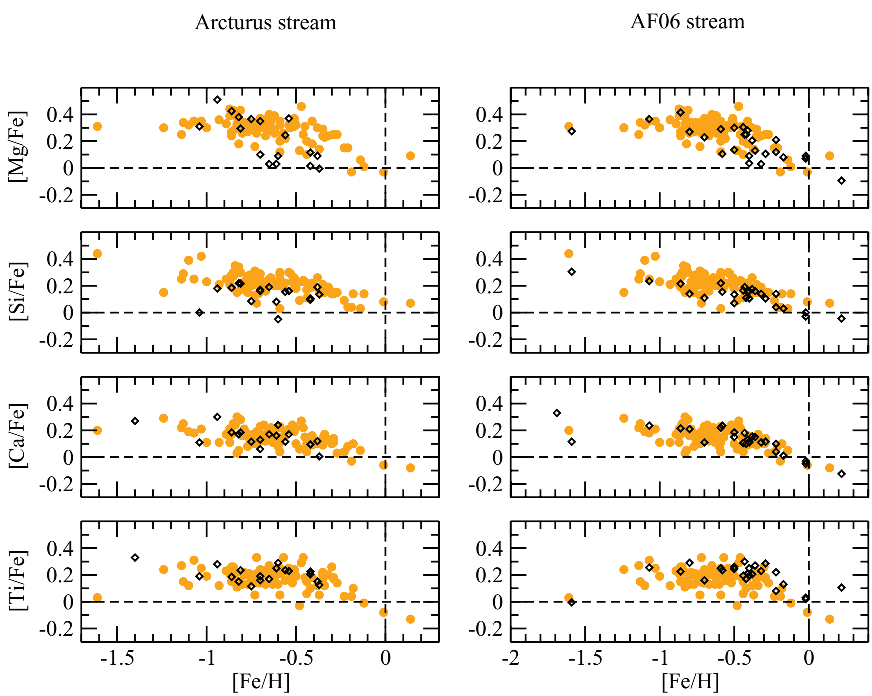

Figure 1. The abundance plots of α-elements (Mg, Si, Ca and Ti). Yellow circles represent field thick disc members from Reddy *et al.* (2006), and the Diamond symbols represent stream members of Arcturus in the left panel and AF06 in the right panel, respectively.

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isochrones taken from Demarque *et al.* (2004), show that the member stars of both the streams are old (10−14 Gyrs) similar to the thick disc component. Thus, the large metallicity range ([Fe/H]= −1.40 to −0.37 dex for Arcturus; [Fe/H] =−1.69 to +0.22 dex for AF06) rules out the possibility that these streams are vestiges of open clusters in the Galactic disc.

Now, we may pose a question whether the debris from the merging dwarf galaxies could form these streams. To understand this, we compared mean α-element abundance of streams with those of some of the known dwarf spheroidal galaxies (dSph) such as Draco, Sculptor, Sextans, Ursa Minor, Carina, Fornax and Leo I (see Fig 2). Data is taken from Venn *et al.* (2004). For Sgr dSph, data is taken from Monaco *et al.* (2005). None of the dSphs abundances compare with the abundance ratio of either of the streams or with thin or thick disc components. This may suggest that it is an unlikely scenario that debris from merging satellites might have formed these streams. Thus, the abundance results indicate insitu formation of streams due to local dynamical perturbations in the Galaxy, and Minchev *et al.* (2009) has shown that merging satellites can perturb the Galactic disc especially the thick disc to form high velocity streams such as Arcturus. More detailed discussions are given elsewhere (Ramya *et al.* 2012).

3. Hercules and Sirius

Member stars of the two streams were taken from Famaey *et al.* (2005) who re-identified these as kinematically coherent groups using maximum likelihood method based on Bayesian approach. Hercules stream is found to have mean kinematics of

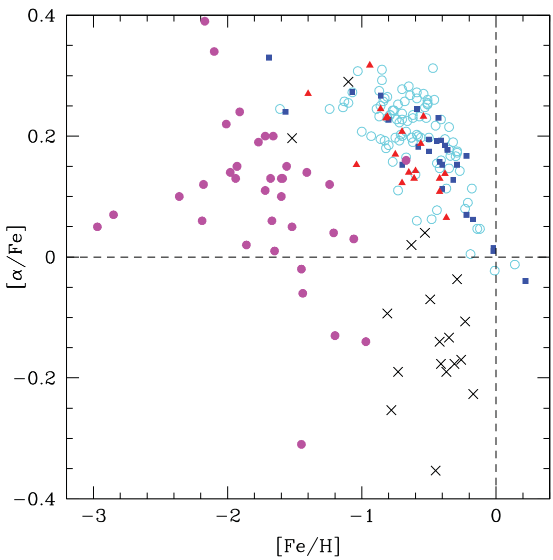

Figure 2. The [α/Fe] versus [Fe/H] plot. Red triangels: Arcturus stream, blue squares: AF06 stream, cyan open circles: thick disc, filled magenta circles: dSph satellite galaxies (see the text), black crosses: Sgr dSph galaxy.

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$U_0 = -42.13 \pm 1.95$, $V_0 = -51.64 \pm 1.07$, $W_0 = -8.06 \pm 1.30$ and Sirius stream of $U_0 = 6.53 \pm 1.93$, $V_0 = 3.96 \pm 0.67$, $W_0 = -5.80 \pm 1.15$. We chose 58 member stars for Hercules and 22 for Sirius streams and subjected them to high resolution spectroscopic studies.

Abundances of a few representative elements against [Fe/H] are shown in Fig 3 along with abundances of sample stars of Galactic thin and thick disc components taken from Bensby *et al.* (2005). Abundance trends seem to be quite similar to thin disc stars. Hercules member stars show mean [Fe/H] = $+0.15 \pm 0.14$ dex with metallicity ranging from -0.17 dex to $+0.43$ dex. On the other hand the 22 member stars of Sirius show relatively a narrow range in metallicity from [Fe/H] = -0.11 to $+0.21$ dex with mean [Fe/H] = $+0.09 \pm 0.1$ dex. Using isochrones we found member stars' ages ranging from 0.17 to 4.2 Gyrs for Hercules stream and less than 2 Gyrs for the Sirius stream. Abundance pattern, metallicity and ages appear to suggest that the member stars in fact came from the thin disc component. However, range in [Fe/H] and also in age for Hercules stream indicate these are unlikely to be members of a dispersed open cluster. Although, one may make the same conclusions about Sirius stream origin too, the narrow range in metallicity should be probed for the contribution of cluster remnants. One could also rule out the possibility of these being the remnants of merged satellites, as none of the surviving dwarf spheroidals in the local group is as metal rich as these streams. The most possible scenario to explain the abundance results is the insitu formation due to dynamical perturbations caused by bar and/or spirals. A more complete discussions with a few more stream results will be presented in our forthcoming article.

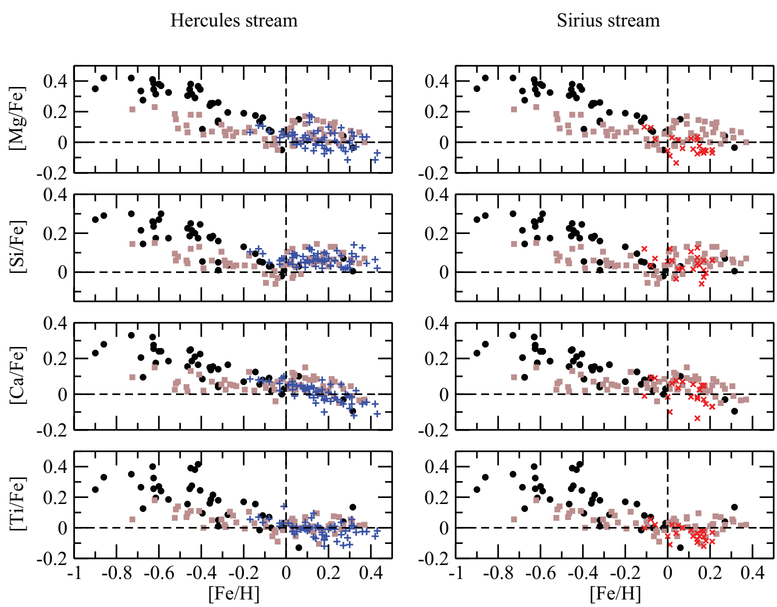

Figure 3. Abundance results of α-element of Hercules stream (blue plus, left panel) and Sirius stream (red crosses, right panel). Results are compared with field thick disc stars (black) and field thin disc stars (brown)

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References

Antoja, T., Valenzuela, O., Pichardo, B., Moreno, E., Figueras, F., & Fernández, D., 2009, ApJL, 700, L78

Arifyanto, M. I. & Fuchs, B., 2006, A&A, 449, 533

Bensby, T., Feltzing, S., Lundström, I., & Ilyin, I., 2005, A&A, 433, 185

Bensby, T., Oey, M. S., Feltzing, S., & Gustafsson, B., 2007, ApJL, 655, L89

Carney, B. W., Latham, D. W., Laird, J. B., & Aguilar, L. A., 1994, AJ, 107, 2240

de Silva, G. M., Freeman, K. C., Bland-Hawthorn, J., Asplund, M., Williams, M., & Holmberg, J., 2011, MNRAS, 415, 563

De Simone, R., Wu, X., & Tremaine, S., 2004, MNRAS, 350, 627

Dehnen, W., 2000, AJ, 119, 800

Demarque, P., Woo, J.-H., Kim, Y.-C., & Yi, S. K., 2004, ApJS, 155, 667

Eggen, O. J., 1958, MNRAS, 118, 154

Eggen, O. J., 1971, PASP, 83, 271

Eggen, O. J., 1996, AJ, 112, 1595

Famaey, B., Jorissen, A., Luri, X., Mayor, M., Udry, S., Dejonghe, H., & Turon, C., 2005, A&A, 430, 165

Gardner, E., Flynn, C., 2010, MNRAS, 405, 545

Fux, R., 2001, A&A, 373, 511

Høg, E., Fabricius, C., Makarov, V. V., Urban, S., Corbin, T., Wycoff, G., Bastian, U., Schwekendiek, P., & Wicenec, A., 2000, A&A, 355, L27

Kalnajs, A. J., 1991, in Sundelius, B., ed., Dynamics of Disc Galaxies Pattern Speeds of Density Waves. p. 323

Minchev, I., Quillen, A. C., Williams, M., Freeman, K. C., Nordhaus J., Siebert, A., & Bienaymé, O., 2009, MNRAS, 396, L56

Monaco, L., Bellazzini, M., Bonifacio, P., Ferraro, F. R., Marconi, G., Pancino, E., Sbordone, L., & Zaggia, S., 2005, A&A, 441, 141

Monari, G., Antoja, T., & Helmi, A., 2013, arXiv:1306.2632v1

Navarro, J. F., Helmi, A., & Freeman, K. C., 2004, ApJL, 601, L43

Pakhomov, Y. V., Antipova, L. I., & Boyarchuk, A. A., 2011, Astronomy Reports, 55, 256

Pompéia, L., Masseron, T., Famaey, B., van Eck, S., Jorissen, A., Minchev, I., Siebert, A., Sneden, C., Lépine, J. R. D., Siopis, C., Gentile, G., Dermine, T., Pasquato, E., van Winckel, H., Waelkens, C., Raskin, G., Prins, S., Pessemier, W., Hensberge, H., Frémat, Y., Dumortier, L., & Bienaymé, O., 2011, MNRAS, 415, 1138

Quillen, A. C., Minchev, I., 2005, AJ, 130, 576

Ramya, P., Reddy, B. E., & Lambert, D. L., 2012, MNRAS, 425, 3188

Reddy, B. E., Lambert, D. L., & Allende Prieto, C., 2006, MNRAS, 367, 1329

Reddy, B. E., Tomkin, J., Lambert, D. L., & Allende Prieto, C., 2003, MNRAS, 340, 304

Sneden C., 1973, PhD Thesis, Univ. of Texas, Austin

Tull, R. G., MacQueen, P. J., Sneden, C., & Lambert, D. L., 1995, PASP, 107, 251

Venn, K. A., Irwin, M., Shetrone, M. D., Tout, C. A., Hill, V., & Tolstoy, E., 2004, AJ, 128, 1177

Williams, M. E. K., Freeman, K. C., & Helmi, A., RAVE Collaboration 2009, in J. Andersen, J. Bland-Hawthorn, & B. Nordström, ed., IAU Symposium Vol. 254 of IAU Symposium, The Arcturus Moving Group: Its Place in the Galaxy. pp 139–144

Discussion

Teresa Antoja: What is the argument to which a bar can not induce moving groups with high rotational lag?

Ramaya Pozath: We are not sure whether the bar perturbations could cause streams that far and with such large velocity lag as it may require much higher force field. Yes, you

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may be right saying that there is no particular reason to believe that the bar/spirals can't induce such velocity lags. In fact, a couple of simulation studies showed that bar/spiral could produce streams like these in the thick disc as well (Antoja *et al.* 2009, Gardner *et al.* 2010, Monari *et al.* 2013).