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 in situ 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 $V = -125 \text{ km s}^{-1}$ and $\sqrt{U^2 + 2V^2} = 185 \text{ km s}^{-1}$ and at $V = -80 \text{ km s}^{-1}$ and $\sqrt{U^2 + 2V^2} = 130 \text{ km s}^{-1}$.

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 $\alpha$-element abundance trends are very similar to those of the thick disc abundance trends. Within the metallicity range of the respective streams, the $\alpha$-abundance ratios are indistinguishable from that of larger thick disc component. The derived ages, based on

![Figure 1](https://www.cambridge.org/core/core/terms). https://doi.org/10.1017/S1743921313006236

**Figure 1.** The abundance plots of $\alpha$-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.
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 $\alpha$-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 in situ 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 [$\alpha$/Fe] versus [Fe/H] plot. Red triangles: 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.](https://www.cambridge.org/core/terms).
U₀ = −42.13 ± 1.95, V₀ = −51.64 ± 1.07, W₀ = −8.06 ± 1.30 and Sirius stream of
U₀ = 6.53 ± 1.93, V₀ = 3.96 ± 0.67, W₀ = −5.80 ± 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. Hercule,
member stars show mean [Fe/H] = +0.15 ± 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 ± 0.1 dex. Using isochrones we found member stars’ ages ranging
from 0.17 to 4.2 Gyr for Hercules stream and less than 2 Gyr 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 satel-
lites, 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 in situ
formation due to dynamical perturbations caused by bar and/or spirals. A more com-
plete discussions with a few more stream results will be presented in our forthcoming
article.

![Figure 3](https://www.cambridge.org/core/terms)

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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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
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).