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Stellar streams in the Galactic thick disk: preliminary results

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Abstract. Here we report preliminary results of our study of chemical tagging of member stars of two Galactic stellar streams. Both the streams, kinematically belong to the thick disk component of the Galaxy. We analysed high resolution spectra of 42 member stars: 17 from Arcturus stream and 25 from "AF06 stream". The LTE (Local Thermodynamic Equilibrium) abundance analysis was performed differentially with respect to the sun. Abundance results suggest that both the streams are metal poor and enhanced in α-process elements (O, Mg, Si, Ca, Ti) very similar to the thick disk chemistry. Also, results suggest that the two streams probably did not originate by the dispersion of open clusters.

Keywords : stellar streams – Arcturus stream – AF06 stream – abundances

1. Introduction

Stellar streams are the group of gravitationally unbound stars having common kinematics. They are the collection of field stars visible as overdensities in the velocity space, i.e, the tight clumps of stars present in the velocity space over and above the large scale structure that the Schwarzschild distribution can reproduce. They are also called moving groups or dynamical streams.

The concept of moving groups was introduced much early (Eggen 1957) and were thought as dispersed cluster remnants retaining the original kinematics. This scenario was supported by the detailed abundance analysis of the HR1614 stream members (De Silva et al. 2007). Hyades-Pleiades, Arcturus, Sirius and Hercules are some other very prominent moving groups in the Galactic disk. The origin of the moving groups is not well understood. There is a number of suggestions ranging from evaporation of open

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clusters to the accretion of satellite galaxies. For example, some studies (Raboud et al. 1998; Dehnen 1999, 2000; Fux 2001) suggested that the Galactic bar could introduce dynamical perturbation and has important role in shaping the velocity distribution of stellar streams. Similarly, the resonances associated with the spiral arms in the Galaxy also could possibly be responsible for moving group formation, and Hyades stream was supposedly having this origin according to some studies (Pompéia et al. 2011). However, the detection of tidal streams in the Milky Way halo gave strong support to the argument that stellar halo was formed from accreted satellites (Helmi et al. 1999). Also, the disruption of satellite galaxies in orbits roughly coplanar with the disk of the Galaxy can form tidal streams even in the Galactic disk (Abadi et al. 2003; Helmi et al. 2003).

A multipronged effort is underway to understand the streams as they hold key to the galaxy formation scenarios. With the availability of accurate astrometry from the Hipparcos satellite (Perryman et al. 1997; van Leeuwen 2007), many studies re-identified streams originally identified by Eggen (Eggen 1996 and references therein) and in the process a few new streams have been identified (Zhao et al. 2009; Klement et al. 2008; Arifyanto et al. 2006). For example, Arifyanto & Fuchs (2006) undertook a search for fine structures in the phase space populated by subdwarfs in the large sample of F and G subdwarfs considered by Carney et al. (1994) for which they refined data on stellar distances and kinematics. Two clumps in phase space of thick disk stars were noted by them. One with $V = -125$ km s^{-1} and $\sqrt{U^2 + 2V^2} = 185$ km s^{-1} was referred to as the Arcturus stream. The second stream with a stronger presence in phase space than the Arcturus stream was at $V = -80$ km s^{-1} and $\sqrt{U^2 + 2V^2} = 130$ km s^{-1} which they called the "AF06 stream".

To understand the origin of the streams, it is important to tag each member of the stream chemically. Here, we report preliminary results of our high resolution spectroscopic study of the member stars of the two streams. Detailed analysis and discussion of different scenarios will be presented elsewhere.

2. Sample, observations and reductions

We chose 17 member stars from Arcturus stream and 25 stars from the AF06 stream. We chose only stars which are nearby and having spectral type F, G and K with high probability of belonging to the respective streams. Selected sample stars were observed with 2d Coude Echelle spectrometer (Tull et al. 1995) fitted to 2.7-m Harlan J Smith telescope at McDonald observatory, Fort Davis, Texas. All the observations were done during the period 2005–2007. The selected observational set-up provided spectral coverage from 4000Å to 10000Å with gaps between orders beyond 5800Å. Spectra were obtained with resolving power of about 60,000 and with S/N ≈ 200-500.

The spectroscopic two dimensional data were reduced to one dimensional flux versus wavelength using the Image Reduction and Analysis Facility (IRAF)[1]. The following steps were performed: raw data were subjected to overscan correction to remove bias and dark current, flat fielding was done to remove pixel to pixel variation. After removing scattered light using IRAF task "apscatter", images were extracted to one dimensional spectra of flux versus pixel. The extracted spectra were converted to flux versus wavelength using the calibration of Th-Ar spectrum obtained during the night. Finally the spectra were normalized to continuum so as to measure line strengths relative to continuum. Radial velocities were measured by cross-correlating numerous lines in the spectra and were used in recalculating kinematics of the sample stars.

3. Analysis

3.1 Stellar atmospheric parameters

Stellar atmospheric parameters: effective temperature $T_{\rm eff}$, surface gravity log g, microturbulent velocity ξ_t and metallicity [M/H] are essential to choose correct model atmosphere to represent the star's spectrum. The parameters were derived from the high resolution spectral analysis and LTE model atmosphere techniques. A set of Fe I and Fe II lines with a good range in lower excitation potential and of medium strength were chosen for deriving atmospheric parameters. Line list was compiled from three studies (Reddy et al., 2003; Aoki et al., 2002; Allende Prieto et al., 2002). For stellar model atmospheres, the Kurucz grids with convective overshoot, based on the ATLAS9 code were adopted (http://kurucz.harvard.edu/grids.html). Models of specific atmospheric parameters were interpolated. The spectral line analysis and synthesis code MOOG (2009 version, Sneden 1973) was used for the analysis.

$T_{\rm eff}$ was obtained by the method of excitation balance (Boltzmann equation) in which right temperature was the one for which abundances from Fe I lines were independent of excitation potentials. Care was taken to minimize the effect of microturbulence in the derivation of $T_{\rm eff}$ by using initially only very weak lines. Similarly, ξ_t was derived by plotting Fe I abundances against reduced equivalent widths ($\log_{10}(W_\lambda/\lambda)$, where W_λ is the measued equivalent width) for a given $T_{\rm eff}$ by demanding abundances were independent of the reduced equivalent widths. log g values were derived using Fe I and Fe II lines by demanding Fe I and Fe II lines gave the same abundance. The procedure was repeated several times until a self consistent set of parameters arrived. The spectroscopically derived $T_{\rm eff}$ and log g were checked with the values derived from photometric calibrations, and the values were in good agreement.

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Table 1. Solar photospheric abundances.

Species	Current study log ε	Current study σ	Current study N	Asplund et al. (2004) log ε	Asplund et al. (2004) σ	Current-Asplund	Reddy et al. (2006) log ε	Reddy et al. (2006) σ	Reddy et al. (2006) N
OI	8.90[a]	0.02	3	8.66	0.05	0.24	8.86[a]	0.05	3
NaI	6.29	0.00	2	6.17	0.04	0.12	6.27	—	2
MgI	7.59	0.05	3	7.53	0.09	0.06	7.54	0.06	3
AlI	6.29	0.07	5	6.37	0.06	−0.08	6.28	0.05	5
SiI	7.55	0.07	7	7.51	0.04	0.04	7.62	0.05	7
CaI	6.27	0.06	5	6.31	0.04	−0.04	6.33	0.07	5
ScII	3.12	0.08	2	3.05	0.08	0.07	3.24	0.14	3
TiI	4.87	0.05	10	4.90	0.06	−0.03	4.90	0.06	7
TiII	5.01	0.07	5	4.90	0.06	0.11	—	—	—
VI	3.88	0.02	4	4.00	0.02	−0.12	3.93	0.03	6
CrI	5.62	0.07	4	5.64	0.10	−0.02	5.68	0.07	4
CrII	5.59	0.00	1	5.64	0.10	−0.05	5.65	—	1
MnI	5.30	0.03	3	5.39	0.03	−0.09	5.37	0.05	3
FeI	7.41	0.04	49	7.45	0.05	−0.04	7.45	0.04	56
FeII	7.42	0.09	12	7.45	0.05	−0.03	7.45	0.07	9
CoI	4.86	0.08	3	4.92	0.08	−0.06	4.93	0.04	3
NiI	6.22	0.04	14	6.23	0.04	−0.01	6.23	0.04	18
Cu	4.26	0.04	3	4.21	0.04	0.05	4.19	0.05	3
ZnI	4.53	0.02	2	4.60	0.03	−0.07	4.47	—	2
YII	2.14	0.04	4	2.21	0.02	−0.07	2.12	0.04	4
BaII	2.20	0.09	3	2.17	0.07	0.03	2.20	0.10	3
CeII	1.54	0.04	3	1.58	0.09	−0.04	1.58	—	3
NdII	1.51	0.04	2	1.45	0.05	0.06	1.50	—	2
EuII	0.55	0.01	2	0.52	0.06	0.03	0.61	—	1

[a] Oxygen abundances not corrected for NLTE effects

3.2 Abundances

Abundance analysis was carried out using the procedures very similar to thick and thin disk studies by Reddy et al. (2006). Line list for about 21 elemental species was adopted from the above mentioned studies. Lines were well defined and mostly free of blends. In general, we used fine analysis (equivalent widths) for deriving abundances. In a few cases we used spectral synthesis, particularly for transitions that were known to have been affected by hyperfine splitting (HFS). We applied hyperfine corrections to Mn, V, Cu and Eu transitions. The hyperfine components and their relative log gf values were taken from Kurucz HFS database. The *blends* driver in MOOG was used to correct for HFS structure.

The derived abundances were accurate to within ± 0.1 to ± 0.15 dex in most cases. Significant amount of uncertainty comes from uncertainties in the derived atmospheric parameters. Uncertainties in the parameters were estimated using abundance trend sensitivity to the particular parameter. This procedure yielded the following uncertainties in the parameters: ± 100K, ± 0.2 cm s^{-2}, ± 0.25 km s^{-1} and ±

0.12 dex for T_{eff}, log g, ξ_t and [M/H] respectively. Another error in the abundances comes from the measured W_λs. For the quality of data that we have, and following the procedure for estimating the possible error in the measurements (Cayrel et al. 1988), we estimated an error of about ± 2mÅ in the W_λ measurements. Final error in the abundances were obtained by adding all the five uncertainties in quadrature.

As a first step in the abundance analysis procedure, and also to remove systematic errors, if any, in the analysis, we analysed solar spectrum. The solar spectrum was treated as one programme star spectrum and with the adopted line list, the solar atmospheric parameters were found out, as explained above. The obtained values of T_{eff}, log g, and ξ_t were 5757 ± 50 K, 4.40 ± 0.2 cm s^{-2} and 1.10 ± 0.2 km s^{-1} respectively. Using the Kurucz model atmosphere characterizing the above values, the elemental abundances in the solar photosphere were found out, and is listed in Table 1. The solar photospheric abundances from Asplund et al. (2004) and from Reddy et al. (2003) are listed in the table for comparison. All the three results seems to be in good agreement with each other, within the quoted uncertainties.

4. Results and discussions

Abundance analysis is carried out to understand the stream origins and to constrain theoretical modelling. From this study we aim to answer questions such as: what is the metallicity distribution of streams? Are they coeval? Are these streams a subset of larger thick disk component in the Galaxy? How do their chemical composition compare with thin disk, thick disk and open clusters? Answers to all or at least a few of them will help to uderstand these kinematically similar stellar aggregates in the Galaxy.

Abundances for a total of 21 elements starting from Oxygen to Europium were derived. Elements include iron group (Fe,Ni), α-process (Mg, Si, Ca, Ti), s-process (Ba, Nd), and r-process (Eu) elements. Each of these groups provide information about the site of nucleosynthesis and also the epoch of star formation. Elements like Fe and Ni mostly come from SNIa and represent metallicity of member stars. On the other hand α-process elements and Eu are known to be predominantly produced in SNII explosions which were frequent in the early epochs.

In Fig. 1, we have presented metallicity distribution for the two streams. Arcturus stream has [Fe/H] range: -1.04 - -0.37 dex. AF06 stream has [Fe/H] range: -1.59 - $+0.22$ dex, with a distribution peaking at [Fe/H] ~ -0.40 dex. There are a few stars with extreme metallicities and we need to ascertain their stream membership. Abundance trends with [Fe/H] for a few representative elements are shown in Fig. 2. Abundance ratios [X/Fe] ([X/Fe] = [X/H] - [Fe/H]) and their trends are compared with those of thick disk. Results in Fig. 2 suggest that chemistry of both streams is very similar to that of thick disk. Also, the large range in the metallicity distribution is not compatible with the metallicity distributions of existing open clusters which have

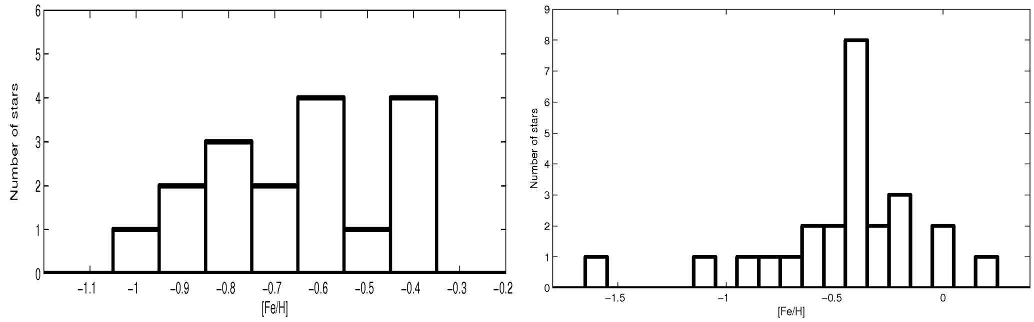

Figure 1. Metallicity distribution of Arcturus stream (left) and AF06 stream (right) members.

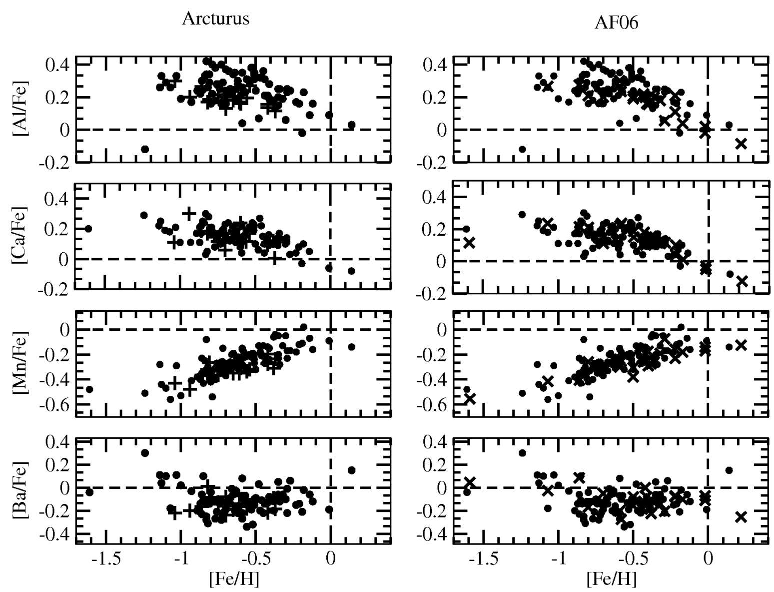

Figure 2. Abundance trends for representative elements for Arcturus stream (black pluses) and New Stream (black crosses). Brown circles correspond to thick disk sample of Reddy et al. (2006). The lines at [X/Fe] = 0 indicate the corresponding solar [X/Fe] ratios.

a small metallicity spread (σ[Fe/H]), roughly of about 0.05-0.20 dex, (Paunzen et al. 2010) implying that the two streams might not have been originated from the cluster dispersion. Other suggestions such as dynamical origin for the streams need to be explored. A full paper with detailed discussion has also been publisehd in MNRAS (2012).

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