A&A 541, A157 (2012)
DOI: 10.1051/0004-6361/201118760

Astronomy
&
Astrophysics

Stellar substructures in the solar neighbourhood

I. Kinematic group 3 in the Geneva-Copenhagen survey*

E. Stonkutė[1], G. Tautvaišienė[1], B. Nordström[2], and R. Ženovienė[1]

[1] Institute of Theoretical Physics and Astronomy (ITPA), Vilnius University, A. Gostauto 12, 01108 Vilnius, Lithuania
e-mail: `[edita.stonkute;grazina.tautvaisiene;renata.zenoviene]@tfai.vu.lt`
[2] Niels Bohr Institute, Copenhagen University, Juliane Maries Vej 30, 2100 Copenhagen, Denmark
e-mail: `birgitta@nbi.ku.dk`

Received 29 December 2011 / Accepted 8 March 2012

ABSTRACT

Context. Galactic archeology is a powerful tool for investigating the formation and evolution of the Milky Way. We use this technique to study kinematic groups of F- and G-stars in the solar neighbourhood. From correlations between orbital parameters, three new coherent groups of stars were recently identified and suggested to correspond to remnants of disrupted satellites.
Aims. We determine detailed elemental abundances in stars belonging to one of these groups and compare their chemical composition with Galactic disc stars. The aim is to look for possible chemical signatures that might give information about the history of this kinematic group of stars.
Methods. High-resolution spectra were obtained with the FIES spectrograph at the Nordic Optical Telescope, La Palma, and analysed with a differential model atmosphere method. Comparison stars were observed and analysed with the same method.
Results. The average value of [Fe/H] for the 20 stars investigated in this study is -0.69 ± 0.05 dex. Elemental abundances of oxygen and α-elements are overabundant in comparison with Galactic thin-disc dwarfs and thin-disc chemical evolution models. This abundance pattern has similar characteristics as the Galactic thick-disc.
Conclusions. The homogeneous chemical composition together with the kinematic properties and ages of stars in the investigated Group 3 of the Geneva-Copenhagen survey provides evidence of their common origin and possible relation to an ancient merging event. The similar chemical composition of stars in the investigated group and the thick-disc stars might suggest that their formation histories are linked.

Key words. stars: abundances – Galaxy: evolution – Galaxy: disk – Galaxy: formation

1. Introduction

The history of our home Galaxy is complex and not fully understood. Observations and theoretical simulations have made much progress and provided us with tools to search for past accretion events in the Milky Way and beyond. The well-known current events are the Sagittarius (Ibata et al. 1994), Canis Major (Martin et al. 2004) and Segue 2 (Belokurov et al. 2009) dwarf spheroidal galaxies, merging into the Galactic disc at various distances. The Monoceros stream (Yanny et al. 2003; Ibata et al. 2003) and the Orphan stream (Belokurov et al. 2006) according to some studies are interpreted as tidal debris from the Canis Major and Ursa Major II dwarf galaxies, respectively (see Peñarrubia et al. 2005; Fellhauer et al. 2007; and the review of Helmi 2008). Accreted substructures are found also in other galaxies, such as the Andromeda galaxy (Ibata et al. 2001; McConnachie et al. 2009), NGC 5907 (Martínez-Delgado et al. 2008), and NGC 4013 (Martínez-Delgado et al. 2009).

Helmi et al. (2006) have used a homogeneous data set of about 13.240 F- and G-type stars from the Nordström et al. (2004) catalogue, which has complete kinematic, metallicity, and age parameters, to search for signatures of past accretions in the Milky Way. From correlations between orbital parameters, such as apocentre (A), pericentre (P), and z-angular momentum (L_z), the so-called APL space, Helmi et al. identified three new coherent groups of stars and suggested that those might correspond to remains of disrupted satellites. In the U–V plane, the investigated stars are distributed in a banana-shape, whereas the disc stars define a centrally concentrated clump (Fig. 1). At the same time, in the U–W plane the investigated stars populate mostly the outskirts of the distributions. Both the U and W distributions are very symmetric. The investigated stars have a lower mean rotational velocity in comparison to the Milky Way disc stars, as we can see in the W–V plane. These characteristics are typical for stars associated with accreted satellite galaxies (Helmi 2008; Villalobos & Helmi 2009).

Stars in the identified groups cluster not only around regions of roughly constant eccentricity ($0.3 \leq \epsilon < 0.5$) and have distinct kinematics, but have also distinct metallicities [Fe/H] and age distributions. One of the parameters according to which the stars were divided into three groups was metallicity. Group 3, which we investigate in this work, is the most metal-deficient and consists of 68 stars. According to the Nordström et al. (2004) catalogue, its mean photometric metallicity, [Fe/H], is about -0.8 dex and the age is about 14 Gyr. Group 3 also differs from the other two groups by slightly different kinematics, particularly in the vertical (z) direction. Holmberg et al. (2009) updated and improved the parameters for the stars in the Nordström et al. (2004) catalogue and we use those values throughout.

In Fig. 1 we show the Galactic disc stars from Holmberg et al. (2009). Stars belonging to Group 3 in Helmi et al. are marked with open and filled circles (the latter are used to mark

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* Table 3 is available in electronic form at `http://www.aanda.org`

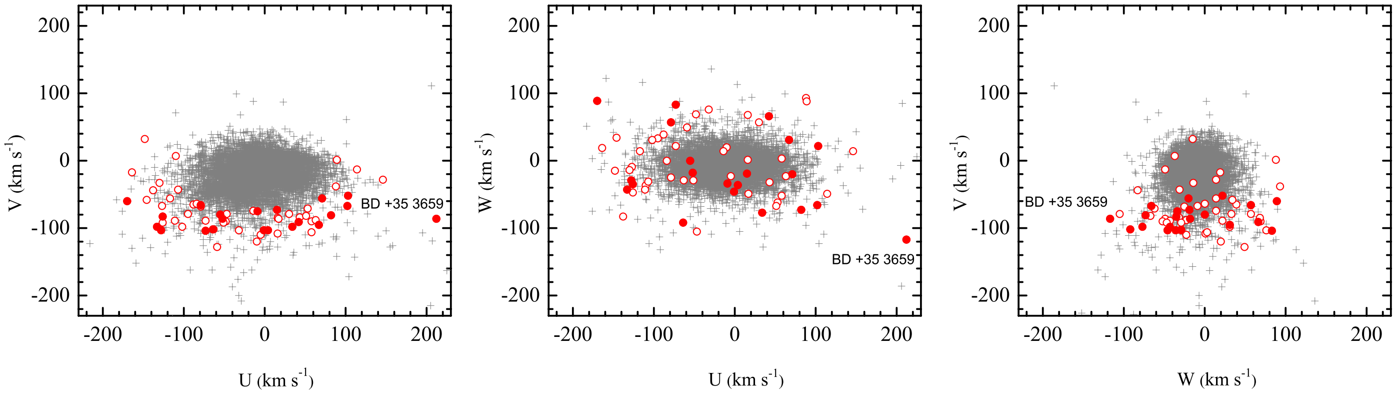

Fig. 1. Velocity distribution for all stars in the Holmberg et al. (2009) sample (plus signs), stars of Group 3 (circles) and the investigated stars (filled circles).

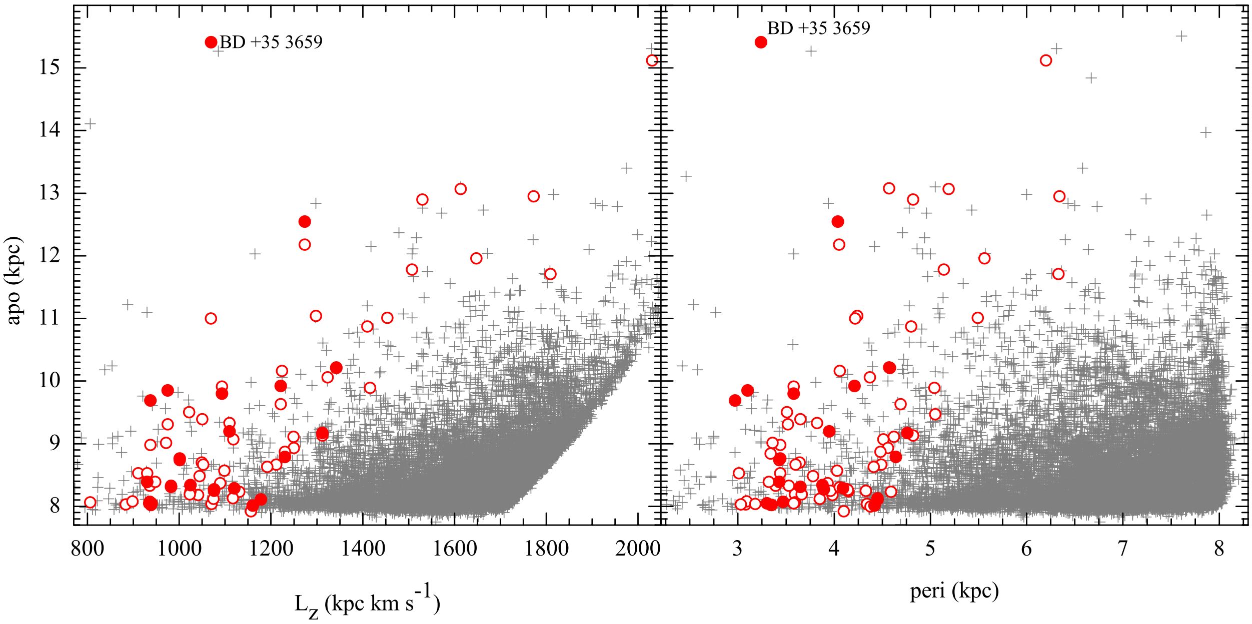

Fig. 2. Distribution for the stars in the APL space. Plus signs denote the Holmberg et al. (2009) sample, circles – Group 3, filled circles – investigated stars. Note that the investigated stars as well as all Group 3 stars are distributed in APL space with constant eccentricity.

stars investigated in our work). Evidently, stars belonging to Group 3 have a different distribution in the velocity space in comparison to other stars of the Galactic disc. In Fig. 2, the stars are shown in the APL space.

From high-resolution spectra we have measured abundances of iron group and α-elements in 21 stars belonging to Group 3 to check the homogeneity of their chemical composition and compare them with Galactic disc stars. The α-element-to-iron ratios are very sensitive indicators of galactic evolution (Pagel & Tautvaišienė 1995; Fuhrmann 1998; Reddy et al. 2006; Tautvaišienė et al. 2007; Tolstoy et al. 2009, and references therein). If stars have been formed in different environments they normally have different α-element-to-iron ratios for a given metallicity.

2. Observations and method of analysis

Spectra of high-resolving power ($R \approx 68\,000$) in the wavelength range of 3680–7270 Å were obtained at the Nordic Optical Telescope with the FIES spectrograph during July 2008. Twenty-one programme and six comparison stars (thin-disc dwarfs) were observed. A list of the observed stars and some of their parameters (taken from the Holmberg et al. 2009, catalogue and Simbad) are presented in Table 1.

All spectra were exposed to reach a signal-to-noise ratio higher than 100. Reductions of CCD images were made with the FIES pipeline FIEStool, which performs a complete reduction: calculation of reference frame, bias and scattering subtraction, flat-field dividing, wavelength calibration and other procedures (`http://www.not.iac.es/instruments/fies/fiestool`). Several examples of stellar spectra are presented in Fig. 3.

The spectra were analysed using a differential model atmosphere technique. The Eqwidth and Spectrum program packages, developed at the Uppsala Astronomical Observatory, were used to carry out the calculation of abundances from measured equivalent widths and synthetic spectra, respectively. A set of plane-parallel, line-blanketed, constant-flux LTE model atmospheres (Gustafsson et al. 2008) were taken from the marcs stellar model atmosphere and flux library (`http://marcs.astro.uu.se/`).

The Vienna Atomic Line Data Base (VALD, Piskunov et al. 1995) was extensively used in preparing input data for the

Table 1. Parameters of the programme and comparison stars.

Star	Sp. type	Age Gyr	M_V mag	d pc	U_{LSR} km s^{-1}	V_{LSR} km s^{-1}	W_{LSR} km s^{-1}	e	z_{max} kpc	R_{min} kpc	R_{max} kpc
HD 967	G5	9.9	5.23	43	–55	–80	0	0.34	0.12	4.09	8.29
HD 17820	G5	11.2	4.45	61	34	–98	–77	0.39	1.62	3.65	8.31
HD 107582	G2V	9.4	5.18	41	–1	–103	–46	0.41	0.76	3.35	8.02
BD +73 566	G0	...	5.14	67	–52	–86	–18	0.36	0.18	3.89	8.27
BD +19 2646	G0	...	5.53	74	103	–52	22	0.38	0.64	4.58	10.21
HD 114762	F9V	10.6	4.36	39	–79	–66	57	0.31	1.57	4.64	8.79
HD 117858	G0	11.7	4.02	61	71	–56	–20	0.32	0.21	4.76	9.17
BD +13 2698	F9V	14.2	4.52	93	102	–67	–66	0.40	1.60	4.21	9.92
BD +77 0521	G5	14.5	5.27	68	4	–103	–36	0.42	0.48	3.30	8.05
HD 126512	F9V	11.1	4.01	45	82	–81	–73	0.40	1.69	3.95	9.20
HD 131597	G0	...	3.06	119	–133	–98	–43	0.52	0.81	3.10	9.85
BD +67 925	F8	13	4.14	139	–128	–103	–29	0.53	0.43	2.97	9.69
HD 159482	G0V	10.9	4.82	52	–170	–60	89	0.51	3.67	4.04	12.55
HD 170737	G8III-IV	...	2.88	112	–64	–102	–92	0.40	2.61	3.47	8.07
BD +35 3659	F1	0.9	5.32	96	212	–86	–117	0.65	5.50	3.24	15.41
HD 201889	G1V	14.5	4.40	54	–126	–83	–35	0.46	0.56	3.58	9.80
HD 204521	G5	2.1	5.18	26	15	–73	–19	0.29	0.18	4.45	8.11
HD 204848	G0	...	1.98	122	42	–91	66	0.36	1.77	3.88	8.34
HD 212029	G0	13.1	4.66	59	67	–95	31	0.44	0.77	3.44	8.76
HD 222794	G2V	12.1	3.83	46	–73	–104	83	0.42	3.02	3.43	8.39
HD 224930	G5V	14.7	5.32	12	–9	–75	–34	0.29	0.44	4.42	8.01
HD 17548	F8	6.9	4.46	55	–14	31	32	0.15	0.88	8.02	10.85
HD 150177	F3V	5.7	3.33	40	–7	–23	–24	0.07	0.25	6.95	7.97
HD 159307	F8	5.2	3.33	65	–14	–21	0	0.06	0.11	7.00	7.95
HD 165908	F7V	6.8	4.09	16	–6	1	10	0.03	0.26	7.97	8.45
HD 174912	F8	6.1	4.73	31	–22	8	–43	0.07	0.69	7.90	9.10
HD 207978	F6IV-V	3.3	3.33	27	13	16	–7	0.11	0.00	7.81	9.68

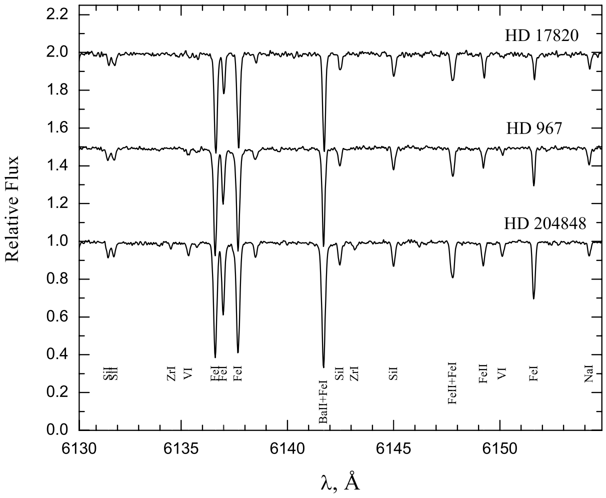

Fig. 3. Samples of stellar spectra of several programme stars. An offset of 0.5 in relative flux is applied for clarity.

calculations. Atomic oscillator strengths for the main spectral lines analysed in this study were taken from an inverse solar spectrum analysis performed in Kiev (Gurtovenko & Kostyk 1989). All lines used for calculations were carefully selected to avoid blending. All line profiles in all spectra were hand-checked, requiring that the line profiles be sufficiently clean to provide reliable equivalent widths. The equivalent widths of the lines were measured by fitting of a Gaussian profile using the 4A software package (Ilyin 2000).

Initial values of the effective temperatures for the programme stars were taken from Holmberg et al. (2009) and then carefully checked and corrected if needed by forcing Fe i lines to yield no dependency of iron abundance on excitation potential by changing the model effective temperature. For four stars our effective temperature is +100 to +200 K higher than in the catalogue. We used the ionization equilibrium method to find surface gravities of the programme stars by forcing neutral and ionized iron lines to yield the same iron abundances. Microturbulence velocity values corresponding to the minimal line-to-line Fe i abundance scattering were chosen as correct values.

Using the gf values and solar equivalent widths of analysed lines from Gurtovenko & Kostyk (1989) we obtained the solar abundances, used later for the differential determination of abundances in the programme stars. We used the solar model atmosphere from the set calculated in Uppsala with a microturbulent velocity of 0.8 km s^{-1}, as derived from Fe i lines.

In addition to thermal and microturbulent Doppler broadening of lines, atomic line broadening by radiation damping and van der Waals damping were considered in the calculation of abundances. Radiation damping parameters of lines were taken from the VALD database. In most cases the hydrogen pressure damping of metal lines was treated using the modern quantum mechanical calculations by Anstee & O'Mara (1995), Barklem & O'Mara (1997), and Barklem et al. (1998). When using the Unsöld (1955) approximation, correction factors to the classical van der Waals damping approximation by widths (Γ_6) were taken from Simmons & Blackwell (1982). For all other species a correction factor of 2.5 was applied to the classical Γ_6 ($\Delta \log C_6 = +1.0$), following Mäckle et al. (1975). For lines stronger than $W = 100$ mÅ the correction factors were selected individually by inspection of the solar spectrum.

The oxygen abundance was determined from the forbidden [O i] line at 6300.31 Å (Fig. 4). The oscillator strength values for ^{58}Ni and ^{60}Ni, which blend the oxygen line, were taken from

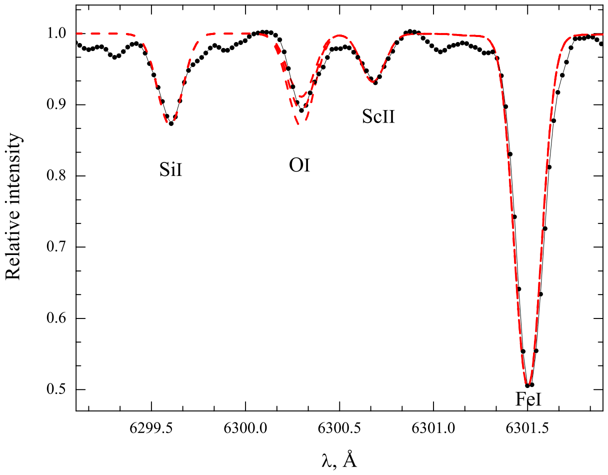

Fig. 4. Fit to the forbidden [O I] line at 6300.3 Å in the programme star HD 204848. The observed spectrum is shown as a solid line with black dots. The synthetic spectra with [O/Fe] = 0.52 ± 0.1 are shown as dashed lines.

Johansson et al. (2003). The [O I] log $gf = -9.917$ value was calibrated by fitting to the solar spectrum (Kurucz 2005) with log $A_\odot = 8.83$ taken from Grevesse & Sauval (2000). Stellar rotation was taken into account if needed with $v \sin i$ values from Holmberg et al. (2007). Abundances of oxygen was not determined for every star due to blending by telluric lines or weakness of the oxygen line profile.

Abundances of other chemical elements were determined using equivalent widths of their lines. Abundances of Na and Mg were determined with non-local thermodynamical equilibrium (NLTE) taken into account, as described by Gratton et al. (1999). The calculated corrections did not exceed 0.04 dex for Na I and 0.06 dex for Mg I lines. Abundances of sodium were determined from equivalent widths of the Na I lines at 5148.8, 5682.6, 6154.2, and 6160.8 Å; magnesium from the Mg I lines at 4730.0, 5711.1, 6318.7, and 6319.2 Å; and that of aluminum from the Al I lines at 6696.0, 6698.6, 7084.6, and 7362.2 Å.

2.1. Estimation of uncertainties

The uncertainties in abundances are due to several sources: uncertainties caused by analysis of individual lines, including random errors of atomic data and continuum placement and uncertainties in the stellar parameters. The sensitivity of the abundance estimates to changes in the atmospheric parameters by the assumed errors Δ[El/H] are illustrated for the star HD 224930 (Table 2). Clearly, possible parameter errors do not affect the abundances seriously; the element-to-iron ratios, which we use in our discussion, are even less sensitive.

The scatter of the deduced abundances from different spectral lines σ gives an estimate of the uncertainty due to the random errors. The mean value of σ is 0.05 dex, thus the uncertainties in the derived abundances that are the result of random errors amount to approximately this value.

3. Results and discussion

The atmospheric parameters $T_{\rm eff}$, log g, $v_{\rm t}$, [Fe/H] and abundances of 12 chemical elements relative to iron [El/Fe] of the programme and comparison stars are presented in Table 3. The number of lines and the line-to-line scatter (σ) are presented as well.

Table 2. Effects on derived abundances resulting from model changes for the star HD 224930.

Ion	$\Delta T_{\rm eff}$ −100 K	$\Delta \log g$ −0.3	$\Delta v_{\rm t}$ −0.3 km s^{-1}
[O I]	0.00	–0.10	–0.01
Na I	–0.06	0.01	0.00
Mg I	–0.04	0.01	0.01
Al I	–0.05	0.00	0.00
Si I	–0.01	–0.03	0.01
Ca I	–0.07	0.02	0.04
Sc II	–0.01	–0.13	0.02
Ti I	–0.10	0.01	0.03
Ti II	–0.01	–0.13	0.03
V I	–0.12	0.00	0.00
Cr I	–0.09	0.01	0.05
Fe I	–0.08	0.00	0.05
Fe II	0.04	–0.13	0.04
Co I	–0.07	–0.02	0.01
Ni I	–0.05	–0.01	0.04

Table 4. Group 3 comparison with previous studies.

	Ours-Nissen		Ours-Reddy		Ours-Ramírez	
Quantity	Diff.	σ	Diff.	σ	Diff.	σ
$T_{\rm eff}$	34	54	86	33	47	45
log g	–0.26	0.16	–0.28	0.15	–0.27	0.14
[Fe/H]	0.03	0.04	0.06	0.07	0.10	0.04
[Na/Fe]	0.02	0.11	0.00	0.04	...	...
[Mg/Fe]	–0.02	0.05	0.02	0.01	...	...
[Al/Fe]	...	...	–0.01	0.07	...	...
[Si/Fe]	–0.05	0.01	0.03	0.05	...	...
[Ca/Fe]	0.00	0.01	0.08	0.05	...	...
[Sc/Fe]	...	...	–0.01	0.05	...	...
[Ti/Fe]	0.06	0.10	0.07	0.06	...	...
[V/Fe]	...	...	–0.01	0.03	...	...
[Cr/Fe]	0.02	0.06	0.08	0.04	...	...
[Co/Fe]	...	...	–0.04	0.03	...	...
[Ni/Fe]	0.01	0.05	–0.01	0.04	...	...

Notes. Mean differences and standard deviations of the main parameters and abundance ratios [El/Fe] for 4 stars of Group 3 that are in common with Nissen & Schuster (2010), 7 stars in common with Reddy et al. (2006), and 10 stars in common with Ramírez et al. (2007).

3.1. Comparison with previous studies

Some stars from our sample have been previously investigated by other authors. In Table 4 we present a comparison with the results by Nissen & Schuster (2010), Reddy et al. (2006), and with Ramírez et al. (2007). Ramírez et al. determined only the main atmospheric parameters. The thin-disc stars we have investigated in our work for a comparison have been analysed previously by Edvardsson et al. (1993) and by Thévenin & Idiart (1999). In Table 5 we present a comparison with the results obtained by these authors. Our [El/Fe] for the stars in common agree very well with other studies. Slight differences in the log g values lie within errors of uncertainties and are caused mainly by differences in determination methods applied. In our work we see that titanium abundances determined using Ti I and Ti II lines agree well and confirm the log g values determined using iron lines.

Effective temperatures for all stars investigated here are also available in Holmberg et al. (2009) and Casagrande et al. (2011). Casagrande et al. provide astrophysical parameters for the Geneva-Copenhagen survey by applying the infrared flux method for the effective temperature determination. In

Table 5. Thin-disc stars comparison with previous studies.

	Ours-Edvardsson		Ours-Thévenin	
Quantity	Diff.	σ	Diff.	σ
$T_{\rm eff}$	86	66	87	68
$\log g$	–0.18	0.21	–0.06	0.14
[Fe/H]	0.10	0.04	0.03	0.03
[Na/Fe]	–0.08	0.09	...	...
[Mg/Fe]	–0.02	0.07	...	...
[Al/Fe]	–0.10	0.07	...	...
[Si/Fe]	–0.02	0.02	...	...
[Ca/Fe]	0.05	0.03	...	...
[Ti/Fe]	–0.02	0.08	...	...
[Ni/Fe]	–0.06	0.06	...	...

Notes. Mean differences and standard deviations of the main parameters and abundance ratios [El/Fe] for 6 thin-disc stars that are in common with Edvardsson et al. (1993) and 5 stars with Thévenin & Idiart (1999).

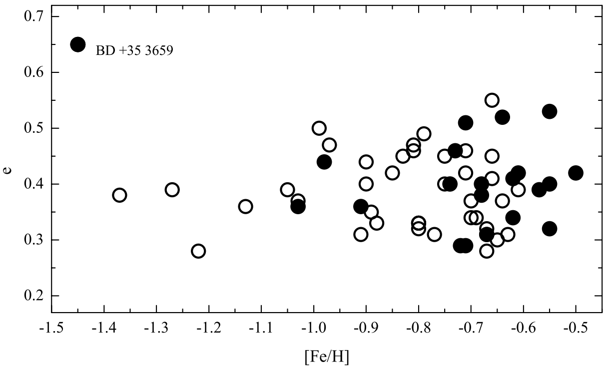

Fig. 5. Diagram of orbital eccentricity e vs. [Fe/H] for all stars of Group 3 (circles) and those investigated in this work (filled circles).

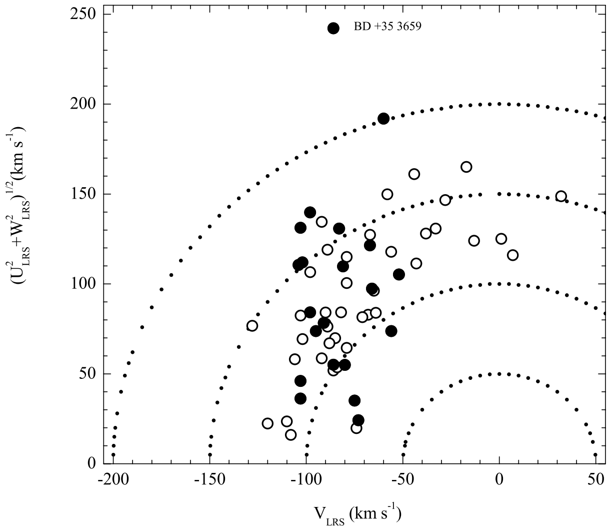

Fig. 6. Toomre diagram of all stars of Group 3 (circles) and those investigated in this work (filled circles). Dotted lines indicate constant values of total space velocity in steps of 50 km s^{-1}.

comparison to Holmberg et al., stars in the Casagrande et al. catalogue are on average 100 K hotter. For the stars investigated here, our spectroscopic temperatures are on average 40 ± 70 K hotter than in Holmberg et al. and 60 ± 80 K cooler than in Casagrande et al. (BD +35 3659, which has a difference of 340 K, was excluded from the average).

[Fe/H] values for all investigated stars are available in Holmberg et al. (2009) as well as in Casagrande et al. (2011). A comparison between Holmberg et al. and Casagrande et al. shows that the latter gives [Fe/H] values that are on average by 0.1 dex more metal-rich. For our programme stars we obtain a difference of 0.1 ± 0.1 dex in comparison with Holmberg et al., and no systematic difference but a scatter of 0.1 dex in comparison with Casagrande et al.

3.2. Comparison with the thin-and thick-disc dwarfs

The metallicities and ages of all programme stars except one (BD +35 3659) are quite homogeneous: [Fe/H] $= -0.69 \pm 0.05$ dex and the average age is about 12 ± 2 Gyr. However, the ages, which we took from Holmberg et al. (2009), were not determined for every star. BD +35 3659 is much younger (0.9 Gyr), has [Fe/H] $= -1.45$, its eccentricity, velocities, distance, and other parameters differ as well (see Figs. 5 and 6). We doubt its membership of Group 3.

The next step was to compare the determined abundances with those in the thin-disc dwarfs. In Fig. 7 we present these comparisons with data taken from Edvardsson et al. (1993), Bensby et al. (2005), Reddy et al. (2006), Zhang & Zhao (2006), and with the chemical evolution model by Pagel & Tautvaišienė (1995). The thin-disc stars from Edvardsson et al. and Zhang & Zhao were selected by using the membership probability evaluation method described by Trevisan et al. (2011), since their lists contained stars of other Galactic components as well. The same kinematical approach in assigning thin-disc membership was used in Bensby et al. (2005) and Reddy et al. (2006), so the thin-disc stars used for the comparison are uniform in that respect.

In Fig. 7 we see that the abundances of α-elements in the investigated stars are overabundant compared with the Galactic thin-disc dwarfs. A similar overabundance of α-elements is exhibited by the thick-disc stars (Fuhrmann 1998; Prochaska et al. 2000; Tautvaišienė et al. 2001; Bensby et al. 2005; Reddy & Lambert 2008, and references therein). Helmi et al. (2006), based on the isochrone fitting, have suggested that stars in the identified kinematic groups might be α-rich. Our spectroscopic results qualitatively agree with this. However, based on metallicities and vertical velocities, Group 3 cannot be uniquely associated to a single traditional Galactic component (Helmi et al. 2006).

What does the similarity of α-element abundances in the thick-disc and the investigated kinematic group mean? It would be easier to answer this question if the origin of the thick disc of the Galaxy was known (see van der Kruit & Freeman 2011, for a review).

There are several competing models that aim to explain the nature of a thick disc. Stars may have appeared at the thick disc through (1) orbital migration because of heating of a pre-existing thin disc by a varying gravitational potential in the thin disc (e.g. Roškar et al. 2008; Schönrich & Binney 2009); (2) heating of a pre-existing thin disc by minor mergers (e.g. Kazantzidis et al. 2008; Villalobos & Helmi 2008, 2009); (3) accretion of disrupted satellites (e.g. Abadi et al. 2003); or (4) gas-rich satellite mergers when thick-disc stars form before the gas completely settles into a thin-disc (see Brook et al. 2004, 2005).

Dierickx et al. (2010) analysed the eccentricity distribution of thick-disc stars that has recently been proposed as a diagnostic to differentiate between these mechanisms (Sales et al. 2009). Using SDSS data release 7, they have assembled a sample

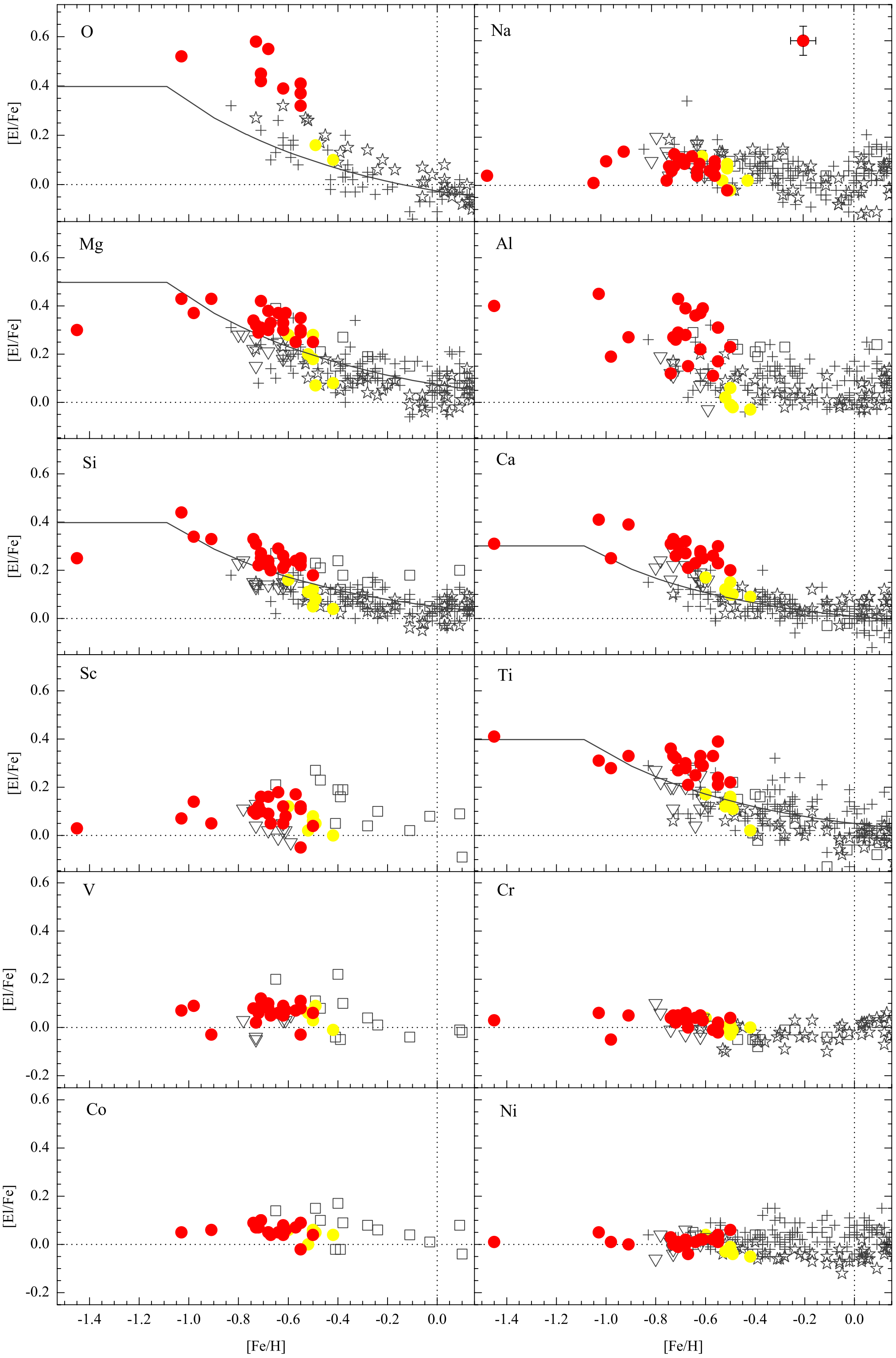

Fig. 7. Comparison of elemental abundance ratios of stars in the investigated stellar group (red black points) and data for Milky Way thin-disc dwarfs from Edvardsson et al. (1993, plus signs), Bensby et al. (2005, stars), Reddy et al. (2006, squares), Zhang & Zhao (2006, triangles), and Galactic thin disc chemical evolution models by Pagel & Tautvaišienė (1995, solid lines). Results obtained for thin-disc dwarfs analysed in our work are shown by yellow circles. Average uncertainties are shown in the box for Na.

of 31.535 G-dwarfs with six-dimensional phase-space information and metallicities and have derived their orbital eccentricities. They found that the observed eccentricity distribution is inconsistent with that predicted by orbital migration only. Also, the thick disc cannot be produced predominantly through heating of a pre-existing thin disc, since this model predicts more high-eccentricity stars than observed. According to Dierickx et al., the observed eccentricity distribution fits well with a gas-rich merger scenario, where most thick-disc stars were born in situ. In the gas-rich satellite merger scenario, a distribution of stellar eccentricities peak around $e = 0.25$, with a tail towards higher values belonging mostly to stars originally formed in satellite galaxies. The group of stars investigated in our work fits this model with a mean eccentricity value of 0.4. This scenario is also supported by the RAVE survey data analysis made by Wilson et al. (2011) and the numerical simulations by Di Matteo et al. (2011). In this scenario, Group 3 can be explained as a remnant from stars originally formed in a merging satellite.

4. Conclusions

We measured abundances of iron group and α-elements from high-resolution spectra in 21 stars belonging to Group 3 of the Geneva-Copenhagen survey. This kinematically identified group of stars was suspected to be a remnant of a disrupted satellite galaxy. Our main goal was to investigate the chemical composition of the stars within the group and to compare them with Galactic disc stars.

Our study shows that

1. All stars in Group 3 except one have a similar metallicity. The average [Fe/H] value of the 20 stars is -0.69 ± 0.05 dex.
2. All programme stars are overabundant in oxygen and α-elements compared with Galactic thin-disc dwarfs and the Galactic evolution model used. This abundance pattern has similar characteristics as the Galactic thick disc.

The homogeneous chemical composition together with the kinematic properties and ages of stars in the investigated Group 3 of the Geneva-Copenhagen survey support the scenario of an ancient merging event. The similar chemical composition of stars in Group 3 and the thick-disc stars might suggest that their formation histories are linked. The kinematic properties of our stellar group fit well with a gas-rich satellite merger scenario (Brook et al. 2004, 2005; Dierickx et al. 2010; Wilson et al. 2011; Di Matteo et al. 2011, and references therein).

We plan to increase the number of stars and chemical elements investigated in this group, and also to study the chemical composition of stars in other kinematic groups of the Geneva-Copenhagen survey. The identification of such kinematic groups and the exploration of their chemical composition will be a key in understanding the formation and evolution of the Galaxy.

Acknowledgements. The data are based on observations made with the Nordic Optical Telescope, operated on the island of La Palma jointly by Denmark, Finland, Iceland, Norway, and Sweden, in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement number RG226604 (OPTICON). B.N. acknowledges support from the Danish Research council. This research has made use of Simbad, VALD and NASA ADS databases. We thank the anonymous referee for insightful questions and comments.

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Table 3. Main atmospheric parameters and elemental abundances of the programme and comparison stars.

Star	$T_{\rm eff}$ K	log g	$v_{\rm t}$ km s^{-1}	[Fe/H]	$\sigma_{\rm FeI}$	$n_{\rm FeI}$	$\sigma_{\rm FeII}$	$n_{\rm FeII}$	[O/Fe]	[Na/Fe]	σ	n	[Mg/Fe]	σ	n
HD 967	5570	4.3	0.9	–0.62	0.05	38	0.04	7	...	0.04	0.03	3	0.33	0.04	4
HD 17820	5900	4.2	1.0	–0.57	0.05	29	0.01	6	...	0.06	0.04	3	0.25	0.06	3
HD 107582	5600	4.2	1.0	–0.62	0.05	32	0.07	5	0.39	0.06	0.04	4	0.30	0.04	3
BD +73 566	5580	3.9	0.9	–0.91	0.05	31	0.02	6	...	0.14	0.03	2	0.43	0.05	3
BD +19 2646	5510	4.1	0.9	–0.68	0.04	31	0.04	5	0.55	0.10	0.08	3	0.38	0.06	4
HD 114762	5870	3.8	1.0	–0.67	0.05	32	0.03	7	...	0.09	0.03	3	0.33	0.05	4
HD 117858	5740	3.8	1.2	–0.55	0.04	34	0.03	6	0.32	0.08	0.02	3	0.29	0.04	3
BD +13 2698	5700	4.0	1.0	–0.74	0.06	28	0.05	5	...	0.02	0.02	2	0.34	0.05	4
BD +77 0521	5500	4.0	1.1	–0.50	0.07	24	0.05	5	...	–0.02	...	1	0.25	0.04	4
HD 126512	5780	3.9	1.1	–0.55	0.05	27	0.03	6	0.41	0.10	0.02	3	0.30	0.07	3
HD 131597	5180	3.5	1.1	–0.64	0.04	32	0.03	6	...	0.12	0.01	4	0.37	0.05	4
BD +67 925	5720	3.5	1.2	–0.55	0.05	24	0.03	6	0.37	0.04	0.02	2	0.35	0.06	3
HD 159482	5730	4.1	1.0	–0.71	0.05	26	0.01	5	0.42	0.13	0.05	4	0.31	0.03	4
HD 170737	5100	3.3	1.0	–0.68	0.04	29	0.05	6	...	0.11	0.02	4	0.30	0.07	3
BD +35 3659[a]	5850	3.9	0.9	–1.45	0.04	25	0.04	4	...	0.04	0.05	3	0.30	0.06	3
HD 201889	5700	3.8	0.9	–0.73	0.05	30	0.03	4	0.58	0.08	0.04	3	0.32	0.03	4
HD 204521	5680	4.3	1.0	–0.72	0.05	30	0.05	5	...	0.06	0.02	3	0.29	0.04	3
HD 204848	4900	2.3	1.2	–1.03	0.04	31	0.05	7	0.52	0.01	0.04	3	0.43	0.03	4
HD 212029	5830	4.2	0.9	–0.98	0.02	20	0.01	2	...	0.10	0.04	3	0.37	0.07	4
HD 222794	5560	3.7	1.1	–0.61	0.04	30	0.05	6	...	0.09	0.05	4	0.37	0.07	4
HD 224930	5470	4.2	0.9	–0.71	0.05	35	0.05	6	0.45	0.08	0.04	3	0.42	0.04	4
HD 17548	6030	4.1	1.0	–0.49	0.05	32	0.03	7	0.16	–0.02	0.04	3	0.07	0.06	4
HD 150177	6300	4.0	1.5	–0.50	0.04	23	0.05	4	...	0.07	0.02	3	0.18	0.04	3
HD 159307	6400	4.0	1.6	–0.60	0.04	17	0.04	4	...	0.12	0.07	3	0.28	0.03	4
HD 165908	6050	3.9	1.1	–0.52	0.04	24	0.03	7	...	0.02	0.02	3	0.20	0.07	4
HD 174912	5860	4.1	0.8	–0.42	0.04	33	0.04	6	0.10	0.02	0.01	3	0.08	0.05	4
HD 207978	6450	3.9	1.6	–0.50	0.04	22	0.04	7	...	0.09	0.05	3	0.28	0.06	4

Star	[Al/Fe]	σ	n	[Si/Fe]	σ	n	[Ca/Fe]	σ	n	[Sc/Fe]	σ	n	[Ti I/Fe]	σ	n
HD 967	0.37	0.00	3	0.26	0.05	17	0.28	0.04	8	0.12	0.04	9	0.33	0.06	14
HD 17820	0.11	0.05	3	0.24	0.04	16	0.26	0.06	9	0.17	0.04	9	0.33	0.05	9
HD 107582	0.22	0.05	3	0.21	0.05	16	0.27	0.06	5	0.05	0.05	8	0.30	0.05	7
BD +73 566	0.27	0.04	2	0.33	0.06	18	0.39	0.06	6	0.05	0.05	7	0.33	0.05	9
BD +19 2646	0.28	0.08	2	0.22	0.06	16	0.32	0.06	8	0.09	0.04	8	0.28	0.04	9
HD 114762	0.15	0.02	2	0.20	0.05	17	0.21	0.05	7	0.05	0.05	10	0.21	0.03	8
HD 117858	0.31	0.06	3	0.24	0.05	17	0.23	0.04	8	0.12	0.02	9	0.24	0.03	9
BD +13 2698	0.12	0.05	2	0.33	0.06	14	0.31	0.05	8	0.10	0.04	7	0.36	0.05	8
BD +77 0521	0.23	0.01	2	0.18	0.07	10	0.20	0.06	6	0.04	0.03	4	0.22	0.05	6
HD 126512	0.17	0.06	2	0.25	0.05	16	0.23	0.04	6	0.11	0.02	8	0.21	0.04	7
HD 131597	0.36	0.04	2	0.29	0.05	16	0.25	0.04	8	0.18	0.02	10	0.25	0.06	16
BD +67 925	0.31	0.00	2	0.22	0.08	17	0.30	0.06	8	–0.05	0.05	4	0.39	0.03	3
HD 159482	0.29	0.04	2	0.27	0.06	15	0.31	0.06	7	0.16	0.03	8	0.27	0.02	4
HD 170737	0.39	...	1	0.24	0.04	15	0.27	0.06	7	0.16	0.02	8	0.30	0.06	12
BD +35 3659	0.40	0.01	2	0.25	0.03	8	0.31	0.08	4	0.03	0.11	7	0.41	0.02	4
HD 201889	0.27	0.01	3	0.31	0.05	15	0.33	0.08	6	0.09	0.03	9	0.33	0.05	9
HD 204521	0.26	0.02	2	0.22	0.05	17	0.26	0.06	8	0.12	0.03	7	0.32	0.05	9
HD 204848	0.45	0.05	3	0.44	0.05	16	0.41	0.05	8	0.07	0.03	11	0.31	0.07	18
HD 212029	0.19	0.05	2	0.34	0.05	11	0.25	0.03	6	0.14	0.02	5	0.28	0.06	5
HD 222794	0.39	0.04	3	0.23	0.05	16	0.25	0.04	7	0.08	0.04	8	0.29	0.04	11
HD 224930	0.43	0.08	3	0.25	0.05	16	0.30	0.04	5	0.10	0.03	11	0.27	0.04	9
HD 17548	–0.02	0.01	2	0.08	0.05	17	0.10	0.04	7	0.05	0.04	10	0.11	0.06	7
HD 150177	0.06	0.04	2	0.05	0.06	12	0.10	0.03	5	0.08	0.03	7	0.15	0.05	3
HD 159307	...	...	...	0.16	0.02	9	0.17	0.04	5	0.12	0.06	7	0.17	0.07	3
HD 165908	0.02	0.02	2	0.11	0.05	15	0.12	0.05	6	0.02	0.04	7	0.12	0.04	6
HD 174912	–0.03	0.04	2	0.04	0.04	17	0.09	0.05	6	0.00	0.04	12	0.02	0.05	9
HD 207978	–0.01	0.02	2	0.12	0.04	15	0.15	0.03	7	0.06	0.02	6	0.16	0.06	3

Star	[Ti II/Fe]	σ	n	[V/Fe]	σ	n	[Cr/Fe]	σ	n	[Co/Fe]	σ	n	[Ni/Fe]	σ	n
HD 967	0.30	0.09	2	0.09	0.05	11	0.05	0.08	17	0.08	0.04	5	0.02	0.07	26
HD 17820	0.30	0.01	3	0.07	0.04	5	–0.01	0.08	14	0.07	0.01	3	0.02	0.04	22
HD 107582	0.27	0.06	2	0.05	0.03	10	0.05	0.06	14	0.04	0.05	9	0.02	0.06	16
BD +73 566	0.35	0.06	3	–0.03	0.04	6	0.05	0.05	11	0.06	0.04	3	0.00	0.05	17
BD +19 2646	0.21	0.04	3	0.10	0.04	8	0.06	0.10	15	0.05	0.06	7	0.00	0.05	18
HD 114762	0.21	0.05	3	0.05	0.05	4	0.00	0.08	11	0.04	0.05	5	–0.04	0.04	16
HD 117858	0.20	0.03	3	0.11	0.03	8	0.01	0.05	16	0.09	0.04	6	0.02	0.05	24
BD +13 2698	0.33	0.05	3	0.08	0.03	7	0.04	0.06	14	0.09	0.03	4	0.03	0.06	19
BD +77 0521	0.17	0.03	2	0.06	0.02	3	0.04	0.10	11	0.04	0.02	2	0.06	0.06	13

Table 3. continued.

Star	[Ti II/Fe]	σ	n	[V/Fe]	σ	n	[Cr/Fe]	σ	n	[Co/Fe]	σ	n	[Ni/Fe]	σ	n
HD 126512	0.29	0.02	2	0.08	0.03	7	0.02	0.06	14	0.09	0.04	5	0.01	0.05	17
HD 131597	0.30	0.03	3	0.06	0.06	11	0.04	0.07	16	0.05	0.06	10	0.01	0.05	25
BD +67 925	0.43	...	1	–0.03	0.08	4	–0.02	0.12	13	–0.02	0.01	2	0.04	0.06	14
HD 159482	0.23	0.01	3	0.09	0.03	7	0.05	0.06	13	0.10	0.04	4	0.01	0.05	15
HD 170737	0.28	0.06	4	0.08	0.05	8	0.03	0.09	16	0.05	0.04	6	0.02	0.07	23
BD +35 3659	0.24	...	1	...	...	...	0.03	0.11	12	...	...	...	0.01	0.08	7
HD 201889	0.33	0.05	3	0.02	0.08	4	0.05	0.06	12	0.07	0.03	6	0.00	0.05	17
HD 204521	0.29	0.04	3	0.06	0.05	7	0.02	0.06	13	0.07	0.05	6	0.00	0.05	18
HD 204848	0.26	0.07	3	0.07	0.03	13	0.06	0.09	17	0.05	0.03	10	0.05	0.06	25
HD 212029	0.36	0.03	2	0.09	0.05	4	–0.05	0.06	12	...	...	...	0.01	0.06	11
HD 222794	0.27	0.04	3	0.07	0.05	10	0.03	0.07	16	0.06	0.03	8	0.02	0.06	18
HD 224930	0.22	0.03	2	0.12	0.03	6	0.05	0.08	14	0.10	0.04	7	–0.01	0.06	21
HD 17548	0.08	0.03	3	0.09	0.04	4	–0.01	0.05	13	0.05	0.03	3	–0.04	0.05	20
HD 150177	0.23	0.05	2	0.03	...	1	–0.03	0.07	14	0.06	0.00	2	–0.02	0.06	12
HD 159307	0.18	0.05	2	...	...	...	0.04	0.05	9	0.06	...	1	0.04	0.02	10
HD 165908	0.07	0.03	3	0.06	0.03	4	0.00	0.04	10	0.00	0.08	5	–0.03	0.06	15
HD 174912	0.00	0.03	3	–0.01	0.05	5	0.00	0.08	14	0.04	0.00	4	–0.05	0.05	21
HD 207978	0.07	0.06	3	...	...	...	0.01	0.07	11	0.05	0.06	5	–0.01	0.05	15

Notes. [a] Probably not a member of Group 3.