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Spectroscopic hint of a cold stream in the direction of the globular cluster NGC 1851*

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ABSTRACT

We present the results of a spectroscopic survey performed in the outskirts of the globular cluster NGC1851 with VIMOS@VLT. The radial velocities of 107 stars in a region between 12′ and 33′ around the cluster have been derived. We clearly identify the cluster stellar population over the entire field of view, indicating the presence of a significant fraction of stars outside the tidal radius predicted by King models. We also find tentative evidence of a cold ($\sigma_v \leqslant 20\ km\ s^{-1}$) peak in the distribution of velocities at $v_r \sim 180\ km\ s^{-1}$ constituted mainly by Main Sequence stars whose location in the color-magnitude diagram is compatible with a stream at a similar distance of this cluster. If confirmed, this evidence would strongly support the extra-Galactic origin of this feature.

Key words: methods: data analysis – methods: observational – techniques: radial velocities – Galaxy: halo – globular clusters: individual: NGC1851 – Galaxy: stellar content.

1 INTRODUCTION

According to the most widely accepted scenario of Galaxy formation many globular clusters (GCs) populating the halo of the Milky Way formed in satellite galaxies accreted in the past by our Galaxy (Searle & Zinn 1978). Such a hypothesis, originally suggested by the lack of an abundance gradient in the GCs at Galactocentric distances > 8 kpc, is also supported by many pieces of circumstantial evidence: the presence of an age-metallicity relation among the "young" clusters at large distances from the Galactic center (Marín-Franch et al. 2009), their peculiar kinematical properties (large, energetic orbits of high eccentricity), larger core radii and higher specific frequency of RR Lyrae stars (Mackey & Gilmore 2004). The fundamental concept of this picture is also consistent with theoretical ideas of the hierarchical formation of structures on galactic scales (White & Rees 1978) and it should therefore hold in other massive galaxies. The evidence of a clear correlation between the large coherent streams in the outer halo of M31 and the position of its GCs seems to confirm this picture (Mackey et al. 2010). In the typical event of late accretion the satellite is progressively disrupted by the Galactic tidal strain and the stripped particles (stars / clusters/ dark matter) continue to move on orbits similar to that of the original galaxy, hence forming multiple filamentary wraps around the parent galaxy (see Law, Johnston & Majewski 2005). On the basis of these considerations, the stellar population of the host galaxy should still be visible in the surroundings of these GCs (van den Berg 2000) as a compact overdensity of objects in the phase-space distribution. Such a direct evidence of association of GCs to confirmed streams have been noticed for some GC (e.g. Pal 12 and NGC4147 associated to the Sagittarius dwarf galaxy, Martínez-Delgado et al. 2002; Bellazzini et al. 2003a) while many other candidates have been proposed to be associated with the Sagittarius galaxy (Dinescu et al. 2000; Bellazzini, Ferraro & Ibata 2003b), the

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Monoceros ring (Crane et al. 2003; Frinchaboy et al. 2004) and the Canis Major overdensity (Martin et al. 2004a).

An intriguing case is represented by the GC NGC1851: this cluster is part, together with NGC1904, NGC2298 and NGC2808, of an apparent system of GCs confined in a sphere with radius 6 kpc (Bellazzini et al. 2003b) with positions which are compatible with the predicted orbital path of the Canis Major stream (Martin et al. 2004a, Conn et al. 2005). In their discovery paper, Martin et al. (2004a) suggested that the same episode of accretion which produced the Canis Major overdensity was also responsible for the Monoceros ring feature previously observed by Newberg (2002). N-body simulations by Peñarrubia et al. (2005) indicate that the debris of a satellite with the kinematical properties of Monoceros would indeed align along the line-of-sight of NGC1851, but the predicted radial velocity of the stream ($v_r \sim 90\ km\ s^{-1}$) would not be compatible with its association with the cluster. However, the nature of these substructures have been questioned by some authors who claimed that the observed overdensities could be due to the Galactic warp (Momany et al. 2004; López-Corredoira et al. 2006, 2007) and/or flare (Momany et al. 2006; Hammersley & López-Corredoira 2011), and a heated debate is still ongoing in the scientific community (see also Martin et al. 2004b; Martínez-Delgado et al. 2005; Vivas & Zinn 2006; Moitinho et al. 2006; Butler et al. 2007; Natarajan & Sikivie 2007; Carraro et al. 2007, 2008; Conn et al. 2007, 2008, 2012; de Jong et al. 2007; Piatti & Claria 2008; Younger et al. 2008; Kazantzidis et al. 2008; Casetti-Dinescu et al. 2006, 2008, 2010; Mateu et al. 2009; Chou et al. 2010; Sollima et al. 2011; Michel-Dansac et al. 2011, Meisner et al. 2012).

On the other hand, the accretion origin of NGC1851 has been also suggested by Carretta et al. (2010) on the basis of the presence of self-enrichment signatures (the Na-O anti-correlation) in both the two cluster stellar populations (previously discovered by Milone et al. 2008; see also Alcaino et al. 1990, Lee et al. 2009). In particular, several observations (the observed small metallicity spread, the bimodal distribution of Horizontal Branch and SubGiant Branch stars, the different content of neutron-capture elements in the metal-rich and metal-poor components, as well as the Na-O anti-correlation later found among both blue and red HB stars by Gratton et al. 2012) are better explained by two originally distinct clusters. They concluded that NGC1851 could be formed by the merger of two GCs, an occurrence that is largely unlikely within the Milky Way but more frequent within dwarf galaxies (van den Bergh 1996).

Furthermore, recent photometric analyses (Olszewski et al. 2009) have also reported that the shape of the density profile of this cluster deviates from the typical King profile, showing a power-law decline visible up to 20′ from the cluster center (see also Carballo-Bello et al. 2012). Carballo-Bello & Martínez-Delgado (2010) proposed that part of the extended stellar population surrounding this stellar system could belong to a low-surface brightness stellar stream surrounding this cluster. Numerical simulations by Bekki & Yong (2012) showed that the same feature would be observed if this cluster is the nucleus or a nuclear star cluster formed within a nucleated dwarf galaxy later accreted by the Milky Way.

In this paper we present the analysis of a sample of 107 spectra of stars observed in the outskirts of NGC1851 with the aim of studying the distribution of radial velocities in the region surrounding this stellar system. Sect. 2 is devoted to the description of the dataset and of the reduction procedure. In Sect. 3 the distribution of velocities is presented and analysed. The estimate of the distance and surface brightness of an hypothetical satellite possibly revealed in our observations is presented in Sect. 4. We discuss our results in Sect. 5.

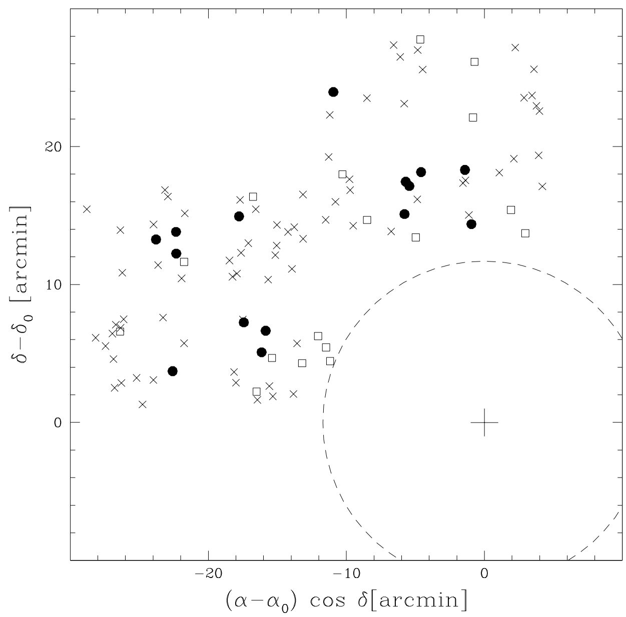

Figure 1. Map of the region sampled by the VIMOS observations. North is up, east towards the right-hand side. The adopted position of the cluster center is $(\alpha_0, \delta_0) = (05h14m06.76s, -40°02'47.6'')$ from the Harris (1996) catalog, 2012 edition. Stars of the "NGC1851", "stream" and "field" samples are marked with open squares, filled circles and crosses, respectively. The cluster center and tidal radius (from Carballo-Bello et al. 2012) are indicated by the black cross and the dashed line, respectively.

2 OBSERVATIONS AND DATA REDUCTION

Observations have been performed during three nights on October 2008 at the Very Large Telescope's (VLT) UT3 at the European Southern Observatory (ESO; Cerro Paranal, Chile), equipped with the VIsible MultiObject Spectrograph (VIMOS). The instrument has been used in Multi-Object Spectroscopy mode with the medium-resolution (MR) grism coupled with the GG475 filter, allowing a spectral coverage from 5000 to 8000 Å with a resolution R∼580. Masks have been constructed by placing ∼110 1.0′′-wide slits on target stars selected from the photometry of Carballo-Bello et al. (2012) sampling a wide range in magnitude and color ($16 < B < 22$, $0.6 < B-R < 2.1$) oversampling the Main Sequence-Turn off (MS-TO) region where both extratidal stars and surrounding streams are expected to be located (Martínez-Delgado et al. 2004). We observed two fields centered outside the nominal tidal radius of the cluster ($r_t = 11.7'$; Carballo-Bello et al. 2012), sampling a re-

Table 1. Radial velocities of target stars.

ID	RA (J2000) deg	Dec (J2000) deg	B	R	v_r [a] $km\ s^{-1}$	ϵ_v $km\ s^{-1}$
451	77.9930363	-40.0237255	16.573	15.313	69.4	30.0
225	78.2332663	-39.8095145	16.535	15.433	-71.4	8.1
9	78.5077249	-39.7947895	16.758	15.754	69.4	11.0
229	78.2059195	-39.8067570	17.025	15.613	124.0	22.3
109	78.3479570	-39.6536523	17.103	15.810	99.0	18.6
232	78.1482069	-39.7765154	17.167	16.114	155.8	11.2
580	78.1494460	-39.8404664	17.295	16.271	34.4	28.7
346	78.0347546	-39.7726088	17.314	16.108	79.0	14.7
466	77.9840459	-39.9916386	17.337	16.312	-20.0	4.4
579	78.1375767	-39.9845703	17.459	16.351	-1.4	13.9

[a] The derived radial velocities are available in electronic form at the CDS (http://cdsweb.u-strasbg.fr/).

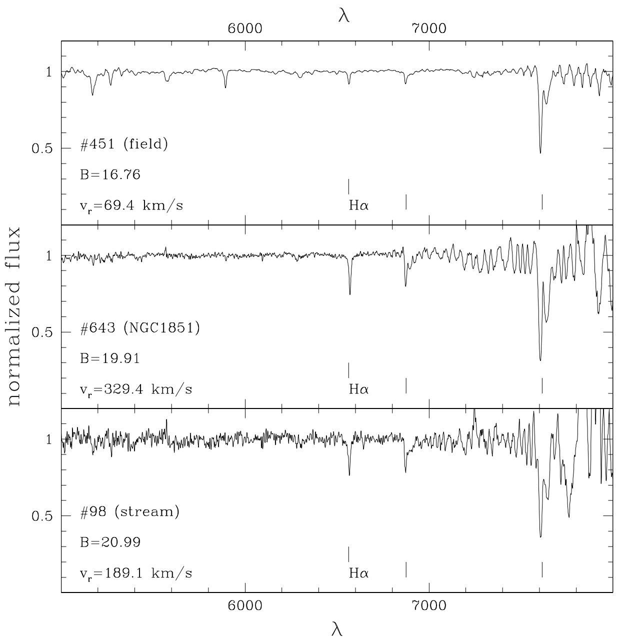

Figure 2. Spectra of the field star #451 (top panel), of the NGC1851 star #643 (middle panel) and of the "stream" star #98 (bottom panel). The Hα line and the telluric bands used in the analysis are also indicated.

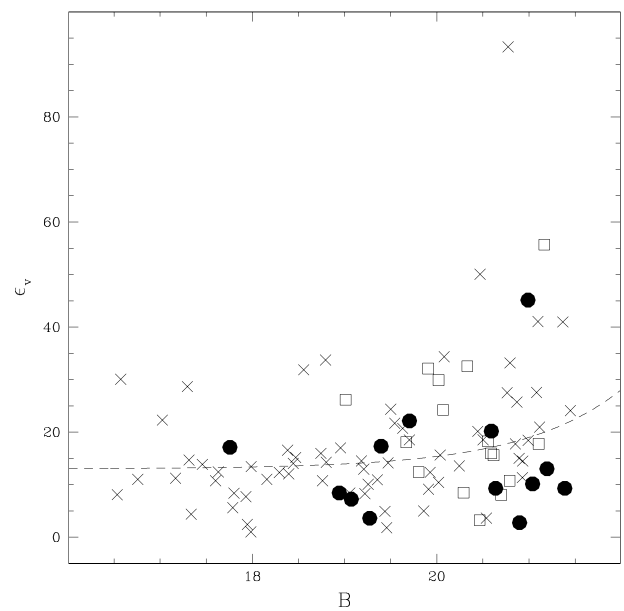

Figure 3. Velocity uncertainties of the 96 stars of our sample with at least three reliable estimates of velocity as a function of their B magnitude. Stars of the "NGC1851", "stream" and "field" samples are marked with open squares, filled circles and crosses, respectively. The bestfit exponential relation (see Sect. 2) is shown with a dashed line.

gion between $12' < d < 33'$ ($r_t < d < 3\ r_t$) to the cluster center (see Figure 1). The spectra have been obtained combining four 1955 s long exposures secured in good seeing conditions (FWHM $< 1.0''$), reaching a signal-to-noise ratio $10 < S/N < 300\ px^{-1}$ depending on the target magnitude. The one-dimensional spectra have been extracted with the VIMOS pipeline. Unfortunately, the solution in wavelength calibration provided by the pipeline was not satisfactory, mainly because of the misalignment of targets within the slits (see also Giuffrida et al. 2010). To overcome this problem, an additive shift in wavelength[1] has been applied to match the strong telluric absorption lines at 6875 Å and $\sim$ 7615 Å. The spectra were then continuum-normalized with IRAF. Spectra of three program stars are shown in Figure 2 to illustrate the quality of our data.

Radial velocities have been then obtained by cross-correlating the spectra of the individual exposures with a GIRAFFE solar spectrum[2] smoothed to the resolution of

[1] The choice of the additive shift is based on the fact that the misalignment within the aperture produces a constant shift in pixel when passing through a grism.
[2] http://www.eso.org/observing/dfo/quality/GIRAFFE/pipeline/solar.html

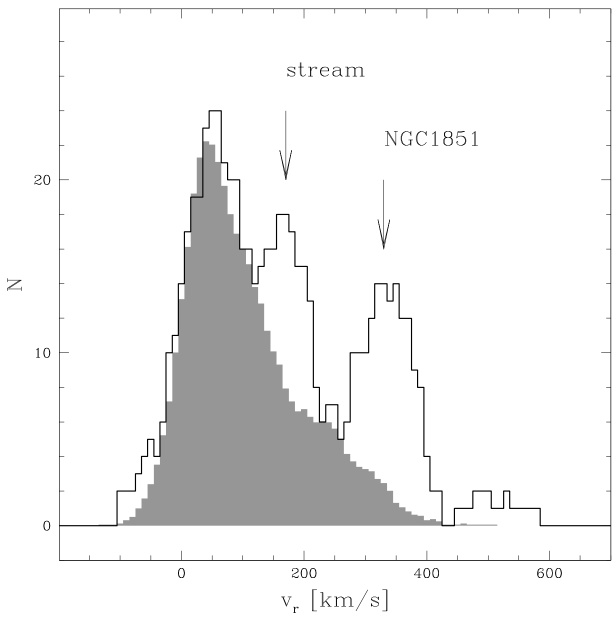

Figure 4. Velocity distribution of the 107 stars of our sample (empty histograms). The prediction of the Galactic model of Robin et al. (2003) is overplotted as grey histograms. The location of the "stream" and of the "NGC1851" peak are indicated with arrows.

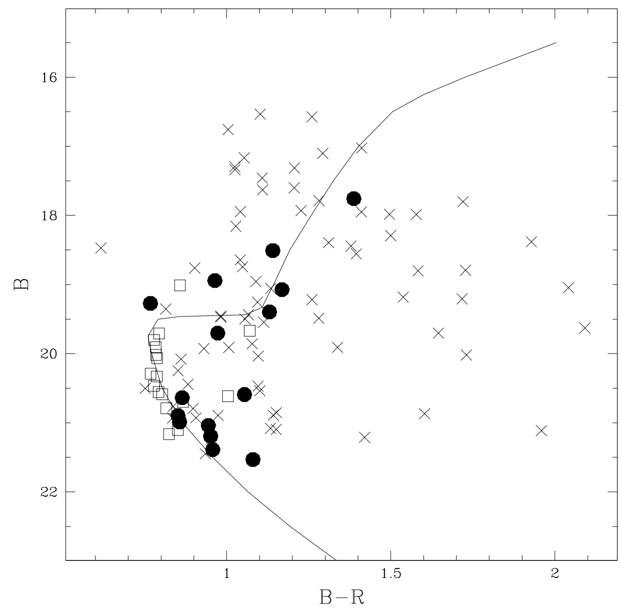

Figure 5. B vs. B-R CMD of the target stars. Stars of the "NGC1851", "stream" and "field" samples are marked with open squares, filled circles and crosses, respectively. The mean ridge line of NGC1851 is overplotted.

our targets. For the cross-correlation we used the region of the Hα line (6540 Å $< \lambda <$ 6590 Å) which is well visible even in the spectra of the faintest stars of our sample. Velocities have been corrected for heliocentric velocity and averaged[3]. Errors have been calculated as the r.m.s of repeated measures for the 96 stars with at least three reliable estimates (see Fig. 3). These stars have been used to fit an exponential relation as a function of the B magnitude that has been used to assign the errors to the other stars. The final dataset consists of 107 radial velocities with average uncertainties of ~ 15 $km\ s^{-1}$. The radial velocities of the entire sample together with their coordinates and magnitudes are listed in Table 1. Line strength indices of the Mg triplet at ~ 5175 Å and the Fe line at ~ 5265 Å have been also measured adopting the bandpasses defined by Worthey (1994). However, given the low resolution of our spectra, the derived metallicities have large uncertainties which prevent their use to identify interlopers from the Galactic halo and thick disk.

3 RESULTS

In Figure 4 the distribution of radial velocities of the entire sample is shown. The histogram has been constructed using the naive estimator (Silvermann 1986)[4] with a window width of 60 $km\ s^{-1}$ and a step of 10 kms^{-1}. The window width has been chosen using the bootstrap-based algorithm described by Faraway & Juhn (1990). The distribution shows three well separated peaks: *i)* a prominent peak at $v_r \sim 30$ $km\ s^{-1}$ due to the foreground population of disk stars, *ii)* an overdensity of stars at $v_r \sim 180$ $km\ s^{-1}$ (hereafter referred as "stream peak") and *iii)* a peak at $v_r \sim 330$ $km\ s^{-1}$ correspondent to the bulk velocity of NGC1851 (320.3±0.4 $km\ s^{-1}$, Carretta et al. 2011; "NGC1851 peak"). The prediction of the Galactic model of Robin et al. (2003) is overplotted. As the target stars have not been selected in an unbiased way (see Sect. 2) the comparison with the Galactic model has been performed adopting the following procedure: we retrieved 100 synthetic field catalogs from the Besançon website[5] each of them covering 1 sq. deg. in the direction of NGC1851. For each catalog we randomly associated a synthetic object to each target according to their euclidean distance in the B vs. R plane. A random gaussian distributed shift with dispersion equal to the velocity error of each target has been then added to each synthetic object. The procedure is repeated for all the 100 extractions and the naive estimator has been calculated on the overall catalog. The distribution has been then normalized to the observed one requiring the same number of stars at velocities $v_r < 120$ $km\ s^{-1}$ (where only field stars are expected). It is apparent that both the stream and the NGC1851 peaks are not reproduced by

[3] The derived radial velocities are available in electronic form at the CDS (http://cdsweb.u-strasbg.fr/).
[4] The naive estimator is defined as a series of histograms having a given width (the "window width") defined over a grid of sampling points separated by a given amount (the "step"). At odds with ordinary histograms, in the naive estimator the step is not necessary equal to the window width. Thus, every point of the grid is the centre of a sampling interval, freeing the histogram from a particular choice of bin positions. The choice of bin width controls the amount by which the data are smoothed to produce the estimate.
[5] http://model.obs-besancon.fr/

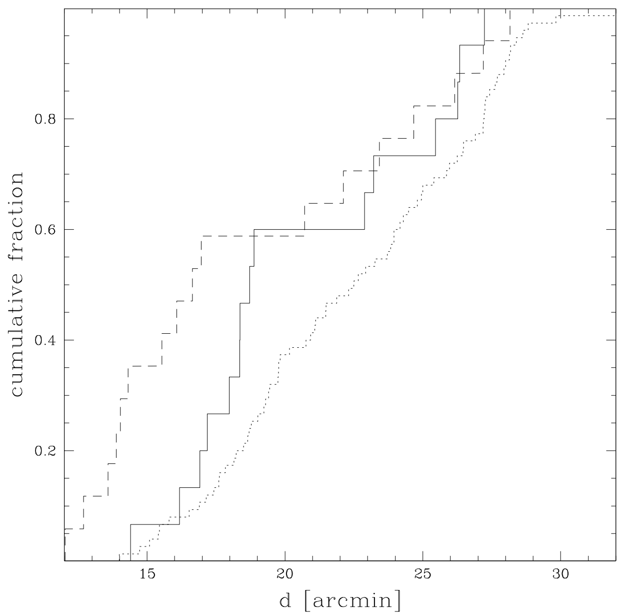

Figure 6. Cumulative radial distribution of the "stream" sample (solid line), "NGC1851" sample (dashed line) and "field" sample (dotted line) as a function of the distance from the cluster center.

the Galactic model of Robin et al. (2003). The peaks shown in Fig. 4 remain apparent even when different choices of the bin width are made ($40 < \Delta v_r/km\ s^{-1} < 100$). In the following analysis we defined two samples of stars in the radial velocity range $160 < v_r/km\ s^{-1} < 210$ (encompassing the "stream peak") and $310 < v_r/km\ s^{-1} < 430$ (around the "NGC1851 peak"), and a "field sample" containing the remaining stars. They contain 15, 17 and 75 stars, respectively. The comparison with the Galactic model indicates an expected contamination from Galactic interlopers of $\sim 6.8\pm0.6$ stars in the "stream" sample and $\sim 2.5\pm0.3$ stars in the "NGC1851" one. So, assuming Poisson fluctuations in number counts, the statistical significances of the "stream" and "NGC1851" peaks are 2.2 and 3.4 σ, respectively. The above significances, in particular that of the "stream peak", are slightly sensitive to the normalization of the Galactic model to the observed data: in the extreme assumption of a normalization to the number of targets over the entire velocity range (instead of the above quoted range $v_r < 120\ km\ s^{-1}$) the significances of the "stream" and "NGC1851" peaks would decrease to 1.6 and 3.3 sigma, respectively. We then performed a Kolmogorov-Smirnov test (independent on the normalization of the two samples): the probability that the observed velocity distribution and that predicted by the Robin et al. (2003) model are drawn from the same population turns out to be 0.003%. If we exclude the stars of the "stream peak" the probability decreases below < 0.001%, while excluding the stars of the "NGC1851" peak we obtain a probability of 3.6%.

The observed velocity dispersion of the two peaks are $\sigma_{v,stream} = 13^{+5}_{-4}\ km\ s^{-1}$ and $\sigma_{v,NGC1851} = 23^{+10}_{-4}\ km\ s^{-1}$ i.e. comparable with the observational uncertainty. This suggests that these features are kinematically cold (with an intrinsic velocity dispersion $\sigma_v \leqslant 20\ km\ s^{-1}$).

In Figure 5 the location of the stars of the "stream peak" and of the "NGC1851 peak" in the B, B-R color-magnitude diagram (CMD) are shown. It can be noted that the stars of the "NGC1851 peak" nicely follow the mean ridge line of the cluster populating the cluster MS region. The distribution of the "stream peak" stars is instead more scattered covering the entire range of magnitudes of the sample while being confined in a narrow range in color ($0.8 < B - R < 1.4$), partly overlapping the red side of the MS of NGC1851.

Fig. 6 shows the cumulative radial distribution of the three groups of stars (field, stream and NGC1851) as a function of the distance from the cluster center. Note that the stars of the "NGC1851" sample are more concentrated toward the cluster center with respect to those of the other groups: a Kolmogorov-Smirnov test indicates a probability of less than 0.2% that the field and NGC1851 samples are extracted from the same population. The same result can be deduced by splitting the sample in two subsets according to their distance from the cluster center ($d \lessgtr 20'$) and calculating the double-normalized ratio between the number of objects in the "NGC1851" and "field" samples contained in the inner and outer subsamples

$$R = \frac{N_{1851}^{out}\ N_{field}^{in}}{N_{field}^{out}\ N_{1851}^{in}} = 0.42 \pm 0.23$$

Note that the bestfit of the density profile provided by McLaughlin & van der Marel (2005) using a Wilson (1975) model and that provided by Carballo-Bello et al. (2012) with the power-law empirical relation by Elson, Fall & Freeman (1987) predict $R = 0.05$ and $R = 0.24$ in the same radial range, respectively. So, in spite of the large errors involved, there seems to be an overabundace of cluster members beyond $20'$ from the cluster center with respect to the model predictions. Unfortunately, the small number of objects prevents from any conclusion on the radial distribution of the "stream" sample. Also, no clear signatures of azimuthal variation of velocities have been found in the three samples. Note that the velocity variation of a cold stream over the field of view covered by our observations should not exceed few $km\ s^{-1}$ (Peñarrubia et al. 2005) so, because of the relatively large velocity uncertainties and the likely presence of field interlopers, we do not expect to detect such differences.

4 THE STREAM HYPOTHESIS

While the natural interpretation of the "NGC1851" peak in the velocity distribution is that these stars are cluster members, the origin of the "stream" peak is not clear. An intriguing possibility is that it is a debris of an accreted satellite in the direction of NGC1851. In this section we try to estimate the distance and the surface brightness of this feature, in the hypothesis that it is constituted by the debris of the Monoceros ring.

For this purpose, we simulated a synthetic CMD of the satellite by randomly extracting a population of stars from a Kroupa (2001) mass function and interpolating through a set of Marigo et al. (2008) isochrones with an age of 9.2 Gyr (Sollima et al. 2011), a metallicity of [Fe/H]=-0.95 with a spread of $\sigma_{[Fe/H]} = 0.15$ (Ivezić et al. 2008; Meisner et al.

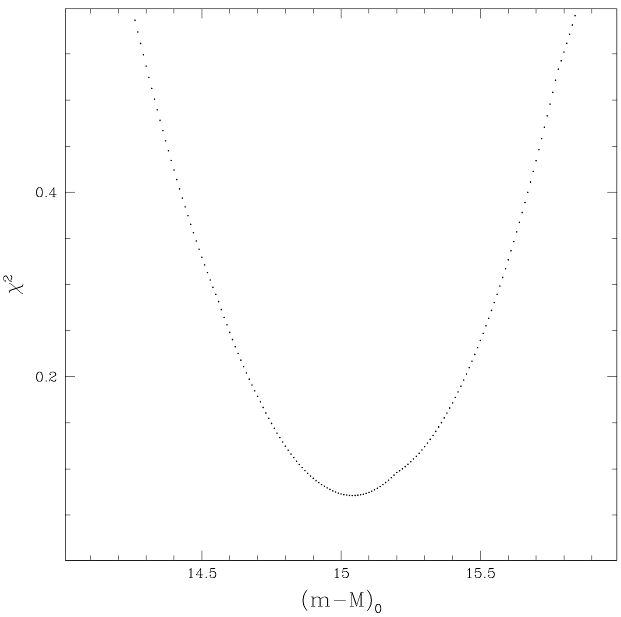

Figure 7. χ^2 of the isochrone fitting of the "stream" sample as a function of the adopted distance modulus for the hypothetical stream population.

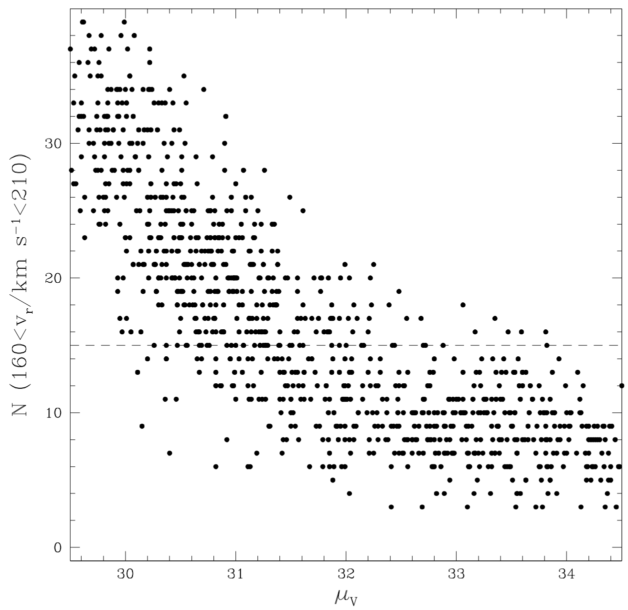

Figure 8. Number of stars in the "stream" sample velocity range ($160 < v_r/kms^{-1} < 210$) as a function of the satellite surface brightness for the set of synthetic stream population. The observed value is indicated by the dashed line.

2012) and a reddening of E(B-V)=0.04 (Schlegel, Finkbeiner & Davis 1998).

To estimate the distance of the stream we performed an iterative weighted fit of the location of the "stream" sample stars with the same isochrone used to compute the synthetic CMD. As a first step we chose a first guess of the distance modulus and converted absolute magnitudes to apparent ones. For each star a weight has been then calculated as the ratio between the densities of stars at the target (B, B-R) position in the synthetic satellite CMD and in the Robin et al. (2003) Galactic model CMD. Only stars in the "stream sample" velocity range have been used to calculate the Galactic field density. The derived bestfit distance has been then adopted for the next iteration and the procedure is repeated until convergence. The above algorithm converges after few iterations and appears to be insensitive to the first guess of the distance. The χ^2 of the fit as a function of the distance modulus is shown in Fig. 7. The bestfit distance modulus turns out to be $(m-M)_0 = 15.04 \pm 0.38$ corresponding to a distance of 10.2 ± 1.8 kpc.

To estimate the surface brightness of this object we simulated the synthetic CMD of the satellite adopting the above derived distance and left the number of simulated objects as a free parameter. A velocity extracted from a gaussian distribution with $< v_r >= 180\ km\ s^{-1}$ and $\sigma_v = 10\ km\ s^{-1}$ has been assigned to each star of the satellite. The CMD of the Galactic model of Robin et al. (2003) has been then added and a synthetic object has been associated to each target of the entire sample[6] (see Sect. 3). A random gaussian distributed shift with dispersion equal to the velocity error of each target has been then added to the synthetic velocities to mimic the observational errors. The number of objects falling in the velocity range of the "stream sample" has been then counted and the surface brightness of the satellite has been estimated by summing the V fluxes of all the simulated sources. The procedure has been repeated 100 times for each adopted number of satellite object and the distribution in the $\mu_V - N_{stream}$ plane is shown in Fig. 8. As expected, the brighter is the adopted satellite the larger is the number of stars in the "stream" range of velocity, while at surface brightness lower than $\mu_V \leqslant 32.8$ the number of objects in the interesting velocity range asymptotically tends to the number of halo stars. The mean surface brightness to observe 15 object turns out to be $\mu_V = 31.4 \pm 0.7\ mag\ arcsec^{-2}$.

5 DISCUSSION

We report the results of a survey of radial velocities in the outskirts of the GC NGC1851. We clearly detect the signal of the cluster stellar population as a strong overdensity of objects with a velocity and location in the CMD compatible with that of the cluster MS, and more concentrated with respect to the Galactic field population. Such a detection confirms that a significant number of cluster stars are present up to 25′ from the cluster center, well beyond the King tidal radius, as already reported by Olszewski et al. (2009) and Carballo-Bello et al. (2012). It is worth noting that the truncation radius predicted by dynamical models depends on their adopted functional form of the distribution function, a choice which is somehow arbitrary. For instance, McLaughlin & van der Marel (2005) showed that Wilson (1975) models, predicting larger tidal radii with respect to King (1966) ones, better fit the overall shape of many GCs.

[6] At odds with the procedure described in Sect. 3 we excluded here the NGC1851 stars with $v_r > 310\ km\ s^{-1}$ as they are not included in our simulation.

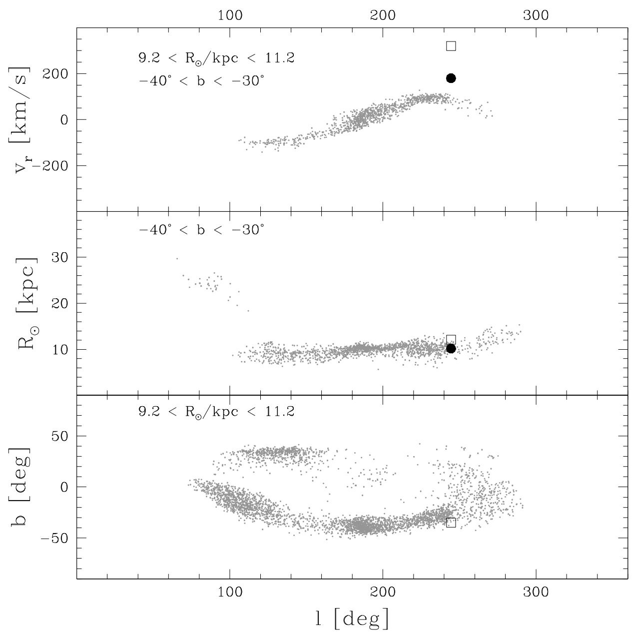

Figure 9. Orbital path of the Monoceros stream predicted by the Peñarrubia et al. (2005) model. The bottom, central and upper panels show the distribution of stars in Galactic longitude, heliocentric distance and radial velocity, respectively, as a function of the Galactic latitude. Only particles in the ranges indicated in each panel have been plotted. The position of NGC1851 is marked by the open square. In the upper and central panels the position of the "stream" sample is marked by the filled dot.

For NGC1851 the tidal radius estimated by McLaughlin & van der Marel (2005) using Wilson (1975) models is $44.7'$, well beyond the extent of our dataset. Anisotropy and mass segregation can also play a role in shaping the radial density profile of the cluster (Gunn & Griffin 1979). However, a physical (model-independent) limit to the distance of bound stars is given by the Jacobi radius at which equilibrium between the effective potentials of the cluster and of the host galaxy settles. Allen, Moreno & Pichardo (2006) estimated a Jacobi radius of $\sim 17'$ for NGC1851. Thus, the outermost targets observed here could be unbound objects. Also in this case, however, caution must be taken since the estimate of the Jacobi radius depends on the adopted cluster orbital parameters and on the Galactic potential, which are subject to significant uncertainties. Even if all the detected cluster stars would be comprised within the Jacobi radius the relative fraction of object at $d > 20'$ exceeds the prediction of all the commonly used dynamical models. The overabundance of these object can be explained assuming these stars to be "potential escapers" i.e. stars whose orbital energy already exceeded the potential of the Lagrangian point but whose orbits have still not intersected it (Küpper et al. 2010). In this scenario, these stars are expected to have also a velocity dispersion significantly larger than those predicted by dynamical models. Unfortunately, the small sample size and the relatively large uncertainties of our data do not allow to confirm this hypothesis. Another possibility is that these objects have been heated by the relaxation process after the last cluster orbital pericentric passage, moving over the tidal boundary (Baumgardt & Makino 2003).

We also found a peak at $v_r \sim 180\ km\ s^{-1}$ not predicted by the Galactic model of Robin et al. (2003) corresponding to a cold ($\sigma_v \leqslant 20\ km\ s^{-1}$) population of stars whose location in the CMD is compatible with a distance of ∼10 kpc and a surface brightness of $\mu_V = 31.4 \pm 0.7\ mag\ arcsec^{-2}$. Note that the deepest wide-field photometric analyses of this cluster reached a surface brightness limit of $\mu_V \leqslant 30$ (Olszewski et al. 2009; Carballo-Bello et al. 2012) and could not detect such a feature. It is necessary to point out that the significance of such a peak is 2.2 σ, leaving a 1.5% probability of false detection (3.6% according to the Kolmogorov-Smirnov test). A non-optimal wavelength calibration of the spectra can also introduce some artifact in the velocity distribution, although it is not expected to produce a spurious peak. Moreover, it is also possible that the Galactic model of Robin et al. (2003) underpredicts the fraction of stars in the velocity interval around 180 kms^{-1} (constituted almost exclusively by halo stars) by a factor of two. However, the mean velocity and the relatively high Galactic latitude ($b = -35.03°$) of this object makes impossible a connection with the warped/flared disk (see Sect. 1). If confirmed this evidence would constitute a strong indication of the presence of a stream in the direction of NGC1851. An identification of this feature with known streams is not easy because of the large uncertainties in the orbit of these satellites. The prediction for the Monoceros stream of the N-body model by Peñarrubia et al. (2005) indicates that a high latitude debris of this stream should align with NGC1851 at a distance compatible with the range estimated here (including the NGC1851, see Fig. 9). However, the connection of this cluster with the stream is unlikely because of the large velocity difference between these two objects ($\Delta v > 200\ km\ s^{-1}$). The velocity difference between the "stream" sample identified here and the prediction for the Monoceros ($\Delta v \sim 90\ km\ s^{-1}$) seems to exclude also a connection between them. Note however that our observations are located far away from the kinematical detection used by Peñarrubia et al. (2005) to constrain the Monoceros orbit, so many uncertainties (including the adopted Galactic potential) make this comparison uncertain. Unfortunately, the small sample size and the low resolution of our data prevent us a statistically significant detection. Further high-resolution spectroscopic studies over a larger field of view are necessary to confirm this evidence.

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