Tidal Remnants Around the Galactic Globular Clusters NGC 1851 and NGC 1904

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Abstract Deep photometry around the Galactic globular clusters NGC 1851 and NGC 1904 obtained with the Wide Field Imager in the 2.2 m ESO telescope reveals a distinct main-sequence of a metal-poor stellar population, consistent with the presence of a very low surface brightness stellar system. The unveiled population might belong to an unkwnon tidal stream in the Milky Way but other possibilities are here discussed.

1 Introduction

Within the hierarchical framework for galaxy formation, galaxies are expected to form and evolve through mass infall and through the successive coalescense of smaller, distinct building blocks, such as satellite galaxies merging with their parent galaxy. This scheme predicts distinct tidal stellar debris around large galaxies like the Milky Way, that should be detectable as coherent stellar overdensities in their halos. In the last years, different large scale photometric surveys (Sloan Digital Sky Survey, 2MASS) have probed for the first time the presence of a significant amount of these substructures in our Galaxy in form of coherent streams or giant stellar clumps ([**?**],[**?**],[**?**]) which have been interpreted as the fossil records of recent merger events in the halo. A complete census of individual merger events is needed to provide a direct test of the scenario of hierarchical structure formation, and to probe the minor-merger tesilence of stellar disks.

The surroundings of globular clusters in the outer halo of the Milky Way are among the best places to look for the remnants of these ancient, tidal disrupted dwarf

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satellites predicted by the ΛCDM theory [?]. The classical Searle & Zinn scenario of the formation of the Milky Way, in which the halo globular clusters formed in larger dwarf galaxies, can nowadays be considered as the local manifestation of this hierarchical galaxy formation. If these clusters have been formed within larger stellar systems or they were the nucleus of ancient disrupted galaxies [?], we would expect to find them surrounded by old stellar populations that can be revealed by deep, wide field photometric surveys.

The objects that we have studied, NGC 1904 (also known as M 79) and NGC 1851, show some peculiarities reported in the last years. It has been suggested that these two clusters might form, together with NGC 2298 and NGC 2808, an apparent system of globular clusters confined in a sphere with radius 6 kpc [?] and possibly associated to the controversial Canis Major dwarf system (Martin et al. 2004).

2 Tidal debris around NGC 1851 and NGC 1904

The objects that we have studied, NGC 1904 (also known as M 79) and NGC 1851, have been suggested that these two clusters might form, together with NGC 2298 and NGC 2808, an apparent system of globular clusters confined in a sphere with radius 6 kpc [?] and possibly associated to the controversial Canis Major dwarf system (Martin et al. 2004).

The main objetive of our project is to investigate the presence of a distintc stellar population around NGC 1904 and NGC 1851. With this aim were observed wide areas including the globular clusters with the Wide Field Imager (WFI) located at the 2.2m ESO telescope at La Silla Observatory (Chile) with a total field of view of 34 x 33 arcmin. For NGC 1904 were obtained two fields located at (5.39^h,-24.32°) and at (5.424^h,-24.33°) where the cluster is contained in the region where both fields overlap. In the case of NGC 1851 only was neccesary a field at (5.21^h,-39.84°) where the cluster is situated in the last two chips of the WFI.

The resulting color-magnitud diagrams (CMDs) are shown in Figure 1. These CMDs show an evident feature in the field surrounding both NGC 1851 and NGC 1904 (bottom panels). This possible unexpected main-sequence (MS) is located in the ranges $0.8 < B\text{-}R < 1.6$ and $20 < V < 23$. Our diagrams are deep enough to reach more than 4 magnitudes under the turn-off level, which is perfectly defined for both clusters. Horizontal branch levels are in agreement with the previous results. The unexpected feature is clearly seen in the diagram corresponding to NGC 1904 due to the more extensive field observed around the globular cluster (0.48 deg^2 in front of the 0.19 deg^2 around NGC 1851). The spatial distribution of these extra-tidal stars do not show any insight of collimated structures, but they are scattered in large sky-area around the clusters, consistent with being associated to a giant stellar overdensity or tidal stream.

It is possible to obtain an rough estimate of the distance to the subyacent stellar population following the method described in [?], which is based on the apparent magnitude of the MS turn-off. In our color-magnitude diagram, the MS appears to

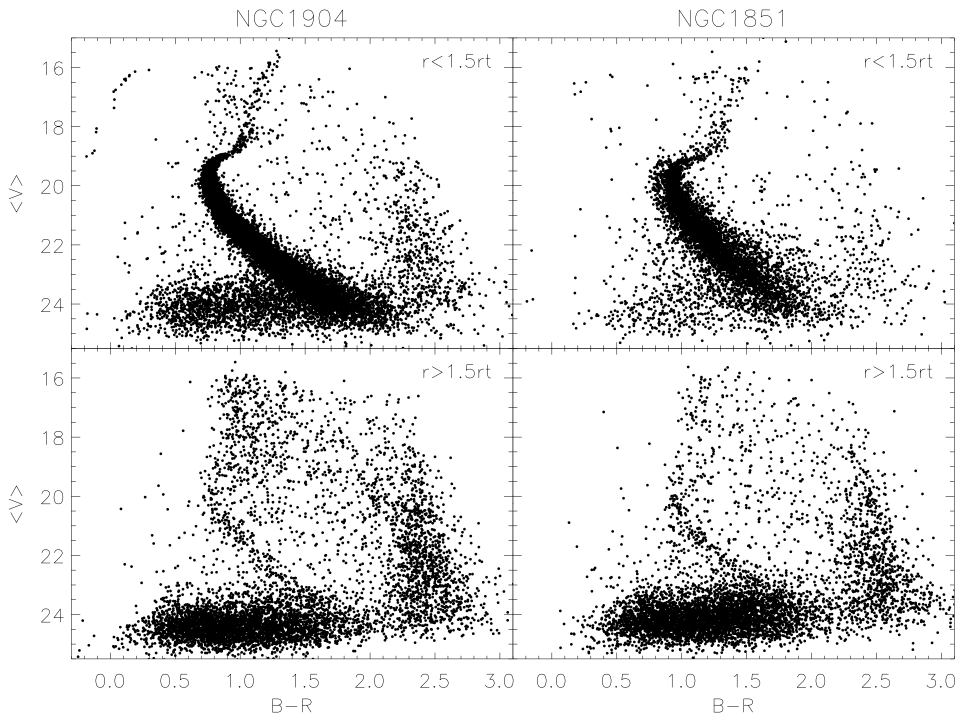

Fig. 1 Color-magnitude diagrams panel: diagrams corresponding to the tidal (top) and extra-tidal (bottom) fields for NGC 1904 (left) and NGC 1851. The unveiled population is observed in both cases as a feature in the bottom diagrams around B-R $\simeq$ 1, V $\simeq$ 23.We have used <V> as (B+R)/2.

terminate at V$\sim$ 20 (based on the approximated position of its bluest point). Assuming from [**?**] a turn-off magnitude range 3.9 $\leq$ M_V $\leq$ 4.2 for and old stellar population and using the reddening maps from [**?**] it is possible to estimate the distance. When V_{Toff} = 20.3 and M_V = 3.9 is adopted, we obtain an upper limit for the distance of 19 kpc while if we take V_{Toff} = 19.7 and M_V = 4.2, the lower limit is placed at 12.7 kpc.This distance range obtained for the tidal debris candidate is consistent with the known distances of NGC 1851 and NGC 1904 (12.1 and 12.9 kpc respectively), suggesting that the subjacent populations could be at the same distance that the globular clusters.

3 Discussion

Without kinematical data, it is very difficult to obtain a definitive conclusion about the origin of the extended stellar population surrounding NGC 1851 and NGC 1904.

Firstly, we have explored whether this stellar population is really part of a tidal tail of these globular clusters. Variying our criterion to separate the extra-tidal field in our catalogue (i.e. extending the separation up to 2 - 2.5 times the tidal radius, that is, up to 29.25 and 20.85 arcmin from the center of NGC 1851 and NGC 1904 respectively) the MS feature is still visible in the CMD. This suggests that both clusters are embebbed in giant cloud of tidal debris composed by a similar old, metal-poor population, that has a minimum sky-projected size of 15.7 deg ($\simeq$ 3.3 kpc) equivalent to the distance between both systems. It would be difficult to explain that this giant cloud could be part of the tidal tails from these globular clusters themselves. We have not found evidence for any collimated structure as would be expected under this assumption.

In the last years, some studies have reported the presence of a conspicuos MS feature in the third Galactic quadrant ([**?**],[**?**]), possibly associated to the remnants of a dwarf galaxy accreted in the disk of the Milky Way in the constellation of Canis Major. The position of our fields are not too far from the center of this overdensity, but the subjacent stellar population is more distant and more metal-poor than that reported for this possible stellar system. The alternatively hypothesis that the MS feature visible in our diagrams is the signature of the stellar population associated to the Galactic warp is also very unlikely. NGC 1851 and NGC 1904 are located at b=-34° and b=-28° in galactic coordinates respectively, that is, at 6.9 and 6.3 kpc below the Galactic plane at the distance reported in Sec. 2.

The best explanation is that this over-density is associated to a tail of the low-galactic latitude tidal stream that surrounds the outer part of the Milky Way, known as Monoceros tidal stream. Numerical simulations [**?**] of this stream showed that both clusters group is very close to the predicted path and distance of this stream, generated by the tidal disruption of a galaxy being accreted on to the Galactic disk, as it is seen in Figure 2. However, the radial velocities of NGC 1904 and NGC 1851 are not in agreement with the model predictions. Moreover, their proper motions suggest that they cannot be originated in a same system due to their orbits, that displays different eccentricities and inclinations.

Finally, it is possible that we have detected the remnants of an unknown stellar system surrounding both globular clusters. If our detections belong to the same stellar system, it would be a very extended system, due to the separation between NGC 1851 and NGC 1904 in the sky. This could be the fossil of an ancient hierarchical formation episode in our Galaxy where both clusters were involved.

4 Conclusions

We have found a subjacent, metal-poor stellar population around NGC 1851 and NGC 1904 that might be associated with the remnants of an accreted dwarf galaxy in the disk of the Milky Way. This population is located at the same distance that of the globular clusters, suggesting the existence of a giant cloud of tidal debris surrounds both systems at $\sim$ 12 kpc from the Sun.

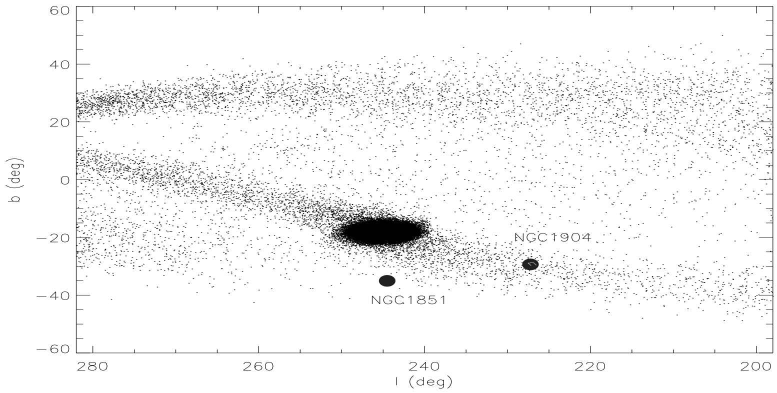

Fig. 2 Position in galactic coordinates of the Monoceros tidal stream according to the model obtained by [**?**] and the globular clusters. The central feature indicates the position of the Canis Major overdensity that has been proposed as the progenitor dwarf galaxy of the stream.

The origin of this unveiled population cannot be explained as a component of the Galactic disk or the tidal tails of the globular clusters themselves. One of the hypothesis the presence in this fields of a tail of the Monoceros tidal stream, a ring-like stellar structure that surround the Milky Way at low galactic latitudes. Simulations show that the path of the stream and the position of NGC 1851 and NGC 1904 are compatible with this hypothesis. However, accurate kinematic and proper motion for the stream and the globulares are needed to conclude the association of these clusters to this stellar stream. It is also plausible that we have found evidences of an unknown tidal stream in the Milky Way at low galactic latitude.

Galactic globular clusters are still the key for the understanding of the Milky Way formation. The detection of a subjacent stellar population around the peculiar clusters NGC 1851 and NGC 1904 fuels evidences that there could still be unknown signatures of the hierarchichal formation of our Galaxy that would help us to understand the assembly process of the Milky Way.