The luminosity function of Palomar 5 and its tidal tails

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Abstract. We present the main sequence luminosity function of the tidally disrupted globular cluster Palomar 5 and its tidal tails. For this work we analyzed imaging data obtained with the Wide Field Camera at the INT (La Palma) and data from the Wide Field Imager at the MPG/ESO 2.2 m telescope at La Silla down to a limiting magnitude of approximately 24.5 mag in B. Our results indicate that preferentially fainter stars were removed from the cluster so that the LF of the cluster’s main body exhibits a significant degree of flattening compared to other GCs. This is attributed to its advanced dynamical evolution. The LF of the tails is, in turn, enhanced with faint, low-mass stars, which we interpret as a consequence of mass segregation in the cluster.

1. Introduction

Palomar 5 is a faint ($M_V = -5.17$), sparse ($M \approx 5000 M_\odot$) and low-concentration ($c = \log(r_t/r_c) = 0.74$) globular cluster (GC) that is currently in a state of advanced dissolution due to the tidal forces exerted by the Milky Way. Its dynamical evolution has been dominated by mass loss that predominantly occurred during passages through the Galactic disk. Direct evidence for this disruption arises from the recent discovery of two tidal streams emanating from the cluster’s main body (Odenkirchen et al. 2001, 2003) which cover at least $\sim 10^\circ$ on the sky. In a study that used deep HST data Grillmair & Smith (2001, hereinafter GS01) derived luminosity functions (LFs) for two separate regions of the cluster’s center and found them to be identical to within their uncertainties. On the other hand they found Palomar 5 to be apparently depleted in low mass stars compared to other GCs.

This work presents the first analysis of the stellar content of a GC’s tidal debris, thus providing the possibility to directly test, whether a flattened LF can have its origin in tidal mass loss. For this, we aim at measuring the luminosity function of the entire cluster and comparing it to that of the tidal tails. Furthermore, if this deficiency is due to mass segregation through energy equipartition, one should expect the LF of the tidal streams to be enhanced in low-mass stars lost from the center.
2. Data

In order to distinguish the luminosity functions in different portions of the cluster we targeted our deep imaging observations at the cluster’s center and several regions in the tidal tail. We obtained data with two different wide field instruments, both of which provide a field of view of approximately $35' \times 35'$. Firstly, we used the Wide Field Camera of the 2.5 m INT at La Palma to obtain deep B and r' images. These data reach a limiting magnitude of approximately 24.5 mag in B. Secondly, we observed Pal 5 using the Wide Field Imager at the 2.2 m ESO/MPG telescope at La Silla, both in V and R. To estimate the contamination by field stars we also took images of two control regions located well away from the cluster (viz., 1.5') and the tails, still representing a field typical for that area. The location of fields is depicted in Fig. 1.

3. Color magnitude diagrams and number counts

The resulting color magnitude diagrams are shown in Fig. 2. The left panel shows stars within 3.6' around the cluster center – corresponding to the cluster’s core radius. Its main sequence is well defined, whereas the horizontal and red giant branch are populated more sparsely. There is also an apparent binary main sequence visible in the INT data, but these objects were not included in the analyses presented here.

A CMD of the tidal tail, on the other hand, is displayed in the right panel of Fig. 2. As the regions in the tails contain an increasing number of field stars, the main features of the cluster population within the tails are overlapped by the field population and do not stick out clearly.

In order to select primarily main sequence star candidates we calculated a $2\sigma$-envelope around the main sequence as defined in Fig. 2, which was smoothed afterwards.

Now for each observed field, using only objects within this $2\sigma$-envelope, we performed number counts in bins of 0.5 mag. Field stars were statistically subtracted and the resulting histogram was corrected for incompleteness effects to construct the final stellar main sequence luminosity function (MSLF).
4. Cluster luminosity function

Fig. 3 presents our MSLFs of the cluster’s central 3’6 in comparison to the results for the northern tail. The outstanding feature of these LFs is the high degree of flattening at the faint end which signifies deficiency in low mass stars. This result is in good agreement with the HST study of a central portion of Pal 5 by GS01. To quantify the flattening, we fit a theoretical LF to the data using isochrones from Bergbusch & VandenBerg (1992, BV92) with an age of 12 Gyr and a metallicity of $-1.48$ dex, both values close to Pal 5’s parameters of 11.5 Gyr (Martell, Smith, & Grillmair 2002) and $-1.43$ dex (Harris 1996). The underlying mass function (MF) consists of a power-law with an exponent of $\alpha \sim -0.5$, which fit our data best. This means that Pal 5’s MF is remarkably shallow, because typical GCs are generally described by $\alpha \sim -0.3$ (Piotto & Zoccali 1999).

5. Tidal tail luminosity function

The MSLF of the tidal tail, on the other hand, is consistent with the cluster’s LF at the brighter end to within the uncertainties, but it is apparently enhanced in low mass stars as can be deduced from a larger number of faint stars in the last magnitude bins. A quantitative measure of the enhancement can be given by the exponent from a power-law fit of the kind $N \propto M^\alpha$. The value of $\alpha$ was determined as $0.6 \pm 0.2$ ($0.7 \pm 0.4$) for the central region and $4.0 \pm 0.3$ ($4.2 \pm 1.4$) for the tidal tail. These numbers refer to our INT data, whereas numbers in brackets were derived from the WFI data. This result confirms the depletion of the core of low mass stars and the complementary enhancement of the tails with these stars.
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Figure 3. Luminosity functions of Palomar 5’s main body (solid line) compared to that from the tidal tail (dashed). INT data are shown left and the WFI results are displayed in the right panel. The errorbars are purely statistical. The dotted line is a theoretical LF based on a mass-luminosity-relation from BV92 using the remarkably low power-law exponent of $-0.5$. The curves were scaled to fit at the bright end.

6. Discussion

Both our datasets from the INT and the WFI consistently show that the central portion of the low concentration cluster Palomar 5 is significantly deprived of low mass stars. These moved to the cluster’s outskirts in the course of dynamical mass segregation, where they were preferentially removed through evaporation and increasingly by tidal stripping. Presently, the faint stars are predominantly found in the tidal tails, which confirms the segregation scenario. However, it cannot be entirely ruled out that the distinctness of this effect is biased to a certain extent by an increasing field contamination.

Since MS is generally believed to be negligible in low concentration GCs (Pryor, Smith, & McClure 1986), it seems that Pal 5 must have undergone severe structural changes during its evolution.

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