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STRucture and Evolution of the GAlaxy (STREGA): The case of Pal 3

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Abstract. In the context of the STRucture and Evolution of the GAlaxy survey, we describe the preliminary results obtained for the fields around the globular cluster Pal 3 (about 2.75 square degrees), by exploiting the obtained g, r, i time series photometry. The final aim is to use variable stars as tools to verify and study the presence of streams around Pal 3. We found 20 candidate variable stars of which 7 RR Lyrae stars possibly belonging to Pal 3, also at large distance from the center. The distribution of the candidate RR Lyrae seems to confirm a preferential distribution in the north-east direction, confirming previous results in literature.

Keywords. (Galaxy:) globular clusters: individual (Pal 3), Galaxy: halo, Galaxy: structure, stars: variables: other

1. Introduction

STREGA is an ESO VLT for Survey Telescope (VST) guaranteed time project to observe extensive regions around a number of Globular Clusters (GCs) and satellite galaxies of the Milky Way (MW), in order to map the existence of extended halos and/or tidal streams with the final aim of constraining formation and evolution of the Galactic halo (Marconi *et al.* 2014). An interesting example is the so called Fornax stream that is expected to include both dSphs such as Fornax, Leo I, Leo II, Sculptor and possibly Sextans and Phoenix and GCs as Pal 3, Pal 4 and Pal 12 (Majewski 1994).

VST with its large field (1 deg^2) and its high resolution (0.21 arcsec/px) is the ideal instrument for this type of investigation. Marconi *et al.* (2014) presented the STREGA survey that has mapped large areas, at least up to 2-3 times the tidal radius (r_T), in the g, r and i bands around several systems. The tools adopted to trace the signatures of the interaction between the selected stellar systems and the Galactic halo are, depending on the distance of the observed object, variable stars (time-series at RR Lyrae magnitude level) and/or Main Sequence Turn-Off stars (MSTO, deep exposures 2-3 mag below the TO). For example, Marconi *et al.* (2014) performed star counts on the area observed around ω Cen (3 r_T) in various evolutionary phases, in particular in the region of the MSTO and of the Sub Giant Branch (SGB). They found overdensities around the r_T and at large distance with an asymmetric elongated shape in the south-east direction.

Similarly, Musella *et al.* (2018) mapped about 2 r_T (0.29 deg) around the GC Pal 12, which is embedded in the Sagittarius Stream. They searched for Pal 12 extra-tidal stars, adopting the MSTO and red giant branch stars as tracers. Due to the presence of the Sgr Stream overdensity in the CMD, the separation between cluster and field stars was quite difficult. To minimize this effect on star counts, these authors used an innovative multi-band method based on a 3D ridge line (magnitude-color-color). As a result, they did not find evidence of significant extra-tidal stellar population around Pal 12, thus suggesting that the presence of the Sgr stream might have simulated a larger r_T in previous studies.

Here we describe the results we obtain by exploring the periphery of the GC Pal 3. We searched for variables in this area to trace the possible presence of Pal 3 extra-tidal structures.

2. Overview: the case of Pal 3

Pal 3 is located at $\alpha = 10^h{:}05^m{:}31.9^s$, $\delta = +00^\circ{:}04'{:}18''$, (l,b)=(240.14, 41.86 deg), with an absolute visual magnitude $M_V = -5.52$ mag, a half-light radius of 0.66 arcmin, r_T of 4.81 arcmin (Harris 1996; Hilker 2006). It has a distance of 92.7 kpc from the Sun and 95.9 kpc from the Galactic center with a metallicity of [Fe/H]= −1.66 dex (Harris 1996). Stetson *et al.* (1999) suggested that Pal 3 might be younger by 1.5-2 Gyr with respect to inner halo GCs with a similar metallicity. It contains 12 variable stars and is considered as a classic example of "second-parameter" cluster and a typical case of loose GC with a predominantly red Horizontal Branch (HB; Gratton, & Ortolani 1984; Catelan *et al.* 2001; Borissova *et al.* 2000; Clement *et al.* 2001).

Sohn *et al.* (2003) studied the stellar distribution around Pal 3 with the aim of searching for tidal features and/or streams of the probable parent satellite galaxy around Pal 3. They suggested a north-south elongation along the directions of the Galactic center and anticenter, and a north-east extension in the direction of the cluster's proper motion. The character of the motion of Pal 3 is debated and a possible extragalactic origin is also suggested, with the Phoenix dwarf spheroidal beeing the best candidate to be associated to Pal 3 (Palma, Majewski & Johnston 2002; Sharina *et al.* 2018).

In this work we have covered a very large area of about 2.75 deg^2 around Pal 3 (r_T 0.08 deg) with three overlapping fields. We obtained time series at the RR Lyrae level in the g, r and i bands with typical values of 28, 14 and 11 epochs, respectively. Panel a) of Figure 1 shows the spatial distribution for more than 45000 sources (grey dots). Red points represent the sources within the r_T of the GC. Several types of candidate variable stars (see Section 3) are highlighted with different symbols as also described in the legend. In particular, one candidate W Virginis star (magenta square), ten LPVs (green squares), two Anomalous Cepheids (AC, cyan squares) and seven RR Lyrae stars (blue squares) are plotted. Candidates for which the Gaia proper motion (see Section 3) is available are also shown (black open squares).

3. Color Magnitude Diagram, Variable stars and proper motion

Panel b) of Figure 1 shows the (g, $g-i$) deep CMD obtained with *STREGA* data down to about 2.5 mag below the HB that shows a color extension in agreement with literature results (e.g. Catelan *et al.* 2001). Using the InterQuartileRange variability index† (e.g. Sokolovsky *et al.* 2017), we found 20 candidate variables among which ten Long Period Variables likely belonging to the MW halo and projected to Pal 3; seven RR Lyrae belonging to Pal 3 of which five new discoveries also at large distance from the center (see Fig. 1). One candidate RR Lyrae star is brighter than the HB (blue square with a magenta circle in Fig. 1) and lies outside the r_T and, if confirmed as RR Lyrae, it might be the signature of a depth effect of an extra-tidal star distribution. We also found two candidate ACs that could be the tracers of an intermediate-age population (about 2-3 Gyr old). Some of the aforementioned candidates have not epochs in i and hence could not be plotted in the g, $g-i$ CMD. Panel c) of Figure 1 shows *VST* g, r, i Pal 3 light curves for two variable candidates (STREGA_ID=149, 179) folded with period obtained with SigSpec (Reegen 2007). After matching our candidates list with literature results, we found that candidate 149 has been classified as RR Lyrae also by the PAN-Starrs

† The IQR is the difference between the median values computed for the upper and lower halves of the data set.

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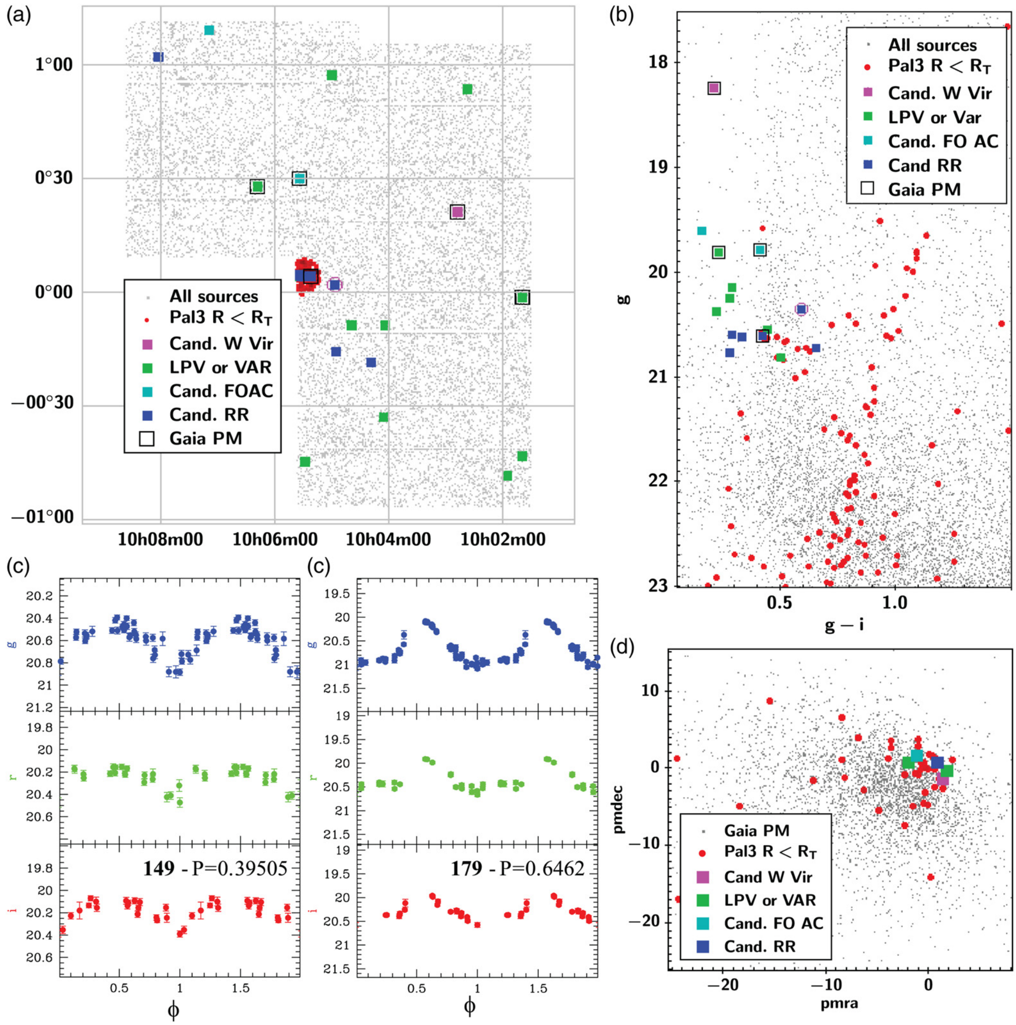

Figure 1. Panel a) field of view of the STREGA observations around Pal 3. All sources are plotted with grey dots, stars within the r_T are highlighted with red points. The various classes of candidates variables are represented with different symbols; in particular we found one W Virginis star (magenta square), ten LPVs (green squares), two anomalous Cepheids (cyan squares), seven RR Lyrae stars (blue squares) of which one brighter (magenta open circle) than HB (see text for details). Candidates for which Gaia proper motion is available are indicated with black open squares. Panel b) g,$g-i$ color magnitude diagram for Pal 3 sources color coded as in panel a). Panel c) g, r and i VST light curves for two candidate variable stars. STREGA IDs and SigSpec Periods in days are indicated. See text for details. Panel d) proper motion for sources in common with the Gaia catalog (color coding as in the panels a and b).

collaboration (Magnier *et al.* 2016), although our period seems more accurate, and star 179 has been reported in Clement *et al.* (2001), although without a period estimate.

We also matched our star list with the Gaia proper motion catalog and found 4170 sources in common down to 22.5 mag in g. Panel d) of Figure 1 shows the Gaia proper motions in our field of view around Pal 3. In particular we have the proper motion for 4 variables and all of them seem to fall in the Pal 3 proper motion region supporting their membership to this GC.

4. Preliminary implications

We present an unprecedented wide (2.75 deg^2), long (one year of observations with tipically 28, 14 and 11 epochs in g, r, i) and deep (about 2.5 mag below the HB) investigation of the Pal 3 outskirts. We searched for variable stars analizing the light curves and finding 20 candidates. We searched for periodicity and analized their position on the g, $g-i$ CMD. Three new RR Lyrae candidates perfectly lie on the Pal 3 HB enforcing their membership to the GC. On the other hand, they are located outside the tidal radius and are almost aligned along the north-east direction. These RR Lyrae stars might trace the stars outside the Pal 3 tidal radius but still belonging to the GC. If this is the case, a north-east elongated shape of the external Pal 3 sources is suggested, confirming the results found by Sohn *et al.* (2003). A possible explanation for this elongation is that Pal 3 interacted with the MW and/or it was originally belonging to another system, such as a dwarf spheroidal galaxy as discussed in literature (e.g. Sharina *et al.* 2018 and references therein). Deeper photometry and accurate proper motion of large areas of the Local Group galaxies from large survey telescopes such as the Large Synoptic Survey Telescope (LSST) are expected to better constrain both the Pal 3 variable star population and the supposed link with the Phoenix dwarf galaxy.

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