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Searching for RR Lyrae stars around ω Centauri (NGC5139)

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Abstract. The well known naked-eye globular cluster Omega Centauri (hereafter ω Cen) may be part of the residues of a dwarf galaxy destroyed by the tidal forces due to the Milky Way (MW). In order to search for debris from the progenitor galaxy, we conducted a survey of RR Lyrae stars (RRLS) in an area of 50 sq deg around ω Cen, which is significantly larger than the area studied by previous works. We present the discovery of an overdensity of stars formed by 13 new RRLS (10 RRab and 3 RRc) at distances similar to ω Cen (5.2 kpc) and located outside its tidal radius (r_t > 57 arcmin), extending up to 9 degrees from the center of the cluster. Very few halo stars (~4) are expected in the survey area at the narrow range of magnitudes found for this group. Thus, the region contains an overdensity of RRLS which may constitute evidence for the remains of the progenitor galaxy of ω Cen.

1. Introduction

The globular cluster ω Cen is the most massive $(4.05 \pm 0.10) \times 10^6$ $M_\odot$ D'Souza & Rix (2012) globular cluster in the MW. It also has several unusual properties that led to the proposal that the cluster is the remaining core of a destroyed dwarf galaxy Bekki & Freeman (2003). Some of these unusual properties are: (*i*) a retrograde, low inclination orbit around the MW Dinescu et al. (1999), (*ii*) an overall rapid rotation Merrit et al. (1997), making it one of the more flattened galactic globular clusters White & Shawl (1987), (*iii*) a color-magnitude diagram showing a complex stellar population, with a wide range of metallicities and two main sequences Bedin et al. (2004), (*iv*) a complex chemical pattern King et al. (2012); Gratton et al. (2011); Marino et al. (2012) and (*v*) a high velocity dispersion toward the center which may be indication of it having an intermediate mass black hole $(4 - 5 \times 10^4$ $M_\odot)$ Noyola et al. (2008, 2010); Jalali et al. (2012). It has been proposed that ω Cen may be the equivalent to the M54 + Sagitarius dwarf system but, in the case of ω Cen, the progenitor galaxy must have been already completely destroyed by now Carreta et al. (2010).

The search for remains of the alleged progenitor has not been without controversy. Although Leon et al. (2000) found significant tidal tails coming from the cluster, their results may be have been influenced by variable reddening in that part of the sky. On the other hand, Da Costa & Coleman (2008) made an extensive spectroscopic survey of red giant stars

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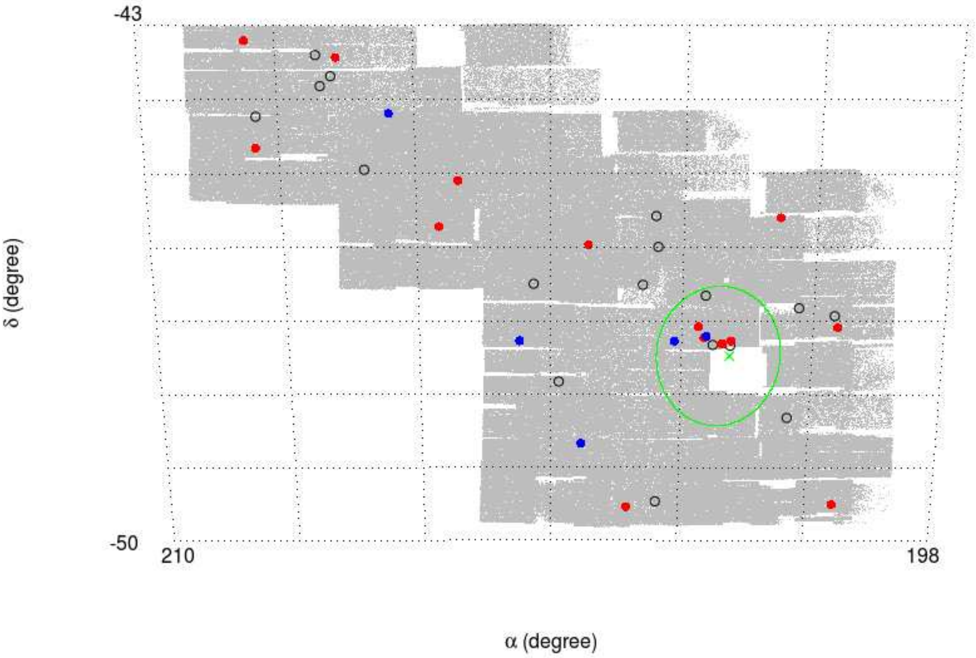

Fig. 1. Spatial distribution of the stars in the survey area. The center of the cluster and its tidal radius are indicated by a green cross and a circle, respectively. RRLS discovered in this work are indicated with small circles, and the ones having mean magnitudes close to the horizontal branch of the cluster are marked with solid circles (red for RRab and blue for RRc).

in the vicinity of the cluster (a region of 2.4 $\times$ 3.9 sq deg) and found no evidence of significant debris. This would have been expected if most of the tidal stripping occurred a long time ago, which is the interpretation given by those authors to their results. More recently, Majewski et al. (2012) found a group of stars in the solar neighborhood with kinematic and, more importantly, chemical properties, which are best interpreted as these stars being associated with ω Cen.

The very particular chemical pattern found in those stars is known to occur only in that cluster. However, in order to understand better the origin of ω Cen, one would like to, ideally, trace debris along other parts of the orbit as well, and most especially near the cluster itself.

ω Cen has a rich population of RRLS Weldrake et al. (2007), as all satellite galaxies of the MW do (e.g. Vivas & Zinn 2006). It is expected that if there really was a galaxy associated with ω Cen, it must has been rich in this type of stars. Although the progenitor galaxy has been completely destroyed by now, debris material should be expected along its orbit. We decided to use this type of stars as tracers of debris around the cluster. Since these stars have almost the same luminosity (they are standard candles), any RRLS in the region having the same magnitude as the horizontal branch of the cluster (V= 14.5 mag) may share a common origin with the cluster.

2. Observations

The techniques used for this survey are similar to the ones used extensively by our group in the galactic halo and the Canis Major overdensity with the QUEST camera Mateu et al. (2009, 2012). The survey was carried out using the 1.0m/1.5m Jurgen Stock telescope (a Schmidt telescope) and the QUEST mosaic camera Baltay et al (2002), at the National Astronomical Observatory of Venezuela. The QUEST camera is a mosaic 16 CCDs (charged coupled devices) with a field of view in the sky of 2.3×2.5 deg^2. Half of the chamber was covered with V filters and the other half with I filters. Multiple observations were obtained for 16 fields around ω Cen during 11 nights over the years 2010 and 2011. We used exposure times of 60s and 90s.

Reductions of the images and aperture photometry were made using custom-built software for the QUEST observations, which makes use of different IRAF tasks. The astrometric calibration was performed using transformation equations obtained by matching our catalogs with UCAC3 Zacharias et al. (2009). Errors in the astrometry are estimated to be of the order of 0.2 arcsec. Instrumental magnitudes were calibrated using as reference catalogs APASS Henden et al. (2012) and DENIS Epchtein et al. (1997), for stars observed in the V and I filters respectively. All magnitudes were normalized to a reference catalog following the methodology used by Vivas et al. (2004). We analysed time series for a total of 659,036 stars, whose distribution in the sky is shown in Figure 1. A color-magnitude diagram of the whole region is shown in Figure 2. Although the survey mostly covers regions well outside ω Cen, the diagram shows some of the expected features of the cluster such as its prominent horizontal branch.

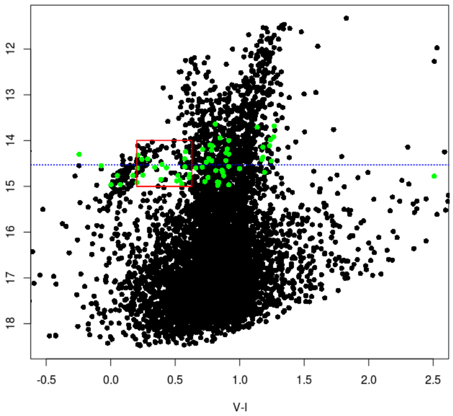

Fig. 2. Color-magnitude diagram of one field observed in this work. Variable stars with $14 \leq V \leq 15$ are indicated with green points. Only the variable stars within the red box were selected for periodicity analysis. The dashed blue line indicates the brightness of the horizontal branch of ωCentauri (V= 14.53mag).

3. Search for RR Lyrae stars

The first step toward identifying RRLS was to detect variable stars in our catalog. We calculated the Pearson distribution (also known as χ^2) for each star. We selected those ones whose probability is $P(\chi^2) < 0.01$, which corresponds to a 99% confidence level of being variable. The list of RRLS candidates was further reduced by selecting only those stars with colors and magnitudes expected for ω Cen (see Figure 2), giving enough space to include possible variations of extinction or distance gradients. Then, all candidates were searched for periodicity in the range between 0.15 and 0.90 days, using the algorithm from Lafler & Kinman (1965). RRLS were finally selected on the basis of its periods, amplitudes and shape of the light curve.

4. Results and conclusions

We detected a total of 36 RRLS in our survey, 29 of which are new discoveries since they were not found in any database in the literature. Examples of light curves are shown in Figure 3. We calculated the distance to these stars assuming an absolute magnitude of M_v=0.55 mag and redenning values from Schlegel et al. (1998), and found that 13 RRLS are at distances similar to the distance of ωCen. These RRLS are spread over the entire survey area, up to $\approx$ 9 deg from the cluster center (see Figure 1). Using the number density profile of

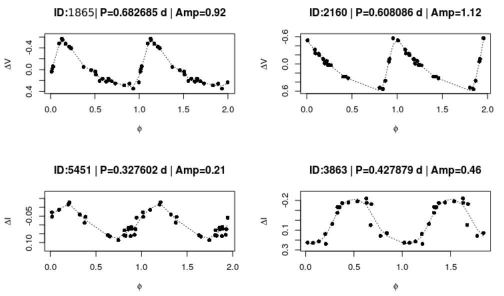

Fig. 3. Sample of lightcurves of RRLS discovered in this work with the QUEST camera at the Venezuelan 1m Schmidt telescope.

RRLS in the halo (e.g. Vivas & Zinn 2006), we calculated the expected number of such stars in the halo in this area of the sky, as a function of distance. For the range of distances between 4.7 kpc and 6.6 kpc, we would expect to find only ~ 4 RRLS. Having found 13 stars in this range of distances is a significant excess and its presence can not be explained as the normal population of the halo.

This excess of RRLS is presumably associated with remnants of a destroyed dwarf galaxy associated with ω Cen, which at some point in the past suffered a gradual process of destruction by tidal forces of the MW (a process also known as galactic cannibalism). Final confirmation requires however the measurement of their radial velocities. The confirmation of these RRLS as part of the ω Cen system will allow us to put constraints on its orbit and on its origin.

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