A&A 577, A99 (2015)
DOI: 10.1051/0004-6361/201424838

Astronomy & Astrophysics

Updated census of RR Lyrae stars in the globular cluster ω Centauri (NGC 5139)★,★★

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Received 20 August 2014 / Accepted 7 January 2015

ABSTRACT

Aims. ω Centauri (NGC 5139) contains many variable stars of different types and, in particular, more than one hundred RR Lyrae stars. This enabled gathering a homogeneous sample (in terms of instrument, image quality, and time coverage) of high-quality near-infrared (NIR) RR Lyrae light curves by performing an extensive time-series campaign aimed at this object. We have conducted a variability survey of ω Cen in the NIR, using ESO's 4.1 m Visible and Infrared Survey Telescope for Astronomy (VISTA). This is the first paper of a series describing our results.

Methods. ω Cen was observed using VIRCAM mounted on VISTA. A total of 42 epochs in J and 100 epochs in K_S were obtained, distributed over a total timespan of 352 days. Point-spread function photometry was performed using DAOPHOT in the inner and DoPhot in the outer regions of the cluster. Periods of the known variable stars were improved when necessary using an ANOVA analysis.

Results. We collected an unprecedented homogeneous and complete NIR catalog of RR Lyrae stars in the field of ω Cen, allowing us to study for the first time all the RR Lyrae stars associated with the cluster, except for four stars that are located far away from the cluster center. We derived membership status, subclassifications between RRab and RRc subtypes, periods, amplitudes, and mean magnitudes for all the stars in our sample. Additionally, four new RR Lyrae stars were discovered, two of which are very likely cluster members. We also discuss here the distribution of ω Cen stars in the Bailey (period-amplitude) diagram. We provide reference lines in this plane for both Oosterhoff Type I (OoI) and Oosterhoff Type II (OoII) components in J and K_S.

Conclusions. We clarify the status of many (candidate) RR Lyrae stars that have been reported as unclear in previous studies. This includes stars with anomalous positions in the color−magnitude diagram, uncertain periods or/and variability types, and possible field interlopers. We conclude that ω Cen hosts a total of 88 RRab and 101 RRc stars, which makes for a grand total of 189 probable members. We confirm that most RRab stars in the cluster appear to belong to an OoII component, as previously found using visual data.

Key words. stars: variables: RR Lyrae – stars: variables: general – globular clusters: individual: ω Centauri – infrared: stars – surveys – stars: horizontal-branch

1. Introduction

RR Lyrae stars (RRLs) are well known for being reliable distance indicators and tracers of the old stellar populations of galaxies (Smith 1995; Catelan 2009; Bono et al. 2011, and references therein). In the dawning era of time-series infrared (IR) photometric surveys, new observations in the near- and mid-IR have recently been providing large and homogeneous samples of RRLs in different environments (e.g., Dékány et al. 2013; Klein et al. 2014), which can be used to improve our understanding of this variability class and are also valuable as tracers of structure in the nearby Universe.

Especially noteworthy, in this context, is the fact that RRLs follow well-defined period-luminosity (PL) relations in the IR (e.g., Longmore et al. 1990; Catelan et al. 2004). Furthermore, the interstellar extinction in K_S is approximately a tenth of the one in the optical, which enables observing RRLs even in the most obscured regions of our Galaxy, for instance, in its inner bulge. Despite these advantages, there are still only a few extensive variability studies in the near-infrared (NIR) because of several drawbacks, including the lack, until recently, of large-format detectors, which rendered NIR surveys extremely costly in terms of observing time. In addition, because many types of variables, including RRLs, have lower amplitudes in the NIR than in the optical, detecting new variables using these filters has proved difficult. The situation has only recently started to

★ Based on observations collected at the European Organisation for Astronomical Research in the Southern Hemisphere, Chile, with the VISTA telescope (project ID 087.D-0472, P.I. R. Angeloni).

★★ Appendices are available in electronic form at http://www.aanda.org change, particularly with the start of operations of ESO's 4.1 m Visible and Infrared Survey Telescope for Astronomy (VISTA), located in Cerro Paranal, Chile (Emerson et al. 2006; Emerson & Sutherland 2010).

The VISTA Variables in the Vía Láctea (VVV) ESO Public Survey is an extensive variability study in the K_S band of the Galactic bulge and an adjacent portion of the disk (see Minniti et al. 2010; Catelan et al. 2011, 2013, and references therein). To automatically classify the large samples of variable stars detected by this survey, our team started to build a database of well-defined, high-quality NIR light curves for various variability classes – the VVV Templates Project[1] (Catelan et al. 2013; Angeloni et al. 2014). In this context, ω Centauri (NGC 5139) was identified early on as one of the most suitable targets to obtain template light curves because it hosts a large number and variety of variable stars.

ω Cen stands out as one of the three most RRL-rich globular clusters known, only surpassed by M3 (NGC 5272, with 230 RRLs; Clementini et al. 2004) and M62 (NGC 6626, with 224 RRLs; Contreras et al. 2005, 2010). From the several variability studies that have been carried out in the optical over the years with different telescopes and temporal baselines, a large (although still incomplete) catalog of RRLs in ω Cen has been produced (Clement et al. 2001; Clement's online catalog[2], 2013 edition, hereafter C13). A wide-field NIR variability survey of ω Cen allows us to derive and calibrate the NIR PL relations of several different types of stars, including SX Phoenicis, Type II Cepheids, and RRL stars. In this sense, our study of ω Cen with VIRCAM mounted on VISTA has provided the largest homogeneous NIR sample of RRLs ever collected in any globular cluster, which leads to tight PL relations, as we will describe in our next papers in this series on ω Cen variables.

ω Cen is the most massive and luminous globular cluster in the Milky Way, and it may have been even more massive in the past (e.g., Valcarce & Catelan 2011, and references therein). Today, ω Cen is well known for hosting at least two stellar populations with metallicity peaks centered at [Fe/H] ~ -1.6 and -1.1 dex (Bedin et al. 2004; Joo & Lee 2013, and references therein). In addition to presenting variations in [Fe/H] that may be correlated with age, it has been found that ω Cen's stars also present variations in the abundances of many other elements, both heavy and light, in addition to helium (at a level $\Delta Y \sim 0.17$ dex) and age (e.g., Norris 2004; Piotto et al. 2005; Dupree et al. 2011; Valcarce & Catelan 2011).

Although He enhancement appears to be required to explain the lower color−magnitude diagram (CMD) morphology of ω Cen, an impact on the cluster's variable stars has not yet been established. Sollima et al. (2006) found that the RRL stars with metal-intermediate composition ([Fe/H] ~ -1.2), fainter than the bulk of the dominant metal-poor population (with primordial helium abundances and [Fe/H] ~ -1.7 dex), agree well with the corresponding horizontal branch (HB) models with $Y = 0.246$. More recently, Marconi et al. (2011) studied the impact of the helium content on the RRL properties based on evolutionary and pulsation models and again found no evidence of He enhancement among the RRL stars. The most likely interpretation of these results is that any He-enhanced populations in the cluster probably end up far toward the blue on the zero-age HB and therefore probably do not populate the classical instability strip (e.g., Joo & Lee 2013).

In addition to describing our VISTA observations, we also update the census of RRLs in ω Cen in this paper. Using our data and comparing them with previous studies, we provide a comprehensive assessment of their number, types, membership probabilities, and light curves, and also report improved light curves for several RRL variables. We point out some erroneous cross-identifications between the Weldrake et al. (2007) and Kaluzny et al. (2004) catalogs and propose a change in classification for a few stars. The membership status of all the suspected field stars is revisited. Last but not least, we present four new RRLs, two of which we classify as genuine cluster members. In future papers of this series, we will study the NIR PL relations for RRL, Type II Cepheids, and SX Phe stars and present the full updated catalog of variable stars (also including eclipsing binaries) in the ω Cen field.

2. Observations

A total of 42 epochs in J and 100 epochs and K_S were taken using VIRCAM (Dalton et al. 2006) mounted on VISTA (Emerson et al. 2006; Emerson & Sutherland 2010). All of the images were centered on the cluster center. The heart of the VIRCAM camera is a 4×4 array of Raytheon VIRGO IR detectors (2048×2048 pixels), with a pixel size of $0\farcs34$ (Dalton et al. 2006). The size of a uniformly covered field (also called a "tile") is 1.501 deg^2, which allows unprecedented spatial coverage in the NIR bandpasses. The effective field of view (FoV) of the camera is larger than that used in the previous studies of Kaluzny et al. (2004) and Weldrake et al. (2007), which were both carried out in the visible, but still not large enough to cover ω Cen in its whole extension (its tidal radius is $\simeq 52'$; e.g., Ferraro et al. 2006, and references therein). Our observations have a baseline of 352 days, which provides an unprecedented phase coverage in the NIR.

The characteristics of the observations, data reduction, and photometry extraction are the same as those explained in Navarrete et al. (2013). In particular, the images were reduced by the Cambridge Astronomy Survey Unit (CASU)[3], and crowded-field, point-spread function (PSF) photometry was performed using the DAOPHOT II/ALLFRAME (Stetson 1987, 1994) and DoPhot (Schechter et al. 1993; Alonso-García et al. 2012) photometry packages for the cluster central (i.e., the innermost $\sim 10'$) and outer regions, respectively.

The DoPhot and ALLFRAME photometries were calibrated independently using the aperture photometry provided by CASU, which is in the VISTA photometric system. As described in detail in Minniti et al. (2010), the CASU pipeline determines the photometric zero points using 2MASS stars (Skrutskie et al. 2006) in the pawprint frames, then transforming these 2MASS magnitudes into VISTA magnitudes according to the equations derived by Hodgkin et al. (2009). We then compared the magnitudes for common stars derived using both packages and found excellent agreement in the magnitude calibration (at the level of RRL stars, the average K_S-band magnitude difference between the DoPhot and ALLFRAME magnitudes is only ~ 0.01 mag).

3. Results

Time-series photometry of most of the previously known variable stars listed by C13 (from V1 to V410) and Weldrake et al. (2007) was recovered using a cross-match between these catalogs and our complete PSF photometric catalog (i.e., photometry

[1] http://www.vvvtemplates.org
[2] http://www.astro.utoronto.ca/~cclement/read.html
[3] http://casu.ast.cam.ac.uk/surveys-projects/vista

for all the stars at all the observed epochs). The matching radius was set at 1″. When one star was not recovered with this procedure, the catalog of Samus et al. (2009) was used as reference. This catalog lists variable stars from V1 to V293, most of them with updated coordinates based on 2MASS observations. The cross-match with this catalog allowed us to recover 16 variable stars (including eight RRL, three SX Phoenicis, four eclipsing binaries, and one spotted variable) that were not recovered using the catalog of C13. When neither of these reference catalogs gave a match for a certain variable star, an increasing matching radius was used until a known variable star was found. To pinpoint the latter, the time series for all stars that were inside the matching radius were phased using the stellar period as listed by C13, until reasonable agreement was found. As a consistency check, periods for these stars were also calculated using the ANOVA algorithm (Schwarzenberg-Czerny 1989) in an effort to determine whether the known variable was present in the area covered by the matching radius, but with a different period according to our observations. This approach led to the discovery of V411 as a new RRL star (Navarrete et al. 2013), which Weldrake et al. (2007) had previously (but incorrectly) claimed to be the same as V144 from the catalog of Kaluzny et al. (2004).

Figure 1 shows the ω Cen K_S vs. $(J - K_S)$ CMD as obtained from our ALLFRAME photometry for the central regions (see Sect. 2). In this diagram, RRLs from the whole observed area are superimposed as red circles for RRab (i.e., fundamental-mode) and blue circles for RRc (first-overtone) types. Star symbols indicate variables from Weldrake et al. (2007; see Appendix B), and new variables are shown as open circles (see Sect. 3.3). Most of the RRLs are located in the horizontal branch (HB), as expected for bona fide cluster members, but a few stars fall close to the main sequence, or even at the turn-off point. A zoom-in around the RRL instability strip (IS) region is shown in the bottom panel of Fig. 1, where there are also two Type II Cepheids, marked as green triangles. All the RRL stars labeled in both figures were considered in our analysis and studied in terms of their periods, variability types, and cluster membership. In the following, we clarify the status of many of the RRL stars in ω Cen that have been reported as unclear in previous studies. This includes stars with anomalous CMD positions, uncertain periods or/and variability types, and possible field interlopers.

Table 1 lists the characteristics of 21 previously known RRL that either have anomalous positions in the CMD, were suggested as field stars by previous studies (and fall within our FoV), or do not have periods (or even variability type) listed in the literature. Column 1 lists the ID of the variables according to C13, except for the two stars from Weldrake et al. (2007), because they are not included in the catalog of C13 (ID-91, ID-99); Cols. 2 and 3 show the coordinates based on VISTA astrometry (which in turn is tied to the 2MASS system); Cols. 4 and 5 display the intensity-weighted mean J and K_S magnitudes; Col. 6 gives our derived periods, while the variability type (RRab, RRc, eclipsing binary (EB), or anomalous Cepheid (ACEP)) is given in Col. 7; the distance to the cluster center for each variable is listed in Col. 8. The membership probability for the stars, according to the two main proper motion studies of ω Cen, are listed in Cols. 9 and 10, as provided by van Leeuwen et al. (2000, hereafter vL00) and Bellini et al. (2009, hereafter B09)[4]. Finally, Col. 11 shows the membership status according to our

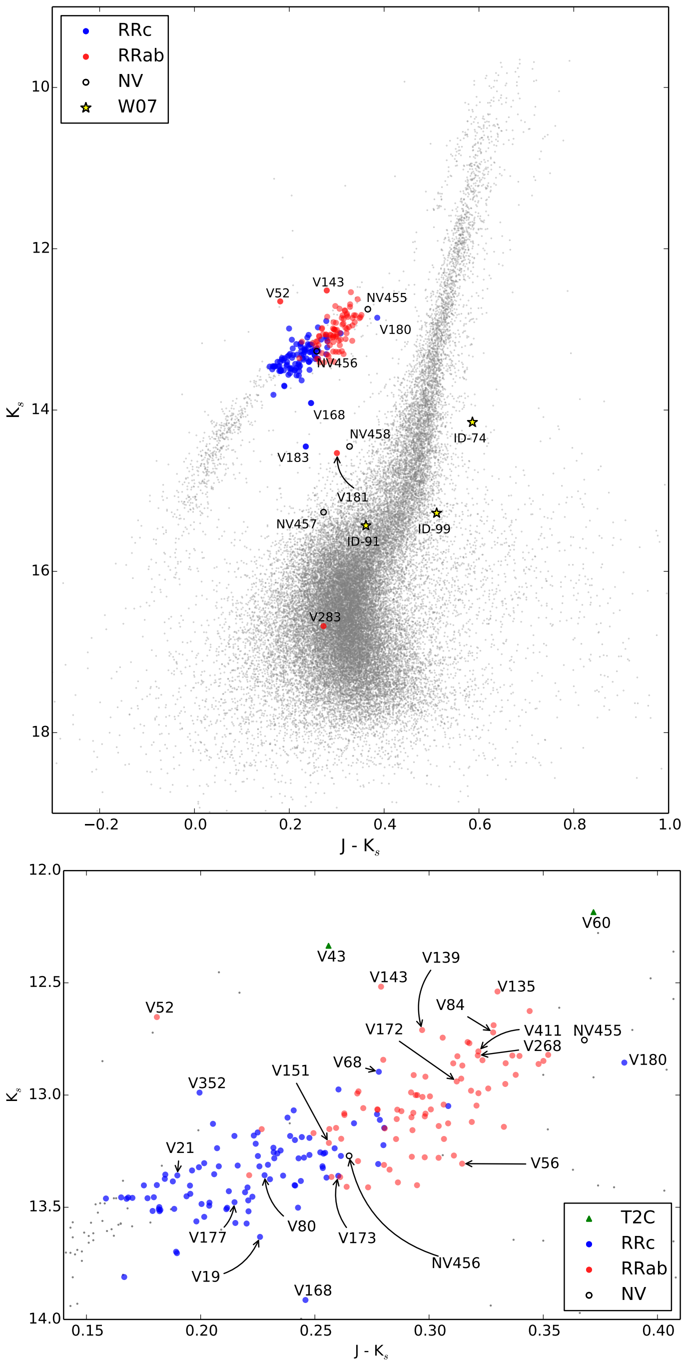

Fig. 1. *Top*: CMD of the central part of the cluster (11 arcmin^2, grey dots). ab- and c-type RRL are marked as red and blue circles, respectively. RRL from Weldrake et al. (2007) are marked as star symbols. Open circles mark the new RRLs found in this work, with NV455 and NV456 (labeled) likely being cluster members (see Sect. 3.3). Field, blended, or erroneously classified stars are labeled and explained in the text. *Bottom*: zoom-in around the RRL region in the CMD of ω Cen, with a few noteworthy stars labeled. V43 and V60, marked with green triangles, are known Type II Cepheids.

[4] van Leeuwen et al. (2000) constructed a proper motion catalogue for stars in ω Cen based on observations of photographic plates of the cluster, taken between 1931 and 1983 with the Yale-Columbia 66-cm telescope. The covered area has a radius of ∼30′ (about 60% of the cluster's tidal radius). The B09 proper motion catalogue was in turn derived from astrometry based on CCD images taken with the Wide-Field Imager on the 2.2-m telescope at ESO La Silla, with a precision of ∼7 mas. The B09 observations were carried out with a baseline of 4 years, and extend to a limiting magnitude of $B \sim 20$ mag, which is up to four magnitudes deeper than previous studies.

Table 1. Properties of member and field RRLs with previously uncertain status.

ID	RA (J2000)	Dec (J2000)	$\langle J \rangle$ (mag)	$\langle K_S \rangle$ (mag)	P^a (days)	Type	d^b (arcmin)	$\mathcal{P}_\mu^{\rm vL00}$ (%)	$\mathcal{P}_\mu^{\rm B09}$ (%)	Memb. status
V19	13:27:30.12	−47:28:05.74	13.852	13.631	0.299551	RRc	7.27	100	100	m
V21	13:26:11.15	−47:25:59.30	13.538	13.362	0.380812	RRc	6.71	100	99	m
V52	13:26:35.15	−47:28:04.33	12.831	12.634	0.660386	RRab	2.16	53	45	m
V56	13:25:55.44	−47:37:44.44	13.612	13.301	0.568023	RRab	12.53	98	100	m
V68	13:26:12.79	−47:19:36.12	13.168	12.897	0.534696	RRc/ACEP?	10.87	100	100	m?
V80[c]	13:28:54.96	−47:30:16.42	13.568	13.360	0.37718	RRc	21.62	out	out	m
V84	13:24:47.47	−47:49:56.18	13.031	12.712	0.579873	RRab/ACEP?	29.24	0	out	m?
V143	13:26:42.59	−47:27:28.98	12.783	12.510	0.820734	RRab	1.51	90	99	m
V151	13:28:25.31	−47:16:00.01	13.455	13.211	0.407756	RRc	20.94	out	out	m
V168	13:25:52.74	−47:32:03.19	14.164	13.916	0.321299	RRc	9.78	0	0	f
V172[d]	13:27:55.04	−47:04:38.50	13.220	12.927	0.7380	RRab	26.72	out	out	m
V173	13:29:43.13	−47:16:53.80	13.624	13.360	0.3590	RRc	32.05	out	out	m
V177[e]	13:29:04.15	−47:36:21.42	13.690	13.479	0.31469	RRc	24.31	out	out	m
V180	13:28:15.22	−47:40:32.02	13.201	12.839	0.39006	W UMa	18.93	0	out	f
V181	13:30:00.35	−47:48:44.96	14.823	14.535	0.5884	RRab	38.17	out	out	f
V183	13:29:39.50	−47:30:18.36	14.690	14.449	0.29603	RRc	29.13	out	out	f
V268	13:26:35.11	−47:26:11.15	13.156	12.827	0.812922	RRab	3.30	70	99	m
V283	13:27:36.53	−47:46:40.44	16.947	16.682	0.517233	RRab	19.73	out	out	f
V411[f]	13:26:40.77	−47:28:17.00	13.123	12.796	0.8449	RRab	1.20	100	99	m
V433[g]	13:29:03.59	−47:48:58.25	14.737	14.151	0.6681	?	30.58	out	out	f
ID−91	13:26:14.03	−47:53:08.20	15.782	15.430	0.637238	RRab?	25.00	out	out	f
ID−99	13:24:40.44	−47:45:22.54	15.777	15.275	0.670361	?	27.07	out	out	f

Notes. [a] Periods are from Kaluzny et al. (2004), except for V80, V172, V173, V177, V180, V181, V183, and V411, which were derived by us. [b] Distance to the cluster center was calculated using the center of ω Cen as reported by SIMBAD: RA = 13:26:47.28, Dec = −47:28:46.1, both in J2000. [c] ID-53 in Weldrake et al. (2007). [d] ID-18 in Weldrake et al. (2007). [e] ID-49 in Weldrake et al. (2007). [f] V411 has the same coordinates and periods as first reported by Navarrete et al. (2013). Mean magnitudes differ from that paper because the values presented in this paper, but not in Navarrete et al. (2013), are intensity-averaged mean magnitudes. [g] ID-74 in Weldrake et al. (2007).

photometric study (m: member, f: field). A brief description of each of these variables is presented in the appendix.

3.1. Bailey diagram

As shown by Clement & Rowe (2000) based on visual data, individual stars in ω Cen predominantly follow a locus on the Bailey diagram (period-amplitude plane) that is characteristic of Oosterhoff Type II (OoII) systems, with individual RRL typically having longer periods at a given amplitude than their Oosterhoff Type I (OoI) counterparts. The details, systematics, astrophysical interpretation, and importance of the Oosterhoff phenomenon are extensively discussed in Catelan (2009).

Figure 2 for the first time shows the distribution of ω Cen RRL stars in the NIR Bailey diagram in the J (top panel) and in the K_S (bottom panel) bands. RRab stars with documented Blazhko effect (Blazhko 1907) in the catalog of Kaluzny et al. (2004) are plotted as open red circles. These plots show several features. First, the positions occupied by c- and ab-type RRL stars are clearly very different, as also seen in the visual. Second, there is significantly more scatter in the K_S-band Bailey diagram than is present in J. This is, at least in part, because the amplitudes in K_S are smaller than in J. Third, and as is also commonly seen in the visible, the Blazhko stars tend to have smaller amplitudes at a given period than their non-Blazhko counterparts. This is particularly noteworthy because the actual amplitude modulation that is caused by the Blazhko effect is not clearly seen in our NIR data for any of ω Cen's RRab stars, which could be either because the amplitude changes are too small in the NIR (notwithstanding the fact that Fig. 2 might hint at amplitude modulations exceeding 0.1 mag in at least some cases), and/or because our time coverage is insufficient to reveal long-term modulation (we recall that our observations have a timespan of ~300 days, with gaps). Indeed, to the best of our knowledge, there have been no precise measurements of the Blazhko effect in the IR, even though Sollima et al. (2008) have reported increased scatter in their NIR light curves of RR Lyr itself, which they attributed to the star's well-known Blazhko-type light-curve modulation. Fourth, there is a tendency for the locus occupied by ab-type RRL to flatten out as one moves from bluer to redder wavelengths. In fact, this trend appears to continue toward the mid-IR regime, where the relation eventually becomes completely flat (Gavrilchenko et al. 2014). Fifth, and again as previously emphasized by Clement & Rowe (2000), most RRab stars in ω Cen tend to clump around a fairly well-defined locus, particularly in the J-band Bailey diagram. Based on our J amplitudes for the OoII-like RRab stars, this locus is fitted by the following expression:

$$\mathcal{A}_J^{\rm OoII} = 0.064 - 2.481 \log P + 10.345 (\log P)^3 , \qquad (1)$$

where the period is given in days. The amplitude-period correlation given by Eq. (1) is plotted as a dashed line in the J-band Bailey diagram (Fig. 2, upper panel). That this indeed corresponds to the OoII component reported by Clement & Rowe can be seen by the fact that this line is significantly displaced toward longer periods, compared to the OoI reference line (also shown in Fig. 2).

As can be seen from Fig. 3, there is a fairly tight relation between J- and K_S-band RRL amplitudes, which is described by the following expression:

$$\mathcal{A}_J = 2.6\, \mathcal{A}_{K_S}^{3/2}. \qquad (2)$$

Equation (2) was used to obtain the K_S-band equivalent of Eq. (1). The OoII reference locus obtained in this way is

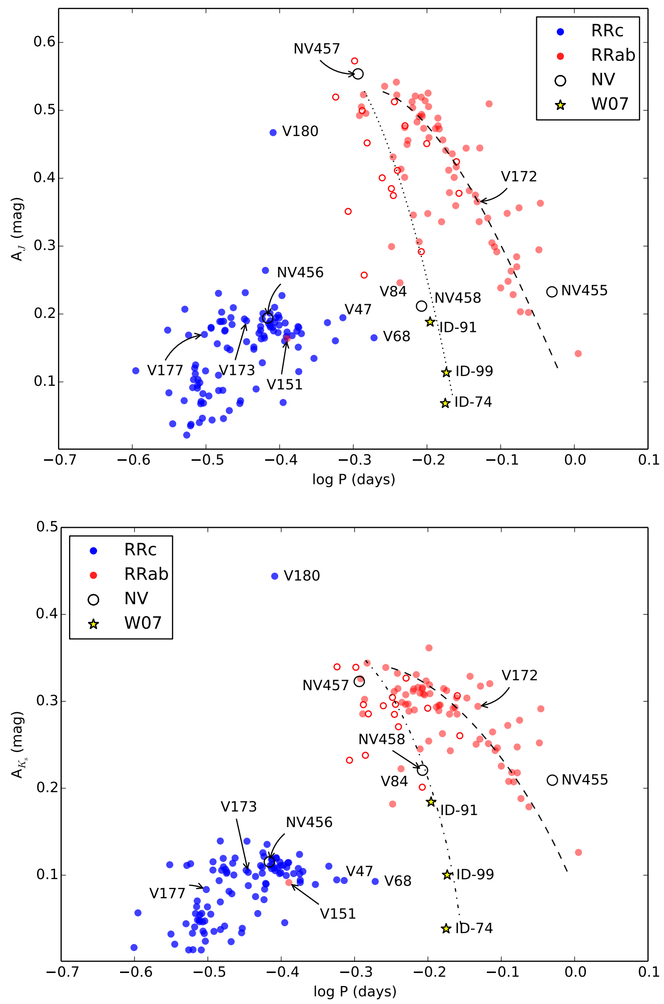

Fig. 2. Bailey diagrams for all the RRL stars known in the ω Cen field, based on J- (*top*) and K_S-band *bottom* light curves. The overplotted lines define representative loci of "OoII-like" (dashed lines) and "OoI-like" (dotted lines) behavior for the ab-type RRL, obtained as described in the text. RRab stars with documented Blazhko effect are marked with open circles. Clearly, V180 has too large an amplitude for its claimed RRc status; instead, we believe that the star is a contact binary of the W UMa type with twice the alternative "RRc-like" period. V151 is clearly an RRc star.

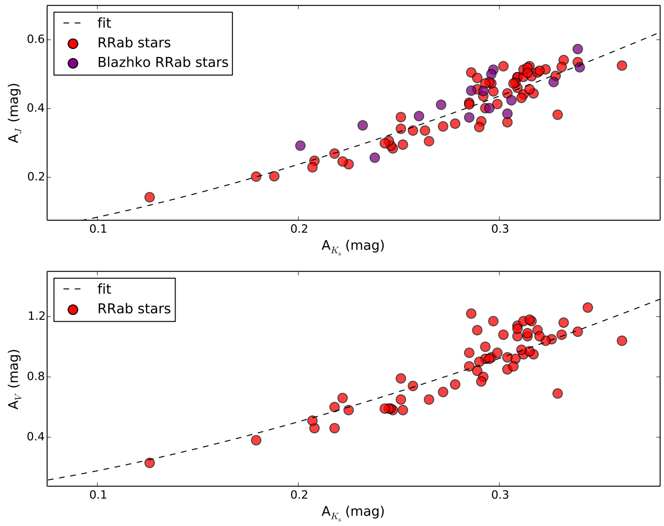

Fig. 3. Relation between K_S- and J-band amplitudes (*top*) and K_S- and V-band amplitudes (*bottom*) for ω Cen RRab stars. The dashed lines are the fit to the data (Eqs. (2) and (4)).

overplotted in the bottom panel of Fig. 2 as a dashed line, clearly showing the expected period shift with respect to the (minority) OoI-like RRL stars in ω Cen.

Unfortunately, there are few stars in ω Cen that belong to the OoI component (Clement & Rowe 2000), and thus we cannot define the OoI reference line reliably based solely on our data. Therefore, to obtain an OoI reference locus in the NIR, we used as a reference the V-band OoI line from Cacciari et al. (2005) and Zorotovic et al. (2010), transformed into the NIR bandpasses by means of the following relations:

$$\mathcal{A}_J = 0.46\,\mathcal{A}_V, \tag{3}$$

$$\mathcal{A}_{K_S} = 0.32\,\mathcal{A}_V^{2/3}, \tag{4}$$

both of which are based on ω Cen RRab stars, with visual amplitudes coming from Kaluzny et al. (2004). The corresponding J- and K_S-band OoI lines are shown in Fig. 2 as dotted lines. The presence of OoI-like RRL stars in ω Cen is confirmed and is especially evident in the J-band Bailey diagram.

These interrelations involving $\mathcal{A}_V$, $\mathcal{A}_J$, and $\mathcal{A}_{K_S}$, compared to those previously presented by Feast et al. (2008), provide a description of the amplitudes that is physically better motivated, because it more properly describes their asymptotic behavior toward vanishing light-curve amplitudes.

It is still debated whether the position of stars on the Bailey diagram, and therefore the Oosterhoff type, is determined primarily by the metallicity of the cluster or by its HB morphology (Clement & Rowe 2000; Rey et al. 2000; Contreras et al. 2005, 2010, and references therein). In this respect, ω Cen provides an interesting test of the relative importance of HB morphology and [Fe/H] in defining the Oosterhoff classification, given that the cluster possesses a predominantly blue HB, as in the case of most OoII clusters, but also shows at least two well-defined metallicity peaks, separated by ≈0.5 dex. To further investigate the possible impact of metallicity upon the distribution of RRL stars in the NIR Bailey diagrams, Fig. 4 again shows the Bailey diagrams in both J and K_S, but separating the RRL into three metallicity bins based on the [Fe/H] values from Sollima et al. (2006) and Rey et al. (2000). The bin sizes were chosen so as to ensure an equal number of RRab stars in each bin. For stars with [Fe/H] measurements in both catalogs, the metallicities of Sollima et al. were preferred.

As shown in Fig. 4, ω Cen can still (as expected) be safely classified as predominantly an OoII GC, which perfectly agrees with its predominantly blue HB morphology. This figure also shows that the NIR Bailey diagrams for ω Cen ab-type RRL stars is mainly insensitive to metallicity, in the sense that the average OoII and OoI loci, defined as above, also adequately represent the mean loci occupied by RRL in each individual metallicity bin. It is interesting to note, however, that the OoI/OoII number ratio does change with metallicity: there are virtually no RRL stars close to the OoI locus in the lowest metallicity bin; conversely, in the highest-metallicity bin, RRab stars are more evenly divided between OoII and OoI subclasses. This confirms previous results from Rey et al. (2000) that were based on visual data, even though the impact of metallicity at low [Fe/H] was stronger in their case. Thus, HB morphology and metallicity both appear to be important in determining the Oosterhoff type.

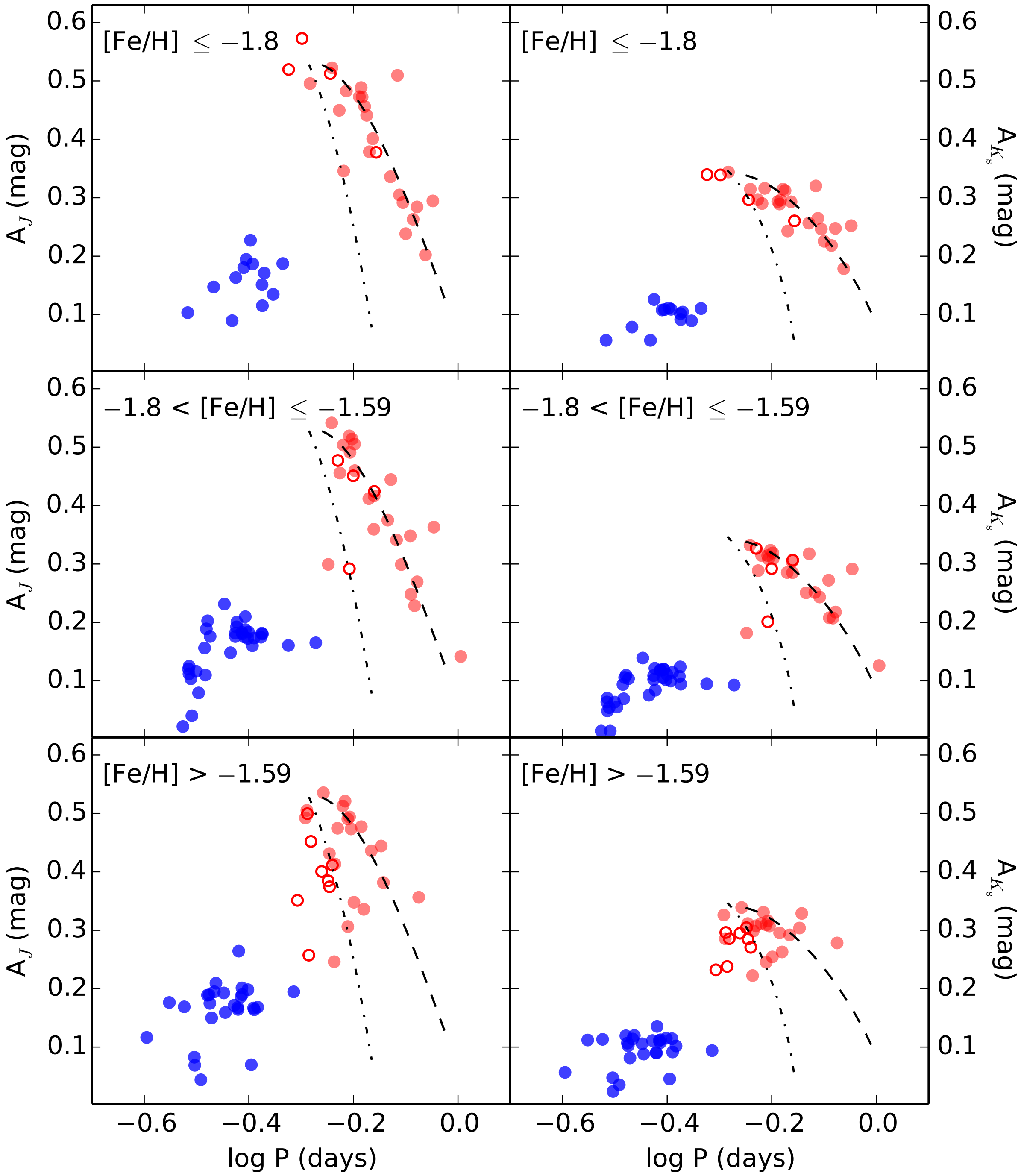

Fig. 4. As in Fig. 2, but separating the RRL stars into three metallicity bins, from lowest (*top*) to highest (*bottom*). The sizes of the bins were chosen so as to include the same number of RRab stars in each.

Interestingly, Fig. 9 in Rey et al. (2000) suggests that the ω Cen ab-type RR Lyrae with the longest periods (i.e., $P \gtrsim 0.71$ d) all belong to the metal-intermediate bin, but this is not immediately obvious from our plot. We tested whether this difference is simply due to the different metallicity bins selected by Rey et al. and our study. Even using the metallicities reported by Sollima et al. (2006), the long-period RRab's of ω Cen occupy a very limited range in [Fe/H], between −1.81 and −1.64 according to our analysis. This can be understood in terms of the evolutionary scenario proposed by Lee (1991), according to which the HB component over this metallicity range is extremely blue and therefore preferentially produces overluminous long-period RRL stars.

3.2. Low-amplitude RRc stars

Some RRc stars in ω Cen are known to have very low amplitudes in the visible, at the level of $\mathcal{A}_V < 0.1$ mag (Kaluzny et al. 2004). Specific examples include V281 ($\mathcal{A}_V \approx 0.07$ mag), V344 ($\mathcal{A}_V \approx 0.08$ mag), V357 ($\mathcal{A}_V \approx 0.05$ mag), and V399 ($\mathcal{A}_V \approx 0.05$ mag). We do not expect to recover the variability of these stars from our NIR observations because the amplitudes in the NIR are even

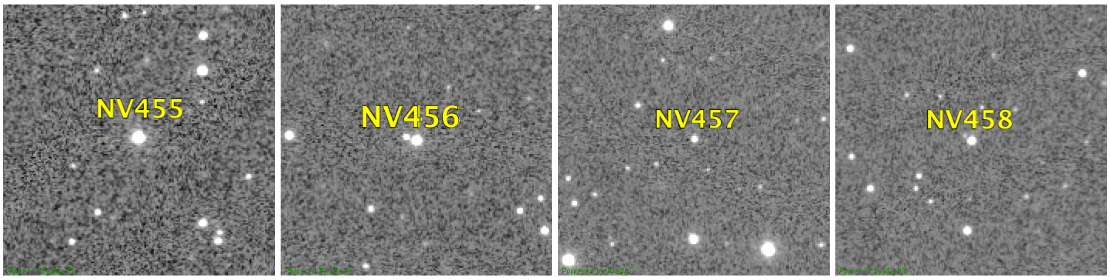

Fig. 5. Finding charts for the 4 new RRL candidates that were discovered in our VISTA images. North is up and east to the left, and each stamp covers a field of 1 arcmin^2. The discovered candidates are the stars at the center of each stamp. The first two stamps correspond to 2 new RRL members of ω Cen, based on their position in the CMD (Fig. 1), whereas the remaining ones, according to the same CMD, are field interlopers, in the cluster background.

Table 2. New RR Lyrae candidate stars.

ID	RA (J2000)	Dec (J2000)	$\langle J \rangle$ (mag)	$\langle K_S \rangle$ (mag)	P (days)	Type	d (arcmin)	Memb. status
NV455	13:27:53.94	−46:55:43.93	13.132	12.760	0.932469	RRab	34.92	m
NV456	13:22:14.49	−47:24:21.64	13.530	13.270	0.383516	RRc	46.33	m
NV457	13:29:54.56	−47:50:46.00	15.530	15.265	0.508593	RRab	38.45	f
NV458	13:30:00.09	−47:13:05.63	14.772	14.441	0.620313	RRab	36.23	f

Notes. Columns have the same meaning as in Table 1.

lower than in the optical (Smith 1995). Indeed, none of these stars were found to be variable in our data.

In this context, we also note that clean light curves for V339 and V340 could not be recovered either, even though their V amplitudes ($\mathcal{A}_V \approx 0.11$ mag and 0.17 mag, respectively) are perhaps high enough that one might have expected non-negligible J and K_S amplitudes. A possible explanation for their non-detection in our data is their marked multiperiodic behavior, which renders even their V-band light curves somewhat noisy (Kaluzny et al. 2004).

3.3. New RR Lyrae stars

To detect additional, previously unknown variable stars in and around ω Cen, we performed a new search for variable stars over the complete area covered by our observations. Our procedure consisted of considering as candidate variables all those stars whose light curves implied root-mean-square magnitude deviations that were higher than the average trend for non-variable stars at the same magnitude. The search was independently performed in J and K_S. With the goal of specifically detecting RRL and other periodic variables, the four most prominent periods for each star, as returned by the ANOVA algorithm (Schwarzenberg-Czerny 1989), were used to plot phase-folded variables. From this search, four variable star candidates have periods and amplitudes in accordance with their being RRL stars. Figure 5 shows the finding chart for these new discovered RRL candidates. None of them appears to present the Blazhko effect. The remaining candidates, which may belong to different variability classes, will be discussed in future papers of this series.

Table 2 gives the ID (following the numbering scheme from the C13 online catalog), coordinates, intensity-weighted mean J and K_S magnitudes, periods, type, and the distance to the center of the cluster. According to their position in the CMD, NV455 and NV456 are probably members of the cluster, whereas the other two stars deviate strongly from the main HB locus – and since they are fainter, they are almost certainly field stars in the cluster background. J- and K_S-band light curves are presented in Fig. 6. According to their light-curve shapes as well as according to their periods (Table 2) and positions in the Bailey diagram (Fig. 2), we assign an RRc type to the new variable NV456 and an RRab type to variables NV455, NV457, and NV458. Incidentally, NV455, with a period of about 0.932 d, is the RRab star with the third longest period known to date in ω Cen (see Fig. 2).

Recently, Fernández Trincado et al. (2013) also performed a variability search in the V band over an area of 50 deg^2 around ω Cen, with the main aim of detecting RRL stars and in this way find evidence for tidal debris from the putative dwarf galaxy progenitor of the cluster (e.g., Dinescu 2002; Altmann et al. 2005; Carretta et al. 2010; Valcarce & Catelan 2011). They found 29 new RRL stars, and recovered 7 previously known ones. Of these, a total of 11 are in the area covered by our observations, and they were all independently recovered in our study as well. Their remaining RRL are all outside ω Cen's tidal radius, and they are reported on in more detail in Fernández-Trincado et al. (2015).

4. Summary

Based on previous ω Cen variability studies, from Bailey (1902) until Kaluzny et al. (2004), C13 reported that there are 193 RRL stars in the field of the cluster. Among these are 92 RRab, 100 RRc, and 1 star classified as RR? (V80). None of the 5 new RRL claimed by Weldrake et al. (2007) were included in the catalog of C13 because, as we have seen, only two of them are really newly discovered – and for these two stars, ID-91 and ID-99, an RRL classification still remains uncertain.

On the other hand, ID-74, which Weldrake et al. (2007) classified simply as "pulsating", was included in the catalog of C13 as a possible RRL, based on its period (0.6671 d). In this way, it was also given the official ID V433 by C13. However, we have been unable to recover the star's variability using our NIR data. Moreover, its NIR magnitude and color place the star close to

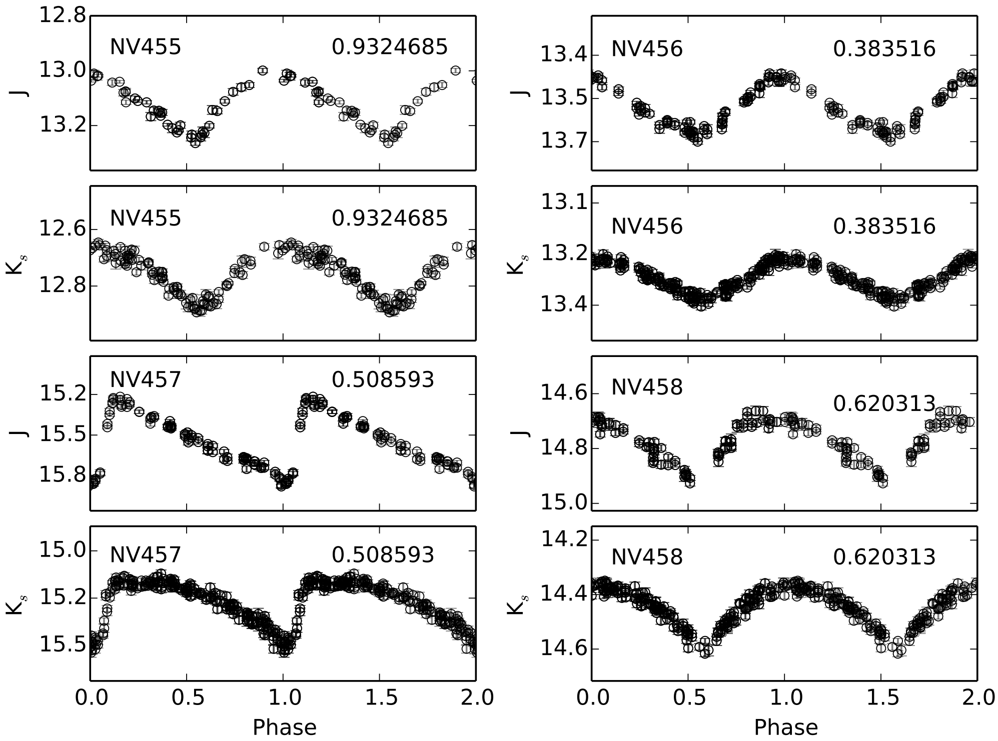

Fig. 6. J and K_S-band light curves of the newly discovered RRL stars that are probably cluster members.

but to the red of the base of the red giant branch, rather than on the classical IS. Recently, Navarrete et al. (2013) found a misidentified RRab star, V411, in the catalog of Weldrake et al. Before this publication, therefore, 194 RRL stars in all (93 and 100 RRab and RRc, respectively) have been listed for the ω Cen field, where we have not included any of the "new" candidates in the catalog of Weldrake et al. in this number count.

Considering the information obtained with the VISTA observations, the light curves of some RRLs were recovered for the first time, leading to changes in the variability classification. In particular, we were able to provide the first light curves ever for V80, thus establishing that it is an RRc star. V151, V173, and V177, all of which had previously been considered ab-types, are shown to be RRc stars from our data. On the other hand, we found that V180 is not an RRc, as previously thought, but rather a contact binary of the W UMa type. Furthermore, 4 new variables were found using VISTA: 3 RRab stars and 1 RRc star. This means that there are now 197 known RRLs in the ω Cen field, including 93 RRab and 104 RRc stars.

Of these 197 RRLs, 4 are RRab (V181, V283, NV457, and NV458) and 2 RRc (V168 and V183) stars that have magnitudes and colors consistent with being field interlopers. In addition, if we exclude V68 and V84 because of their controversial classification (with the distinct possibility that they may be ACEP stars, rather than RRLs), the final census of probable RRL members of ω Cen includes 88 RRab and 101 RRc stars, which make up a grand total of 189.

It was not possible for our team to observe some distant RRLs such as V171, V178, V179, and V182 because they fall outside the FoV of VIRCAM at VISTA, but they are located outside the tidal radius of the cluster and are therefore most probably field stars. Such distant RRLs in the neighborhood of ω Cen were recently studied by Fernández-Trincado et al. (2015), to which we refer the interested reader for further information.

In a forthcoming paper, we will present a detailed analysis of the NIR period-luminosity relations followed by RRLs as well as Type II Cepheids and SX Phoenicis stars in the ω Cen field, based on our VISTA observations. This will be followed by a paper providing the complete updated catalog of variable stars in ω Cen, including the full list of RRL, Type II Cepheids, SX Phoenicis stars, eclipsing binaries, and anomalous Cepheids, along with their NIR properties.

Acknowledgements. We warmly thank A. K. Vivas for useful discussions and information regarding her team's variability search around ω Cen. We also thank the anonymous referee for useful comments that helped improve the presentation of our results. Support for this project is provided by the Ministry for the Economy, Development, and Tourism's Programa Iniciativa Científica Milenio through grant IC 120009, awarded to the Millennium Institute of Astrophysics (MAS); by Proyecto Basal PFB-06/2007; and by FONDECYT grants #1141141 (C.N., F.G., M.C.), #1130196 (F.G., D.M.), #3130320 (R.C.R.), and #3130552 (J.A.-G.). C.N. and F.G. acknowledge additional support from CONICYT-PCHA/Magíster Nacional (grants 2012-22121934 and 2014-22141509, respectively).

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Appendix A: Notes on individual RR Lyrae stars

V19 and V21: in the catalog of C13, these variables are listed as possible non-members because their Fourier parameters are anomalous compared with other variables with similar periods (Clement & Rowe 2000). However, and as indicated in Table 1, the proper motion studies of vL00 and B09 found a membership probability $\mathcal{P}_\mu$ of (100%, 100%) and (100%, 99%) for V19 and V21, respectively. The membership status for these two stars is further supported by their position in our NIR CMD, which locates them in the middle of the RRL IS (see the bottom panel of Fig. 1).

V52: this star appears to be much brighter than other RRab stars in ω Cen, as can be noted in Fig. 1. Its light curve has high photometric errors despite its high luminosity, thus suggesting contamination due to blending. Indeed, vL00 reported that V52 may have an unresolved companion, which would account for the fact that it is brighter and has a lower amplitude than other RRL variables with the same period. According to vL00 and B09, the membership probability of this star is 42% and 53%, respectively. Based on its position in our NIR CMD, the projected distance to the cluster center, $d \sim 2'$, and the high amount of noise in the light curve, V52 is most likely a member of the cluster in a very marked blend. Inspection of *Hubble* Space Telescope (HST) images (Anderson & van der Marel 2010) confirms the presence of a companion that is unresolved in our images, located just about $0.5''$ from the RRL star, but brighter by about 0.5 mag in V, and bluer by about 0.25 mag in $B - V$.

V56 and V168: the field status of these two stars was based on a radial velocity study by Liller & Tokarz (1981). Subsequently, V56 was again considered a member of the cluster based on its high membership probability of 98% and 100% found by vL00 and B09, respectively – a status in excellent agreement with its position in our NIR CMD. These inconsistent conclusions can probably be explained as follows: When assessing membership status of an RRL variable from its radial velocity, it is necessary to take into account the phase in its light and velocity cycle. Liller & Tokarz obtained this information from Dickens (1980, priv. comm.), based on an epoch established in 1974. The observations of Liller & Tokarz were made in 1978. A period change study by Jurcsik et al. (2001) indicates that V56 undergoes random period changes. Thus it is highly likely that the light-curve phase assumed by Liller & Tokarz was incorrect. In contrast, all proper motion studies agree in classifying V168 as a non-cluster member, which also agrees with our photometric classification as a field star: Fig. 1 clearly shows that this RRL star is a background interloper.

V68 and V84: these two stars have controversial mode classification in the literature. First thought to be RRLs by Bailey (1902), they were later suggested to belong to the ACEP group by Nemec et al. (1994) because their optical magnitudes are brighter than those of the other RRLs of the cluster. ACEP stars are Population II stars with periods between 0.4 and 2.4 days that do not follow either the RRL or the Type II Cepheid PL relations. Most of them are found in dwarf spheroidal galaxies (Nemec et al. 1994) and the Large Magellanic Cloud (Soszyński et al. 2008), a few ACEPs are known in Galactic globular clusters (see Zinn & Dahn 1976; Sollima et al. 2010; Osborn et al. 2012; Arellano Ferro et al. 2013) and only one in the Galactic field (XZ Ceti; Teays & Simon 1985; Szabados et al. 2007).

V68 appears to be an RRc cluster member star according to its proper motions and its position in the CMD (see Table 1 and the bottom panel of Fig. 1). Although it has the longest period among the RRc stars of the cluster (0.56 days), which is longer than even the short-period end of the RRab period distribution, the amplitude of its light curve is small enough to place it within the RRc stars group (see Fig. 2). V68 also follows the PL relations for RRc stars in J and K_S (Navarrete et al., in prep.). This star, on the other hand, also appears to follow the optical (B, V) PL relations for ACEP stars, as derived by Nemec et al. (1994).

On the other hand, V84 was discarded as a cluster member by vL00, with a membership probability $\mathcal{P}_\mu = 0\%$. Unfortunately, we were unable to confirm this result using proper motions from B09, since V84 is outside their FoV. Our NIR CMD shows that V84 is clearly located in the RRL instability strip, opening the possibility that it is a cluster member. However, as Del Principe et al. (2006) pointed out, V84 does not follow the NIR PL relation for RRab stars. This result is confirmed using our PL relations (Navarrete et al., in prep.), with V84 appearing brighter than other stars with the same period. Conversely, Nemec et al. (1994) found that V84 was placed slightly below the B- and V-band PL relations for ACEPs, which could be explained if the star was not an ACEP but instead an RRL star leaving the HB.

Using our NIR observations, we cannot adopt a definitive classification for either of these stars. If they are RRLs, the most probable scenario is that V68 is an RRc member and V84 is an RRab star from the field. However, the ACEP classification cannot be completely discarded. Indeed, V68 and V84 follow the K_S-band PL relation for ACEPs in the Large Magellanic Cloud derived by Ripepi et al. (2014), assuming a distance modulus for ω Cen of $(m - M)_0 = 13.63 \pm 0.1$ mag – which agrees well with the one derived by Matsunaga et al. (2006) using Type II Cepheids. If these two stars are indeed ACEPs, they probably are cluster members.

V80: this star was detected in the first variability study on ω Cen carried out by Bailey (1902). In that work, V80 was reported as difficult to measure because it is distant from comparison stars, and accordingly only sparse measurements of differential magnitudes were published, without an accompanying light curve. Bailey suggested a period of 0.45 or 0.31 days for this star, wherewith it was tentatively classified as an RRL-type star. Based on our wide-field VISTA observations, we determined its period, $P = 0.37718$ d (Table 1), and derived its complete, phase-folded light curve (Fig. A.1).

According to its coordinates, ID-53, $P = 0.377$ d from Weldrake et al. (2007), appears as the nearest star to V80 among the list of new variables discovered by these authors. However, Weldrake et al. did not associate ID-53 with V80, probably because a period value had never previously been published for V80 – and accordingly, they claimed that their ID-53 was a newly discovered variable star. Instead, our independently derived period and coordinates alike indicate that V80 and ID-53 are one and the same star.

V80 is not present in any proper motion study. Its derived period and position in the CMD indicates that V80 is an RRc star that is also a cluster member.

V118, V135, and V139: these three stars appear to be clearly located within the RRab region in the IS (see Fig. 1). Based on the vL00 and B09 proper motion studies, V118 has a membership probability of $\mathcal{P}_\mu = (100\%, 96\%)$, respectively, whereas V139 has $\mathcal{P}_\mu = (100\%, 90\%)$. V135 is only present in B09, with a membership probability of 97%. However, all appear to be brighter than the other RRab stars with similar periods in the J and K_S PL relations (Navarrete et al., in prep.).

V118 is located in a very crowded region. According to the HST catalog of Anderson & van der Marel (2010), there are more than ten stars inside a $1''$ radius around its coordinates.

A similar situation occurs with V139, having a neighbor located at only 0.432″, according to the catalog of Anderson & van der Marel – which is a difference of less than two pixels, given the VIRCAM pixel scale. Hence, this star is almost certainly brighter in our photometry than it would be if it were isolated.

V135 is suffering the influence of a disturbing neighbor, located 2.5″ away, which is saturated. This situation was previously reported by Samus et al. (2009), with both stars being labeled in that study as visual binaries.

V143: it is certainly a member of the cluster according to vL00, with 99% membership probability. B09 give instead $\mathcal{P}_\mu$ = 90% for this star. However, it appears a few tenths of a magnitude brighter than other RRab stars with the same color. A visual inspection of this star in some of our images suggested to us that its anomalous position in the CMD is not due to a blend effect of an unresolved system, but rather to a saturated companion located close by (i.e., at a distance of ≈3.4″) that is somehow disturbing the photometric quality in its neighborhood. Indeed, this situation was explicitly reported by Shokin & Samus' (1996), where the presence of a bright star located southwest from the position of V143 is remarked upon. Therefore, despite its anomalous position in the CMD, we suggest that V143 is indeed a cluster member.

V151: listed as an RRab star by Kaluzny et al. (2004) with a period of 0.4078 days, this star would appear to be the shortest-period fundamental-mode RRL in ω Cen. However, despite the fact that our estimated period (P = 0.407756 d) excellently agrees with the one derived by Martin (1938), we note that its light curve shows a very small amplitude, which is among the lowest for RRab stars in our study. Small amplitudes are unusual for short-period RRab stars. Figure 2 shows the position of V151 in the Bailey (period-amplitude) diagram, as compared to other ω Cen RRL stars. This plot clearly shows that V151 is well located among the RRc-type variables. In addition, its position in the PL relation (Navarrete et al., in prep.) is also consistent with first-overtone pulsation. Thus, we conclude that this star should be classified as an RRc. We note that Martin (1938) also classified V151 as an RRc star, hence the erroneous RRab type adopted by Kaluzny et al. is probably a typographical error, which was later inadvertently reproduced in the online catalog of C13. V151 was not included in the proper motion studies of vL00 and B09; however, our NIR CMD suggests that this variable probably belongs to the cluster.

V172, V173, V175, V177, and V180: Wilkens (1965) announced the discovery of V171-V180. Of these ten stars, V176 was subsequently discarded as a non-variable star, V174 classified as an EB, and the remaining stars classified as RRab's, except for V180, which was classified as an RRc instead. To the best of our knowledge, no further variability studies of these stars have been carried out, except for V172 and V177, which were included in the observations by Weldrake et al. (2007) as ID-18 and ID-49, respectively. None of them has had a period assigned in the catalog of C13.

Four of Wilkens's stars, namely, V171, V175 (without a previous type assigned), V178, and V179 are all very far from the cluster center and thus were not observed by us, despite VIRCAM's large FoV. Consequently, only light curves for V172, V173, V177, and V180 were derived, and they are shown in Fig. A.1. Only V180 has membership probability derived based on proper motions studies, being considered a non-member of the cluster with a null membership probability by vL00. According to their positions in the CMD (bottom panel of Fig. 1), we suggest that V172, V173, and V177 are cluster members. We confirm the ab-type classification for V172, but contrary to Wilkens, we did not find an RRab behavior for either V173 or V177, and we suggest instead an RRc classification for both these stars. This is consistent with their positions in the Bailey diagram, as can be seen from Fig. 2. V175, according to Vivas (2014, priv. comm.; see also Fernández Trincado et al. 2013) is a foreground c-type RRL. As can be seen in Fig. 1, V180 is located in the RRab region, redder than any other RRc star. Moreover, it has a larger amplitude than other RRc stars (Fig. 2). Our estimated period produces a light curve clearly showing two different minima. Accordingly, we propose to classify V180 as a contact EB of the W Ursae Majoris type, rather than as an RRc, which is consistent with its fairly red color and the fact that this star is not a cluster member.

V181 and V183: V181, V182, and V183 were discovered by Wesselink (1969, unpublished, priv. comm. to Sawyer-Hogg), who indicated the stars' coordinates and periods, but without providing light curves or variability types for these stars. Clement et al. (2001), based on Wesselink's periods, classified V181 and V182 as RRab's, and V183 as an RRc. These stars were outside the FoV in subsequent investigations by other authors. Unfortunately, V182, at 59.7 arcmin from the center of the cluster, is also outside the FoV of VISTA.

Figure A.1 shows the first complete light curves for V181 and V183. They are ab- and c-type RRL stars, respectively, in agreement with the periods originally derived by Wesselink. These two stars are very distant from the cluster center (though still inside its tidal radius), and thus they are absent from proper motion studies of the cluster. However, based on their positions in the CMD (see the top panel of Fig. 1), they both appear to be field RRL stars.

V268: vL00 claimed that V268 is a field star with a membership probability of 0%. However, we found some inconsistencies in this membership status using our coordinates and those from the literature: in fact, the nearest star to V268 in the catalog of vL00 has a membership probability of 70%. Moreover, according to B09, this star has a 99% membership probability. Using the NIR CMD to determine the membership status of this star, it is found that V268 is located well inside the RRL instability strip, as the other RRab members of the cluster (Fig. 1, bottom panel). We thus conclude that V268 is indeed a cluster member.

V283: this star was neither studied by vL00 nor by B09. Based on its faint visible magnitude, Kaluzny et al. (1997) claimed that it is a background halo RRL. This field status is confirmed by our photometry, which locates the star a few magnitudes below the HB, even fainter than the turn-off point level (see CMD in the top panel of Fig. 1).

V349 and V351: these two RRc variables were discovered by Kaluzny et al. (2004) and are located ~1.5 arcsec away from the cluster center. The huge amount of crowding at their positions did not allow those authors to present properly calibrated light curves. Interestingly, Kaluzny et al. noted that V351 is a multiperiodic variable, and suggested that it may show non-radial pulsation modes, as previously proposed by Clement & Rowe (2000) for several other RRL stars in ω Cen. Using the coordinates and periods provided by Kaluzny et al. (2004), these two variables were not found either in our ALLFRAME or in our DoPhot photometry. The matching radius used was 1 arcsec. Increasing the matching radius to 10 arcsec still did not return any variable stars. The last check step was to consider all the stars within 30 arcsec around the listed coordinates, and check for the presence of periodicity in this enlarged sample using the analysis of variance statistic (ANOVA; Schwarzenberg-Czerny 1989). Again, no periodic variables were detected in this way.

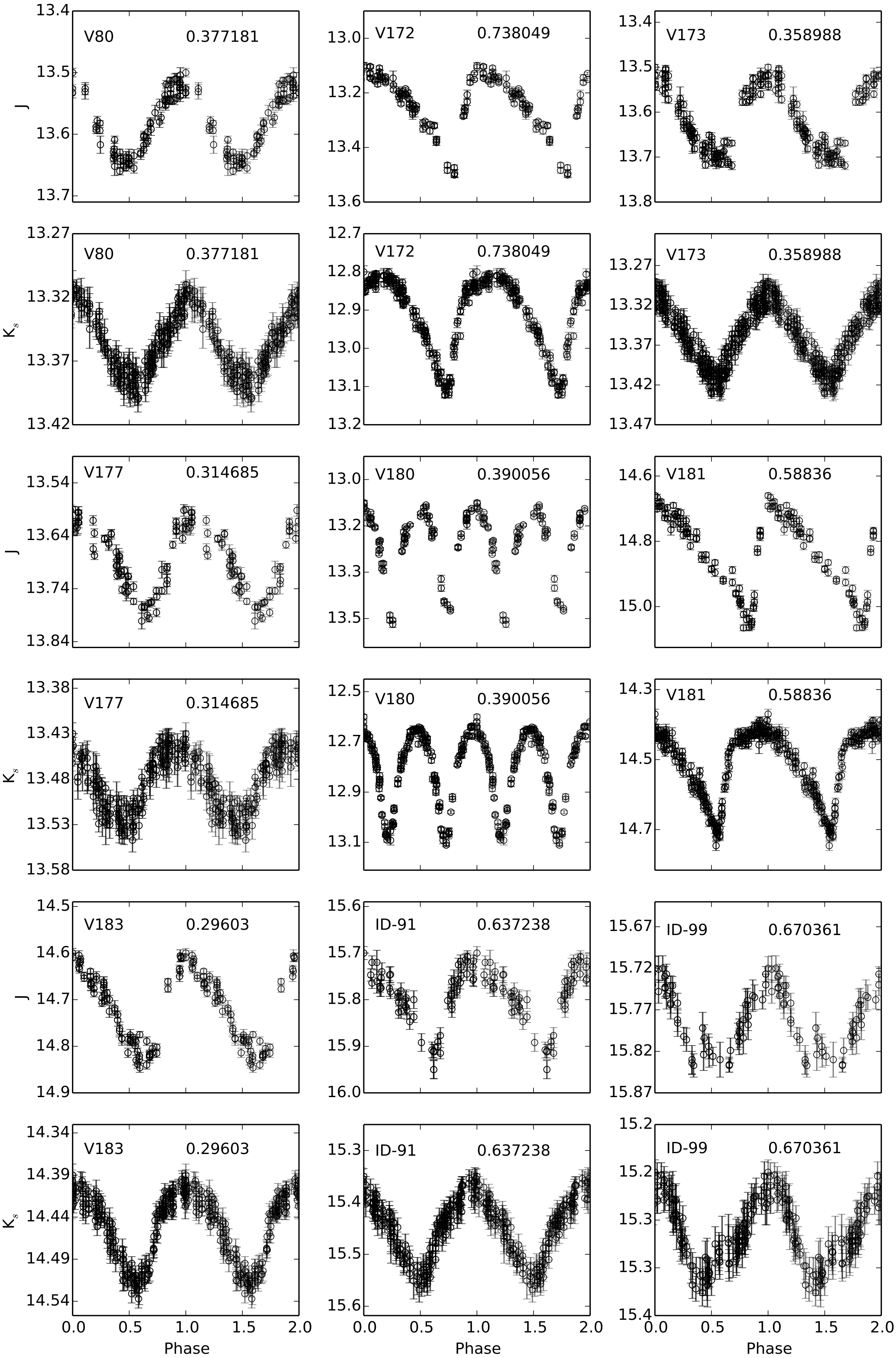

Fig. A.1. VISTA NIR light curves for all the RRLs that lacked a derived light curve or period in the literature. For each star, *upper panel*: *J*-band curve, whereas the lower one displays the K_S band instead. Our derived period for each star is provided in each panel. Note that the V180 light curve is consistent with a W UMa classification. Variables ID-91 and (especially) ID-99, from Weldrake et al. (2007), have light-curve shapes that are different from all the other RRab in ω Cen, and are suspected to be field stars.

Therefore, V349 and V351 could not be recovered using PSF photometry in our VISTA images.

Appendix B: RR Lyrae stars from Weldrake et al. (2007)

Weldrake et al. (2007) reported the discovery of five new RRL stars in ω Cen: ID-53, ID-91, ID-99, ID-144, and ID-145. By carefully checking the positions and periods of these stars, we have been able to establish that three out of these five variables were not really new discoveries. More specifically, according to our analysis, we were able to establish that ID-53 = V80, ID-144 = V272, and ID-145 = V15.

ID-91 and ID-99, on the other hand, do appear to be bona fide new variables. Weldrake et al. (2007) listed optical magnitudes of $V \sim 17.1$ and 17.45 mag for these two stars, respectively, which is consistent with their being field interlopers. Unfortunately, neither star appears in the proper motion catalogs of vL00 and B09. For their variability status, Weldrake et al. suggested that ID-99 could be either a long-period RRc with a 0.671-d period or an EB with a period twice as long. For ID-91, in turn, they assigned an RRab type. Both stars' light curves are shown in Fig. A.1, according to which the RRab status of ID-91 seems reasonable, whereas the RRL nature of ID-99 remains a possibility. However, if indeed an RRL, ID-99's long period might more naturally suggest an RRab classification, as opposed to the RRc type suggested by Weldrake et al. To further check their classification, ID-91 and ID-99 were plotted in the Bailey diagram (see Fig. 2). Their location suggests that both stars are either extreme examples of OoI RRab stars and/or show a modulation in their light curves (e.g., the Blazhko effect), and/or are unresolved blends. The latter possibility receives some support from the positions of the stars in the CMD (Fig. 1), which show that both stars are slightly redder than expected for RRL stars. However, these stars are also quite far away (~25′) from the cluster center, and inspection of our images reveals that they are in relatively unpopulated areas, which makes blends seem unlikely. Unfortunately, HST images of these fields are not available, therefore we cannot conclusively establish that unresolved companions to these stars are indeed absent. Similarly, no Blazhko effect is supported by either our photometry (Fig. A.1) or the photometry of Weldrake et al. (2007).

Based on the astrometry that is provided along with the VISTA images (which is tied to the 2MASS system), we found some erroneous matches between some of the known variables in the catalogs of Weldrake et al. (2007) and Kaluzny et al. (2004): ID-115 = V264 (instead of V48) and ID-135 = V266 (not V356). Moreover, Weldrake et al. erroneously claimed that ID-133 was the same star as V144 from the catalog of Clement et al. (2001). However, as already reported by Navarrete et al. (2013), ID-133 is indeed a different variable star. C13 has already added this new RRab star in her online catalog, where it is now officially listed as V411.

C13 has included ID-74 of Weldrake et al. (2007), a possible RRL based on its period (0.6671 d, according to Weldrake et al.), as V433 in her catalog. This star has $V \approx 16.5$ and $(V - I) \approx 1.0$ mag, which suggests that it is a field star. Indeed, according to our NIR magnitudes, V433 is placed above the cluster's turn-off point, above the main sequence and close to (but redder than) the base of the red giant branch (see the top panel of Fig.1). Still, the star does appear to show some short-period variability, with a period of (0.6681 ± 0.0004) d, and an amplitude that probably does not exceed 0.05 mag in K_S, again preventing us from classifying it as an RRL. The star's red color is probably not caused by a blend with a red star, since it is ~30′ away from the cluster center, and without any obvious close companions in our images. According to Da Costa & Coleman (2008), the star is a radial velocity non-member. In conclusion, we follow Weldrake et al. (2007), and consider V433 as a variable star with an uncertain variability type.