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NGC 2419: an "intergalactic wanderer" or a simple Galactic globular cluster?

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Abstract. We have carried out a new photometric study of the remote Galactic globular cluster NGC 2419, using proprietary and archive B, V, I time-series CCD photometry of the cluster, that allowed us to discover a large number of new variable stars and to obtain a new colour magnitude diagram that reaches $V \sim 26$ mag over a field of 50x43 square arcmin centered on NGC 2419. The new variables include 39 RR Lyrae and 11 SX Phoenicis stars. The pulsation properties of the new RR Lyrae stars confirm and strengthen the classification of NGC 2419 as an Oosterhoff type II cluster.

Key words. Stars: variable stars – Stars: Population II – Galaxy: globular clusters –

1. Introduction

NGC 2419 is one of the most distant and luminous globular clusters (GCs) in the Milky Way (MW, R_{GC}=90 kpc, Harris et al. ,1997) but has several unusual properties for an outer halo GC; in particular with $M_V = -9.5$ mag (Harris, 1996) and [Fe/H]= -2.1 dex it is much more luminous and metal-poor than the majority of the other outer halo clusters. The cluster horizontal branch (HB) also resembles that of much closer "canonical" metal-poor clusters like M15 or M68. However, NGC 2419 is not an inner halo cluster migrated out on an elliptical orbit, since its dynamical parameters and orbital properties are typical of an outer halo cluster. NGC 2419 is also anomalous in the half-light radius (Rh) vs M_V plane, where occupies the same strange position of M54 and ω Cen. In fact they all look significantly looser that expected for their brightness. All these peculiarities and the similarity with ω Cen and M 54 suggest that NGC 2419 could have an extragalactic origin and be the relict of a dwarf galaxy tidally disrupted by the MW (Mackey & Van den Berg, 2004); from here the appellative "Intergalactic Wanderer" used in the literature. Our project aims to study in detail, both the cluster color-magnitude diagram (CMD) and the variable star population, using B, V and I time-series CCD photometry covering an area that extends well beyond the cluster published tidal radius, in order to verify whether multiple stellar populations and tidal tails exist in

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Table 1. Instrumental set-ups and logs of the observations

Dates UT	Telescope	Instrument	Detector (pixel)	Resolution (″/pixel)	FOV	N_B	N_V	N_I
Sep., 2003 – Feb., 2004	TNG	Dolores	2048×2048	0.275	$9.4' \times 9.4'$	20	22	–
May, 1994 – Mar., 2000	HST	WFPC2	$3 \times 800 \times 800$	0.1	$3 \times 2.5' \times 2.5'$	–	18	10
Nov., 1997	HST	WFPC2	$3 \times 800 \times 800$	0.1	$3 \times 2.5' \times 2.5'$	–	7	39
Dec., 2002	SUBARU	Suprime – Cam	2048×4096	0.20	$34' \times 27'$	–	165	16

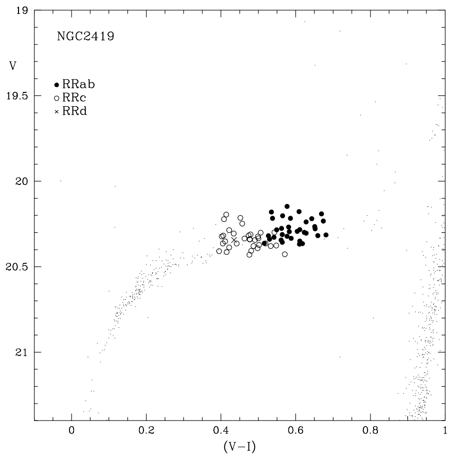

Fig. 1. Portion of the cluster V vs $V-I$ CMD, from the SUBARU dataset, zoomed at the level of the HB, with the RR Lyrae stars overplotted using filled and open symbols for fundamental-mode and first-overtone pulsators, respectively.

the cluster, and to check whether the properties of the RR Lyrae stars support an extragalactic origin for NGC2419.

2. Observation and data reduction

Logs of the observations used for the present investigation and details of the instrumental set-up at the various telescopes are provided in Table 1. Images were pre-reduced following standard techniques (bias subtraction and flat-field correction) with IRAF. We measured the star magnitudes by PSF-fitting photometry, running the DAOPHOTII/ALLSTAR/ALLFRAME packages (Stetson 1987, 1994) on the TNG, HST and SUBARU datasets, separately. Typical internal errors of the V band photometry for single phase points at the level of the HB are in the range from 0.01 to 0.02 mag.

The large field of view of the Suprime-Cam (34×27 arcmin^2) and dithering of the telescope pointing resulted in the survey of a total area of 50×43 arcmin^2 centered on NGC 2419, including both the TNG and HST fields. The absolute photometric calibration was obtained by using local standards in NGC 2419 from P.B. Stetson's list[1]. Fig.1 shows the V, $V-I$ CMD of NGC 2419 obtained from the SUBARU dataset, zoomed at the level of the HB. The main features of this CMD have been presented in (Ripepi et al. 2007) and will be further discussed in Federici et al. (2008, in preparation). Here we focus on the discovery of many new variable stars in the cluster, and of several new first-overtone (RRc) RR Lyrae stars, in particular.

3. Some results

Periods and classification in types for the new candidate variables (identified with independent techniques, details in Di Criscienzo et al. 2007, in preparation) were derived using GRaTiS (Graphycal Analizer of Time Series), a custom software developed at the Bologna Observatory (see Clementini et al. 2000). Reliable periods were obtained for 100

[1] Available at http://cadcwww.dao.nrc.ca/standards/

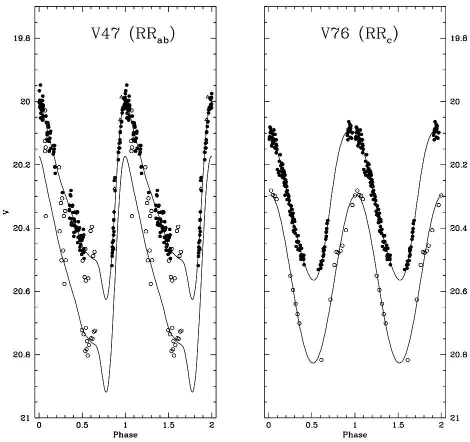

Fig. 2. *V* (upper curve) and *B* (lower curve) light curves of two new RR Lyrae stars discovered in NGC 2419. Lines are models obtained by properly scaling down the star's *V* light curve.

stars: 75 RR Lyrae, 1 Population II Cepheid, 11 SX Phoenicis, 2 δ Scuti, 3 binaries, 5 long period variables near the Tip of the Red Giant Branch, plus 3 more candidate variables not classified yet. The newly discovered RR Lyrae variables include 11 fundamental-mode (RRab) and 28 first-overtone (RRc) pulsators (see Fig.1). Examples of the *V* and *B* light curves of RRab and RRc variables are shown in Fig. 2. With these new discoveries, the ratio of the number of RRc stars over the number of RRc+RRab variables changes from 0.28 (based on the census by Pinto & Rosino, 1977) to 0.49, in much better agreement with the expectations for a metal-poor cluster, and with the classification of NGC 2419 as an Oosterhoff type II (OoII) cluster. A classification confirmed and strengthen by the average period of the RRab stars and the period-amplitude distribution derived in our study (see Ripepi et al., 2007; Di Criscienzo et al. 2007). The pure OoII nature of NGC 2419 seems to disfavor the possibility of an extragalactic origin for the cluster, since field and cluster RR Lyrae stars in extragalactic systems generally have properties intermediate between the two Oosterhoff types (e.g. Catelan 2004). However, since five of the Large Magellanic Cloud GCs also have OoII type, and also Ursa Minor and Bootes I, among the dwarf spheroidal galaxies are pure OoII systems, an extragalactic origin of NGC 2419 may not be totally ruled out. On the other hand, as noted by Ripepi et al. (2007), the apparent lack of multiple stellar populations and of metallicity spreads does not corroborate the hypothesis that NGC 2419 might be the core of a defunct galaxy. From our data, this cluster appears indeed a "normal", low metallicity Galactic GC. The only exceptional feature is the presence of the HB "blue-hook", a feature that, up to now, has been detected only in very few Galactic GCs, all showing signs of multiple stellar populations, such as NGC 2808 (Piotto et al., 2007) and/or an extragalactic origin. Interestingly, the occurrence of an extended HB seems to correlate with the mass of the cluster (Recio-Blanco et al. 2006). Indeed, NGC 2419 is one of the most massive Galactic GCs. Our next step will be to investigate this HB "anomaly", and to study in the detail the CMD to confirm or discard the "normal" nature of NGC 2419 as a Galactic GC, suggested by the properties of the cluster RR Lyrae stars.

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