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Variable stars in nearby galaxies

V. Search for Cepheids in field A of NGC 6822*

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Abstract. The results of a CCD survey for variability of stars in the nearby galaxy NGC 6822 are presented. The goal of the survey was to obtain good light curves of Cepheids for Fourier decomposition and to detect shorter period Cepheids. Since the program was carried out with a relatively small telescope, the Dutch 0.9 m at ESO-La Silla, the observations were unfiltered (white light, or Wh–band). The analysis revealed the presence of more than 130 variable stars. 21 population I Cepheids are detected; 6 of them were already known from previous works (Kayser 1967). For at least three Cepheids, however, the previous identification or period was wrong. Some probable population II (W Vir) stars are also identified. The dispersion of the fundamental mode Cepheid PL relation appears to be small.

Key words. stars: oscillations – stars: variables: Cepheids – stars: variables: general – galaxies: individual: NGC 6822 – local group – galaxies: stellar content

1. Introduction

Cepheids are variable stars that are used to measure distances of galaxies in the Local Group and nearby clusters (e.g. Madore et al. 1998), and are the primary calibrator for the secondary standard candles that are applied at much greater distances (e.g. Jacoby et al. 1992). However, they are not only fundamental stars as primary distance indicators, but are also an essential tool for testing the theories on the internal constitution of stars and stellar evolution. There are several problems yet to be solved. The radiative codes used to construct nonlinear pulsation models proved to be unable to agree with observations when applied to the comparison of Cepheid characteristics in the Galaxy and in Magellanic Clouds (e.g. Buchler 1998). Resonances among the pulsation modes give rise to observable effects on the light curves which can be exploited to put constraints on the pulsational models and on the mass-luminosity relations. When these resonances observed in Cepheids of the Galaxy and Magellanic Clouds are used to constrain purely radiative models, one obtains stellar masses that are too small to be in agreement with stellar evolution calculations. According to Buchler et al. (1999), it is clear that some form of convective transport and of turbulent dissipation is needed to make progress; this has been proved for example for the first overtone mode Cepheids in the Galaxy (Feuchtinger et al. 2000).

The MACHO, EROS and OGLE projects dedicated to the detection of microlensing events in the direction of the Magellanic Clouds produced enormous amount of data on variable stars in these galaxies (e.g. Welch et al. 1997; Beaulieu & Sasselov 1997; Udalski et al. 1999). More recently, the project DIRECT was dedicated to the massive CCD photometry of M 31 and M 33 with the purpose of detecting Cepheid and eclipsing binaries for direct distance determination of these galaxies (e.g. Kaluzny et al. 1999; Macri et al. 2001). The purpose of our project was to obtain good light curves of Cepheids to extend the comparison of the characteristics of these stars in different galaxies. In order to exploit the telescope time and reach the faintest luminosities, our strategy was to observe in white light, i.e. without filter. Massive CCD photometry of the nearby galaxy IC 1613 has been already discussed in the previous papers of this series (Mantegazza et al. 2001, and references therein; see also the recent survey by Udalski et al. 2001), while in this paper we present the first results for NGC 6822.

2. Observations of NGC 6822

The irregular galaxy NGC 6822 [$\alpha(2000) = 19^{\rm h}44^{\rm m}56^{\rm s}$, $\delta(2000) = -14°48'02''$, $l = 25°$, $b = -18°$], was studied by Hubble (1925, who discovered 11 Cepheids and other bright irregular variables, and then surveyed by Kayser (1967) using photographic plate material obtained by Arp and Baade at the prime focus of the Palomar 5 m telescope. She found 13 Cepheids, with period P in the range

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* Based on observations collected at ESO-La Silla.

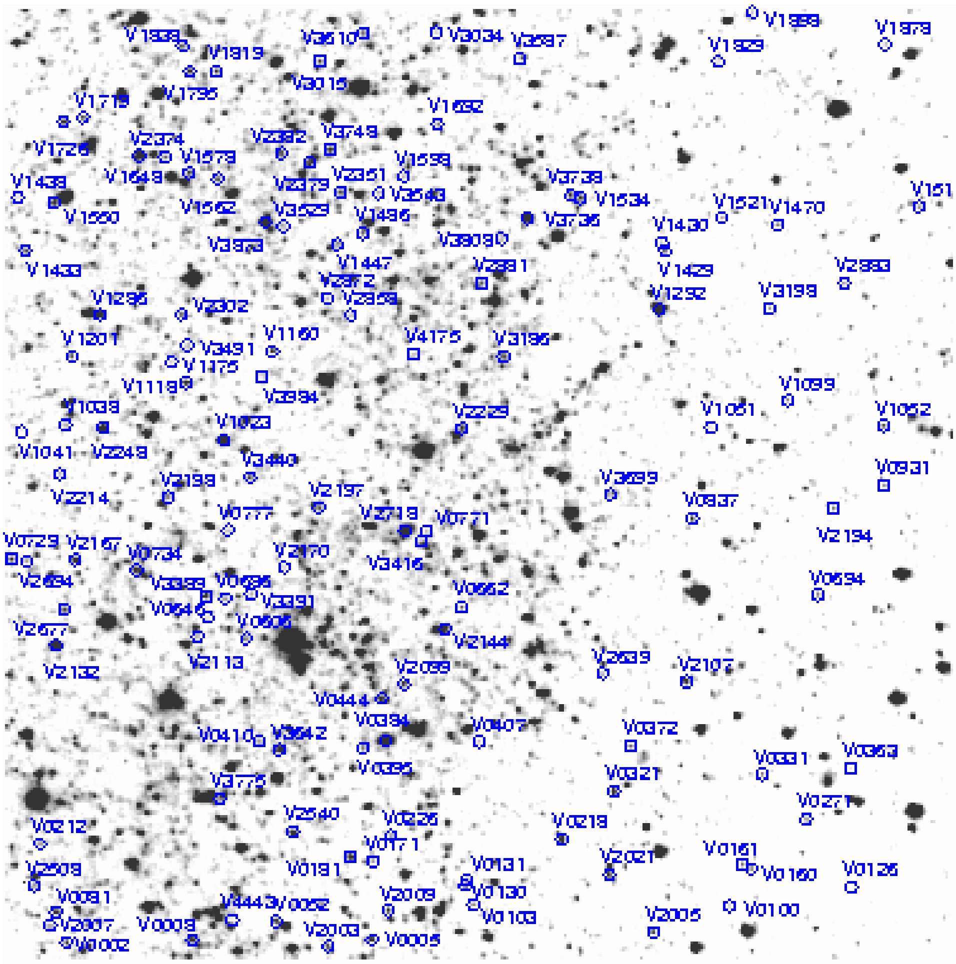

Fig. 1. Field A in NGC 6822 with the detected variable stars; north is up and east is to the right.

bewteen 10 and 90 d. More recently, CCD light curves were obtained for 6 known Cepheids by Schmidt & Spear (1989). NGC 6822 is close to the galactic plane, resulting in large foreground reddening. A short review of the problems related to the period-luminosity PL relation and distance modulus estimates of this galaxy was given by Madore & Freedman (1991).

Our observations were performed with the direct CCD camera attached to the Dutch 0.91 m telescope of the La Silla Astronomical Observatory (ESO) during 3 runs from 1996 to 1998. The available CCD detector was the ESO chip No. 33, which is a TEK CCD with 512 × 512 pixels, pixel size of 27 μm and spatial resolution of $0\farcs44$, providing a field of view of $3\farcm77 \times 3\farcm77$. Given the limited size of the field of view, the need to observe not too far from the meridian and at the same time to be able to get two images of the same field on the same night, we were forced to limit our programme to a few selected fields of NGC 6822. Most of the observations were performed without filter (white light, hereinafter Wh) in order to get the best photon statistics for the study of faint Cepheid light curves. The properties of this photometric band are discussed in Paper I (Antonello et al. 1999a) and Paper III (Antonello et al. 2000) of this series; other information can be obtained from the paper by Riess et al. (1999). Moreover, two images were taken in Johnson V and R filter to obtain information on star colors. In this paper we present the results regarding Field A which contains the largest number of previously–known variable stars.

3. Data reduction, calibration and analysis

The methods of data reduction and calibrations were the same as those discussed in Paper III. The instrumental wh magnitudes were transformed into our "standard" Wh system using 150 stars with at least 31 measurements; all the variable candidates were excluded. We found:

$$V - wh = -1.28 - 0.04(V - R) + 0.38(V - R)^2 \qquad (1)$$

and hence

$$Wh = wh - 1.28. \qquad (2)$$

The search for variable stars was performed with the various techniques described in Papers I and III in order to minimize the probability of wrong identifications. In addition, we made the following test. By means of numerical simulations we generated 10 000 time-series of random

Table 1. Cepheids in field A of NGC 6822.

Name	$\alpha(2000)$ $[^{\rm h}\ ^{\rm m}\ ^{\rm s}]$	$\delta(2000)$ $[^\circ\ '\ '']$	P [d]	Wh	$V-R$	mode/type	
V0052	19 44 55.50	−14 50 05.3	8.3288	20.70	0.69	F	
V0171	19 44 57.14	−14 49 50.1	3.6500	21.82	1.25	F	
V0271	19 45 04.57	−14 49 38.0	6.0220	21.11	0.83	F	
V0372	19 45 01.54	−14 49 20.5	6.7361	20.99	0.99	F	
V0410	19 44 55.15	−14 49 20.8	3.9993	21.22	0.80	F	
V0444	19 44 57.24	−14 49 09.7	3.5946	20.18	0.67	1O?	
V0686	19 44 54.53	−14 48 45.6	5.2889	21.28	1.32	F	
V0729	19 44 50.85	−14 48 36.5	9.3647	20.40	1.00	F	V25
V0734	19 44 53.00	−14 48 38.9	16.82	19.75	1.07	F	V9
V0771	19 44 57.97	−14 48 28.0	16.74	22.02	0.96	W Vir	
V1286	19 44 52.31	−14 47 35.9	41.92	19.81	0.70	Ceph?	
V1292	19 45 01.90	−14 47 32.3	122.7	17.72	0.85	F	V13
V1433	19 44 51.01	−14 47 20.2	6.8586	20.81	0.46	F	
V1447	19 44 56.36	−14 47 17.4	3.0504	22.02	0.97	F	
V2113	19 44 54.07	−14 48 55.2	6.15	22.77	0.78	W Vir	
V2374	19 44 52.93	−14 46 56.3	29.21	19.13	1.14	F	
V2382	19 44 55.37	−14 46 55.1	3.8831	21.06	0.78	F	V3
V2858	19 44 56.61	−14 47 34.9	5.483	22.82	0.69	W Vir	
V3015	19 44 56.01	−14 46 32.2	5.4927	21.06	0.76	F	
V3186	19 44 59.25	−14 47 44.6	4.5561	21.05	1.09	F	
V3529	19 44 55.43	−14 47 13.2	1.7112	21.25	0.81	1O?	
V3543	19 44 57.06	−14 47 04.7	22.1	21.90	1.00	W Vir	
V3736	19 44 59.62	−14 47 10.3	30.499	18.94	0.93	F	V1
V3738	19 45 00.36	−14 47 04.4	8.9464	20.70	1.20	F	
V3873	19 44 55.12	−14 47 12.2	37.52	18.36	0.78	F	V2
V3984	19 44 55.10	−14 47 50.5	1.4230	21.84	0.68	1O?	

numbers normally distributed for each set of observations (from 25 to 34 data points), we analyzed them with the least-squares power spectra for different frequency intervals of investigation, and computed the distributions of the amplitudes of the highest peak in each spectrum. Among the stars selected as variable candidates with the previous methods, we confirmed only those whose highest peak in the least-squares power spectrum had a probability less than 0.01 of being generated by random noise. As a result of the application of these techniques we detected 130 variable stars, i.e. 21 Cepheids, 18 other periodic variables and 91 irregular or semiregular variables. Previously in this field only 6 Cepheids and 3 long period variables were known (Kayser 1967). The location of the variables in the field is shown in Fig. 1; the color-magnitude diagram is shown in Fig. 2.

4. Results

Cepheid variable stars are listed in Table 1, along with their equatorial coordinates, the period P, the mean Wh magnitude, the random phase $V-R$ index, the pulsation mode or stellar type, and the previous identification number (Kayser 1967). The light curves phased according to the periods of Table 1 are shown in Fig. 3. It should be noted that, given the data distribution, the determination

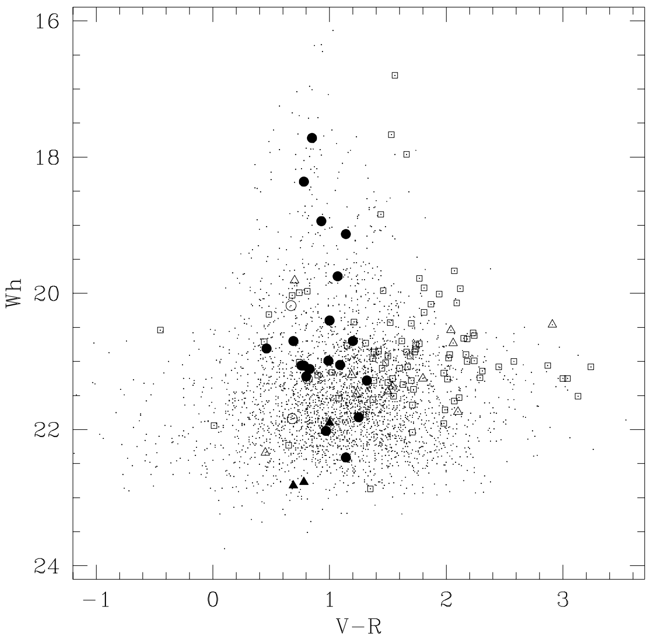

Fig. 2. Color-magnitude (V–R, Wh) diagram of stars in Field A. *Filled circles*: fundamental mode Cepheids; *open circles*: probable first overtone mode Cepheids; *filled triangles*: probable population II Cepheids (W Vir); *open triangles*: other periodic variables; *squares*: other semiregular, irregular and possible long P variables.

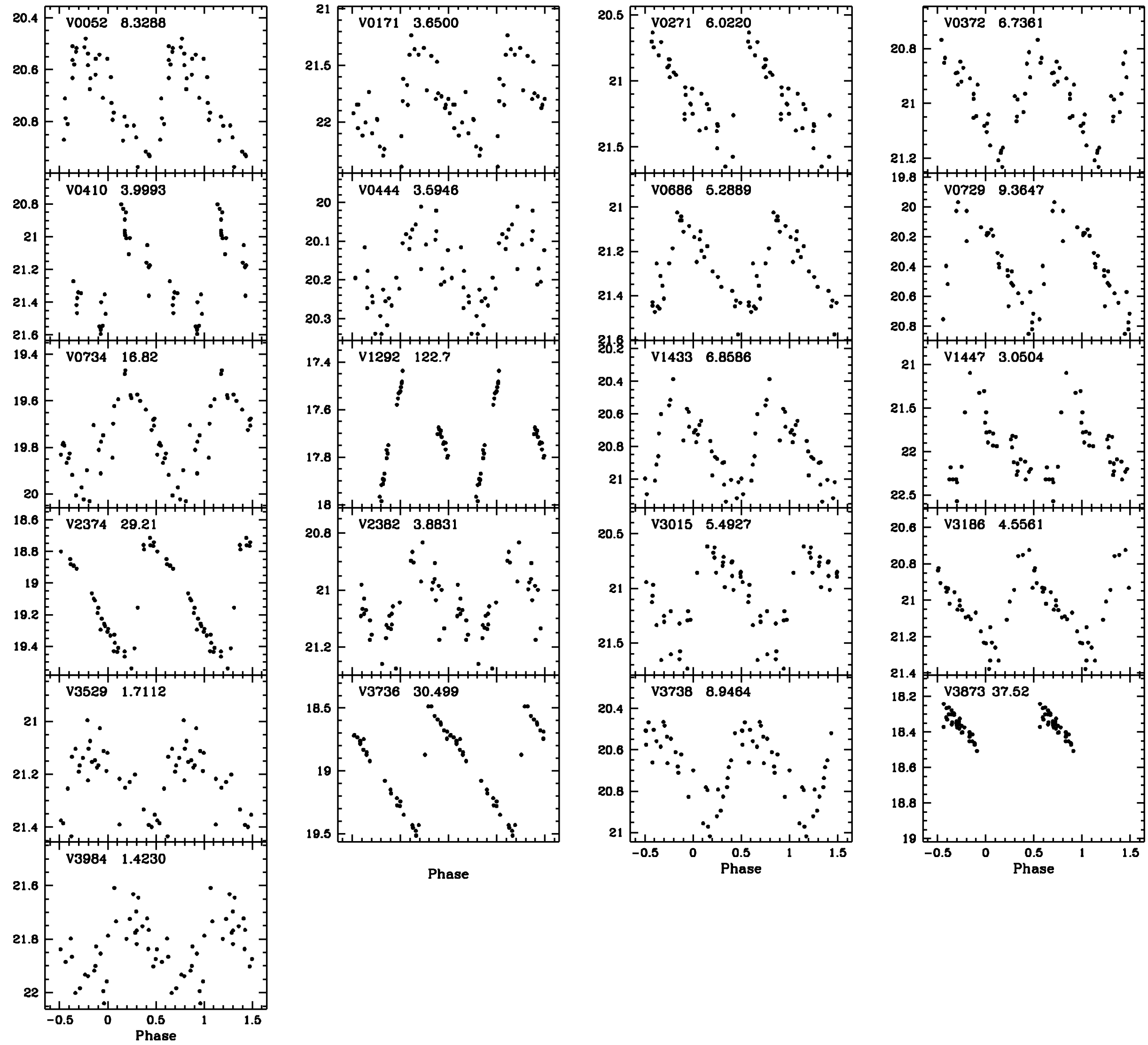

Fig. 3. Cepheid Wh light curves. For each star, the identification number and the period are reported.

of the right period for values longer than about 20 d is not easy, since a number of peaks in the power spectrum supply equivalent fits. Some comments on a few objects follow.

V0729: Kayser classified this star as an irregular variable, without ruling out a possible P of about 13 d. Our data show unambiguously that the star is periodic with $P = 9.364$ d.

V0734: Hubble (1925) classified it as a Cepheid, but according to Kayser it should be a rapid irregular variable. Our data support Hubble's conclusion and give a period of 16.8 d, which is in agreement with the value of 16.9 d supplied by him.

V1292: this is the longest period Cepheid of our sample. Our data set indicate $P \sim 123$ d while Kayser obtained $P = 90$ d. As a check, we analyzed her data and found that the best–fitting P is actually about 120.7 d; in the power spectrum the peak corresponding to 90 d is much lower. By merging our and the Kayser datasets, shifting them to a common zero–point and rescaling the amplitude, we obtained a best–fitting P of 120.66 d. The light curve probably does not repeat exactly from cycle to cycle; this characteristic is common among the longer P Cepheids both in the Milky Way and Magellanic Clouds. The long P value places the star beyond the limit of about 100 d which is usually assumed for the validity of the PL relation (in metal–poor galaxies); owing to the nonlinear pulsation cycle characteristics (e.g. Aikawa & Antonello 2000), the PL relation in this P range tends to have a negligible slope.

V3873: also in this case our (marginally) best P, 25.35 d differs from Kayser's one, 37.44 d. However, the analysis of the merged dataset supports 37.44 d as the best P.

Other periodic variables have been detected and four of them are probable W Vir stars. V1286 ($P = 41$ d), which has an intermediate colour, is too bright to be a W Vir, and is probably too faint to be a Cepheid. The list of all the other periodic variables and of 91 long P and irregular ones are available upon request from the first author.

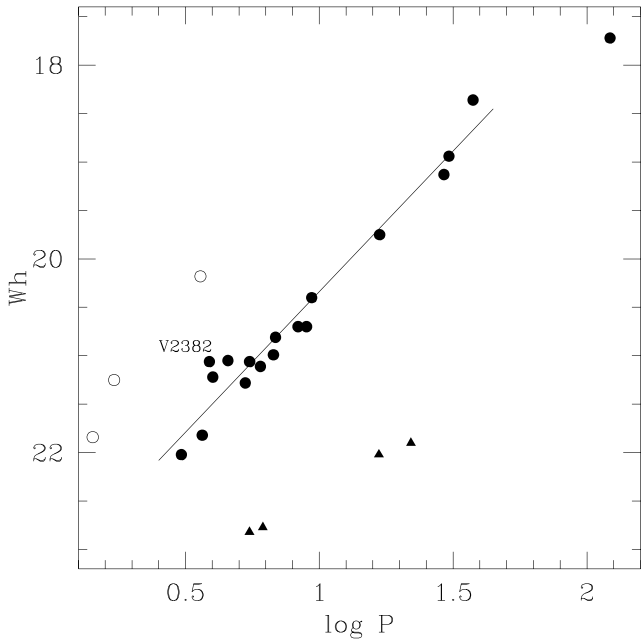

Fig. 4. *PL* diagram for Cepheids in Field A of NGC 6822. *Filled circles*: fundamental mode Cepheids; *open circles*: probable first overtone mode Cepheids; *filled triangles*: probable population II Cepheids. The line is the statistical relation obtained for fundamental mode Cepheids; for these stars $V \sim Wh + 0.3$, typically.

5. Conclusion

We have presented the first results of a survey of NGC 6822 for detecting and studying Cepheids; since a relatively small telescope was used, the observations were performed without a filter. Fainter Cepheids than $V \sim 22$ were found. In the analogous case of IC 1613 we were able to detect Cepheids as faint as $V \sim 23$; the better performances are probably due to the unique characteristics of IC 1613, i.e. a very low background and less severe problems given by crowding, and to the large number of observations (more than 60 data points per star). In NGC 6822, 21 population I Cepheids were identified, while only 6 of them were previously known in the same field. Of these six Cepheids, V0729 and V0734 were previously classified as irregular variable by Kayser (1967; Hubble however indicated V0734 as a Cepheid), and V1292 has a much longer P than previously reported. The PL diagram is shown in Fig. 4. It is possible to derive a PL relation for Cepheids in the Wh band, with a similar slope to that which could be obtained for V and R data; the slope is -2.89 and the zero-point is 23.23. The relation appears to be narrow. We note in particular that the star V2382 has the lowest amplitude ($\Delta Wh = 0.29$), therefore we could suspect it is a binary, and the true luminosity of the Cepheid should be fainter. As in the case of IC 1613, we have performed a few observations in the $BVRI$ bands with the WFI at the 2.2 m ESO telescope, in order to apply the method devised by Freedman (1988) for deriving the PL relation in the various bands of the standard photometry, using the Wh light curves (e.g. Antonello et al. 1999b). Presently the Wh observations of NGC 6822 are almost completed, and in the next papers we will report on the other observed fields, discuss the Cepheid light curve characteristics and make a comparison with the stars of other galaxies in the Local Group; moreover we will present the results of the standard photometry PL relations.

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