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Variable stars in nearby galaxies ⋆

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Abstract. We present a summary of the results of a survey for variable stars, in particular Cepheids, in galaxies of the Local Group, IC 1613, NGC 6822, and discuss the main features of the adopted technique. Moreover, we mention some of the current problems concerning the requirement of very high precision photometry with CCDs.

Key words. Cepheids – Local Group – Stars: oscillations

1. Introduction

In 1995 we started a program for the CCD photometric survey of variable stars in the galaxies of the Local Group. The main scientific goal is the accurate observation of pulsating star (e.g. Cepheids) light curves for a comparison with the theoretical model predictions. Another goal is an improvement of the distance determination; in this context we intend to increase the number of shorter period Cepheids, which can then be used to test the different slopes of the relation between period and luminosity in different period ranges (Tammann et al. 2001). Given the scientific requirements and the availability of only relatively small telescopes for this program, we decided to perform unfiltered CCD observations in order to get the best photon statistics. The results and the comparison with other surveys allow us also to discuss some limitations of the present CCD technique to produce high precision differential photometry measurements.

2. White-light Wh band

The main advantage of unfiltered observations is the larger number of collected photons. For example, Wh observations of hot and intermediate color stars with a 0.9 m telescope are roughly equivalent to V observations with a 2 m telescope, for the same observing conditions and exposure times. Of course the advantage is larger in the case of cooler stars. However, one should take care of the very wide bandpass of this band. The effective wavelength of the Wh-band is more dependent on instrument than that of standard bands, e.g. V or R, and it is also more sensitive to the spectral type or color of the source. In general, for later than A-spectral type, the effective wavelength is intermediate between that of V and R bands. There are two main contaminating effects

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⋆ Based on observations collected at ESO La Silla related to the background, one is that given by the moonlight and the light pollution, and the other is the local background, i.e. the galaxy where the sources are located. If we compare the performances in the Wh with those in the R band, we note that there is no dependence on the Moon phase. In V light, there is a larger relative contamination during the *new* Moon than during the $full$ Moon phase. The reason is that during the full Moon phase the spectral distribution of the sky background is closer to that of the Sun. If we consider the error budget, the Wh-band advantage over the V-band is larger during the full Moon phase. The local background changes significantly from galaxy to galaxy, but it is quite clear that for galaxies with strong red background the use of the Wh band is of less advantage. In this respect, the good results obtained for IC 1613 were due also to the lack of significant local background (we detected new Cepheids as faint as $V \sim 23$ with the 0.9 m telescope); we could not reach the same limiting magnitudes in NGC 6822. Owing to the sensitivity in the red, Wh images obtained with thinned CCDs such as those of the ESO WFI are characterized by fringing effects. One should take account of the very wide bandpass also in the context of atmospheric extinction correction and of the merging of data taken with different instruments; i.e. an adequate calibration is needed. A discussion of the calibration of unfiltered CCD observations is reported by Antonello et al. (2000b), to be compared with the method adopted by Riess et al. (1999). The results of the simulations and the observations, reported by Antonello et al. (1999a) and Antonello et al. (2000b), indicate that the Wh-band is of advantage in the study of stellar variability when one is interested to get precise light curves of faint sources.

3. IC 1613

The observations of this galaxy were performed from 1995 to 1998 with the 0.9 m Dutch telescope, for a total of about 50 observing nights and yielded about 60 data points per star. The total exposure time per data point is 1800 sec. The FWHM of the PSF was usually about 1.6 arcsec; it is worse than that given by the seeing conditions owing to the focus instability of the telescope. In spite of these limitations, we were able to get standard deviations less than 0.02 mag for $Wh = 20$ and about 0.1 mag for $Wh = 22$ that allowed us to detect Cepheids as faint as $Wh \sim 23$ (or $V \sim 23.3$, since $V \sim Wh + 0.3$ for Cepheids), and in particular to detect first overtone mode Cepheids (they were the first stars of this class observed in a galaxy located beyond the Magellanic Clouds). The field of view of the telescope was small (about 3.8 x 3.8 arcmin) and four different fields were surveyed. In these fields we detected a total of 322 variable stars: 82 fundamental mode Cepheids, 34 first overtone mode Cepheids, 2 suspected second overtone mode Cepheids, 4 W Vir stars and other 8 candidates of this class, 10 eclipsing binaries, 1 nova (the variable star V0588-D) and a number of RV Tau, semiregulars, irregulars and Mira candidates (Mantegazza et al. 2000), (Antonello et al. 2002).

Observations in V and R bands with the same telescope were also performed to get color information. More recently, $BVRI$ images of IC 1613 were taken with the WFI at 2.2 m. These data will allow us to perform a complete study of the variable stars. In particular we will use the single phase measurement method devised by Freedman (1988) for obtaining the PL relation of Cepheids in the $BVRI$ bands, by exploiting the Wh-band light curves; see e.g. Antonello et al. (1999b).

The results of the survey of IC 1613 allowed us to point out the present shortcomings of the pulsation models of fundamental mode Cepheids. A comparison with the Milky Way Cepheids (Antonello et al. 2000a), taking into account also the OGLE observations of Magellanic Cloud Cepheids, shows that presently the nonlinear pulsation models are not able to explain the low sensitivity to metallicity of the resonance between the fundamental and the second overtone mode.

4. NGC 6822

A series of $BVRI$ and Wh images of NGC 6822 were obtained in service mode with the WFI at 2.2 m telescope. Here we present a preliminary result concerning the star counts in the V, R and Wh bands. The observations were made in the same conditions during the night of 7 July, 2001. The PSF has an average FWHM value of 1.2, 1.5 and 1.4 arcsec, and the total exposure time is 1100, 800 and 1050 sec for the V, R and Wh band, respectively. We have considered different thresholds, that is, photometric error less than 0.175, 0.20 and 0.175 mag in V, R and Wh, respectively, allowing for the different exposure times. We detected about 38000 stars in the V band, 40000 stars in the R band, and 67000 stars in the Wh band in the WFI field of view (about 34 x 33 arcmin). The histogram of the number of stars against the magnitude is shown in Fig. 1. In comparison with the R band, bright stars are lacking in the Wh band owing to saturation, while there is clearly a larger number of fainter stars. It is interesting to note that, even if the sky background is quite high in the Wh band, it is possible to detect very faint stars.

5. High precision relative photometry

In high precision *differential* or *relative* CCD photometry one should be able to achieve better precisions than 0.001 magnitude; to date, however, the best results with CCD imagers are near 0.003 magnitudes for single observations with modest size telescopes. Current CCD error values are still a factor of about 10 or more above the theoretical limit for a CCD. The precise OGLE-DIA (Difference Image Analysis) data (Zebruń et al. 2001) allowed us to make a test. OGLE II used a 1.3 m telescope in Las Campanas, with a wide field of view, for observing the Magellanic Clouds in BVI bands. The more precise observations are those in I band. In principle, it would be possible to detect signals at the level of 0.001 mag, since typically DIA data of almost constant stars have standard deviations as small as 0.004 mag, and more than 500 data points can be available per star. This means that the noise level can be less than 0.0002. However, stars in the OGLE archive (and also those in other archives) show in general long term variations with periodicities of few hundred days (and their aliases) with small amplitude. This should indicate the presence of seasonal variations, that is, variations with long time scales that complicate the search for further periodicities with smaller amplitudes. For example, for the Cepheid shown in Fig. 2 the σ of the 11th order fit for 461 datapoints is 0.0041. There are two peaks of similar height in the power spectrum, located at 0.9974 c/d and at its alias at 0.0026 c/d (semi-amplitude=0.0019 $\pm$ 0.0003). The results indicate a possible seasonal variation with $P \sim 400$ d. Its origin should be probably technical, due to the instrumentation (e.g. slow temperature changes of the camera control electronics), or to observational and data reduction pro-

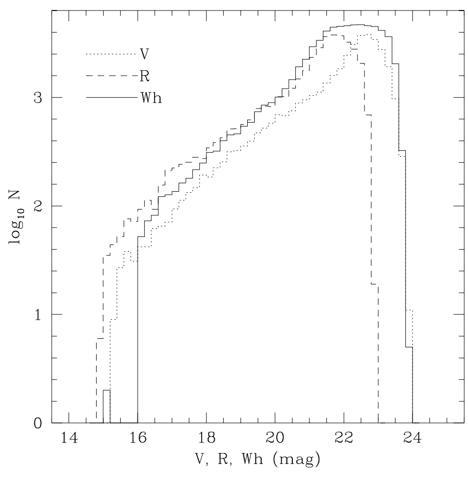

Fig. 1. Distributions in V, R and Wh band of stars in the field of NGC 6822, observed with the ESO WFI at 2.2 m telescope

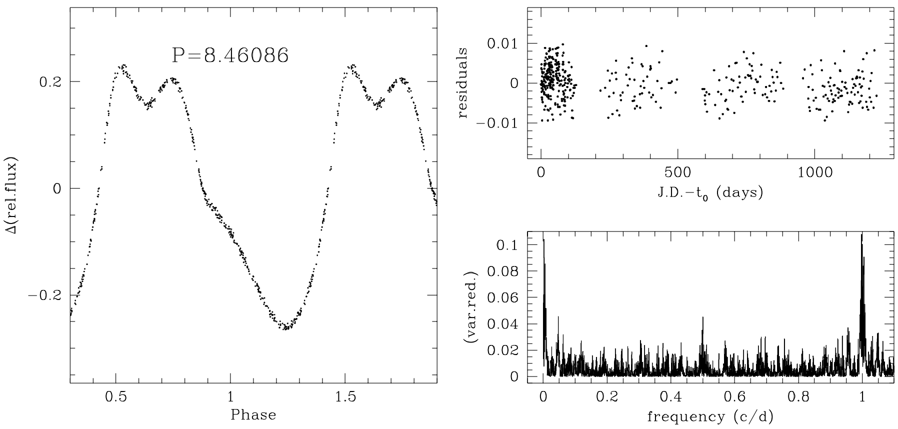

Fig. 2. *Left panel:* light curve of the bright Cepheid OGLE051755.36-694546.4 ($I = 13.94, P = 8.460$ d) in the LMC. *Right, upper panel:* the residuals of the 11th Fourier fit plotted against J.D. *Right, lower panel:* the power spectrum obtained taking into account the 11 known terms of the Cepheid; a long P term with its alias is present

cedures. We think that a true improvement of the ground-based, high-precision CCD photometry will be obtained when enough attention will be payed to these problems.

6. Conclusions

We have essentially reported our experience on the CCD photometry for the study of stellar variability, and discussed the present practical limitations of high precision CCD photometry. Taking into account the increasing scientific requirements, we remark that important research areas in which very high precision photometry, much better than 0.01, is desired include astrosismology, searching for extrasolar planets, and variability of faint galactic and extragalactic objects over large fields of view. All of them require photometric results of the highest precision possible, and wide-field imaging in order to be productive.

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