Mem. S.A.It. Vol. 74, 878

Memorie della

The VSNG Project: variable stars in nearby galaxies *

G. Clementini[1]

INAF - Osservatorio Astronomico, via Ranzani 1, 40127 Bologna, Italy

Abstract. We describe the VSNG Project, a collaboration between researchers of Bologna, Padova, Napoli and Merate Observatories, to study variable stars in a number of galaxies in the Local Group. We briefly review results obtained for the galaxies analyzed so far.

Key words. Hertzsprung-Russell Diagram – Local Group – Stars: oscillation – Tecniques: photometric

1. Introduction

Variable stars are fundamental tools for the definition of the astronomical distance scale and for tracing stellar populations in galaxies.

The VSNG project: Variable Stars in Nearby Galaxies, is a collaboration between researchers of Bologna, Padova, Napoli and Merate Observatories, who have joined their efforts and their skills to make a systematic study of the variable star populations in a number of Local Group (LG) galaxies. Started a few years ago, the project has already gathered data on 6 galaxies of different morphological type, namely: the Large Magellanic Cloud (LMC), Fornax, Leo I, Phoenix, NGC 6822 and M31. Complete studies have been carried out or are in progress for the LMC (Bragaglia et al. 2001, Clementini et al. 2002a), Leo I (Held et al. 2001), and NGC 6822 (Clementini et al. 2002b). Analysis has just been started in Fornax. Feasibility projects have been conducted in Phoenix, and M31 (Clementini et al. 2001). Many people are involved in the above studies. Participation and co-authorship is described for each specific subproject.

The different parts of the VSNG project are handled by the collaborating teams according to their specific skills and expertise. Different approaches and most suited data reduction and analysis strategies are adopted, depending on the available data:

- Wide Field Imager (WFI) and Very Large Telescope (VLT) photometric time series data for Leo I, Fornax and Phoenix are handled in Padova by E.V. Held and collaborators (L. Rizzi, Y. Momany, I. Saviane), who developed dedicated software (Wide Field Padova Reduction Package: WFPRED) and au-

Send offprint requests to: G. Clementini

* Based on data collected with the ESO and HST telescopes

Correspondence to: INAF - Osservatorio Astronomico, via Ranzani 1, 40127 Bologna, Italy

tomatic reduction procedures Rizzi & Held (2003, in preparation). PSF photometry is performed with DAOPHOT and ALLFRAME (Stetson 1994)

- variable stars identification and study is done in Bologna by G. Clementini and her collaborators (L. Baldacci, M. Maio, F. Matonti, in particular) using both private dedicated software (VARFIND, GRphycal Analyzer of TIme Series: GRATIS), and image subtraction techniques (ISIS 2.1, Alard 2000).
- spectroscopic and photometric data of the LMC subproject have been handled jointly by people in Bologna and Padova (A. Bragaglia, G. Clementini, M. Maio, E. Taribello, E. Carretta, R.G. Gratton)
- HST data for the M31 Globular Clusters are reduced with ROMAFOT (Buonanno & Iannicola 1989). Identification of the candidate RR Lyrae stars is done through comparison with template light curves.
- theoretical pulsational models are provided by the Napoli team (M. Marconi).

2. The Large Magellanic Cloud

Involved people: G. Clementini, A. Bragaglia, E. Carretta, L. Di Fabrizio, R.G. Gratton, M. Marconi, M. Maio, E. Taribello

The LMC is the first step of the astronomical distance scale. Many different distance indicators coexist in the LMC, thus allowing a direct comparison of the distance scale they provide. We observed 2 fields close to the bar of the LMC with the 1.5 m Danish telescope at ESO (La Silla) and obtained B,V light curves for 152 variables, among which 125 are RR Lyrae stars (see contribution by Maio et al. in these Proceedings). Reddening in the two areas was estimated from the pulsational properties of the RR Lyrae stars. Low resolution spectroscopy (R$\sim$815) was obtained in 2001 with FORS at the VLT for a hundred of the RR Lyrae stars, and for about 300 clump stars. Examples of our FORS1+UT1 spectra for RR Lyrae and clump stars in the LMC are shown in Figure 1. Metal abundances for the RR Lyrae stars were derived using a revised version of the ΔS technique (Preston 1959), as fully described in Gratton et al. (2003, in preparation). The average metal abundance of the sample is $<$[Fe/H]$>=-1.48$ (σ=0.29). The new metal abundances and the apparent average luminosities of the RR Lyrae stars were used to derive the following luminosity-metallicity relation:

$$< V_0(RR) >= 0.214\times([\text{Fe/H}]+1.5)+19.064$$

This relation is shown in Figure 2. The dereddened average luminosity of the RR Lyrae stars is: $< V(RR)_0 >=19.06\pm0.06$ at [Fe/H]$=-1.5$. When combined with the absolute magnitude of RR Lyrae stars provided by the Main Sequence Fitting of Galactic Globular clusters (Gratton et al. 2002) this value gives μ_{LMC}=18.45±0.09. A re-analysis of the distance moduli derived for the LMC using various different distance indicators and techniques and the results of our LMC photometric and spectroscopic study leads to μ_{LMC}=18.515±0.085, with no longer dichotomy existing between short and long LMC distance scales Clementini et al. (2002a).

3. Fornax and Leo I

Involved people: G. Clementini, E.V. Held, E. Poretti, L. Rizzi, L. Baldacci, L. Di Fabrizio, M. Maio, F. Matonti, Y. Momany, L. I. Saviane Time series B, V data for the dwarf spheroidal galaxies Leo I and Fornax were obtained with the Wide Field Imager of the 2.2 m MPG/ESO telescope.

Data reduction of the Fornax data (18 V and 62 B frames covering about 1/4 of the galaxy) is in progress. Variable stars identification has been successfully performed with ISIS2.1 on one of the 8 CCDs of the WFI mosaic. The search will be extended soon to the other CCDs.

For Leo I we have 40 V, 22 B and 5 I WFI frames covering the body of the galaxy and

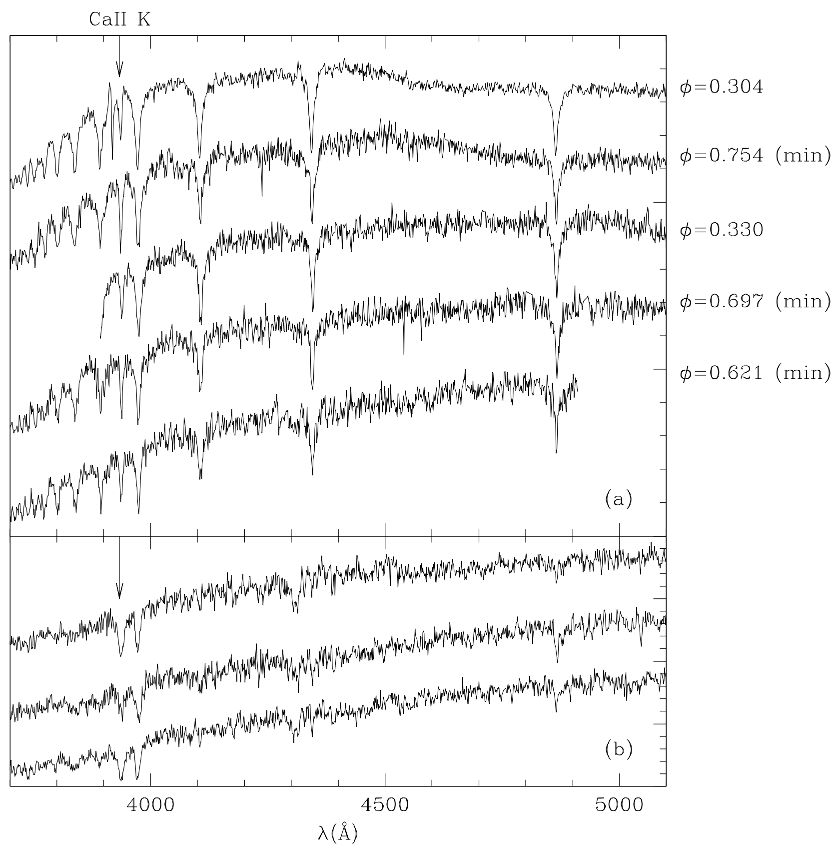

Fig. 1. Spectra of RR Lyrae (panel *a*), and clump stars (panel *b*) in the bar of the LMC, obtained with FORS at UT1. For the RR Lyrae stars we label phases at which spectra were acquired.

its surrounding fields. Data have been fully reduced using the Padova pipeline for WFI frames. This consists of the following steps:

(a) bias subtraction and flat-fielding of the data with MSCRED (Valdes 1997), a public package available into IRAF

(b)reduction with WFPRED. This software, developed within the IRAF environment by E.V. Held and L. Rizzi, allows to make:

– photometry of Landolt standard stars
– astrometry of the science frames in automatic way to remove geometric distortions and generate the master catalogues
– coaddition of dithered images

Due to technical problems, our time series images of Leo I were not aligned, and astrometry was used to trim the whole set

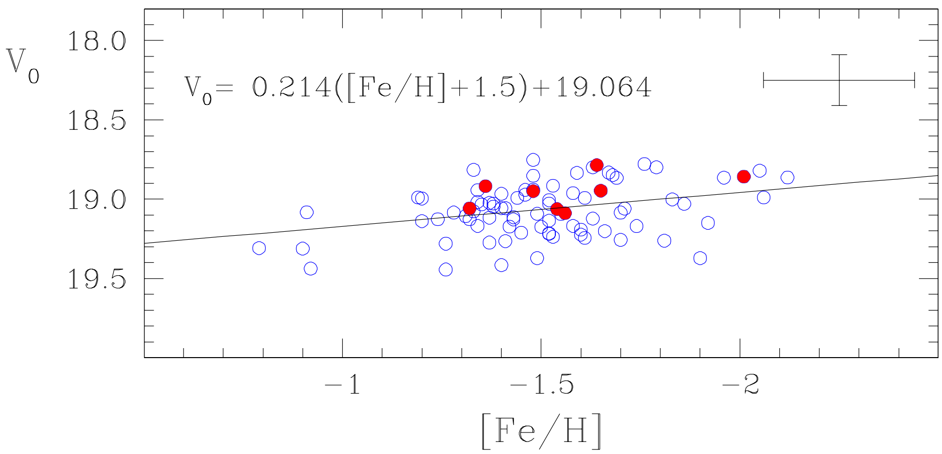

Fig. 2. Luminosity-metallicity relation defined by RR Lyrae stars in the LMC. Filled (red) dots mark the double-mode pulsators in our sample (Clementini et al. 2002a).

of images to a common intersection region, and to remove geometrical distortions

(c) photometry of the bias-subtracted, flat-fielded images with ALLFRAME. The package requires one PSF for each exposure for each CCD of the mosaic. The 496 PSF's needed for our 62 WFI images of Leo I were generated through a fully automatic algorithm developed in Padova. ALLFRAME was then run on the pretreated images. The package produces a master object list by finding stars on the stack of all images, and performs PSF fitting photometry on the individual images using the master list. For each star the program returns both the average magnitude and a record listing all measurements on the single frames.

Catalogues were then moved to Bologna to perform the identification of the variable stars and the period definition. Variables in Leo I were first identified in the three CCD's hosting the main body of the galaxy using the program VARFIND. VARFIND is a private software developed at the Bologna Observatory by P. Montegriffo, which allows to pick up candidate variable stars from the scatter diagram of the time series measurements. The code is interactively linked to GRATIS, a private software which allows to perform period search and study of single and multi-mode periodicities. GRATIS has been developed at the Bologna Observatory by P. Montegriffo, G. Clementini and L. Di Fabrizio.
For the first time RR Lyrae stars were detected in Leo I (Held et al. 2001), thus proving that the galaxy started forming stars at an early epoch. The distance modulus of Leo I derived from the luminosity level of the Horizontal Branch traced by the RR Lyrae stars is: μ_{LeoI}=22.04±0.14 (Held et al. 2001). A deeper search of variable stars has been performed on the whole mosaic of the 8 CCDs using the ISIS2.1 package. Results are presented in Clementini et al. (2003, in preparation).

4. Phoenix and NGC 6822

Involved people: G. Clementini, E.V. Held, L. Baldacci, L. Di Fabrizio, Y. Momany, L. Rizzi, I. Saviane
Both Phoenix and NGC6822 were observed with the VLT. Phoenix time series arise from archival data and consist of: 10 V,

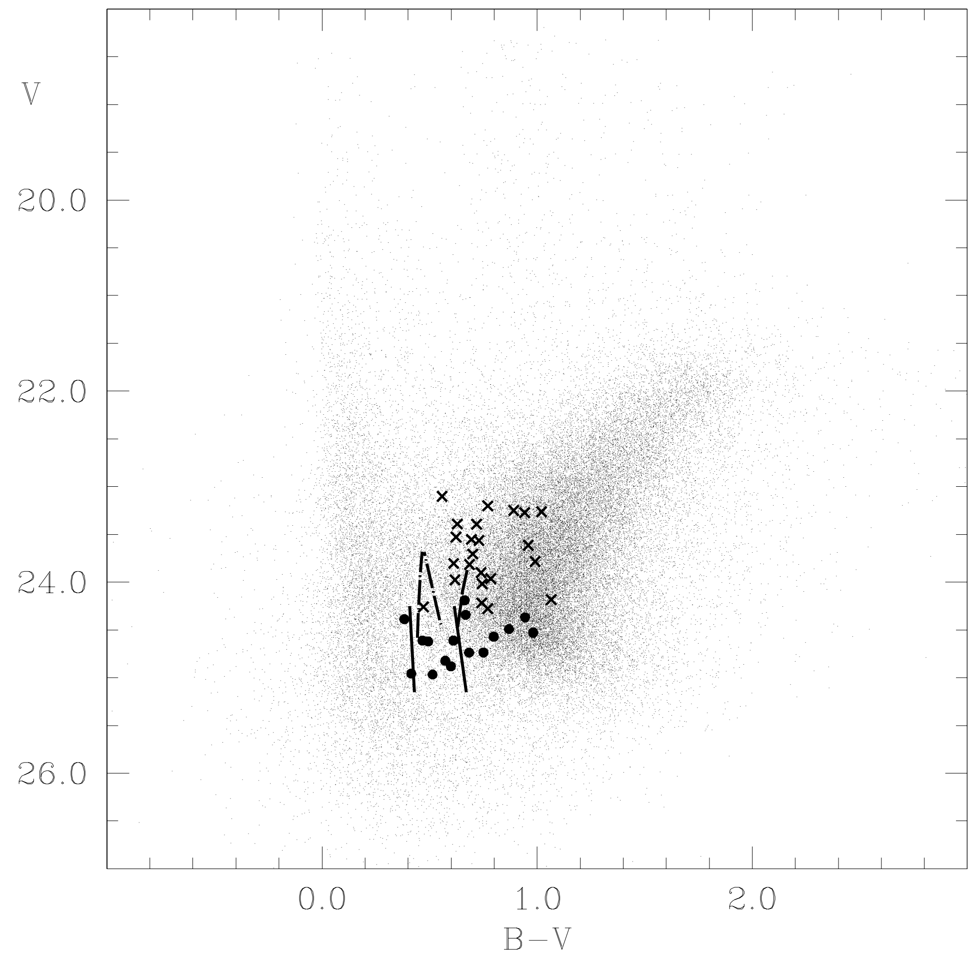

Fig. 3. Color-magnitude diagram of NGC 6822 (from Clementini et al. 2002b) showing the location of the newly discovered RR Lyrae (filled circles) and Anomalous Cepheids (crosses) variable stars. Solid lines show the edges of the RR Lyrae instability strip of M 3 (Corwin & Carney 2001), dashed lines are the the instability strip boundaries for 1.5 $M_{\odot}$ models (Bono et al. 1997).

7 *B* and 4 *I* frames. The color magnitude diagram of Phoenix shows a very well defined HB (Held et al. 2003, in preparation) at raw magnitude about $v \sim 15.5$, and a well defined RR Lyrae gap around $b-v \sim 0.8$. Indeed, the scatter diagram obtained with VARFIND clearly shows large σ's corresponding to the RR Lyrae *finger* at $v \sim 15.5$. Although we only have a few frames for Phoenix, using the scatter diagram and playing with data in the three different bands we were able (i) to identify candidate RR Lyrae stars, and (ii) to build up multicolor light curves that can then be compared with RR Lyrae template light curves.

NGC6822 time series consist of 36 V, 11 B, and 4 I VLT frames. Variable star identification performed with ISIS2.1 led to the discovery of a conspicuous number of RR Lyrae stars and Anomalous Cepheids in the galaxy. A more thorough description of the variable star identification technique and results is provided in Baldacci et al. (2003, these Proceedings). Figure 3 shows the location of the newly discovered RR Lyrae (filled circles) and Anomalous Cepheid (crosses) stars in the calibrated color-magnitude diagram of NGC 6822 obtained with ALLFRAME. Solid lines show the edges of the RR Lyrae instability strip of M 3 (Corwin & Carney 2001), dashed lines are the instability strip boundaries for 1.5 $M_\odot$ models (Bono et al. 1997). A preliminary estimate of the average luminosity of the RR Lyrae stars identified in NGC 6822 is $< V(RR) >$=24.61±0.14, leading to a distance modulus of: $\mu_{NGC6822}$=23.35±0.15, for E(B-V)=0.24, [Fe/H]=−1.8 and $M_V(RR)$= 0.57 mag (Clementini et al. 2002b).

5. M31

Involved people: G. Clementini, L. Federici, C. Corsi, C. Cacciari, M. Bellazzini, H.A. Smith.

A feasibility study was performed on archival HST data of 4 Globular clusters (GCs) in the Andromeda galaxy. We used 4 F555W and 4 F814W observations of four M31 GCs to identify RR Lyrae stars. Candidate variables were selected from the VARFIND scatter diagrams for the 4 clusters. Time series data for each candidate variable were then compared with template light curves of RR Lyrae stars in the Galactic globular cluster M3 (Carretta et al. 1998). We were able to identify 2, 4, 11 and 8 such candidate RR Lyrae stars in G11, G33, G64 and G322, respectively, as fully described in Clementini et al. (2001).

Acknowledgements. Part of this work was supported by the MURST Cofin98 under the projects "Stellar Evolution" and "Processing of large astronomical images", and by MURST - Cofin00 under the project "Stellar observables of cosmological relevance"

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