Distance determination to the Andromeda Galaxy using variable stars

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Abstract Distance determinations to Local Group galaxies conform the basic rungs of the cosmological distance scale. The chief goal of our project is obtaining direct and accurate distance determinations to M 31 from two important stellar populations: eclipsing binaries and Cepheids. A variability survey in the North-Eastern quadrant of M 31 was performed (in B and V passbands) with the Isaac Newton Telescope (La Palma) to identify suitable targets. The resulting catalog of 3 964 variable stars contains 437 eclipsing binaries and 416 Cepheids with ~ 250 epochs per filter. The selection of the 68 Cepheids less affected by blending were selected to determine a distance to M 31 of $(m-M)_0 = 24.32 \pm 0.12$ mag. At the same time, the analysis of the eclipsing binary sample (with the acquisition of Gemini/GMOS spectroscopy) has provided two direct distance determinations to M 31: $(m-M)_0 = 24.44 \pm 0.12$ mag and $(m-M)_0 = 24.46 \pm 0.19$ mag. All the obtained distances are in complete agreement and provide a direct and accurate distance determination to M 31. The combination of these results with additional data could well reduce the distance uncertainty to M 31 to better than 4%.

1 Context

Local Group galaxies are the basic calibrators of most distance indicators. Being the major component (together with the Milky Way), the Andromeda galaxy (M 31)

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represents an unavoidable step for accurate extragalactic distance determinations. In order to determine a direct an accurate distance to M 31, a photometric program was started in 1999 at the Isaac Newton Telescope (La Palma) [1]. The main goal of the project was to identify eclipsing binaries suitable for distance determination. The resulting variability survey contains 3 964 variable stars, with 437 eclipsing binaries and 416 Cepheids, having ~ 250 epochs in both Johnson B and V.

2 Cepheids

The sample of 416 Cepheids is almost as complete as the David Dunlap observatory sample in the Milky Way. Therefore, the Cepheid sample was used to obtain a distance determination to M 31. In order to distinguish the fundamental mode and first overtone Cepheids, Fourier series were fitted to the obtained light curves in *both passbands* (B and V, Fig. 1). The relationship between the Fourier coefficients allowed a clear distinction between fundamental and first overtone Cepheids, identifying 356 fundamental mode and 75 first overtone pulsators [4].

The detailed analysis of the obtained photometry enabled a comprehensive analysis of the effect of blending on Cepheids. It was shown that the effect of blending on the mean magnitude of a Cepheid could be computed from the observed amplitudes and that large amplitude Cepheids should be, on average, less affected by blends. The fundamental mode sample could be used to estimate the effect of blending, revealing that blending is as important as the metallicity corrections when obtaining distance determinations with Cepheids. In particular, the distance modulus to M 31 changed by almost 0.1 mag when considering only large amplitude Cepheids [4].

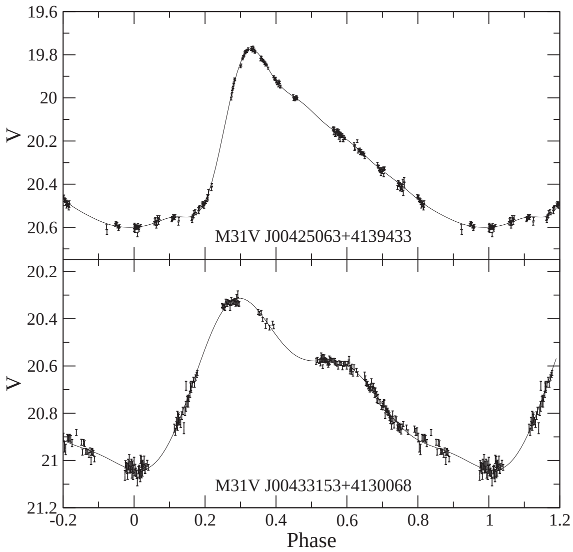

Fig. 1 Fourier fits in V passband for two of the 416 Cepheid light curves. Observations have been aliased in order to better display the pulsation cicle.

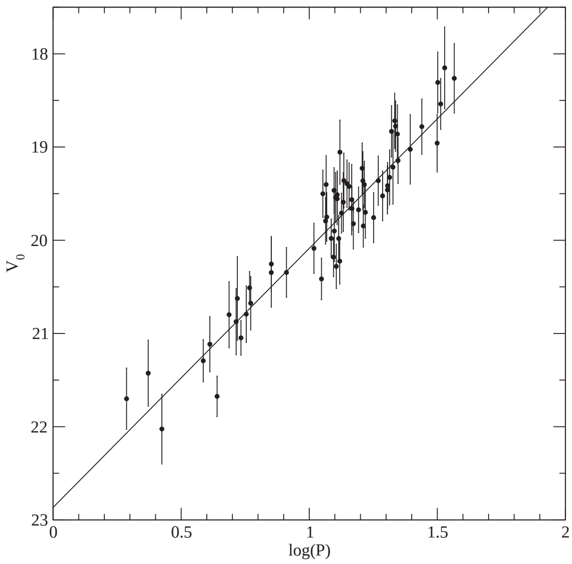

Fig. 2 Absorption-corrected V magnitude as a function of period for Cepheids with an amplitude larger than 0.8 mag. Black line represents [3] period-luminosity relations for a distance modulus of $(m-M)_0 = 24.32 \pm 012$ mag.

The 68 largest amplitude (and less blended) Cepheids were corrected for absorption and metallicity to derive a period-luminosity relationship (Fig. 2). The fit of OGLE LMC period-luminosity relationship [3] to the obtained data provides a distance modulus to M 31 of $(m-M)_0 = 24.32 \pm 0.12$ mag [4].

3 Eclipsing binaries

The eclipsing binary sample has provided 24 candidates suitable for distance determination [5]. Medium resolution spectroscopy (R=3700) was obtained for five of these targets with GMOS at Gemini-North, allowing radial velocity and temperature determinations. These results, when combined with the obtained photometry, are providing the first direct and accurate fundamental properties (masses, radii and temperatures) for stars in M 31. The analysis of two of these systems (Fig. 3 and [6]) has also provided the first two direct distance determinations to M 31 (Table 1). Both distance determinations are completely consistent with the Cepheid value and provide a direct and robust distance to the most important galaxy in the Local Group. In addition, the analysis of the remaining targets observed with GMOS (not shown here), combined with already obtained HST/ACS spectrophotometry, are providing valuable information on the fundamental properties of massive stars in M 31.

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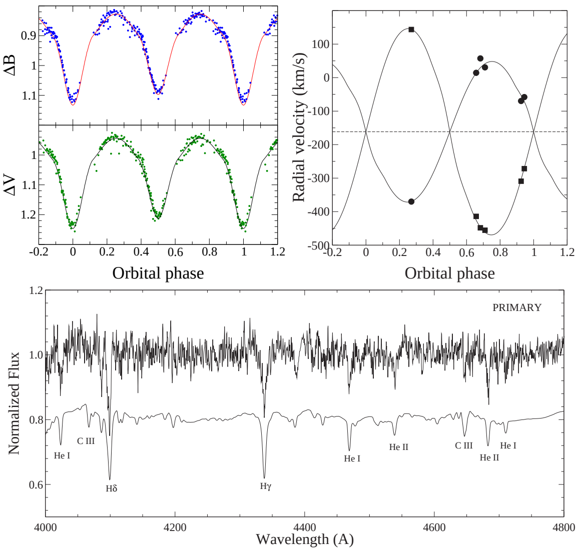

Fig. 3 Modeling of M31V J00443610+4129194 light curves (top-left), radial velocity curves (top-right) and primary spectrum (bottom). The combination of the three fits has enabled the determination of the fundamental properties shown in Table 1.

Table 1 Fundamental properties of the two eclipsing binary stars providing a direct distance to M 31.

	M31V J00443799+4129236		M31V J00443610+4129194[a]	
$(m-M)_0$	24.44±0.12 mag		24.46±0.19 mag	
M_V	-5.77±0.06 mag		-5.03±0.18 mag	
$E(B-V)$	0.19±0.03 mag		0.17±0.02 mag	
	Primary	Secondary	Primary	Secondary
Mass	23.1±1.3 $M_\odot$	15.0±1.1 $M_\odot$	23.9±1.9 $M_\odot$	16.1±1.3 $M_\odot$
Radius	13.1±0.3 $R_\odot$	11.3±0.3 $R_\odot$	8.3±0.3 $R_\odot$	7.8±0.3 $R_\odot$
Temperature	33900±500 K	27700±500 K	33600±600 K	30800±600 K

[a] Preliminary results based on the temperature of the primary component

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