Abstract. Long-slit observations of 4 dwarf spheroidal galaxies in the M81 group are presented. We have obtained a heliocentric velocity of globular cluster candidate located near the center of DDO78 to be $55 \pm 10$ km s$^{-1}$ by cross-correlation with template stars. We estimated a heliocentric radial velocity of $-116 \pm 21$ km s$^{-1}$ for an HII region seen in the K 61. A red diffuse object near the K64 center is found to be a remote galaxy with a heliocentric velocity of $+46530$ km s$^{-1}$.

Key words: galaxies: dwarf — galaxies: star clusters — galaxies
Radial Velocities of Dwarf Spheroidal Galaxies in the M81 Group*

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1. Introduction

This work continues our study of dwarf spheroidal galaxies (dSphs) in the M81 group. dSphs are diffuse spheroidal objects with central surface brightnesses of \( \mu_v(0) \gtrsim 22^m/\text{arcsec}^2 \), absolute magnitudes \( M_V \gtrsim -14^m \), and \( H_\text{I} \) masses \( M_\text{HI} \leq 10^6 M_\odot \) (Grebel 2000). Being among the faintest galaxies, dSphs are rather difficult to observe. As gas-poor galaxies, they are usually undetectable in the \( H_\text{I} \) line. In the case of the M81 group an additional observational difficulty arises, because of the group location in an area of the sky that is contaminated with dense Galactic \( H_\text{II} \) emission (van den Bergh 1959) and Karachentseva (1968), as well as BK5N, BK6N, KK77, F8D1, FM1, and KKH57 found in more recent studies (Börngen & Karachentseva 1982, Karachentsev 1994, Caldwell et al. 1998, and Froebrich & Meusinger 2000).

Almost half of the galaxies in the M81 group are dSphs. There are DDO 71, DDO 78 and K 61, K 64 discovered many years ago by van den Bergh (1959) and Karachentseva (1968), as well as BK5N, BK6N, KK77, F8D1, FM1, and KKH57 found in more recent studies (Börngen & Karachentseva 1982, Karachentsev 1994, Caldwell et al. 1998, and Froebrich & Meusinger 2000). Based on the presence of \( H_\text{II} \) region, some blue stars and a probable presence of neutral gas Karachentsev et al.(2000) assumed K61 to be dSph/dIrr transition type.

All these objects have been resolved into stars with Hubble Space Telescope Wide Field Planetary Camera 2 and confirmed as members of the M81 group via a tip of red giant branch stars (Caldwell et al. 1998, Karachentsev et al. 2000, Karachentsev et al. 2001).

The HST images have allowed us to find globular cluster candidates in five galaxies of the M81 dSphs sample (Karachentsev et al. 2000). The images of four dSph galaxies in the M81 group are presented in Fig.1. Globular cluster candidates and central background galaxy in the case of K64 are indicated by arrows. The images were obtained aboard the Hubble Space Telescope as part of a snapshot survey of nearby dwarf galaxy candidates (program GO 8192, PI: Seitzer) and produced by combining the two 600 s exposures taken through the F606W and F814W filters. The galaxies are centred in the WFC3 chip.

Basic photometric properties of globular cluster candidates from Karachentsev et al.(2000) are listed in Table 1. Its lines contain : (1) integrated apparent magnitude, (2) integrated color after correction for Galactic reddening, (3,4) angular and linear half-light radius, (5) the central surface brightness, and (6) integrated absolute magnitude. Globular clusters in dSphs are relatively bright objects. In most cases, spectroscopy of them is the only way to get radial velocities of parent galaxies. Data on radial velocities together with accurate distances for dSphs allow us to trace the structure and kinematics of the M81 group in more detail.
correction. After wavelength calibration and sky subtraction, the spectra were corrected for atmospheric extinction and flux-calibrated. Then rows of every linearized two-dimensional spectrum were summed in the spatial direction to yield a final one-dimensional spectrum. All individual exposures of the same object were then co-added to increase the signal-to-noise ratio. At last, the spectra of globular cluster candidates and template stars were divided by normalized continuum and wavelength rebinning was done linearly in ln $\lambda$, as appropriate for the cross-correlation analysis.

3. Radial velocities

Heliocentric radial velocities of the observed objects are summarized in Table 4.

3.1. DDO78

DDO78 has a very flat surface brightness profile with the central surface brightness $\mu_v(0) = 24.5''/\text{arcmin}^2$, the exponential scale length $h = 28''$ and the integrated magnitude $V_1 = 15.1$ (Karachentsev et al. 2000). It is surprising that the galaxy contains the bright globular cluster candidate. The quality of the DDO78 globular cluster candidate spectrum (Fig.2) is adequate to derive its radial velocity. The spectra obtained independently in two observational nights have typically a signal-to-noise ratio of about 10 each.

The spectrum of the globular cluster in DDO 78 was cross-correlated with stellar template spectra using the method of Tonry & Davis (1979). A procedure of MIDAS ”XCORRELATE/IMAGE” correlates two one-dimensional frames in pixel coordinates. The spectral resolution is approximately as twice as the expected internal velocity dispersion in the cluster, so we have not artificially broadened the template star spectra before the procedure of cross-correlation. The globular cluster spectrum was individually cross-correlated against the velocity templates observed in the corresponding night. Then the spectrum was divided into four parts. These parts were similarly cross-correlated against the corresponding spectral regions of the velocity templates. We also estimated the radial velocity by measuring redshifts of individual absorption lines. The latest method gave a larger rms error of radial velocity estimates when compared with the cross-correlation method. So the mean radial velocity from cross-correlation served as a final guess to the mean wavelength-shift determination. The results and errors are summarized in Table 3.

Finally, we conclude that the observed object is a true globular cluster belonging to DDO78. Its mean heliocentric velocity is $+55 \pm 10$ km s$^{-1}$, where the error includes ”internal” cross-correlation errors and statistical errors from different cross-correlation manners.

3.2. K61 and DDO71

The DDO71 and K61 globular cluster candidates have fainter apparent magnitudes: $V_T = 20.95$ and 20.70, respectively (Karachentsev et al. 2000). Being divided by normalized continuum, their spectra are presented in Fig.3. The signal-to-noise ratio for them is poor and the cross-correlation peak vanishes into the noise. In the case of DDO71 an additional difficulty arises, because the slit position was chosen to cross a foreground star. As a result, night sky lines have not been subtracted correctly.

We have also obtained a spectrum of the HII region in K61 (Fig.4). Note, that K61 is the brightest dSph galaxy in the M81 group and the closest companion to M81. Johnson et al. (1997) revealed a bright HII knot situated NE of the galaxy center. It shows high excitation emissions with a radial velocity of $-135 \pm 30$ km s$^{-1}$.

Our velocity estimate agrees well with the previous data. The strongest lines in the spectrum, H$\beta$, [OIII] $\lambda\lambda 4959,5007$ and H$\alpha$, were used to measure the radial velocity of K61. As a result, the mean heliocentric velocity is $-116 \pm 21$ km s$^{-1}$, where the error is the standard deviation calculated from different lines.

3.3. K64

Binggeli & Prugniel (1994) ascribed the central star-like object of K64 as a ”quasi-stellar nucleus”. However, the large-scale HST images indicate this object to be a remote red galaxy (Karachentsev et al., 2000). Our spectral data confirm this conclusion. Fig.5 shows location of the measured cross-correlation peak. The spectra of the object and a template star are presented too. We have derived for the galaxy the mean heliocentric velocity $46530$ km s$^{-1}$.

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Table 1. Properties of globular cluster candidates from Karachentsev et al. (2000).

| Parameter                      | DDO78 | K61 | DDO71 | K64  |
|-------------------------------|-------|-----|-------|------|
| $V_T$                         | 19.45 | 20.70 | 20.95 | (19.5) |
| $(V - I)_0$                   | 1.07  | 1.00 | 0.99  | (1.44) |
| $R(0.5L)$, (")                | 0.30  | 0.20 | 0.26  | (1.08) |
| $R(0.5L)$, pc                 | 5.3   | 3.6  | 4.6   | —     |
| $\mu_v(0)$                    | 18.0  | 18.5 | 19.2  | (19.6) |
| $M_v$                         | $-8.48$ | $-7.37$ | $-7.17$ | —     |

K64: The central object appears to be a background galaxy.

Table 2. Observing log

| Object                        | Date             | Exposure | PA of the slit |
|-------------------------------|------------------|----------|----------------|
| Globular cluster candidate    | 18.01.2001       | 2 x 1200 s | 49.°0           |
| in DDO78                      | 18.01.2001       | 2 x 2400  |                |
| HII region and globular cluster candidate in K61 | 18.01.2001 | 2 x 1200 | 60.°9         |
| Background galaxy projected onto K64 | 23.01.2001 | 3 x 1800 | 60.°0          |
| Globular cluster candidate in DDO71 | 23.01.2001 | 2 x 1800 | 78.°2          |
| BF 10078 (F8 V)               | 18.01.2001       | 3 x 10   |                |
| BF 49601 (G8 V)               | 18.01.2001       | 3 x 30   |                |
| BF 13987 (F8 VI)              | 18.01.2001       | 3 x 60   |                |
| BF 18804 (G9 V)               | 19.01.2001       | 2 x 20   |                |
| BF 18757 (G9 V)               | 19.01.2001       | 2 x 10   |                |
| BD 28                         | 18.01.2001       | 2 x 90   |                |
|                               | 19.01.2001       | 2 x 150  |                |

Table 3. Measured heliocentric radial velocities of globular cluster (GC) in DDO78.

| Method                       | $\lambda$ Å | $V_h$, km s$^{-1}$ |
|------------------------------|--------------|--------------------|
| Cross-correlation            |              |                    |
| GC versus BF13987            | 4700 ÷ 6700  | +52                |
|                              | 4700 ÷ 5200  | +56                |
|                              | 6200 ÷ 6700  | +58                |
| GC versus BF18804            | 4700 ÷ 6700  | +61                |
|                              | 4700 ÷ 5200  | +81                |
|                              | 6200 ÷ 6700  | +46                |
| GC versus BF49601            | 4700 ÷ 6700  | +40                |

Individual Wavelength Shifts

| GC regarding to BF18804      | H$\alpha$ 6562.78, +76 ± 39 |
| Fe+CaI                       | H$\beta$ 4861.33               |
| GC regarding to BF49601      | Fe 6562.78, +71 ± 35           |
|                              | H$\beta$ 4861.33               |

Table 4. Heliocentric radial velocities of the observed objects.

| Object                        | $V_h$, km s$^{-1}$ |
|-------------------------------|--------------------|
| Globular cluster candidate in DDO78 | 55 ± 10            |
| HII region in K61             | 116 ± 21           |
| Background galaxy projected onto K64 | 46530 ± 23         |

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Fig. 1. WFPC2 images of four dSph galaxies in the M81 group. Each galaxy is centered in the WF3 chip (WF3-FIX mode). The field size of each image is 1.3’. Globular cluster candidates and the central background galaxy in the case of K64 are indicated by arrows.
Fig. 2. Cross-correlation function for the globular cluster candidate in DDO78 vs BF18804.
Fig. 3. Spectra of globular cluster candidates in K61 and DDO71 divided by normalized continuum.
Fig. 4. Spectrum of HII region in K61.
Fig. 5. Cross-correlation function for the remote red galaxy projected onto K64 vs BF49601.