

Letter to the Editor

Fundamental properties of the new dwarf galaxy And VI – alias ‘Pegasus Dwarf’ – another companion of M31

Ulrich Hopp¹, Regina E. Schulte-Ladbeck², Laura Greggio^{1,3}, and Dörte Mehlert^{1,*}

¹ Universitätssternwarte München, Scheiner Strasse 1, D-81679 München, Germany (e-mail: hopp@usm.uni-muenchen.de)

² University of Pittsburgh, Pittsburgh, PA 15260, USA, (e-mail: rsl@phyast.pitt.edu)

³ University of Bologna, I-40100 Bologna, Italy

Received 11 November 1998 / Accepted 24 November 1998

Abstract. We present medium deep CCD imaging in B, V, and I of the Pegasus Dwarf galaxy (And VI) which was recently found by Karachentsev & Karachentseva (1998), and independently also by Armandroff et al. (1999). The Calar Alto 2.2m images show a low surface brightness galaxy. Its structure resembles that of the other known dSph companions of M31 And I, II, III, and V. The brightest stars are resolved in all three colors. Color-magnitude diagrams in either B–V or V–I show the tip of the red giant branch which allows us to estimate a true distance modulus of 24.5 ± 0.2 . The color-magnitude diagrams and the structure show no evidence for recent star formation, thus, a classification as spheroidal dwarf galaxy with a rather old population seems appropriate. The total absolute magnitude of this dwarf is $M_{V,0} = -10.4 \pm 0.2$.

Key words: galaxies: dwarf – galaxies: structure – galaxies: distances and redshifts – galaxies: individual: And VI

1. Introduction

Until recently, only three dwarf spheroidal (dSph) companions of M31 were known, namely And I, II, and III while no less than 9 such systems are associated with the Milky Way Galaxy (MWG). The M31 companions have been known since 1972 and were found by a visual inspection of the (old) Palomar Sky Survey by van den Bergh (1972). Recently, new searches were initiated based on the new, deeper plates of the POSS II. Armandroff et al. (1998) found and confirmed a new M31 companion which they named And V. Karachentsev & Karachentseva (1998) announced the finding of two low surface brightness objects, namely the Cassiopeia Dwarf of $B \sim 16$ and the Pegasus Dwarf of $B \sim 14.5$. The Pegasus dwarf was meanwhile found independently by Armandroff et al. (1999), they called it And VI. According to the location in the sky and the morphology,

both newly identified dwarf candidates might be additional M31 companions. As argued by Armandroff et al., the new survey plates are not only more sensitive than those available to van den Bergh, but were searched also to larger M31-centric distances, since the MWG companions implied larger dimensions of the companion systems. We here present ground-based CCD observations done with the Calar Alto 2.2m telescope of the later candidate in constellation Pegasus and will show that it is indeed a dSph companion to M31. Therefore, one might prefer Armandroff’s et al. designation as And VI. In the following, we will use this later name which refers (as the name Pegasus dwarf) to a faint, low surface brightness object at RA $23^h 49.2^m$ DEC $+24^\circ 19'$ (1950), see Table 1. The name And VI avoids confusion with the Pegasus irregular dwarf galaxy and outlines that the new dwarf galaxy belongs to the M31 system.

The observations are briefly presented in Sect. 2 of this letter and discussed in Sect. 3. We conclude on the distance and thus on the satellite nature of the And VI galaxy in Sect. 4, while all other aspects which can be derived from our data are postponed to a later paper.

2. Observations and reductions

The Calar Alto 2.2m telescope and its focal reducer Cafos was used in August 1998 to obtain images in B, V, and I. We obtained 3 frames in every band, slightly shifted from one exposure to the next. Total exposure times were 1800, 1500, and 1500 sec, respectively. The observations were accompanied by the usual CCD calibration measurements for flat-fielding and de-biasing. The flux calibration was established by observing two Landolt (1992) faint standard fields several times at various airmass. The seeing was 1.5 (I), 1.5 (V), and 1.7 (B) arc sec (FWHM). An I fringe pattern frame was derived from all 24 science frames of this run with various locations on the sky. This fringe pattern frame was subtracted after debiasing and flatfielding, while the B and V frames were only debiased and flatfielded. The field of view of the frames is 12 by 12 arcmin, far larger than the extent of the And VI dwarf galaxy, estimated as 2 by 4 arc min by Karachentsev & Karachentseva.

Send offprint requests to: U. Hopp

* Visiting Astronomer, German-Spanish Astronomical Center, Calar Alto, operated by the Max-Planck-Institut für Astronomie jointly with the Spanish National Commission for Astronomy

Table 1. Overall properties of And VI from the literature and as derived in this paper. Absolute magnitudes are corrected for galactic reddening with the given extinction value from Burstein & Heiles (1978), distance depend values are converted with the new distance estimate of 795 kpc.

property	value	reference
RA (1950)	23 49 12	Karachentsev &
Decl. (1950)	+24 19	Karachentseva (1998)
Galactic latitude	-36.6	
A_B	0.15	Burstein & Heiles 1978
distance	795 ± 75 kpc	this paper
V_0	14.17 ± 0.2	this paper
$M_{V,26.5}$	-10.43	this paper
$(B-V)_0$	$+0.65 \pm 0.1$	this paper
$\mu_{0,V}$ [mag/arc ²]	22.24 ± 0.1	this paper
scale length V [pc]	305 ± 11	this paper
mean ellipticity	0.20 ± 0.04	this paper

The co-added And VI frames were searched for stellar objects in each band independently by the MIDAS 97NOV version of Daophot (Stetson, 1987). The PSF was constructed from some 30 to 40 brighter, non-saturated, and well isolated stars. The PSF-photometry was done with the ALLSTAR routine. Several thousand objects were detected in each of the bands. Aperture photometry of the standard stars allowed us to calibrate the PSF magnitudes. We are using here only those stars which are detected in at least two colors, either V and I, or B and V. This largely reduces false detections. 794 stars were simultaneously identified in B and V while 979 were found in V and I. The PSF photometric errors become larger than 0.15 at 23.75 (B), 23.25 (V), and 21.75 (I). The faintest objects detected are typically a magnitude fainter than this, but we will use in the following only those stars with errors less than 0.15 mag.

As we here intend only to describe the dwarf galaxy and to establish its distance from the location of the tip of the red giant branch (TRGB), we postpone artificial star tests to evaluate the incompleteness to a later paper.

To get a quantitative description of the structure of And VI, we cleaned the V frame from the brightest stars (about 18, they are probably MWG foreground) and smoothed the images with a large spatial filter (11 by 11 arc sec). On this smoothed frame, we derived the structural parameters by applying the ellipticity fit of Bender & Möllenhoff (1987).

3. Results and Discussion

Fig. 1 shows the V frame of the And VI dwarf galaxy. It is clearly resolved into individual, faint stars. Similarly, the B and I band frames show faint, resolved stars. The images resemble those of the other M31 dSph companions (see e.g. And V in Armandroff et al., 1998). The stars are very regularly distributed and show no structure or knots which might indicate recent star formation as in dwarf irregular galaxies. From the smoothed frame, we measured a central surface brightness $\mu(0)$ in V of 24.24 ± 0.1 mag/arc² (24.13 when corrected for galactic reddening using the value of Burstein & Heiles (1978) and the extinction law of

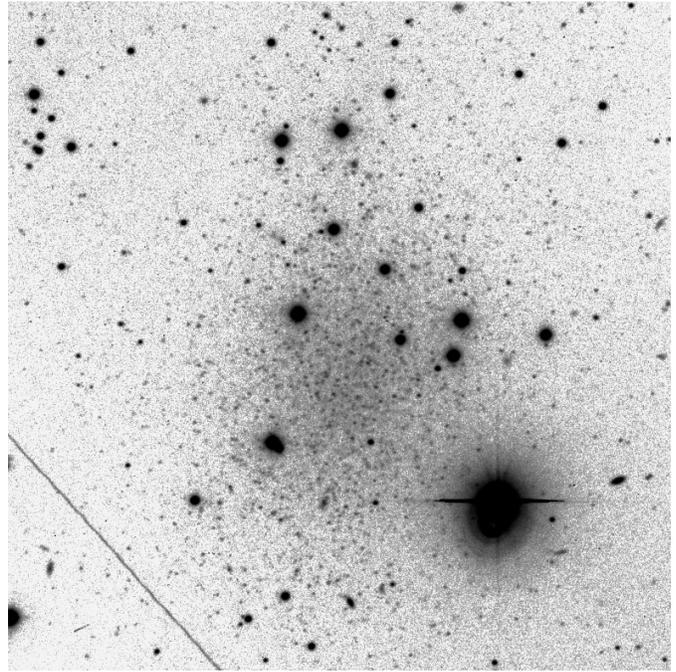


Fig. 1. Calar Alto 2.2m telescope CCD image in V of the Pegasus dwarf galaxy = And VI. North top, East left, field of view shown is 399.5 arc sec each side.

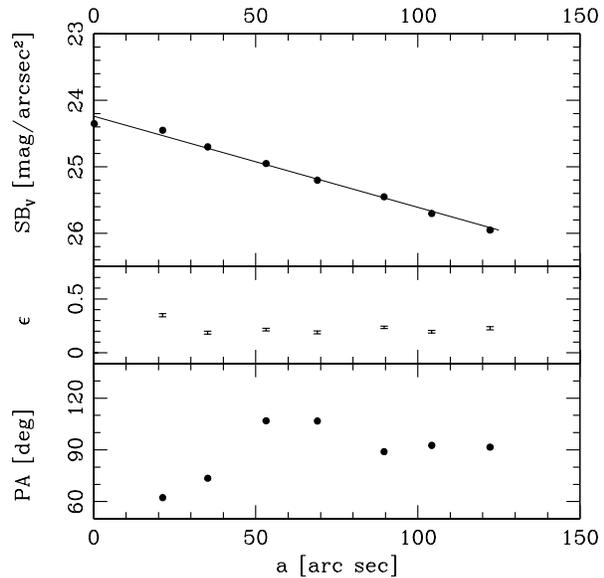


Fig. 2. Results of the surface photometry on the V frame. *Top:* Surface brightness versus major axis a , the line shows the fit. *Middle:* Ellipticity of the isophotes versus a . *Bottom:* Position angle versus a .

Savage & Mathis (1979)). The light distribution follows nicely an exponential law of scale length 79 ± 3 arc sec and has an overall ellipticity of 0.20 ± 0.04 (Fig. 2). From this smoothed image, we constructed a mask which allowed to measure the total magnitude inside the 25.5 mag/arc² V isophote (which essentially corresponds to the Holmberg radius). We found $V_0 = 14.17 \pm 0.2$ and $(B-V)_0 = +0.65 \pm 0.1$ (already corrected for

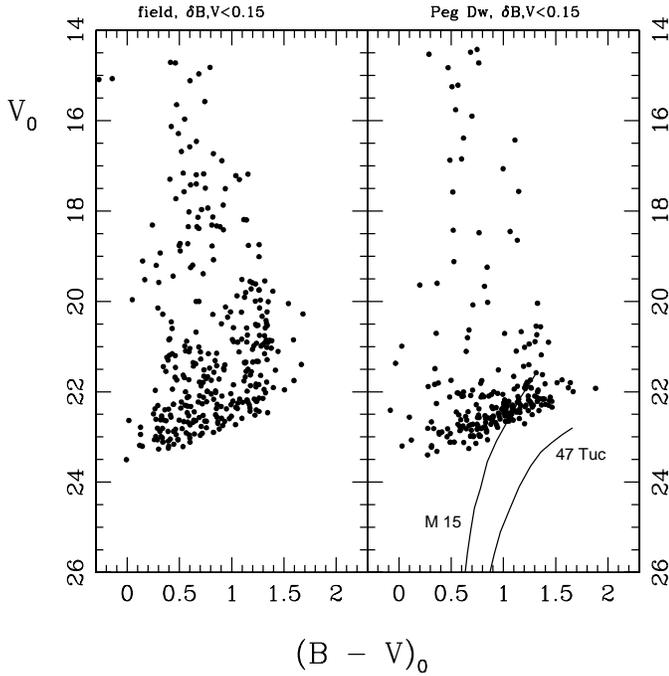


Fig. 3. V , $B-V$ color magnitude diagram. *Left:* Stars in the field surrounding And VI, illustrating the MWG contamination. *Right:* Stars either belonging to the And VI dwarf galaxy or MWG stars being projected on it. The *left panel* contains stars from the rest of the CCD frame, an area 3.5 times larger than the area of the dwarf galaxy. Both CMDs are corrected for galactic foreground reddening of 0.15 mag. in B . The *right panel* also shows as solid lines the red giant branches for M15 from Durrel & Harris (1993), a very low metal abundance globular cluster, and for 47 Tuc from Hesser et al. (1987), a high metal abundance globular. The RGB's of the two MWG globulars have been shifted to a distance modulus of 24.5.

a galactic reddening). These data which are summarized in Table 1 indicate a classification as dSph (compare e.g. to the tables in Mateo (1998) for the other dSph in the local group).

Fig. 3 shows the V , $B-V$ color magnitude diagram (CMD) and Fig. 4 the V , $V-I$ CMD. They are already corrected for a foreground reddening of 0.15 mag in B which was derived from Burstein & Heiles (1978).

The right panels of Fig. 3 and 4 show only those stars with distances from the center of the And VI dwarf galaxy smaller than 175 arc sec. The left panels represent the stars from the rest of the CCD frames, a field about 3.5 times larger. A careful comparison indicates that essentially all stars brighter than $I \sim 20.5$ (Fig. 4) and $V \sim 21.5$ (Fig. 3) are MWG stars. Also, any faint and blue stars with $V-I < 0.6$ (Fig. 4) either belong to the MWG, or they are unresolved background galaxies.

Stars which are fainter than $I = 20.5$ and redder than $V-I = 0.6$ ($V = 22.0$, $B-V = 0.3$) are much more abundant within the area encompassed by the And VI dwarf galaxy than they are in the field. In particular, a strongly populated clump of stars is visible around $V-I \sim 1.0$ in the right panel of Fig. 4. An analogous feature is present in the right panel of Fig. 3. These are the brightest stars of the And VI dwarf galaxy.

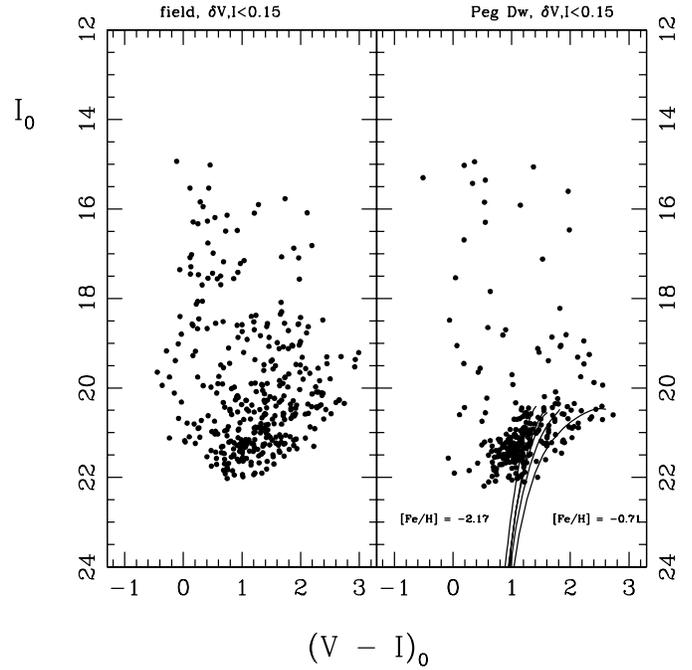


Fig. 4. Same as Fig. 3 for the I , $V-I$ color magnitude diagram of the And VI dwarf galaxy. The *right panel* also shows the mean RGB lines of five MWG globular clusters from da Costa et al. (1990) ranging in metallicity from very low values (M15) to high ones (47 Tuc) as indicated. The RGB's of the MWG globulars have been shifted to a true distance modulus of 24.5.

These brightest stars could be – according to their colors – either red supergiants and intermediate aged AGB stars or old RGB stars. As there is no evidence for recent star formation, neither in our images (no knotty distribution of the stars, unresolved clumps) nor in the CMDs (no blue and yellow supergiants which are usually brighter and easier to detect, no blue blume), most of these stars are probably RGB stars of an old population. Indeed, a comparison with the RGB tracks of galactic globular clusters strongly supports this identification (Figs. 3 and 4). This is further strengthened by the fact that Armandroff et al. (1999) did not detect $H\alpha$. This comparison also indicates that the RGB of the And VI dwarf galaxy seems to be a mixed bag of metallicities, with most of the stars occupying the region of the low metallicity tracks. Our CMDs also resemble those found for other dSph companions of M31 (see Armandroff et al., 1998, and references therein).

A clear discontinuity in population density is visible in the $V, V-I$ CMD at $I = 20.5$. We did I -band star counts inside and outside the area of the And VI dwarf galaxy in a color range of $0.6 < V-I < 2.5$. The field number counts were used to statistically correct the counts inside the dwarf galaxy for the foreground contamination. The resulting luminosity function is shown in Fig. 5. The I -band number counts show a strong step at $I = 20.5 \pm 0.2$. We identify this feature with the TRGB. As we are dealing with a low-metallicity system (see above), we can apply the calibration of Lee et al. (1993), thus, $M(I)_{\text{TRGB}} = -4.0$. This yields a true distance modulus of 24.5 ± 0.25 . The error

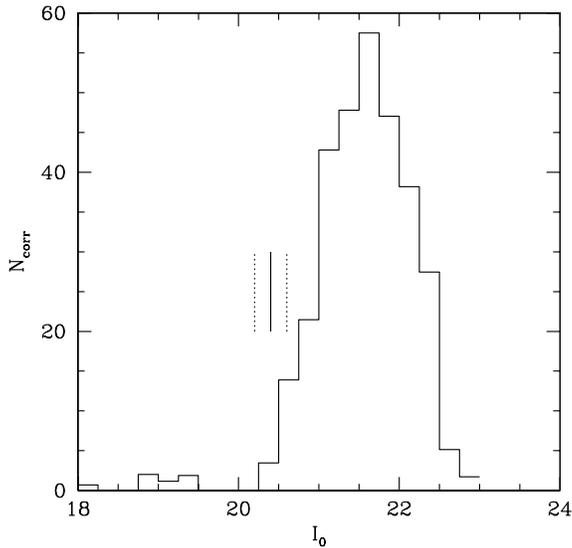


Fig. 5. Foreground-corrected I-band number counts of And VI RGB and AGB stars (color range $0.6 < V-I < 2.5$). The horizontal bar indicates the value and errors of the TRGB.

gives the measurement error as derived from the location of the TRGB above, and includes the systematic error which was estimated following Schulte-Ladbeck et al. (1998). The leading error in our case is the accuracy with which we can derive the TRGB magnitude in the I counts.

The I-band number counts shown in Fig. 5 are still to be corrected for incompleteness which normally set in about 2 magnitudes above the observational limits. Thus, while the counts shown should not be used to construct luminosity functions, the TRGB brightness is still well above the regime of severe incompleteness.

4. Conclusions

We resolved a red population of stars in the newly found And VI dwarf galaxy, also designated Pegasus dwarf. This ‘red tangle’ is most probably composed of red giant stars, plus some stars from an old asymptotic giant branch. The population seems to be old and metal-poor. Applying the TRGB method, we derived a true distance modulus which places And VI at the distance of M31. Thus, the total magnitude turns into a rather low absolute one, $M_{V,0} = -10.4 \pm 0.2$ only! This is one of the faintest

galaxies found so far. The metric value of the scale length of the surface brightness distribution is 305 ± 11 pc. The structural parameters and the resolved population indicate that And VI is a dSph galaxy.

The newly derived distance modulus suggests that And VI is a companion of M31. The projected distance between M31 and the And VI dwarf galaxy is about 271 kpc, as large as that of the most distant dSph companion of the MWG (Leo I, Mateo, 1998). And VI is situated in a region which so far was free of known M31 satellites (see Fig. 2 of Armandroff et al., 1998). The question has arisen whether or not the M31 dSph system is different from the MWG, which is populated by at least 9 dSphs. The detection of two new dSph galaxies associated with M31, namely And V (Armandroff et al., 1998) and And VI (Karachentsev & Karachentseva, 1998, Armandroff et al. 1999, this work) now brings the census of M31 dSph companions up to 5 (or 8 including the dE’s NGC 147, 185, and 205), close to what has been observed in the vicinity of the MWG. We derive a very faint absolute V magnitude for And VI, confirming that dSphs as faint as Draco and Ursa Minor exist around M31, as previously suspected (Armandroff et al. 98).

Acknowledgements. We like to thank the Calar Alto staff for his kind assistance during the observations. We were supported by the DFG (hopp/1801-1) and by the SFB 375, and by GO-07859.01-96A (to rsl).

References

- Armandroff, T.E., Davies, J.E., Jacoby, G., 1998, AJ Nov. 1998 in print
- Armandroff, T.E., Davies, J.E., Jacoby, G., 1999, in preparation, see <http://aloe.tuc.noao.edu/jacoby/dwarfs.html> (IAU Coll. 171, Cardiff)
- Bender, R., Möllenhoff, C., 1987, A&A 177, 71
- Burstein, D., Heiles, C., 1978, AJ 225, 40
- Da Costa, G.S., Armandroff, T.E., 1990, AJ 100, 162
- Durrel, P.R., Harris, W.E., 1993, AJ 105, 1420
- Hesser, J.E., Harris, W.E., Vandenberg, D.A., Allwright, J.W.B., Shott, P.S., Stetson, P.B., 1987 PASP 99, 739
- Karachentsev, I.D., Karachentseva, V., 1998, Dwarf Tales, 3, 1
- Landolt, A.U., 1992, AJ 104, 340
- Lee, M.G., Freedman, W.L., Madore, B.F., 1993 ApJ 417, 553
- Mateo, M., 1998, ARA&A 36, 435
- Savage, B.D., Mathis, J.S., 1979 ARA&A 17,73
- Schulte-Ladbeck, R.E., Crone, M.M., Hopp, U., 1998, ApJ 493, L23
- Stetson, P., 1987, PASP 99, 191
- van den Bergh, S., 1972, ApJ 171, L31