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A SEARCH FOR NEW VARIABLE OBJECTS IN THE FIELD OF OB81 ASSOCIATION IN M31 GALAXY

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Abstract. We obtained an astrometric solution with 0.05′′ accuracy for 678 stars in a 5.6′×′5.6′ field within OB81 association in M31 galaxy. Their UB photometry was carried out by Kurtev (2002) on CCD images, obtained with the 2m telescope at NAO-Rozhen. The comparison with the stellar photometry within the same field, published in the LGS M31 catalog (Massey et al. 2016) showed no zero-point difference in B-band, whereas in U-band, a systematic difference of 0.13 ± 0.03 mag has been found.

Thirteen candidates for variable objects have been detected at level, greater than 3σ. Five of them are known variables of the δ Cep type and one star has been detected as IR variable by WISE mission. The remaining 7 candidates are newly detected variables, but only one of them at detection level, greater than 4σ.

1. INTRODUCTION

Almost a century ago, in 1919 the study of variable and transient objects in the M31 galaxy field was initiated by Edwin Hubble who observed with the 2.5m telescope, completed in 1917, at Mount Wilson Observatory. His first results (Hubble, 1925) proved the existence of variables like cepheids and novae in M31 and M33 galaxies. Since then and especially during the last decades that field is a focus of an increasing interest, both amateur's and professional. We are kindly redirecting the reader to the paper 'Time-domain studies of M31' of Lee (2017) which is the latest review of the topic from a professional point of view.

There are three main M31 CCD surveys of point-like sources in the optical, namely McGraw-Hill BVRI (Magnier et. al. 1992), LGS UBVRI (Massey et al. 2006) and HST PHAT (Panchromatic Hubble Andromeda Treasury; Williams et al. 2014). These surveys, equally spaced in time with a step of 10 years, cover a total span of 20 yr. When compared to each other they provide an important although rather sparse information on the variability of much larger time scales than the modern time-domain studies (typically 2-3 yr).

In this pilot search we focus on a small program Rozhen field (see Figure 1) for which we have original CCD photometry. We compared it with the photometry from the LGS by using the magnitude differences to detect variable candidates at detection level, greater than 3σ.

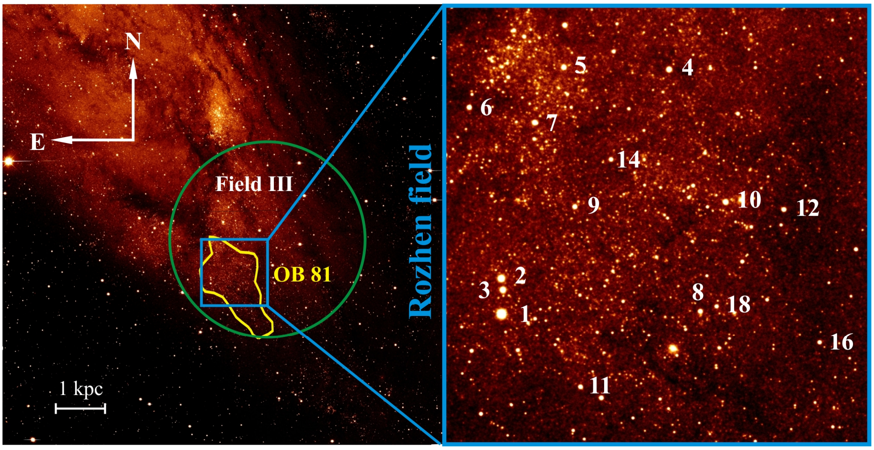

Figure 1: Left: OB 81 association location within LGS (Massey et al. 2006) program field M31F8 together with Field III (Baade and Swope 1965) and program Rozhen field (Kurtev 2002). Right: Zoomed Rozhen field with selected astrometric standards. V-band Mosaic image credit: LGS.

Baade and Swope (1965) discovered 334 variables in their Field III and Rozhen field falls within its boundaries with 75 variables in total, among which 57 are cepheids, 7 eclipsing, 7 semiregular, 4 irregular and peculiar variables. More recently Kodric et al. (2013) confirmed 82 cepheids within Rozhen program field with 61 of them pulsating in the fundamental mode, 6 – in the first overtone and 14 with unidentified pulsation mode and one Population II cepheid.

2. INITIAL DATA SAMPLES

The first source is an unpublished UB stellar photometry and pixel positions by Kurtev (2002) who presented the data only as a color-magnitude diagram graphic. The photometry was carried out on CCD images, obtained with the first professional CCD camera Photometrics mounted on the 2m RCC telescope at NAO-Rozhen. It was kindly provided by the author to our disposal in a machine readable format. Landolt (1992) standards were use to transform the instrumental magnitudes into the Johnson's UB system.

The second source of photometry and astrometry is the revised version of the LGS stellar catalog of M31 galaxy (Massey et al. 2016). It was originally published in 'A Survey of Local Group Galaxies Currently Forming Stars. I. UBVRI Photometry of Stars in M31 and M33' where Massey et al. (2006) presented photometry, carried on the mosaic images of M31, obtained with Mayall 4m telescope at Kitt Peak at US National Observatory, Arizona. The final catalog contains 371 781 entries each of which has been detected at least in the BVR bands together.

We summarize the basic information on the used observation data within Rozhen program field in Table 1.

Table 1: Rozhen field observation data.

Photometry source	Kurtev (2002)	Massey et al. (2016)
Total number of stars	678	5046
Observation dates (B passband)	Aug 6/7 2000	Oct. 4 2000 – Sept. 11 2002
Seeing	1.5′′–1.8′′	0.9′′–1.2′′
Number of stars with UB photometry	678	3946
PSF fitting	DAOPHOT	DAOPHOT
Photometric accuracy at B~21.0 mag	<0.15 mag	<0.015 mag
Total exposure time/per frame	900 s	3000 s
CCD detector size in px	1k×1k	Mosaic 8 × (4k×2k)
Telescope	2m RCC NAO-Rozhen	4m Mayall Kit Peak NAO
FoV per frame	5.6′×5.6′	36′×36′

3. ROZHEN FIELD ASTROMETRIC SOLUTION

The coordinate's cross-identification is substantial for an effective search of variable objects in the Rozhen field. For this purpose, it is necessary to determine the equatorial coordinates of all stars, i.e. to obtain accurate astrometric solution for that particular field. We used 12 bright stars (see Figure 1, right) with known both pixel (Kurtev 2002) and celestial (Massey et al. 2016) coordinates to produce the matched coordinate list (see Table 2) and the standard IRAF routine *ccmap* in order to calculate the image field solution.

Later on we used *cctran* IRAF routine to transform all 678 stars pixel coordinates from the photometry of Kurtev (2002) to celestial coordinates on the base of the *ccmap* Rozhen field solution.

The accuracy of the computed equatorial coordinates of 678 stars is ~0.05´´ both on R.A. and DEC. It corresponds to a radius of ~0.07´´. A small rotation angle of the CCD detector with respect to the North pole is estimated to 1.5°.

Table 2: Matched Rozhen/LGS coordinate list used to compute the Rozhen field astrometric solution.

Star number	X [pixels]	Y [pixels]	RA h m s	DEC ° ′ ″
3	137.9	372.9	00:40:34.89	40:31:35.1
4	581.7	918.7	00:40:23.22	40:34:28.1
5	313.5	933.6	00:40:30.53	40:34:30.5
6	68.5	840.5	00:40:37.14	40:33:59.5
7	234.3	796.1	00:40:32.58	40:33:47.2
8	639.4	300.7	00:40:21.20	40:31:17.0
9	329.1	578.1	00:40:29.85	40:32:40.4
10	713.8	576.5	00:40:19.37	40:32:43.1
12	861.7	552.2	00:40:15.35	40:32:36.9
14	425.7	695.3	00:40:27.31	40:33:17.6
16	940.6	210.3	00:40:12.94	40:30:51.3
18	681.4	311.9	00:40:20.06	40:31:20.8

4. PHOTOMETRIC SYSTEMS COMPARISION

We adopted value of 0.21´´=3×0.07´´ as a 3σ clipping search radius and successfully cross-identified 387 stars from Kurtev (2002) with a single counterpart in LGS.

The direct comparison of B-band magnitudes where the consistency is good is shown in Figure 2 and for U-band where a systematic shift exists – on Figure 3. As expected, the dispersion of the stellar magnitudes increases with the magnitude itself. That increase, however, is mainly due to the larger errors of the Rozhen's photometry. The B-band magnitude histogram indicates a completeness magnitude of that photometry B=21.5 mag where Kurtev (2002) pretends for error of ~0.15 mag. At the same B-magnitude the photometry of LGS photometry (which goes much deeper) is only ~0.025 mag. An approximation of the difference (B_{lgs}– B_r) within the magnitude range 20.8 mag < B_{lgs} < 21.2 mag with a Gaussian function shows (see Figure 4) mean value of –0.03 ± 0.02 mag and a standard deviation of 0.20 mag proving that accuracy of the Rozhen photometry is overestimated. Analogous approximation at other magnitude ranges with taking outliers into account allows a precise quantitative analysis of the budget errors of Kurtev's photometry, which is not known a priori.

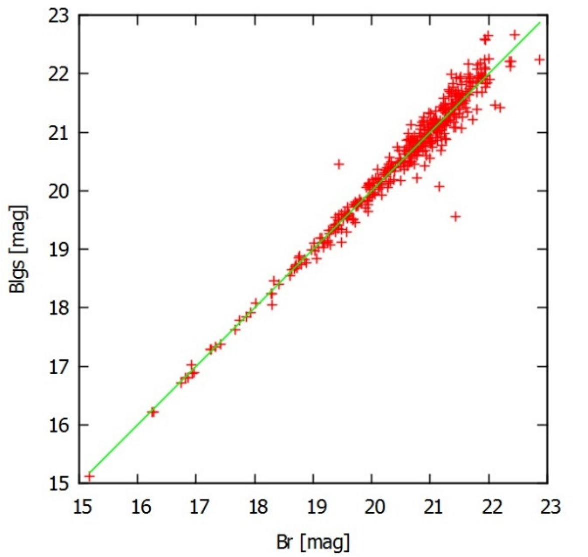

Figure 2: B-band comparison between photometry of Kurtev (2002) and that of Massey et al. (2016) for 387 stars in common.

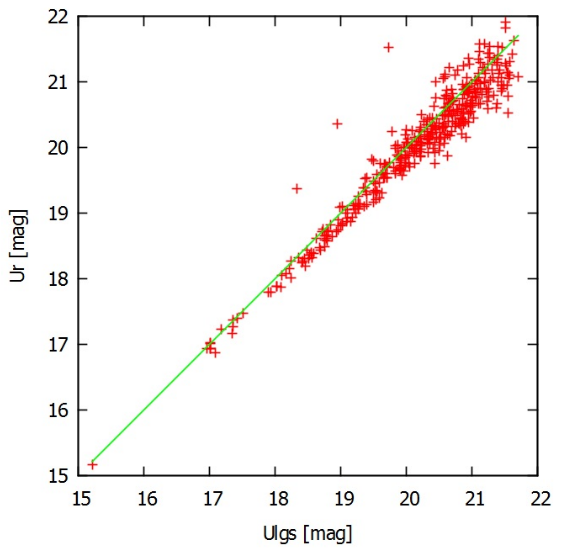

Figure 3: U-band comparison between photometry of Kurtev (2002) and that of Massey et al. (2016) for 387 stars in common.

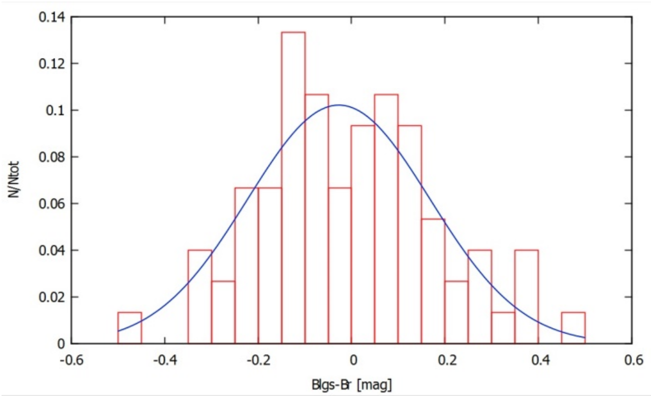

Figure 4: Approximation of the difference (B_{lgs}– B_r) histogram within the magnitude range 20.8 mag < B_{lgs} < 21.2 mag with a Gaussian function. The mean value is –0.03 ± 0.02 mag and the standard deviation – 0.20 ± 0.02 mag.

When two photometries are compared it is important not only to check the magnitude differences for a systematic shift but also to see whether these differences vary with color. We performed such tests and found that there is no strong correlation of either B or U differences with color. We also found that there is no significant shift in B-band, whereas in U-band, the systematic difference of $\Delta U = 0.13 \pm 0.03$ mag is three times larger than the zero-point magnitude accuracy of 0.04 mag claimed by Kurtev (2002).

5. VARIABLE OBJECTS DETECTION

The detection of variable objects is based on the B-band magnitudes difference modulus $|B_{lgs}–B_r|$, normalized to the error of that difference:

$$\sigma = \sqrt{\sigma_{Blgs}^2 + \sigma_{Br}^2}.$$

We call that quantity 'level of detection'. The Rozhen field photometry B_r is taken from Kurtev (2002) and LGS photometry B_{lgs} and its error σ_{Blgs}– from the revised version of the M31 catalog (Massey et al. 2016). The typical error of the Rozhen magnitudes σ_{Br} at a given B_r magnitude is derived from the standard deviation of maginitudes difference (B_{lgs}–B_r), described in the previous section.

We plotted on Figure 5 the B-band magnitudes difference modulus $|B_{lgs}–B_r|$ as function of B_{lgs} for all successfully cross-identified 387 stars from Kurtev (2002) with a single counterpart in LGS. We also constructed approximating polynomials for the quantities: σ (at two levels of detection: 1σ и 3σ), σ_{Blgs} and σ_{Br} as a function B_{lgs} magnitude. As clearly seen in the same figure, the error of the magnitudes difference σ is dominated by the error of the Rozhen photometry σ_{Br}. We found 13 candidate variable objects at the detection level, greater than 3σ and list them in Table 3.

Table 3: Variable objects in the program Rozhen field detected at level, greater than 3×standard deviation of the magnitude differences (B_{lgs}– B_r).

№	*RA [deg]*	*DEC [deg]*	*σ*	*Name*	*Ref.*	*Var. Type*
1	10.09802	40.51178	3.2	J004023.54+403042.4	LGGS	
2	10.13827	40.51916	4.5	J004033.12+403107.7	LGGS	
3	10.14069	40.51204	3.7	M31 V0418	GCVS	CEP
4	10.08728	40.51318	3.1	J004020.96+403047.4	LGGS	
5	10.10084	40.53334	3.3	J004024.23+403200.2	LGGS	
6	10.08655	40.55610	3.0	M31 V0285	GCVS	DCEP
7	10.08293	40.51323	3.6	J004019.93+403047.7	LGGS	
8	10.08832	40.52137	3.7	J004021.21+403117.1	LGGS	
9	10.14698	40.55776	9.4	M31 V0438 J010.1469+40.5577	GCVS Kod13	DCEP FM
10	10.13570	40.51632	12.9	M31 V0411	GCVS	DCEP
11	10.09008	40.54896	3.1	J004021.64+403256.5	LGGS	
12	10.04950	40.50658	6.1	M31 V0215 J010.0495+40.5065	GCVS Kod13	DCEP FM
13	10.11720	40.50244	6.0	J004028.12+403008.5	WISE	high prob. var

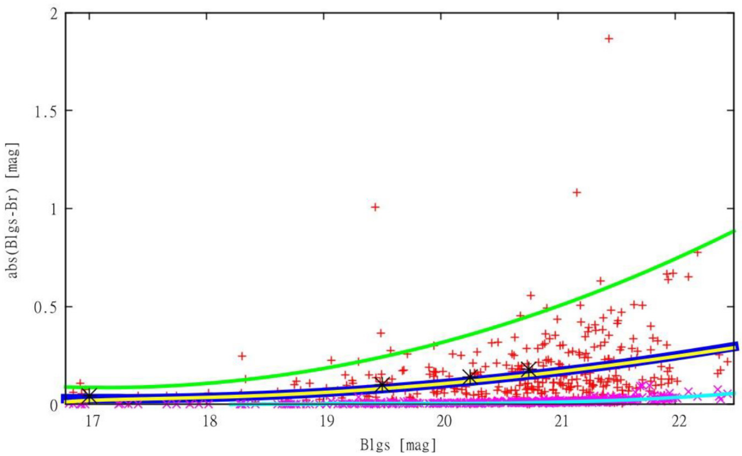

Figure 5: B-band magnitudes difference modulus $|B_{lgs}–B_r|$ as function of B_{lgs} for all successfully cross-identified 387 stars (red crosses) from Kurtev (2002) with a single counterpart in LGS (Massey et al. 2016). Four approximating functions of B_{lgs} of are also plotted: (B_{lgs}–B_r) standard deviation (blue line); (B_{lgs}–B_r) 3×standard deviation (green line), B_{lgs} standard deviation (azure line through the pink squares) and B_r standard deviation (yellow line). All 13 detected variable objects lie above the solid green line, representing 3σ detection level.

Five of them are known variables of the δ Cep type and one star has been detected as IR variable by WISE mission. The remaining 7 candidates are newly detected variables, but only LGSJ004033.12+403107.7 at a detection level, greater than 4σ. Our test recovers only ~6% of all known variables within Rozhen field which is not unexpected since we compare only two epoch magnitudes in a single pass-band.

Rozhen field was observed on Aug 6/7 2000 while the time span of the LGS B-band observations of the same field covers three consecutive years (Oct. 4 2000 – Sept. 10 2002) for the program fields F7, F8 and F9. Thus, most of the LGS B-magnitudes are averaged upon several independent but indistinguishable measurements, a problem that will be solved in a forthcoming paper. There we will exploit magnitude estimates related to unique epochs of observations rather than averaged over a number of detections.

5. CONCLUSIONS

The intention of this pilot search was to show the potential of two epoch comparison of photometry for finding new variable objects in the field of OB81 – a huge stellar complex in the south-eastern part of M31 galaxy disk. We used UB photometry and pixel coordinates of Kurtev (2002) and UB photometry and celestial coordinates from LGS (Massey et al. 2016) to obtain an astrometric solution of the Rozhen field and to check the magnitude differences of coinciding objects. Significant systematic shift of 0.13 ± 0.03 mag has been found in U-band.

Thirteen candidates for variable objects have been detected at level, greater than 3σ. Five of them are known variables of the δ Cep type and one star has been detected as IR variable by WISE mission. The remaining 7 candidates are newly detected variables, but only one of them, namely LGSJ004033.12+403107.7, at detection level, greater than 4σ.

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References

Baade, W., Swope, H. H.: 1965, *Astron. J.*, **70**, 212–268.
Hubble, E. P.: 1925, *The Observatory*, **48**, 139–142.
Kodric, M., Riffeser, A., Hopp, U. et al.: 2013, *Astron. J.*, **145**, 106–127.
Kurtev, R. G., 2002, *Publications of the Astron. Observatory of Belgrade*, **73**, 163–168.
Lee, C.-H.: 2017, *Astron. Rev.*, **12**, 1–23
Magnier, E. , Lewin, W., van Paradijs, J. et al.: 1992, *Astron. Astrophys.*, **96**, 379–388.
Massey, P., Olsen, K., Hodge, P. et al.: 2006, *Astron. J.*, **131**, 2478–2496.
Massey, P., Neugent, K., Smart, B.: 2016, *Astron. J.,* **152**, 62–78.
Williams, B., Lang, D., Dalcanton, J. et al., 2014, *Astron. J.,* **215**, 9-43.