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Multiband photometric re-classification of ROTSE-I δ Scuti type stars*

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Abstract. We present multi-passband CCD photometry of 20 ROTSE-I δ Scuti type pulsating stars and 1 RR Lyrae star to re-classify their variable types using the comparison of amplitudes between V and I passbands. For the re-classification, we used a criterion that pulsating stars have larger amplitude differences between passbands than eclipsing binaries because brightness changes of pulsating stars are mainly due to the temperature variations. As a result, only six stars were re-confirmed as δ Scuti variables and thirteen stars turned out to be W UMa type eclipsing binaries. The other two stars were identified as one cataclysmic variable and one non-variable, respectively. Our results suggest that a number of ROTSE-I δ Scuti type stars, which do not show typical pulsating light curves of high amplitude δ Scuti stars, are W UMa type eclipsing binaries.

Key words. stars: variables: δ Sct – stars: binaries: eclipsing – techniques: photometric

1. Introduction

δ Scuti-type variables are short periods ($<0\overset{d}{.}3$) pulsating stars located in the lower part of the Cepheid instability strip. Their luminosities range from the zero-age-main-sequences (ZAMS) to about 2 mag above the main sequence and they have spectral types from about A2 to F2 (Breger 2000). A total of 636 δ Scuti variable stars are listed in the recent catalogue by Rodríguez et al. (2000). More than 50% of these variables have been discovered during the last six years by photometric survey projects such as the *Hipparcos* mission (ESA 1997), OGLE (Udalski et al. 1997) and MACHO (Alock et al. 2000), and by other individual groups.

The Robotic Optical Transient Search Experiment (ROTSE), a famous gamma-ray burst observing group, discovered a number of new variable stars using the ROTSE-I instruments (Akerlof et al. 2000). Among their 1781 periodic variable stars, they identified a total number of 91 δ Scuti type pulsating stars. They classified their variable types according to the periods and ratios of the Fourier coefficients. However, W UMa type eclipsing binaries have no restrictions for periods and show sinusoidal light curves, which are similar to those of RRc and δ Scuti type pulsating stars. The ratios of the Fourier coefficients for W UMa stars tend to overlap with RRc and δ Scuti stars. Therefore, Akerlof et al. (2000) applied another criterion, sign of the greatest deviation. They proposed that the greatest deviation is fainter than mean magnitudes for eclipsing binaries, on the other hand, it tends to be brighter than the mean for pulsating stars.

From the visual inspections of light curves for ROTSE-I δ Scuti stars, we found that several stars appear to have very broad maximum brightness. This tendency is not typical for high amplitude δ Scuti stars (hereafter, HADS) which are defined as δ Scuti stars with V amplitudes larger than $0\overset{m}{.}3$. The HADS are known to be excited in one or two radial modes (Breger 2000). As shown in the OGLE database, the Fourier decomposition parameters of the HADS are quite similar to those of RRab type pulsating stars (Poretti 2001). Most of the HADS show asymmetric light curves with fast increase and slow decrease. On the other hand, small amplitude δ Scuti stars show sinusoidal symmetric light curves.

Recently, Branicki & Pigulski (2002) found that V357 Her, a previously known HADS, seemed to be a W UMa type eclipsing binary. In addition, TU UMi was discovered as a variable star by the *Hipparcos* satellite (ESA 1997) and then catalogued as a δ Scuti star by Kazarovets et al. (1999), but later, turned out to be a W UMa-type eclipsing binary by Rolland et al. (2002).

In this paper we analyze new photometric data of 20 ROTSE-I δ Scuti stars with two passbands in order to re-classify their variable types. In contrast with eclipsing binaries, pulsating stars have large amplitude differences between

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* Table 3 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/404/621

Table 1. Observation log of selected variable stars.

ROTSE Name	Obs. date (in 2002)	Start H.J.D. +2452000	Running (hours)	data points V	I
J125140.01+371546.2	18 Mar.	351.97099	9.45	68	65
	25 Apr.	390.15087	3.81		
J134113.76+314725.5	29 May	423.99324	4.72	37	37
J140105.55+244216.2	27 Jun.	453.00261	4.66	51	51
J152406.95+365200.9	27 May	421.99615	4.94	47	44
J161520.21+354226.1	25 May	420.01303	7.32	70	65
J163117.94+115952.4	28 May	423.05793	6.16	59	59
J164839.21+302745.6	25 Jun.	451.01845	6.73	46	47
J170724.41+361525.7	28 Jun.	453.99891	7.37	10	102
J171640.25+293412.9	24 May	419.01770	7.13	54	53
J173937.28+501202.0	12 Nov.	590.89171	1.70	45	46
	22 Nov.	600.89044	2.09		
J181123.41+303641.4	24 Sep.	541.94057	3.82	48	47
J181324.63+255008.4	08 Oct.	555.92317	3.63	50	50
J181613.28+495205.0	01 Nov.	579.92289	2.97	58	60
	04 Nov.	582.89772	3.73		
J182943.22+280955.2	23 Sep.	540.94632	4.18	52	52
J183206.54+403555.9	26 May	421.10625	5.02	45	41
	27 May	422.21114	2.53		
J184522.47+455321.0	05 Nov.	583.90206	2.05	18	22
J191516.94+475914.5	10 Oct.	557.99338	3.65	51	39
J192108.38+510200.8	23 Oct.	570.90879	4.89	85	85
J193210.39+454409.7	24 Oct.	571.92139	1.48	62	63
	29 Oct.	576.89928	4.08		
J193445.28+455416.9	22 Oct.	569.96542	3.44	61	61
J194505.99+532334.5	23 Nov.	601.88943	4.26	49	49

passbands because their brightness changes are mainly due to the temperature variations. We introduce the observation and data reduction of 20 δ Scuti stars and 1 RRa star classified by the ROTSE-I group in Sect. 2. In Sect. 3, we present our V, I photometric results and in Sect. 4, we discuss on the classification method of variable stars discovered in photometric survey projects.

2. Observation and data reduction

CCD photometric observations of 21 ROTSE-I variable stars were carried out for 25 nights from March to November, 2002. There was no special criterion to choose the 21 variable stars among the 91 ROTSE-I δ Scuti stars, except for a few stars which showed well defined light curves of the HADS. Instead we selected the observing targets to have the best observing coordinates during our available observation time. ROTSE-I δ Scuti data were collected from their database which has made the data publicly available in their web site[1]. One of the 21 targets, ROTSE J163117.94+115952.4 = DY Her, was classified as a RRa variable by the ROTSE-I group but also as a HADS by others (Hoffmeister et al. 1985; Rodríguez & Breger 2001).

We obtained time series CCD images with a SITe 2K CCD camera attached to a 61 cm telescope at the Sobaeksan Optical Astronomy Observatory (SOAO) in Korea. The field of view of a CCD image is about 20.5 × 20.5 arcmin^2 on the f/13.5 Cassegrain focus of the telescope. The CCD chip was cooled down to −110 °C using liquid nitrogen so that there were negligible dark currents in our images. In order to compare amplitudes between two passbands, the observations were performed with V and I filters. The exposure times was adjusted from 20 to 150 s depending on brightness of variable stars and atmospheric seeing condition.

[1] http://umaxp1.physics.lsa.umich.edu/~mckay/rsv1/rsv1_home.htm

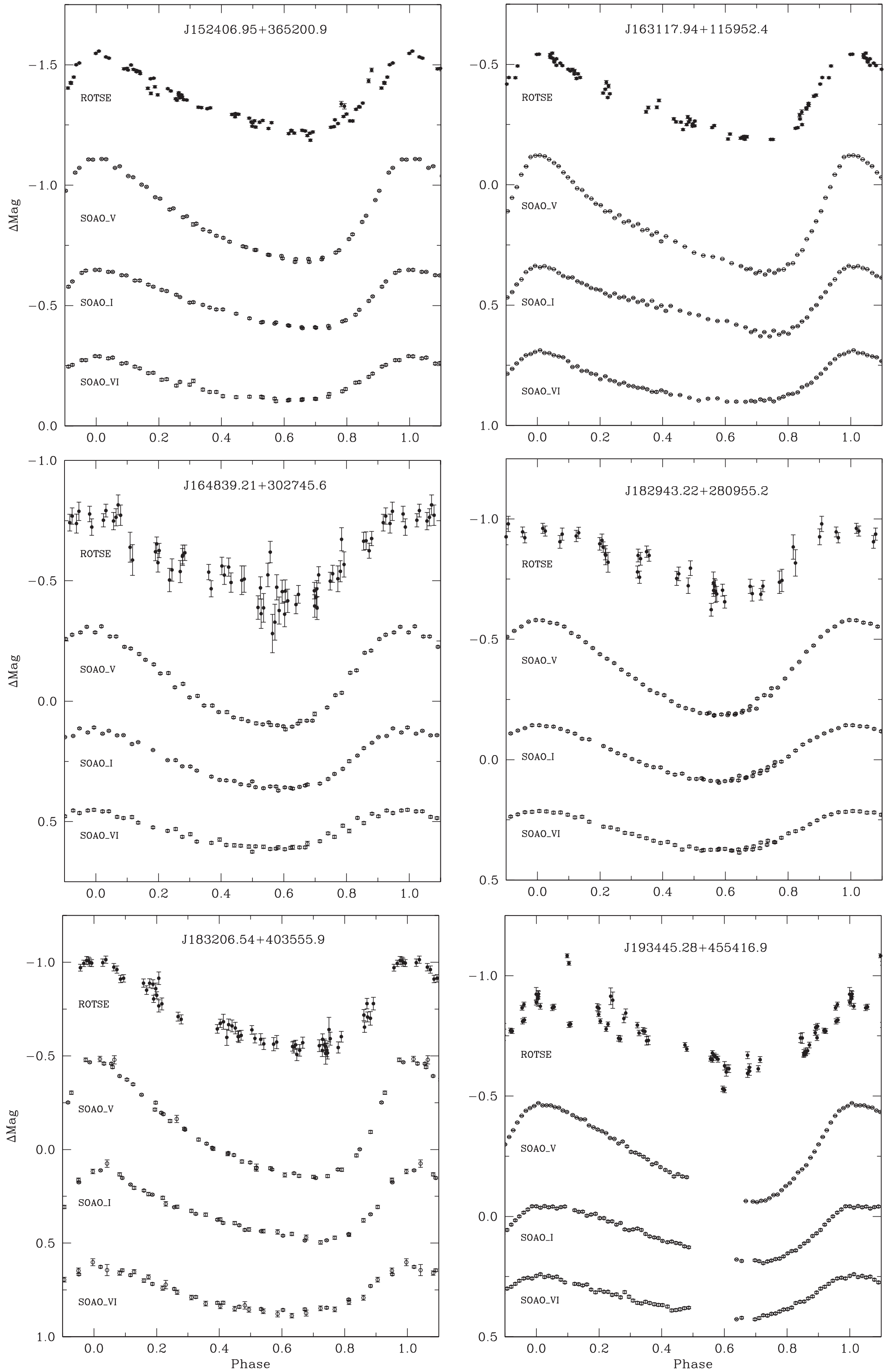

Fig. 1. Light curves of six δ Scuti type pulsating stars whose classification is re-confirmed in the present study. In each panel, the used data are as follows: ROTSE (ROTSE-I), SOAO_V (our V-magnitude), SOAO_I (our I-magnitude), and SOAO_VI (our $(V - I)$ color). Mean magnitudes of each data set are expressed in an arbitrary scale.

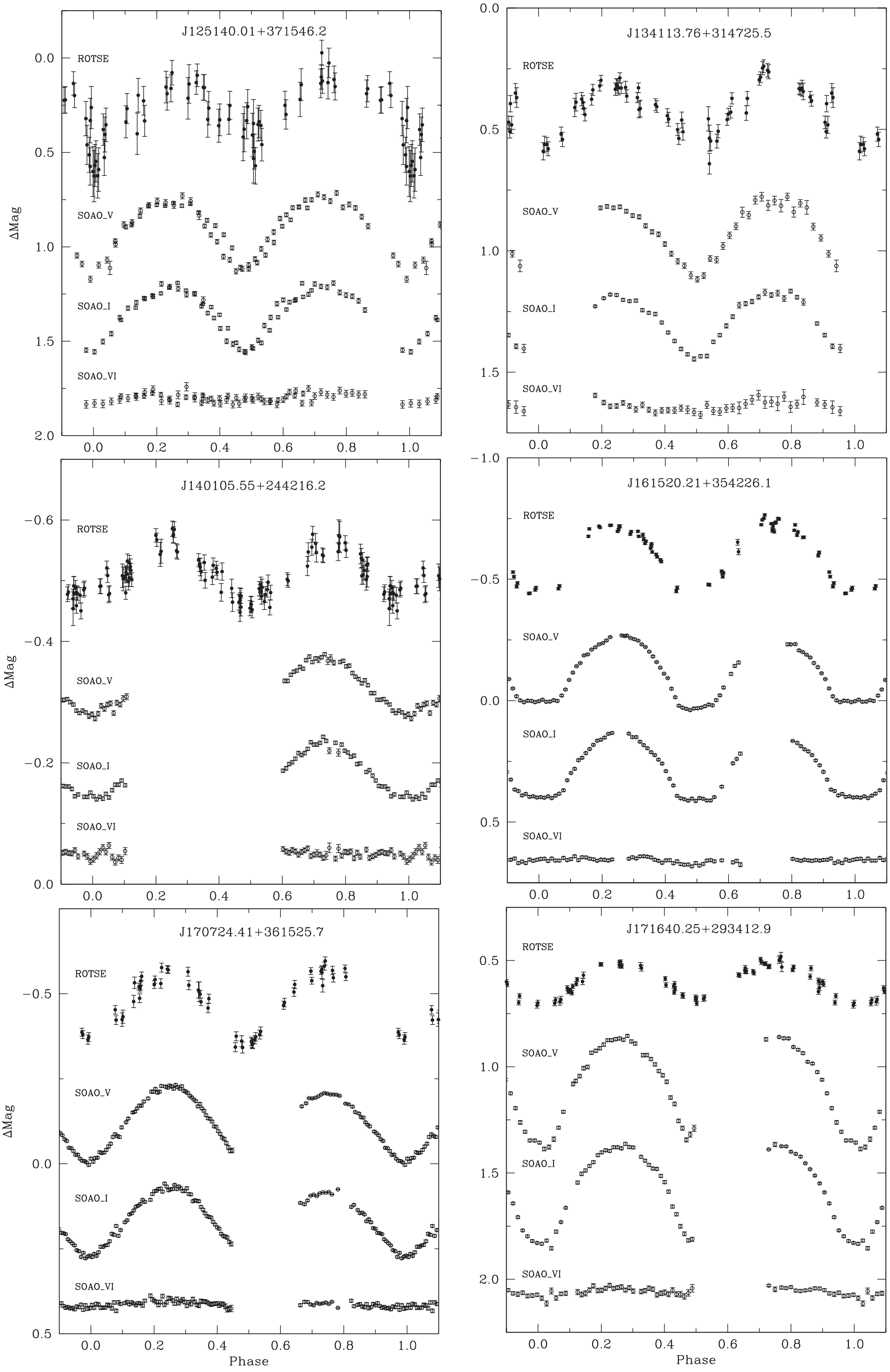

Fig. 2. Light curves re-classified as W UMa type eclipsing binary stars. The data symbols are the same as Fig. 1.

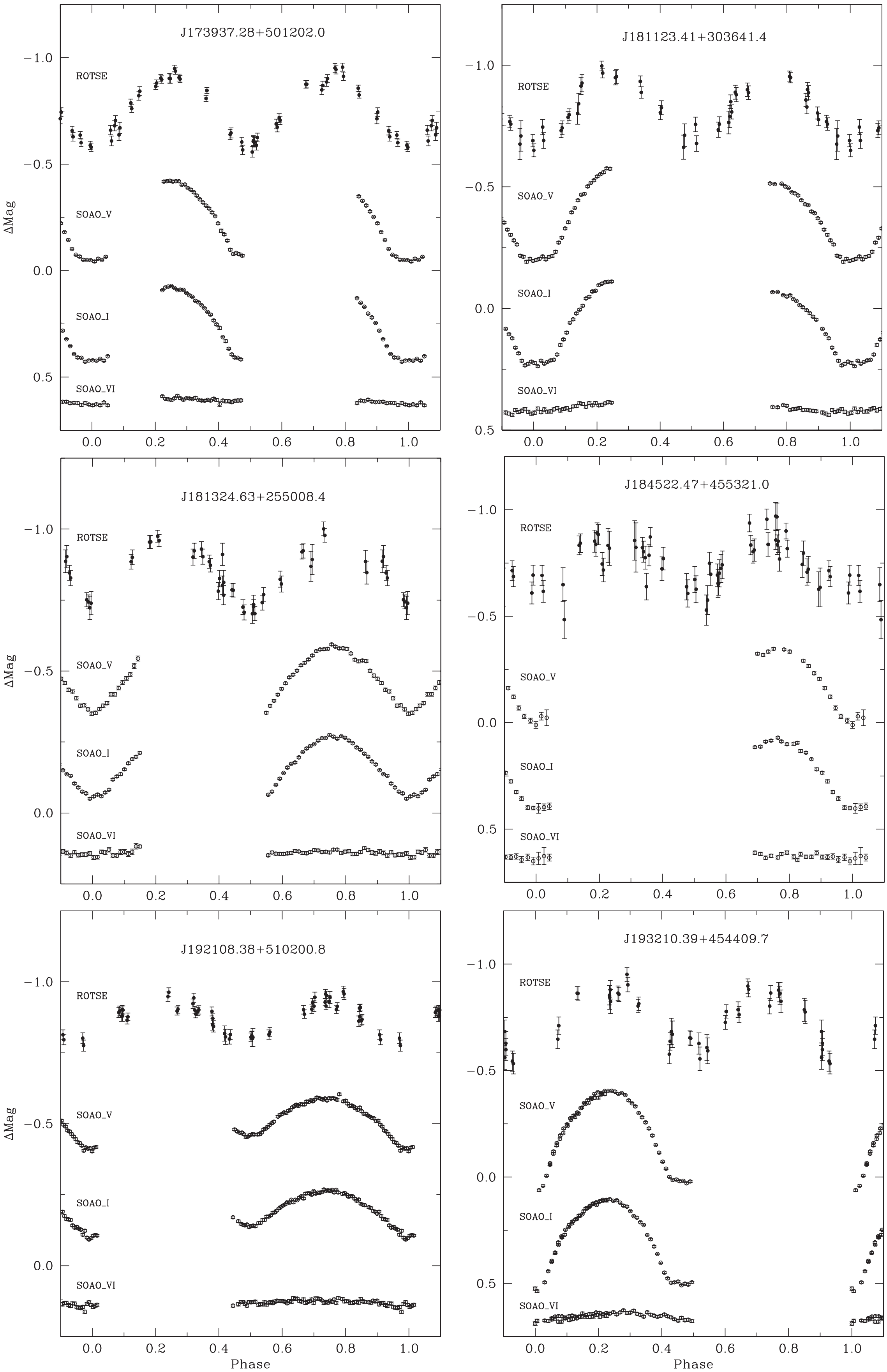

Fig. 2. continued.

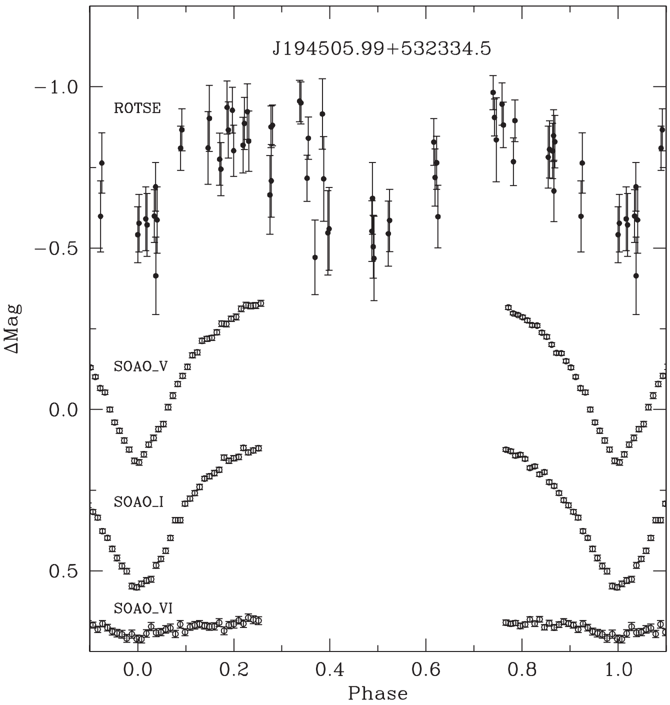

Fig. 2. continued.

The CCD frames were automatically obtained using the observation software *SOAO* (Kim et al. 2001), which was optimized for the differential photometry of variable stars. Typical atmospheric seeing was about 2.5 arcsec. Using the IRAF/CCDRED package, we processed the CCD images to subtract bias frames and correct the pixel-to-pixel inhomogeneity of quantum efficiency, flat fielding. Instrumental magnitudes were obtained via the simple aperture photometric routine in the IRAF/APPHOT package. The aperture radius was chosen to be 7.2 arcsec. Then, we calculated differential magnitudes of each variable star using a nearby comparison star with similar brightness and color to the variable. Detailed observation log is listed in Table 1.

3. Results

We examined V and I-bands light curves of 21 variable stars. The periods derived by the ROTSE-I group were slightly changed to match the phases of the ROTSE-I data and ours. From the $(V-I)$ color variations and the comparison of amplitudes between V and I-bands, we re-classified 13 stars as W UMa type eclipsing binaries. Our detailed results are summarized in Table 2.

Figure 1 shows the phase diagrams of 6 HADS (including the known variables, YZ Boo and DY Her) which have been re-confirmed in the present work. These diagrams are made with the use of the ROTSE-I data, our V and I magnitudes, and $(V-I)$ colors. The mean magnitudes of each data set are expressed in arbitrary scales. The observed light curves are quite similar to typical ones of HADS (e.g. Hintz & Joner 1997), implying that our identification is reasonable. Phase diagrams of 13 W UMa type stars are shown in Fig. 2. The periods of eclipsing binaries are about two times larger than the values estimated by the ROTSE-I group. Their $(V-I)$ color light curves does not show any remarkable changes with the maximum variations of $(V-I)$ color less than 20% of their magnitude variations. The light curves are also different from those of typical HADS but quite similar to those of W UMa type eclipsing variables (Hoffmeister et al. 1985).

Figure 3 represents the phase diagrams of two other variables, ROTSE J181613.28+495205.0 and ROTSE J191516.94+475914.5. The former object is a AM Her, strongly magnetic cataclysmic variable. It does not have any systematic variation phases (de Martino et al. 2002). It is the reason that ROTSE phase diagram shows a quite different light curve in comparison with our result. The latter object did not show any noticeable light variations in our observations even though the ROTSE-I reported systematic variations. In addition, we could not find any variable stars around this object within our observation field of view. The complete data sets of Figs. 1–3 are listed in Table 3.

Figure 4 displays the amplitude differences of eclipsing binaries as well as pulsating stars between two passbands, V and I. The slopes of ΔI against ΔV are about 0.92 for thirteen W UMa stars but 0.59 for six HADS. This large difference indicates that the light variation mechanism of pulsating stars is quite different from that of eclipsing variables. That is, pulsating stars have much larger amplitude differences between passbands than eclipsing binaries because their brightness changes are mainly due to the temperature variations. The amplitudes of pulsating stars decrease rapidly in the regime of the infrared passband. Figure 5 shows the relationship between V-amplitudes and periods for δ Scuti stars. As seen in the figure, the relationships of our re-confirmed six HADS are consistent with those of previously known δ Scuti stars (Rodríguez et al. 2000).

Figure 6 displays the color-magnitude diagram, $(B-R)$ versus R, to show difference of color distributions between pulsating and eclipsing stars. The left panel was made from the observation results of Everett et al. (2002) with 222 variable stars. The right panel shows the diagram for 91 ROTSE-I δ Scuti stars whose B and R magnitudes were obtained from the USNO catalogue. Although it does not show the difference clearly due to the reddening effect, it should be noted that the pulsating stars concentrate in a small region of bluer $(B-R)$ color indexes. We suggest a possibility that most of the objects with $(B-R)$ color larger than 1.1 are eclipsing variables.

4. Discussion

From the comparison of amplitudes between two passbands, we have re-confirmed only six δ Scuti stars out of our 21 target stars. They are qualified to include in the catalogue of δ Scuti stars (e.g., Rodriguez et al. 2000). Our results show that other 13 stars are not δ Scuti variables but W UMa type eclipsing binaries.

We have found that a number of ROTSE-I δ Scuti type stars, which do not show typical pulsating light curves of the HADS such as fast increasing, slow decreasing and sharp maximum brightness, seem to be W UMa type eclipsing binaries. This

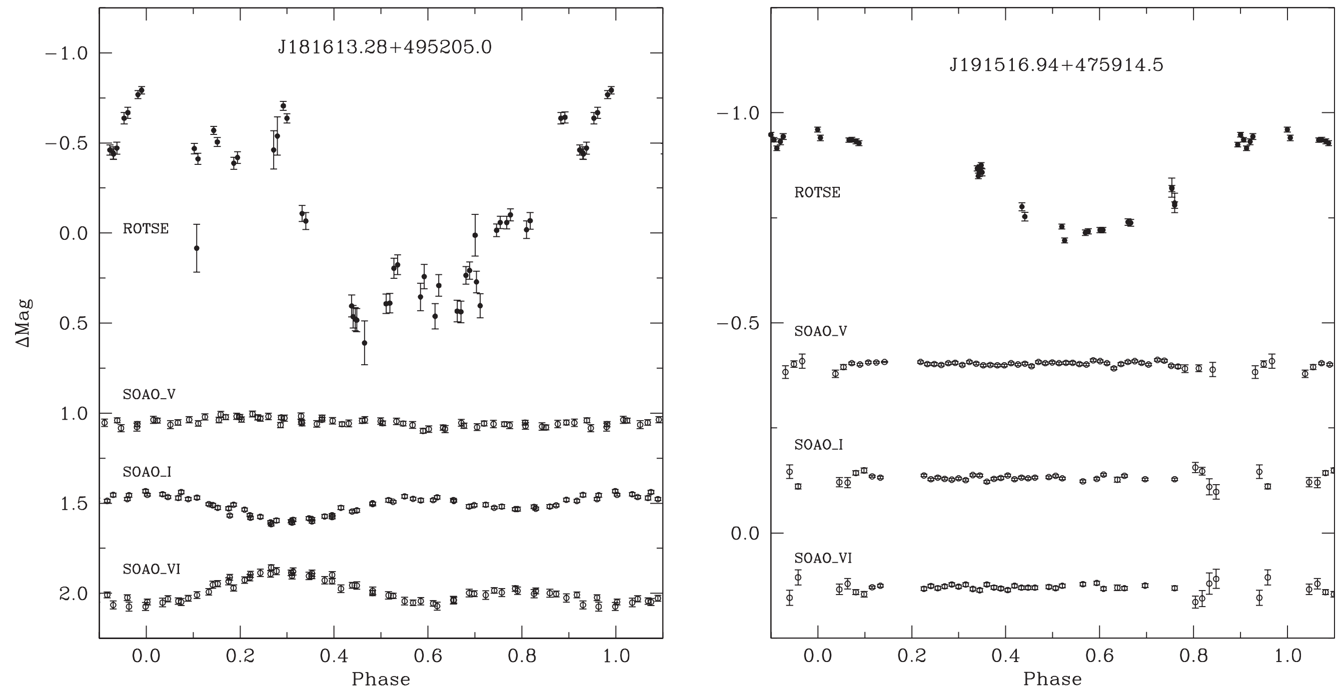

Fig. 3. Peculiar light curves of two variable stars. (Left) ROTSE J181613.28+495205.0 is a AM Her, strongly magnetic cataclysmic variable. (Right) ROTSE J191516.94+475914.5 does not show any noticeable light variations in our observations.

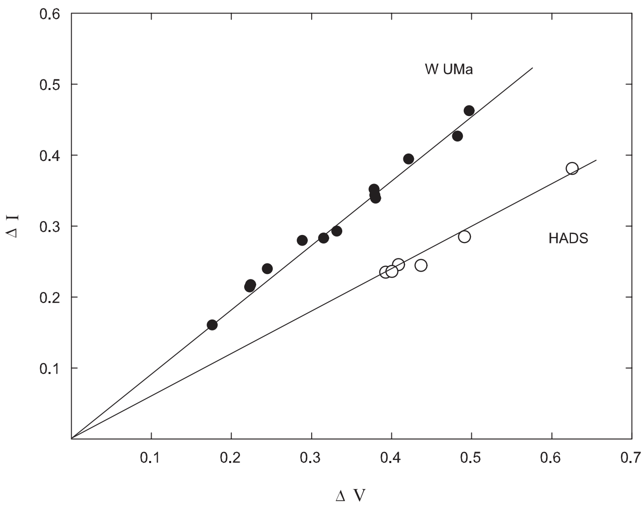

Fig. 4. ΔV versus ΔI amplitudes difference diagram. Filled circles represent thirteen W UMa type eclipsing binaries and open circles denote six δ Scuti type pulsating stars. The slopes of ΔI against ΔV, are much different between two variable types.

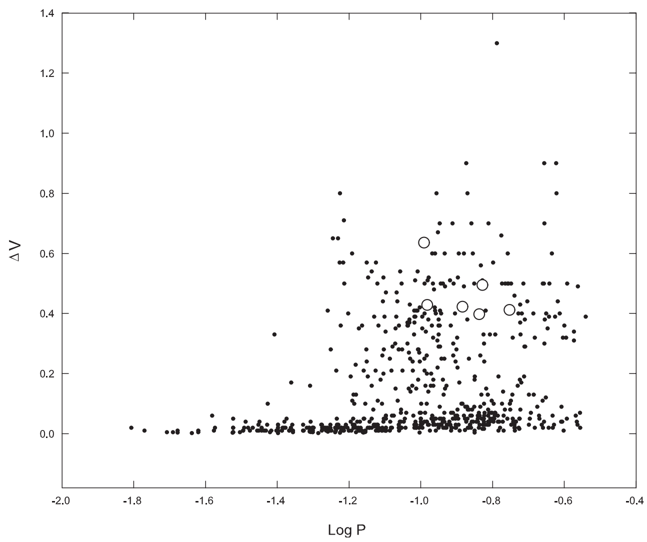

Fig. 5. V-amplitudes versus periods diagram of δ Scuti stars. Open circles represent six δ Scuti stars observed in this study. Dots denote known δ Scuti stars, which were catalogued by Rodríguez et al. (2000).

fact implies that previous ROTSE-I classifications of variable types to the HADS are partially wrong. We suggest that the classifying methods of survey data should be more precise by adding more criteria, specifically to discriminate between the HADS and W UMa stars.

Blake et al. (2003) studied the period changes of 18 ROTSE-I δ Scuti stars by comparing their result with ROTSE-I data. Four of their objects are the same with this study. According to our results, three objects are W UMa eclipsing variables and the other one is a δ Scuti star, YZ Boo. Even though they reported the period change and identified as a new pre-main sequence δ Scuti star for ROTSE 4861 (J173937.28+501202.0), our results show this star to be an eclipsing variable star.

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Table 2. Observation summary of 20 δ Scuti type variable stars and 1 RRa in ROTSE-I field. Last two columns represent the identifications of ROTSE-I group and ours.

ROTSE Name	m (ROTSE)	ΔV	ΔI	Period(day)	Epoch	ROTSE	ours
J163117.94+115952.4[a]	10.86	0.437	0.244	0.148619	2452423.256	RRa	HADS (DY Her)
J152406.95+365200.9[b]	10.99	0.491	0.285	0.104090	2452422.068	DS	HADS (YZ Boo)
J164839.21+302745.6	13.49	0.409	0.245	0.130597	2452451.077	DS	HADS
J182943.22+280955.2	12.7	0.393	0.235	0.145513	2452541.012	DS	HADS
J183206.54+403555.9[c]	12.87	0.625	0.381	0.102141	2452422.310	DS	HADS
J193445.28+455416.9	11.81	0.402	0.236	0.176617	2452570.024	DS	HADS
J125140.01+371546.2	14.29	0.379	0.343	0.307161	2452352.262	DS	W UMa
J134113.76+314725.5	13.03	0.315	0.283	0.263548	2452424.205	DS	W UMa
J140105.55+244216.2	12.23	0.245	0.240	0.387810	2452453.155	DS	W UMa
J161520.21+354226.1	11.1	0.288	0.280	0.360920	2452420.090	DS	W UMa
J170724.41+361525.7	12.09	0.223	0.214	0.393530	2452454.130	DS	W UMa
J171640.25+293412.9	11.93	0.497	0.462	0.384512	2452419.125	DS	W UMa
J173937.28+501202.0	12.44	0.378	0.352	0.352264	2452590.950	DS	W UMa
J181123.41+303641.4	12.81	0.380	0.339	0.321704	2452542.022	DS	W UMa
J181324.63+255008.4	12.74	0.224	0.217	0.254573	2452556.038	DS	W UMa
J184522.47+455321.0	13.44	0.331	0.292	0.256002	2452583.979	DS	W UMa
J192108.38+510200.8	12.06	0.176	0.160	0.361900	2452571.108	DS	W UMa
J193210.39+454409.7	12.79	0.421	0.394	0.356456	2452576.895	DS	W UMa
J194505.99+532334.5	13.82	0.482	0.427	0.365716	2452601.973	DS	W UMa
J181613.28+495205.0[d]	13.7	0.093	0.184	0.128905	2452580.040	DS	CV (AM Her)
J191516.94+475914.5	11.04	–	–	0.167167	2451280.348	DS	Non-variable

[a]: DY Her was classified as RR Lyr type stars (GCVS). But It was identified as a HADS (Hoffmeister et al. 1985).
[b]: It is a well-known δ Scuti star, YZ Boo.
[c]: It was also observed by Wils et al. (2002).
[d]: It is a well-known cataclysmic variable star, AM Her.

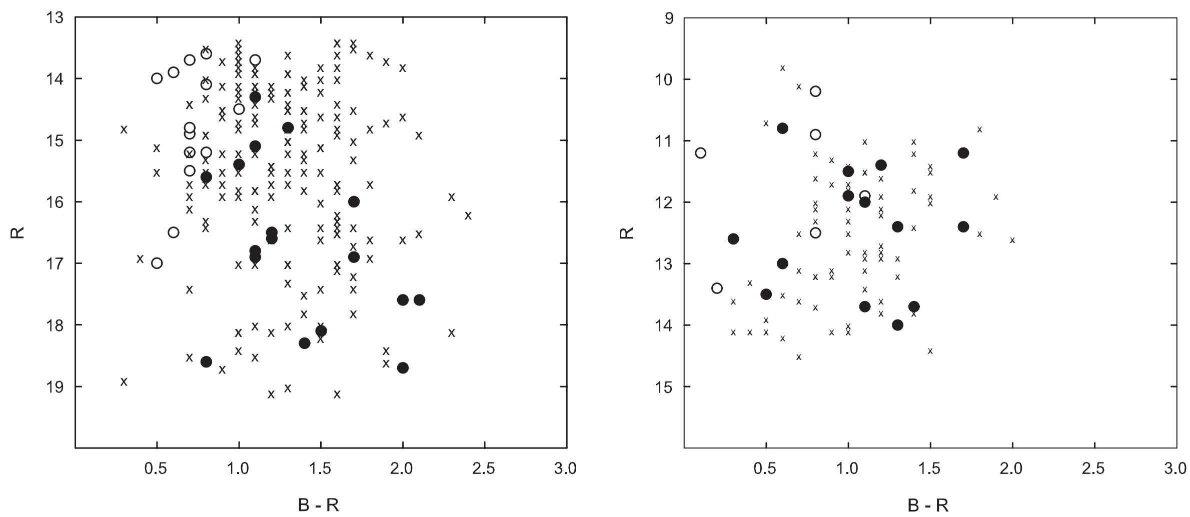

Fig. 6. Difference of color distributions between pulsating and eclipsing stars. (Left) $(B-R)$ versus R diagram using the observational data of Everett et al. (2002). Filled circles are EA/EW stars, open circles are SX Phe/δ Scuti stars, and small crosses are un-classified variable stars. (Right) $(B-R)$ versus R diagram of ROTSE-I δ Scuti stars. B and R magnitude obtained from the USNO catalogue. Filled circles are eclipsing variables and open circles are pulsating variables observed in this study. Small crosses are un-observed stars.

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