COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5640

Konkoly Observatory
Budapest
3 August 2005

HU ISSN 0374 – 0676

NEWLY DISCOVERED VARIABLE STARS IN THE GLOBULAR CLUSTERS NGC 5634, ARP 2 AND TERZAN 8

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Cosmological arguments suggest that dwarf galaxies may constitute the fundamental building block of larger galaxies. Therefore, comparing the oldest stellar components of giant galaxies with those of their surrounding dwarf satellite galaxies may provide us with an excellent opportunity to empirically constrain the extent to which the dwarfs may have played a role in assembling the giants. Unmistakably old and easy to identify in relatively nearby systems, RR Lyrae variables may prove of vital importance in this regard (Catelan 2004; Kinman, Saha, & Pier 2004).

In the case of our own Milky Way, several previously unknown dwarf galaxies have recently been reported on in the literature, some of which clearly in the process of being engulfed by the Milky Way. A particularly striking example is provided by the Sagittarius dwarf spheroidal galaxy (Ibata, Lewis, & Gilmore 1994). An important question one must ask is whether the ongoing Sagittarius merger is representative of the process that led to the formation of the Milky Way. In this sense, comparing the RR Lyrae variables in the globular clusters which have been suggested to be associated with Sagittarius (e.g., Da Costa & Armandroff 1995; Dinescu et al. 2000; Bellazzini et al. 2002) and those in the Galaxy's halo may shed light on whether the Galactic halo globular cluster system originated from Sagittarius-like mergers. In the present note, we focus on four Sagittarius-related globulars, namely: Arp 2, Terzan 8, Palomar 12, and NGC 5634.

NGC 5634 had seven previously known variables (Baade 1945), while Pal 12 had three reported variables (Kinman & Rosino 1962). Neither Arp 2 nor Terzan 8 have variable stars listed in the Clement et al. (2001) catalog.

Our search for variable stars in these clusters is based on images acquired on the Danish 1.54m telescope in La Silla, Chile, over four consecutive nights, from June 27 to June 30, 2003. In the course of these nights, the seeing conditions varied from 0.9 to 1.5 arcsec. The 2048×2048 RINGO CCD was used. With a pixel scale of $0\farcs395$, the total observed field was $13\farcm5 \times 13\farcm5$.

The total set of images consists in 32 B, V pairs for NGC 5634, 37 pairs for Arp 2, 27 pairs for Ter 8, and 34 pairs for Pal 12. In this note we shall restrict ourselves to relative-flux light curves based on the B-band images.

Table 1. Locations and tentative periods for new variable stars in NGC 5634.

Variable	$x('')$	$y('')$	Period (d)	Type
V8	55.3	−43.4	0.330	RRc
V9	0.4	−4.7	0.583	RRab
V10	13.0	−0.8	0.646	RRab
V11	10.7	7.9	0.660	RRab
V12	−2.4	9.5	0.624	RRab
V13	−14.2	12.6	0.645	RRab
V14	21.3	18.6	0.720	RRab
V15	7.9	18.6	0.852	RRab
V16	9.9	31.6	0.670	RRab
V17	−0.4	43.1	0.289	RRc
V18	−20.9	−38.3	0.325	RRc
V19	0.8	−26.1	0.296	RRc
V20	−7.9	0.0	0.648	RRab
V21	−30.8	−28.0	0.0666	SX Phe

Table 2. Locations and tentative periods for new variable stars in Arp 2.

Variable	$x('')$	$y('')$	Period (d)	Type	Note
V1	−101.1	27.6	0.568	RRab	Valenti's V4
V2	−58.1	73.5	0.821	RRab	Valenti's V5
V3	160.4	−27.6	0.565	RRab	Valenti's V25
V4	223.2	1.2	0.458	RRab	Valenti's V28
V5	128.8	−327.5	0.763	RRab	
V6	−190.8	−100.7	0.445	RRab	
V7	289.1	288.0	0.530	RRab	
V8	4.0	−40.0	0.292	RRc	
V9	97.6	−63.6	0.517	RRab	
V10	90.1	−125.2	0.0473	SX Phe	
V11	20.9	68.3	0.0611	SX Phe	
V12	−43.8	−237.0	0.0604	SX Phe	

Table 3. Locations and tentative periods for new variable stars in Terzan 8.

Variable	$x('')$	$y('')$	Period (d)	Type	Note
V1	−113.4	−187.6	0.686	RRab	Montegriffo's 117
V2	124.0	−23.3	0.392	RRc	Montegriffo's 1350
V3	−179.0	−193.2	0.601	RRab	
V4	95.6	37.1	0.0616	SX Phe	

Using the image subtraction technique (ISIS v2.1; Alard 2000), we were able to rediscover six of the seven known variables in NGC 5634, and to discover 14 new variables in the cluster. In Arp 2, we discovered 8 new variables and confirmed 4 previously reported ones (Valenti 2001). Other variables reported by Valenti were not found to be variable in our data. In Ter 8 two new variables were found and a two more previously suspected variables (Montegriffo et al. 1998) were confirmed. We do not confirm the variable status of stars V1, V2, and V3 that had previously been reported in Pal 12 (Kinman & Rosino 1962).

The location, classification and tentative periods for the new variables in NGC 5634, Arp 2, and Ter 8 are given in Tables 1, 2, and 3, respectively. In these tables, the x and y coordinates are in arcseconds with respect to the cluster centers, as given in the online Clement et al. (2001) catalog. Because the time coverage was not extensive, the periods are probably good only to the third decimal place, and some may actually be aliases of the correct period. Light curves based on the reported periods are shown in Figure 1 for NGC 5634, and in Figure 2 for Arp 2 (first three rows) and Ter 8 (bottom row).

Finding charts for the newly discovered variable stars in the three clusters are provided in Figures 3 (NGC 5634), Figure 4 (Arp 2), and Figure 5 (Ter 8).

One of the variables found by Baade (1945) in NGC 5634, V7, could not be confirmed by our analysis. Likewise, the variable was not present in the Liller & Sawyer-Hogg (1976) analysis, although in their case this was due to blending. Since Alard's (2000) image subtraction technique is particularly powerful in the center of concentrated clusters, we conclude that V7 is not a variable. For V2 in NGC 5634, we find that the period given by Liller & Sawyer-Hogg ($P = 0.605148$ d) does not give us a clean light curve; $P = 0.601$ d provides a better solution. For the remainder of the variables, the periods that we found are the same as in Liller & Sawyer-Hogg's study. Of the twelve variables discovered in Arp 2, four (NV1-NV4) had previously been found by Valenti (2001). Two of the Ter 8 variables (NV1-NV2) were previously identified by Montegriffo et al. (1998). Since their studies were based on very few datapoints, our periods represent a significant improvement over the ones previously reported.

Note that we detect candidate SX Phoenicis variables in NGC 5634, Arp 2, and Ter 8. Although their light curves tend to be a bit noisy, they are all located in the blue straggler region in their respective clusters' color-magnitude diagrams (Salinas et al. 2005, in preparation); together with their short periods, this suggests to us that their SX Phe classification is reliable.

In a future paper, we will attempt to incorporate additional data into our analysis, calibrate the light curves into standard magnitudes, construct Bailey diagrams and analyze the Sagittarius globular cluster system in the context of the Oosterhoff dichotomy and the formation history of the Milky Way (Catelan 2004, 2005).

Acknowledgement: We thank C. Cacciari and E. Valenti for interesting discussions. R.S. acknowledges support by FONDAP 15010003. M.C. acknowledges support by Proyecto FONDECYT Regular No. 1030954. H.A.S. acknowledges the NSF for support under grant AST 02-05813.

References:

Alard, C., 2000, *A&AS*, **144**, 363
Baade, W., 1945, *ApJ*, **102**, 17
Bellazzini, M., Ferraro, F.R., Ibata, R. 2002, *AJ*, **124**, 915
Catelan, M., 2004, *ASP Conf. Ser.*, **310**, 113, in Variable Stars in the Local Group, IAU Colloq. 193, ed. D.W. Kurtz & K.R. Pollard, (San Francisco: ASP)
Catelan, M., 2005, *ASP Conf. Ser.*, in press, in Resolved Stellar Populations, ed. D. Valls-Gabaud & M. Chávez, (astro-ph/0507464)
Clement, C.M., et al., 2001, *AJ*, **122**, 2587
Da Costa, G.S., Armandroff, T.E., 1995, *AJ*, **109**, 2533
Dinescu, D., Majewski, S., Girard, T., Cudworth, K., 2000, *AJ*, **120**, 1892
Ibata, R., Gilmore, G., Irwin, M., 1994, *Nature*, **370**, 194
Kinman, T.D., Rosino, L., 1962, *PASP*, **74**, 499
Kinman, T.D., Saha, A., Pier, J.R., 2004, *ApJ*, **605**, L25
Liller, M., Sawyer Hogg, H., 1976, *AJ*, **81**, 628
Montegriffo, P., Bellazzini, M., Ferraro, F.R., et al., 1998, *MNRAS*, **294**, 315
Valenti, E., 2001, *Ricerca delle variabili RR Lyrae neglie amassi globulari NGC 6304 e Arp 2*, Tesi di Laurea (Università degli studi di Bologna, Bologna)

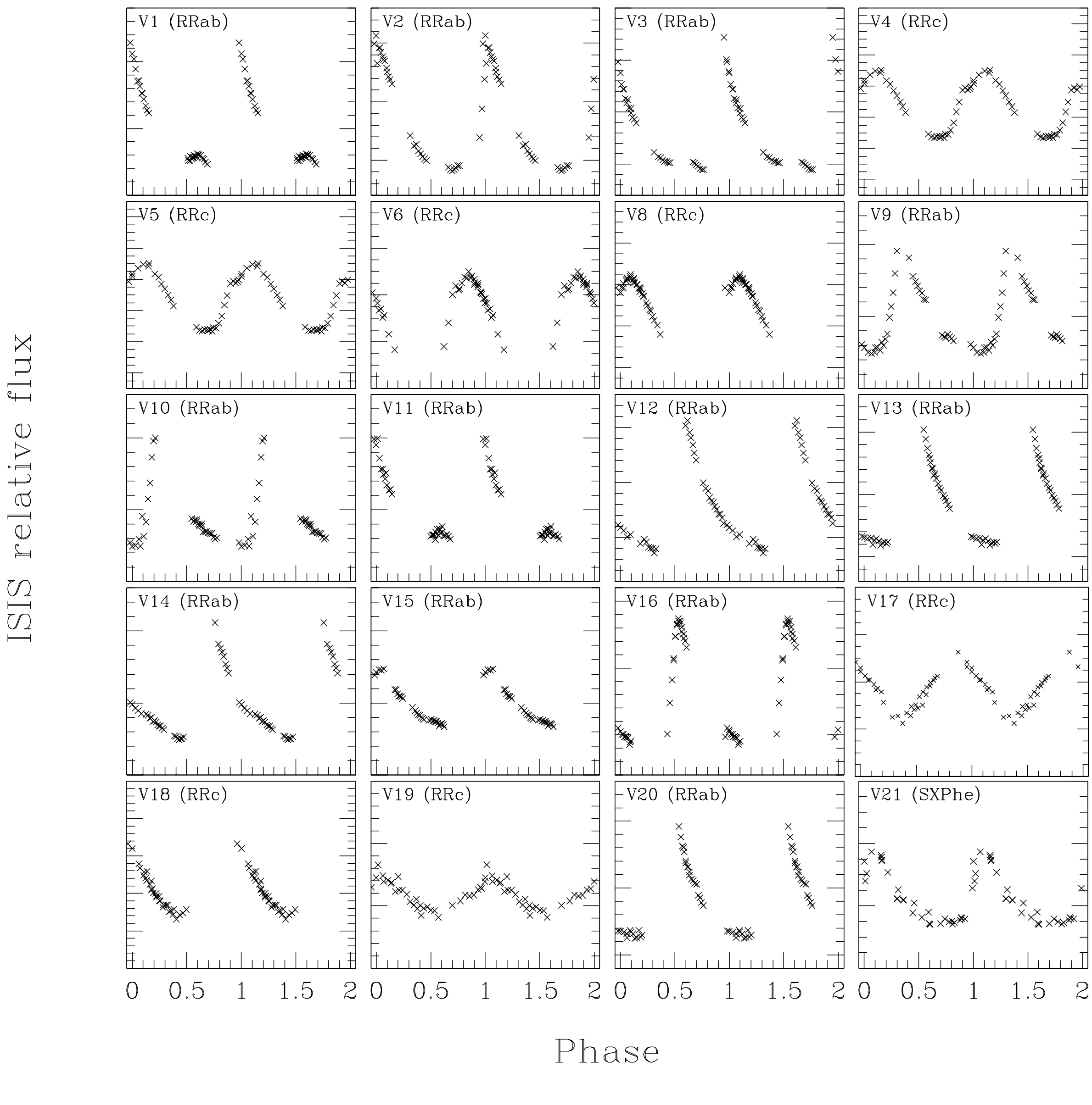

Figure 1. *B*-band differential light curves for six previously known RR Lyrae variables and fourteen newly discovered variables in NGC 5634.

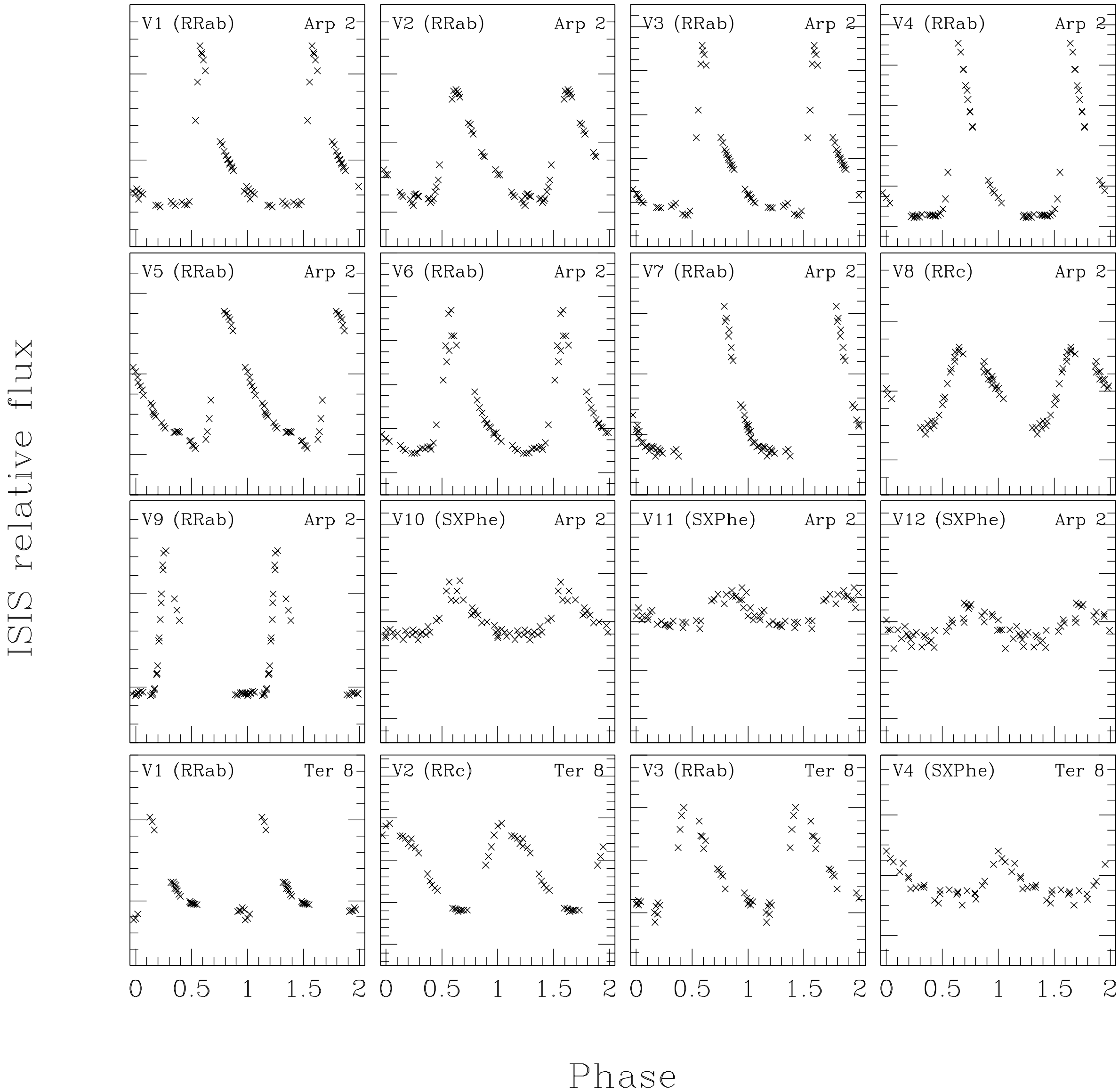

Figure 2. *B*-band differential light curves for the twelve variables detected in Arp 2 and four variables in Terzan 8 (last row).

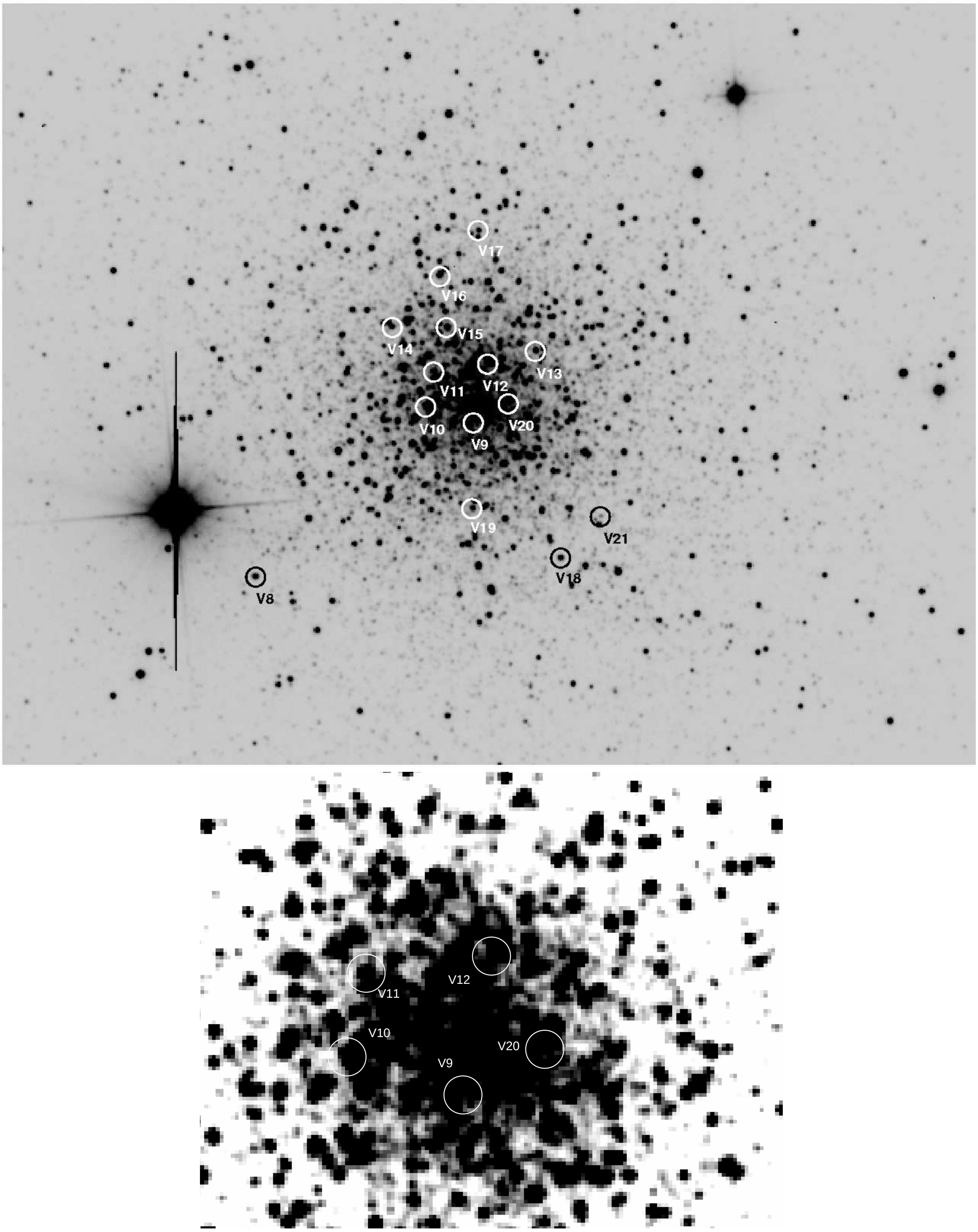

Figure 3. *Top*: Finding chart for newly discovered variable stars in NGC 5634. The field size is approximately $4' \times 3'$. North is up and East to the left.
Bottom: Same as the upper plot, but zooming in on a central region of approximately $1' \times 1'$ in size. This plot illustrates the power of ISIS to reliably detect and perform relative photometry for variable stars in extremely crowded fields.

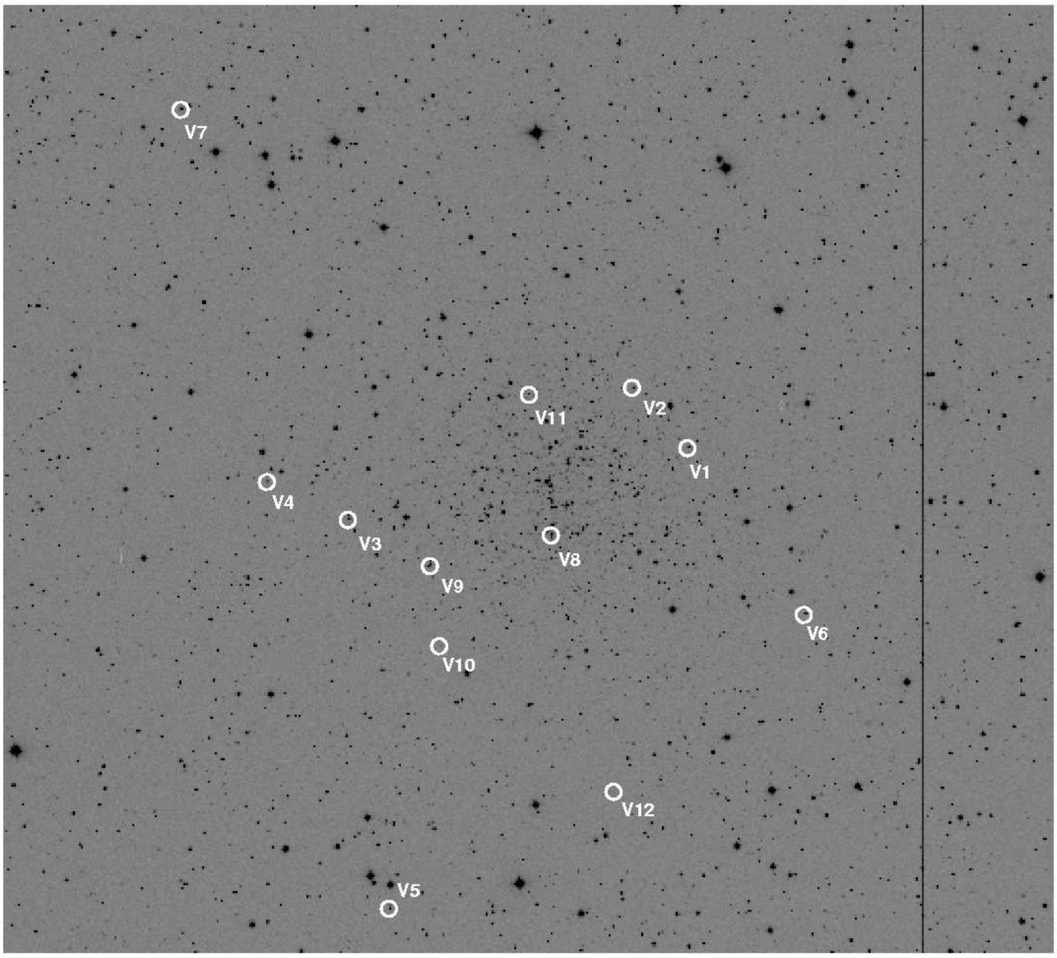

Figure 4. Finding chart for newly discovered variable stars in Arp 2.The field size is approximately $13' \times 13'$. North is up and East to the left.

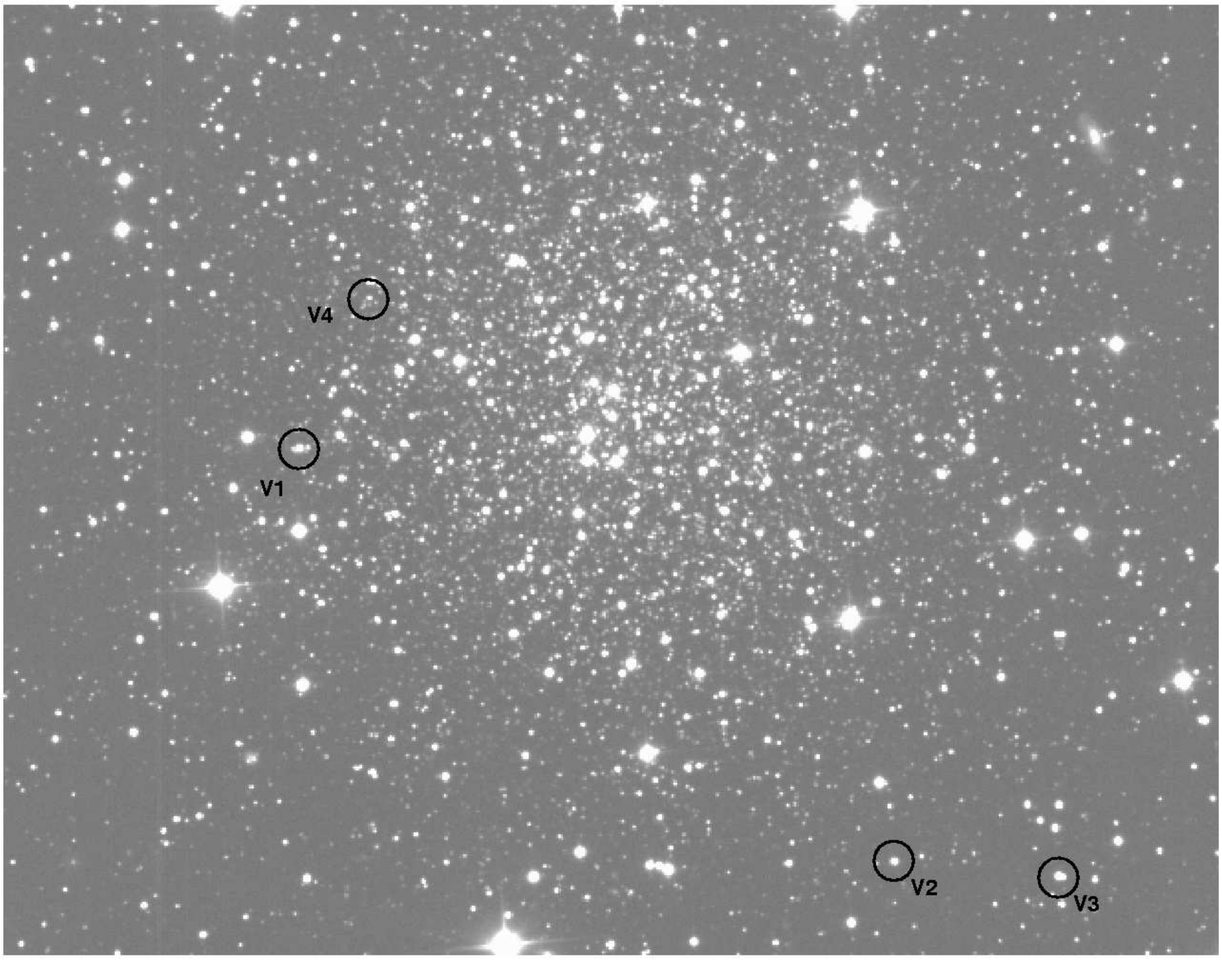

Figure 5. Finding chart for newly discovered variables in Terzan 8. The field size is approximately $8' \times 6'$. North is up and East to the left.