

DIRECT DISTANCES TO NEARBY GALAXIES USING DETACHED ECLIPSING BINARIES AND CEPHEIDS. IX. VARIABLES IN THE FIELD M31Y DISCOVERED WITH IMAGE SUBTRACTION

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ABSTRACT

The DIRECT Project aims to obtain direct distances to two Local Group galaxies, M31 and M33, which occupy a crucial position near the base of the cosmological distance ladder. The first step is to search for detached eclipsing binaries (DEBs) and Cepheids using 1 m class telescopes to select good candidates, which will be followed up spectroscopically on 6.5–10 m class telescopes. **In this ninth paper, we present a catalog of variable stars discovered with image subtraction in field M31Y ($\alpha = 10^{\circ}97$, $\delta = 41^{\circ}69$; J2000.0).** The data were obtained with the Fred Lawrence Whipple Observatory 1.2 m telescope on 25 nights, over a period of 6 months. **In our search covering $22' \times 22'$, we discovered 41 eclipsing binaries, 126 Cepheids, and 97 other periodic or nonperiodic variables, including a luminous blue variable candidate, a nova, and a Galactic cataclysmic variable.** The catalog of variables, as well as their photometry and finding charts, is available electronically via anonymous ftp and the World Wide Web. The complete set of the CCD frames is available upon request.

Key words: binaries: eclipsing — Cepheids — distance scale — galaxies: individual (M31) — stars: variables: other

On-line material: color figures, machine-readable tables

1. INTRODUCTION

Starting in 1996, we undertook a long-term project, DIRECT (i.e., “direct distances”), to obtain the distances to two important galaxies in the cosmological distance ladder, M31 and M33. These “direct” distances will be obtained by determining the distance to Cepheids using the Baade-Wesselink method and by measuring the absolute distance to detached eclipsing binaries (DEBs).

M31 and M33 are the stepping-stones to most of our current effort to understand the evolving universe at large scales. Walker (2003) stresses the importance of M31: as a spiral galaxy, it is a more suitable local galaxy for calibrating the distance scale than the Large Magellanic Cloud, even though it is not as easy to observe. The difficulties include the large angular extent of M31 on the sky, the variable (internal) reddening, and crowding. M31 and M33 also constrain population synthesis models for early galaxy formation and evolution and provide ample data for the stellar luminosity calibration. There is one simple requirement for all this—accurate distances. These distances are now known to no better than 10%–15%, since there are discrepancies of 0.2–0.3 mag between various distance indicators.

DEBs have the potential to establish distances to M31 and M33 with an unprecedented accuracy of 5%. DEBs (for

reviews, see Andersen 1991; Paczyński 1997) offer a single-step distance determination to nearby galaxies and may therefore provide an accurate zero-point calibration of various distance indicators—a major step toward very accurate determination of the Hubble constant, currently an important but daunting problem for astrophysicists. In the last few years, DEBs have been used to obtain accurate distance estimates to the Large Magellanic Cloud (e.g., Guinan et al. 1998; Fitzpatrick et al. 2003) and the Small Magellanic Cloud (Harries, Hilditch, & Howarth 2003). Distances to individual DEBs in these papers are claimed to be accurate to 5%–10%.

DEBs have yet to be used as distance indicators to M31 and M33. The DIRECT project has begun a massive search for periodic variables, discovering so far four good DEBs, now that large-format CCD detectors are available and that CPUs are inexpensive. These DEBs will be spectroscopically followed up with the powerful 6.5–10 m telescopes.

The study of Cepheids in M31 began with Hubble (Hubble 1929). Later, Baade’s photographic plates of fields I–IV (Gaposchkin 1962; Baade & Swope 1963, 1965) and Magnier’s CCD survey (Magnier et al. 1997) led to the discovery of a few hundred Cepheids. Welch et al. (1986) obtained infrared photometry of several Cepheids in Baade’s fields. Freedman & Madore (1990) obtained CCD observations of known Cepheids in M31 to determine more accurate periods and study metallicity effects. Recently, Joshi et al. (2003) have obtained *R*- and *I*-band observations

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of a $13' \times 13'$ region in the disk of M31 galaxy and derived a Cepheid period-luminosity distance. However, the existing photometry of M31 is sparse and does not provide a good basis for obtaining direct Baade-Wesselink distances (see, e.g., Krockenberger, Sasselov, & Noyes 1997) to Cepheids—the need for new digital photometry has been long overdue.

As the first step of the DIRECT project, we have searched for DEBs and new Cepheids in the M31 and M33 galaxies. We have analyzed five $11' \times 11'$ fields in M31, A–D and F (Kaluzny et al. 1998; Stanek et al. 1998, 1999; Kaluzny et al. 1999; Mochejska et al. 1999, hereafter Papers I, II, III, IV, and V, respectively). A total of 410 variables, mostly new, were found: 48 eclipsing binaries, 206 Cepheids, and 156 other periodic, possible long-period or nonperiodic variables. We have analyzed two fields in M33, A and B (Macri et al. 2001; hereafter Paper VI) and found 544 variables: 47 eclipsing binaries, 251 Cepheids, and 246 other variables. Follow-up observations of fields M33A and M33B produced 280 and 612 new variables, respectively (Mochejska

et al. 2001a, 2001b, hereafter Papers VII and VIII, respectively). Variables from two more DIRECT fields, one in M31 and the other in M33, remain to be reported.

In this paper, ninth in the series, we present a catalog of variable stars found in field M31Y. The paper is organized as follows: § 2 provides a description of the observations; the data reduction procedure, calibration, and astrometry is outlined in § 3; and the catalog of variable stars is presented in § 4, followed by a brief discussion in § 5.

2. OBSERVATIONS

The data for M31 field Y was taken with the 1.2 m telescope at the Fred Lawrence Whipple Observatory (FLWO) on Mount Hopkins, Arizona, between 1999 July 19 and 2000 January 2, over 25 nights. We used the “4Shooter” camera (Szentgyorgyi et al. 2003), with four thinned and AR-coated Loral 2048² pixel CCDs. The pixels are $15 \mu\text{m}$ in size and map to $0''.33 \text{ pixel}^{-1}$ on the focal plane, making each image $11'$ on the side. The camera was centered at

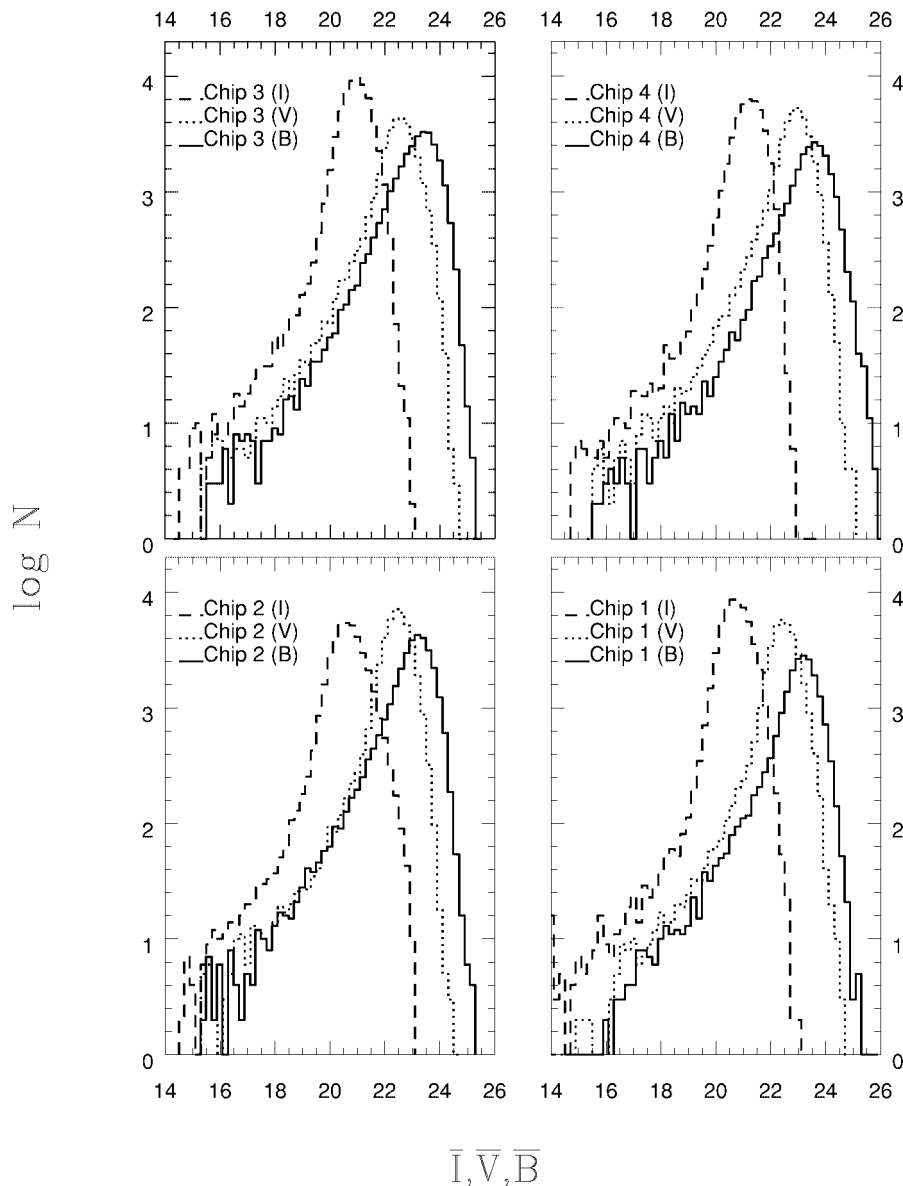


FIG. 1.—Distribution of stars in each filter and chip, showing the depth to which our survey is complete

$\alpha = 10^{\circ}97$, $\delta = 41^{\circ}69$ (J2000.0), which is approximately $0^{\circ}48$ or 6.6 kpc from the nucleus, assuming a distance to M31 of 784 kpc (Stanek & Garnavich 1998). The data consists of 126×900 s exposures in the V filter, 21×1200 s exposures in the B filter, and 36×600 s exposures in the I filter. The median value of the seeing in V was $1''.7$. The field was observed through air masses ranging from 1.02 to 2.11, with the median being 1.15. The completeness of our photometry starts to drop rapidly at about 20.5 in I , 22.5 in V , and 23.5 in B , as shown in the distribution of stars in Figure 1. On two photometric nights of the run, several images of standard Landolt (1992) fields were taken.

3. DATA REDUCTION, CALIBRATION, AND ASTROMETRY

Preliminary processing of the data was performed with standard routines in the IRAF² CCDPROC package. The photometry for the variable stars was extracted using the ISIS image subtraction package (Alard & Lupton 1998; Alard 2000) from the V -band data.

The ISIS reduction procedure consists of several steps. Initially, all the frames are transformed to a common coordinate grid. Next, a reference image is created by stacking several frames with the best seeing. For each frame, the

² IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

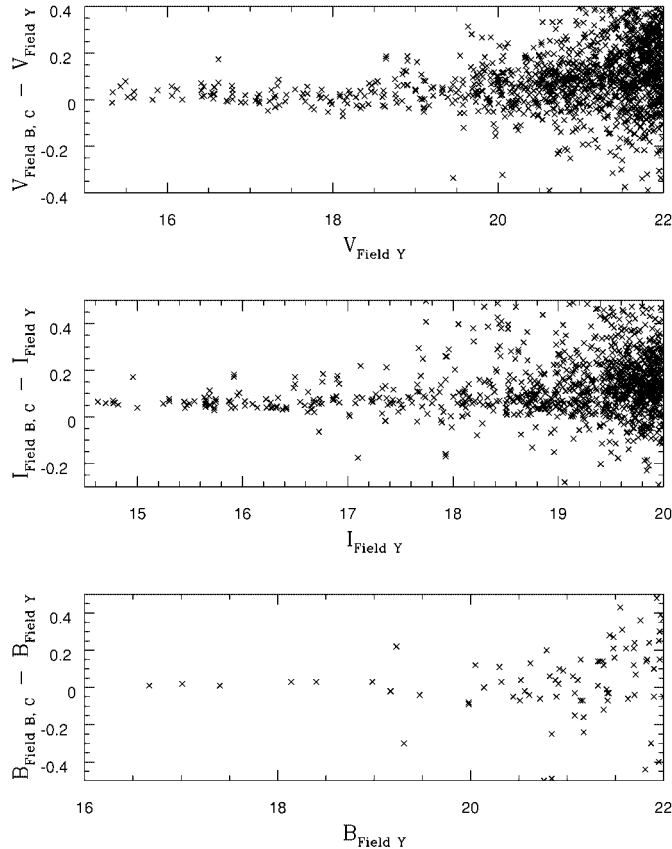


FIG. 2.—Comparison of our photometry with overlapping fields B and C (Papers I and III) in V , I , and B bands. The median offsets found in each are 0.02, 0.06, and 0.03 mag, respectively.

TABLE 1
TRANSFORMATION COEFFICIENTS FOR EACH CHIP

Instrumental Magnitude	χ	ξ	κ
$b_1(B-V)$	-5.25	-0.025	0.216
$v_1(B-V)$	-5.30	0.039	0.145
$v_1(V-I)$	-5.30	0.035	0.146
$i_1(V-I)$	-4.47	0.002	0.088
$b_2(B-V)$	-5.00	-0.056	0.192
$v_2(B-V)$	-4.92	0.037	0.136
$v_2(V-I)$	-4.92	0.032	0.137
$i_2(V-I)$	-4.37	0.012	0.079
$b_3(B-V)$	-5.48	-0.033	0.220
$v_3(B-V)$	-5.47	0.047	0.136
$v_3(V-I)$	-5.47	0.041	0.136
$i_3(V-I)$	-4.69	0.040	0.070
$b_4(B-V)$	-5.16	-0.046	0.225
$v_4(B-V)$	-5.28	0.038	0.146
$v_4(V-I)$	-5.29	0.033	0.146
$i_4(V-I)$	-4.61	0.009	0.066

reference image is convolved with a kernel to match its point-spread function and then subtracted. On the subtracted images, the constant stars will cancel out, and only the signal from variable stars should remain. A median image is constructed of all the subtracted images, and the variable stars are identified as bright peaks on it. Finally, profile photometry is extracted from the subtracted images. Paper VII describes this procedure in more detail.

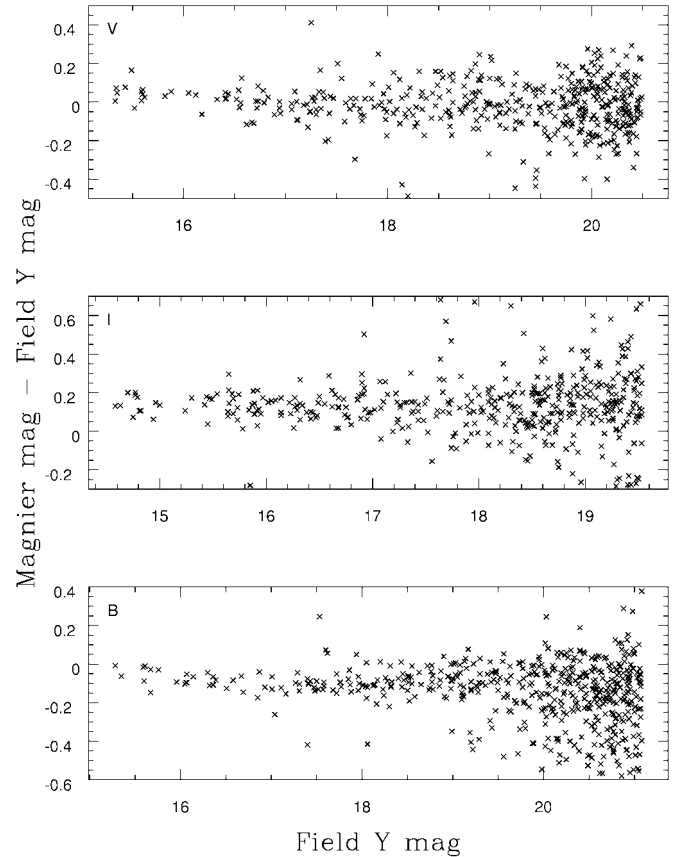


FIG. 3.—Comparison of our chip 2 photometry with the Magnier catalog (Magnier et al. 1997) in V , I , and B bands. The median offsets found in each are 0.01, 0.133, and -0.101 mag, respectively.

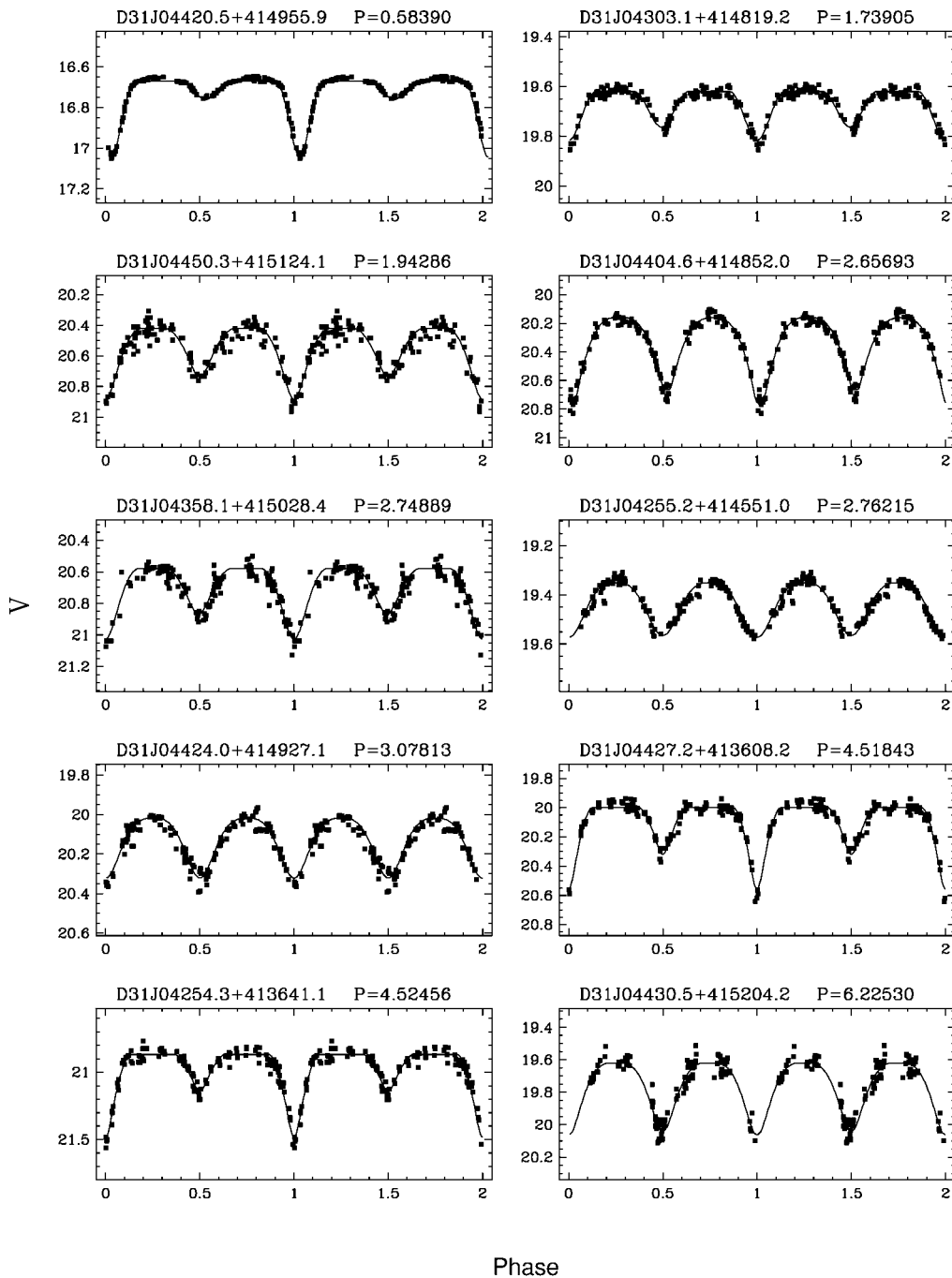


FIG. 4.—Sample V -band light curves of EBs found in M31Y. The solid line is the best-fit model to the binary.

3.1. Photometric Calibration and Astrometry

During each of the photometric nights of 1999 October 11 and November 3, we observed seven Landolt (1992) fields in the BVI filters at air masses ranging from 1.12 to 1.97 in I , 1.12 to 2.00 in V , and 1.13 to 2.05 in B . The transformation from the instrumental to the standard system was derived for each chip in the following form:

$$\begin{aligned}
 b &= B + \chi_b + \xi_b(B - V) + \kappa_b X, \\
 v &= V + \chi_{v1} + \xi_{v1}(B - V) + \kappa_{v1} X, \\
 v &= V + \chi_{v2} + \xi_{v2}(V - I) + \kappa_{v2} X, \\
 i &= I + \chi_i + \xi_i(V - I) + \kappa_i X,
 \end{aligned}$$

where lowercase letters correspond to the instrumental magnitudes, uppercase letters to standard magnitudes, and X is the air mass. The values of the zero point (χ), color (ξ), and air-mass coefficients (κ) are given in Table 1. The zero points for the two nights agree to 0.02 mag. Since the color coefficients are small, we took $B - V = V - I = 1$ when transforming the magnitudes of our stars, which is approximately the color of a Cepheid.

We compared our photometry with overlapping DIRECT field M31B and M31C photometry (Papers I and III) and also with Magnier's photometry (Magnier et al. 1997). The median magnitude offsets with DIRECT field B and C photometry are 0.02 mag in V , 0.06 mag in I , and 0.03 mag in B , as shown in Figure 2. We compared 2299 stars in

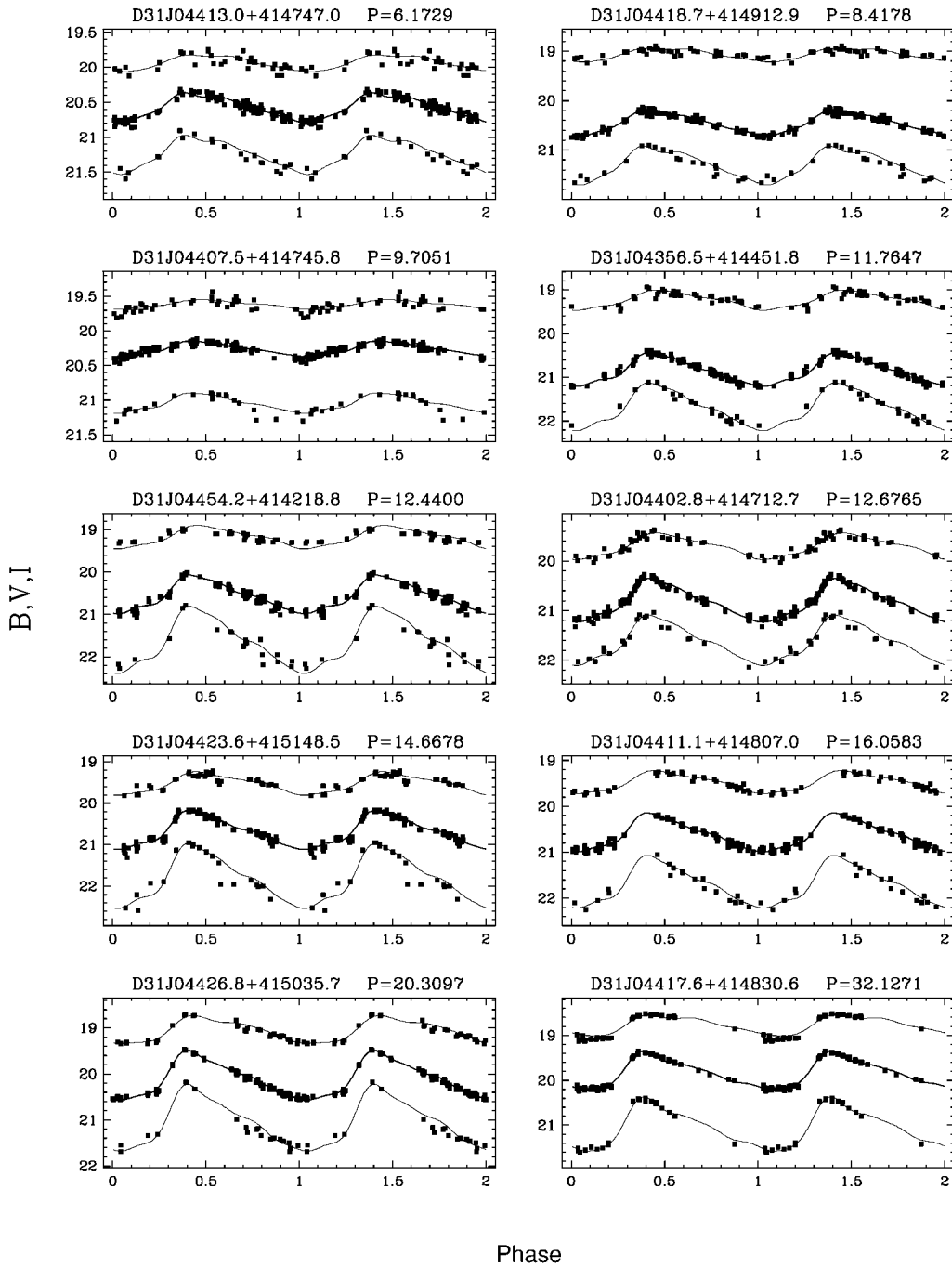


FIG. 5.—Selected B , V , and I light curves for Cepheids in M31Y chip 3. The solid line is the best-fit model.

V , 2383 in I , and 320 in B . Our I -band photometry is slightly brighter (0.06 mag) than in Paper I, while the photometry of Joshi et al. (2003) is fainter by 0.13 mag. We believe that the I -band magnitudes of Joshi et al. (2003) are off.

Figure 3 shows the comparison of our photometry with Magnier's photometry for chip 2, which is representative of the other chips as well. The average V -magnitude differences between Magnier's photometry and ours, for stars brighter than 18th magnitude, for chips 1–4 were -0.06 , 0.01 , -0.03 , and -0.14 mag, by comparing 1560, 3783, 747, and 206 matching stars, respectively. In I , the offset with Magnier is ~ 0.1 mag, while in B the offset is roughly -0.2 mag. Since there is good agreement with Paper I in these bands, we

believe that the Magnier B and I magnitudes are off and should be used with caution.

Equatorial coordinates were determined for the V star list. The transformation from rectangular to equatorial coordinates was derived for chips 1–4 using 135, 117, 191, and 221 transformation stars, respectively, with $V < 20$ from the USNO-A2.0 (Monet et al. 1996) catalog. The average difference between the catalog and the computed coordinates for the transformation stars was less than $0''.3$ in right ascension and $0''.3$ in declination. We also compared the astrometry to Magnier's catalog and found 262, 313, 307, and 72 matches for chips 1–4, having a median offset less than $0''.4$. We use these derived equatorial coordinates

to name the variables, adopting the convention after Macri et al. (2001) based on the J2000.0 equatorial coordinates, in the format D31Jhhmmss.s+ddmss.s. The first three fields (hhmmss.s) correspond to right ascension expressed in hours, the last three (ddmss.s) to declination, expressed in degrees, separated by the declination sign.

4. CATALOG OF VARIABLES

The preliminary classification process used, as described in Paper I, classified the variable stars as eclipsing, Cepheids, or miscellaneous. In order to obtain a clean Cepheid sample, we reclassified Cepheids with highly discrepant colors on a color-magnitude diagram (CMD; shown in Fig. 8) as other periodic variables. In addition, extreme outliers on the period-luminosity relation in V and I (see Fig. 9) were reclassified as other periodic variables, since they most likely are type II Cepheids. Next, we present the catalog of light curves and parameters of 264 variables.³

³ The BVI photometry and V finding charts for all variables are available from the authors via anonymous ftp from cfa-ftp.harvard.edu, in the `pub/kstaneck/DIRECT` directory and can be also accessed through the World Wide Web at <http://cfa-www.harvard.edu/~kstaneck/DIRECT/>.

4.1. Eclipsing Binaries

We found 41 EBs in field M31Y. In Table 2, we list their name, period P , magnitudes B_{\max} , V_{\max} , and I_{\max} of the system outside of the eclipse, and the radii R_1 and R_2 in the units of the orbital separation. We also give the inclination angle i of the binary orbit to the line of sight and the eccentricity e . These values are determined from a simple model of the eclipsing system, so they should be treated only as reasonable estimates of the “true” values. The table also includes the flux EBs, for which only the position and period are given. Figure 4 presents the phased light curves of 10 sample EBs. Table 3 presents all the EB light curves.

4.2. Cepheids

A total of 126 Cepheids were found in field M31Y. In Table 4, we present their light curves and parameters, ordered by increasing period. Specifically, the table lists the Cepheid name, period P , V -band amplitude A_V , and flux-weighted average magnitudes $\langle V \rangle$, $\langle I \rangle$, and $\langle B \rangle$. For Cepheids with flux light curves, only the name and period are given. There are 15 previously identified Cepheids, for which we reference their discovery name. Figure 5 presents

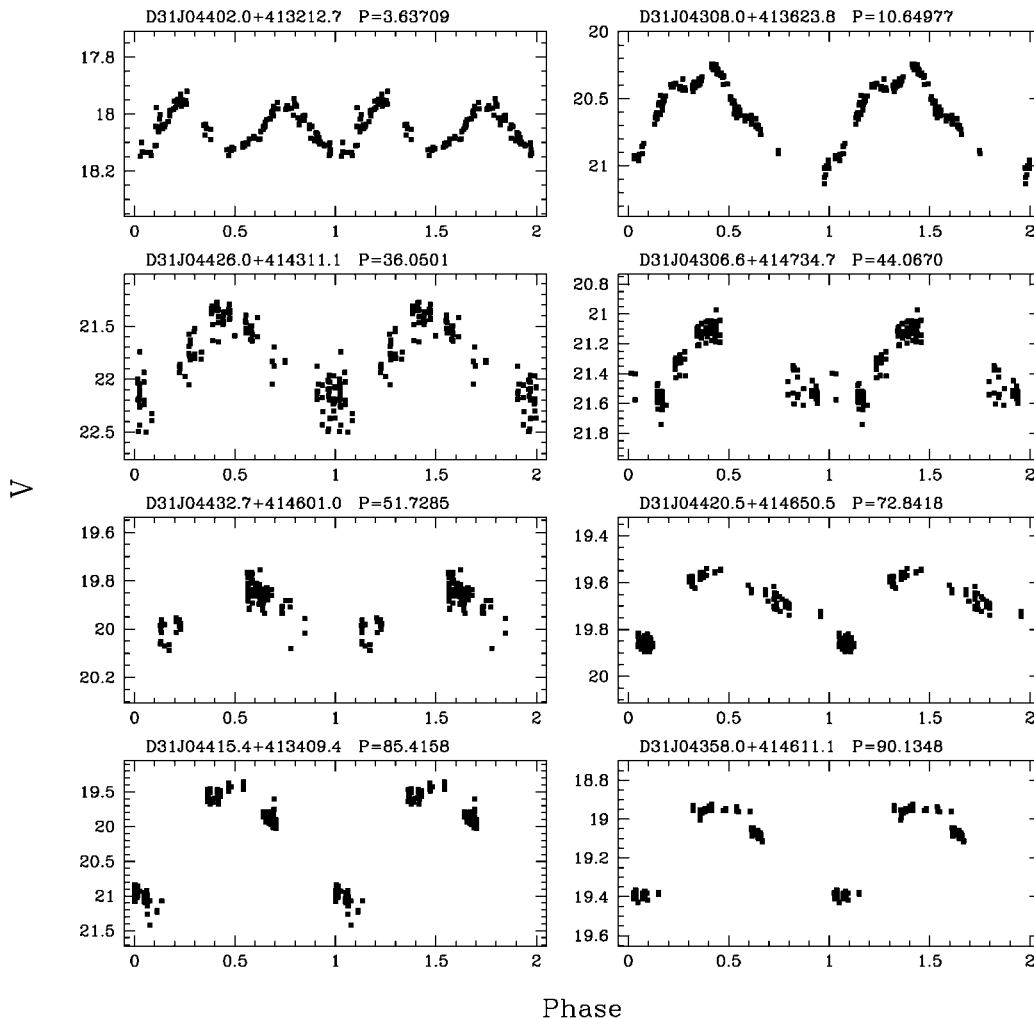


FIG. 6.—Sample V -band light curves of eight other periodic variables

TABLE 2
DIRECT ECLIPSING BINARIES IN M31Y

Name	P (days)	B_{\max}	V_{\max}	I_{\max}	R_1	R_2	i (deg)	e	Comments ^a
D31J04422.4+413851.1	0.23278	18.75	17.84	16.62	0.66	0.34	61.78	0.03	V438, WUMa
D31J04420.5+414955.9	0.58390	16.97	16.67	16.38	0.38	0.36	67.96	0.00	Foreground
D31J04255.7+414013.0	0.83605	21.03	21.20	20.23	0.65	0.34	66.48	0.00	
D31J04301.0+414259.8	1.17912	21.55	21.44	21.00	0.50	0.37	82.60	0.01	



NOTES.—Table 2 is presented in its entirety in the electronic edition of the *Astronomical Journal*. A portion is shown here for guidance regarding its form and content.

^a Identifications of EBs found in M31B (Kaluzny et al. 1998) and Magnier et al. 1997 are listed.

TABLE 3
LIGHT CURVES OF ECLIPSING BINARIES IN M31Y

Name	Filter	HJD –2,450,000	Mag/Flux	$\sigma_{\text{mag}}/\sigma_{\text{flux}}$
D31J04256.2+413341.4	B	1,379.9287	20.831	0.019
		1,428.8263	20.740	0.021
		1,429.8771	20.777	0.020
		1,432.8958	20.758	0.019

NOTES.—Table 3 is presented in its entirety in the electronic edition of the *Astronomical Journal*. A portion is shown here for guidance regarding its form and content.

TABLE 4
DIRECT CEPHEIDS IN M31Y

Name	P (days)	A_V	$\langle V \rangle$	$\langle I \rangle$	$\langle B \rangle$	Comments
D31J04255.7+413531.2	2.7600	0.28	22.00	
D31J04331.5+415140.9	2.8773	0.36	22.43	
D31J04302.1+414248.7	3.0787	0.46	22.00	21.41	22.32	
D31J04337.3+413441.1	3.1150	0.30	22.31	20.40	23.05	



NOTES.—Table 4 is presented in its entirety in the electronic edition of the *Astronomical Journal*. A portion is shown here for guidance regarding its form and content.

TABLE 5
LIGHT CURVES OF CEPHEIDS IN M31Y

Name	Filter	HJD –2,450,000	Mag/Flux	$\sigma_{\text{mag}}/\sigma_{\text{flux}}$
D31J04336.9+413141.8	b	1,379.9287	–76.527	97.018
		1,428.8263	–456.584	125.975
		1,429.8771	–253.044	111.878
		1,432.8958	381.949	107.811

NOTES.—Table 5 is presented in its entirety in the electronic edition of the *Astronomical Journal*. A portion is shown here for guidance regarding its form and content.

TABLE 6
DIRECT OTHER PERIODIC VARIABLES IN M31Y

Name	P (days)	$\langle V \rangle$	$\langle I \rangle$	$\langle B \rangle$	Comments
D31J04321.5+415124.2	1.8741	21.83	20.79	22.20	
D31J04310.5+414331.0	3.0461	22.13	...	22.50	
D31J04402.0+413212.7	3.6371	18.04	16.84	18.78	
D31J04345.4+414850.5	4.1334	20.62	20.17	...	

NOTES.—Table 6 is presented in its entirety in the electronic edition of the *Astronomical Journal*. A portion is shown here for guidance regarding its form and content.

TABLE 7
 LIGHT CURVES OF OTHER PERIODIC VARIABLES IN M31Y

Name	Filter	HJD -2,450,000	Mag/Flux	$\sigma_{\text{mag}}/\sigma_{\text{flux}}$
D31J04308.0+413623.8	<i>b</i>	1,379.9287	817.266	88.453
		1,428.8263	-66.370	108.510
		1,429.8771	-372.652	99.494
		1,432.8958	803.898	94.021

NOTES.—Table 7 is presented in its entirety in the electronic edition of the Astronomical Journal. A portion is shown here for guidance regarding its form and content.

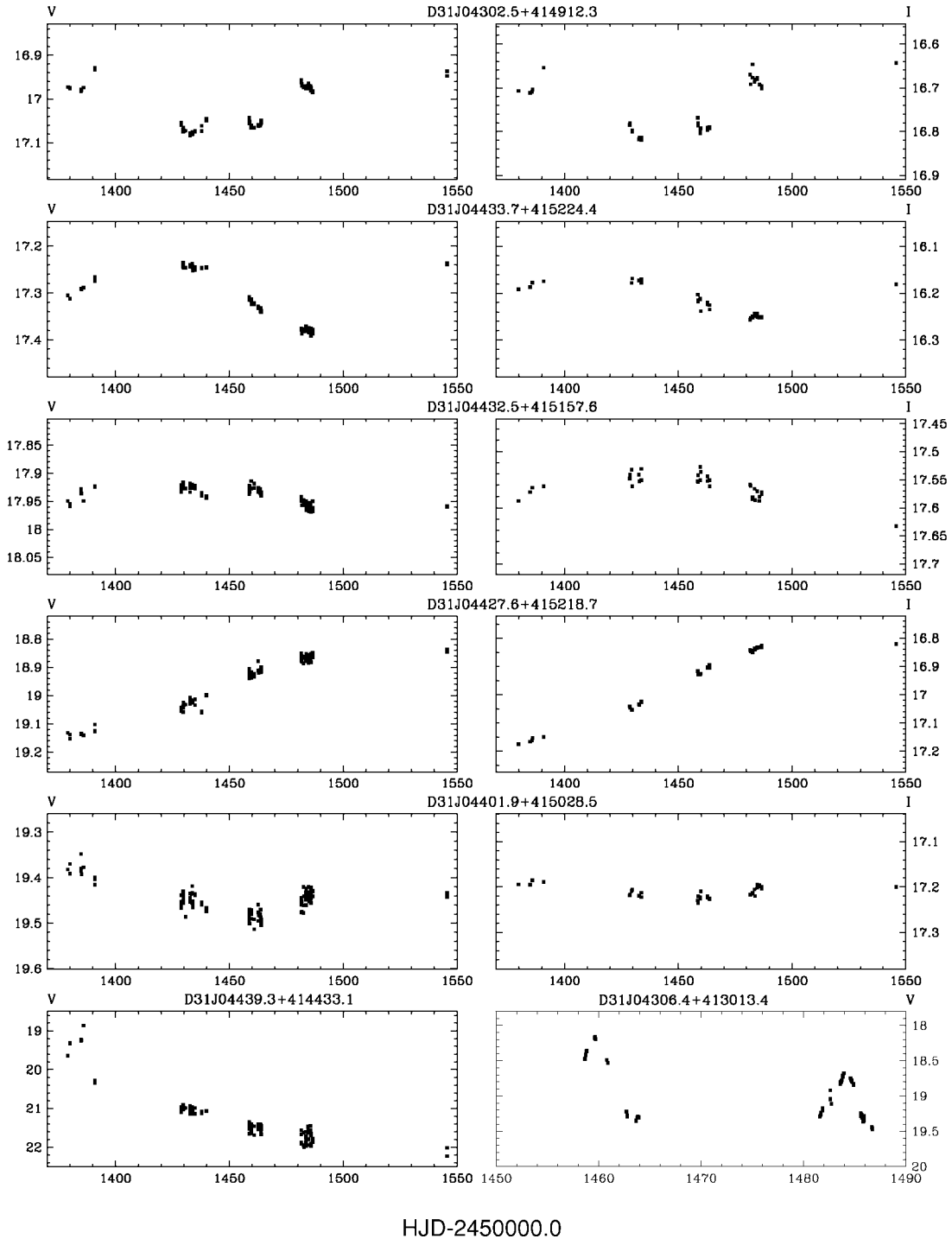


FIG. 7.—Sample light curves of miscellaneous variables

the phased light curves of 10 sample Cepheids. Table 5 presents all the Cepheid light curves.

4.3. Other Periodic Variables

In Table 6, we present parameters of 48 periodic variables, ordered by increasing period. We list each variable's name, period P , and flux-weighted average magnitudes $\langle V \rangle$, $\langle I \rangle$, and $\langle B \rangle$. Figure 6 presents phased light curves of eight sample periodic variables. Several of these are type II Cepheids. Table 7 presents all the light curves of other periodic variables.

4.4. Miscellaneous Variables

In Table 8, we present parameters of 49 miscellaneous variables, ordered by increasing right ascension. We list the name of each variable and the average V , I , and B magnitudes. Figure 7 presents V - and I -band light curves for several miscellaneous variables. Table 9 presents all the light curves of miscellaneous variables.

There are several interesting variables in this category worth mentioning: D31J04439.3+414433.1 is a possible nova, which dropped 3 mag over 100 days in V ;

TABLE 8
DIRECT MISCELLANEOUS VARIABLES IN M31Y

Name	\bar{V}	\bar{I}	\bar{B}	Comments
D31J04254.1+414033.9	19.75	16.37	...	
D31J04254.3+413219.4	23.27	19.43	...	
D31J04256.0+413509.2	18.62	17.52	18.87	
D31J04257.6+413245.3	20.91	19.80	21.41	

NOTES.—Table 8 is presented in its entirety in the electronic edition of the *Astronomical Journal*. A portion is shown here for guidance regarding its form and content.

D31J04302.5+414912.3 seems to be a luminous blue variable; and finally, D31J04306.4+413013.4 is probably a foreground cataclysmic variable, similar to Z Cam. Near both maxima, it has $B - V = 0.24$ and $V - I = 0.5$.

5. DISCUSSION

In Figure 8, we plot the location of the variables on the CMD. In the left panel, the positions of EBs (*open circles*)

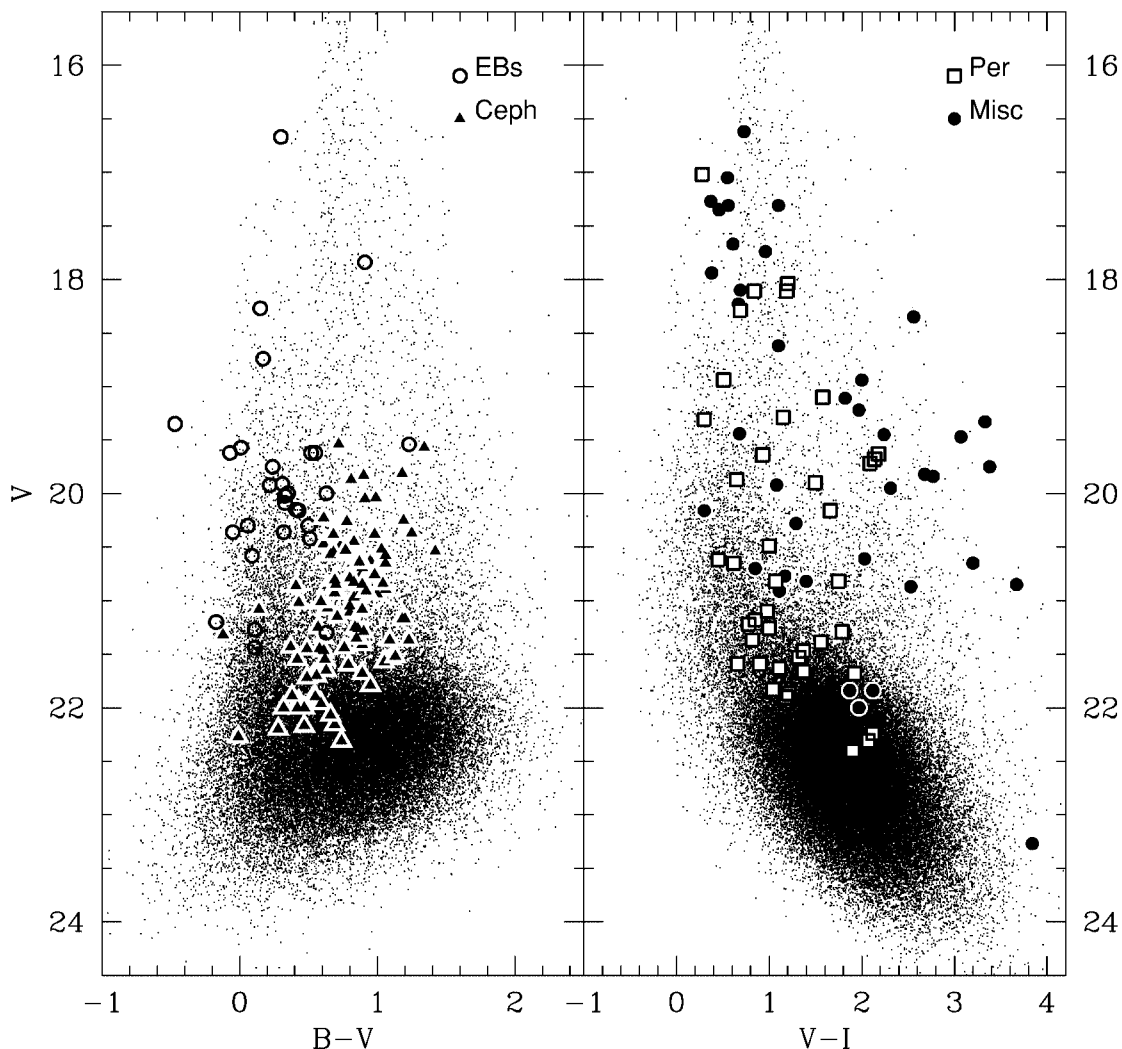


FIG. 8.— V vs. $B - V$ and V vs. $V - I$ CMD for stars in M31Y. *Left*: The EBs are marked with open circles, and Cepheids with filled triangles. *Right*: The periodic variables are open squares, and the miscellaneous variables are marked with filled circles.

and Cepheids (*filled triangles*) are shown on a $V/B-V$ CMD. In the right panel, the location of other periodic (*open squares*) and miscellaneous variables (*filled circles*) are shown on a $V/V-I$ CMD. Most of the EBs occupy the upper main sequence. Variable D31J04420.5+414955.9, with $V = 16.67$ and $B-V = 0.3$, is most likely a foreground DEB, since it is bright and has a period of only 0.58390 days, even though it is projected onto the spiral arms. No extinction correction has been applied, resulting in a spread of the EBs and Cepheids on the CMD.

The Cepheid period-luminosity relation for the I , V , and B bands is shown in Figure 9. The size of the circles representing Cepheids is proportional to their amplitude. The scatter in each plot is due to extinction and errors in the period determination and the photometry.

Figure 10 shows the distribution of Cepheids found in all the DIRECT M31 fields, and Figure 11 shows field Y separately. The period of a Cepheid depends on its age, since its mass determines the period of variability and the main-sequence lifetime of the star. Therefore, the distribution of Cepheids should trace star formation and thus the spiral arms, which is the case. The longer period or younger Cepheids appear to lie along the spiral arms. The fact that the longest period of a Cepheid in M31Y is 25 days, while in other fields there are Cepheids with 50 day periods, might

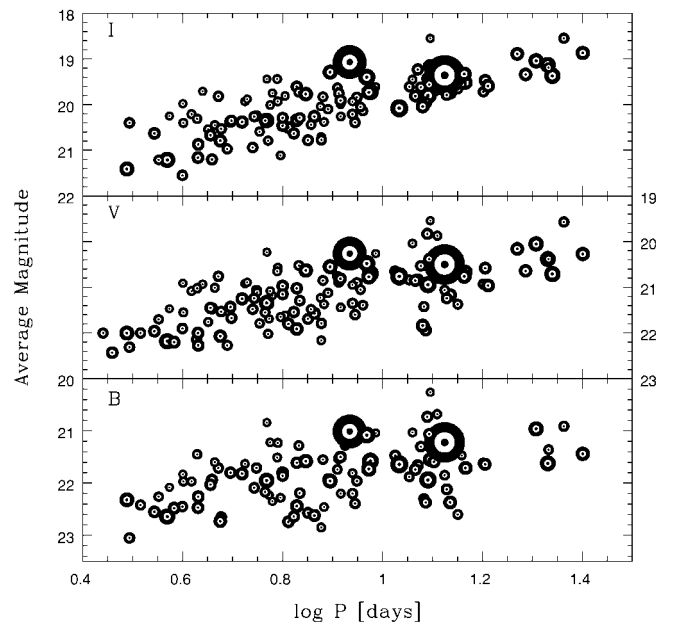


FIG. 9.—Period-luminosity relation for M31Y Cepheids in I , V , and B . The size of the circle is proportional to the amplitude of the Cepheid in each band.

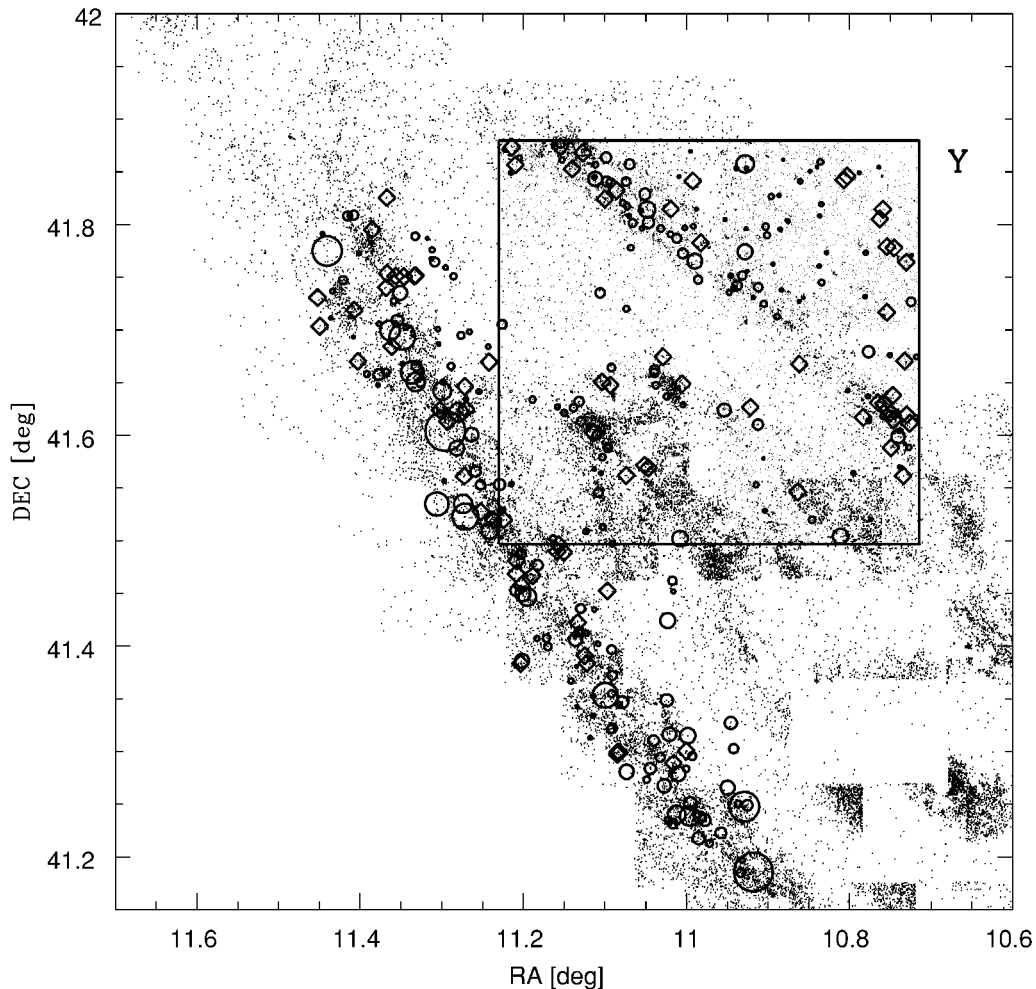


FIG. 10.—Distribution of Cepheids and EBs in the northeastern part of M31. Magnier's catalog (Magnier et al. 1997) is used to outline the galaxy. For field Y, 14,000 of our stars ($V < 21.8$) are also overlaid. Circles represent the Cepheids and are proportional to the period; diamonds represent the EBs. The lack of Cepheids in field Y with periods greater than 25 days may suggest more recent star formation on the eastern side of M31.

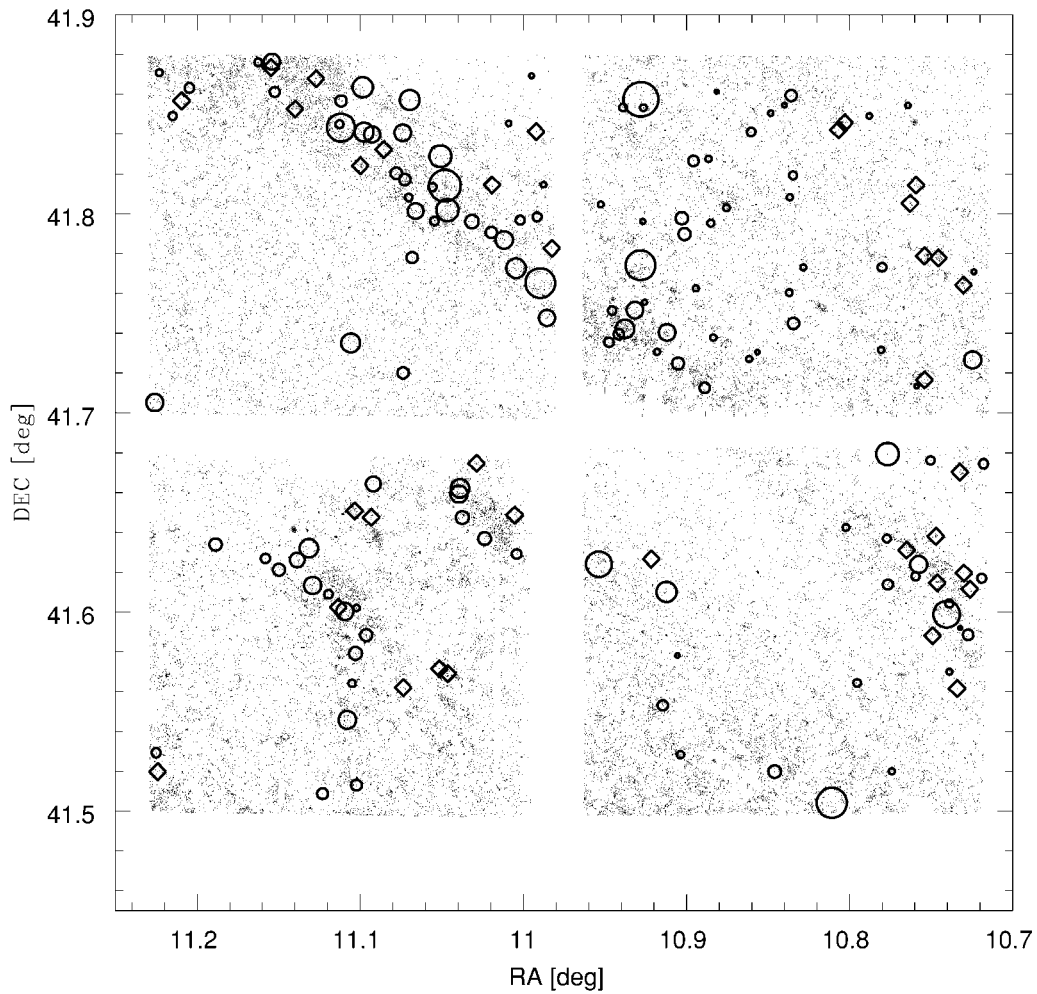


FIG. 11.—Distribution of Cepheids and EBs in field Y; symbols are as in Fig. 10

TABLE 9
LIGHT CURVES OF MISCELLANEOUS VARIABLES IN M31Y

Name	Filter	HJD $-2,450,000$	Mag/Flux	$\sigma_{\text{mag}}/\sigma_{\text{flux}}$
D31J04254.3+413219.4	<i>b</i>	1,379.9287	35.327	79.835
		1,428.8263	-106.313	94.983
		1,429.8771	-55.733	87.618
		1,432.8958	-61.530	83.257

NOTES.—Table 9 is presented in its entirety in the electronic edition of the *Astronomical Journal*. A portion is shown here for guidance regarding its form and content.

TABLE 10
COMPARISON OF VARIABLES IN M31 DIRECT FIELDS

Field Name	Total Variables	EBs	Cepheids	Others	DIRECT Papers
M31A	75	15	43	17	Paper II
M31B	85	12	38	35	Paper I
M31C	115	12	35	68	Paper III
M31D	71	5	38	28	Paper IV
M31F	64	4	52	8	Paper V
M31Y	264	41	126	97	This paper
Totals	674	89	332	253	

indicate more recent star formation on the eastern side of the galaxy.

Table 10 shows the number of each kind of variable found in each DIRECT field. This paper thus almost doubles the DIRECT variables in M31. Comparatively, field M31Y is not as rich in variables as fields A, B, and C, which lie along the spiral arms, whereas it is richer than fields D and F.

To summarize, the observations of field M31Y with the 4Shooter camera on the FLWO 1.2 m telescope resulted in the discovery of 41 EBs, 126 Cepheids, 48 other periodic variables, and 49 miscellaneous variables, almost doubling the number of M31 variables found by DIRECT. Currently, there are 674 variables in M31 from the DIRECT project: 89 EBs, 332 Cepheids, and 253 other variables. Of the 264 variables in M31Y, four EBs and 20 Cepheids had been previously discovered. We presented light curves and

parameters for these variables in this paper. A catalog of *BVI* photometry of stars in this field will be a subject of a future paper.

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