BLENDING OF CEPHEIDS IN M33

Chavez.et al. 2012,AJ,114,113 (arXiv:1208.1048)

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OUTLINES

- INTRODUCTION
- DATA AND ANALYSIS
- BLENDING CALCULATION
- RESULT
- COMPARISON WITH PREVIOUS WORK

INTRODUCTION

- An accurate and precise measurement of the Hubble constant at the few-percent level imposes significant constraints on the equation of state of dark energy and other cosmologically relevant parameters (Komatsu et al. 2011).
- Cosmological applications of the Extragalactic Distance Scale (Freedman & Madore 2010) primarily rely on the Period-Luminosity relation of Cepheid variables as the primary distance indicator.
- Enable a 1% measurement of H0 if all sources of systematic error are properly accounted for.

INTRODUCTION

- Blending

- One of these sources of systematic error occurs when two or more neighboring stars fall within the same resolution element of an instrument and cannot be fit with separate point-spread functions (PSFs). This effect is commonly referred to as blending.
- Blending will bias the measured flux of a Cepheid towards larger values, shifting the Leavitt law to brighter magnitudes and leading to systematically shorter distances and larger values of H0.
- Extreme blends can be readily identified by their effects on Cepheid colors and/or amplitude ratios and such tests are routinely carried out .(Pellerin & Macri 2011; Scowcroft et al. 2009; Macri et al. 2006)
- However, low-level blends are unlikely to be identified by such cuts and may affect studies of the metallicity dependence.

INTRODUCTION

- The Local Group galaxy M33 is a good testbed for studies of Cepheid systematics:

Relative proximity: D=895-965kpc (Bonanos et al .2006)

Moderate inclination angle: i=55° (Ho et al. 1997)

Recent episodes of star formation which have resulted in large numbers of Cepheids throughout its disk (Hartman et al. 2006).

Image data: Subaru Telescope, Robert Gendler 2012.

INTRODUCTION

- Previous studies of the influence of blends on the Cepheid Distance Scale, based on comparisons between ground-based and HST images of nearby galaxies :

  - In M31, Mochejska et al. (2000) ;
  - In M33, Mochejska et al. (2001);
  - In NGC 300, Bresolin et al. (2005).

- Compare to Mochejska et al. (2001):

Mochejska et al. (2001) used HST/WFPC2 images and the Cepheid sample of the DIRECT survey (Macri et al. 2001).

This paper:

1. Additional HST observations using both WFPC2 and the Advanced Camera for Surveys (ACS), which enable us to study more Cepheids and, in the case of ACS, with greater depth and finer pixel scale.

2. Furthermore, this paper rely on a new synoptic survey of M33 (Pellerin & Macri 2011) carried out at the WIYN 3.5-m telescope with more Cepheids and better angular resolution than the DIRECT catalog.

DATA and Analysis

Cepheid Sample from Pellerin & Macri 2011

1. DIRECT survey of M33 (Macri et al. 2001) :

F. L. Whipple Observatory (FLWO) 1.2 m telescope on Mount Hopkins, Michigan–Dartmouth–MIT 1.3 m telescope on Kitt Peak, Arizona. (251 cepheids)

2.New images obtained at the 3.5-m Wisconsin-Indiana-Yale-NOAO (WIYN) telescope, the typical FWHM of the WIYN images was 0. ″75, sampled at a plate scale of 0. ″28/pix.

Detect 563 Cepheids ranging in period from 2 to 110 days. The photometry and astrometry were calibrated using the catalogs of Massey et al. (2006).

Designation [M33SSS]	R.A.	Decl.	Period	V^{a}	I	B	σV	σI	σB	Amp V	Amp I	Amp B
J013425.57+310029.2	23.60654	31.00812	2.052	22.202	21.590	22.613	0.002	0.006	0.011	0.085	0.054	0.119
J013319.01+302512.3	23.32920	30.42008	2.096	21.963	21.484	22.438	0.007	0.037	0.033	0.103	0.100	0.183
J013438.46+310155.9	23.66026	31.03220	2.319	21.835	21.370	99.999	0.001	0.004	9.999	0.151	0.147	0.121
J013256.63+301849.8	23.23594	30.31382	2.370	22.024	21.405	22.340	0.013	0.043	0.033	0.496	0.313	0.718
J013258.16+302505.2	23.24235	30.41810	2.387	21.830	21.191	22.230	0.014	0.030	0.043	0.186	0.148	0.238
J013243.21+302653.2	23.18006	30.44811	2.483	22.274	21.799	22.684	0.017	0.125	0.053	0.389	0.252	0.533

Pellerin, A. & Macri, L. M. 2011, ApJS, 193, 26.

DATA and Analysis

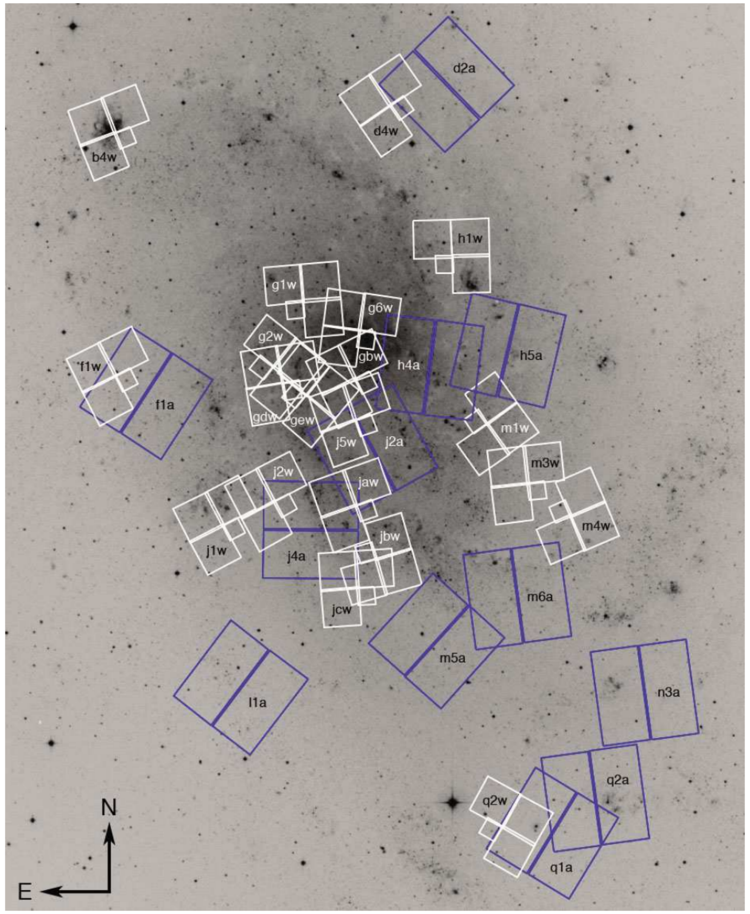
TABLE 1
HST OBSERVATIONS OF M33 USED IN THIS STUDY

Field Name	RA (J2000, deg)	Dec	Camera	Filters #1	#2	Exp. time (s) #1	#2	Prop. #	N Ceph.	Comments
b4w	23.6384	30.7818	WFPC2	555	814	400	400	5237	3	16 in P07
d2a	23.4066	30.8111	ACS	606	814	10414	20828	9873	7	U49 in S06

- Selected HST observations :

1. Multiple exposures to allow for cosmic-ray removal.
2. Minimum of 100 s of total exposure time, to ensure a depth that would enable the detection of faint companions around the Cepheids.
3. Restricted study to fields that were imaged in V (HST filters F555W or F606W) and I (HST filter F814W).

The HST fields contained 149 (~ 25%) of the Cepheids listed in Pellerin & Macri (2011).



The blue rectangles are from ACS, and the white boxes are from WFPC2.
The field label names end in 'a' for ACS, and 'w' for WFPC2

DATA and Analysis

Photometry

1. Performed point-spread function (PSF) photometry using DAOPHOT and ALLSTAR (Stetson 1987). Derived model PSFs using grids of artificial stars created with TinyTim (Krist & Hook 2004) for the appropriate bandpasses, cameras and CCDs.

2. Ran the FIND algorithm twice on each image, removing all stars found on the first iteration before proceeding to the second one. This increased the detection efficiency of faint stars, such as possible companions of a Cepheid. ALLSTAR was run one final time on the merged star list.

3. Based on the observed luminosity functions, the photometry is complete to V ~ 25.5, I ~ 24.7 and V ~ 24.3, I ~ 23 mag for ACS and WFPC2, respectively.

4. Instrumental magnitudes were converted to the HST VEGAMAG system.

DATA and Analysis

Cepheid Search

The HST and WIYN images are vastly different resolution and depth, and The astrometric solution provided by the automated STScI pipeline (for HST) is only accurate to a few arcseconds:

1. Refine the astrometric solution of the HST images by use the common brightest stars between HST and WIYN.

2. Cepheids were then selected based on the coordinates tabulated by Pellerin & Macri (2011).

3. Visually inspected every Cepheid to ensure the star in the HST frame was indeed a match to the same star in WIYN image.

4. Lastly, estimated the disk surface brightness by averaging the background flux values reported by ALLSTAR for stars within 7″ of each Cepheid.

BLENDING CALCULATION

$$S_F = \sum (f_i)/f_C$$

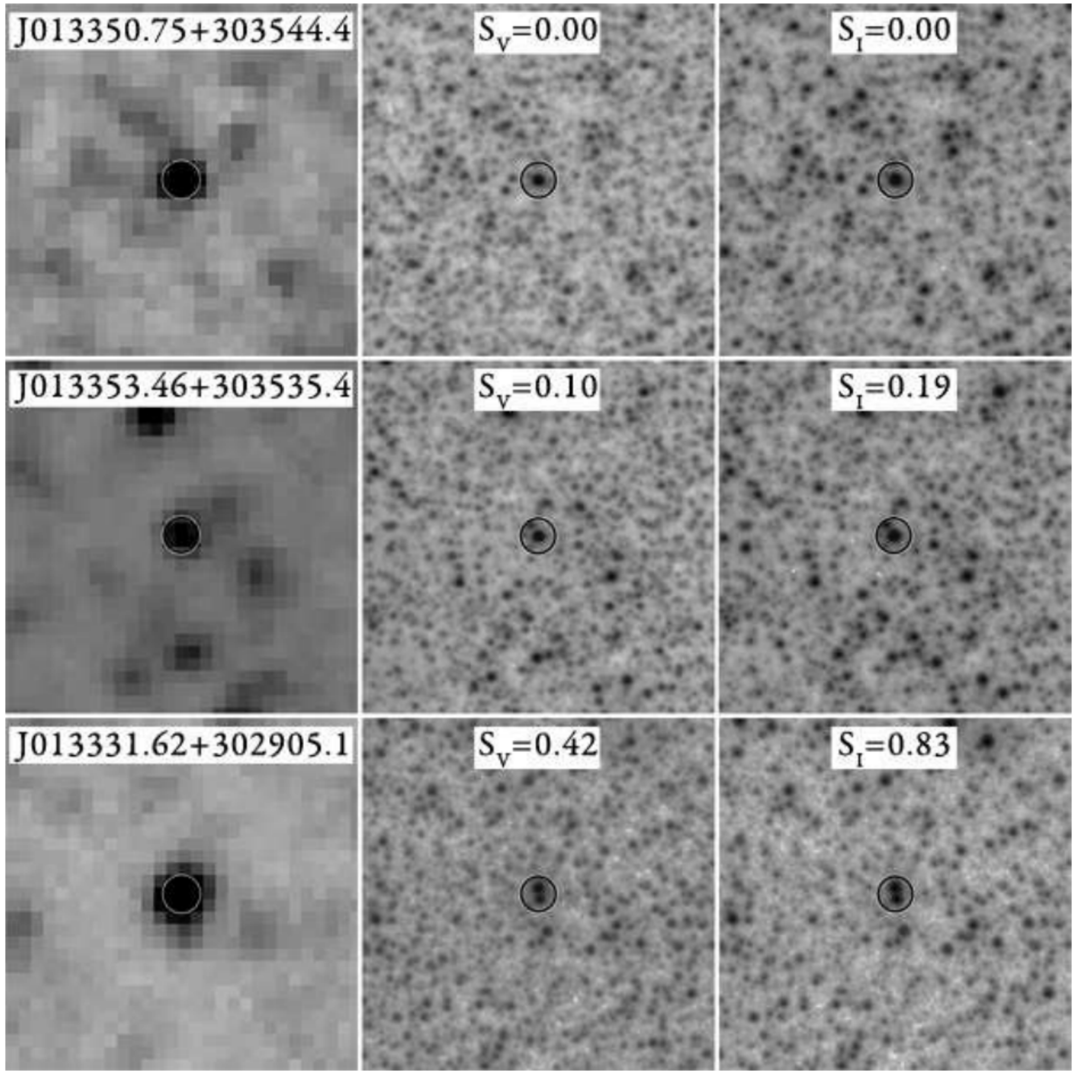
Mochejska et al. (2000)

S_F is the total flux contribution from the companions relative to the Cepheid in filter F;
f_i is the flux of an individual companion star located within the critical radius;
f_C is the flux of the Cepheid.

Calculated the values of S separately for V and I, using a critical radius of 0. 375'' which is the average value of the half-width at half-maximum (HWHM) of the WIYN PSF.

TABLE 2
CEPHEID PROPERTIES (ABRIDGED)

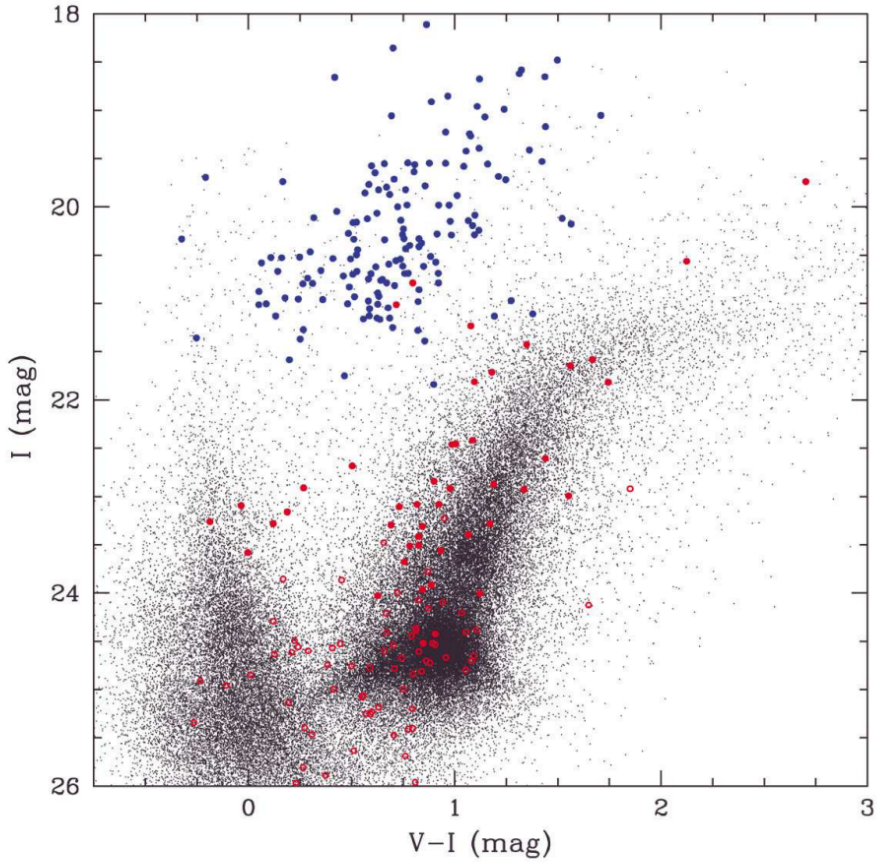
ID	P (d)	V (mag)	σ_V	S_V	σ_{S_V}	I (mag)	σ_I	S_I	σ_{S_I}	SB_V (mag/□'')	SB_I	Field HST	WIYN
J013332.36+302819.8	2.689	21.635	0.038	0.000	0.000	21.008	0.032	0.000	0.000	21.92	21.26	m5a	m0f
J013324.20+302248.9	2.695	21.620	0.038	0.073	0.005	21.369	0.029	0.155	0.008	21.51	20.96	q1a	m0m



BLENDING CALCULATION

They only include companions that contribute 4% or more of the flux of a Cepheid in order to provide a conservative estimate of the blending value.

Used the HST star lists to tabulate all companions within a 2″ radius of each Cepheid, presented in Table 3. Companions are labeled using the Cepheid ID from Table 2 and are numbered in increasing order of radial distance from the variable.



Color-magnitude diagram of M33 Cepheids (in blue) and companions within 0.″375 (in red), contributing more (filled) or less (open) than 4% of the Cepheid flux. Black dots are used to plot 3.5% of the stars detected in the ACS frames with I < 26 mag.

TABLE 3
STARS FOUND WITHIN 2″ OF CEPHEID VARIABLES (ABRIDGED)

ID	Δx	Δy (″)	Δr	V	σ_V	I (mag)	σ_I
J013302.03+302553.4-c001	-0.112	0.010	0.112	24.021	0.434	...	...
J013302.03+302553.4-c002	-0.109	0.221	0.247	25.333	0.134	25.139	0.115

RESULT

TABLE 4
BLENDING STATISTICS

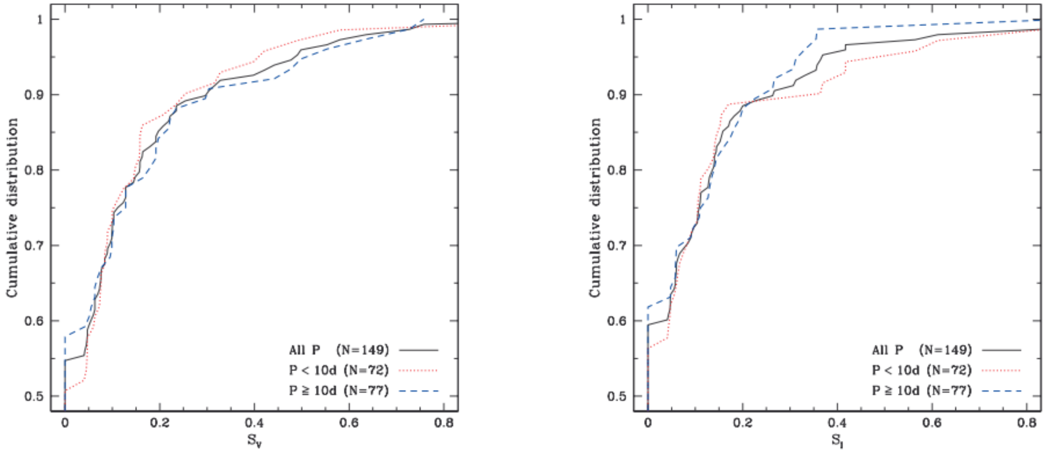
Blending level	Sub-sample	N	Blending criteria CMP12 %	M01 %
$S_V = 0$	all	149	55 ± 4	30 ± 4
$S_V = 0$	$P < 10$d	72	50 ± 6	22 ± 5
$S_V = 0$	$P > 10$d	77	57 ± 6	35 ± 5
$S_V = 0$	$\Sigma_V < 21.4$	71	61 ± 6	30 ± 5
$S_V = 0$	$\Sigma_V > 21.4$	78	47 ± 6	28 ± 5
$S_V < 0.1$	all	149	73 ± 4	45 ± 4
$S_V < 0.1$	$P < 10$d	72	74 ± 5	43 ± 6
$S_V < 0.1$	$P > 10$d	77	70 ± 5	46 ± 6
$S_V < 0.1$	$\Sigma_V < 21.4$	71	76 ± 5	44 ± 6
$S_V < 0.1$	$\Sigma_V > 21.4$	78	68 ± 5	45 ± 6
$S_I = 0$	all	149	60 ± 4	30 ± 4
$S_I = 0$	$P < 10$d	72	56 ± 6	19 ± 4
$S_I = 0$	$P > 10$d	77	61 ± 6	38 ± 6
$S_I = 0$	$\Sigma_I < 20.7$	74	60 ± 6	24 ± 5
$S_I = 0$	$\Sigma_I > 20.7$	75	57 ± 6	33 ± 5
$S_I < 0.1$	all	149	72 ± 4	41 ± 4
$S_I < 0.1$	$P < 10$d	72	71 ± 5	33 ± 5
$S_I < 0.1$	$P > 10$d	77	71 ± 5	47 ± 5
$S_I < 0.1$	$\Sigma_I < 20.7$	74	66 ± 5	32 ± 5
$S_I < 0.1$	$\Sigma_I > 20.7$	75	76 ± 5	48 ± 5

NOTE. — CMP12: this work; M01: Mochejska et al. (2001)

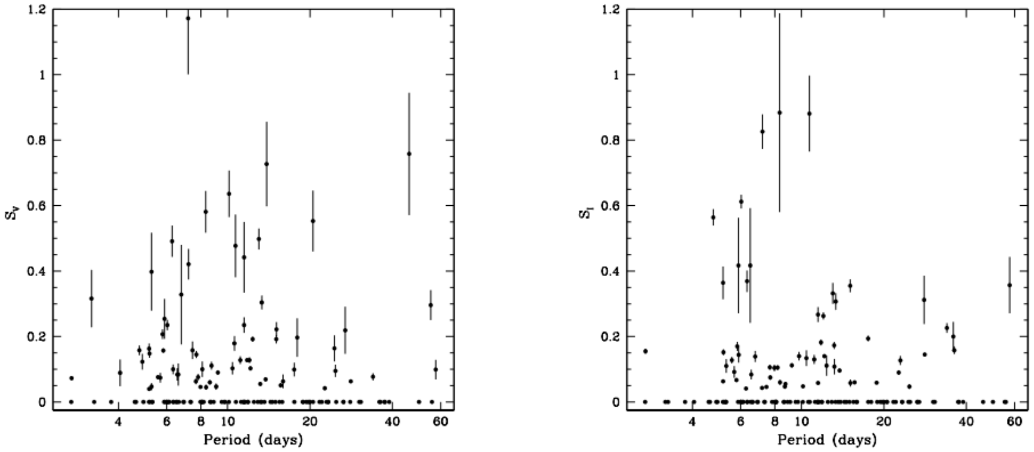
$$\sigma(f) = \sqrt{f(1-f)/N}$$

where f is the fraction value and N is the number of Cepheids meeting a particular set of criteria.

The fraction of Cepheids with no blending is marginally lower for Cepheids with P < 10 d than for ones with P > 10 d. However, the difference vanishes when comparing the statistics of Cepheids affected at the 10% level.



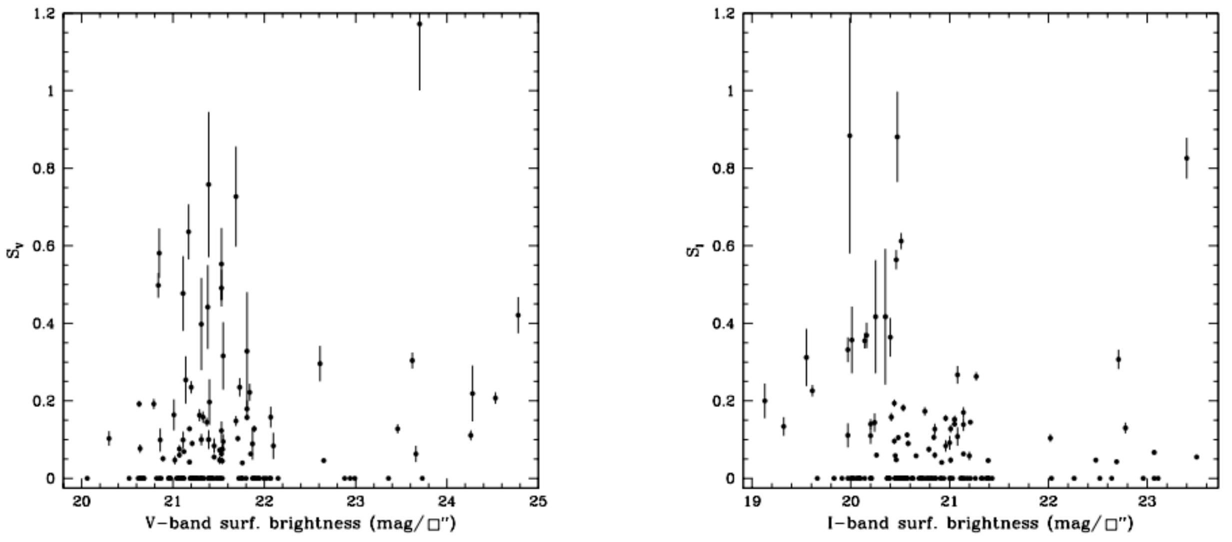
Shows cumulative distributions of blending values.



Blending values as a function of the period of the Cepheid.

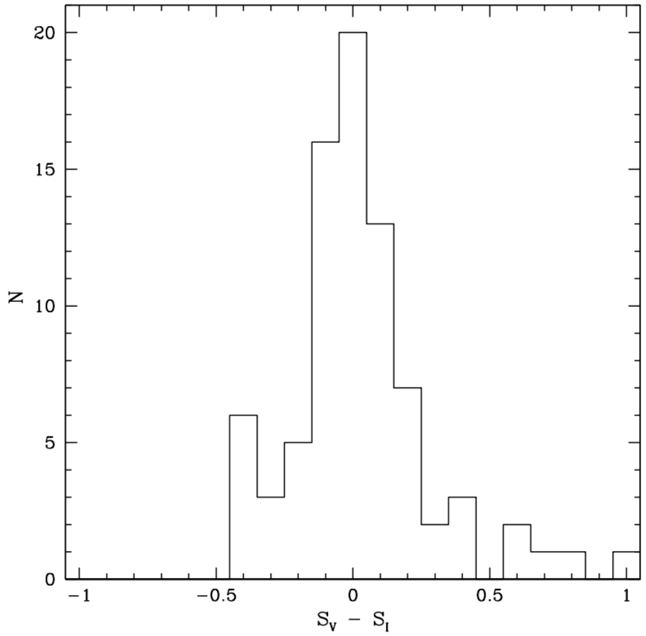
RESULT

There is no significant difference in the statistics of Cepheids located in areas with “high” or “low” surface brightness.

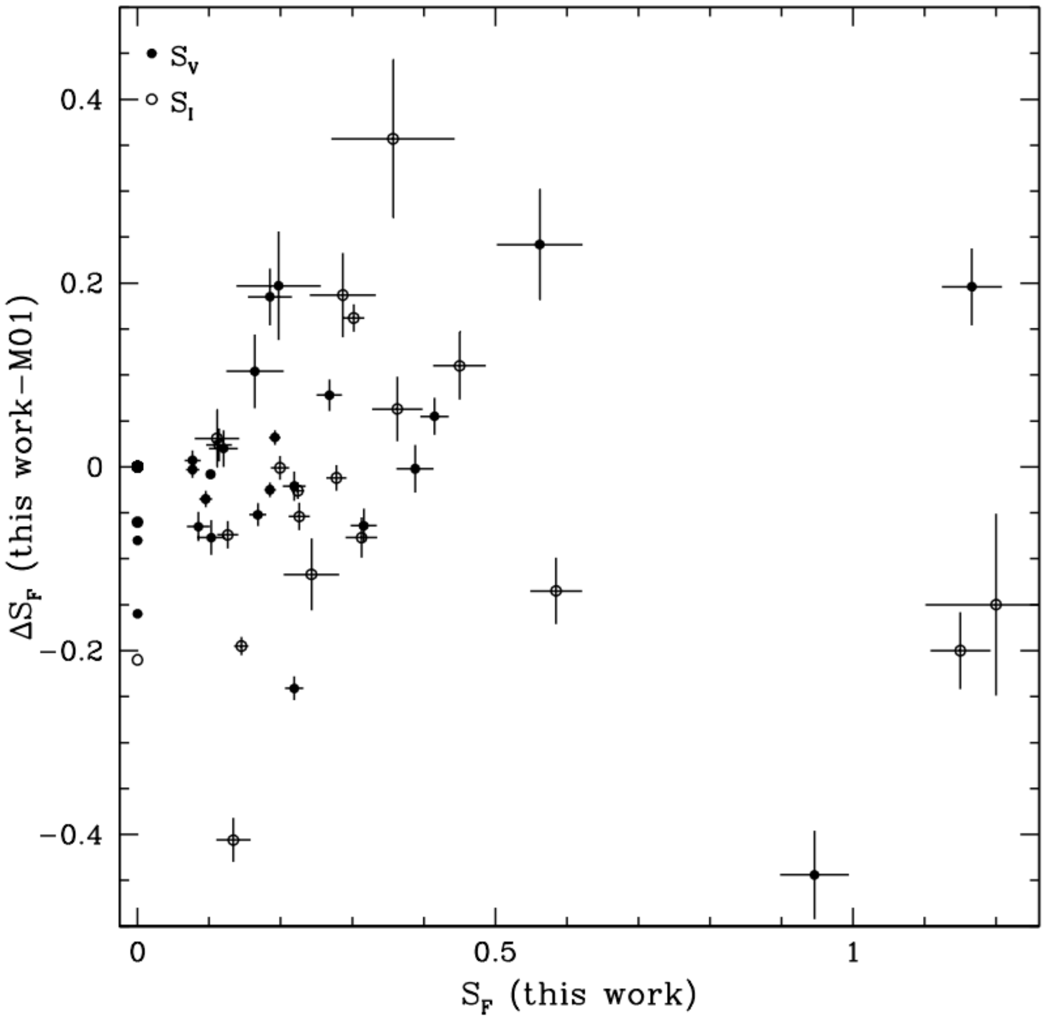


Blending values as a function of the sky background.

Distribution of the “color” of the companions relative to their Cepheid, shows that most blends do not appreciably change the color of the Cepheids: $\langle S_V - S_I \rangle = 0.03 \pm 0.27$.



COMPARISON WITH PREVIOUS WORK



Comparison of blending values for Cepheids in common (found in WFPC2 images) with Mochejska et al. (2001); Filled (open) circles are used to plot the blending values in the V (I) filter.

33 common stars in V snd 28 in I band.
There is good agreement with $\langle \Delta S_F \rangle = -0.02 \pm 0.13$.

CONCLUSION

They have presented a survey of Cepheids in M33 and their companions within 2″, as resolved by HST with the ACS and WFPC2 cameras.

They calculated the flux contribution of the companions when they are blended (unresolved) in ground-based images with a seeing of 0. ″75. We find that more than half of the Cepheids in our sample exhibit no blending at V and I, regardless of period or surface brightness. The majority of companion stars are located in the red giant branch and do not significantly alter the derived color of the Cepheids.

They plan to combine the ground-based photometry of Pellerin & Macri (2011) with the blending values derived in this paper to investigate possible biases in the determination of distance moduli and "metallicity corrections" when using samples that lack such higher-resolution imaging. Additionally, our compilation of companions may be useful to derive empirical photometric bias corrections for Cepheids in more distant galaxies studied with the Hubble Space Telescope, provided the variables are located in similar environments to the M33 sample.

THANK YOU!