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Multi-Epoch BVRI Photometry of Luminous Stars in M31 and M33

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Summary

This catalog covers the first four years of BVRI photometry from an on-going survey to annually monitor the photometric behavior of evolved luminous stars in M31 and M33. Photometry is measured for 199 stars at multiple epochs, including 9 classic Luminous Blue Variables (LBVs), 22 LBV candidates, 10 post-RGB yellow supergiants, and 18 B[e] supergiants. The spectroscopic component of this survey is outlined in Humphreys et al. (2016)[1]. At all epochs the brightness is measured in V and at least one other band to a precision of 0.04 - 0.10 magnitudes down to a limiting magnitude of 19.0 - 19.5. Thirty three (33) stars in our survey exhibit significant variability, including at least two classic LBVs caught in S Doradus type outbursts. An online hyper-linked version of the photometry catalog is at:

http://go.uis.edu/m31m33photcat.

Images and Photometry

Beginning in 2012, images were obtained annually between August and February using an Apogee U42 CCD Camera with a back-illuminated E2v CCD42-40 chip through Astrodon BVRI filters on the F/13 20-inch telescope (FOV 19.4'x19.4', 0.57 "/pix) at the Univ. of IL Springfield Barber Observatory near Pleasant Plaines, IL. Imaging was mostly done under dark, transparent conditions with no Moon. Typical seeing ranged from 3-5 arcseconds.

At each epoch, fields are imaged in V and at least one additional filter. B images began in 2014 and I images began in 2015.

Photometry was measured using DAOPHOT PSF fitting (to distinguish overlapping stars) using the LGGS[2] catalog to identify the stars to be fit.

Photometric zero points for each image are determined from an ensemble of 5-30 comparison stars (ranging from 12-16 mag) from APASS[3] catalog. Colors transforms were applied using coefficients derived from separate images of M67.

Most errors fell between 0.04-0.10 mag (Fig.1). The measurement error (Fig.2) is dominated by the error in the photometric zero point. Lower precision of the comparison stars causes greater zero point errors in R and I. Check stars (brightness comparable to the targets) confirm typical photometric errors < 0.07 mag (Fig.3).

Unresolved blends and poor PSF fits are noted in the catalog and using LGGS[2] are classified as contributing more or less than the measurement error.

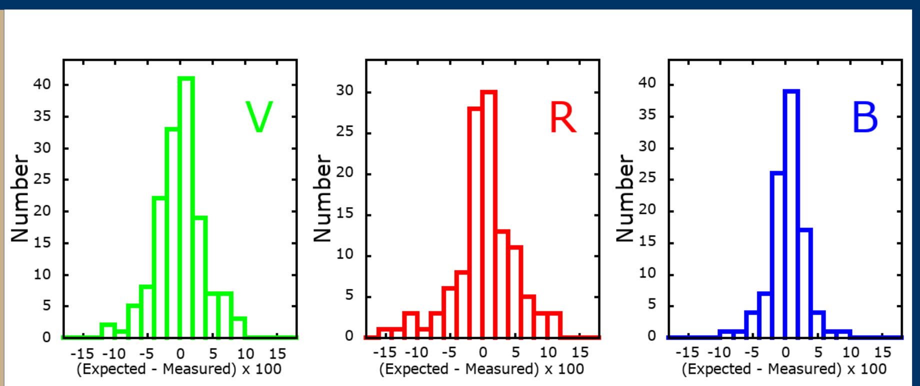
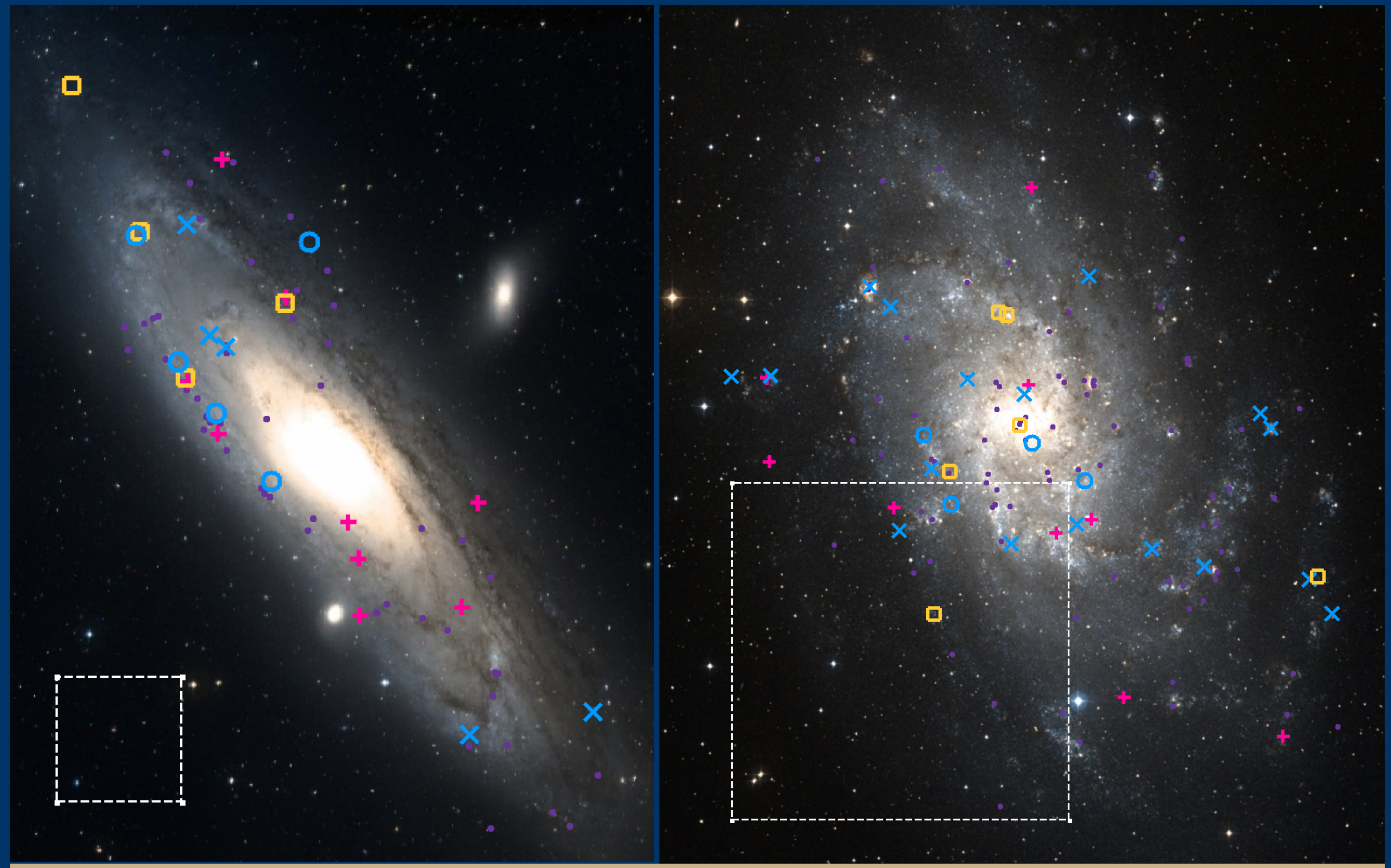


Figure 3 Histograms of difference between check stars' expected and measured brightness in each filter.



M31 (left) and M33 (right) with locations of luminous star targets. The white dashed square in each shows size of 19.4'x19.4' image field. Blue Circles: LBVs; Blue Xs: Candidate LBVs; Yellow Squares: warm hypergiants; Magenta +: B[e] Supergiants; purple dots: other targets.

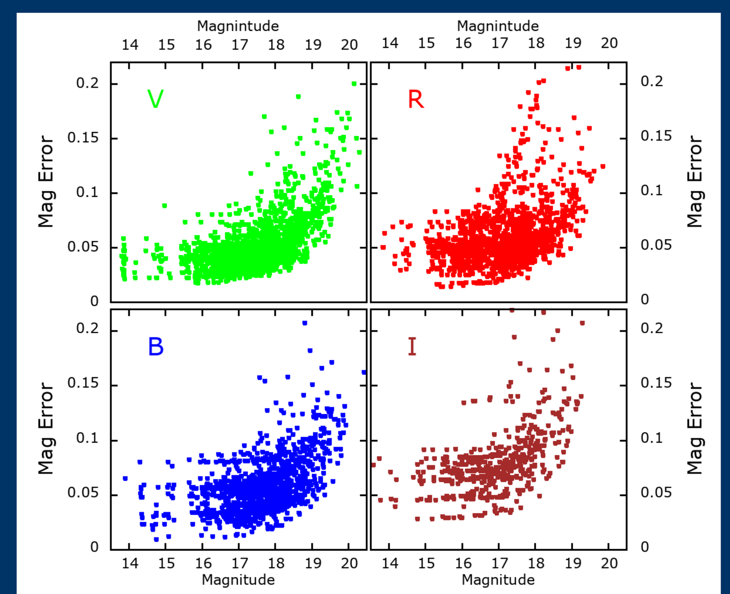


Figure 1 Error as a function of brightness in each filter for targets and check stars.

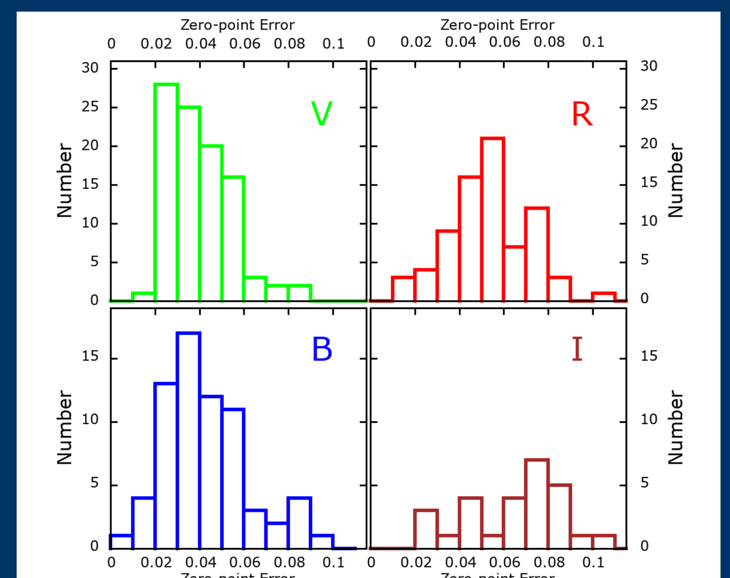


Figure 2 Histograms of the error in the magnitude zero point for images in each filter.

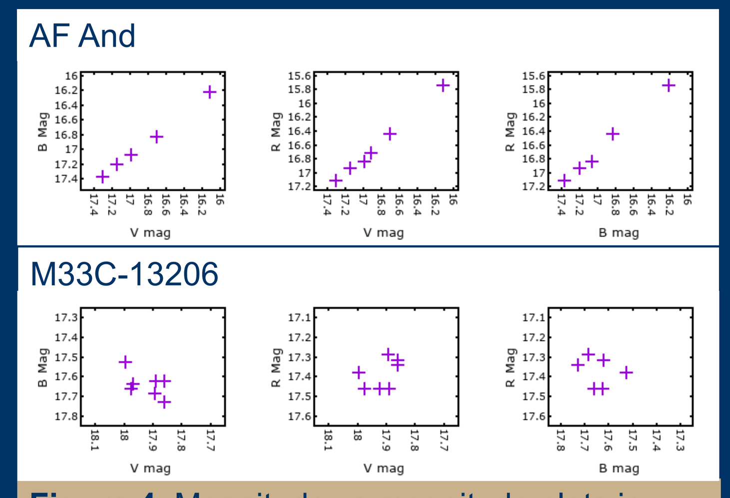


Figure 4 Magnitude vs magnitude plots in different bands for AF And and M33C-13206. The high degree of correlation between bands for AF And indicates it is likely to be a variable.

Table A

Class	N	N (V>19.)	Median V mag	Percent Variable	Detection Bin Very Likely	Detection Bin Likely
Of/late-WN	15	0	17.95	0.0%	0	0
OB Supergiants	47	1	17.67	10.6%	2	3
Yellow Supergiants	35	2	17.36	22.9%	3	5
Warm Hypergiants	10	1	18.12	20.0%	0	2
Classical LBVs	9	0	16.99	77.8%	4	3
B[e]sg (all)	18	8	18.85	11.1%	1	1
B[e]sg (V < 19.0)	10	0	18.17	20.0%	1	1
Candidate LBVs	10	1	17.86	20.0%	1	1
Unknown	19	3	17.75	26.3%	3	2
Peculiar	3	0	17.11	0.0%	0	0

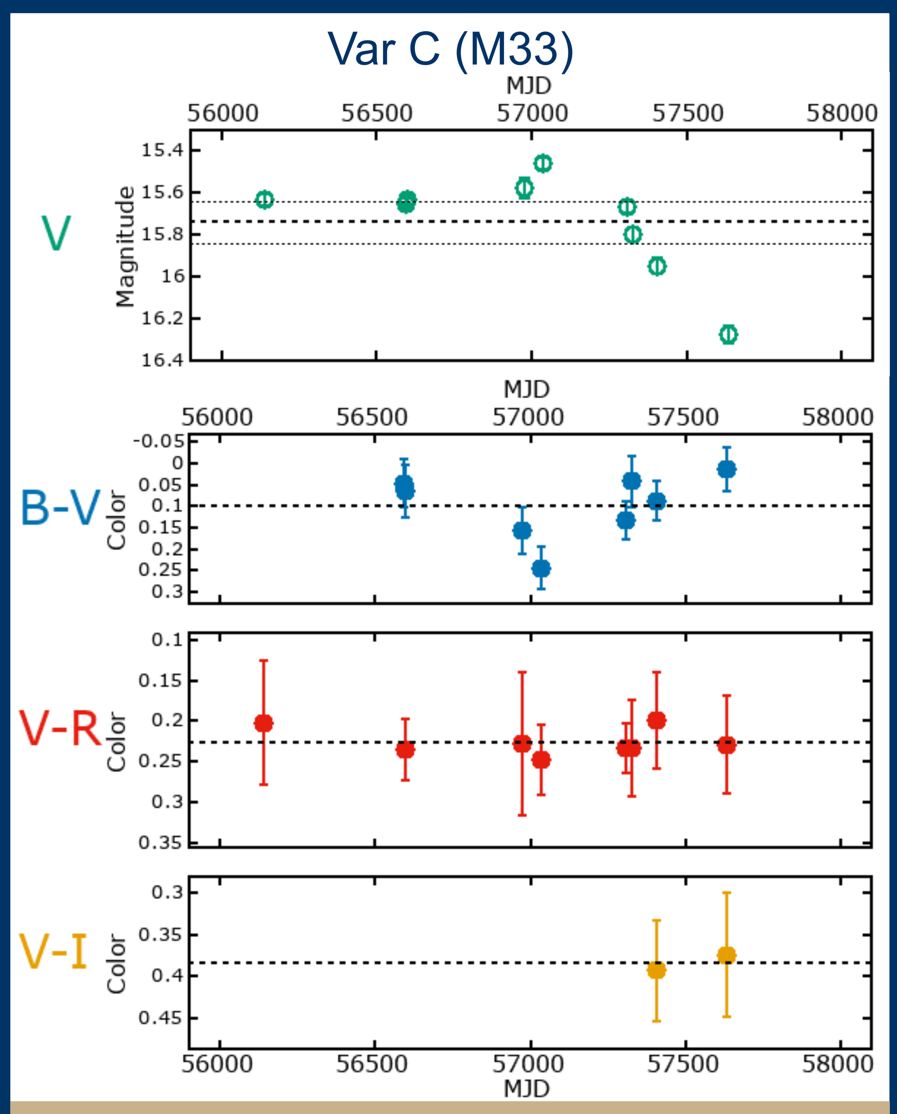


Figure 5 The latest S Dor outburst of Var C (M33) began in 2010[4] prior to the start of this survey. Photometry indicates that it may have begun to return to quiescence in 2016.

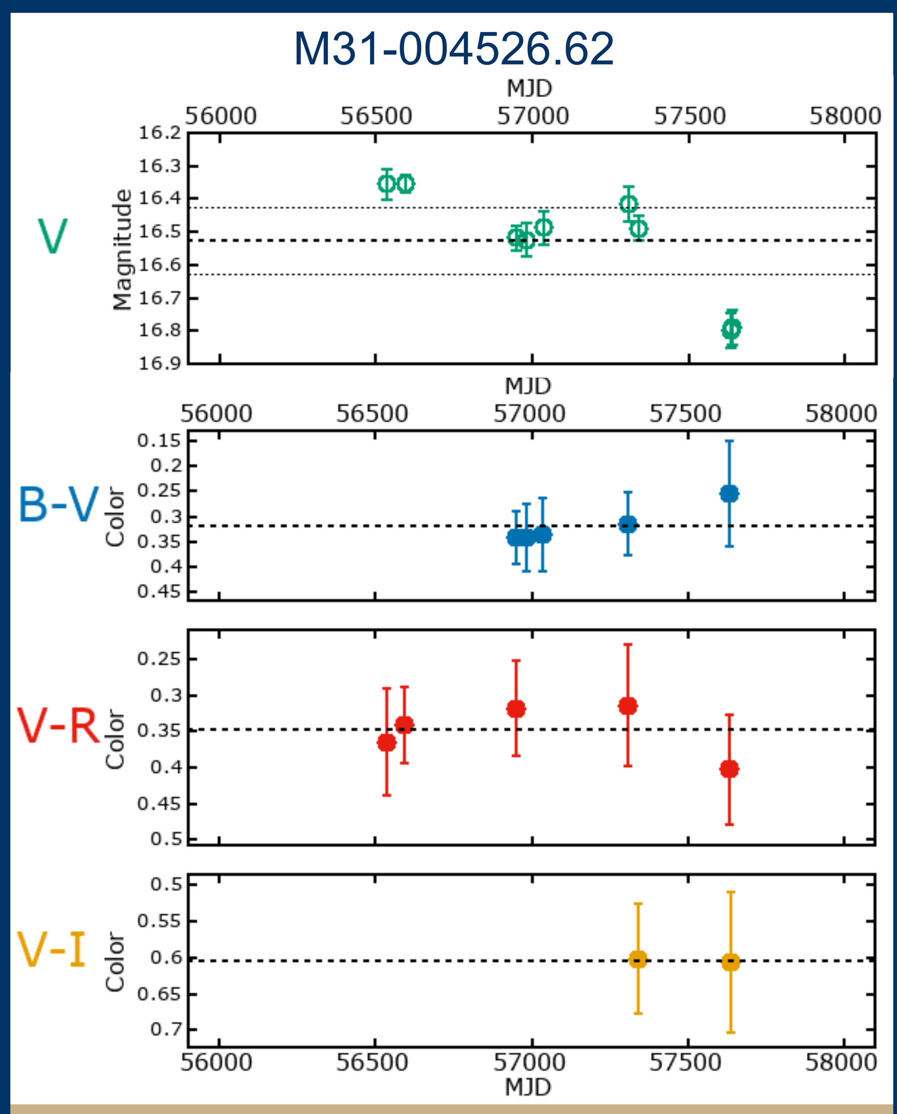


Figure 6 Between 2006 and 2013 (prior to the first epoch observed by this survey) the spectrum of M31-004526.3 transitioned from an Fe-emission star to a A-type supergiant. It is the 5th classical LBV discovered in M31[5].

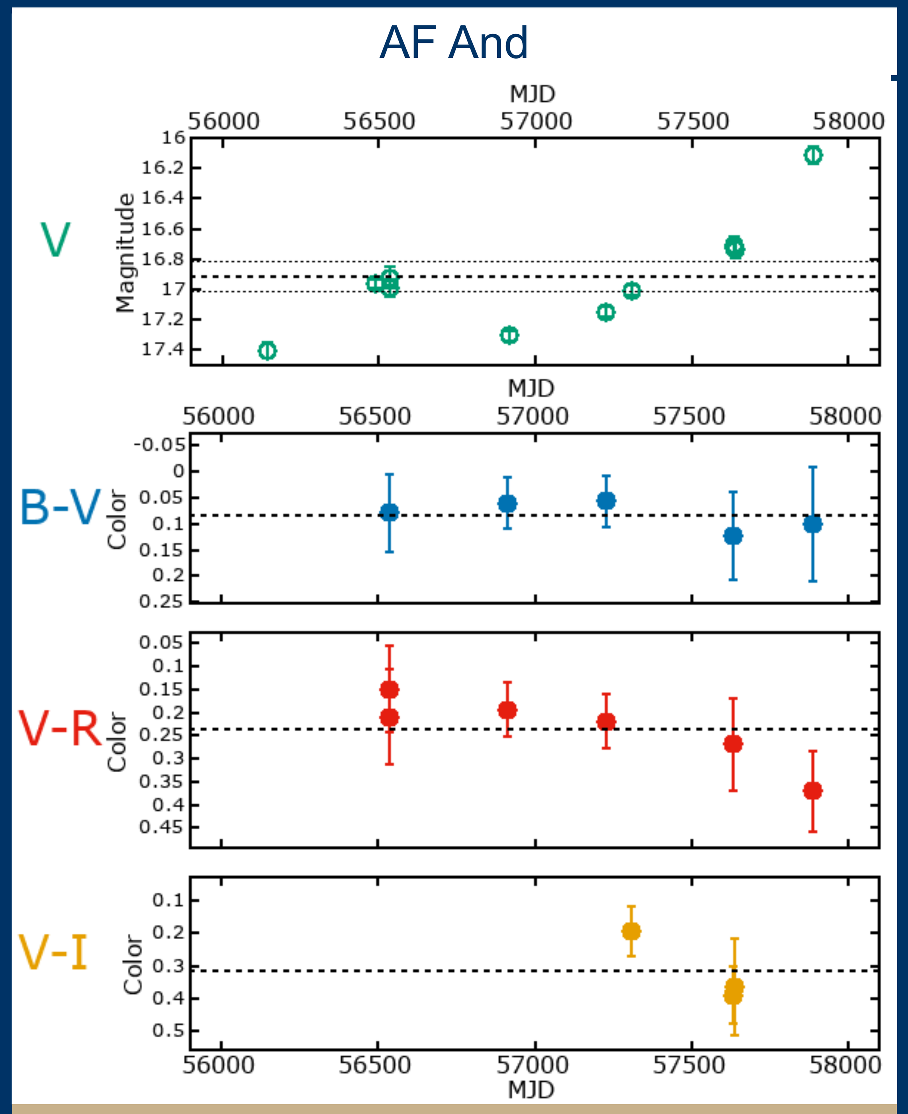


Figure 7 Recent observations show that AF And may be beginning an S Dor outburst[6] hinted at by measurements in 2016 and our recent follow-up in May 2017.

Stellar Classifications

Targets were classified using LBT spectra (Humphreys et al.)[1]

Luminous Blue Variable (LBV)

An evolved post-MS supergiant that *has undergone at least one S Doradus outburst*. In quiescence an LBV may resemble a B-type supergiant or an Of/late-WN type star with H emission. Some have He I emission, and most show Fe II and some times [Fe II] emission.

Candidate LBV

A star with the spectroscopic qualities of a classic LBV in quiescence which *has **NOT** been observed undergoing an S Doradus outburst*.

Warm Hypergiant

An evolved supergiant (likely post-RSG) with spectral type A to G (a YSG) and evidence for high mass loss (H P Cygni profiles) and/or dusty SED. Most have large IR excess.

B[e]sg

A B-type supergiant with hydrogen, [O I], and [Fe II] emission lines. Some also exhibit [Ca II] emission. Most also have confirmed warm circumstellar dust in their SED.

Variability

This survey is sensitive to variations in brightness on the order of 0.1 magnitude. Most hot supergiants exhibit Alpha Cygni type variability on the order of 0.1-0.2 mag. Others exhibit variability associated with high mass loss. An S Doradus outburst (characteristic of LBVs) is an increase in visual brightness >1 mag accompanied by a change in spectrum to an A or F type supergiant.

Brightness changes due to true variability (not error) will correlate in separate photometric bands (example in Fig.4). In the first four years of data we found 13 "very likely" variables (correlation >70% in three band pairs) and 20 "likely" variables (correlation >70% in two band pairs) (Tab.A).

This method is biased against detecting fainter variables because brightness errors are larger for fainter targets (Fig.2) and the number of epochs are small. B[e]sg tend to be less luminous so bright B[e]sg are given in Table.A to allow a fair comparison with the other classes.

During the inaugural four years of the survey we detected at least two S Dor outbursts: Var C[4] (M33, Fig.5), M31-004526.62[5] (Fig.6) and the beginning of what is yet to be confirmed as a slow outburst in AF And[6] (Fig.7).

References & Acknowledgements

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[2] Massey, P., et al. 2016, AJ, 152, 62
[3] Henden, A.A., et al. 2016, VizieR Online Data Catalog, 2336.
[4] Humphreys, R.M., et al. 2014, ApJL, 782, L21
[5] Humphreys, R.M., et al. 2015, PASP, 127, 347
[6] Martin, J.C., et al. 2017, The Astronomer's Telegram, 10383.

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