AAS 234 June 2019
POSTER 303.02

# Update on a Survey of the Most Luminous Stars in M31 and M33

J.C. Martin (University of Illinois Springfield)

## Summary

At 6+ years and counting, this is the longest running contiguous photometric survey of M31 and M33. The survey's goal is to to monitor the color and brightness evolved luminous stars in M31 and M33. On at least an annual basis, BVRI photometry is measured for 189 stars. Targets include: 9 classic Luminous Blue Variables (LBVs), 24 LBV candidates, 10 post-RGB yellow supergiants, and 19 B[e] supergiants. The spectroscopic classification of the targets is outlined in Humphreys et al. (2017, , ApJ, 836, 64). At all epochs brightness is measured in V and at least one other band to a precision of 0.04 - 0.10 magnitudes and a limiting magnitude of 19.0 - 19.5. To date, fifty three (53) stars in the survey exhibit signs of significant variability, which is a 50% increase over what was detected after just four years.

## Images and Photometry

Since 2012, images have been 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 is mostly done under dark, transparent conditions with no Moon. Typical seeing ranges from 3-4 arcseconds.

Photometry is measured on the system of the APASS catalog (Henden, A.A., et al. 2016, VizieR Online Data Catalog, 2336) and color transformed using images of M67. To avoid confusion in crowded fields, DAOPHOT PSF fitting is employed using the LGGS (Massey, P., et al. 2016, AJ, 152, 62) catalog to identify stars and deblend them. See Martin & Humphreys (2017, AJ, 154, 81)

The photometry and variability information for each target in the survey are available online at http://go.uis.edu/m31m33photcat.

We welcome collaboration, Photometry can be extracted for other targets serendipitously captured in the survey.

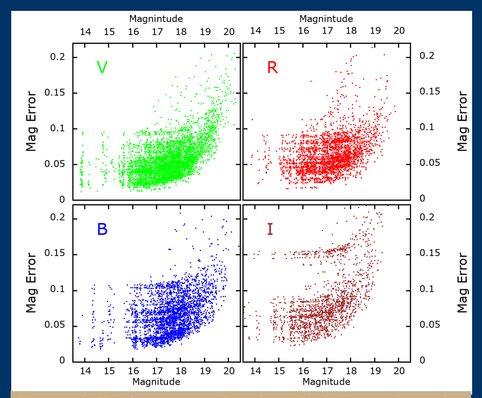



**Figure 1** Total error as a function of brightness in each filter for targets and check stars. Note fainter targets have larger errors.

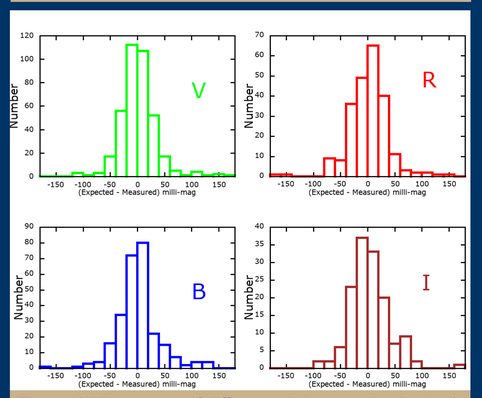
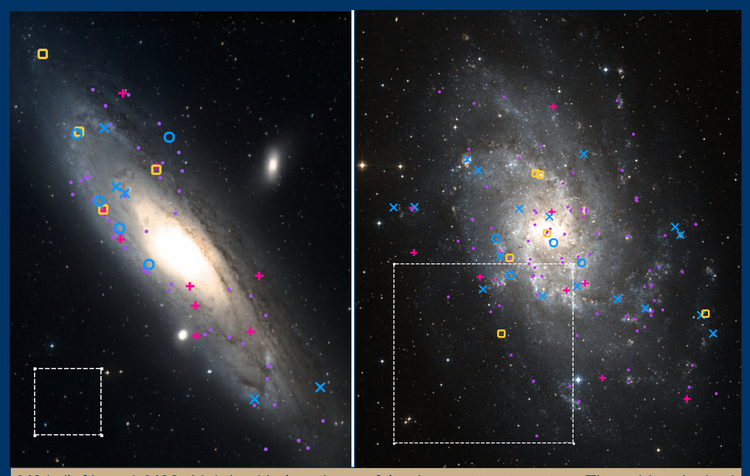
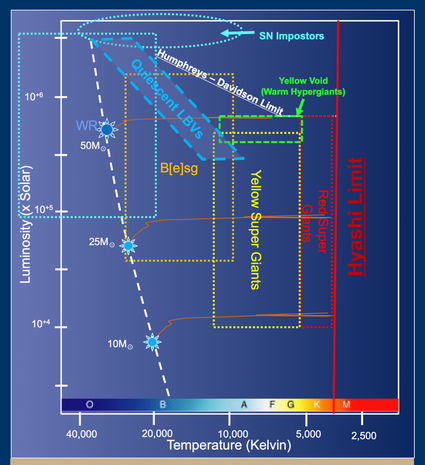



**Figure 2** Histograms of difference between check stars' expected and measured brightness in each filter. All check starts are brighter than 18.



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.




The high luminosity part of the HR Diagram with the approximate locations of the classes of luminous stars in this survey. Overlapping classifications and evolutionary paths complicate efforts to observe the order of post-MS evolution for massive stars.

## Variability

The survey is sensitive to brightness variations 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. Classical LBVs are characterized by S Doradus outbursts; an increase in visual brightness >1 mag accompanied by a change in spectrum to an A or F type supergiant. Many targets in our survey also lay near or in the Instability Strip.

Brightness changes due to true variability (not error) will correlate in separate photometric bands (example in Fig.3 and 4). Correlation is checked in up to six different band pairs. Only the band pairs where there are at least five epochs observed are included in the analysis. In six years of survey data there are 34 "very likely" variables (correlation >60% in three or more band pairs) and 17 "likely" variables (correlation >60% in two band pairs) (Tab.A). A higher incidence of variability is detected in later spectral types and more evolved stars.

Field crowding and a limited number of epochs biases the detection of variability against fainter targets. In this survey so far, that bias is roughly equal for all stars brighter than V~18.5 (only two fainter variables are detected). Therefore, Table A is limited to V < 18.5.

A plot of the "I" variability index (Welch & Stetson, 1993) in Fig 5 demonstrates that the method employed to detect variables is conservative. More variables should be detected as the number of epochs accumulate. Over the last two years of data the number of "very likely" variables doubled and the total detected increased by 50%.

The data so far also demonstrate that the survey is sensitive to detecting S Doradus eruptions and other significant evolutionary events in the targets as they occur (see Fig 6 and 7)

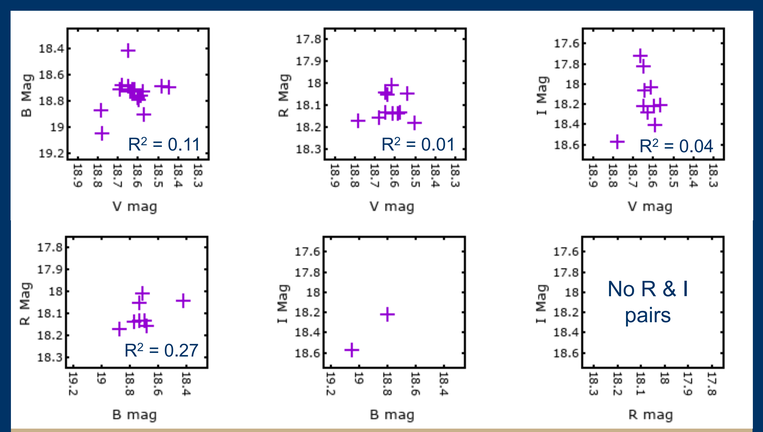
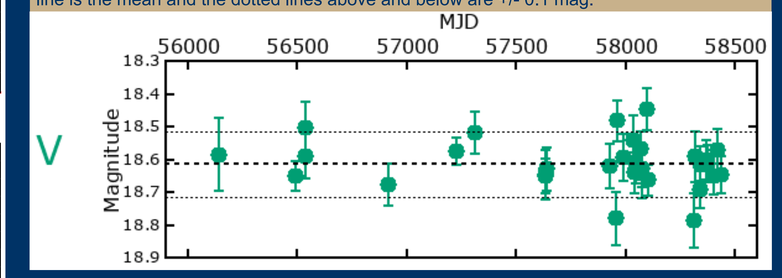



**Figure 3** M31-004339.28, an OB-supergiant, does not show enough correlation between band pairs to be considered variable. In Fig 5 it is plotted at $I_{BV}$ = 0.28 and $I_{VR}$ = 0.14. Below is a plot of the V-band brightness of the star with respect to time. The heavy dashed line is the mean and the dotted lines above and below are +/- 0.1 mag.



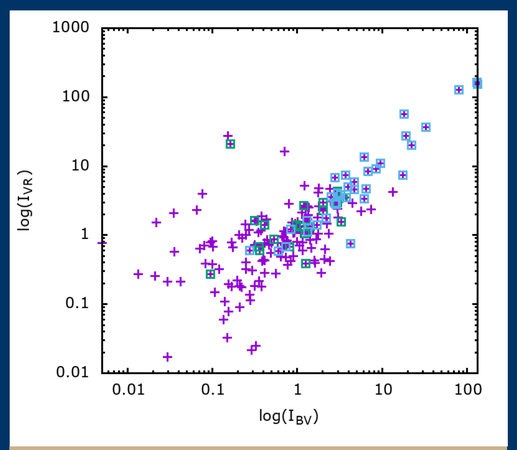




**Figure 5** The Welch & Stetson (1993) "I" variability indices for BV (x-axis) and VR (y-axis) band pairs. The expectation value of I is zero for stars that are not variable. Likely (green) and very likely (blue) variables are highlighted with boxes.

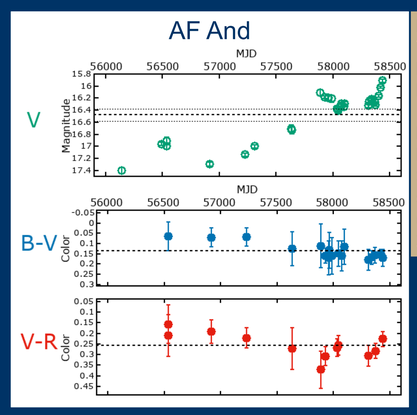



**Figure 6** The S Doradus eruption by AF And continues. Note the characteristic 1-2 mag rise in brightness accompanied by reddening of colors. Spectra confirm a change F-type. (Humphreys, et al. 2017, ATEL, 10752).

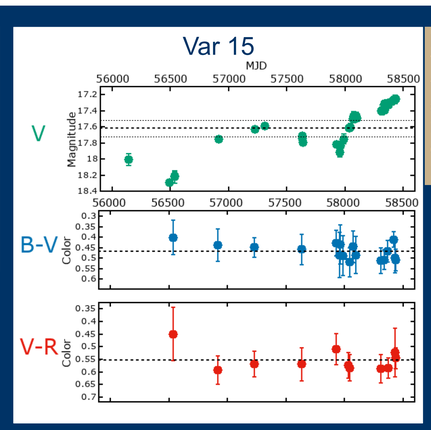



**Figure 7** The latest photometry from LBV Var 15 (M31) shows some signs of an impending S Doradus eruption (brightening and reddening).

## Acknowledgements

This work was initiated under NSF grant AST- 1108890 with ongoing support from the Univ. of IL Springfield Henry R. Barber Astronomy Endowment. The AAVSO Photometric All-Sky Survey (APASS), is funded by the Robert Martin Ayers Sciences Fund.

## Stellar Classifications

Targets were classified using LBT spectra (Humphreys et al. 2017, , ApJ, 836, 64)

**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. (Gordon, M. et al. 2016, ApJ, 825, 50).

**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.

### Table A: Variability by Stellar Class

| Class | N | N (V>18.5) | Percent Variable | Detection Bin Very Likely | Likely |
|---|---|---|---|---|---|
| Of/late-WN | 15 | 12 | 8% | 1 | 0 |
| OB Supergiants | 47 | 44 | 16% | 5 | 2 |
| Yellow Supergiants | 35 | 33 | 46% | 6 | 9 |
| Warm Hypergiants | 10 | 8 | 38% | 2 | 1 |
| B[e]sg | 18 | 8 | 38% | 2 | 1 |
| Classical LBVs | 9 | 9 | 89% | 8 | 0 |
| Candidate LBVs | 23 | 19 | 26% | 4 | 1 |
| Unknown | 20 | 9 | 78% | 5 | 2 |
| Peculiar | 3 | 2 | 50% | 0 | 1 |

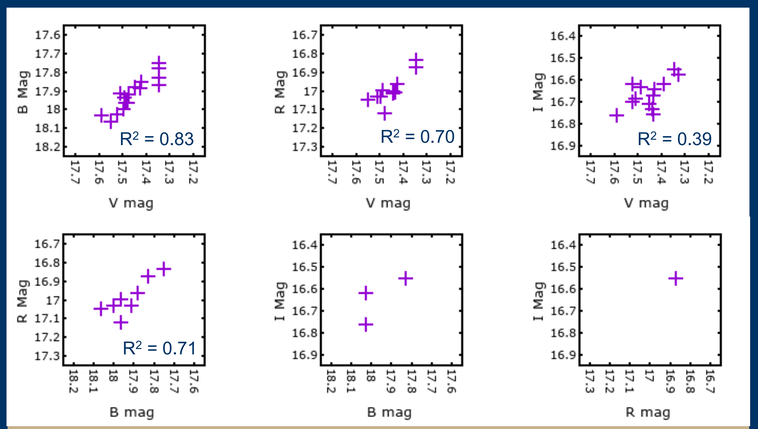
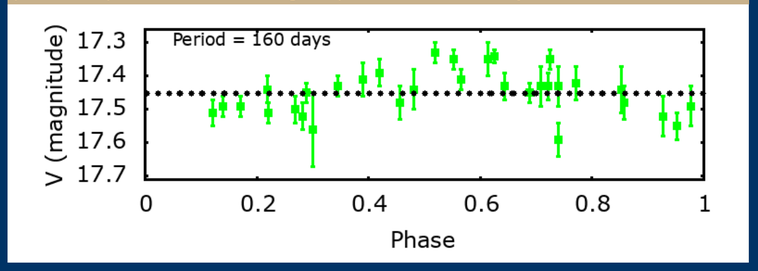



**Figure 4** M31-004341.84, an Of/late-WN, is considered very likely variable because it has an $R^2$ correlation factor > 0.60 in three band pairs. In Fig 5 it is plotted at $I_{BV}$ = 3.75 and $I_{VR}$ = 3.59. Below is a phased plot of the V-band photometry showing that this star has a periodic amplitude of about 0.1 mag and period of about 160 days.




http://go.uis.edu/m31m33photcat