Multi-Epoch Photometry of Luminous Blue Variables (LBVs) in M31 and M33

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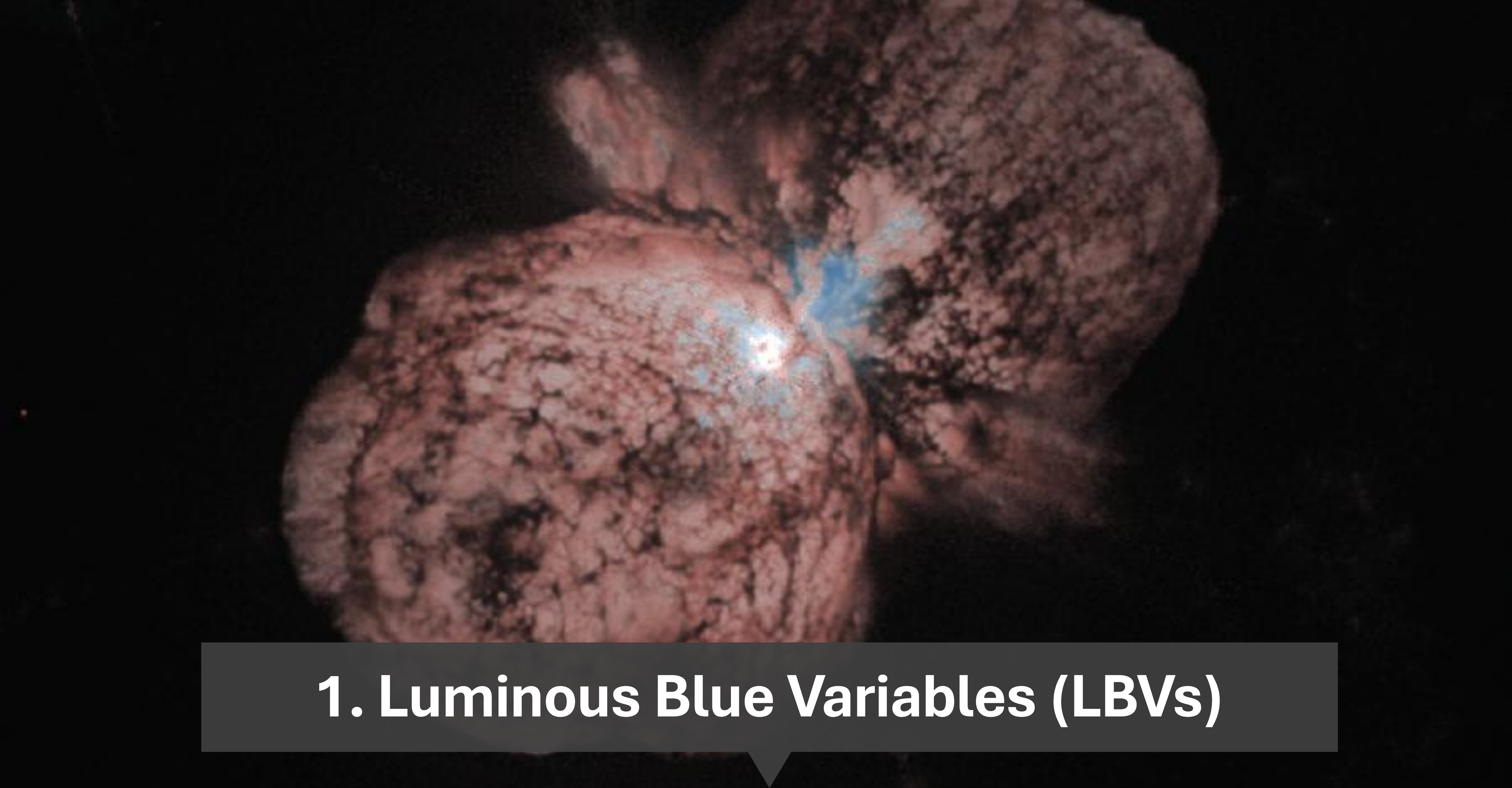
Agenda

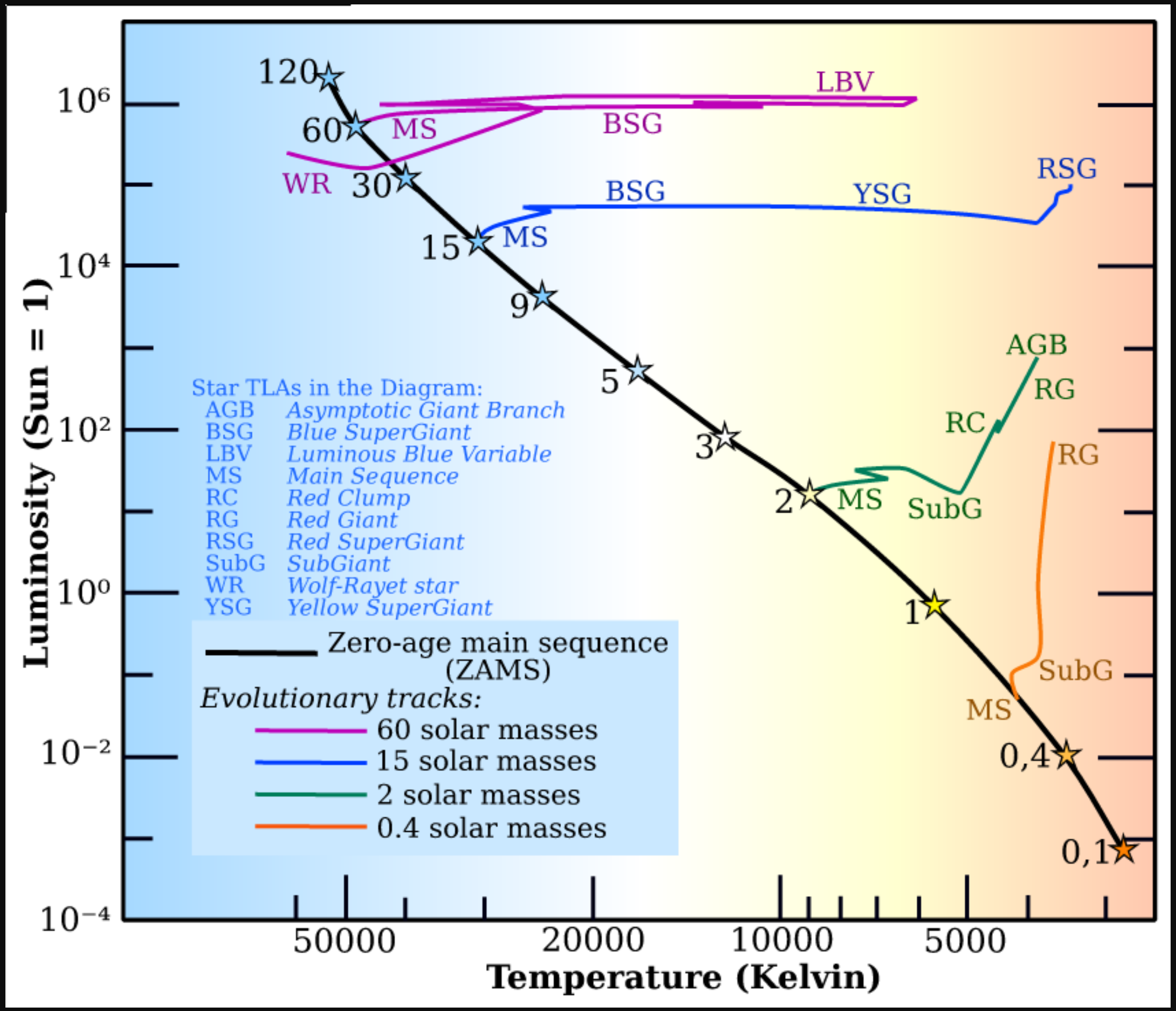
01	Luminous Blue Variables
02	Methodology
03	Preliminary Results
04	Future Implications



1. Luminous Blue Variables (LBVs)

Post-MS Evolution of Massive Stars

- Post-MS evolution for stars with $M_{ZAMS} \geq 30\ M_{\odot}$ is different from those with lower mass
  - Evolve with constant bolometric luminosity
  - Vary depending on luminosity
    E.g., stars with $\log\left(\frac{L}{L_{\odot}}\right) > 5.8$ may not become RSGs (Humphreys & Davidson 1994)
  - Mass loss also plays a *deterministic* role (Smith & Tombleson 2015)
- One of the typical evolutionary scheme is: (Sholukhova et. al. 2018, see also Smith & Tombleson 2015)
  $\mathrm{O} \rightarrow \mathrm{Of/\ WNH} \rightarrow \underline{\mathbf{LBV}} \rightarrow \mathrm{WN} \rightarrow \mathrm{WC} \rightarrow \mathrm{SN}$

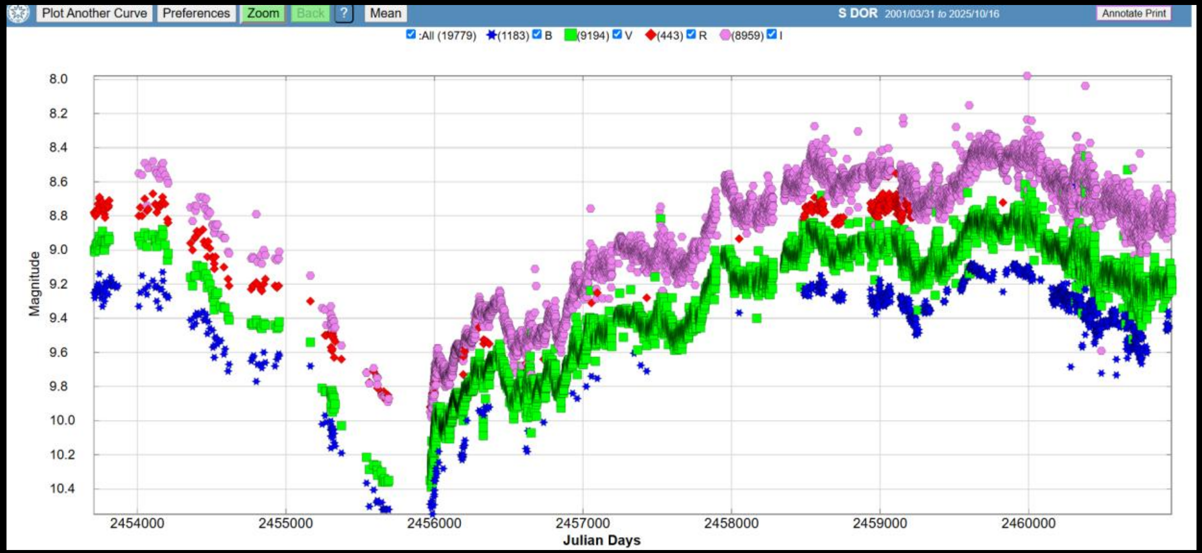


LBVs

- Also classified as Hubble-Sandage variables (Hubble & Sandage 1953) or S Dor variables (Wolf 1989)

- Have the **highest** mass loss rates of any stars (Smith et. al. 2020)

- Unstable, massive, evolved stars with irregular outbursts, leading to the formation of a "pseudo-photosphere" (Szeifert et. al. 1996)

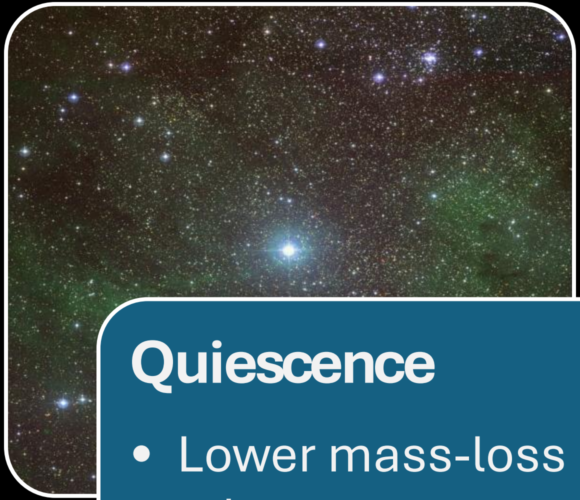


(Credit: AAVSO enhanced LCG)

Pseudo-photosphere?

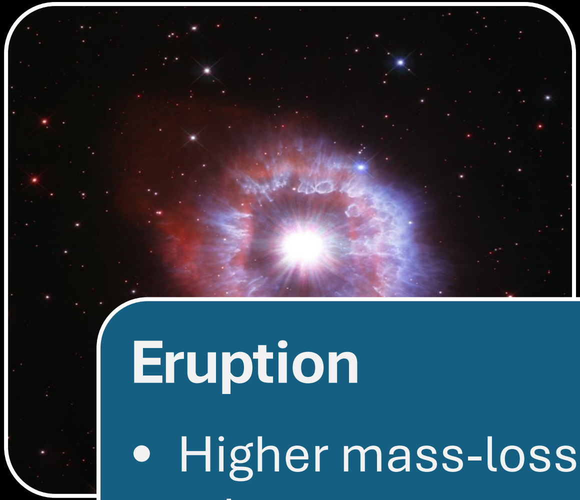
(Credit: NASA, ESA, STScI)

Pseudo-photosphere?



Quiescence

- Lower mass-loss rate
- “Normal” high temperature (> 15,000 K)



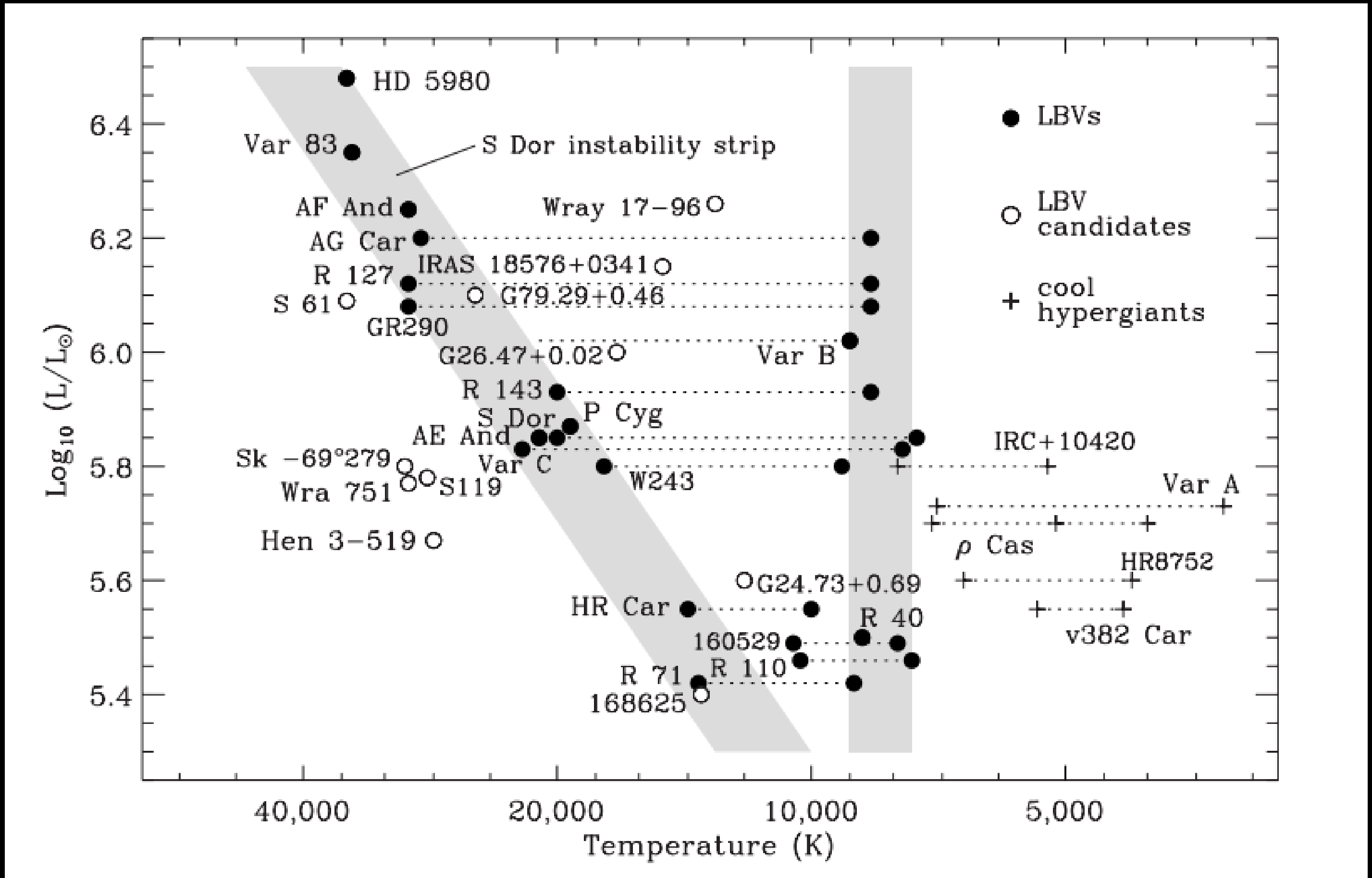
Eruption

- Higher mass-loss rate
- Cool (7000-9000 K) and dense ($N \sim 10^{11}$ cm^{-3}) expanding envelope

⟶ Brightening in visible wavelengths at **constant bolometric luminosity**

(Szeifert et. al. 1996, see also Humphreys & Davidson 1994)

S Dor instability & constant-temperature strips



(Smith, Vink, & de Koter 2004)

2. Methodology

Methodology

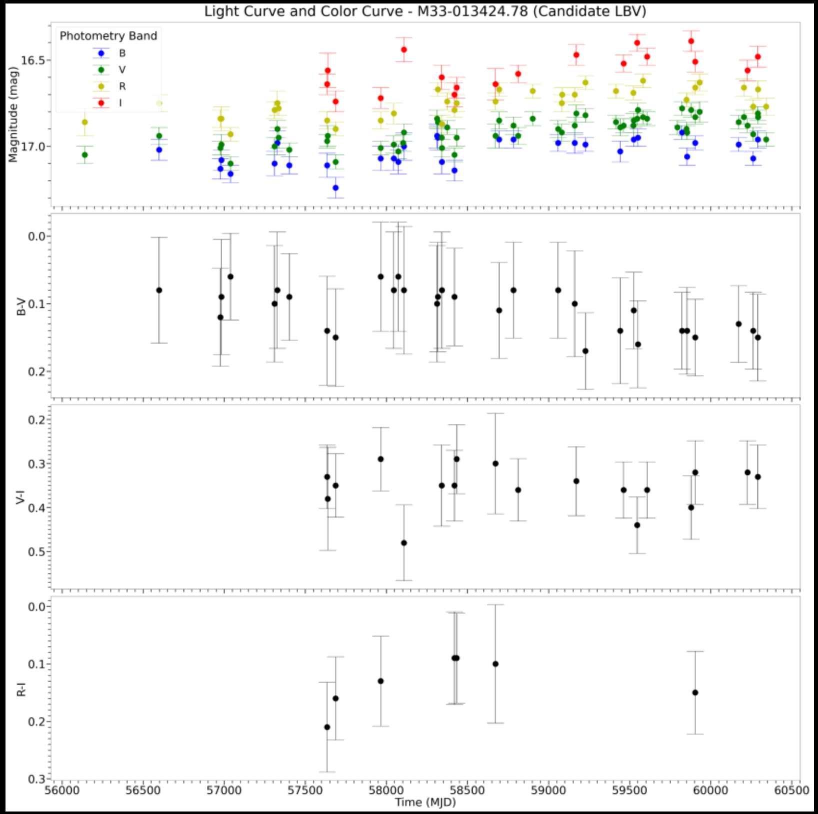
- Data Analysis:
  - All LBV and LBV candidates: John Martin at the University of Illinois Springfield Henry R. Barber Research Observatory
  - For M31 AE And & AF And and M33 Var 2 and Var C: American Association for Variable Star Observers

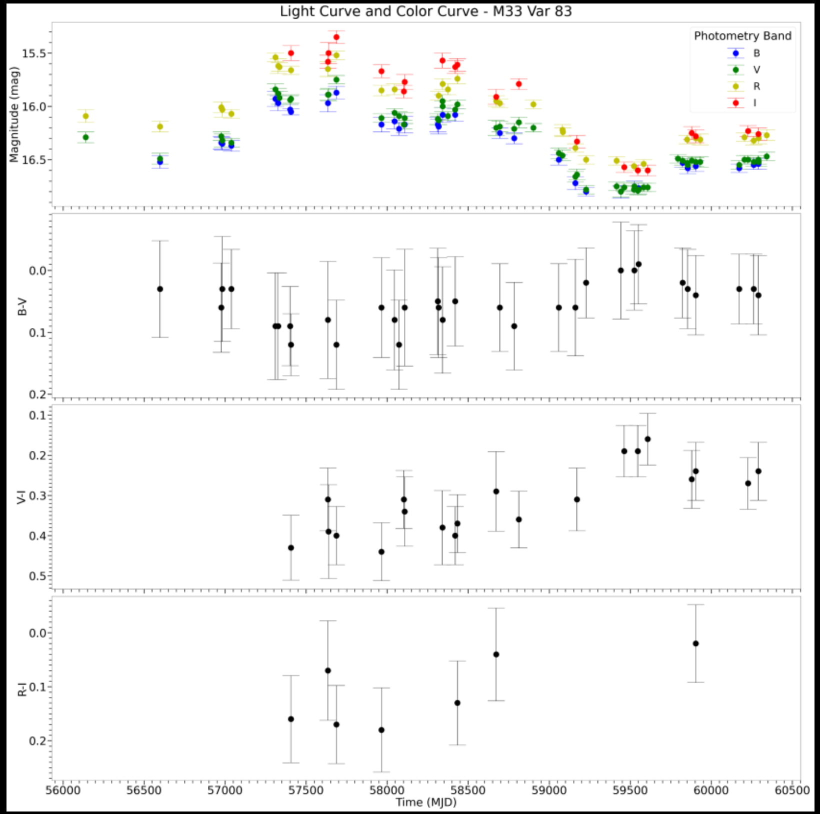
Methodology

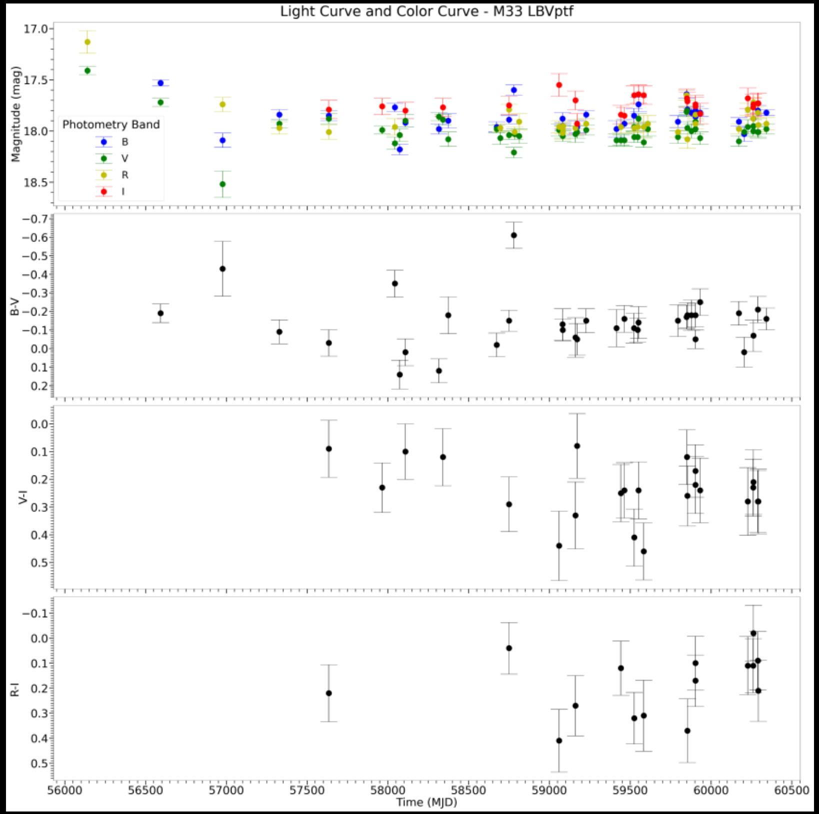
- Photometric Data Acquisition
  - Calculate color index
  - Apply color correction: $E(B-V)$ = 0.16 for M33 and 0.48 for M31
    $$m_V = V - 3.1 \times E(B-V)$$
  - Convert to absolute V-band magnitude: $d = 784 \pm 0.006\ kpc$ for M31 and $d = 869 \pm 0.018\ kpc$ for M33
    $$M = m - 5\log\left(\frac{d}{10}\right)$$
  - Plot a Color-Magnitude Diagram ($B-V$ vs. M_V)
    - Stellar evolution tracks from MESA Isochrone and Stellar Tracks (MIST)
    - S Doradus instability strip and constant-temperature strip
  - Plot the change in (color-corrected) color indices against the change in absolute V-band magnitude
    $$\Delta M_V = M_{V,peak} - M_{V,trough}$$
    $$\Delta(B-V) = (B-V)_{peak} - (B-V)_{trough}$$

3. Preliminary Results

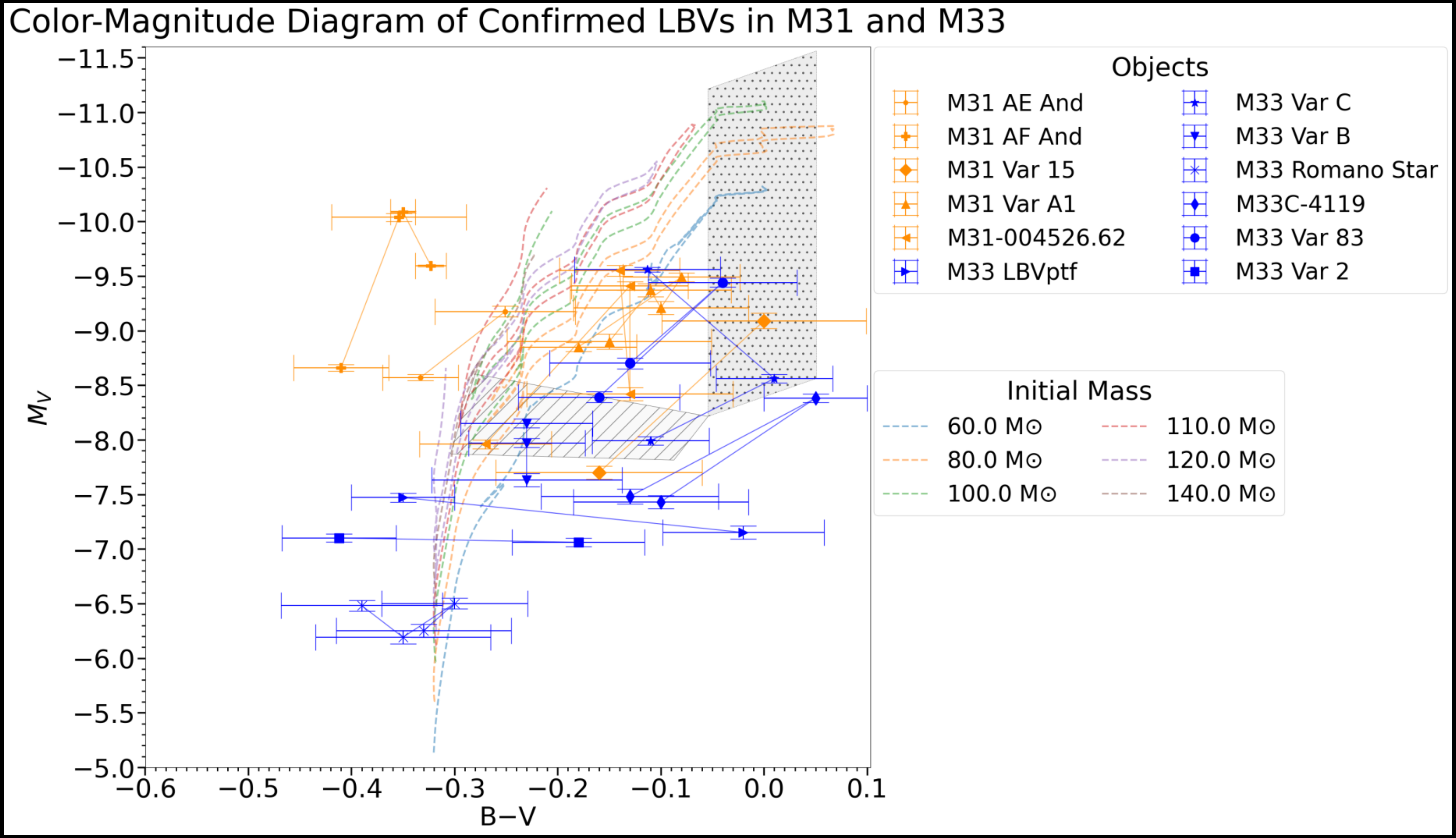
Light Curves and Color Curves



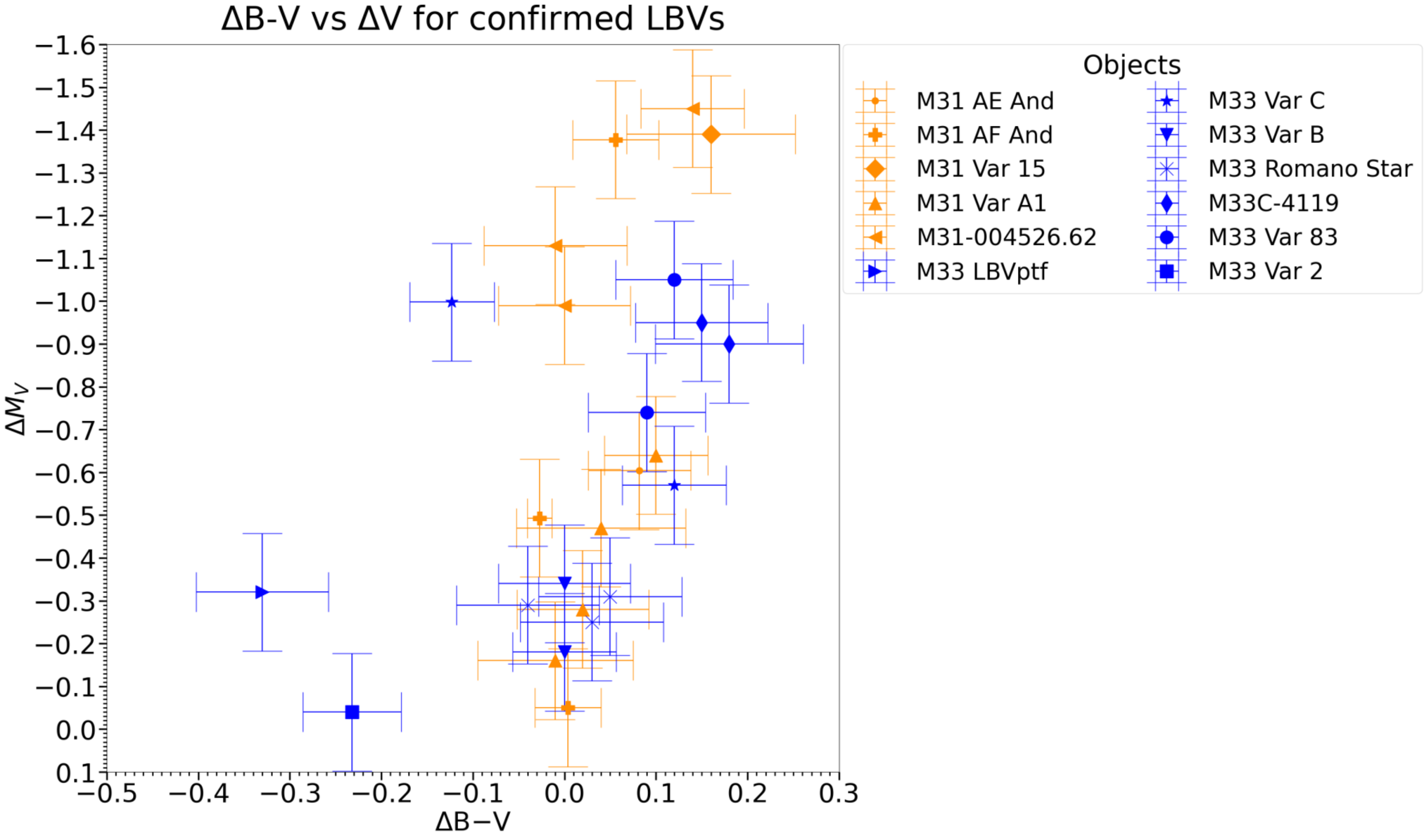




Color-Magnitude Diagram



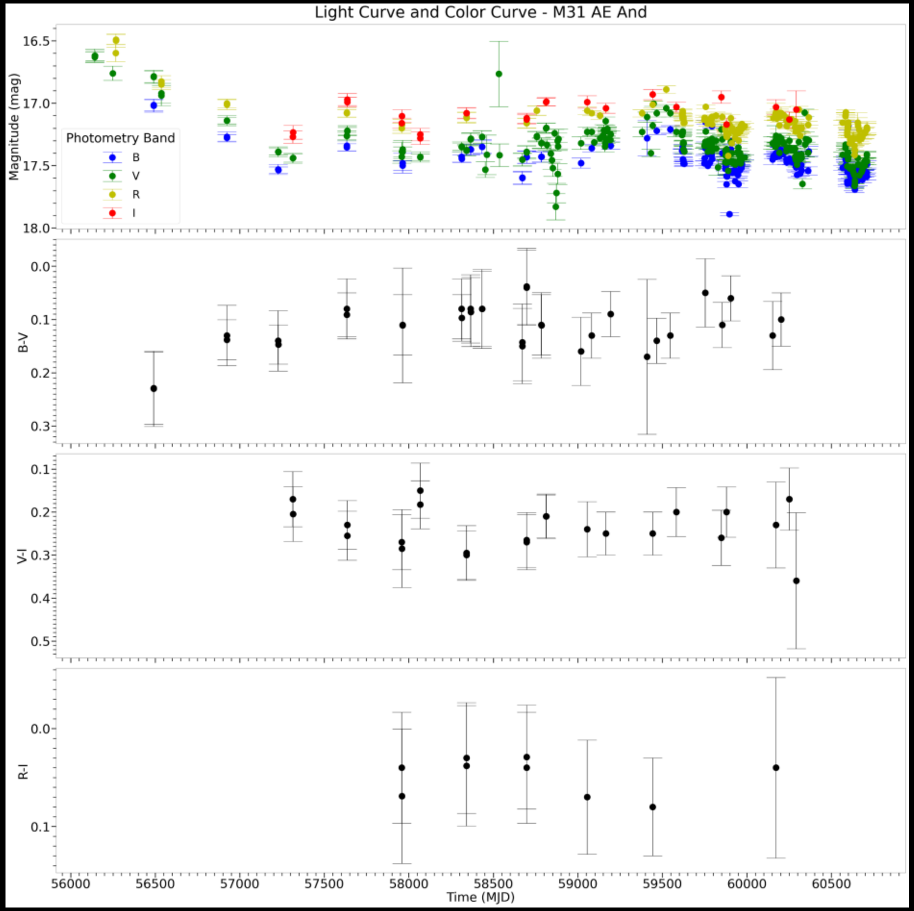
$\Delta(B - V)$ vs. ΔV

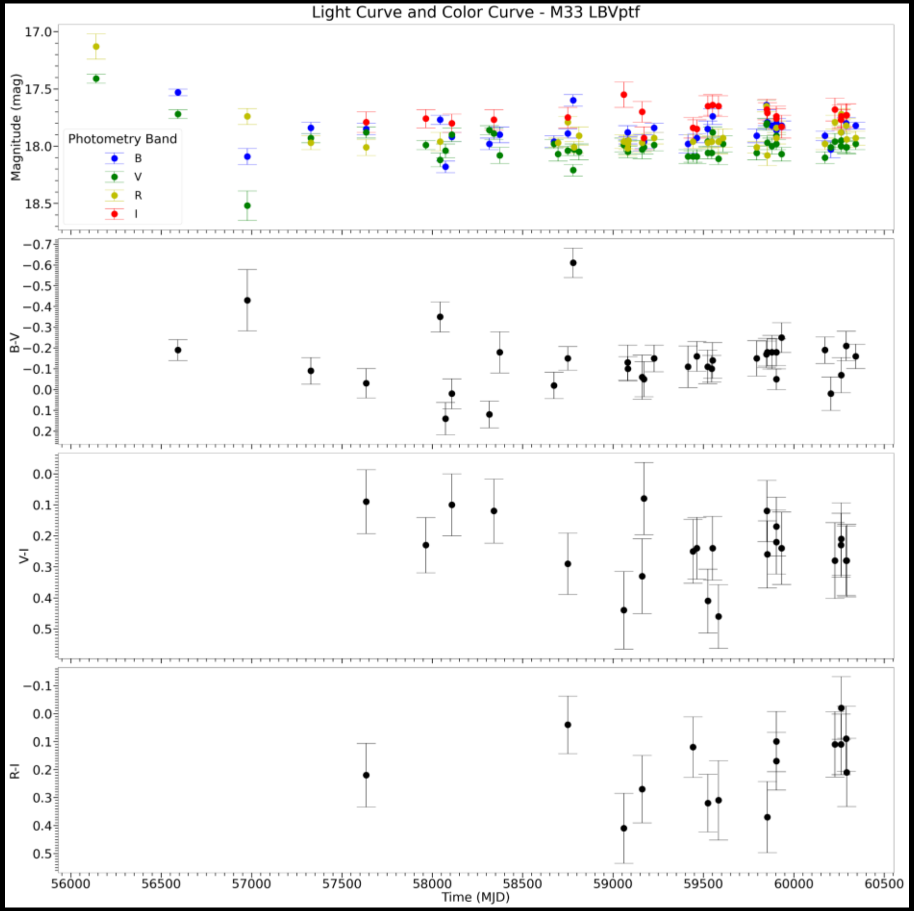


4. Future Implications

Future Implications

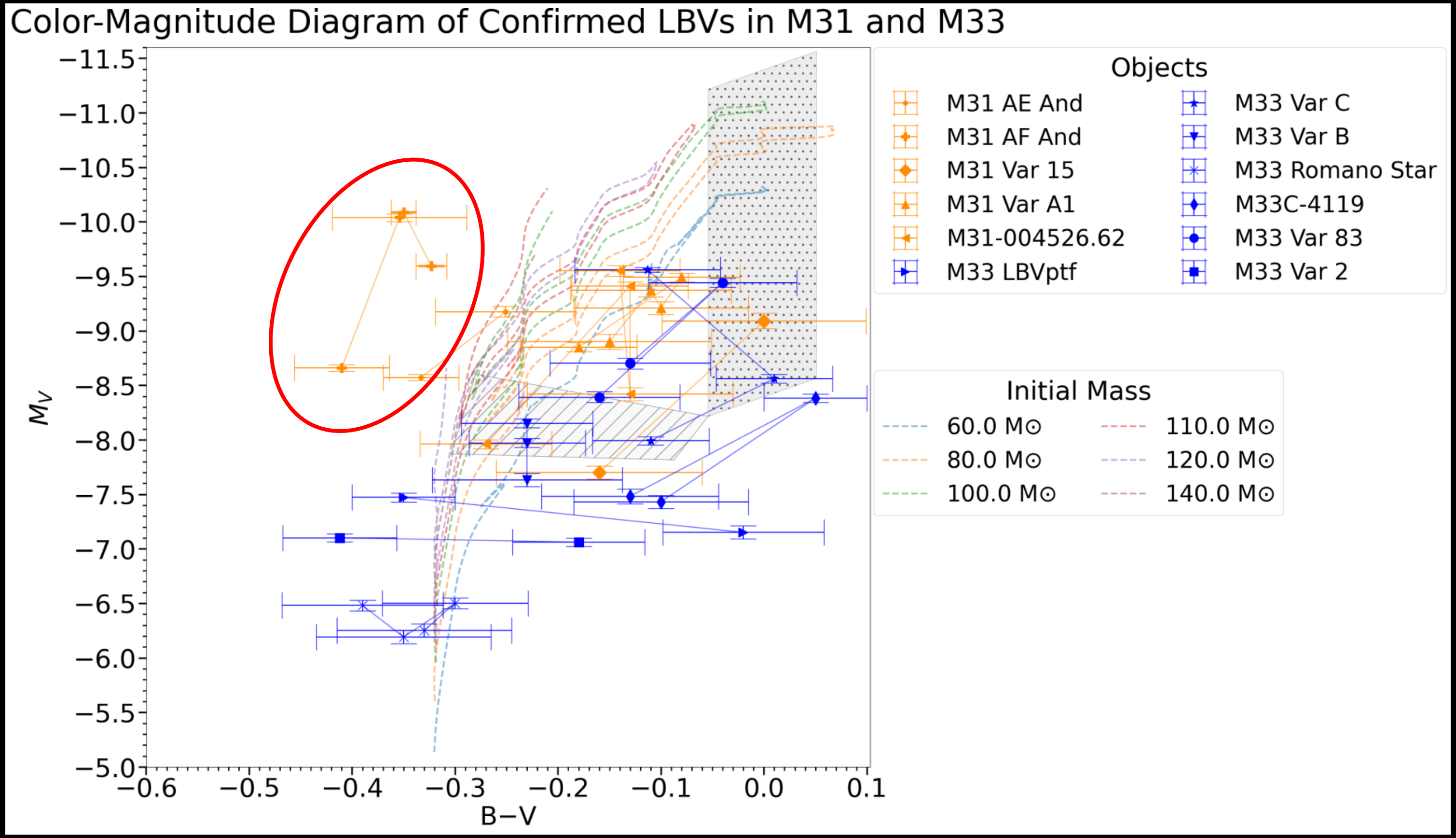
- Obtain more photometry to capture missing outbursts





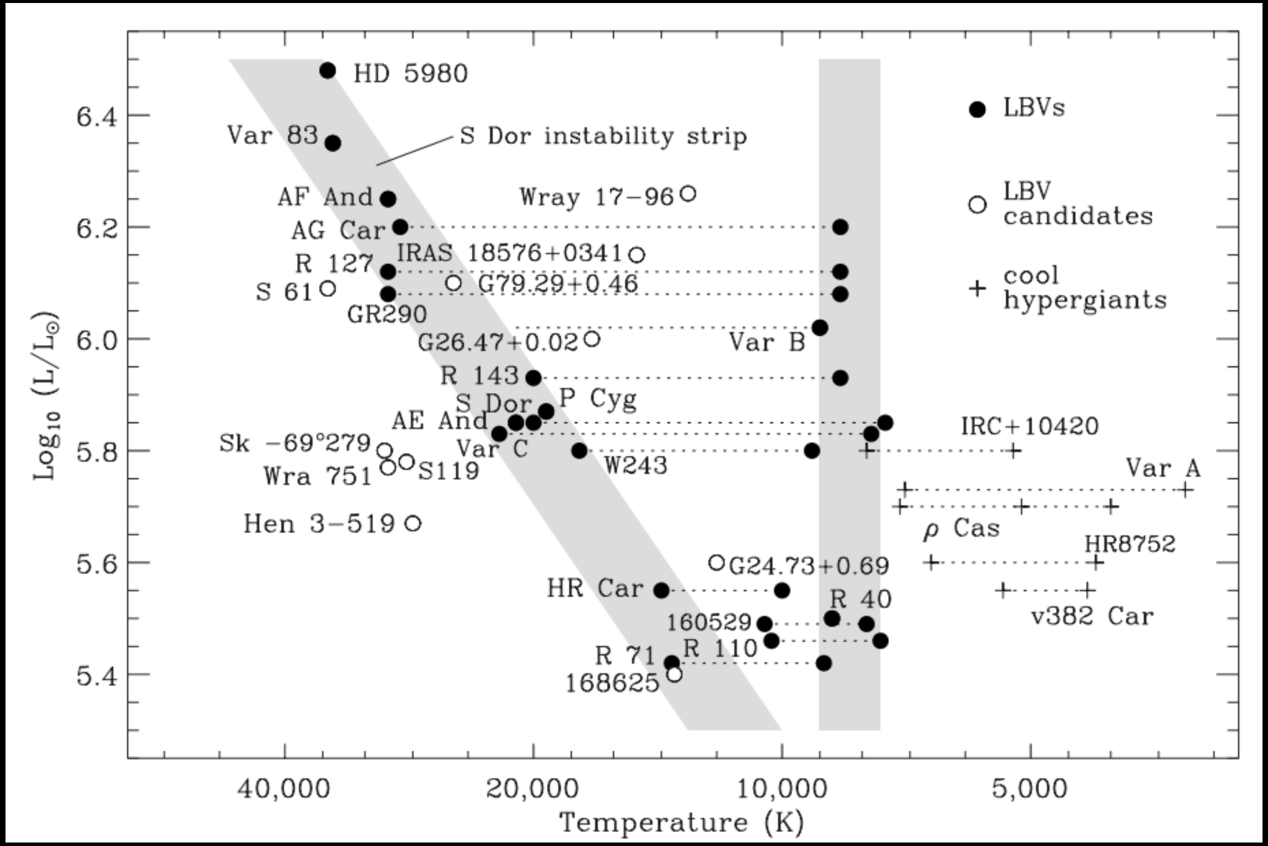
Future Implications

- Apply color correction for individual objects



Future Implications

- Do they get brighter with constant bolometric luminosity?



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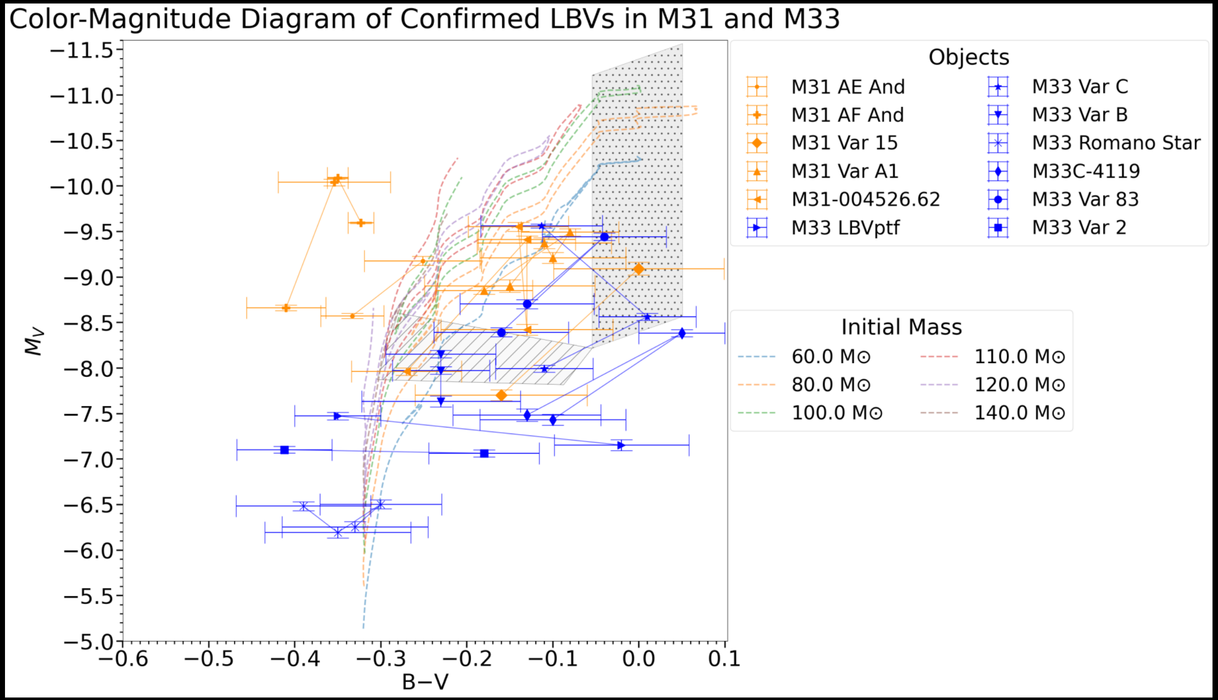
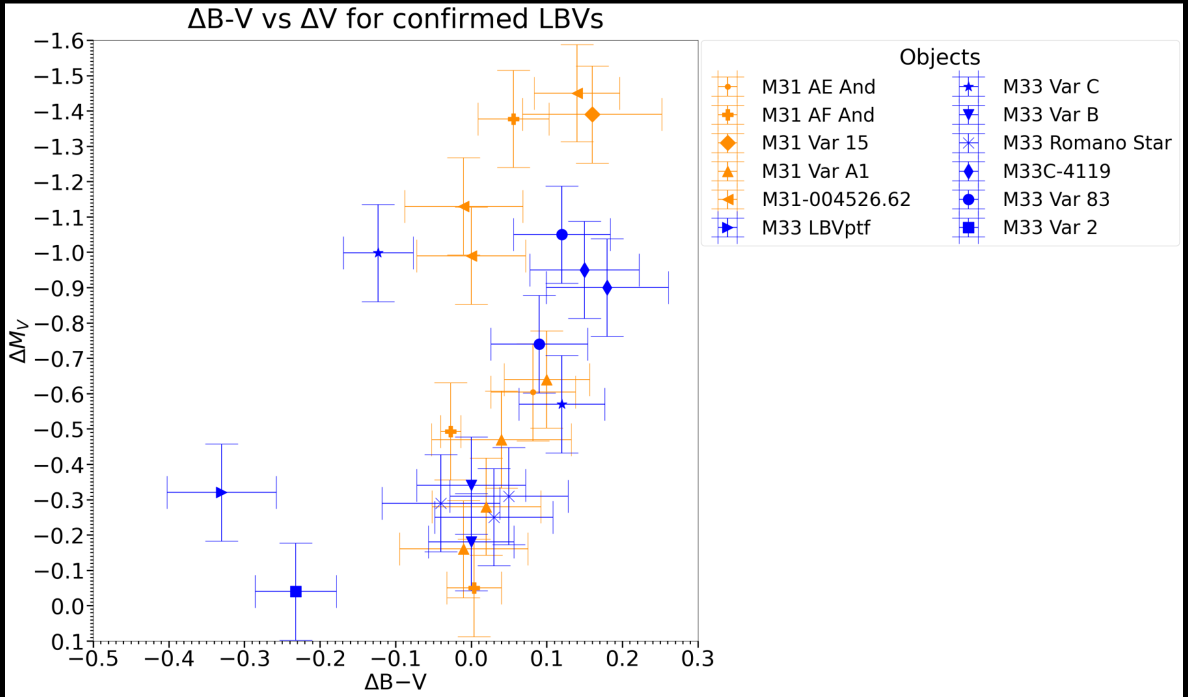
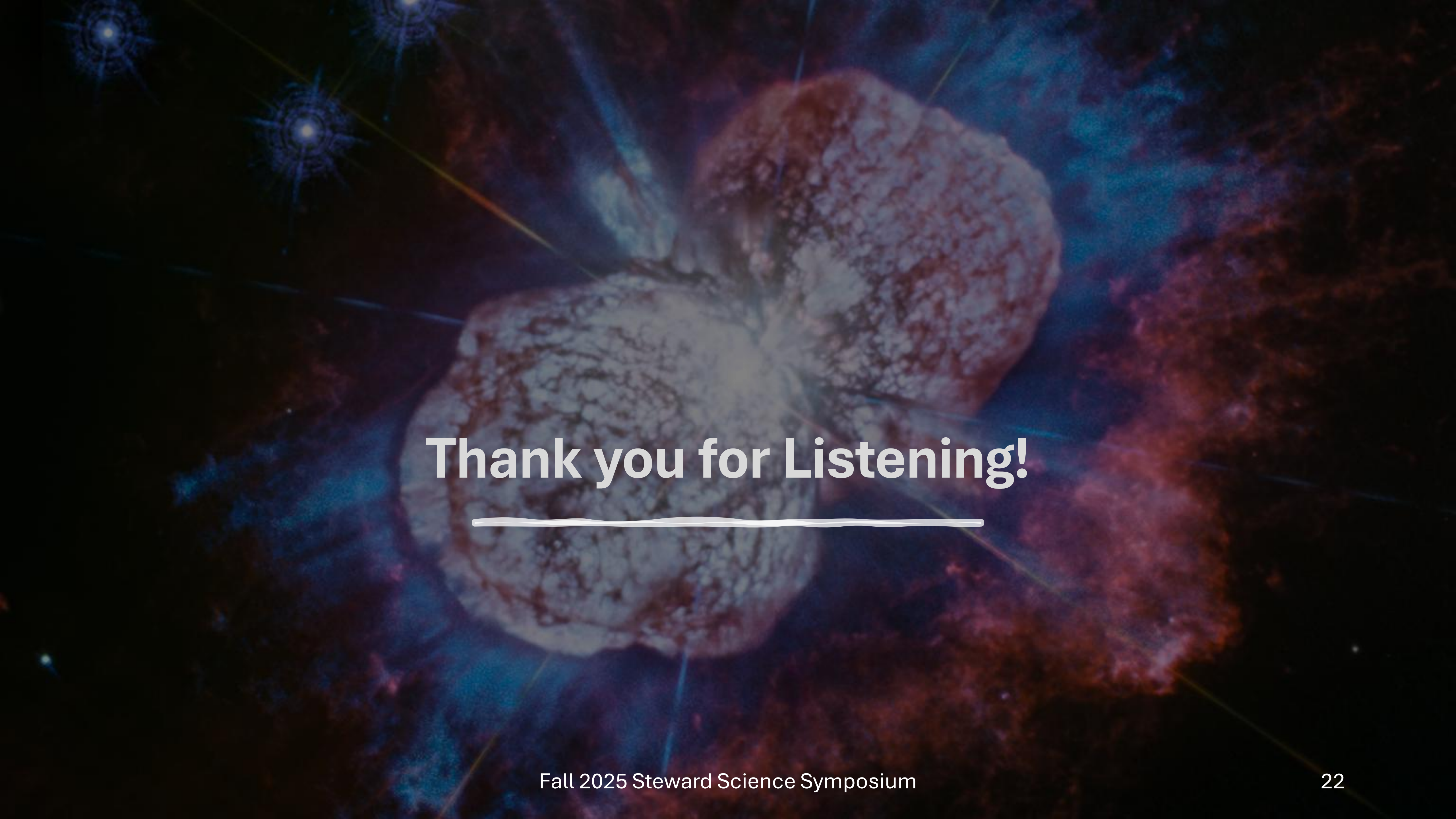




References

- Humphreys, R. M., & Davidson, K. 1994, PASP, 106, 1025
- Sholukhova, O. N., Fabrika, S. N., Valeev, A. F., & Sarkisian, A. N. 2018, AstBulletin, 73 (4), 413-424
- Smith, N., Vink, J. S., de Koter, A. 2004, ApJ, 615, 475-484
- Smith, N. & Tombleson R. 2015, MNRAS, 447, 602-621
- Smith, N., Milne, P., Bilinski, C., et. al. 2020, MNRAS, 492, 5897-5915
- Szeifert, Th., Humphreys, R. M., Davidson, K., Jones, T. J., Stahl, O., Wolf, B., Zickgraf, F. J. 1996, A&A, 314, 131-145
- Wolf, B. 1989, A&A, 217, 87-91



Thank you for Listening!