High Resolution Imaging of VY Canis Majoris: Constraining Mass Loss

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Introduction

VY CMa is one of the most luminous red supergiant stars known. HST WFPC2 images revealed complex circumstellar structure of its reflection nebula, indicative of multiple asymmetric ejection episodes (Ref. [4]). Comparison of multi-epoch HST images (0.4 to 1μm) taken in 1999 and 2005 provided detailed mapping and kinematics of numerous arcs and knots of ejecta (Ref. [1]). Combined with HST/ACS imaging polarimetry (Ref. [3]), the morphology and kinematics of the knots and arcs are likely associated with large-scale convective activity. First-light LBT/LMIRCam AO images (2.2 to 4.8μm) obtained in November 2011 extend observations of VY CMa's complex nebula into the thermal infrared.

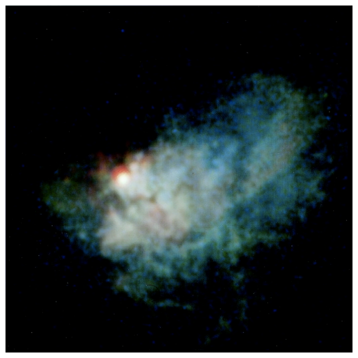


Fig. 1: Composite color HST image of VY CMa from Ref [4]. FOV = 10" x 10". Filters: F410M (blue), F547M (green), F656N and F1042M combined (red). Observed 1999 March 22.

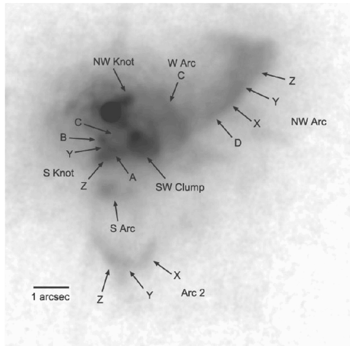


Fig. 2: F1042M image from Ref. [2], defining Southwest Clump and other features. Observed 2005 June 13.

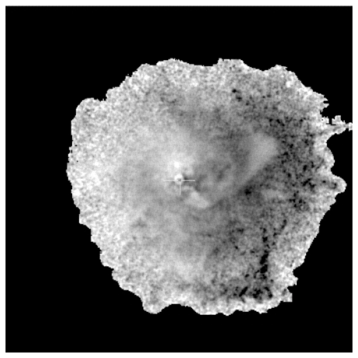


Fig. 3: HST [547] - [1024] instrumental color map from Ref. [3]. Brighter = redder. The SW Clump and NW Arc appear as redder than other features.

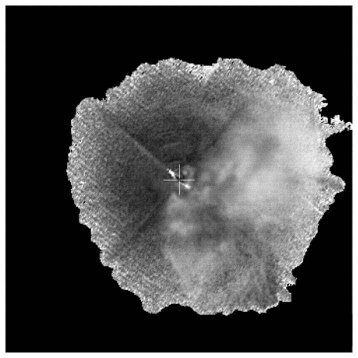
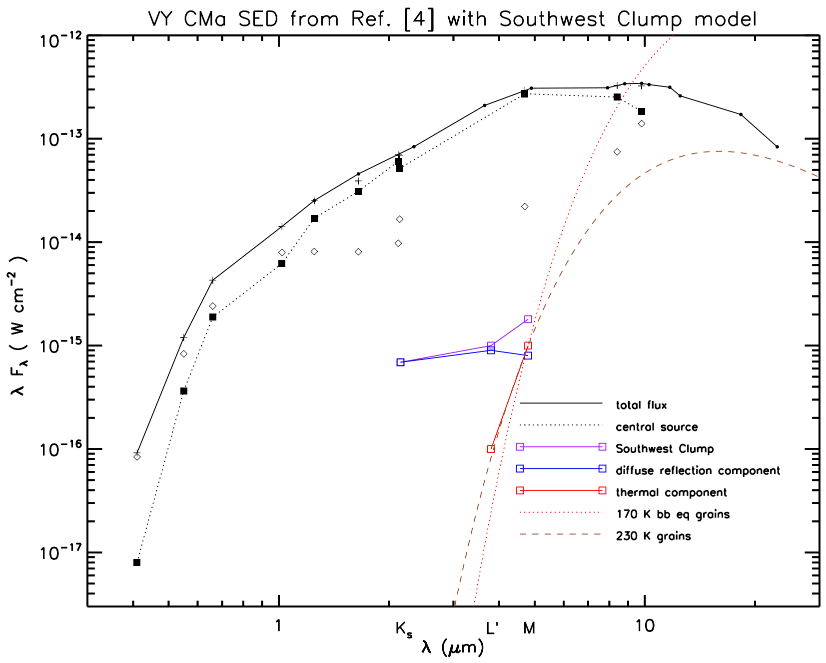
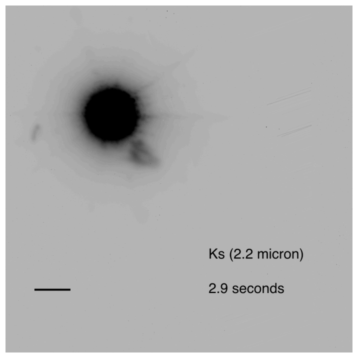
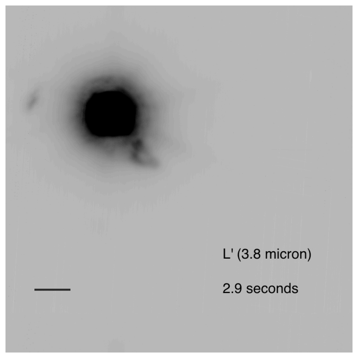


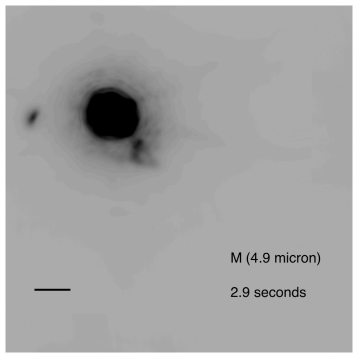
Fig. 4: Fractional polarization map from Ref.[3]. Dimmer areas (e.g., NW Arc and SW Clump) are less polarized than brighter surroundings, indicative of multiple scatterings.

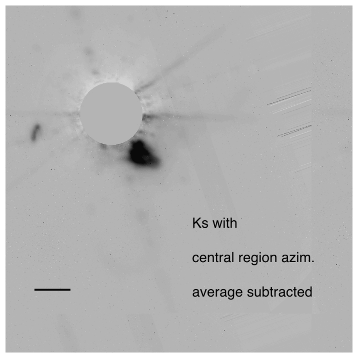


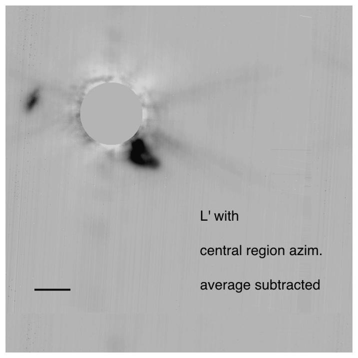
LMIRCam Images of VY CMa in Ks, L' and M filters

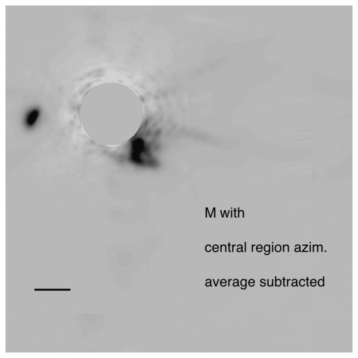












Analysis

The top row of images above show VY CMa as imaged by LMIRCam on UT 2011 November 16 for 2.9 seconds in each of three filters: Ks (2.2 μm), L' (3.8 μm) and M (4.9 μm). The lower left bar measures 1". The prominent feature is the "Southwest Clump", identified by Smith et. al. 2001 (Ref. [4]). Humphreys, Helton & Jones (2007) described the SW Clump as a highly obscured feature seen only the WFPC2 F1042M filter, ejected approximately 500 years ago and moving slightly away from the plane of the sky (Ref [2]). Prominent features in the HST visible and F1042M images such as the Northwest Arc, South Arc and Arc 2 were not detected in the LMIRCam images. The prominence of the SW Clump combined with the absence of any obvious feature opposite it, which would be more easily visible in the longer wavelength images even if obscured in the visible, is consistent with VY CMa exhibiting a history of localized mass ejections from active regions on its surface which are not strongly aligned with a presumed axis or equator (Ref. [2]).

We estimated a lower limit of $7 \times 10^{-4}\ M_\odot$ for the mass of the SW Clump by modelling its flux as optically thick diffuse reflection (Ref. [1]) from spherical dust grains and assuming a gas-to-dust ratio of 100. The dust was modelled as silicate grains following a power law distribution, with an average radius ~ 0.2 μm obtained by attributing all the flux at Ks to diffuse reflection with a negligible thermal component. Using this average grain size, the diffuse reflection flux of the SW Clump at L' and M was estimated, with slightly more than half the remaining flux at M attributable to thermal emission from the grains. An equilibirum temperature of ~ 230 K for the grains (somewhat higher than the 170 K blackbody equilibrium temperature, assuming a distance to VY CMa of 1.2 kpc, per Ref.[5]) would allow the SW Clump to account for most of VY CMa's flux in the 5 - 20 μm range as thermal emission.

References:

[1] Chandrasekhar, S., Radiative Transfer, 1950 Dover Books.
[2] Humphreys, R. M., L.A. Helton, & T. J. Jones, 2007 AJ 133, 2716.
[3] Jones, T. J., R. M. Humphreys, L.A. Helton, C. Gui, & X. Huang, 2007 AJ 133, 2730.
[4] Smith, N., R. M. Humphreys, K. Davidson, R. D. Gehrz, & M. T. Schuster, 2001 AJ 121, 1111.
[5] Zhang, B., M. J. Reid, K. M. Menton, & X. W. Zheng, 2012 ApJ 744, 23.