High Mass Loss Events in Hidden Clumps and the SW Clump in ALMA Observations of the Red Hypergiant VY CMa

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The Red Hypergiant VY CMa

VY CMa is famous for its very visible record of high mass loss events in its circumstellar ejecta, complex chemistry and molecular emission. It is one of the most important evolved massive stars for understanding the role of high mass loss episodes on their evolution. Our recent high resolution images with ALMA revealed three previously unknown large arcs or outflows in CO emission (Singh et al. 2023) and this paper.

ALMA Science Verification images of VY CMa (Richards et al. 2014, O’Gorman et al. 2015) earlier discovered a large, massive “clump” near the star, not visible in the HST optical images. With an estimated mass of ~ 5 x 10⁻² Msun, Clump C is potentially one of the most massive ejecta in VY CMa. Kaminski (2019) identified three additional smaller knots near Clump C. To distinguish them from the numerous knots etc. in the HST visible images, we call them the ALMA Clumps.

Results for the ALMA Clumps are published in AJ, 167, 94, 2024

The SW Knots

We recommend referring to this structure as the SW knots.

The ALMA Clumps

The four clumps or knots are identified in the 249 GHz continuum image in Fig. 1. Fig. 2 shows the ¹²CO emission at the clumps in two representative channels.

The line of sight and outflow velocities of the four clumps are derived from the ¹²CO emission towards the clumps, and are discussed in the published paper. Clumps C and D are redshifted relative to the star and projected away from us, behind the plane of the sky while Clump A is blue shifted and moving towards us. The derived parameters are summarized here in the table. The age or time since ejection of the knots is measured from the proper motions and distance from the star.

The Infrared – Bright “SW Clump”

HST images from 0.4 to 1 micron reveal at least three knots and an arc-like feature with diffuse condensations extending from the east to its south arc. Fig. 5. This is not a coherent structure, an expanding bubble or loop (Humphreys et al. 2021). We recommend referring to this structure as the SW knots.

The SW Knots in the ALMA 12CO Images.

The SW knots appear in different channels in the 12CO image cube depending on their line of sight LSR velocity. Fig 6 right shows the 12CO contours in red superposed on the L’ 3.6 micron LMRRCam image of the SW knots. A peak in the 12CO emission overlaps the SW A knot at 3.6 µm at 27 km/s while the 21.5 km/s is consistent with the diffuse arc.

Fig. 7 shows the same contours on the HST 0.665 and 1.04 micron images. Notice the significant offset to the south especially for the “S arc” most likely due to outward motion of the diffuse ejecta in the 23 yrs between observations. The near IR data (Fig 6) precede the ALMA data by 11 yrs about half that time.

The Clump D Outflow

The position-velocity map in Fig. 3 for LSR velocity range -20 to +80 km/s reveals the morphology of the ¹²CO emission associated with Clumps D and C. The prominent diffuse emission feature from VLSR +45 to about +25 km/s extends from Clump C to D. Clump C is visible as the bright spot at the top of the arc, and based on its position, Clump D is near the tip of the arc. Fig. 3 shows an arc-like diffuse feature with increasing velocity with distance from VY CMa that is not linear, suggesting an arc-like outflow from the star. Clumps D and C have different projection angles and are therefore not from the same active region. Clump C is nearly in the plane of the sky while D is redshifted and moving away from us.

Fig. 3 also show bands of wispy or cirrus-like emission stretching across the lower half and top of the figure which probably represent older ejecta surrounding VY CMa.

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The derived parameters are summarized here in the table. The age or time since ejection of the knots is measured from the proper motions and distance from the star.

<table>
<thead>
<tr>
<th>Clump</th>
<th>Total Vel.</th>
<th>Proj. Angle</th>
<th>Dist</th>
<th>Age</th>
<th>Mass(Msun)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>50</td>
<td>21</td>
<td>691</td>
<td>66</td>
<td>0.1</td>
</tr>
<tr>
<td>B</td>
<td>23</td>
<td>35</td>
<td>326</td>
<td>69</td>
<td>0.01</td>
</tr>
<tr>
<td>C</td>
<td>21</td>
<td>11</td>
<td>375</td>
<td>86</td>
<td>0.006</td>
</tr>
<tr>
<td>D</td>
<td>57</td>
<td>23</td>
<td>895</td>
<td>75</td>
<td>0.0006</td>
</tr>
</tbody>
</table>

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The synthesized beam (FWHM) is shown as an ellipse in the lower left corner.