Fate of a Massive Star: New ALMA Images of VY CMa

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Hypergiants: The Most Massive Stars

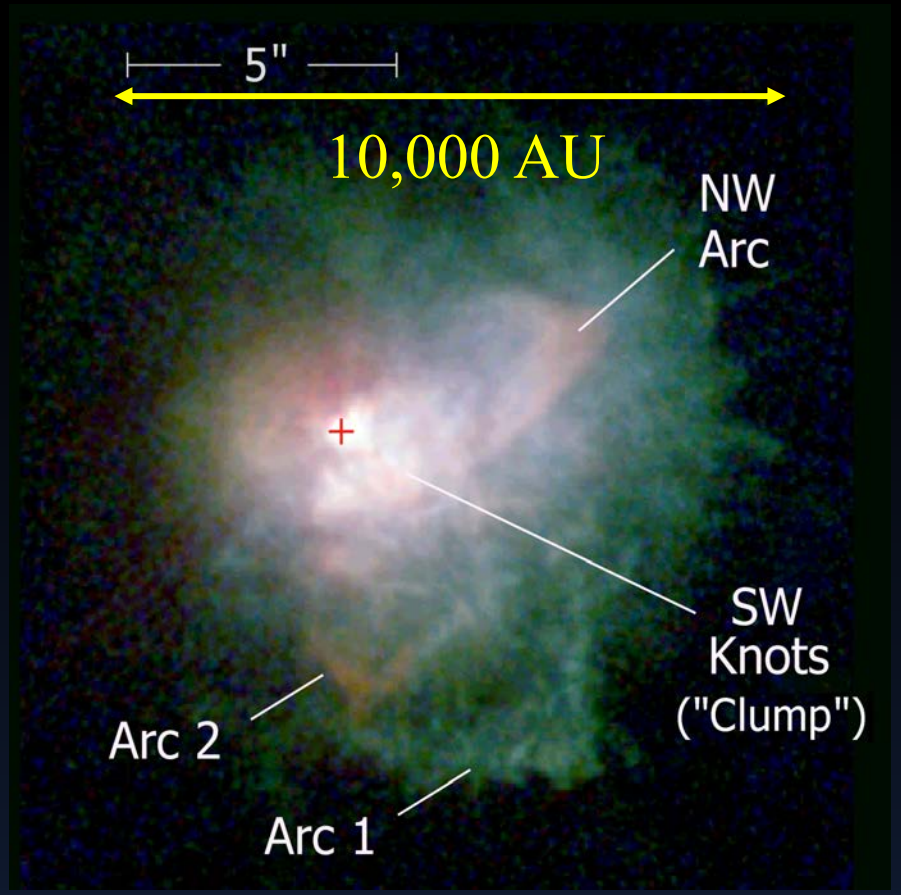
- Hypergiants: Rare stars with masses between 20 to 40 $M_{\odot}$
- Originally thought to end their lives as massive SUPERNOVAE EXPLOSIONS
- May perhaps simply collapse to BLACK HOLES, or other evolution
- Transition through intense, episodic, and sporadic mass loss
- Mass launched from stellar surface in many directions
- Similar to Coronal Mass Loss from SUN, but a billion times larger

VY CMa (Artist impression)

Credit: NASA, ESA, Roberta Humphreys (UMN), Joseph Olmsted (STScI)

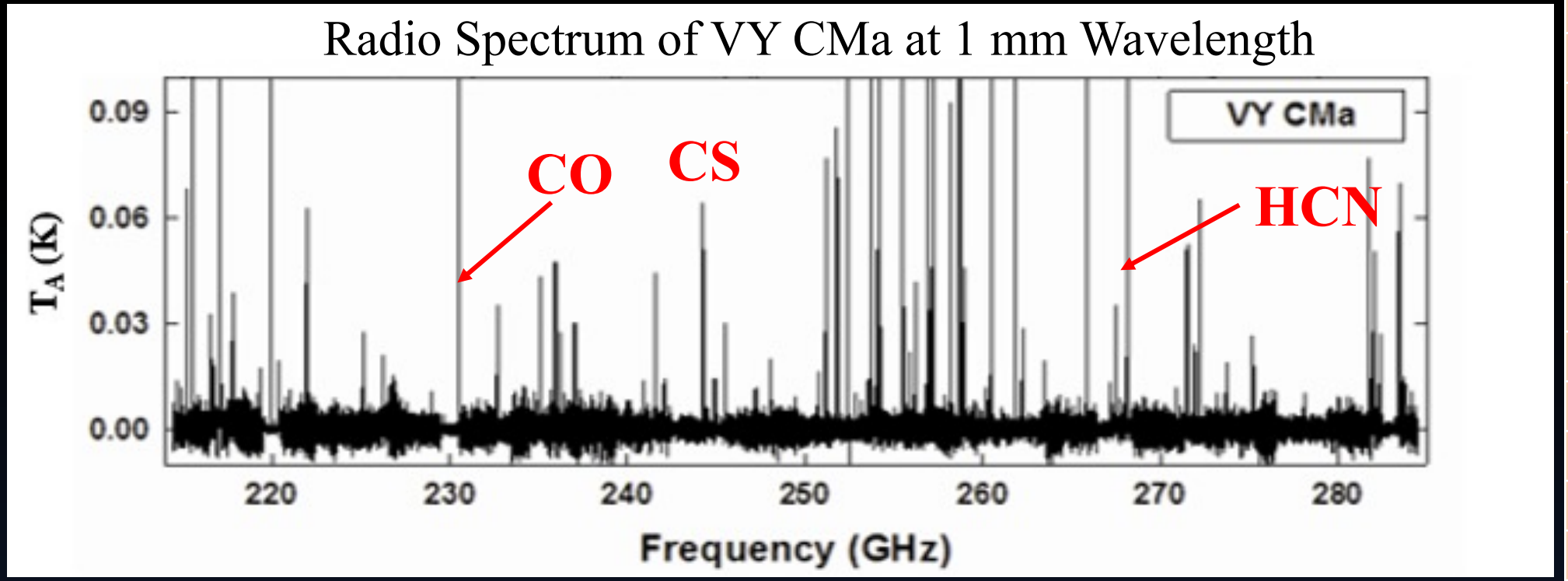
Most Famous Hypergiant: VY Canis Majoris

- One of the most MASSIVE STARS KNOWN
- M > 25 $M_\odot$ with a radius ~ 2100 $R_\odot$ (~ 8.5 AU)
- Distance ~ 1.3 kpc (~ 4000 Light Years) to Canis Major
- Ejecting mass at an ENORMOUS RATE (> 10^{-4} $M_\odot$ /yr)
- NOT SYMMETRIC mass loss but in arcs, tails, clumps
- Creates a large (~10,000 AU) dusty, irregular envelope around star
- VY CMa: ***Betelgeuse on steroids***



VY CMa (HST optical image)

Envelope of VY CMa: Full of Gas-Phase Molecules



- See many Carbon-bearing Molecules
- Also Exotic Species: AlO, AlOH, VO
- Important Biological Molecule: PO (First P-O Bond observed in space)

But WHERE are the molecules located?

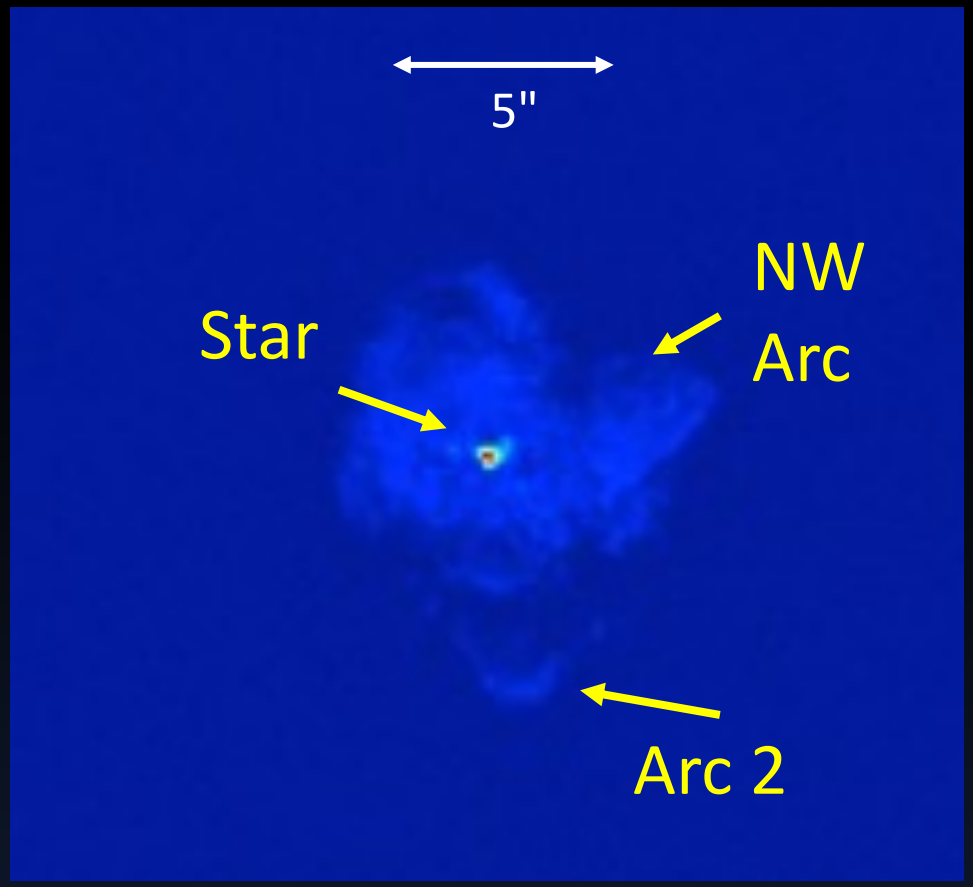
TiO_2
CO
SiO
SiS
SO
CS
CN
NS
NaCl
PN
PO
AlO
H_2O
H_2S
HCN
HNC
SO_2
HCO^+
AlOH
VO
TiO

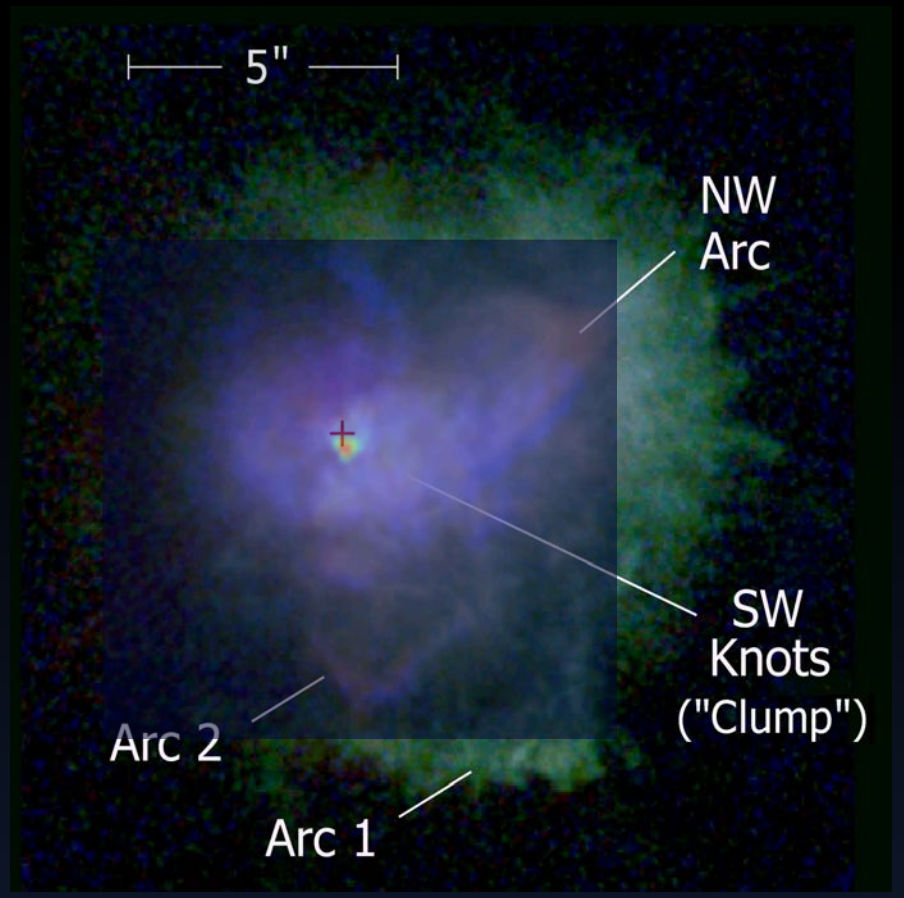
Atacama Large Millimeter Array (ALMA)

- Make images of molecule distributions in space

- Are molecules associated with Mass Loss Events ?

SO_2: Molecular Image of Outflows in VY CMa





SO_2: $J_{Ka,\,Kc} = 14_{0,\,14} \rightarrow 13_{1,\,13}$
Transition near 244 GHz

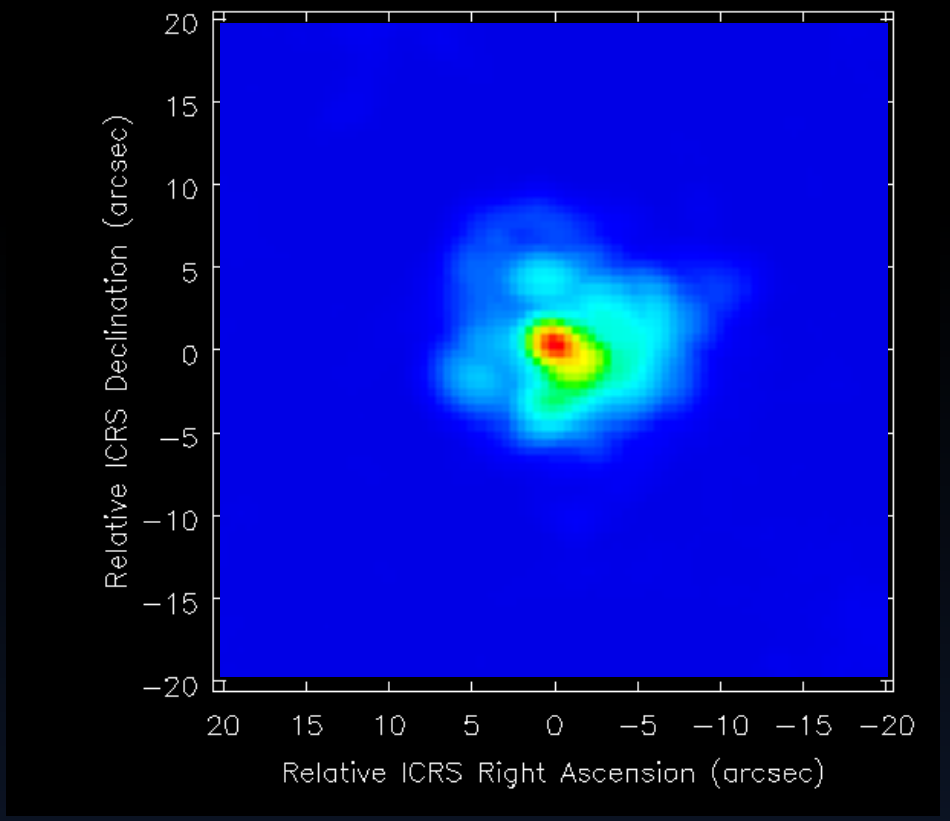
- Detailed Velocity Information for Outflows For First Time

ALMA: Outflows in SO_2 Velocity Movie

VY CMa (Artist impression)

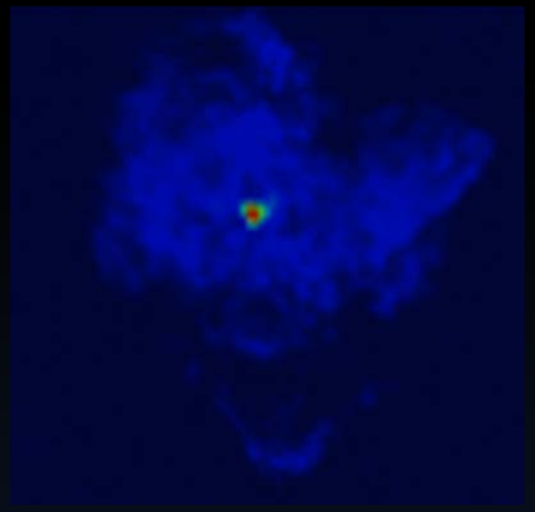
Credit: NASA, ESA, Roberta Humphreys (UMN), Joseph Olmsted (STScI)

Resembles Artist Impression!

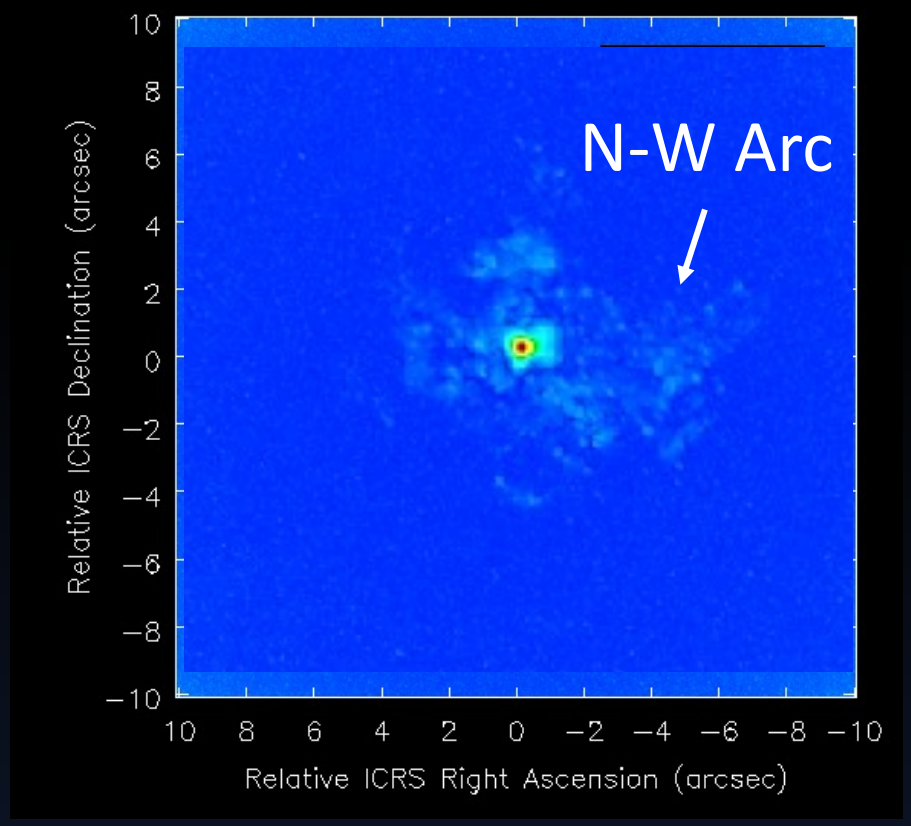


HCN

J = 3 →2: 265 GHz



SO_2



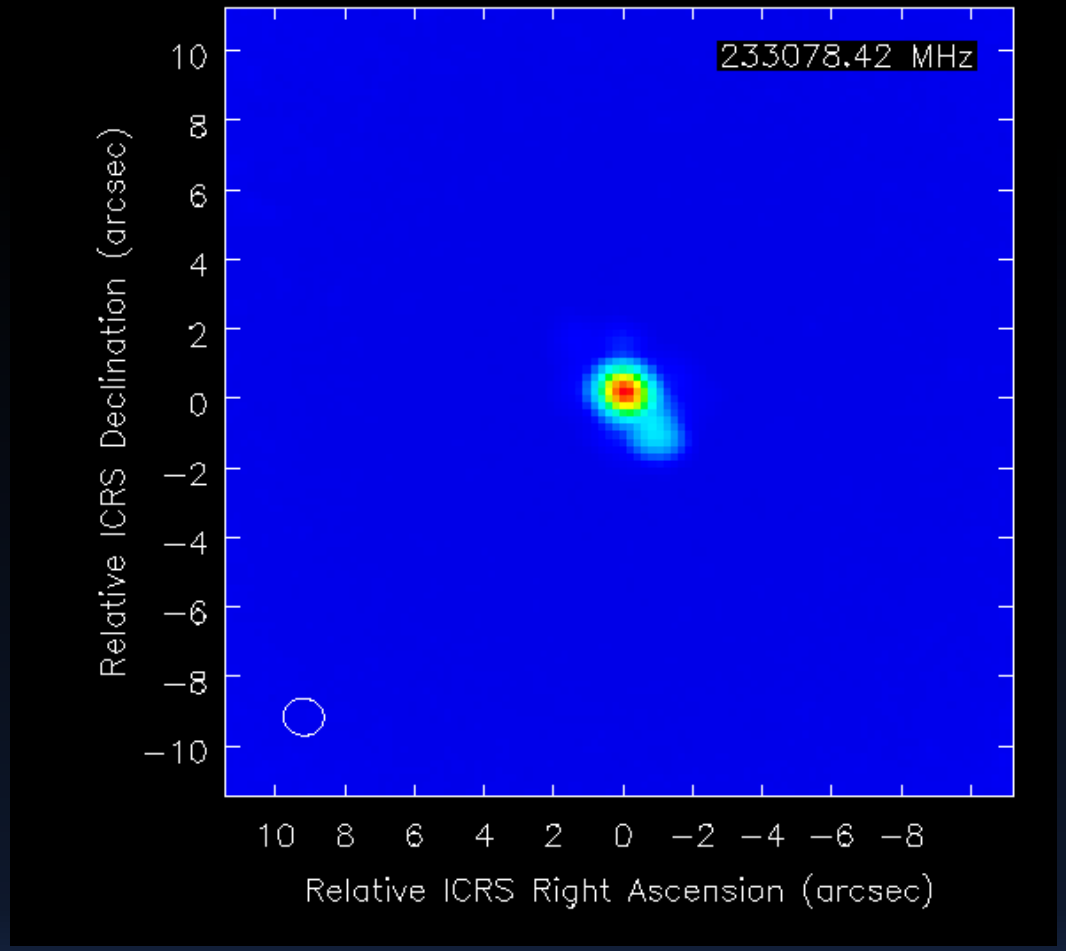
PO

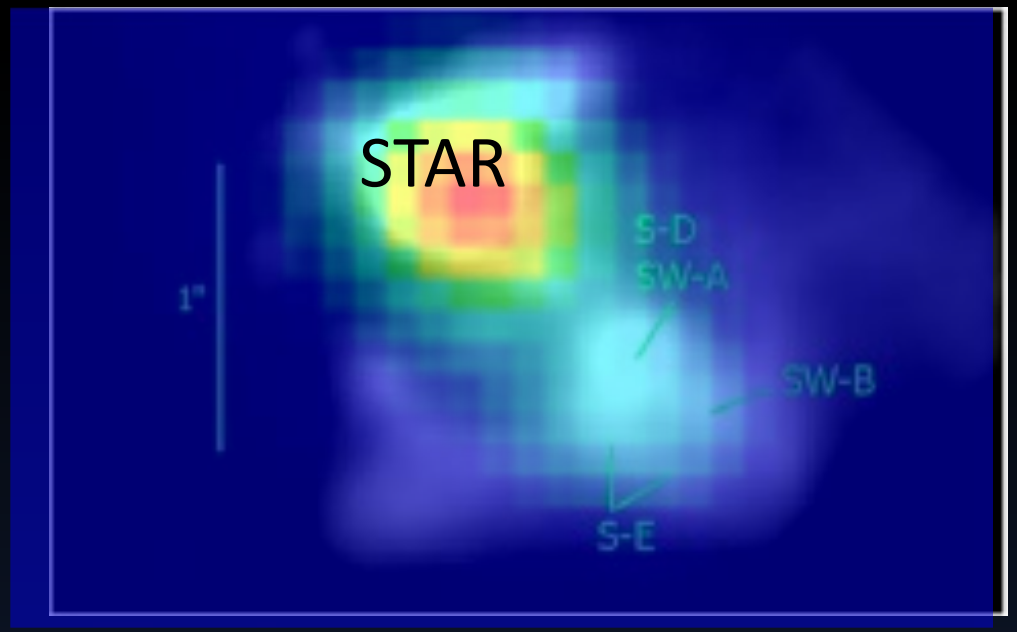
J = 11/2 → 9/2: 240 GHz

HCN: Traces Ejecta closer to star

PO: Present in extended outflow (NW Arc)

VY CMa: Throwing Salt Over the Shoulder





NaCl
J = 18 →17: 233 GHz

- NaCl centered mostly on star; also traces SW Clump A (ejected by star ~ 230 years ago)

Implications

- Molecules trace individual knots, clumps, arcs of individual mass loss events clearly been in HST images of VY CMa
- Molecular data gives unprecedent velocity information (factor of 10-100 better than optical observations)
- ALMA molecular images plus HST data will enable Mass Loss History to be elucidated and mechanisms to be determined
- Do these violent ejecta eventually create a Black Hole, or another pathway ?
- Are they similar to coronal mass loss from the Sun ?
- Understanding the dynamics of the envelope of VY CMa is crucial to understanding the evolution of the most massive stars

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