Zooming in on VY CMa ejecta: Hint to the mass ejection of RSGs

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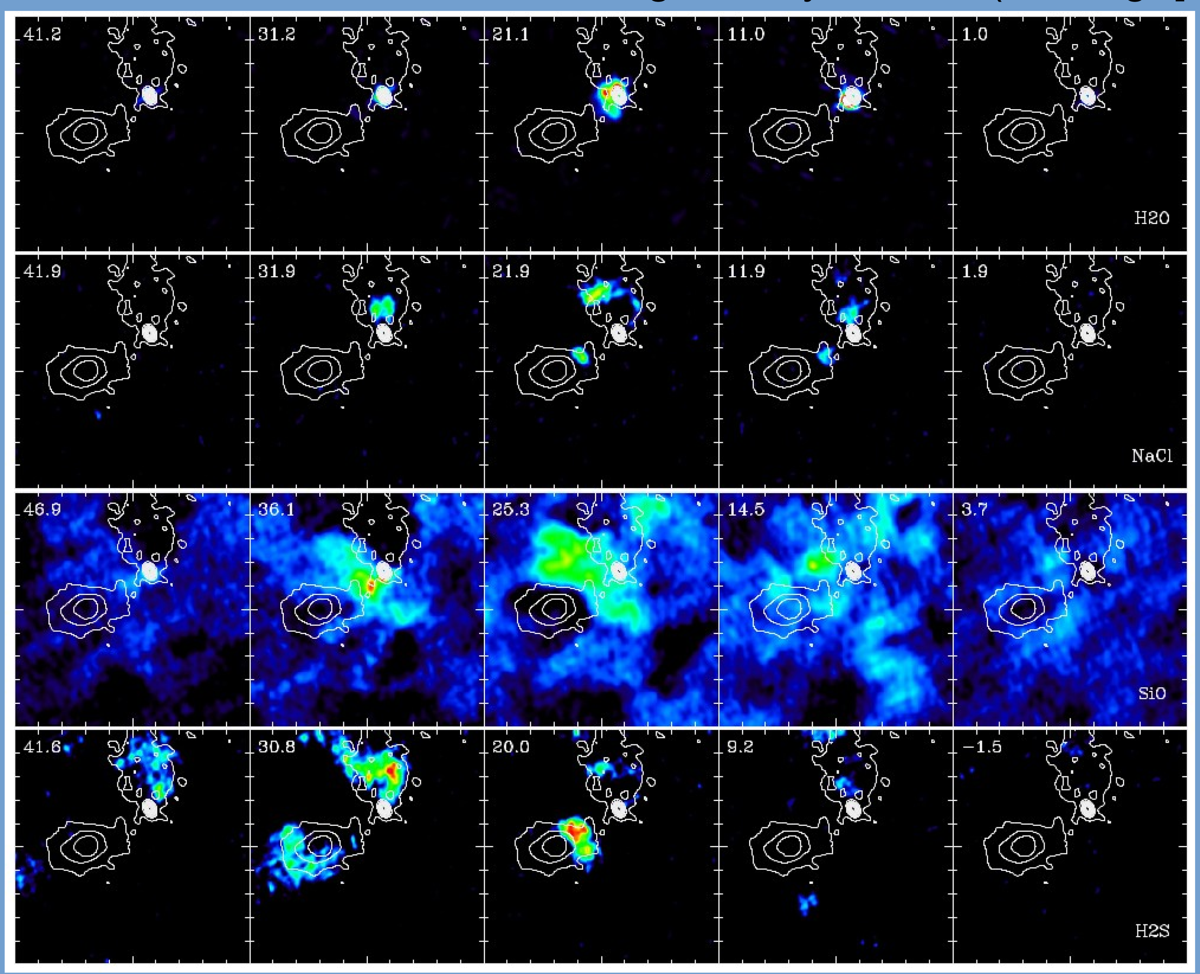
Introduction

VY CMa is an extensively studied red supergiant star (RSG) showing an O-rich chemistry, and one of the brightest known evolved stars. Its distance is around 1.2 Kpc [1], its mass is > 15 M_{sun} , and its luminosity is ~ 2 x 10^5 L_{sun}. VY CMa is characterized by a very high mass loss rate, of the order of 2-4 10^{-4} M_{sun} yr^{-1}, that has created an extended and dusty circumstellar envelope. The CSE shows a complex morphology at optical wavelengths, with arcs, filaments and bright knots. [7] have shown that the arcs correspond to episodic ejection events occurred in the last 1000 yr. [10] mapped the CO emission of this object. These maps, despite their poor quality, show a complex morphology. This was later on confirmed by [9] which classified the structures into four groups: a point like central structure, a southern secondary source, a ring structure observed in CN and an extended multiple and complex structure. The point-like structure was revealed to be also a double source by [2].

We obtained high angular resolution interferometric maps with ALMA which has revealed a much more complex structure. These maps would allow us to study the formation of such ejecta, the chemical processes taking place in the innermost regions, as the formation of dust, and the processes driving the mass ejections in the Red Supergiant phase.

Chemical Complexity

Up to recent dates, the chemistry of O-rich stars was considered to be relatively poor in comparison to C-rich objects as IRC +10216. However, recent observations, in particular lines surveys towards these type of objects, and in particular toward VY CMa has revealed an astonishing density of lines (see e.g. [1],[2],[3],[7]). In addition



to these works we have conducted spectral surveys with HIFI and the IRAM 30m radiotelescope which have confirmed the chemical complexity of this object (Quintana-Lacaci et al. in prep). Among the species detected are CO, H_2O, SiO, SO, SO_2 , SiS, SiN, NaCl, PN, NH_3, HCN, HNC, CN, and H_2S, and some of their isotopologues. The data obtained during Cycle 5 shows that the different species probe regions in VY CMa with different excitation/chemical conditions (see figure, continuum in contours).

Mass loss in the Red giant phase

The processes driven the mass ejection in the RSG phase remain unknown. The AGB driving mechanism, i.e. the pulsation and the formation of a dust formation zone fails to work in the case of RSG stars ([8]). In particular the pulsation of massive stars is irregular and, more important, with low amplitude.

Certain mechanism have been proposed (see. e.g. [11]). In particular the presence of convective cells arising at the photosphere and also magneto-hydrodinamical disturbances which would generate cold spots, similar to the sunspots, where the tempereture would drop to several thousand kelvin, thus producing a massive dust formation ([11], [13]). The radiation pressure on this dust would power the mass ejection in a similar way to that taking place in AGB stars. ***However the mass ejection in RSG phase would be in random directions.***

Recent observations from [5] suggest that the expansion velocity of the ejecta in both AGBs and RSGs are directly related with the metallicity and the luminosity, i.e. the dust and the radiation pressure.

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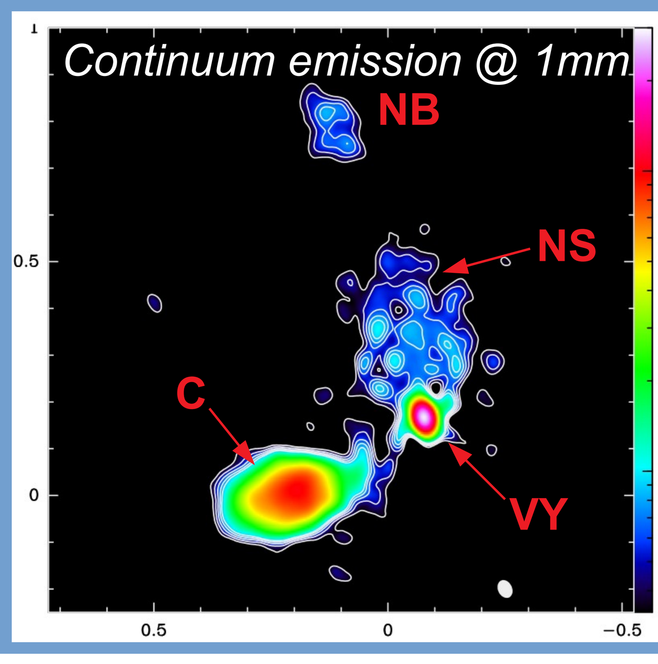
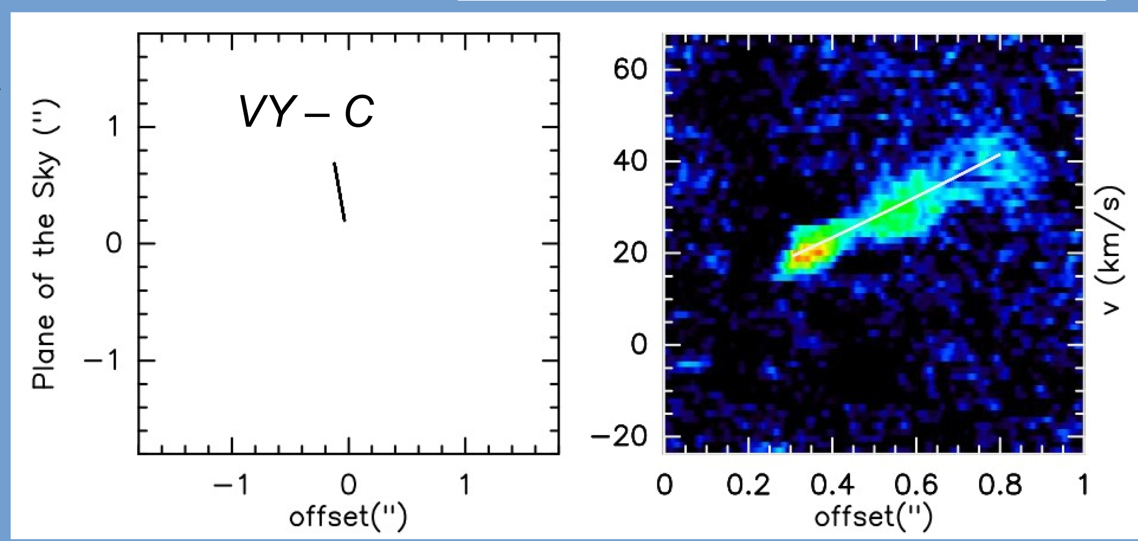
Structural complexity

We observed the ejecta around VY Cma with an unprecedented spatial resolution (0.03'' x 0.02''). The continuum emission shows certain structures. VY: the central star; C: A continuum blob with no molecular emission associated with cold dust ([11]); NS: a northern shell-like structure; NB: a northern bullet-like jet.

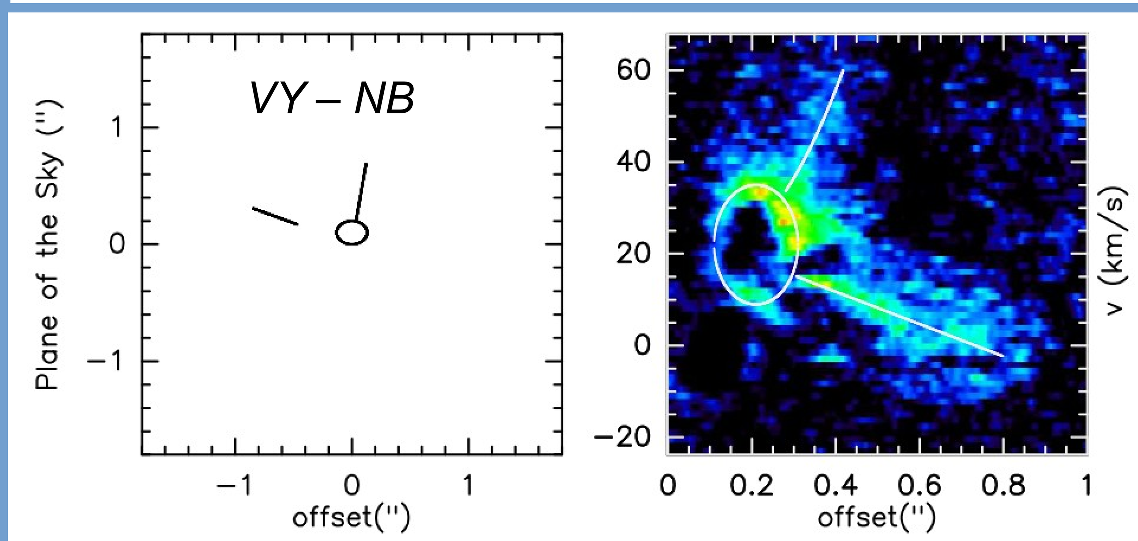


We obtained and PV diagrams along the lines connecting VY and C, and VY and NB for the emission from H_2S. A simple kinematic model of the structures observed is presented.

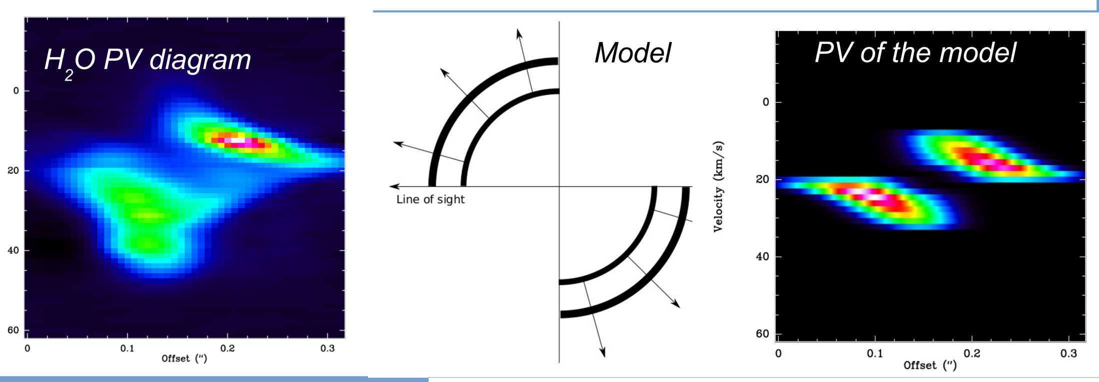
1) The PV diagram connecting ***VY and C*** corresponds to an outflow with a constant velocity gradient. The velocity at VY is negative compared with the v_{lsr}, which suggest and infall of material from C toward the star.



2) The PV diagram along ***VY-NB*** presents three different structures. First an outflow almost in the plane of the sky connecting VY and NB, a shell probably disrupted by such outflow, and a second outflow to the rear of the envelope.

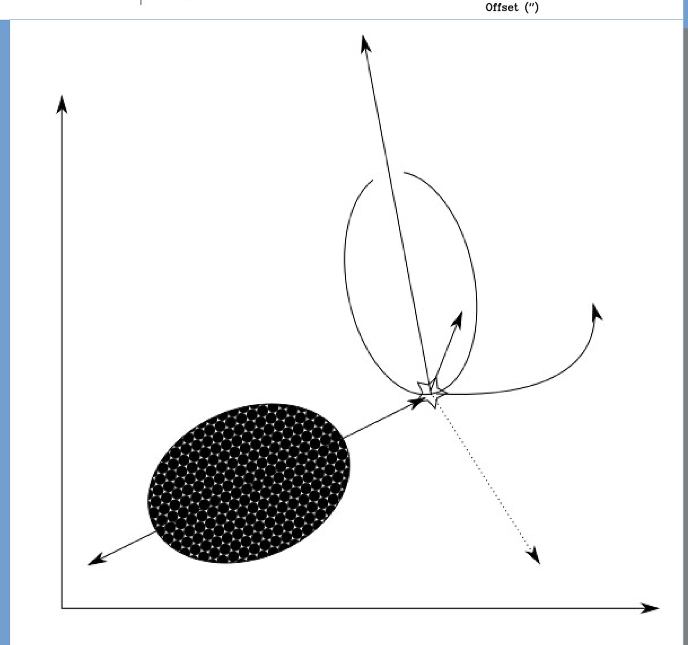


3) We observed ***H_2O v=2***, which traced the innermost regions. It presented two blobs. We obtained a PV diagram connecting both blobs, and the structure was found to suggest a bipolar and relatively flat outflow.



In addition to these structures we also found two additional features. A curved structure observed in SO and SiO presenting a gradient in velocity, which seems to be compatible with an accelerated gas, and some southern blobs compatible with an outflow observed in infrared emission at the HST.

In summary, *the structures observed present a multiplicity of outflows and a really complex velocity field towards VY CMa.*



Sketch of the strucutures in VY CMa

Conclusions

The structure of VY CMa has been found to be more complex than anticipated. We have obtained PV diagrams in different directions and created simple kinematic models to reproduces the features observed. We have detected a **variety of outflows arising at different directions and, in general, with no bipolar counterpart**. *This suggest the MHD scenario to explain the mass ejections in this RSG star*.

An approved ALMA program would complement these data to derive density and temperature maps of the structures observed.

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