A search for AGB binaries: the case of V Hydrae

Léa Planquart, Université libre de Bruxelles, **Lea.Planquart@ulb.be**

Supervisor: Alain Jorissen

ESO-supervisor: Claudia Paladini & Ana Escorza

Artistic view of V Hydrae, credits: ALMA, S. Dagnello

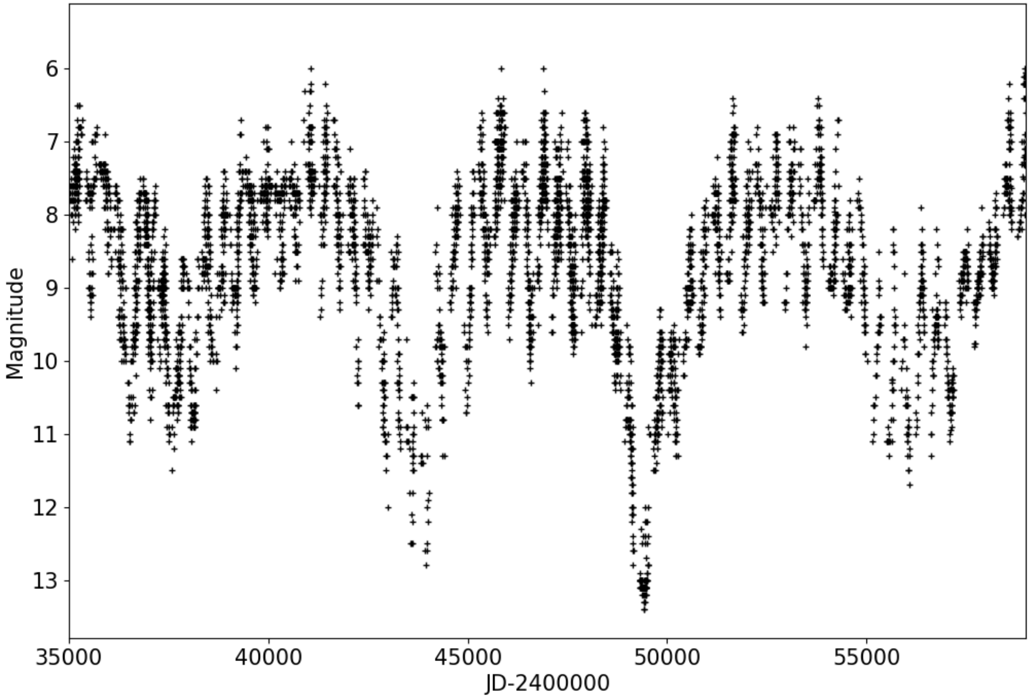
Context: Finding binaries among AGB stars

In the current paradigm, bipolar planetary nebulae (PN) are believed to be shaped by binary interaction (de Marco, 2009). However, due to their brightness and variability, there is a lack of observational evidence for binaries among their progenitors (AGB stars).

Best candidate: the carbon star V Hydrae

1) Suspected AGB-binary: UV-excess and 17-year variation in its light-curve (Knapp et al. 1997, Lloyd Evans et al. 1997, Sahai et al. 2008).

Lightcurve (AAVSO)



Context: Finding binaries among AGB stars

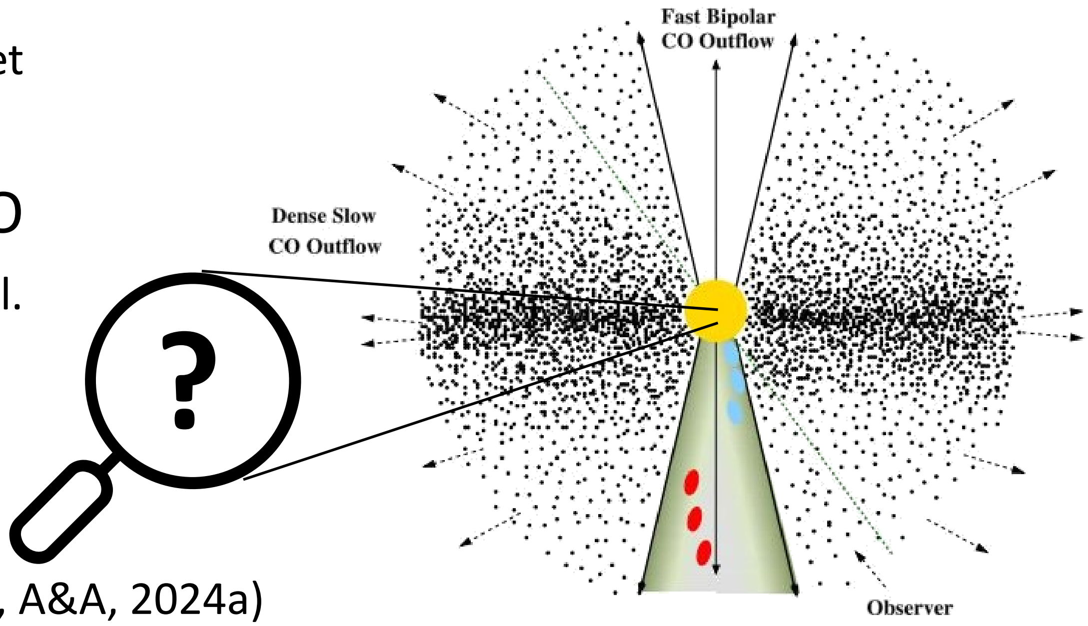
In the current paradigm, bipolar planetary nebulae (PN) are believed to be shaped by binary interaction (de Marco, 2009). However, due to their brightness and variability, there is a lack of observational evidence for binaries among their progenitors (AGB stars).

Best candidate: the carbon star V Hydrae

1) Suspected AGB-binary: UV-excess and 17-year variation in its light-curve (Knapp et al. 1997, Lloyd Evans et al. 1997, Sahai et al. 2008).

2) Pre-(bipolar) planetary nebula: asymmetric CO outflows mapped in radio (Knapp et al. 1994, Hirano et al. 2004, Sahai et al. 2022).

Sketch of the system outflows

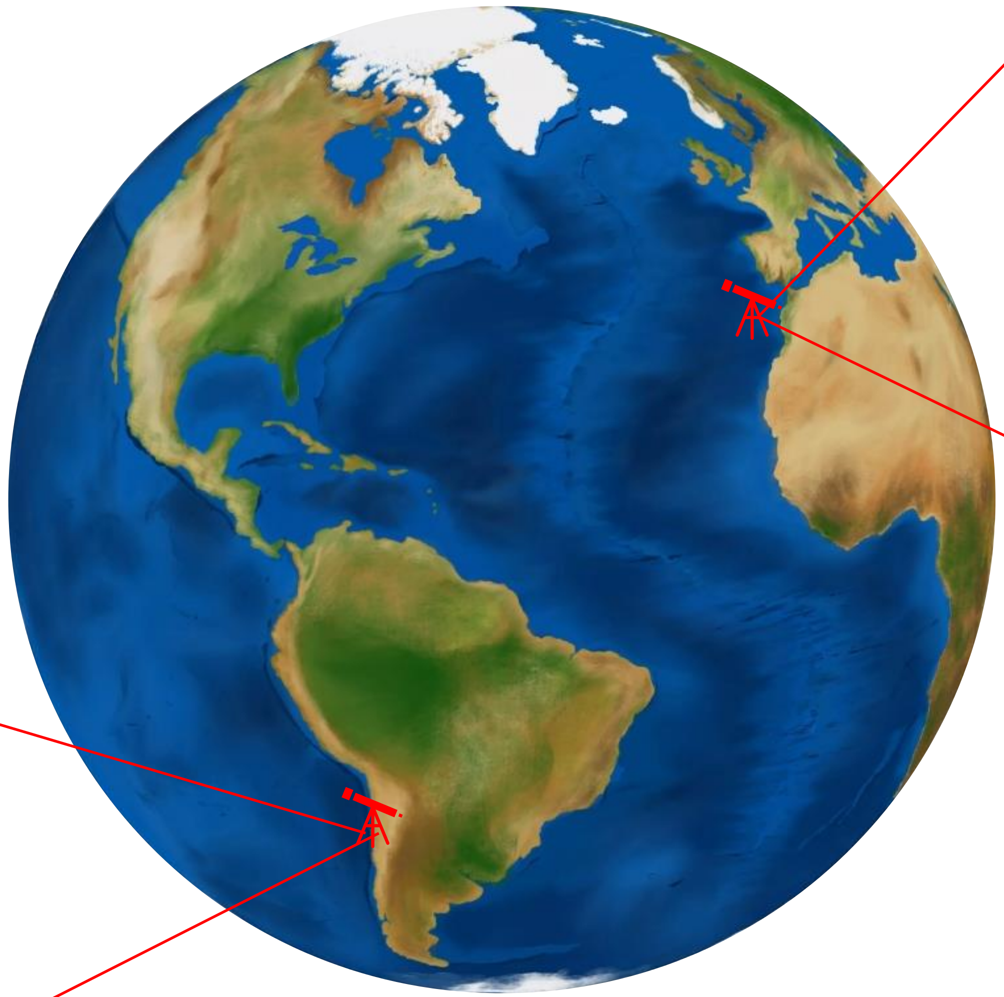


Scibelli et al. 2019

Multi-instrumental study

I. Temporal constraints: Orbit & Gas (Planquart et al., A&A, 2024a)
II. Spatial constraints: Dust & Companion (Planquart et al., A&A,2024b)

The observations



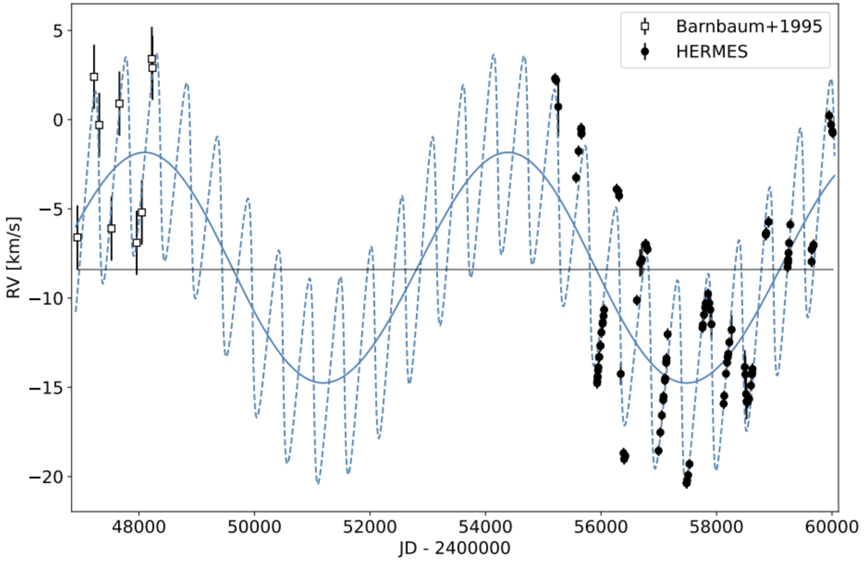
Spectroscopic monitoring with Mercator/**HERMES** since 2011 ∈ “long-period evolved binaries“ program (PIs: Van Winckel/Jorissen)

Interferometric observation with VLTI/**MATISSE** in Spring 2022 ∈ BIN-AGB Large Program (PI: Paladini)

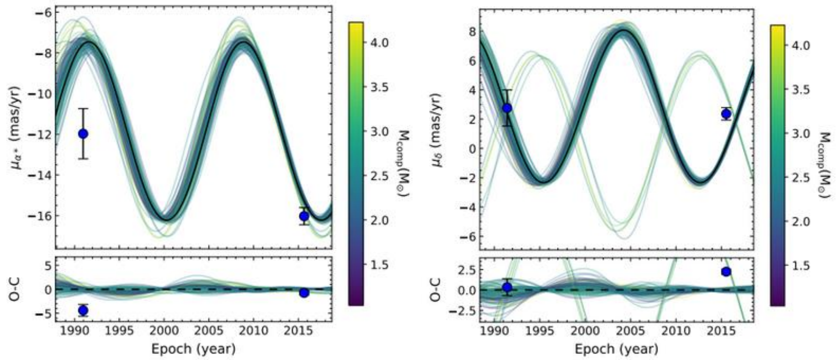
The orbit retrieval from spectroscopy

Method: Radial-velocity (RV)-monitoring, cleaned from pulsation, combined with proper motions to obtain the orbital parameters (orvara technique, Brandt et al. 2020)

- RV-curve from HERMES spectrograph



- Proper motion from Gaia& Hipparcos



Orbital parameters

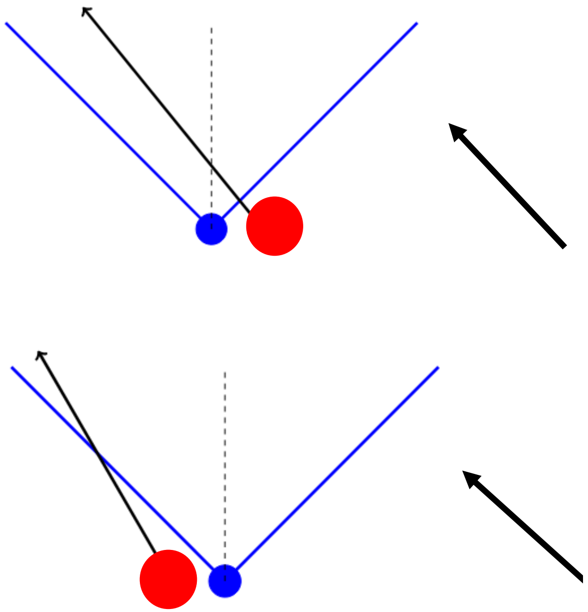
Parameter	Value
inclination (deg)	$37.7^{+2.2}_{-2.0}$
ascending node (deg)	$159.7^{+3.0}_{-3.3}$
mean longitude (deg)	$49.9^{+2.6}_{-2.4}$
period (yrs)	$17.45^{+0.34}_{-0.29}$
eccentricity	$0.024^{+0.027}_{-0.017}$
semimajor axis (mas)	$25.8^{+2.9}_{-3.6}$
a (AU)	$11.2^{+1.2}_{-1.5}$
T0 (JD)	2458684^{+2128}_{-2582}
mass ratio	$1.36^{+0.68}_{-0.29}$

-The obscuration events are associated with the superior conjunction
- "V Hya B" is likely to be a main-sequence star
- Degeneracy on the rotation direction

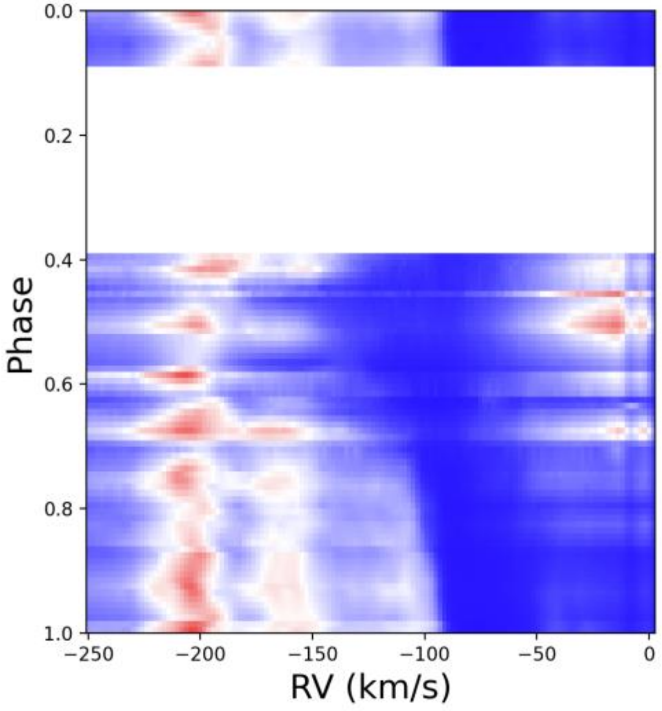
Modelling the spectral lines modulation

Data: Varying high-velocity blue-shifted absorption in the resonant lines of Na I and K I
Methods: Spatio-kinematic model of a conical gaseous jet attached to the companion, developed for Hα in post-AGB binaries (Bollen et al., 2022)

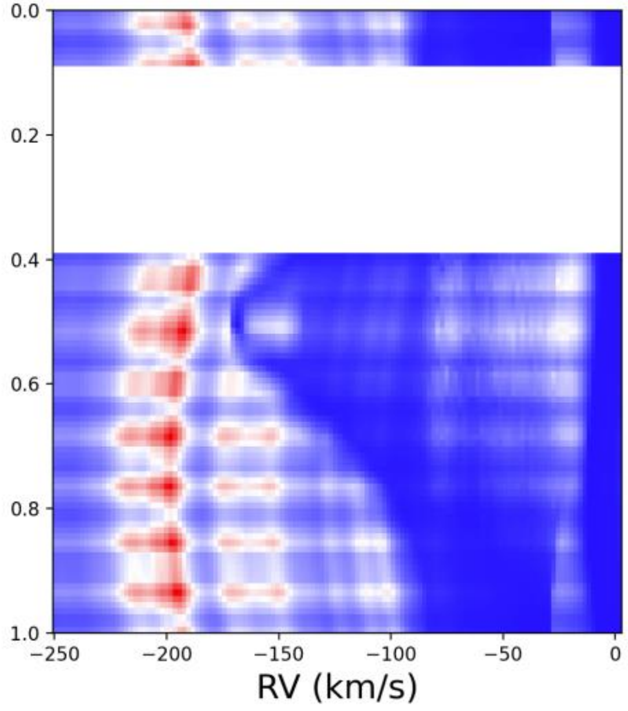
- Superior Conjunction
  $\phi = 0.5$
- Inferior Conjunction
  $\phi = 0 \; or \; 1$



Dynamic spectrum of Na D1 (5895.92 A)

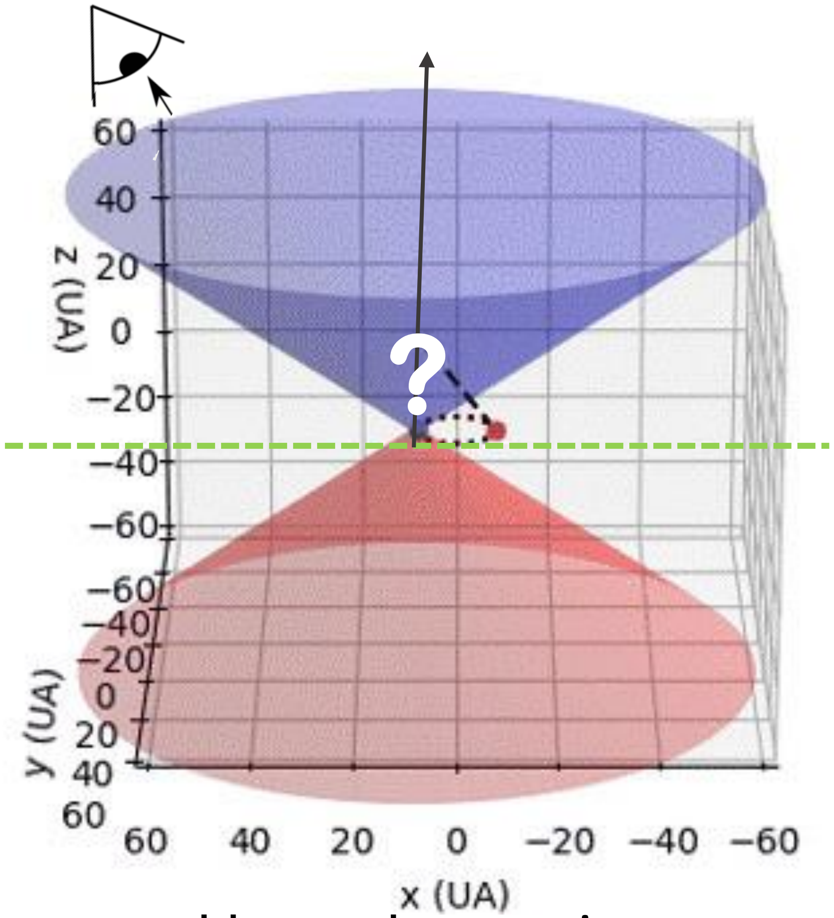


Best-fitting model

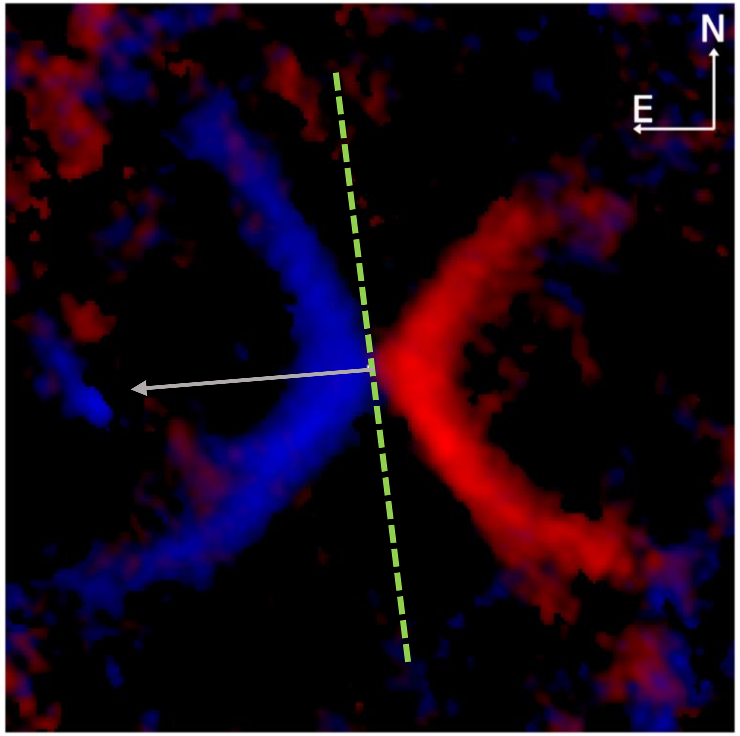


Link with the hourglass nebula

Best-fitted structure: hollow wide-open cone, opening angle of 65° and v_{max} = 190 km/s.



The spatio-kinematic model bears the same orientation/geometry as the large-scale observation of the molecular jet.

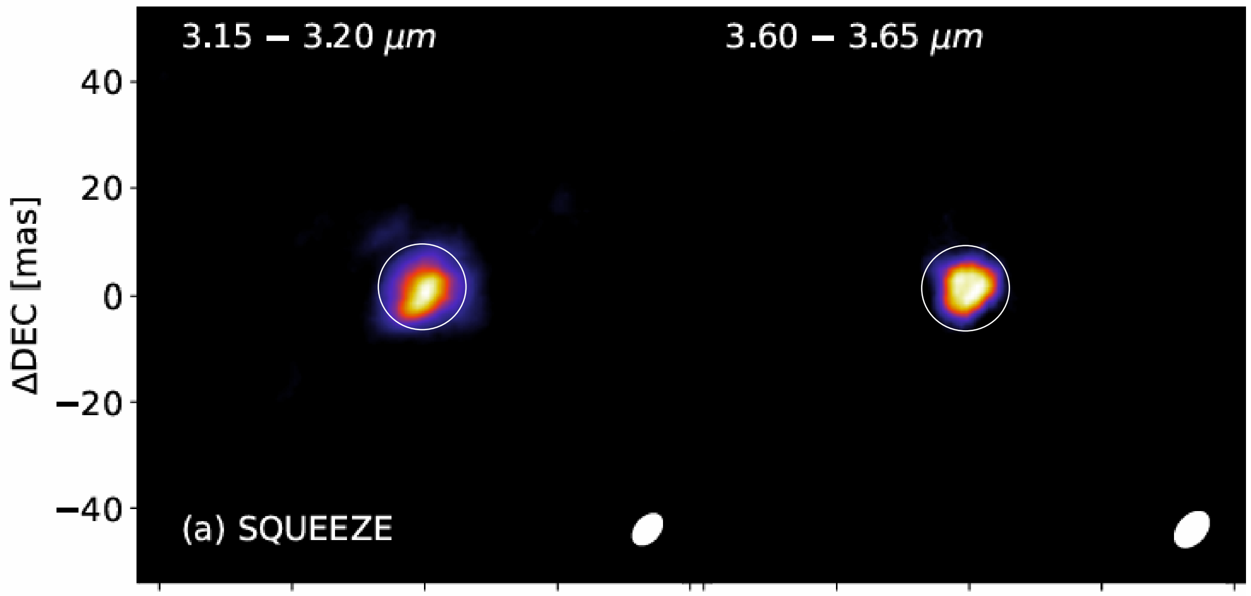


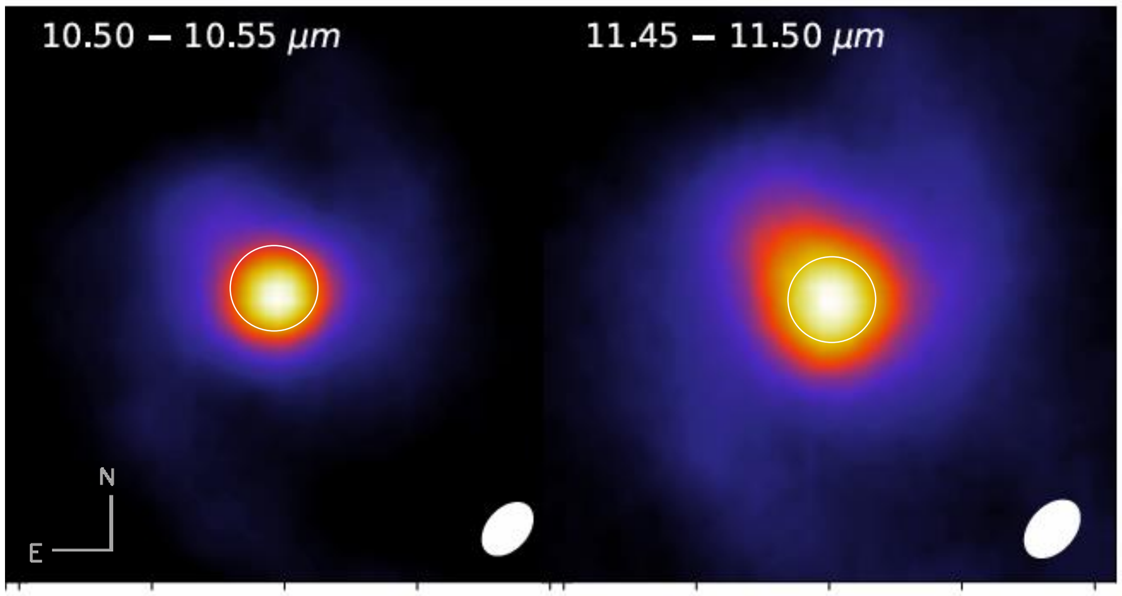
ALMA, 12CO map -/+ 100km/s

Deep and long obscuration occurring at SC. Is there also dust involved?

Probing the dust-forming region with MATISSE

Methods: Image reconstruction of the close circumstellar environment using VLTI/MATISSE observation in the L (3-4 μm) and N (8-12 μm) bands.





$C_2H_2 + HCN$ absorption

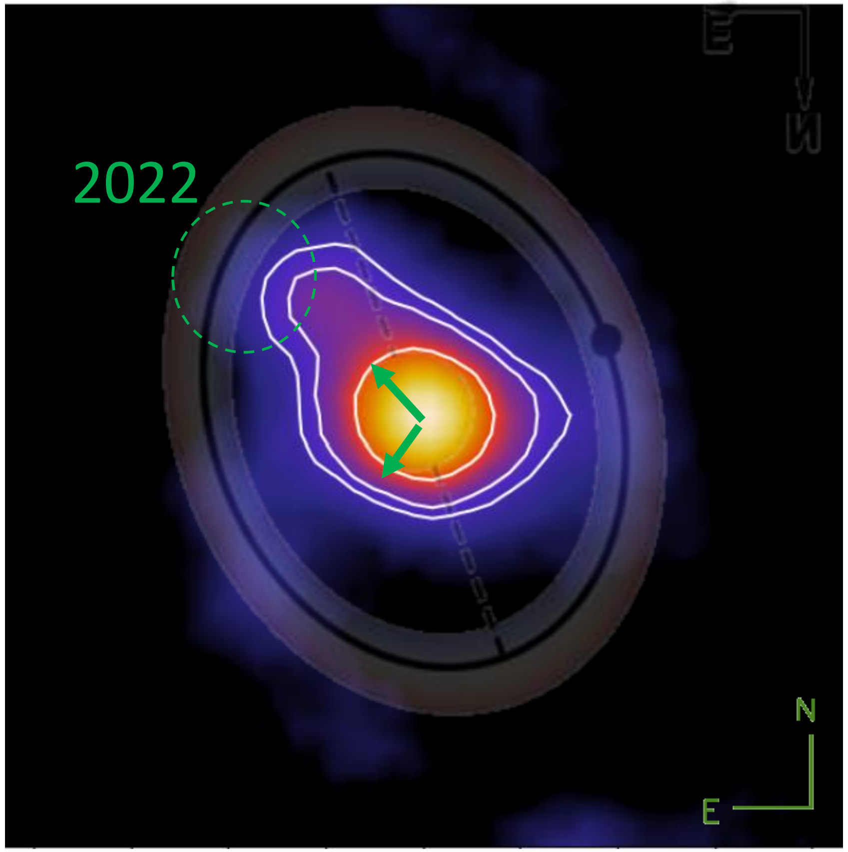
Pseudo-continuum

AmC emission

SiC emission

An impressionist & dynamic view of V Hya

Comparison of the orbit prediction with the reconstructed images



Field of view of 80x80 mas
spectral bandwidth: 10.5->11.5 µm

- Dusty clump position (distance and orientation) is compatible with the orbital prediction, assuming the clockwise rotation.
- Dynamical change of morphology compared with MIDI observations (from 2009).

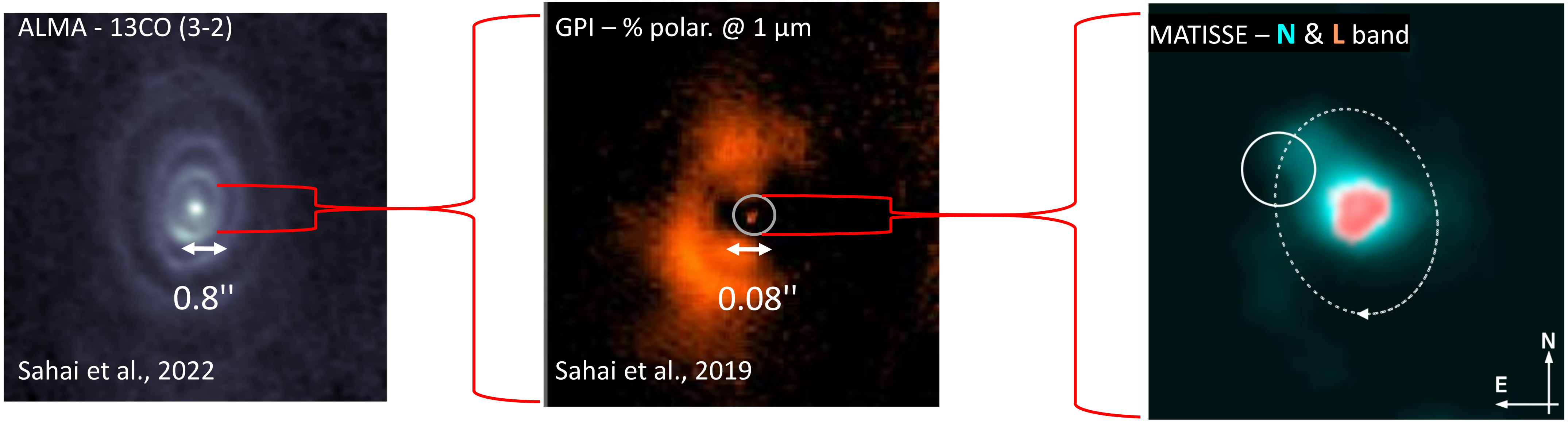
The northeast clump could be related to enhanced (dust) particles surrounding the companion.

What is inside the complex nebula?

Six concentric rings and a bipolar jet…

… A thick dusty torus…

… An AGB star & an Asymmetric Giant Blob.



Asymmetric morphology from large-scale (bipolar nebula, dust enshrouded) to the innermost part, hinting at a common shaping mechanism originating at the scale of the orbital separation.

Take-home message

I. Orbit & Gas

From spectroscopic monitoring: 17 yr orbit and a phase-dependent gaseous jet, modeled as a conical jet attached to the companion, consistent with a large-scale hourglass structure.

II. Dust & Companion

From the mid-infrared images: detection of asymmetries. By incorporating the orbital prediction, these features are interpreted as a particle/dust enhancement around the unresolved companion.

=> Further evidence that binary interaction shapes the bipolar nebula of late AGB stars.

Prospects and open questions

- ❑ How to model the light-curve dimmings? To obtain a phase-dependent dust distribution around the system and understand the gas-dust interaction.
- ❑ How is the jet launched? To constrain the launching mechanism of the jet using magneto-hydrodynamic models and to locate the gaseous jet.