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A search for AGB binaries: the case of V Hydrae

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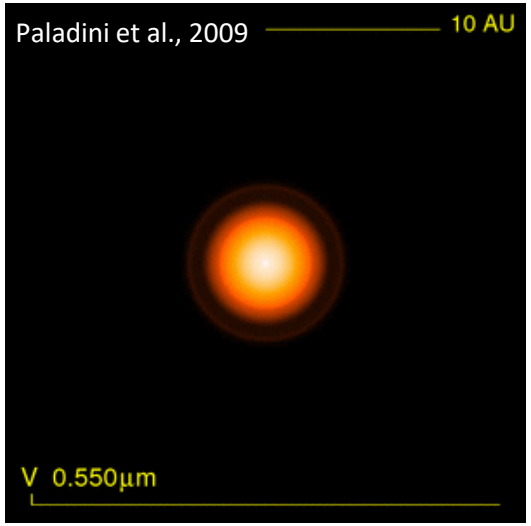
The BIN-AGB team

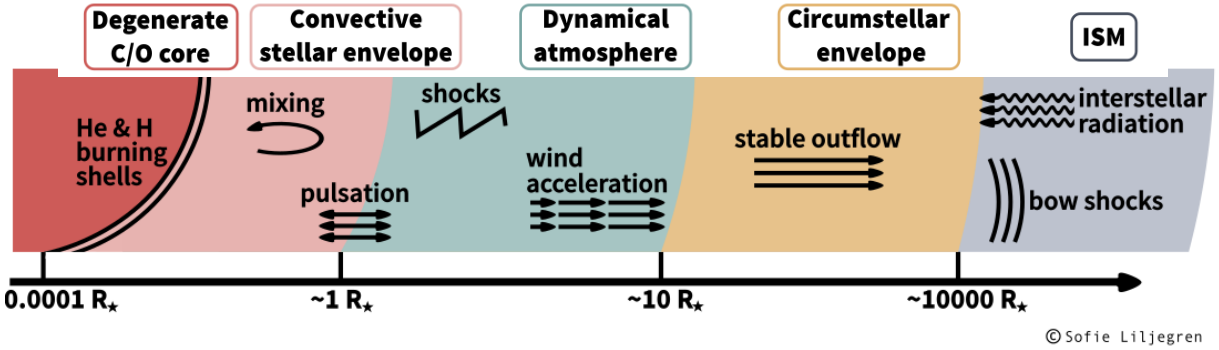
Artistic view of V Hydrae, credits: ALMA, S. Dagnello

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: the AGB stars.

AGB Star





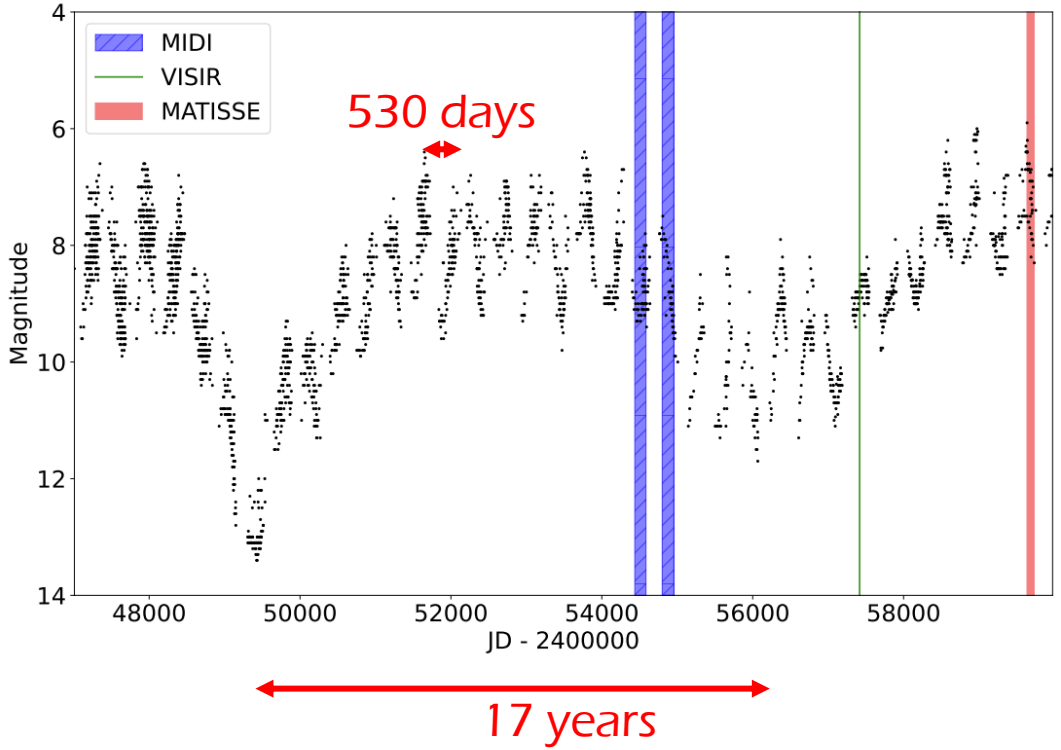
Planetary nebulae

>80% Bi- multi- polar structure

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).

Light curve (AAVSO)



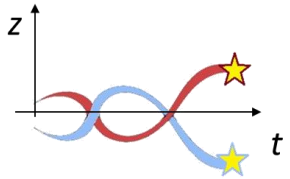
Candidate: the carbon star V Hydrae

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).

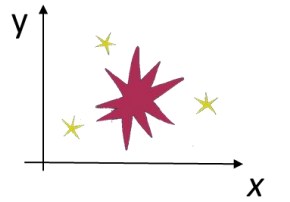
2) Pre-(bipolar) planetary nebula: asymmetric CO outflows mapped in radio (Knapp et al. 1994, Hirano et al. 2004, Sahai et al. 2022).

Multi-instrumental study

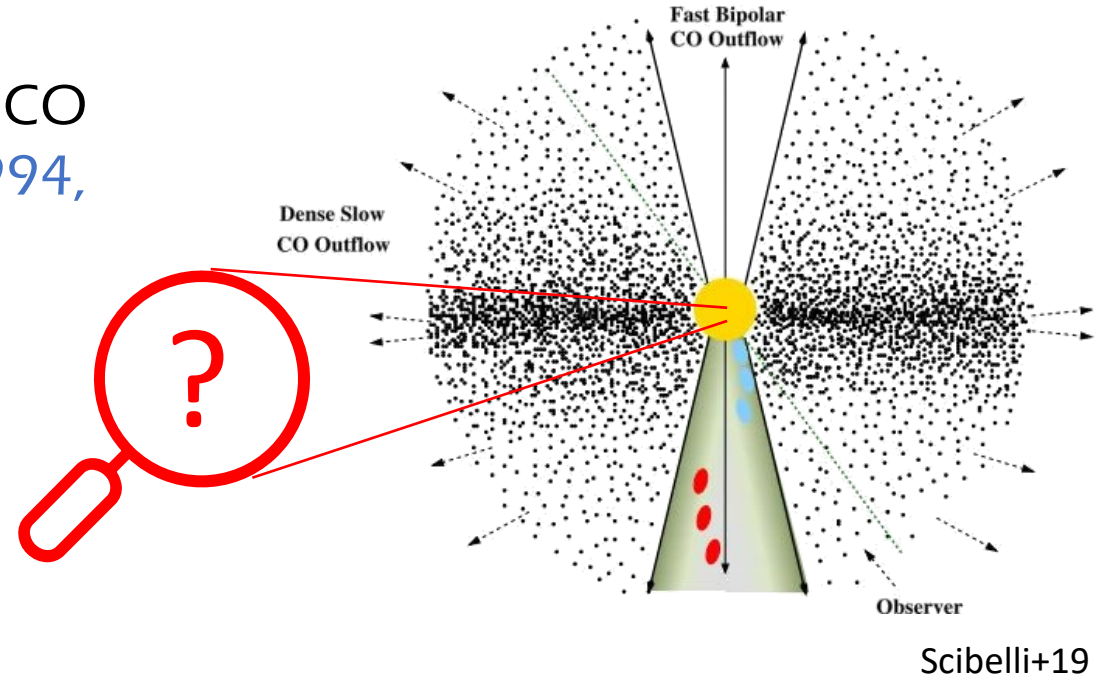
I. Temporal constraints (link: Planquart et al. 2024a)



II. Spatial constraints (link: Planquart et al.,2024b)



Sketch of the system outflows

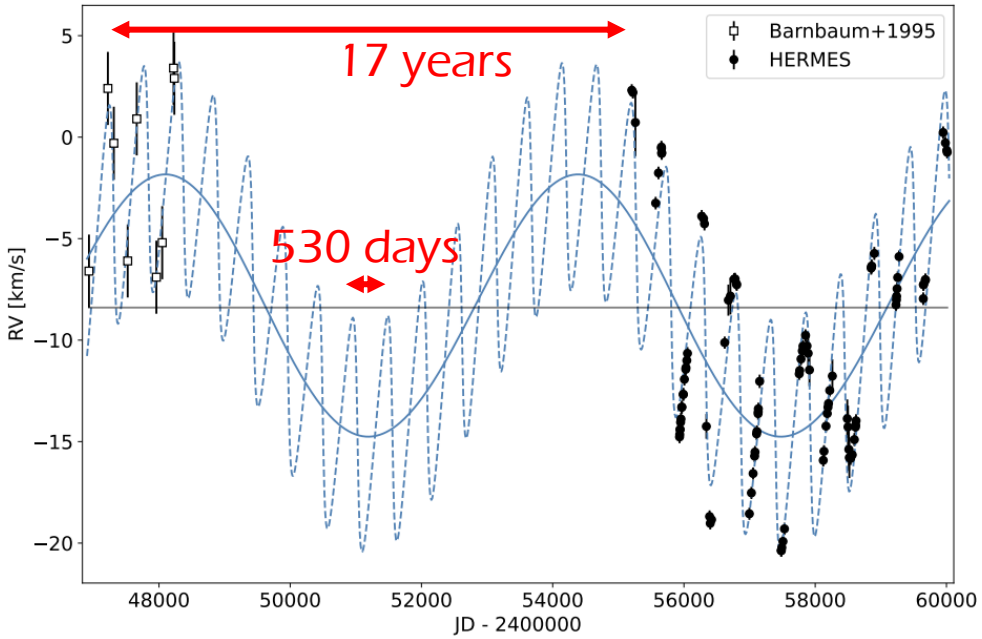


Scibelli+19

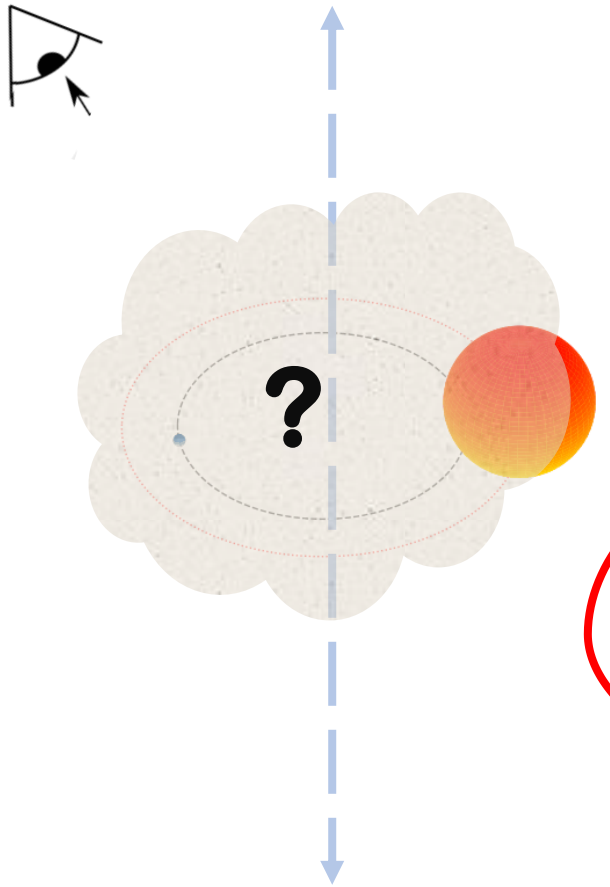
The dynamic view of the system

Long-term monitoring with HERMES spectrograph, to disentangle the stellar pulsation of the AGB from its orbital motion.

Radial-velocity curve



Gaseous polar jet ~150km/s



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	$1.36^{+0.68}_{-0.29}$

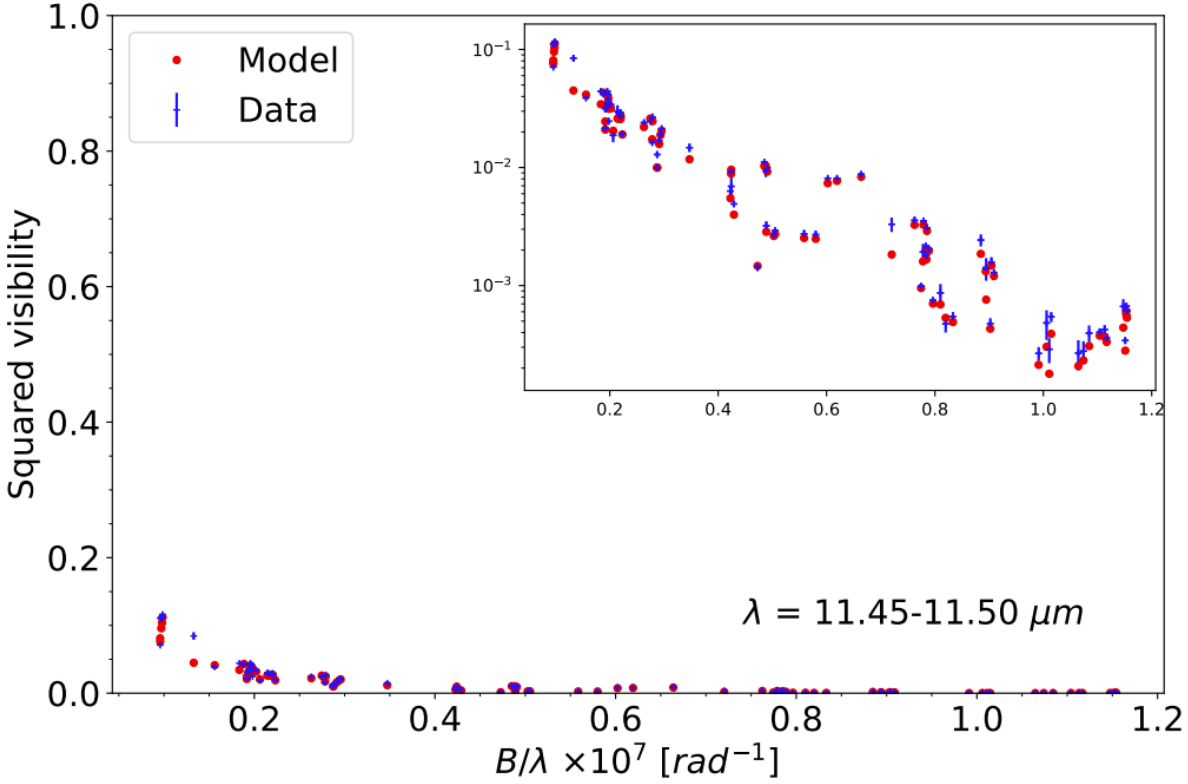
In MATISSE F.O.V.

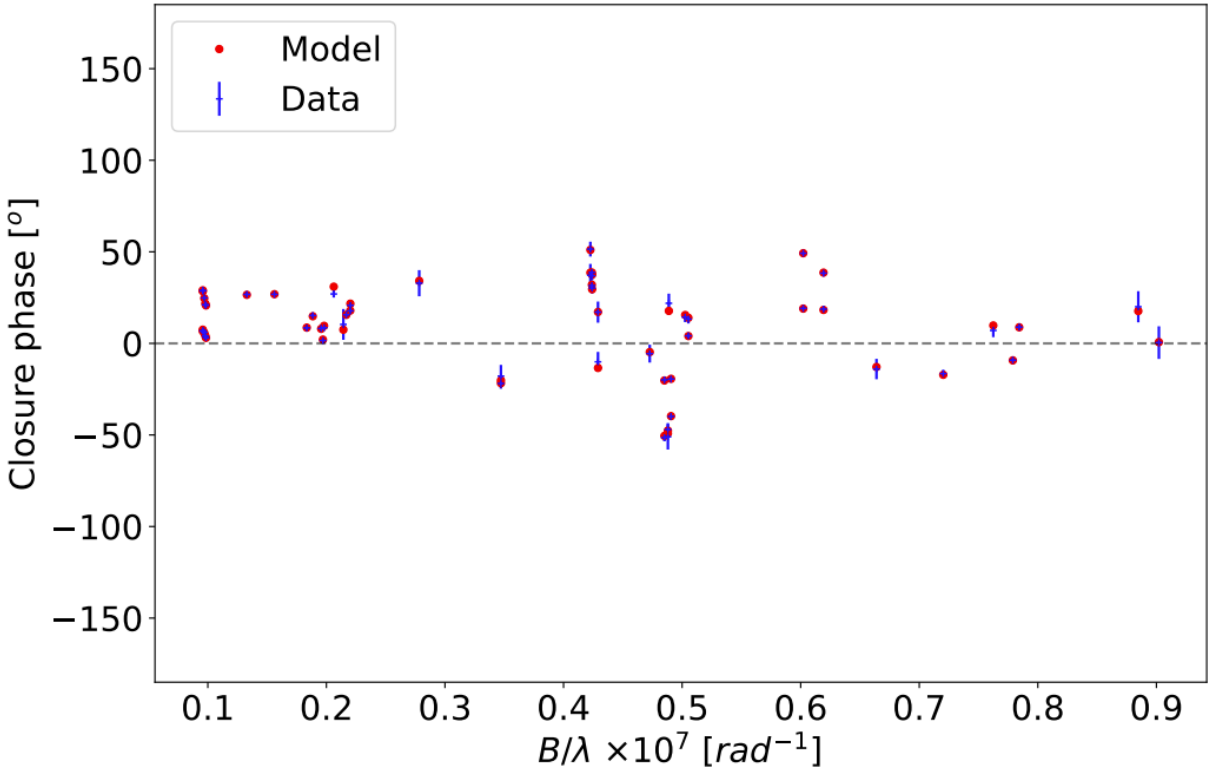
Deep obscuration (3 mags). How is the dust distributed around the system?

Interferometric observables

Observation with VLTI/**MATISSE** in Spring 2022 ∈ BIN-AGB Large Program (PI: Paladini)
In low spectral resolution mode (*R* = 30), in the L and N band

N-band data



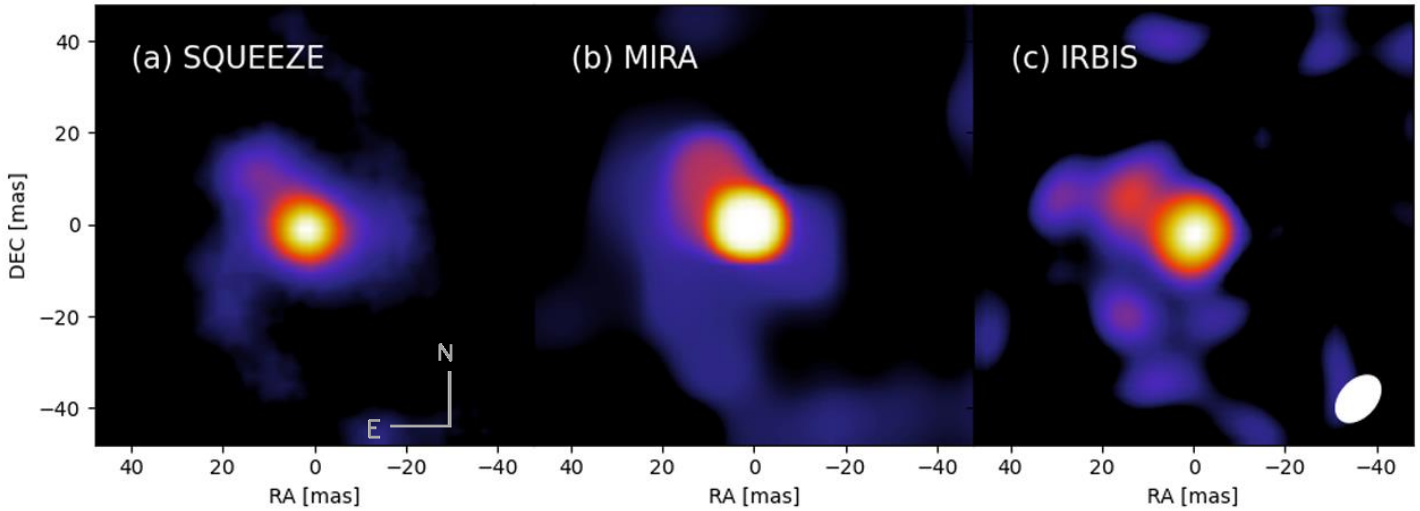


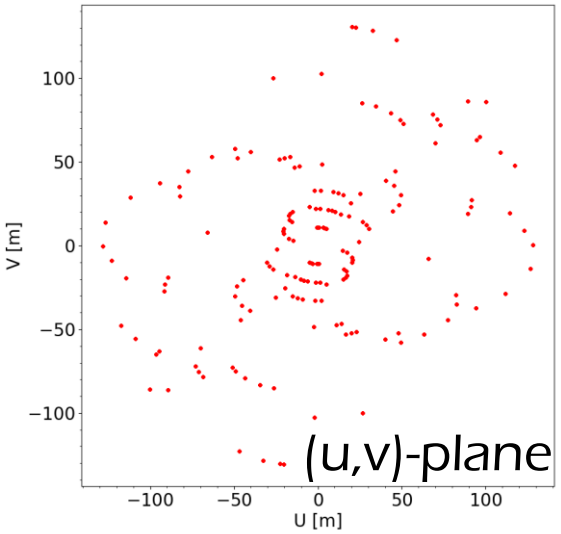
Low squared visibility
=> Extended background emission

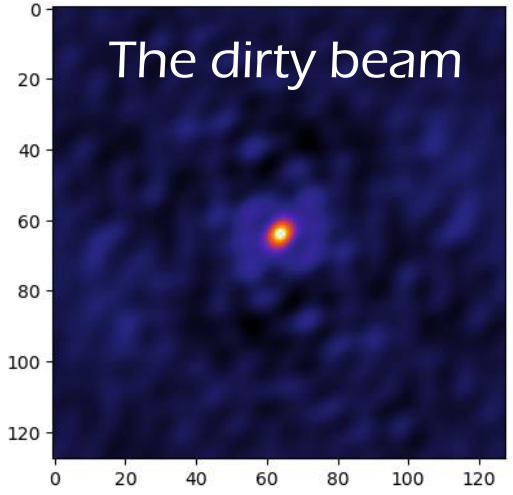
Non-zero closure phase
=> Asymmetrical morphology

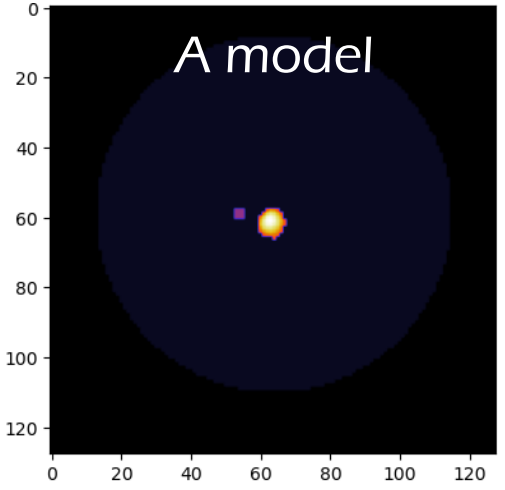
Image reconstruction

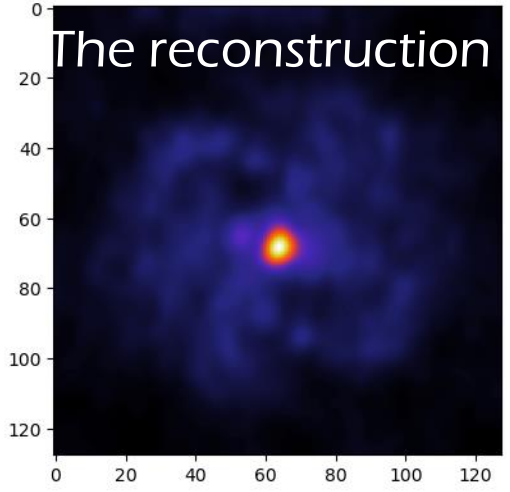
- Images reconstructed using SQUEEZE (Baron, 2010), MIRA (Thiébaut, 2008), and IRBIS (Hofmann et al., 2014) to assess the inversion method
- Simulations to assess the effect of the (u,v)-plane coverage **=>spiral-shaped artifact**



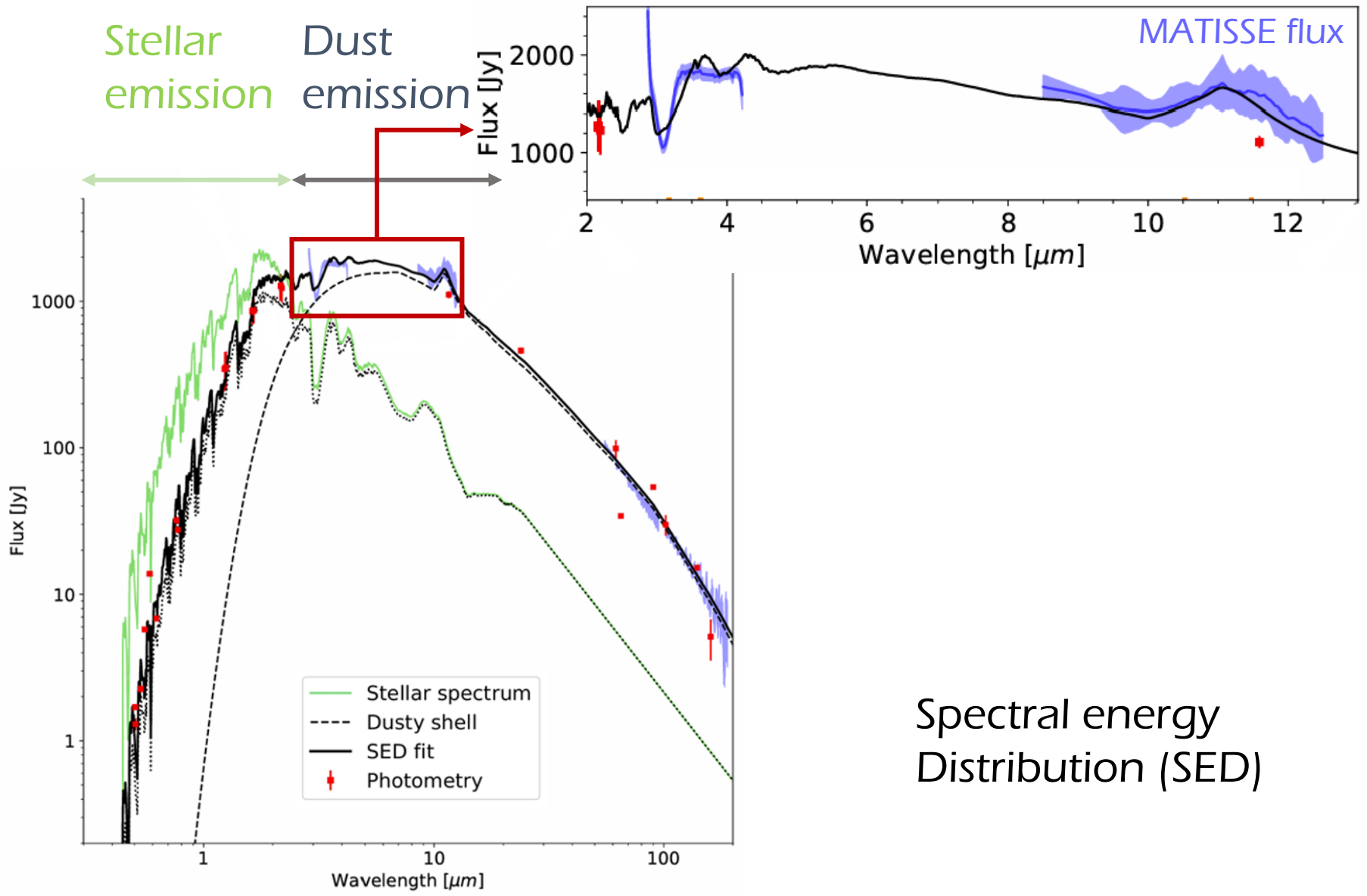






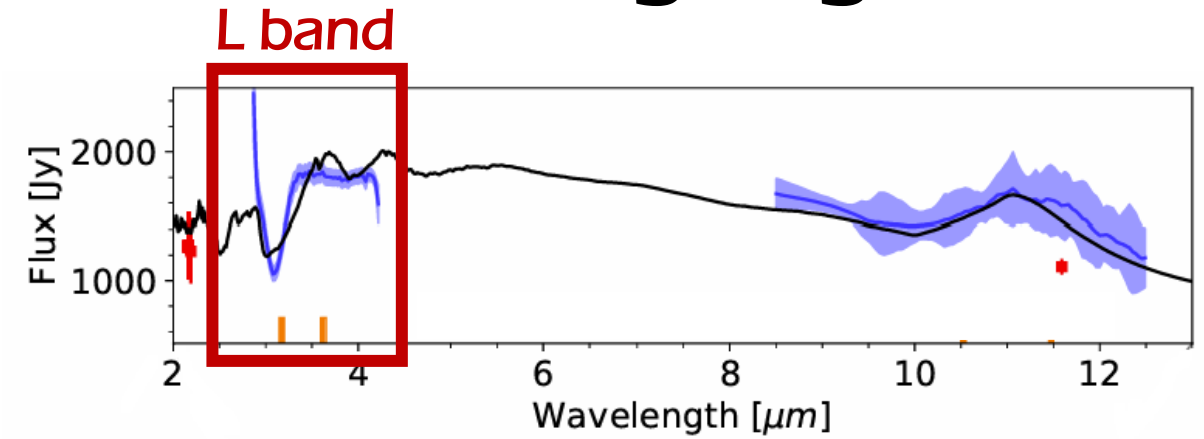


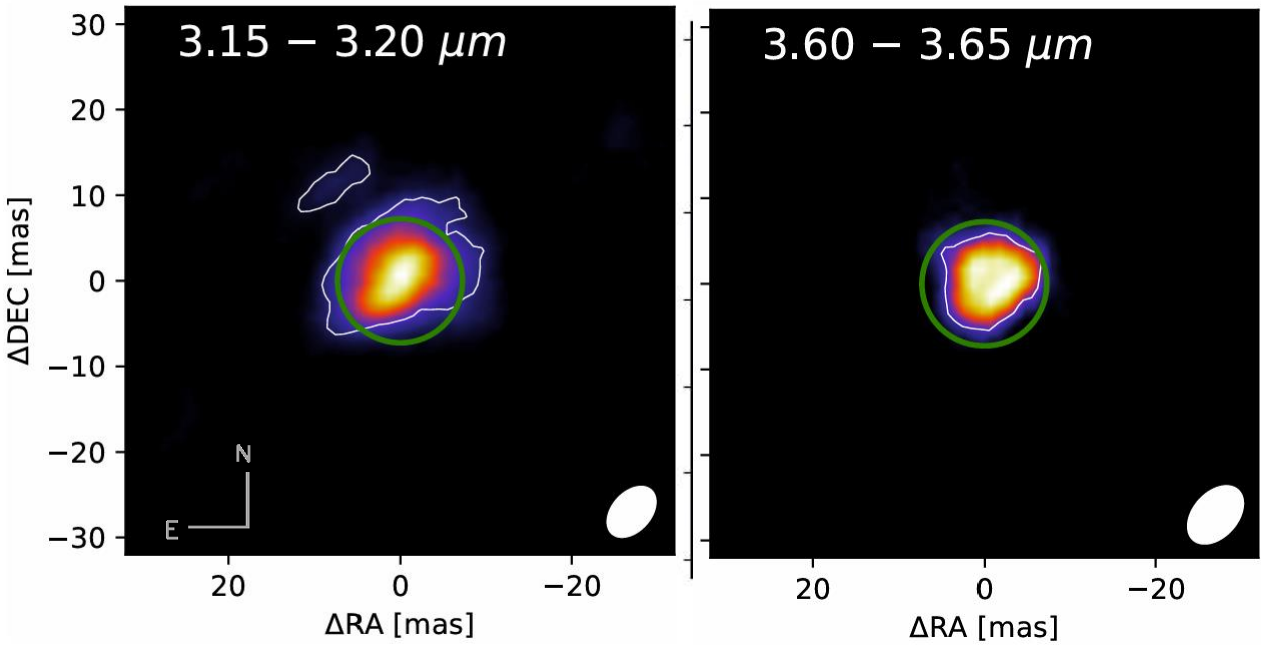
Probing the dust-forming region



Spectral energy Distribution (SED)

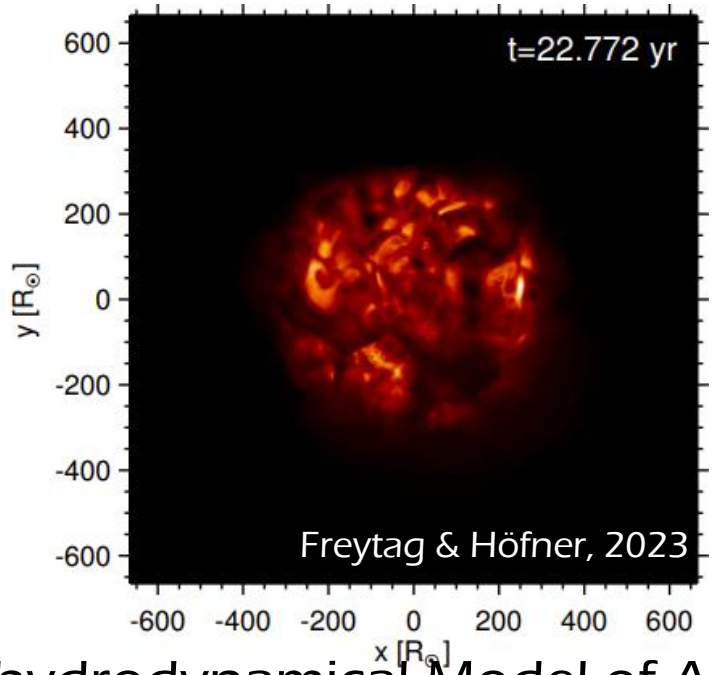
Probing the dust-forming region





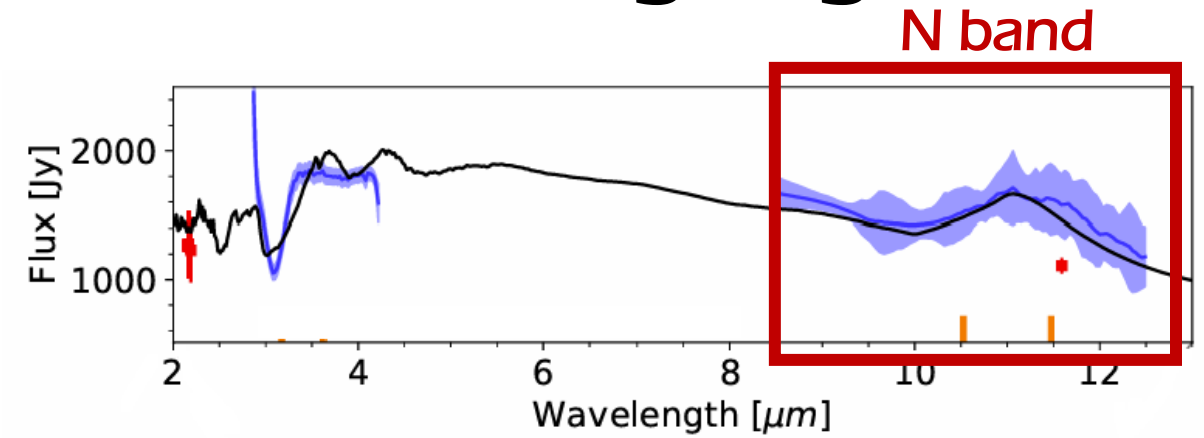
C_2H_2 + HCN absorption

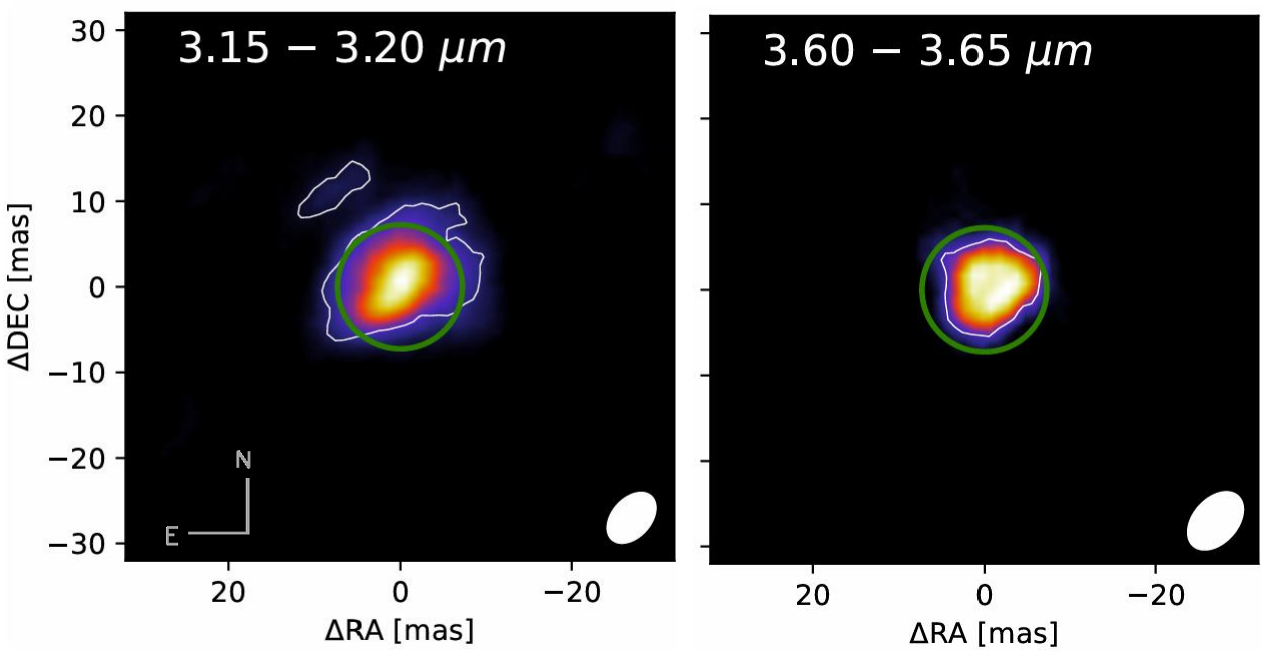
Pseudo-continuum



3D hydrodynamical Model of AGB

Probing the dust-forming region





C_2H_2 + HCN absorption

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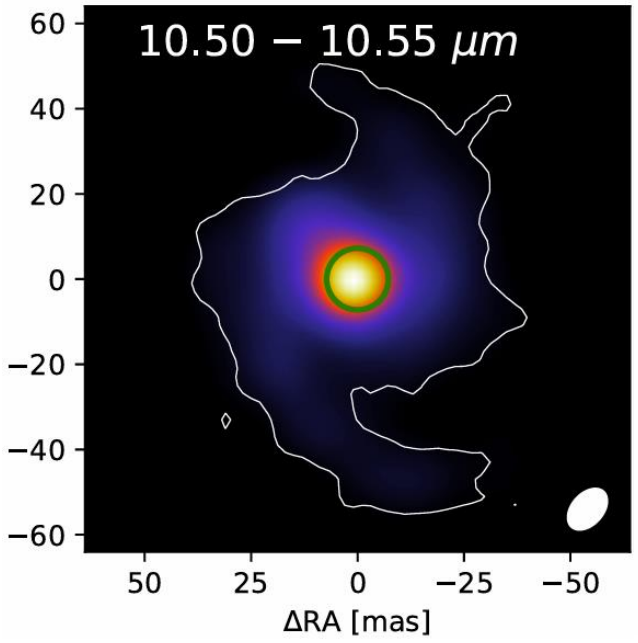
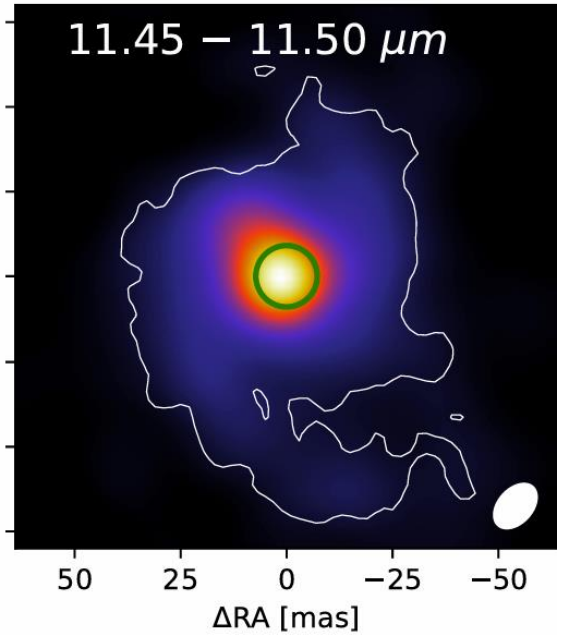


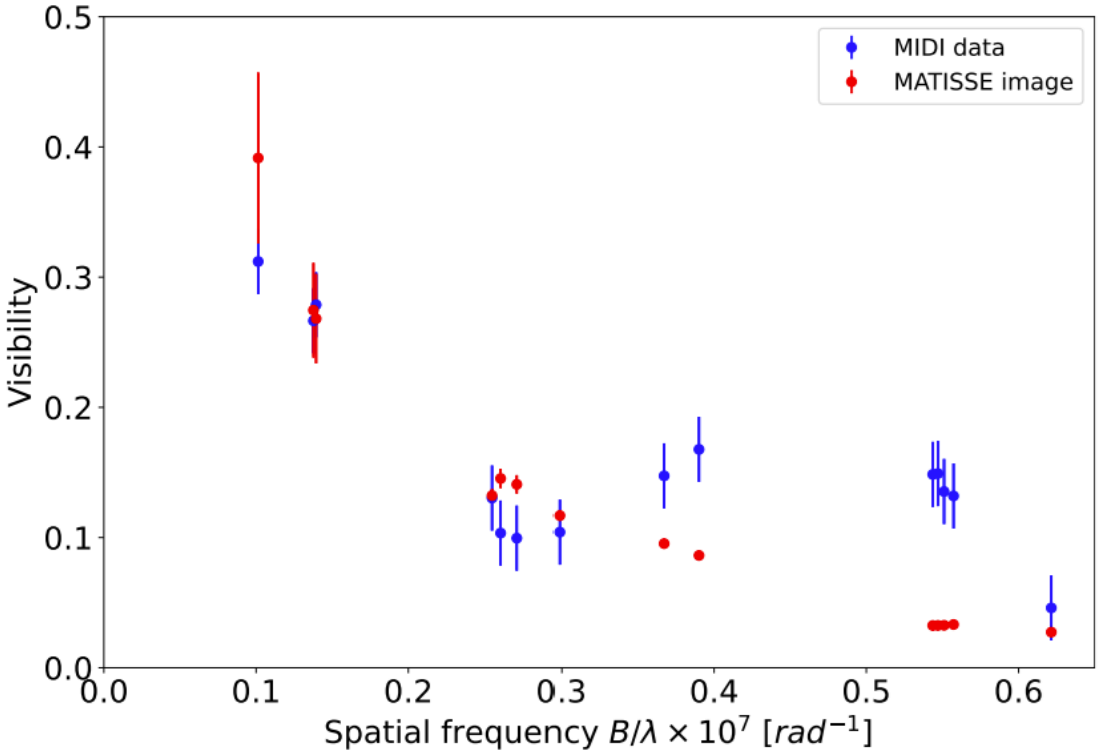
amC emission



SiC emission

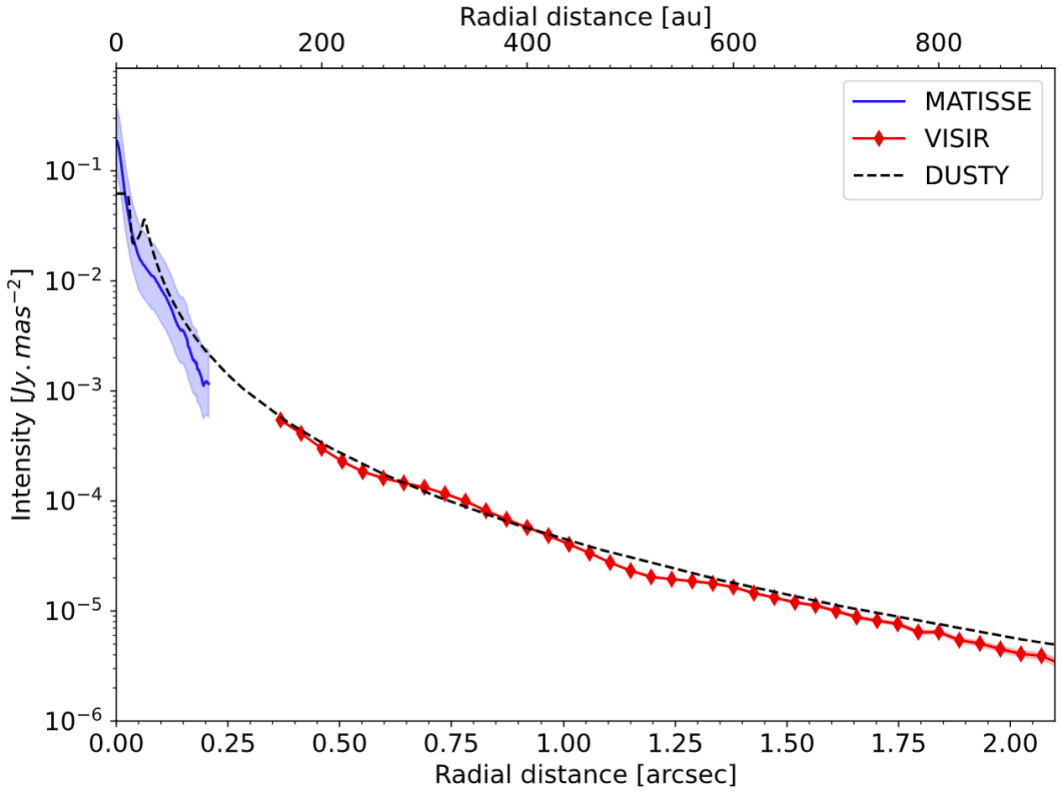
Complementary observation in N-band

Comparison with VLTI/MIDI data (in 2009)
Sparse (u,v)-plane coverage & no closure phase: Comparison of visibility at same (u,v) points.



- Dynamical process shapes the circumstellar environment

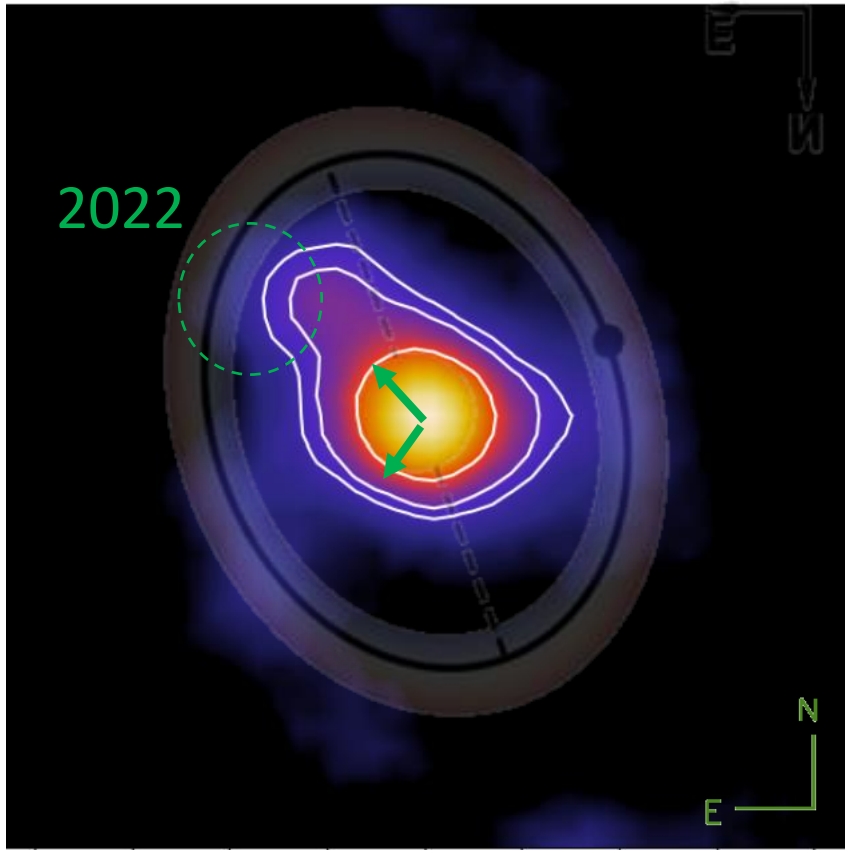
Large-scale observation with VISIR
coronographic mode combined with flux-calibrated MATISSE image.



- Consistent with a model of a spherical dust shell following a r^{-2} distribution

An Impressionist 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.

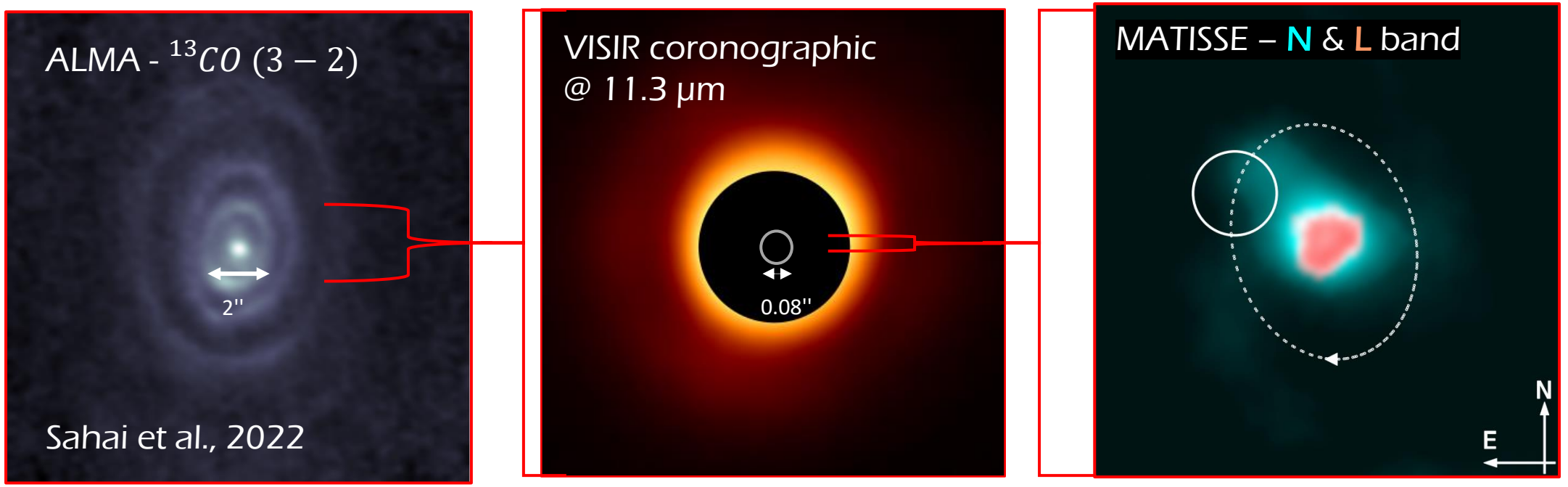
➢ The northeast clump could be related to the presence of enhanced (dust) particles surrounding the companion.

What is inside the nebula ?

Six concentric rings and a bipolar jet...

... A large circular dusty shell...

... An AGB star and an asymmetric giant blob.



The asymmetric morphology from the large-scale to the innermost part hints at a common shaping mechanism that originates at the scale of the orbital separation.

Take-home message

- ✓ The MATISSE images (probing the first 10 R_*) reveal that the circumstellar environment of V Hydrae is shaped by **non-spherical** processes and that the dust-forming region undergoes a **dynamical** change of morphology.
- ✓ The image asymmetries combined with the orbital prediction are compatible, suggesting that the **extension is likely to be linked to a (dust) particle enhancement surrounding the unresolved companion.**
- ✓ Further evidence that binary interaction shapes the bipolar nebula of late AGB stars.

Prospects and open questions

What's the impact of different chemistry and binarity on the inner CSE of AGBs?
⇒ The BIN-AGB large program.
For V Hya: What is the 3D structure of the dust clump surrounding the companion?
⇒ To obtain a phase-dependent dust distribution around the system and model the gas-dust interaction.
To extend to other types of binary involving a giant star, such as symbiotic systems

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