Asymmetries start in the AGB phase

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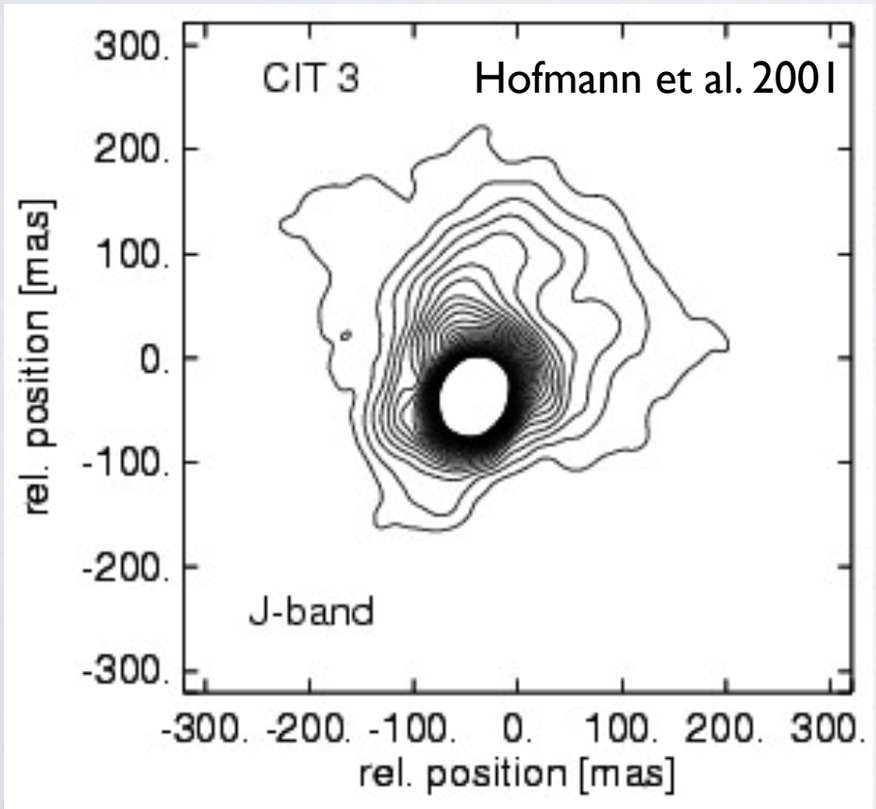
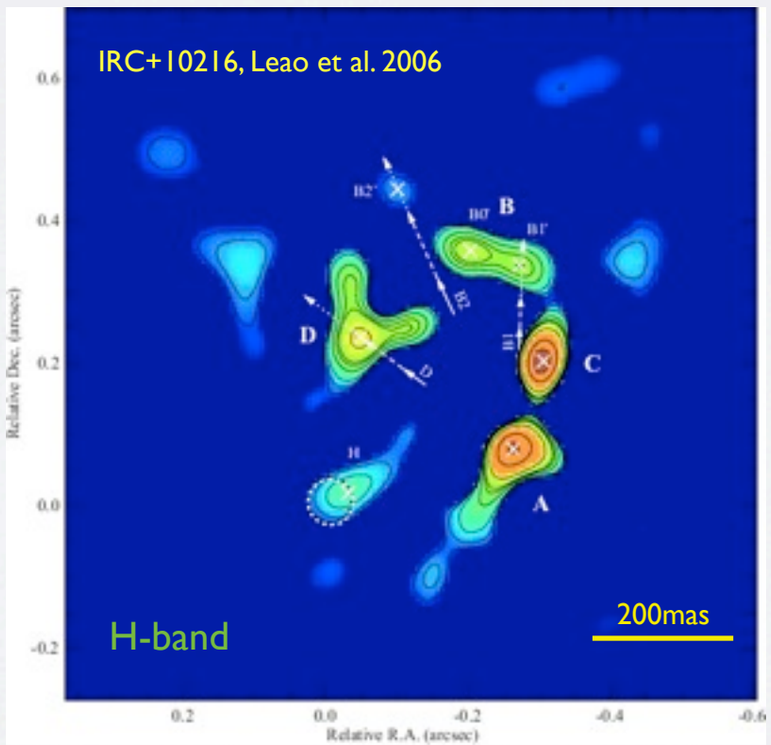
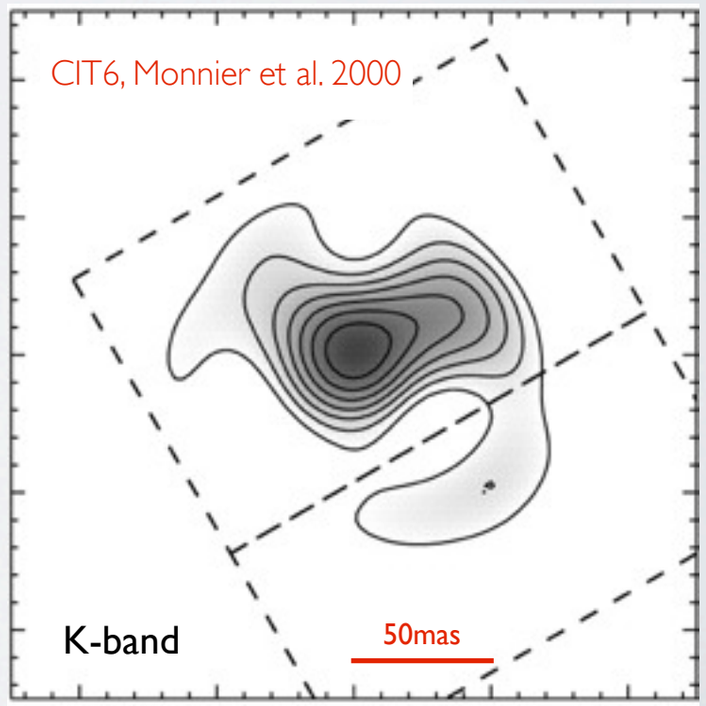
Why do we look at AGB stars?

- We have been studying asymmetries (bipolar ejections, torii, disks, ...) in PNe and post-AGB stars for decades, but we mention that they should be initiated in the AGB phase.
- Current consensus is that binarity is the main shaping agent for the majority of PNe. But can we observe this in AGB stars? What other asymmetries can we observe?
  Some examples: Mira, W Aql, R Aqr, π_1 Gru, SS Lep, AFGL3068
- The circumstellar envelopes of AGB stars are thought/known to be spherical. Are they really? (talks by A. Mayer, C. Paladini, E. Lagadec, K. Ohnaka, S. Ramstedt, M. Leal-Ferreira)







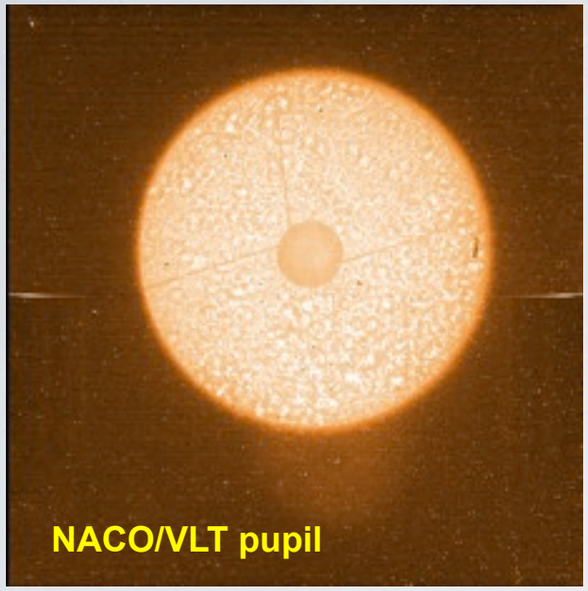
How do we observe them?

- Study circumstellar **hot, dusty** environment at **small spatial scales** (within <0.5" from the star).

- Use **interferometry** in the **near-infrared**. For very small spatial scales (<30mas), the VLTI is the main tool in the field (talk by Paladini).

- Or use interferometry on a single telescope, in this case **aperture masking**.
  - VLT 8.2-m telescope and NACO (J, H, K, L and M)
  - a selection of masks for **excellent uv-coverage** (baselines 0.5-m to 8-m)
  - need of bright targets (K<9 mag); AGBs are excellent candidates
  - **diffraction-limited** images (20mas in H) within a relatively **large f.o.v.** (~400mas)

Aperture masking in a nutshell



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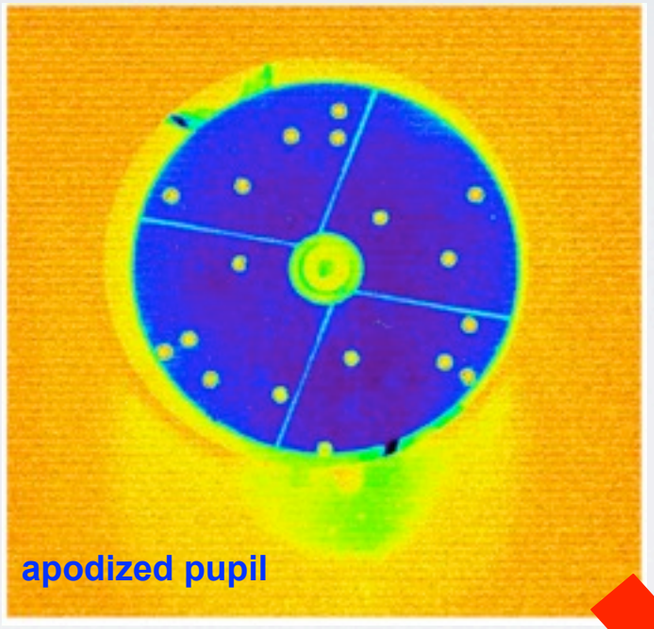

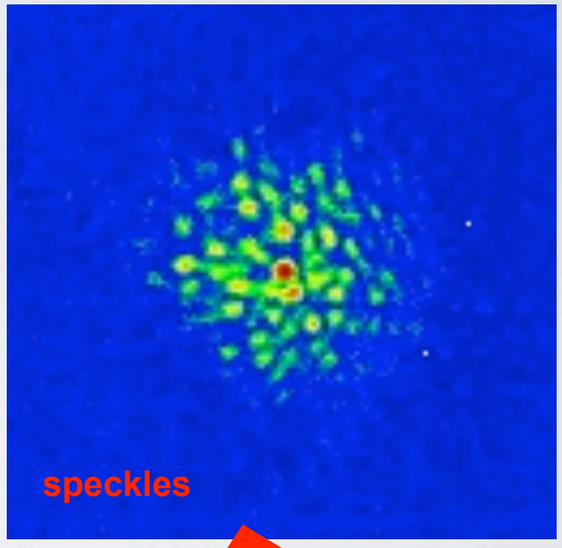

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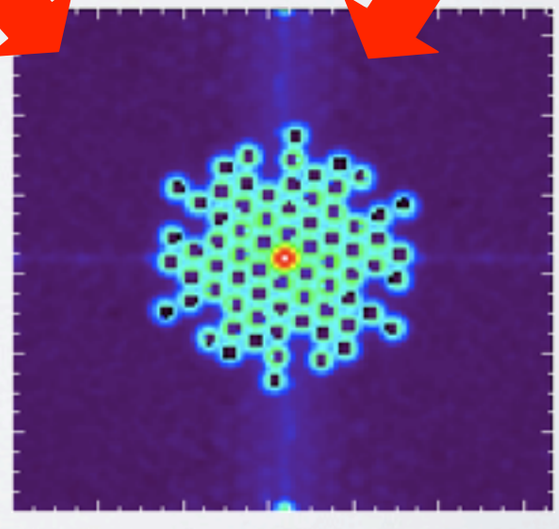


Roughly speaking the Fourier transform of the intensity will give you the visibility, which is complex, i.e. $|V| * \exp(-i2\pi\varphi)$. This is what we measure here.

The case of the C-rich V Hya

An AGB star in transition to post-AGB with a peculiar variability
590 days pulsation period (ΔV~1.5 mag)
17 years obscuration event (ΔV~6 mag) possibly due to a companion (Knapp et al. 1999, Lloyd Evans 2009)

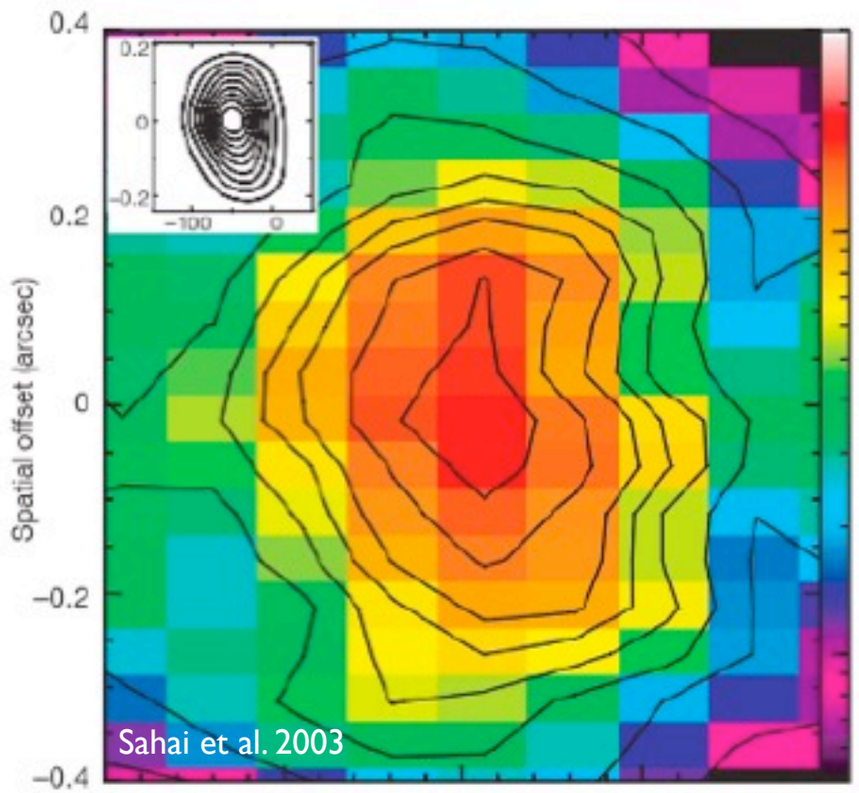
Bipolar, high-velocity jet ~150 km/sec in CO submm+near-IR (Hirano et al. 2004, Knapp et al. 1996, Sahai et al. 1988, etc)

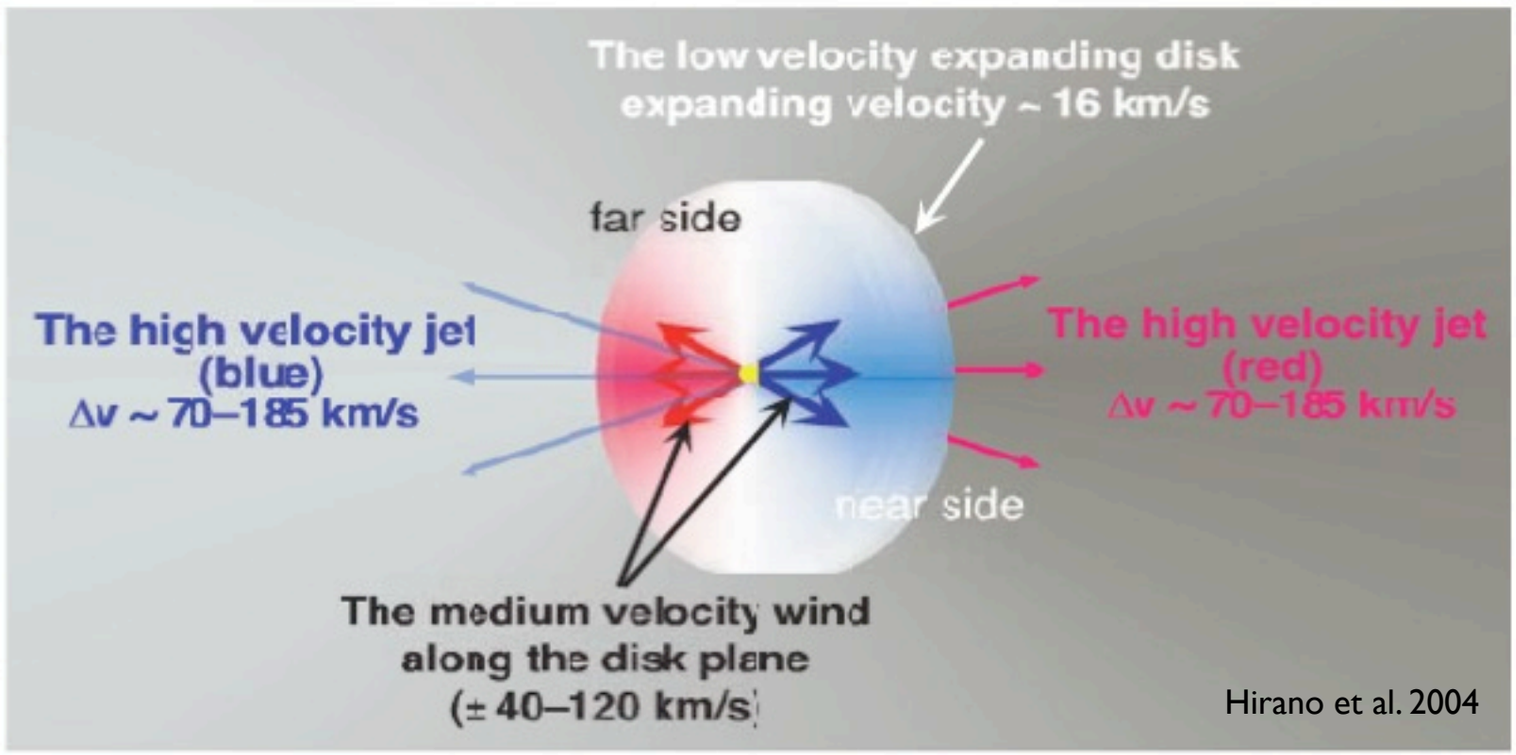
Submm CO with SMA revealed a gaseous torus, diameter~8" (Hirano et al. 2004)

Scattering in Hα from HST revealed a disk, diameter~0.5" (Sahai et al. 2003)

Two components (star+disk <150mas) were required for MIDI/VLTI observations (Zhao-Geisler et al. 2012)

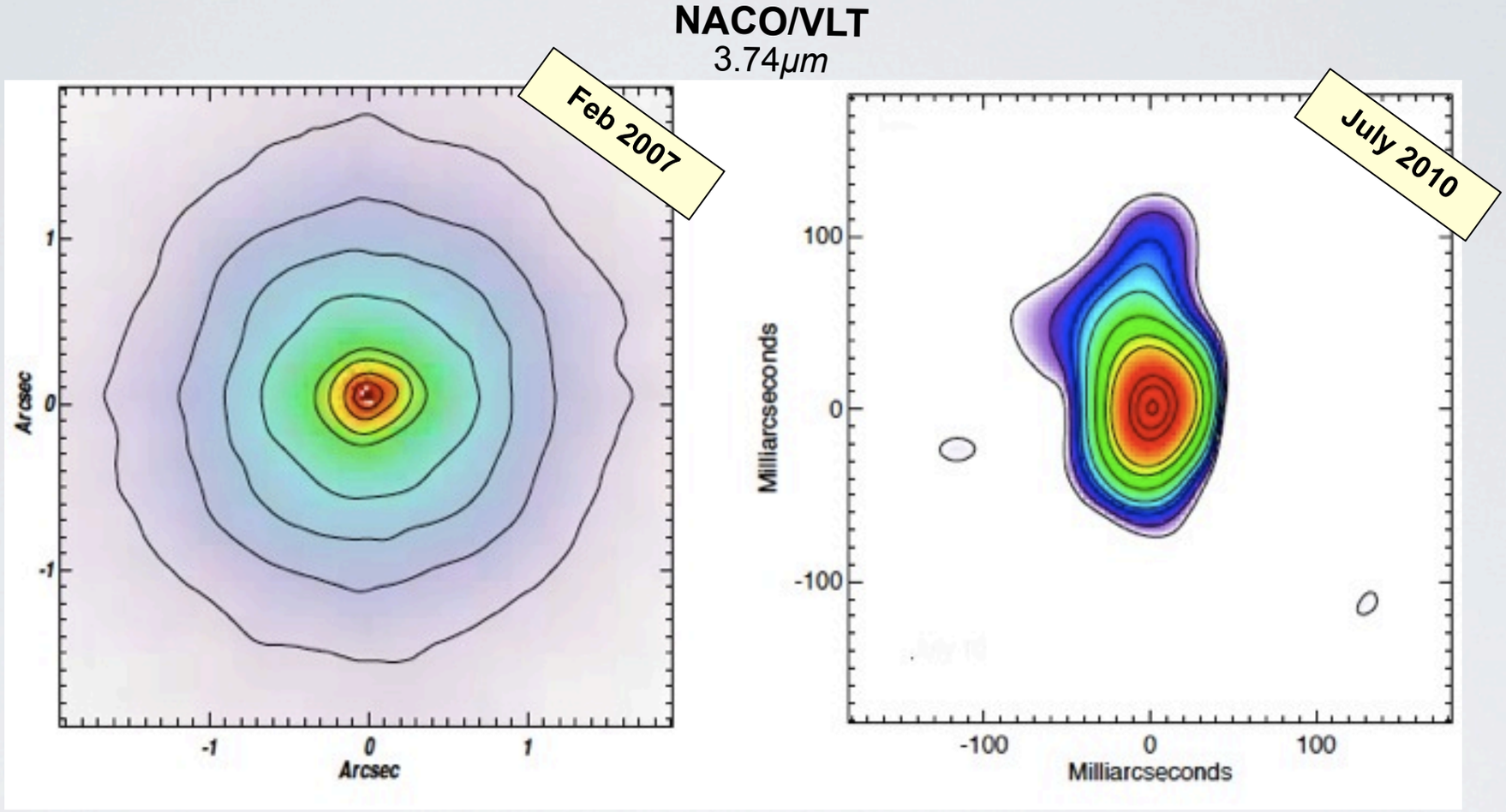
Variable stellar radius; approximate diameter~20mas in H-band (Lykou et al. in prep)





V Hya and its inner dusty torus

roughly 3" envelope
unresolved (elliptical)
core <0.3"

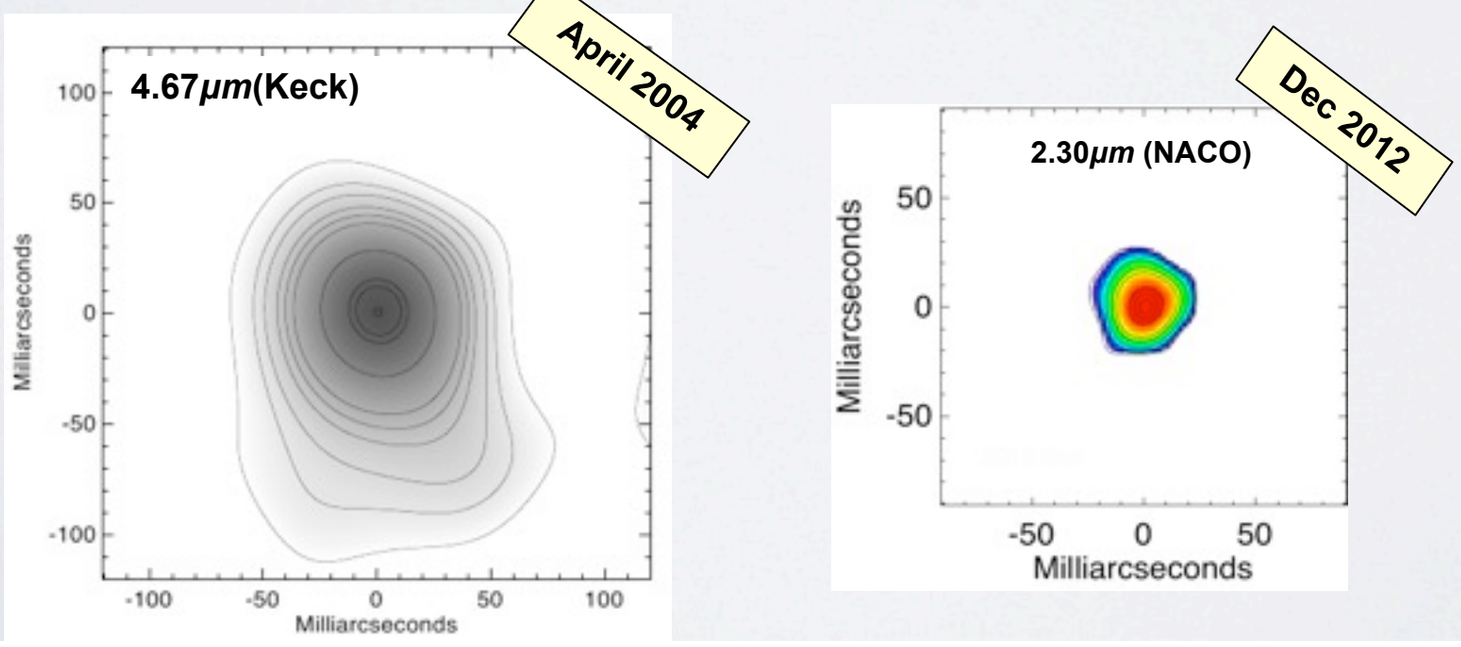


N-S dusty torus
150mas x 90mas

unresolved core
<50mas

N-S ejecta
150mas x 100mas

unresolved core
<50mas



aspherical envelope 50mas
unresolved core <30mas

Lykou 2013
Lykou et al. in prep

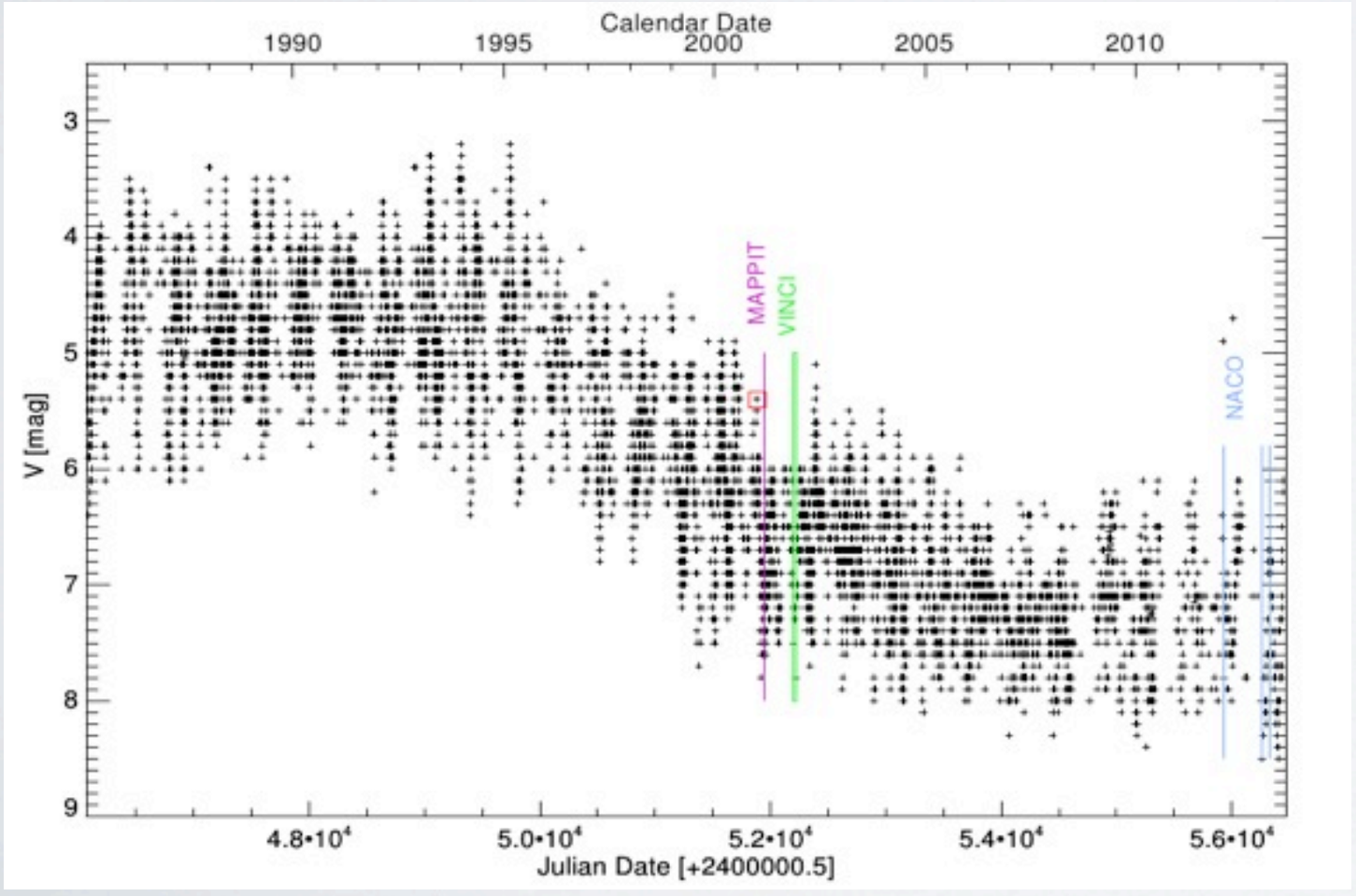
The case of the O-rich L_2 Pup

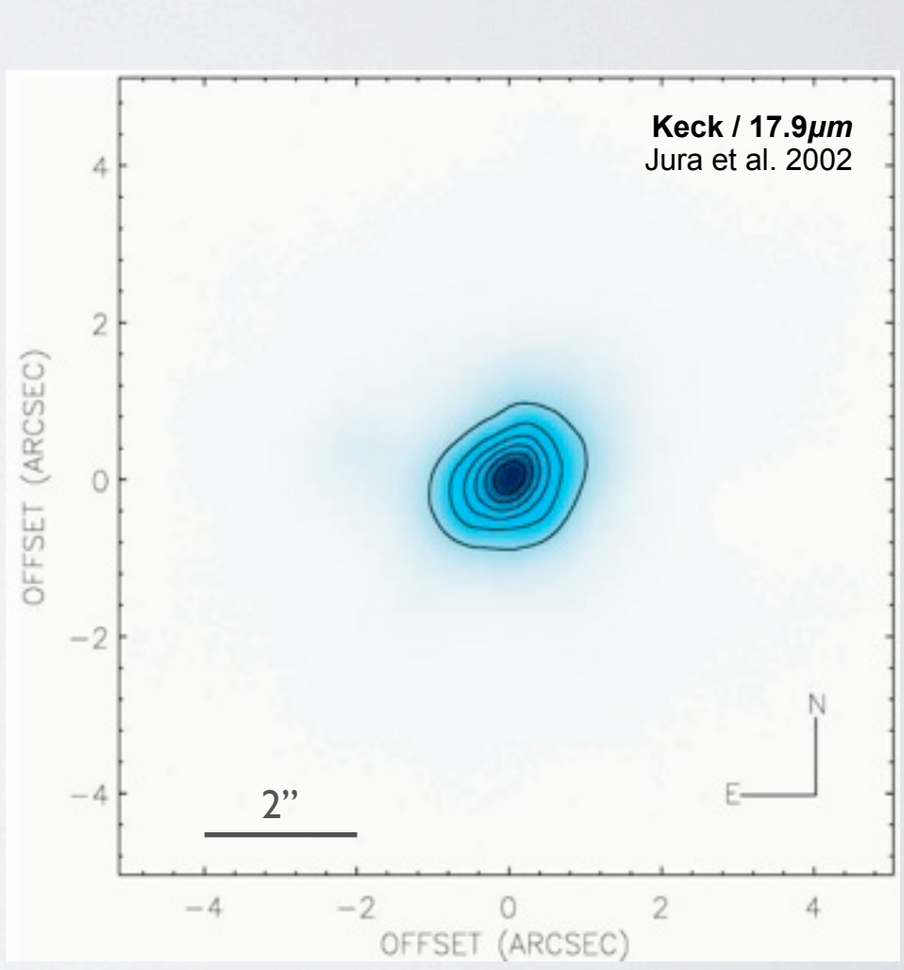
An O-rich AGB star with one of the slowest outflows (2.5 km/s; Kerschbaum et al. 1999). Typical AGB winds 5-10 km/s

It experienced a dimming event in 1994 (Bedding et al. 2002). The star hasn't recovered ever since.

Jura et al. 2002 hint on asymmetric envelope in the mid-infrared as seen by Keck (average size < 2.5").

Aperture masking 1D observations TiO with the AAT required two components to model the visibilities: 25mas star + 80mas spherical envelope (Ireland et al. 2006).

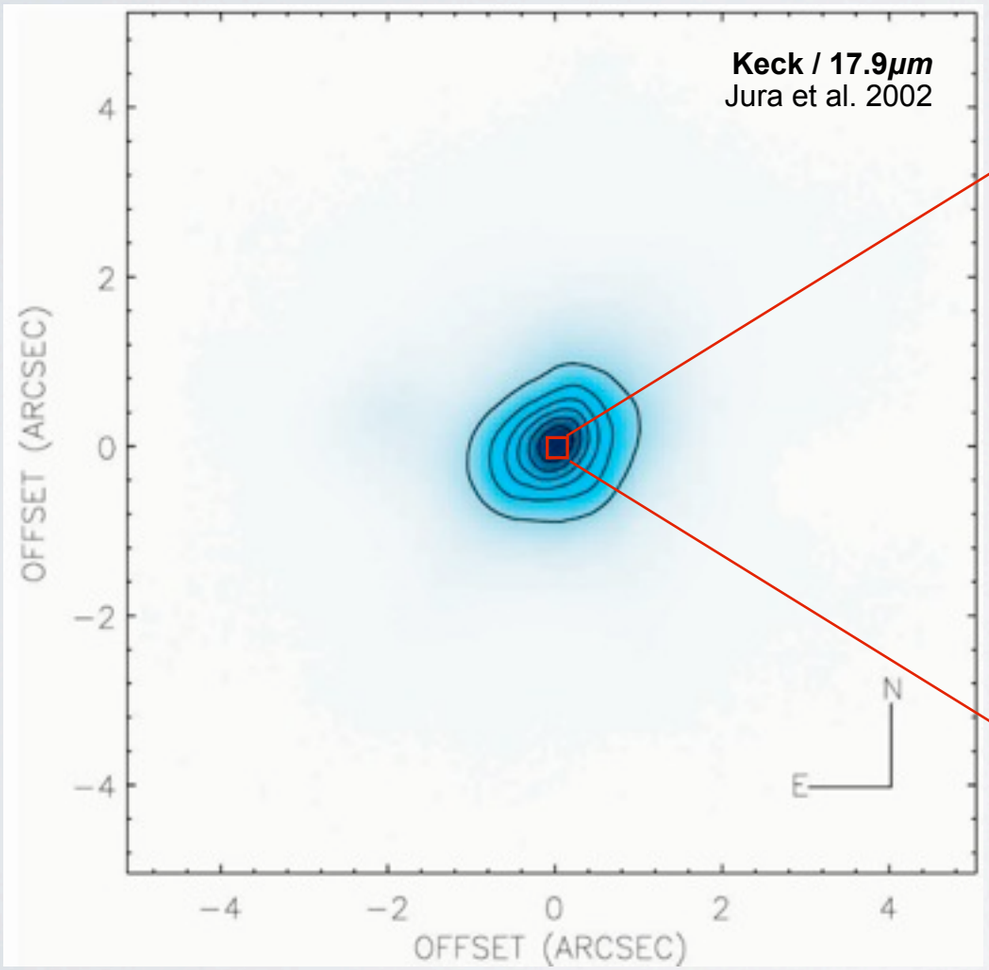


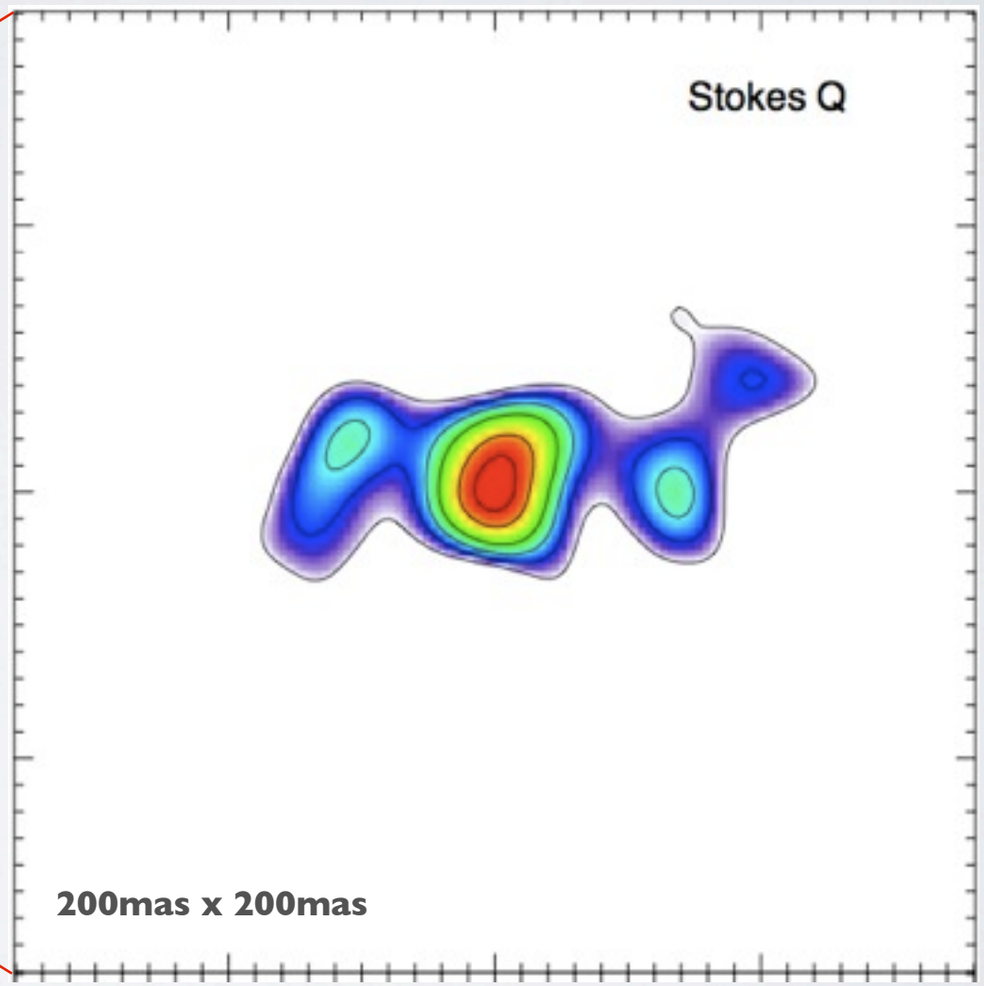


The case of the O-rich L_2 Pup

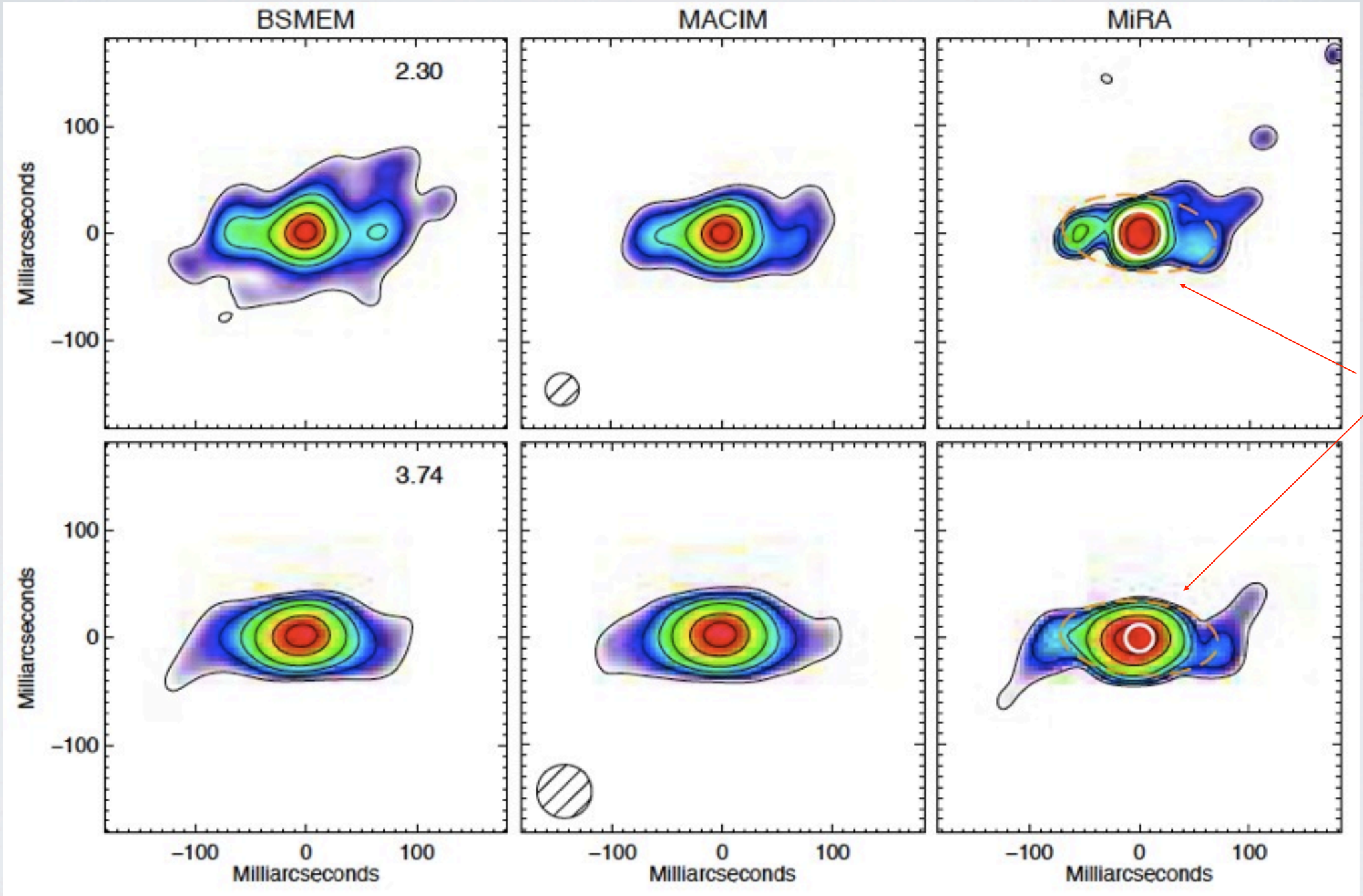
Polarimetric aperture masking (1.24μm) indicates asymmetric circumstellar dusty envelope (Norris et al. in prep.)

Polarimetric aperture masking (2.30μm) reveals the asymmetries! Same structure seen in all Stokes vectors (Lykou et al. A&A submitted)





L_2 Pup and its inner dusty torus/spiral



A toroidal structure at 3.74 while within the same structure lie two clumps bilaterally (~30mas) to the main star (~30mas). CO gas + dust torus or hints of a spiral??

Independent geometric model fitting with GEMFIND (Klotz et al. 2012) required a UD (star) and an elliptical Gaussian (torus) with similar alignment.

Lykou et al. A&A submitted

What did we learn so far

- Asymmetries are detected even in the AGB phase. Stars may be round(-ish) but their ejecta are not both at small and large spatial scales (see also Paladini et al. 2012, Klotz et al. 2012, Mayer et al. 2013, Cox et al. 2012, Ramstedt et al. 2012, Castro-Carrizo et al. 2010, ...).

- These asymmetries appear in the forms of torii and/or spirals, as opposed to thinner, dusty disks seen in post-AGBs and PNe (Lykou et al. 2011, Chesneau et al. 2006, 2007, Deroo et al. 2007, **poster B24**).

- Even AGBs that appear round (e.g. W Hya, Norris et al. 2012) have ejecta with irregular shapes at larger scales (W Hya, Zhao-Geisler et al., in prep).

Some open questions

- Is it too soon to link them with binarity? They have a torus and bipolar ejecta (e.g. V Hya). Torii and rotating disks are seen in bipolar post-AGBs (Bujarrabal et al. 2013). PNe surveys keep finding binaries; they surely have gone through the AGB phase.

- Can we detect these binaries?

Solutions

Yes, we can detect them!

- wide + short binaries with imaging interferometry. Use aperture masking: NACO and ERIS, or large arrays: AMBER, PIONIER, GRAVITY and MATISSE on the VLTI, and CHARA
- wide binaries with coronagraphy

Do you want to know more? Do you want to work on this? ***Ask me!*** *(even better, offer me a job :-)*