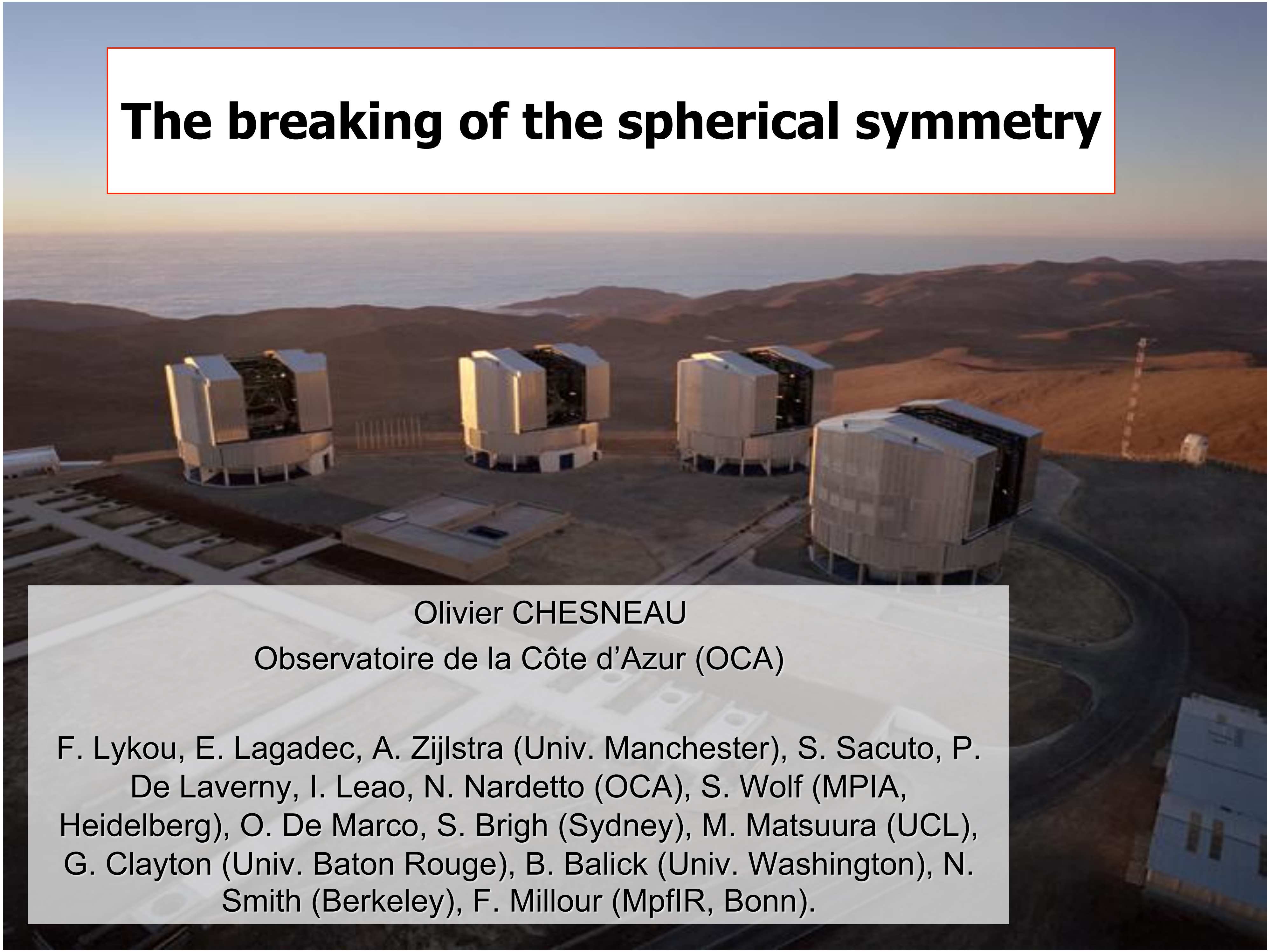
The breaking of the spherical symmetry



Olivier CHESNEAU
Observatoire de la Côte d’Azur (OCA)

F. Lykou, E. Lagadec, A. Zijlstra (Univ. Manchester), S. Sacuto, P. De Laverny, I. Leao, N. Nardetto (OCA), S. Wolf (MPIA, Heidelberg), O. De Marco, S. Brigh (Sydney), M. Matsuura (UCL), G. Clayton (Univ. Baton Rouge), B. Balick (Univ. Washington), N. Smith (Berkeley), F. Millour (MpfIR, Bonn).

Outline of the talk

1. Breaking of the spherical symmetry of the ejecta of AGBs/post-AGBs/PNs
    1. A better definition of equatorial overdensity and disks
    2. A few words about binarity,
2. The hunting of disks in the core of bipolar nebulae,
3. The born-again phenomenon and the fast formation of equatorial overdensity,
4. What can be learned from the novae events, and the fast formation of bipolar nebulae

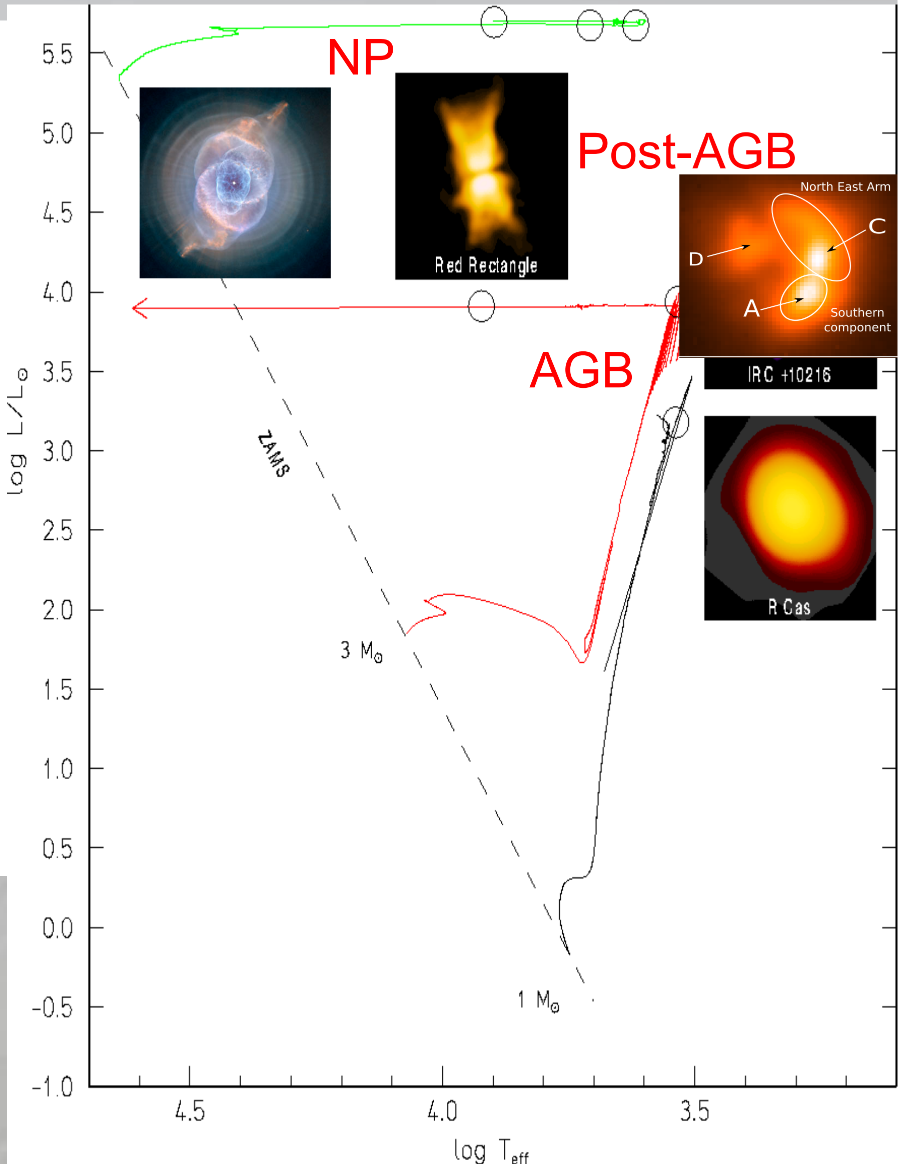
The ejecta from evolved star: a tool to evidence many physical phenomena

- A star that leaves the main sequence increases its radius, and its luminosity

- The external layers are diluted, the gravity decreases

- Thus the external layers become very sensitive to *external (stellar and sub-stellar companions) or internal (magnetic fields, pulsations…) perturbations*

- The spherical symmetry of the ejecta is almost universally broken

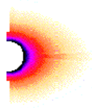


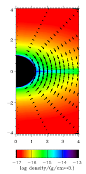
Equatorial overdensity versus disks

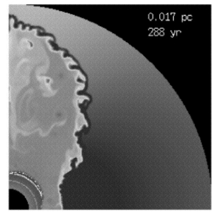
• Circumstellar shells form from a dense wind. If there is a co-latitude dependence of the density/velocity, an ***equatorial overdensity*** forms. The kinematics of such a structure is dominantly *radial*, and the *angular momentum is limited*.

• For the massive stars, the ingredients for a theory for making an equatorial overdensity are the radiative flux, the rotation via the Von Zeipel effect, a magnetic field and non-radial pulsations

- Wind-Compress disk model (Bjorkman & Cassinelli, 1993)
- Magnetically confined wind model (ud-Doula & Owocki 2002)







• For the formation of PNs, the collision between a high and low velocity wind can lead to the formation of equatorially enhanced environments:

- wind-wind model for the PNs: Kwok et al. 1978,
- wind-wind collision LBV/WR winds, Garcia-Segura et al. 1995, 1996

• Equatorial overdensities are short-term structures without replenishment (these are deflected winds).

The stratified disks

• Observed universally around YSO. (quasi)-keplerian kinematics, small apertures, and vertical stratification.

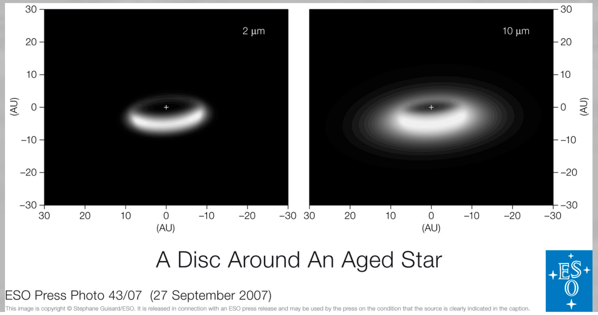
• The key point for stabilization of the disk is to provide enough angular momentum (Soker & Livio, 1989, 1994; Soker 1997),

• A star may supply this angular momentum via magnetic fields (Garcia-Segura et al. 1999, Frank & Blackman 1994, ud-Doula & Owocki 2002)

• Millimetric interferometry provided crucial constraints on the budget of linear momentum is many PNs and PPNs, that seem to exceed what can be provided by a single star (Bujarrabal et al. 2001)

• The angular momentum provided by a companion is necessary for forming most of the bipolar PNs (Nordhaus , Blackman, & Frank 2007)

• These difficulties are encountered also for massive stars. Only for the fast rotating Be stars, the disk may be explained without invoking a companion (Stefl et al. 2010, Cranmer 2009, Neiner et al. 2009).



-MANY examples of compact disks:

- Chesneau et al. 2005, 2007, Lykou et al. 2010…
- Deroo et al. 2007a, 2007b, 2006
- Verhoest et al. 2009,
- see also talk from Hans van Vinkel…

Binarity: DIRECT detections difficult

Many solar-like stars are in binary systems (more than 50%). Moreover, many solar-like systems harbor a (giant) planet (statistics growing!), and this frequency increases when increases the metallicity, i.e. in the thin galactic disk.
Bipolar PNs also are more numerous in the disk, for other reasons (dominated by more massive stars).

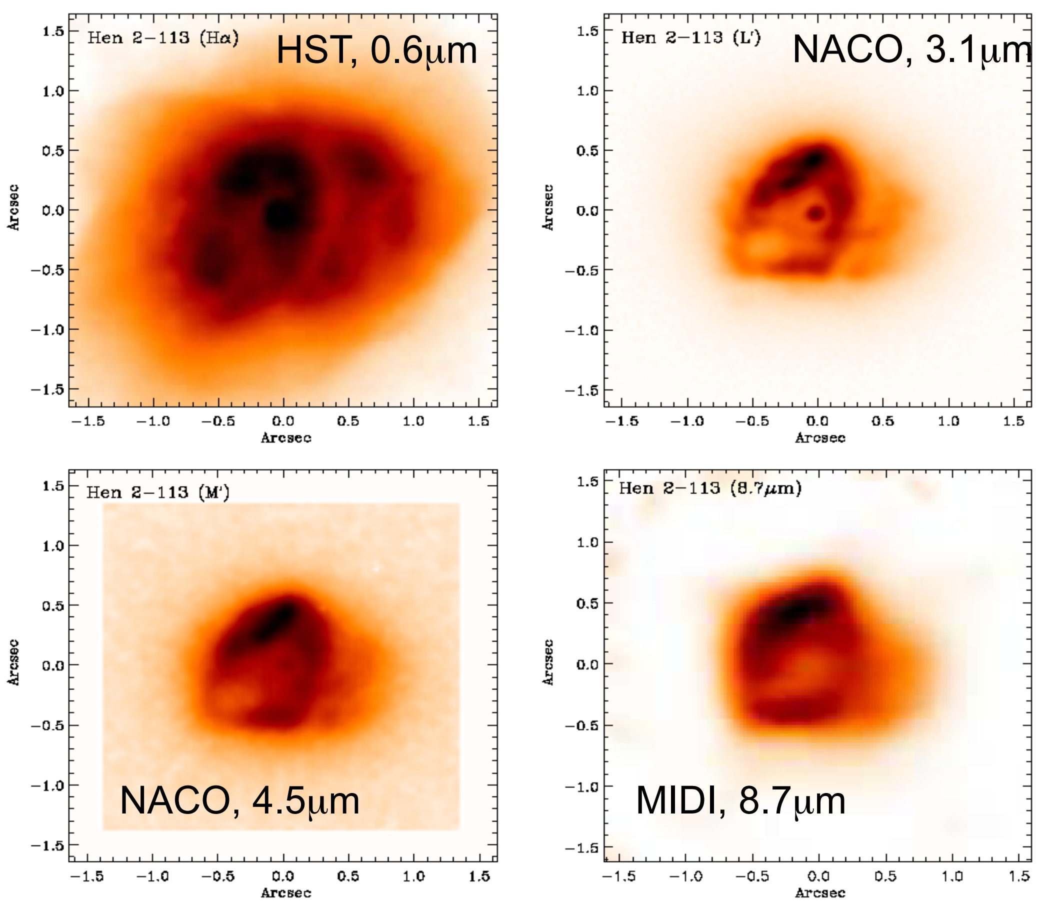
- Optical interferometry works mainly in the IR region:
Allows only the detecting low Teff companions with a limiting contrast of about 5mag, within a area of about 10-100mas

BUT *AGB stars are also bright low Teff sources*.

AND the more complex the environment, the more difficult is the search of a faint point source in this environment

Thus: detection easier around hotter primary sources (many detection around hot massive stars currently). Post-AGBs stars is a more favorable case, but the circumstellar medium still dominates if there is a disk (see next talk)

Two targets with double chemistry dust: CPD-56 et Hen2-113



Observations:
Bipolarity→ old, dissipating dusty disk

Wolf-Rayet central star (Teff~30000K), dust dominated by carbon, strong stellar wind (v~200km/s).

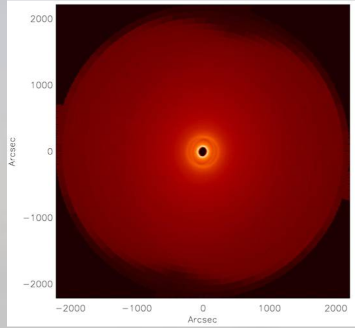
Central star should be invisible in the near-IR. Surrounded by newly formed dust.

Origin of the bipolarity??? What the origin of the newly formed dust? And the old disk?

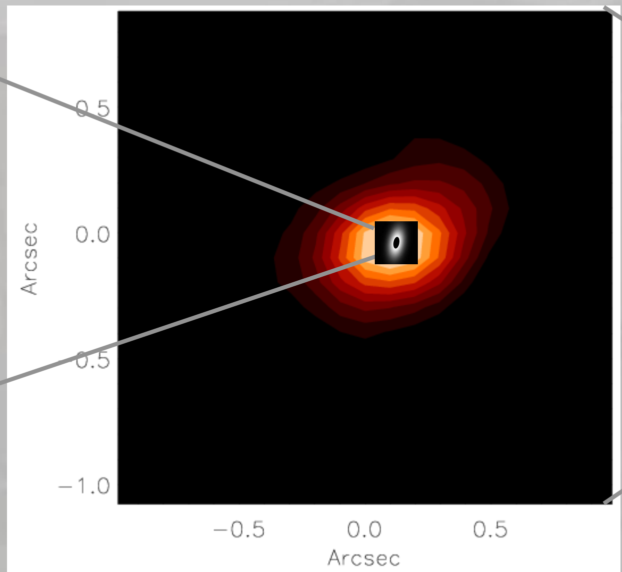
Lagadec E., Chesneau O., Matsuura et al., 2006, A&A

CPD –568032: an increase into complexity…

10 μm simulation

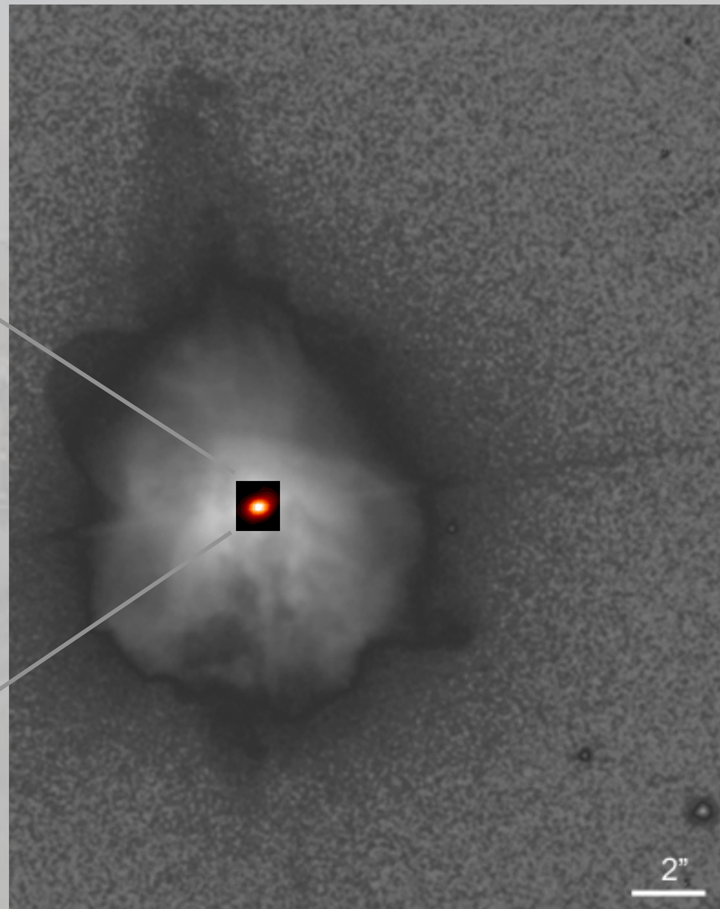


0.1 arcsec



MIDI 8.7 μm image

1 arcsec



12 arcsec
HST

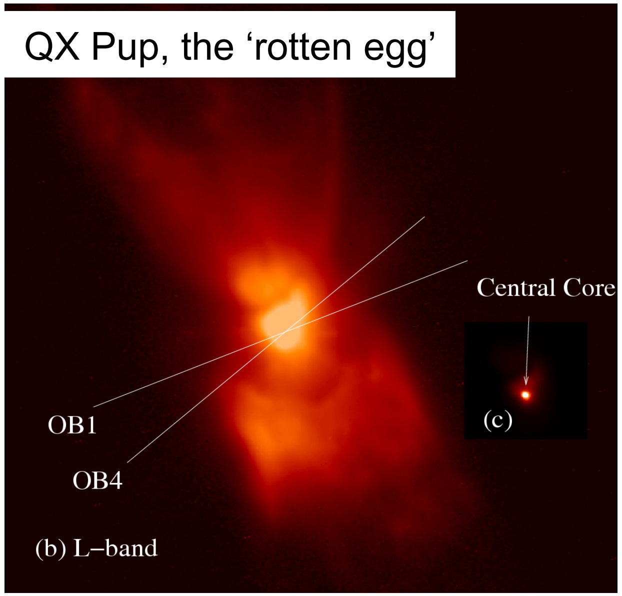
Chesneau, O., Collioud, A., De Marco O. et al., 2006, A&A

The hunting of disks in the core of bipolar PNs

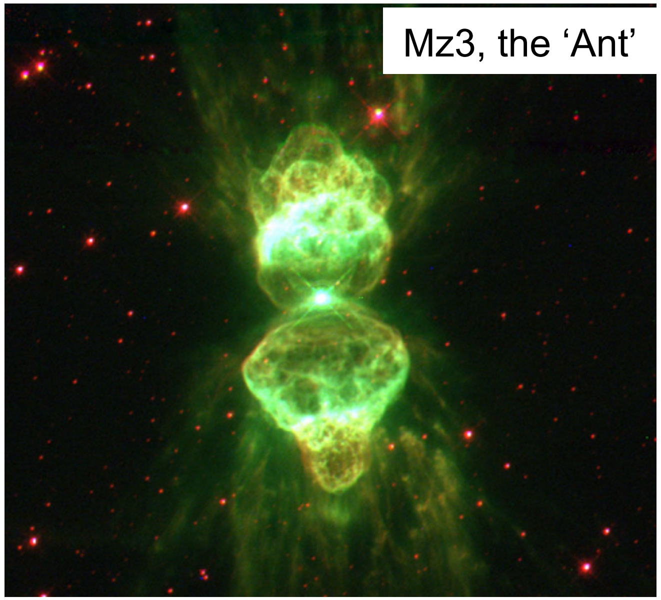
Strategy: concentrate on the most bipolar sources (Smith & Gehrz 2005).
Studying the disk MIDI: complementary observations using HST, NACO, VISIR. Sources to extended and faint for using AMBER.

Team: O. Chesneau, E. Lagadec, M. Matsuura, A. Zijlstra, S. Wolf , O. De Marco, A. Acker, G. Clayton, N. Smith, B. Balick et al.
Lagadec, Chesneau et al. 2006, Matsuura, Chesneau et al. 2006, Chesneau, Collioud et al. 2006, Chesneau, Lykou et al. 2007, Lykou et al. 2010

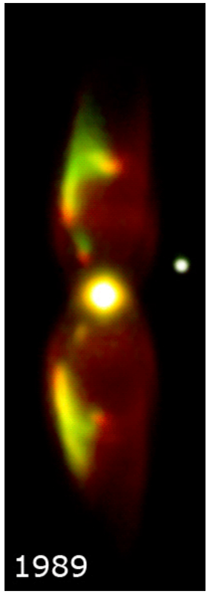
Matsuura et al. 2006



Chesneau et al. 2007

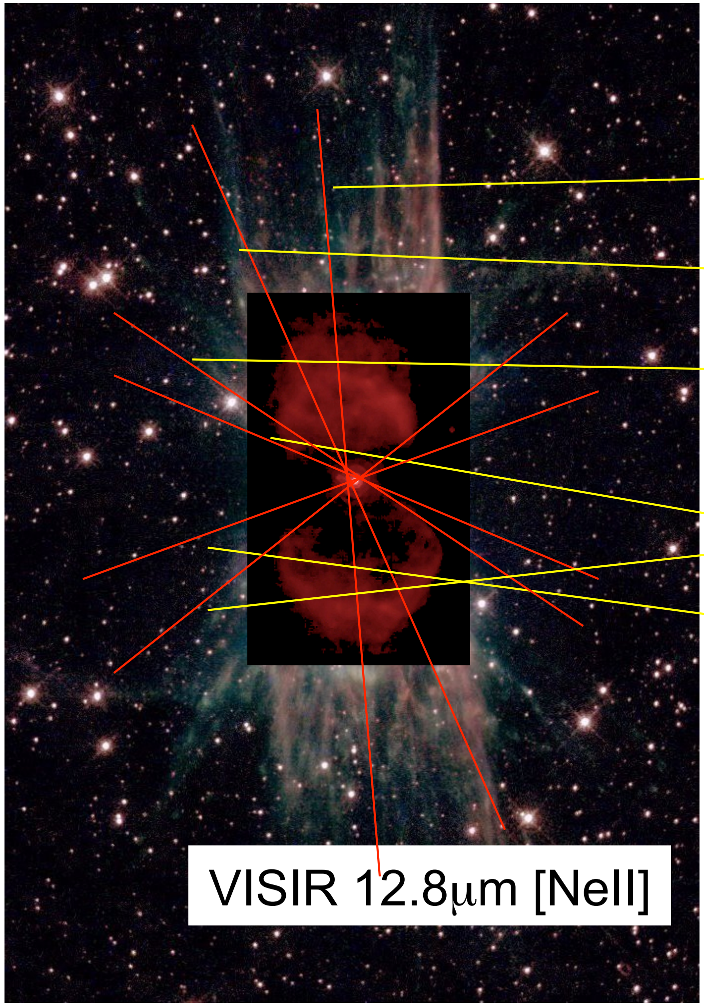


Lykou et al. 2010

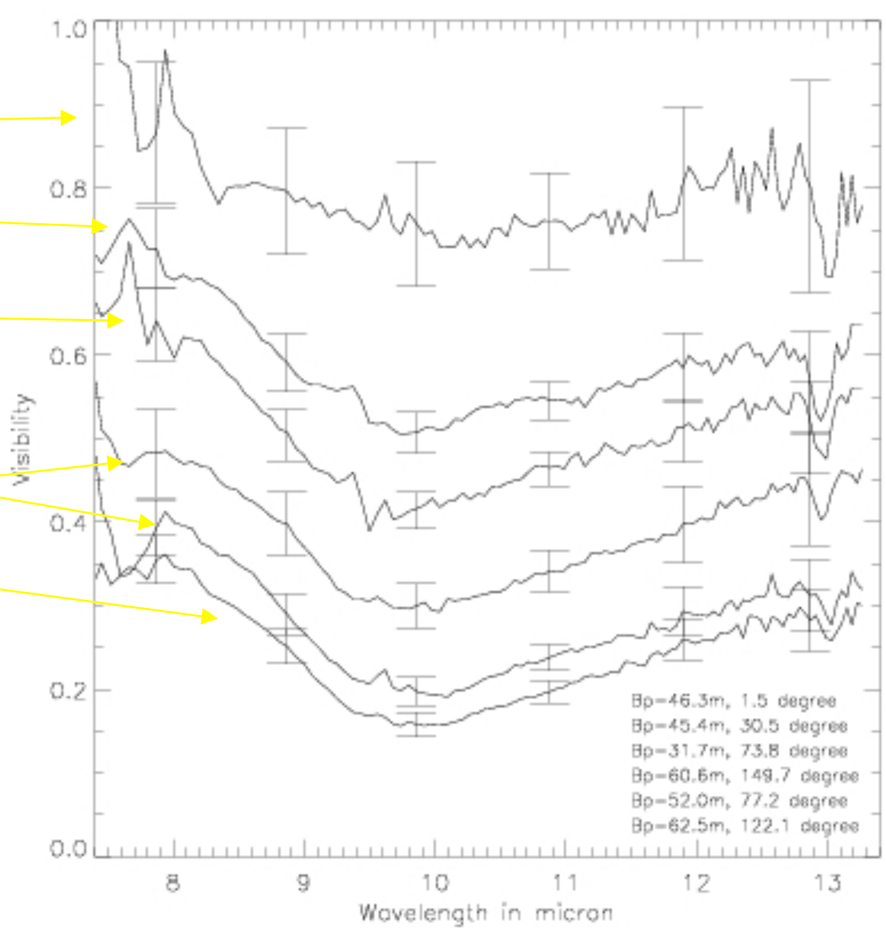


An amorphous silicate disc in the Ant nebula, Mz 3

Chesneau, O., Lykou, F. et al., 2007, A&A



HST observations



MIDI visibilities for different baselines orientations

Mz3: A stratified disk

Density (2d disk)

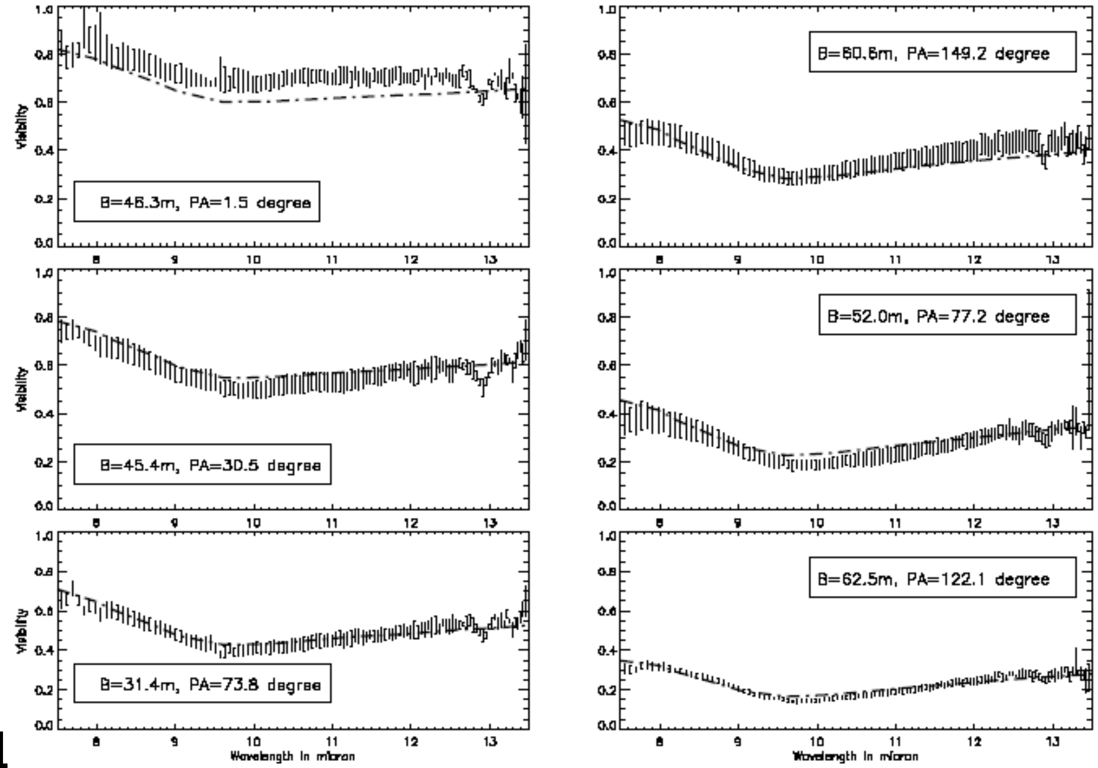
$$\rho(r,z) = \rho_o \left(\frac{R_*}{r}\right)^{\alpha} \exp\left[-\frac{1}{2}\left(\frac{z}{h(r)}\right)^2\right]$$

with

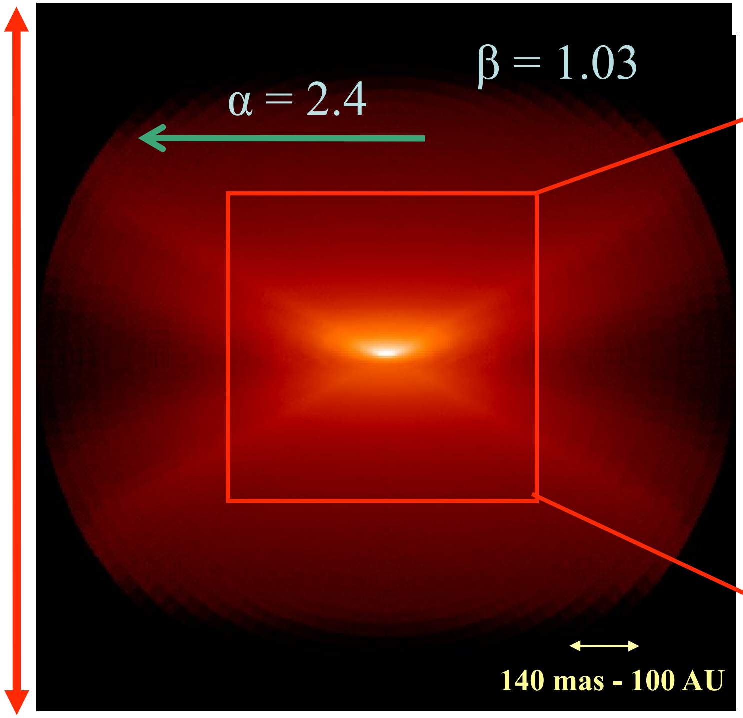
$$h(r) = h_o \left(\frac{z}{R_*}\right)^{\beta}$$

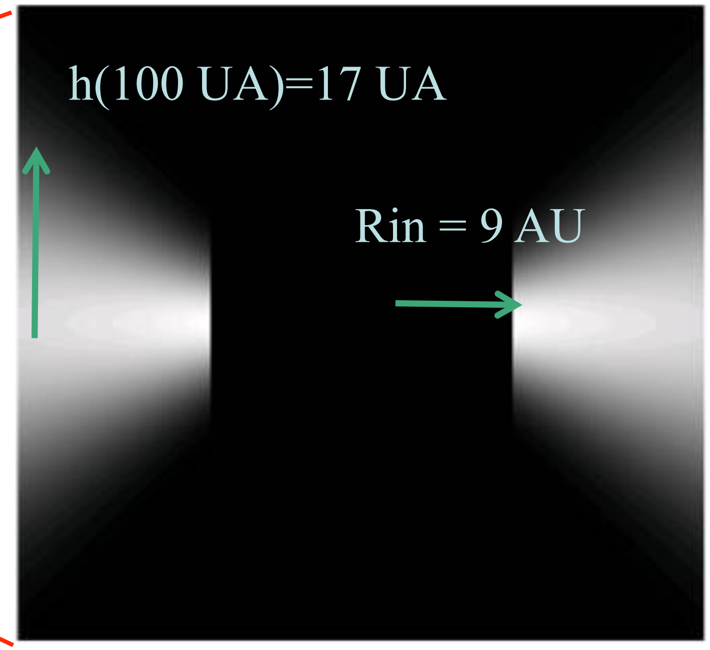
$\alpha = 2.4 \quad \beta = 1.03 \quad h_{100AU} = 17$ AU

VERY GOOD FIT, VISIBILITY+SED



500 AU

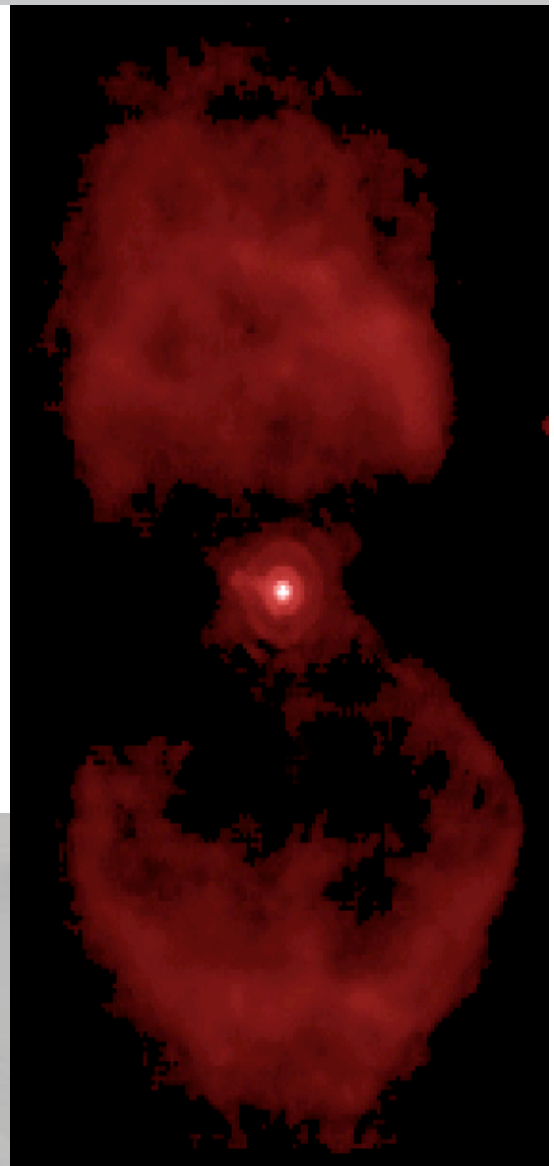




Which scenario for the formation of Menzel 3?

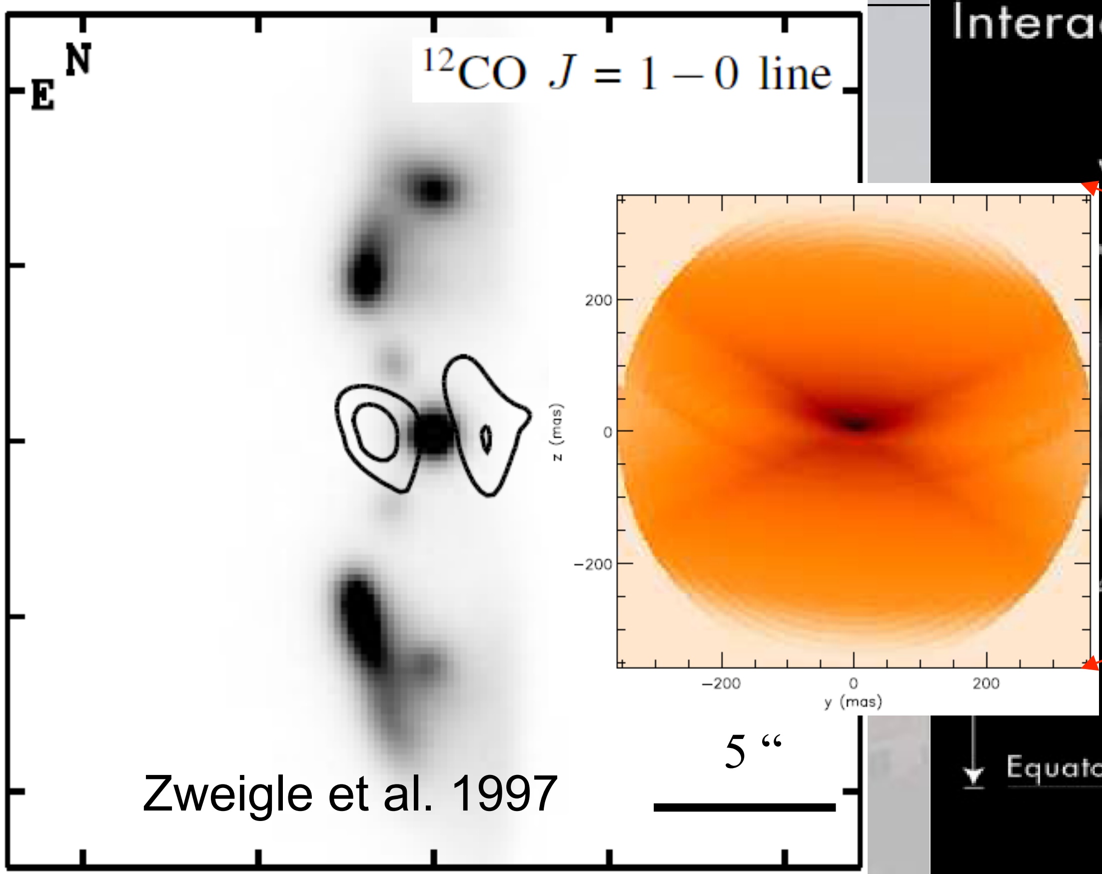
We have:
- A large amount of dust in lobes (~solar mass, age ~1000yr),
- A disk representing 1% of this mass,
- The disk is formed of amorphous silicate → young,
- Well defined limits for the lobes (shadowing effec!),
- Most probably a binary system, including a star with initial mass larger than the sun

Hypothesis:
- Formation of the lobes in one short (1yr?) event, the disk being a by-product of the event,
- The event may have a ‘single-star’ origin (rotation/magnetism…)
- Or ‘catastrophic’ interaction between the primary is fast expansion and a companion (no common envelope phase)

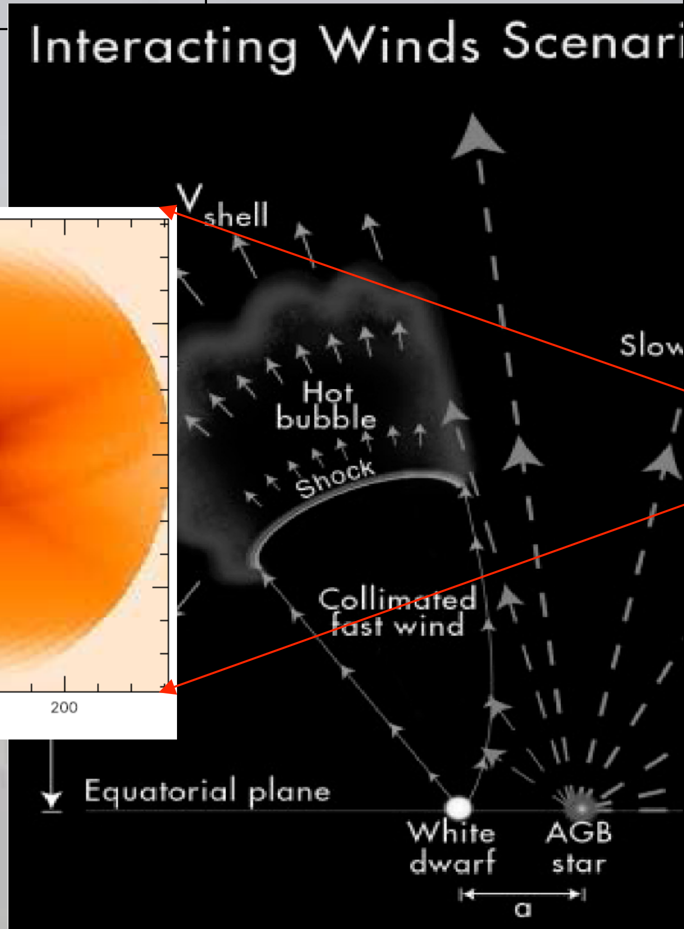


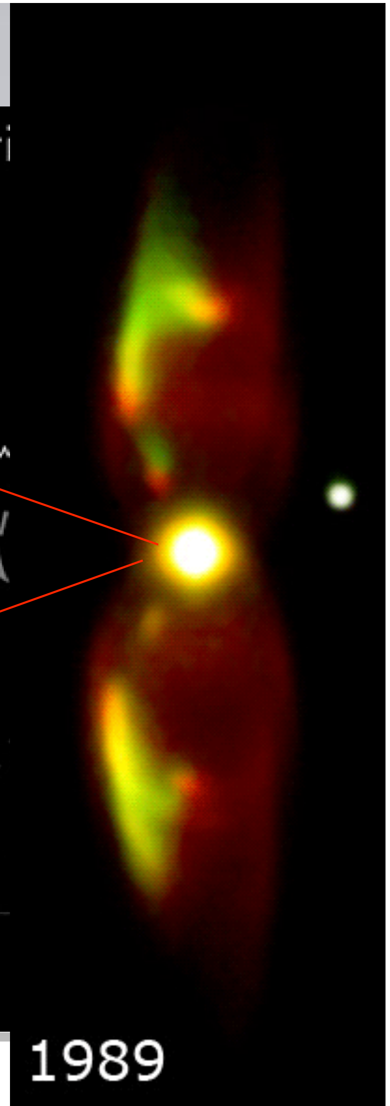
Chesneau, O., Lykou, F. et al., 2007, A&A

The core of M2-9



Plateau de Bure observations





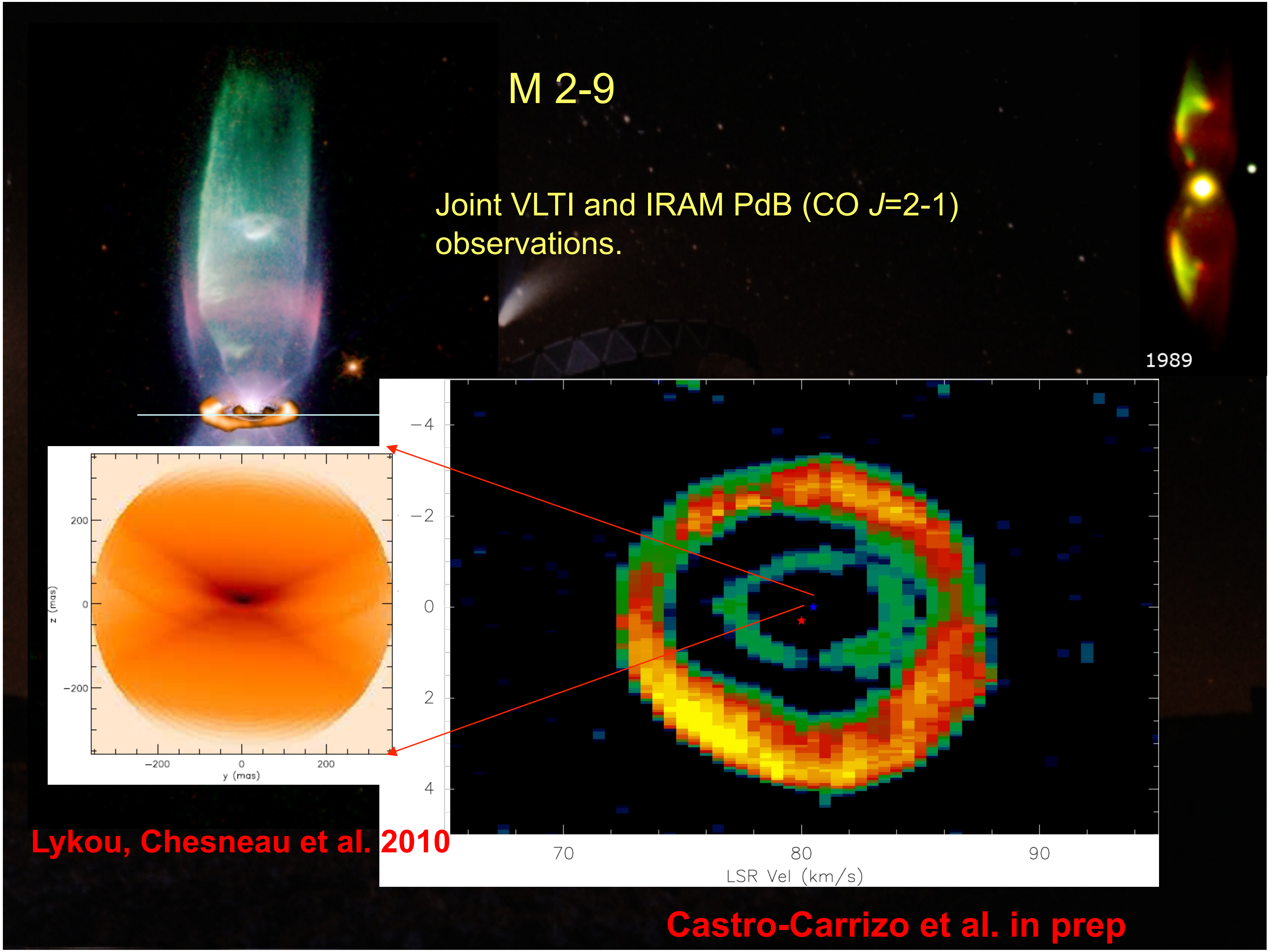
Soker & Livio (2001),

a~10-20mas, expected disk ~30-60mas

Lykou, F., Chesneau, O et al. submitted

-Conclusion:

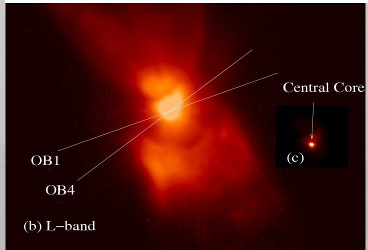
- concentration of dust, at first order this is a disk
- small internal diameter. Where is the companion?


M 2-9
Joint VLTI and IRAM PdB (CO J=2-1) observations.
1989
200
0
−200
z (mas)
−200
0
200
y (mas)
−4
−2
0
2
4
70
80
90
LSR Vel (km/s)
Lykou, Chesneau et al. 2010
Castro-Carrizo et al. in prep

Hen2-113

Hen2-113 broad equatorial overdensity, evident bipolarity: dissipating disk, no detected compagnon
Lagadec, Chesneau et al. 2006
CPD-56: Complexity too difficult. No detected companion. Collioud, Chesneau et al. 2006

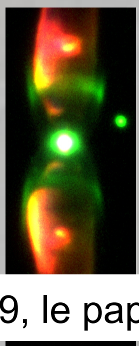
QX Pup, the 'rotten egg'



QX Pup/OH231.8: equatorial overdensity, no stratified disk, disk in formation? Detection of a companion in uv
Matsuura, Chesneau et al. 2006, Lagadec et al. en préparation

Menzel 3, la fourmi

Menzel 3: Small stratified disk. Companion suspected from X-ray observations, jets. Polar ejection?
Chesneau, Lykou et al. 2007

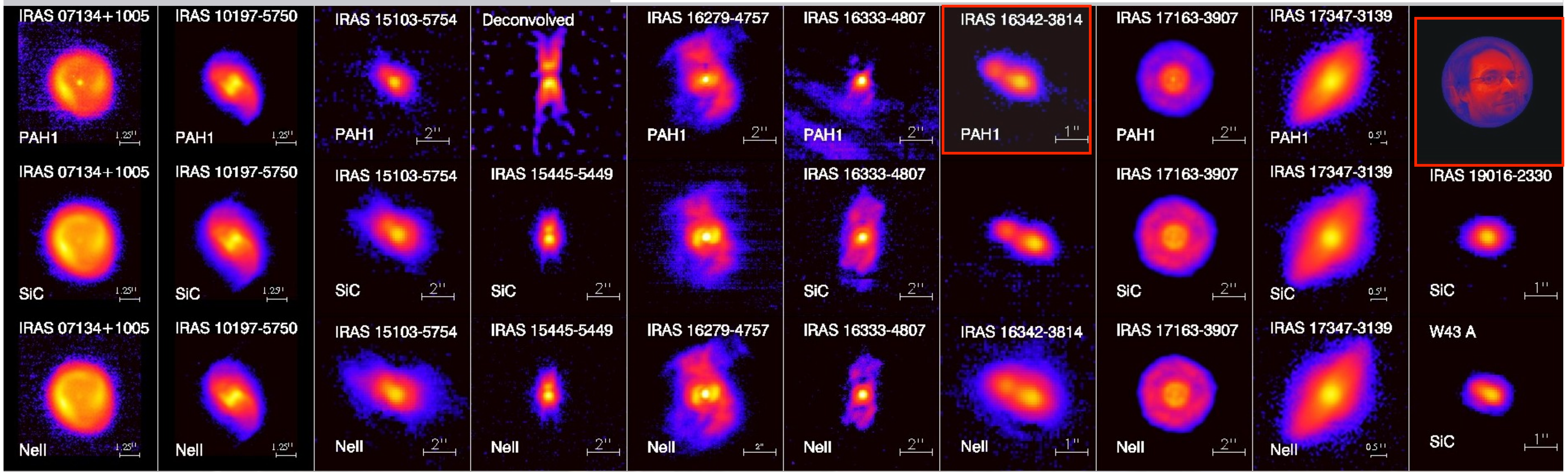


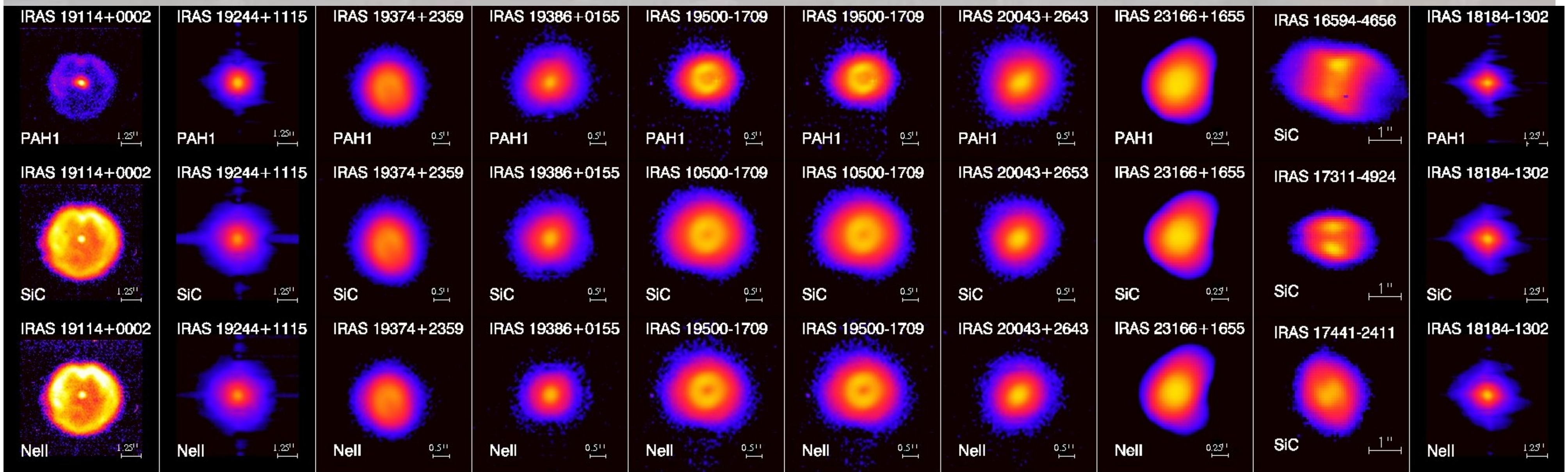
M2-9, le papillon

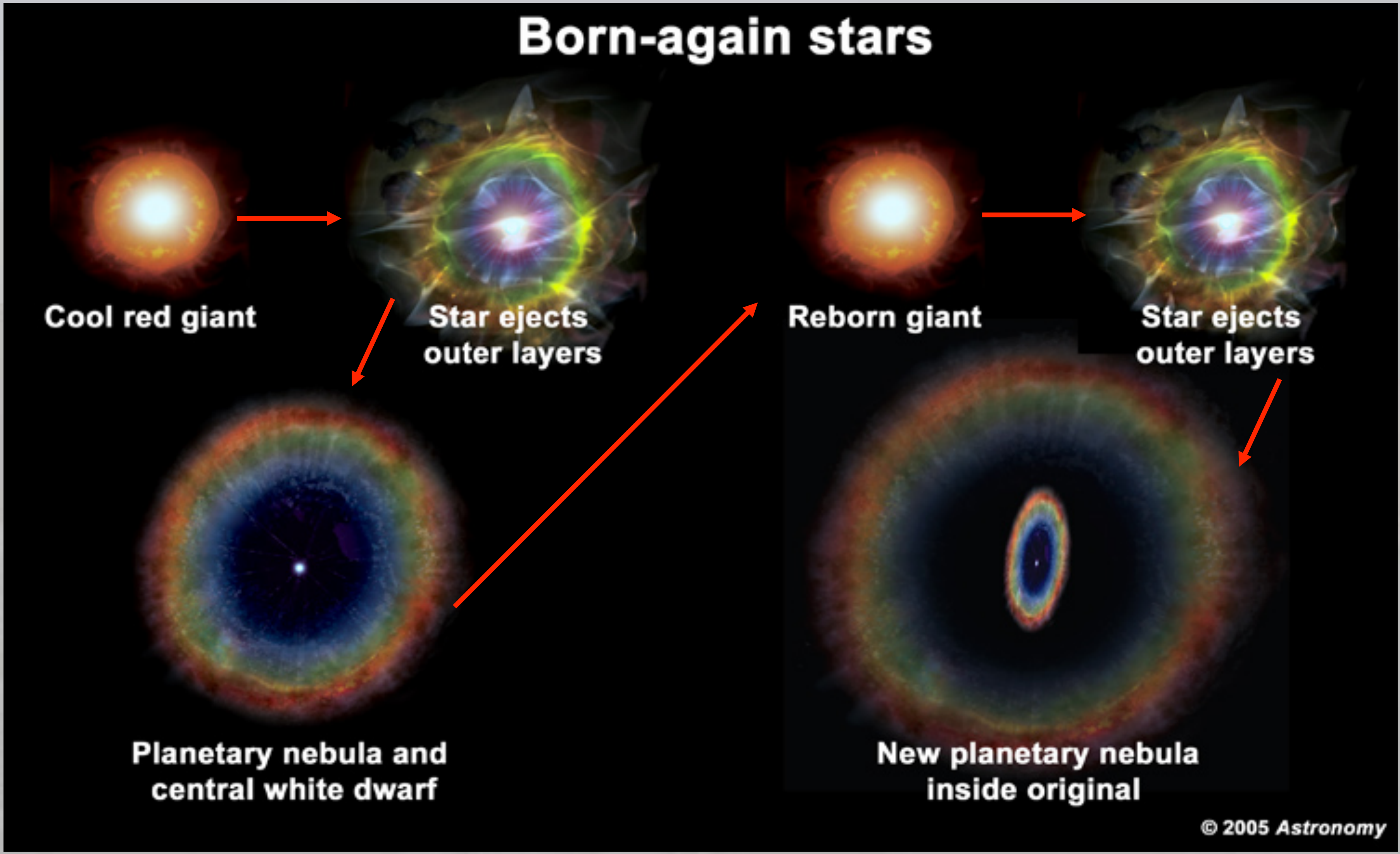
M2-9: Disk at first order, but complexity. Compagnon evidenced by light-house effect. Polar ejection?
Lykou, Chesneau, et al. 2010, Castro-Carrizo et al. en préparation

Choosing the targets: mid-IR diffraction limited survey: ~100 sources

P.Is: Lagadec, Verhoelst, based on Szcerba et al catalogue

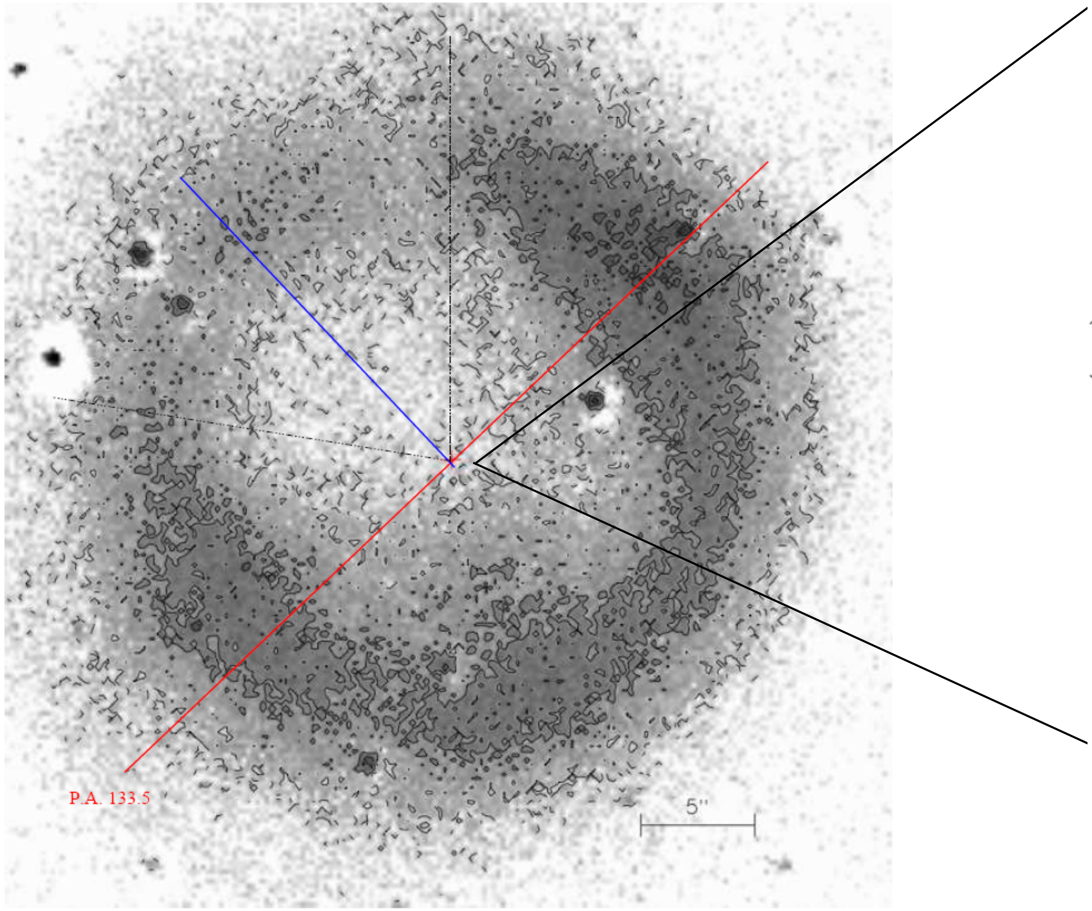


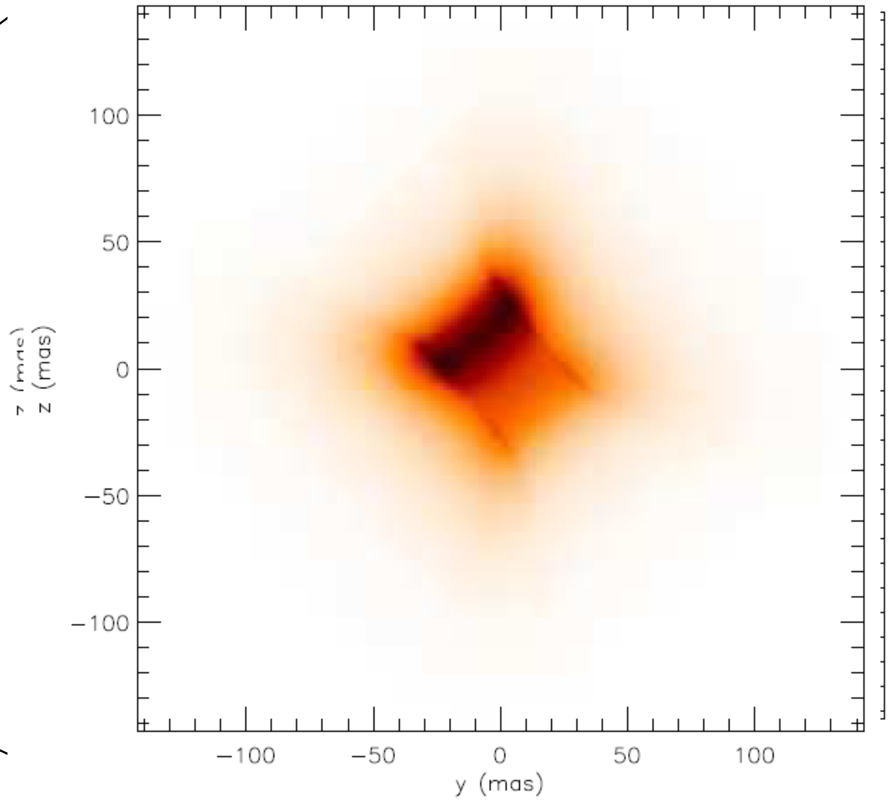



Born-again stars
Cool red giant
Star ejects outer layers
Reborn giant
Star ejects outer layers
Planetary nebula and central white dwarf
New planetary nebula inside original
© 2005 Astronomy

Sakurai's object: a Very Late Thermal Pulse (VLTP)
Outburst in 1996 (quasi-nova event), then deeply embedded in a cocoon of dust,
Discovery of a faint, old PN around → born-again (VLTP) event

MIDI observations in 2007
Discovery a dust concentration at a PA coinciding with structures in the PN
Fit of visibilities and SED with a model of stratified disk difficult, complex geometry.
PA well constrained but inclination and vertical density structure not well accounted by the stratified model. The equatorial overdensity follow a shallower increase of density.





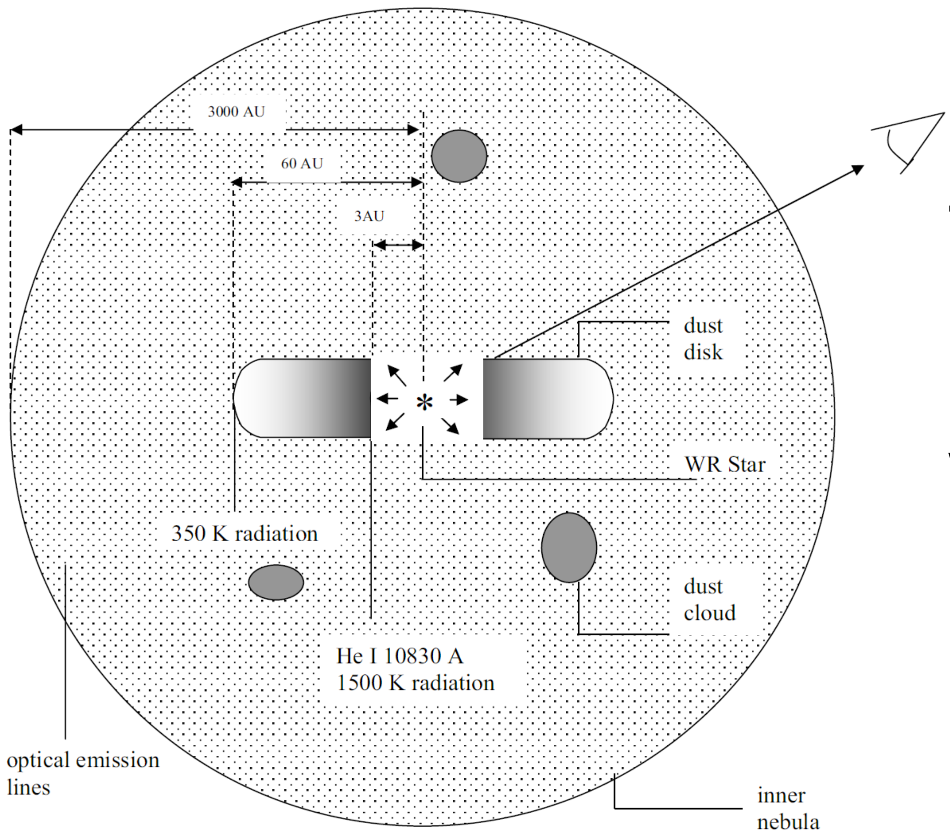
Chesneau, Clayton, Lykou et al. 2009

A&A 479, 817–826 (2008)
DOI: 10.1051/0004-6361:20077738

Astronomy & Astrophysics

Imaging ejecta from the final flash star V605 Aquilae

K. H. Hinkle[1], T. Lebzelter[2], R. R. Joyce[1], S. Ridgway[1], L. Close[3], J. Hron[2], and K. Andre[2]



Two rare examples of VLTPs

- A marked equatorial overdensity,
- PN sharing the same principal axis, but weak asymmetries visible,
- Intrinsic asymmetrical VLTP ejection?
- Or effect of a close companion?

Questions

The flattened structures (disks?) observed around born-again raise many questions

- How can such a flat structure be formed so rapidly?
- Was a dusty disk pre-existing?
  - Not really possible close to a White Dwarf at short distance,

- Effects of companions?
  - Not probable for companions orbiting at large distance (5AU), given the time scale,
  - Possible if a hot Jupiter is in the vicinity,
  - BUT how can such a companions could have survived the AGB phase of the star?
- Fast Rotation: the almost naked core may rotate fast, but WD statistically slow rotators (see also Charpinet et al. 2009)…
- A strong magnetic field, not screened out anymore by the hydrogen envelope,
  - Co-latitude dependence of the VLTP and the ejection?
  - Effect of the magnetic field to suppress convection at equator (Hadjuck et al. 2005) →completely different outburst in the equatorial plane→dusty disk rapidly formed.

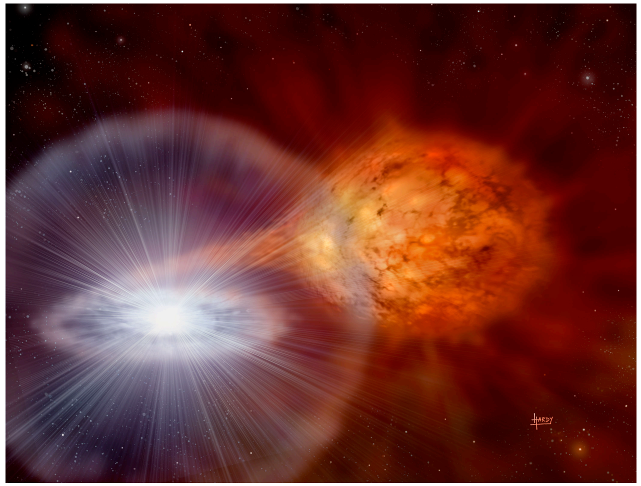
Novae: well-suited targets for interferometry

Optical interferometry is perfectly suited to resolve the expanding ejecta (500-4000 km/s) of a nova located at 3kpc during the first 3-5 months, and this from the 2-3rd day. Such an event happens about 5-8 times per year, but only 0.25-1/year within the VLTI observability and sensitivity limits,

Novae may provide us crucial information on the formation of bipolar structures.

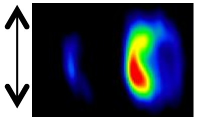
Information requested from the 'novae' community

1. Which is the distance of the source?
2. Is the outburst spherical?
3. Is the nova wind spherical?
4. How dust can form?
5. How jets can form?



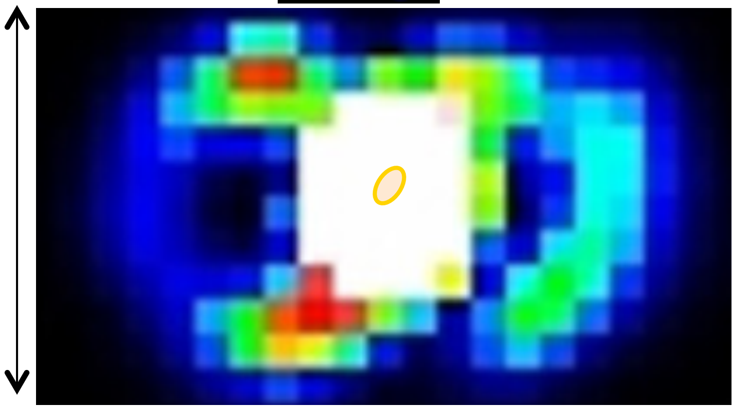
The asymmetric outburst of the recurrent nova RS Oph

40 mas
65 AU

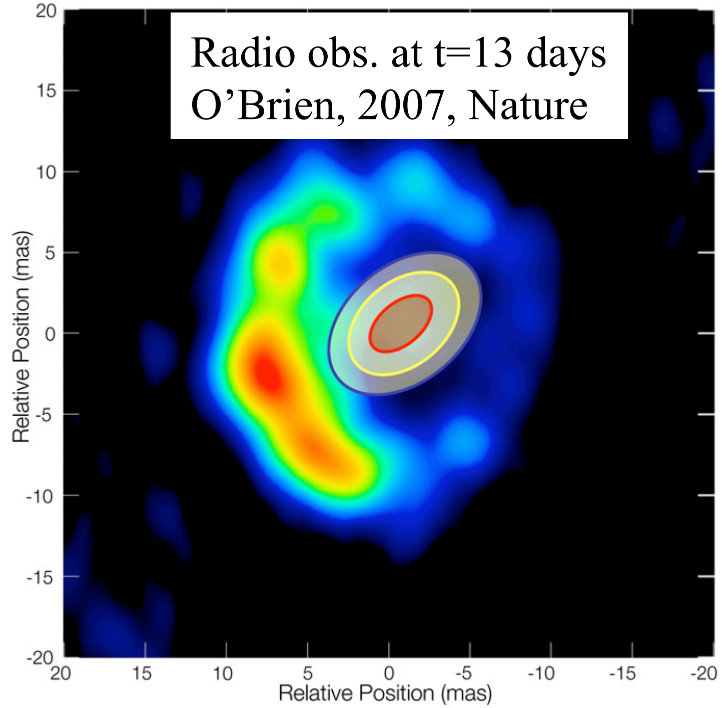


Radio obs. at t=22 days

240 mas
380 AU

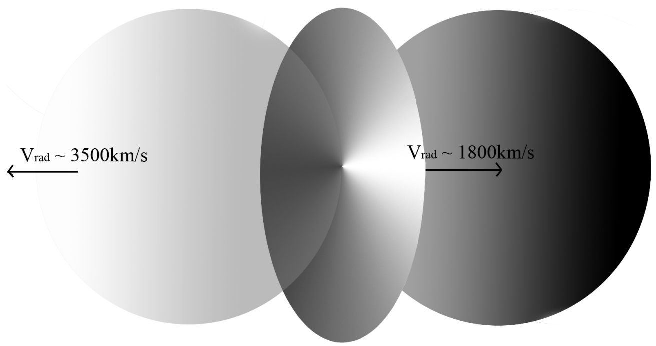


HST visible image at t=150 days



The Erupting Nova RS Ophiuchi

ESO Press Photo 06c/07 (21 February 2007)

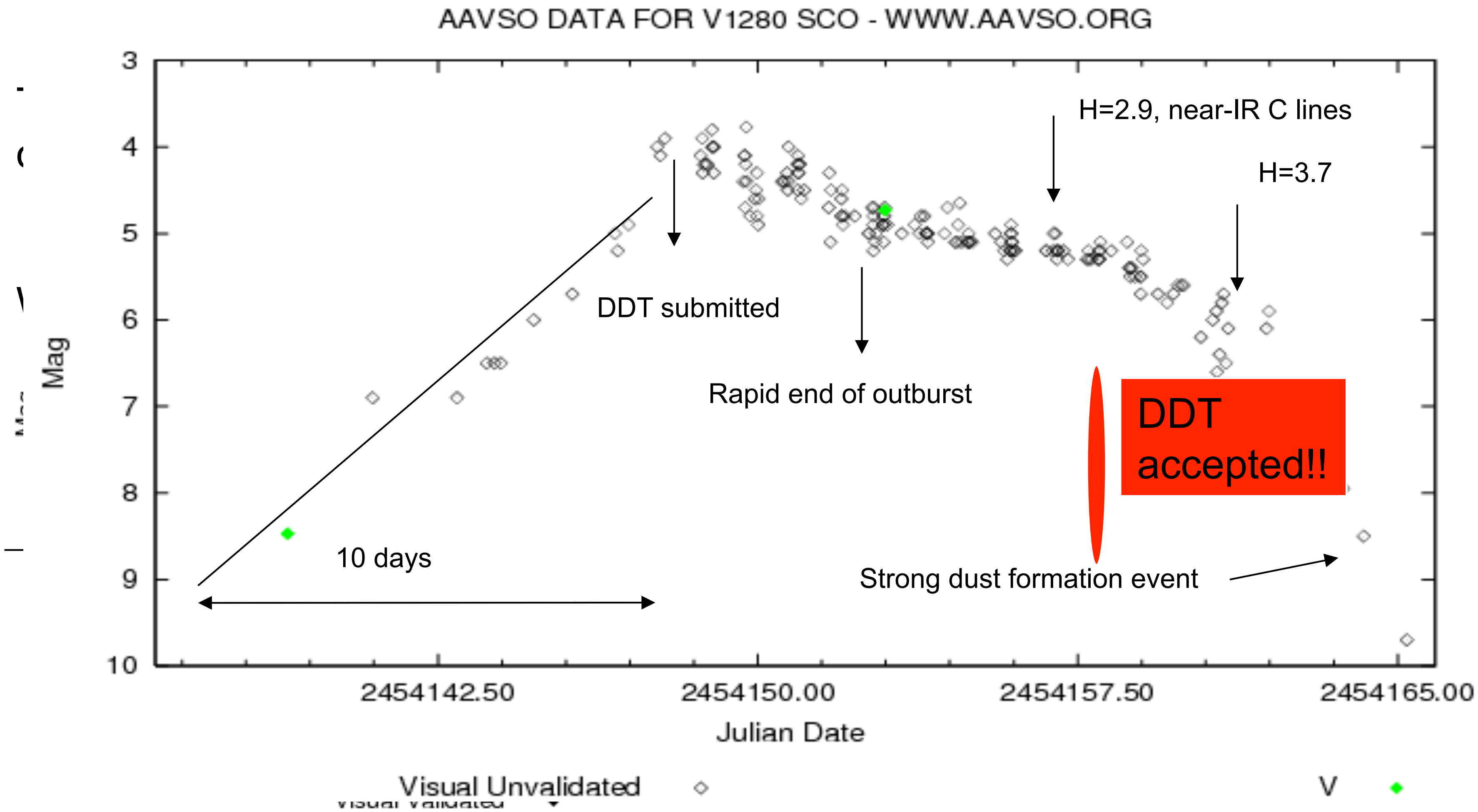


A complex explosive event

What is the origin of the bipolar structure?
-Probably an intrinsically bipolar event.
Rapidly rotating WD (P_{rot}~ minute).
Fast rotation is a consequence of the large accretion rate.

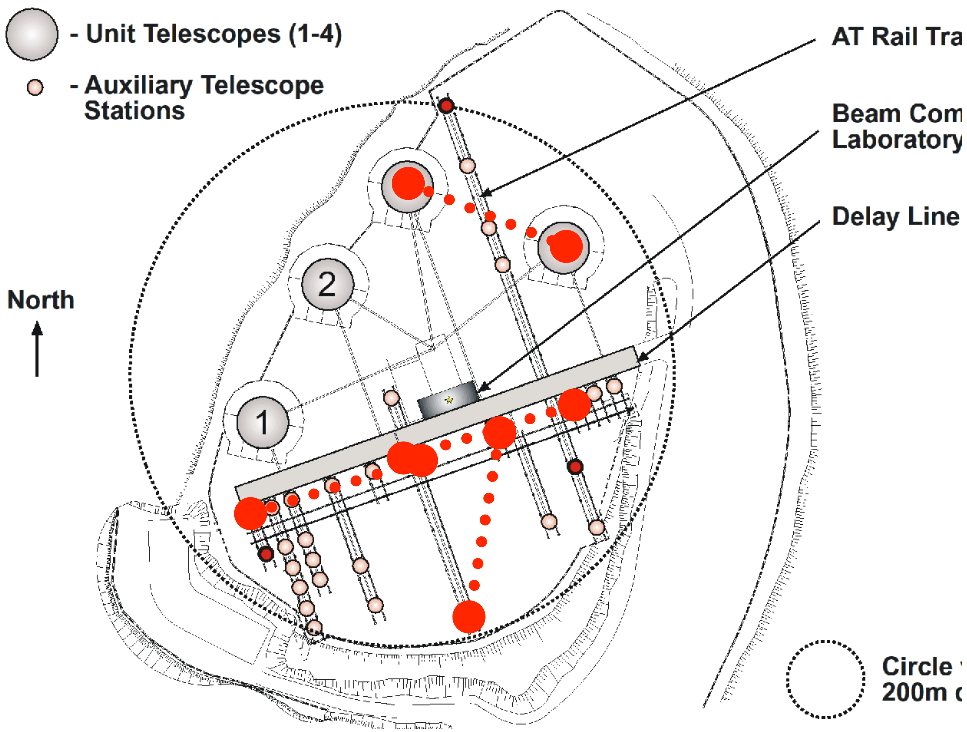
V1280 Sco : a dust forming classical nova

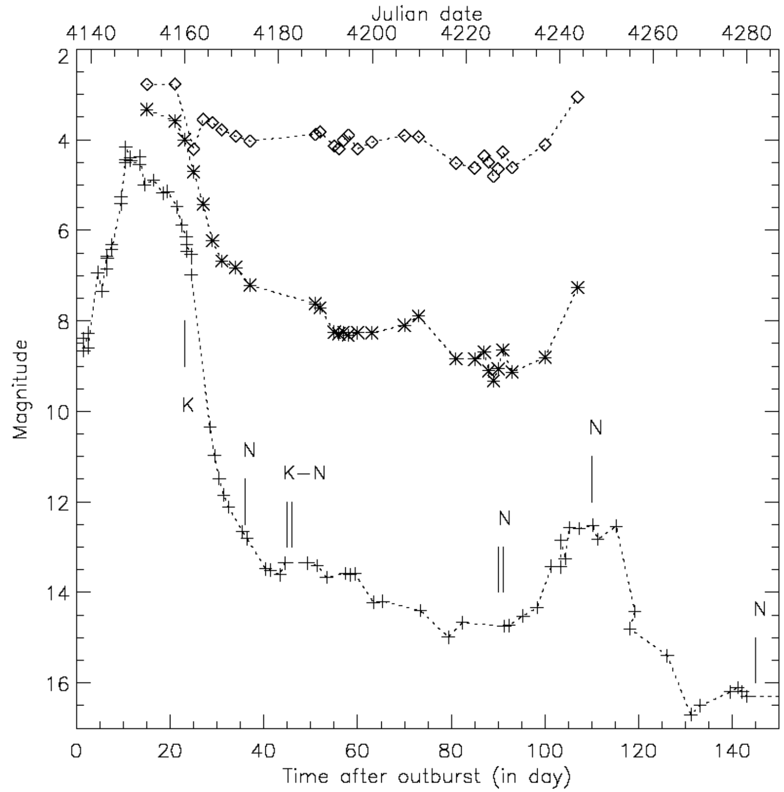
RS Oph was a recurrent nova: the evolution of the photometry/SED (V, H, K…) is known in advance!

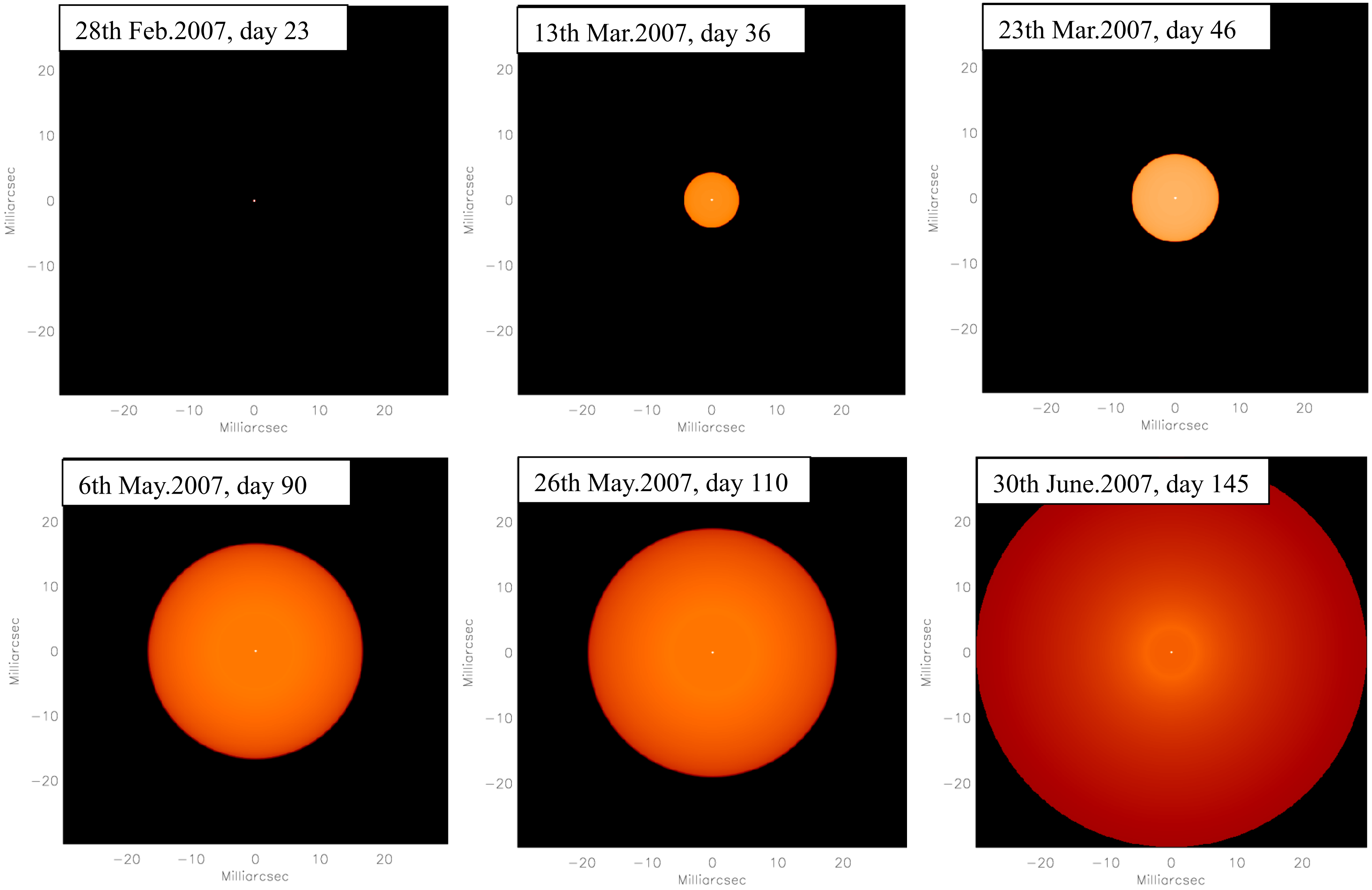


Julian Day	2007 UTC Date	Day[1]	Instrument	Magnitude	Base	Projected baseline Length [metre]	PA [degrees]
2454160.4	2007-02-28T08	23	AMBER 2T (H-K)	3.8 (K)	G1 - H0	71	175
2454173.3	2007-03-13T07	36	MIDI 2T (N)	1 (N)	G0 - K0	51	25
2454173.3	2007-03-13T07	36	MIDI 2T (N)	1 (N)	G0 - K0	56	41
2454173.3	2007-03-13T07	36	MIDI 2T (N)	1 (N)	G0 - K0	60	53
2454181.3	2007-03-22T07	45	AMBER 3T (H-K)	4.2 (K)	E0-G0-H0	14/29/43	46/46/46
2454182.4	2007-03-23T09	46	MIDI 2T (N)	0.3 (N)	A0 - G0	63	61
2454182.4	2007-03-23T09	46	MIDI 2T (N)	0.3 (N)	A0 - G0	64	67
2454227.2	2007-05-06T05	90	MIDI 2T (N)	-0.8 (N)	U3 - U4	60	102
2454227.4	2007-05-06T09	90	MIDI 2T (N)	-0.8 (N)	U3 - U4	58	132
2454228.3	2007-05-07T08	91	MIDI 2T (N)	-0.8 (N)	U3 - U4	59	128
2454247.0	2007-05-26T01	110	MIDI 2T (N)	-1.6 (N)	U3 - U4	35	75

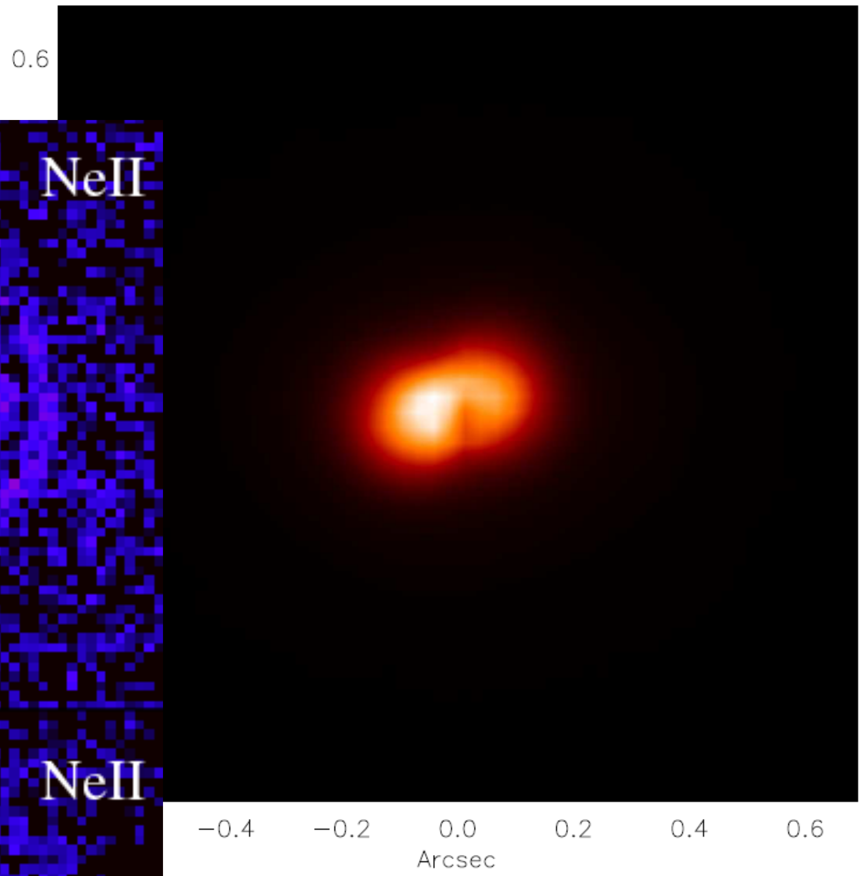
[1] From discovery, Feb. 4.85 UT. JD=2454136.85

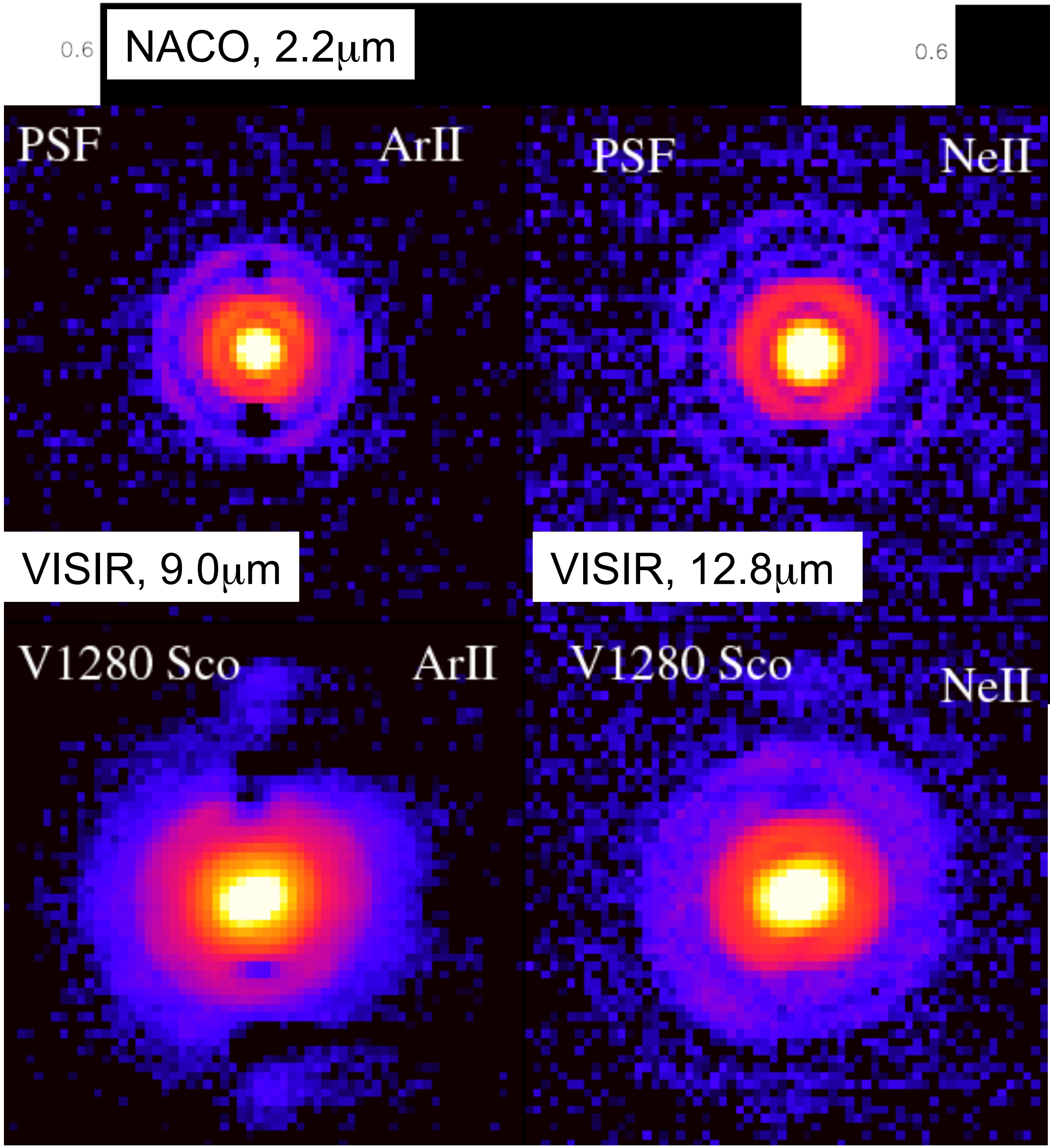






Chesneau, O., Banerjee, D., Millour F., Nardetto N. et al., 2008, A&A
Use of the DUSTY code for the interpretation.





VLTI baselines: by chance (?) oriented in the direction of major axis…

NACO (burst) et VISIR (burst) new observations to come. Kinematics needed.

Conclusions:

• In many cases the binarity is invoked for the shaping of bipolar PNs
• As direct detection is difficult, indirect detection methods are used
• The best method is too detect *compact, stratified dusty disks*

Not mentioned in this talk: detection of many flat disks around B[e] stars

• *The first observations of novae by the VLTI demonstrated the potential of the technique BUT the complexity of the ejecta was under-estimated,*

• Large *uv* coverage is mandatory to get asap an hint of the bipolarity of the source,

•In general the lack of *uv* coverage is the principal limitation for getting an inclination and the vertical stratification. There is a strong degeneracy between the disk parameters increasing with decreasing inclination,

• The MATISSE instrument will be able to combine 4 telescopes, observing simultaneously in the L (3.8 micron), M (5 micron) bands and N (10 micron),

•for better constraining the disks, it is crucial to obtain their kinematics. This is currently done with AMBER on supergiants with disk (R=12000), but the second generation instruments won't have this capability

• Hence, the synergy between ALMA and the VLTI is an asset for characterizing extensively the stratified disks around YSO and evolved stars.