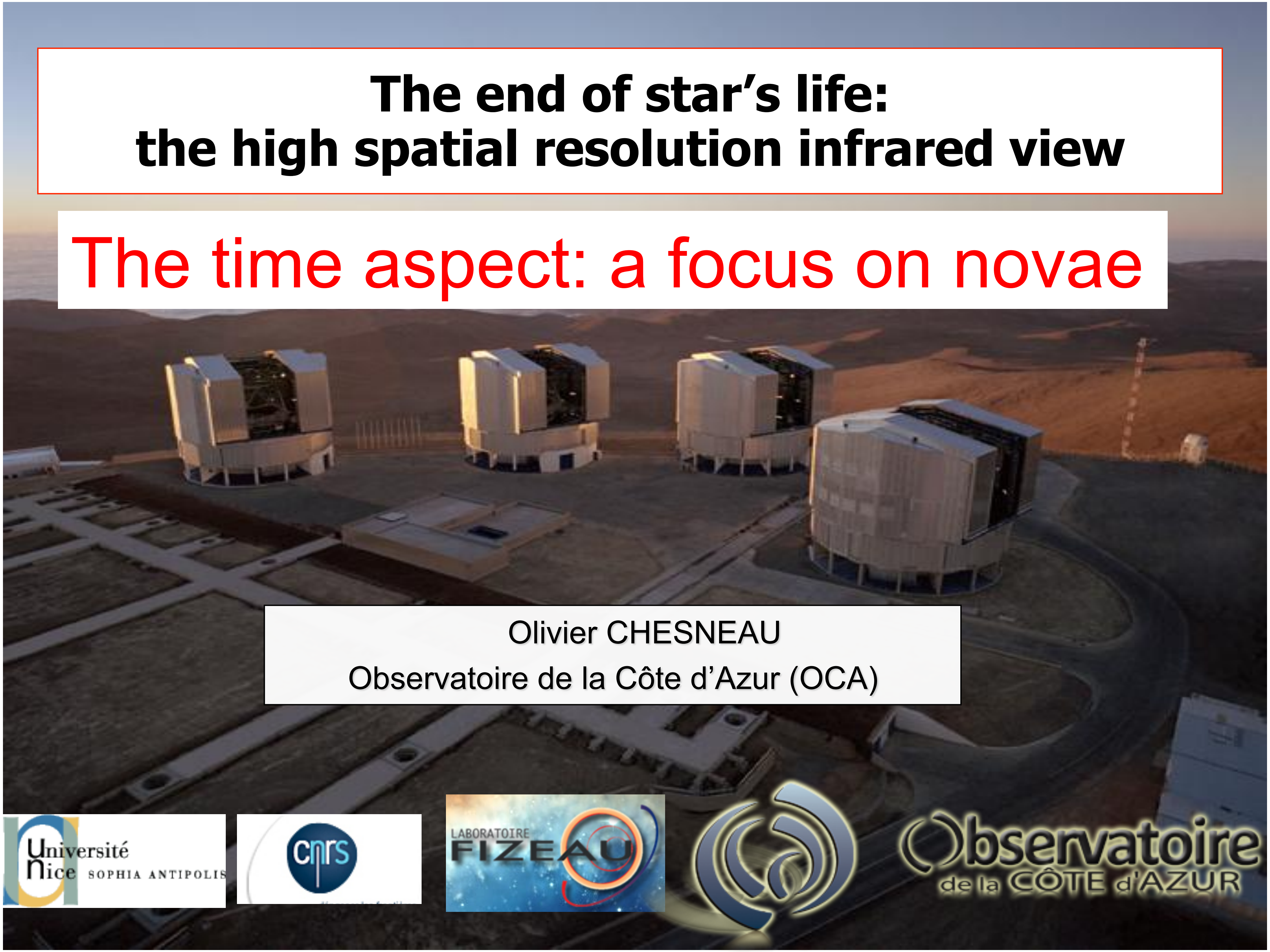
The end of star's life: the high spatial resolution infrared view

The time aspect: a focus on novae



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Université Nice Sophia Antipolis · CNRS · Laboratoire Fizeau · Observatoire de la Côte d'Azur

The end of stars: large mass-loss rates

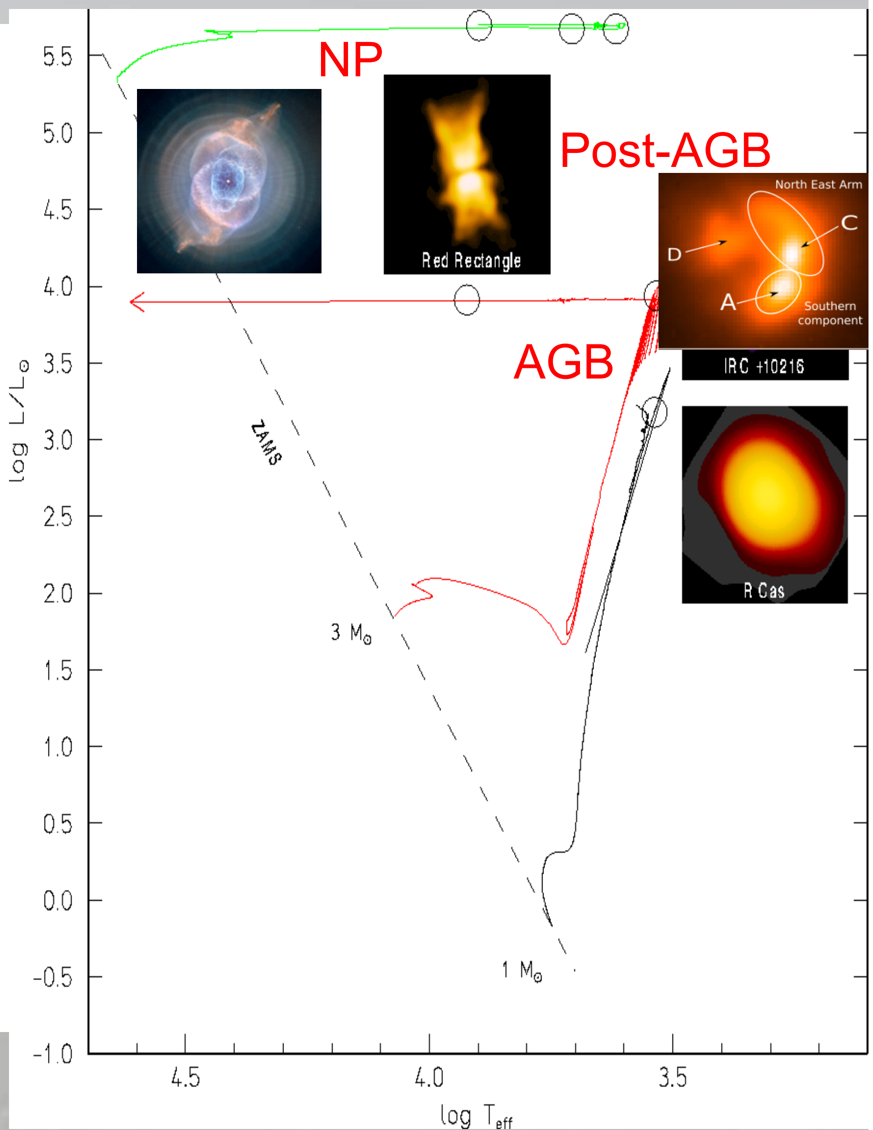
- A star that leaves the main sequence increases its radius, and its luminosity

- 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*

- Dense winds appear, a large mass-loss takes places, and clumpiness is growing,

- The spherical symmetry of the ejecta is almost universally broken,



The end of stars: binarity matters!

The Origin and Shaping of Planetary Nebulae:

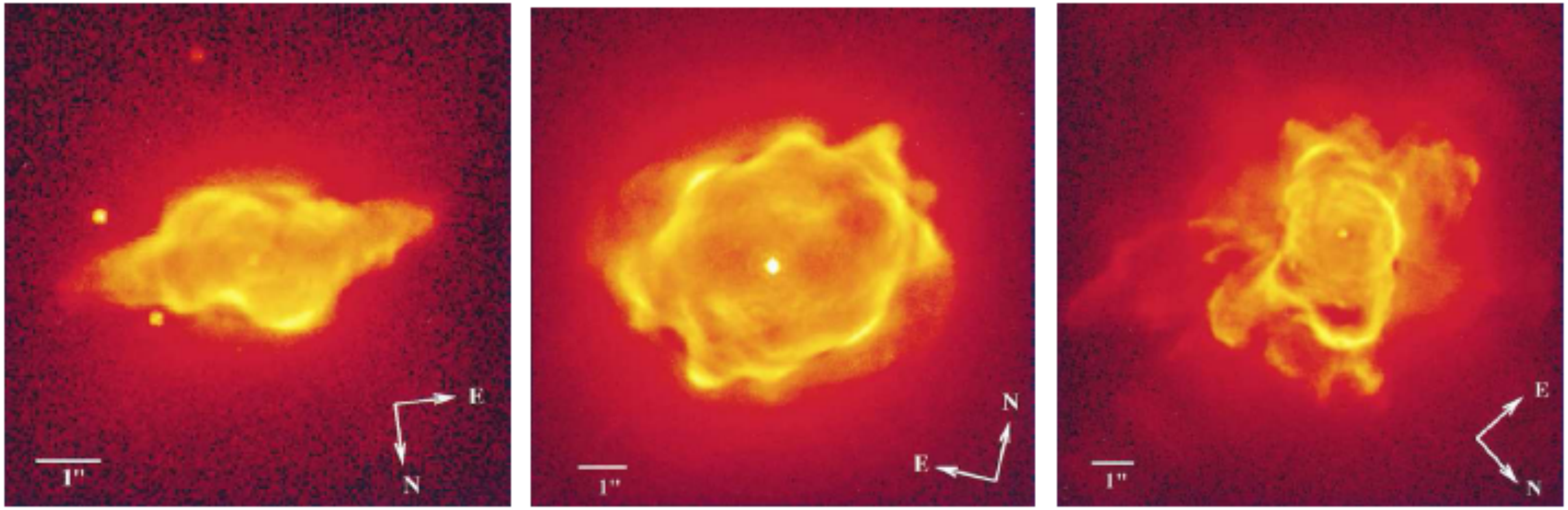


Fig. 1.— HST Hα images of very young PNe (He 2-115, left, He 2-138, center and M 1-26, right) demonstrating the extreme morphologies exhibited by these objects. From Sahai & Trauger (1998), reproduced by permission of the AAS.

Do most planetary nebulae come from binaries?

"the PN population does not need to mirror the main sequence population, but it derives from only a subset of it".

Hot issues: low mass stars to the most massive ones

Mass-loss at the end of the life:

- dusty winds, pulsations, Chromospheres / wind interplay,
- 'hot' radiative winds, clumping,
- The critical rotation and mass-loss (massive stars, Be stars)

Bifurcations in the evolution, taking binarity into account:

- amount of stars that skip the AGB or red supergiant stages due to binarity
- better constraints on mergers,
- supernova Ia progenitors,
- spun-up stars,

Mechanisms of common envelope phase

- duration,
- impact on angular momentum budget,
- survival probability of small, dense object,
- feedbacks mechanisms (jets / accretion disks / magnetic fields…),
- New: the fate of planets on their (non-negligible!) impact on PNs,

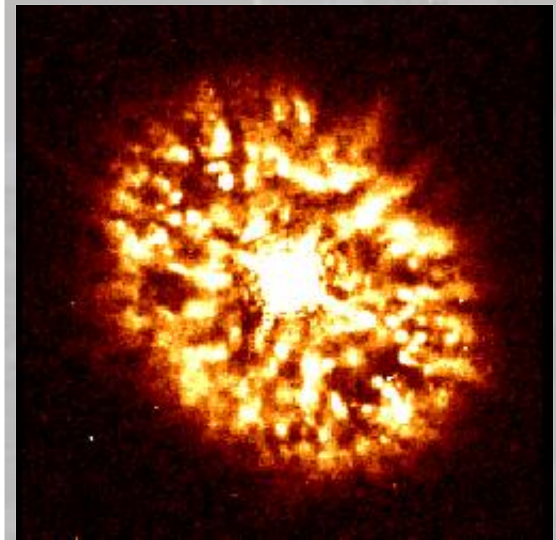
Impact of the VLTI in this context:

- Mass-loss, pulsations, winds (Wittkowski, Ohnaka, Oudmajer, Karovikova, Richichi, Domiciano, Sacuto, Hron …),
- Multiplicity (Sana, Le Bouquin…), Rotation (Domiciano, Rivinius, Kervella)
- Interacting binaries, post-common envelop systems (Wheelwright, Millour, Blind, Weigelt, Ohnaka…),
- 'Naked' post-AGBs with disks versus bipolar PNs (Deroo, Hillen, Acke, Chesneau, Verhoelst, Lykou…),
- Novae: excellent laboratory for testing common envelop mechanisms (Chesneau,…)

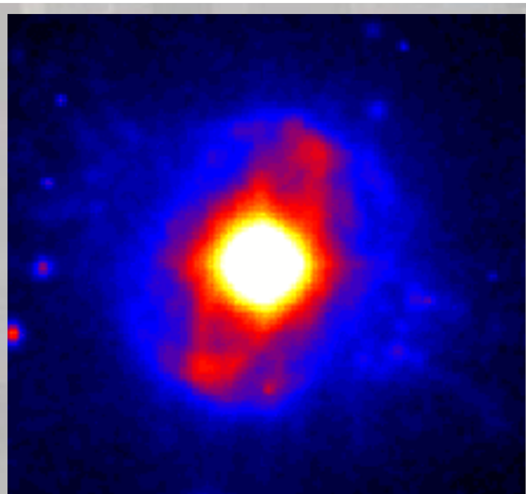
Novae: good laboratories for common envelop physics

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 0.3-1/year within the VLTI observability and sensitivity limits,

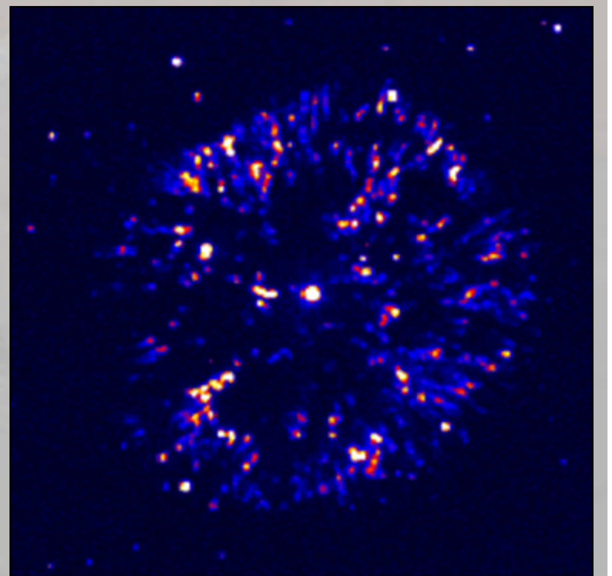
Nova ejecta experience a strong common envelop stage: good laboratory.



HR Del (1967, - Hα



RR Pic (1925, **S**)

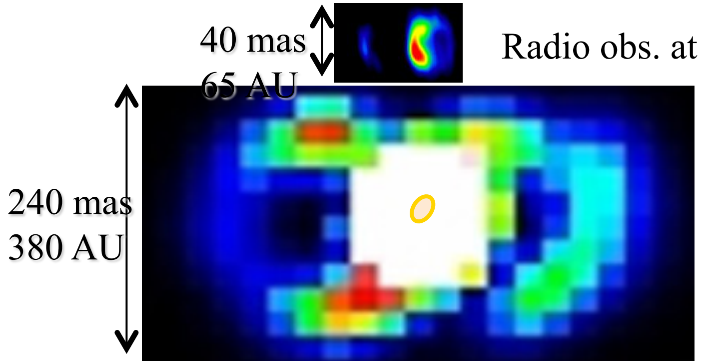


GK Per (1901, **VF**)

>40 optical; ~10 radio (O'Brien & Bode 2008)

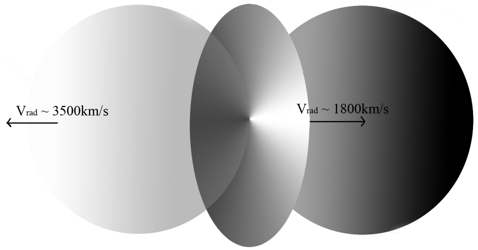
Novae: well-suited targets for high angular resolution techniques

Recent examples of bipolar nebulae observed less than 1-2yrs after outburst

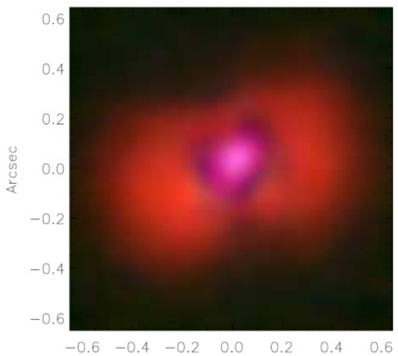


Radio obs. at t=22 days

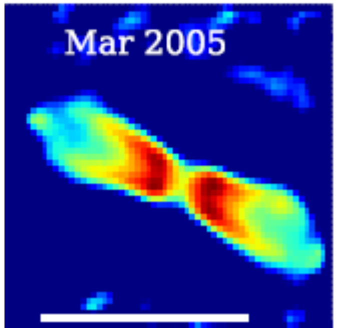
HST visible image at t=150 days



The *recurrent* RS Oph:
O'Brien et al. 2006,
Chesneau et al. 2007,
Bode et al. 2008…
Outburst: 1898,1933, 1958, 1967, 1985, 2006

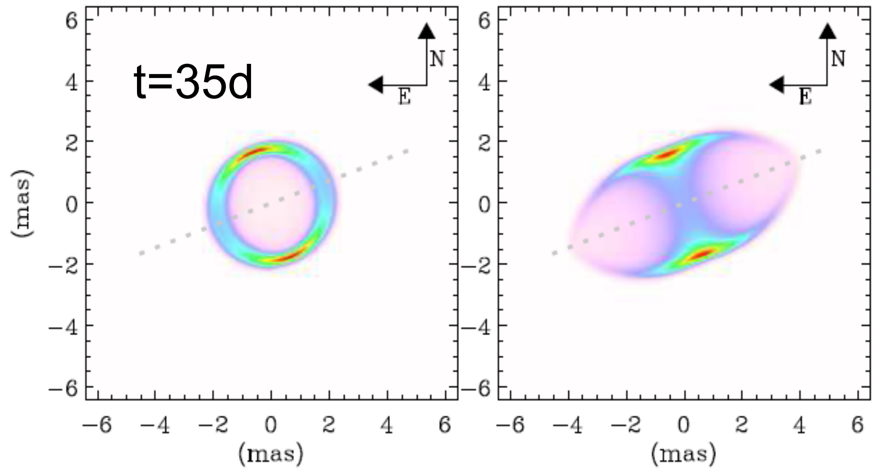


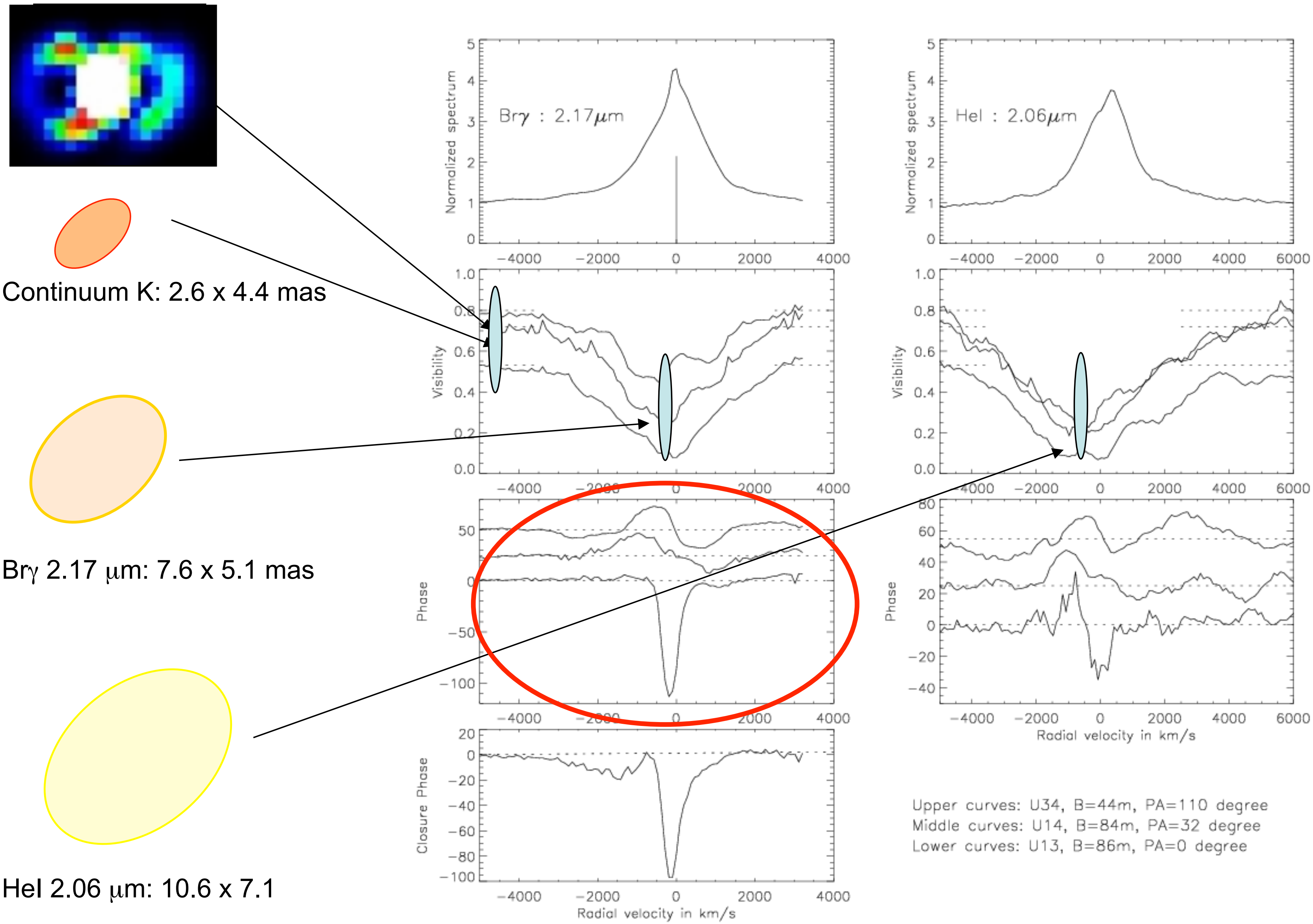
The classical V1280 Sco:
Chesneau et al. 2008,
Chesneau et al. in preparation
A slow nova (Vej~500km/s): common envelop hypothesis favored



The classical V445 Pup:
Woudt et al. 2009,
Slow event (~7 month) but fast wind (Vej~4000km/s): An extremely asymetrical outburst?

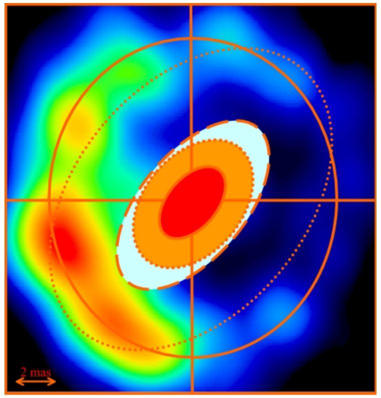
The *recurrent* T Pyx: a near-pole on bipolar nebula
Chesneau et al., 2011, Outburst: 1898,1933, 1920, 1944, 1966, 2011





AMBER observation of the Recurrent Nova RS Oph: t=3.5d, one triplet only…

Intense activities



H/K IOTA / KI: Monnier et al. 2006

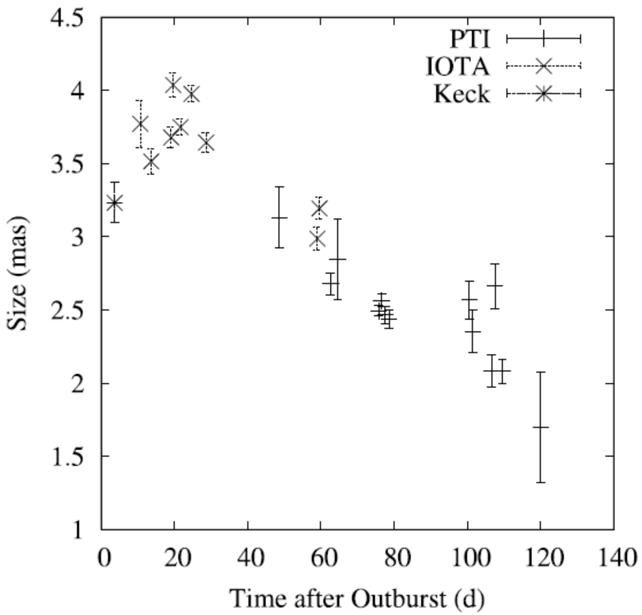
Asymmetries and indications of pre-existing material

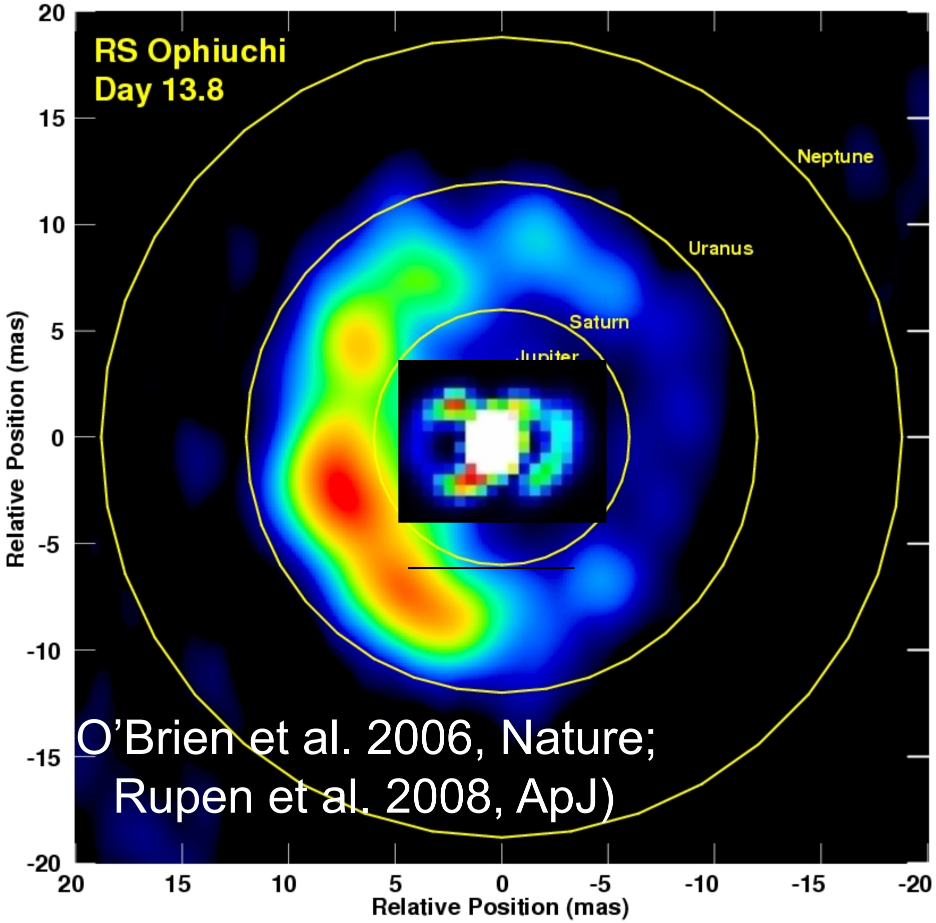
K PTI: Lane et al. 2006

The complex free-free signature of the expanding ejecta and the wind of the shrinking WD

N KI/nulling: Barry et al. 2008

Confirmation of pre-existing material, spiral pattern. Effect on ejection?

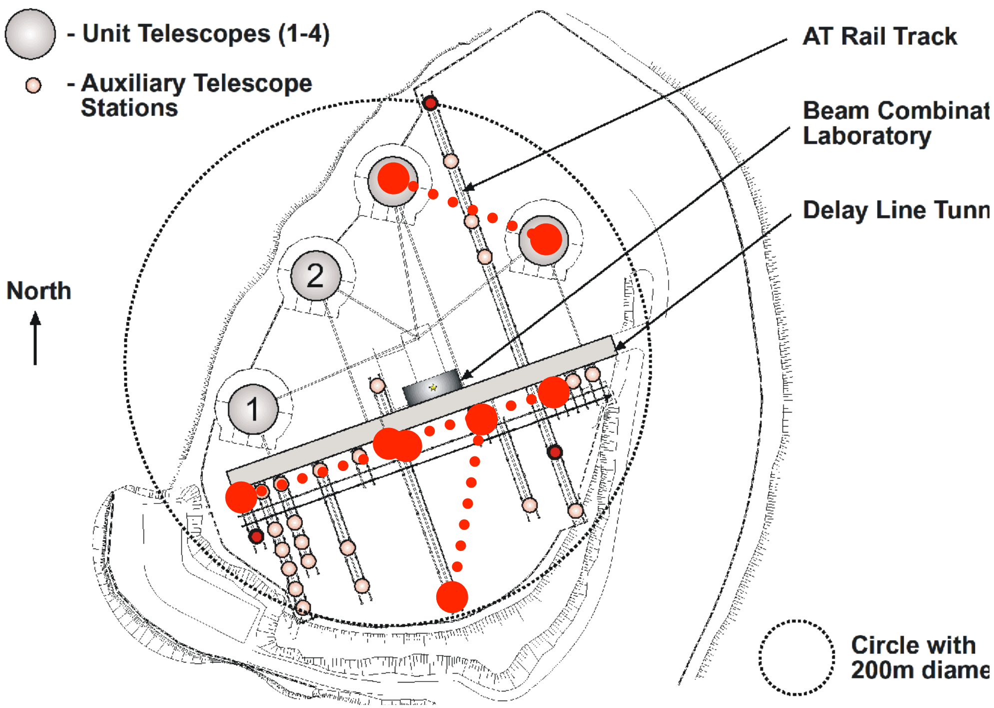


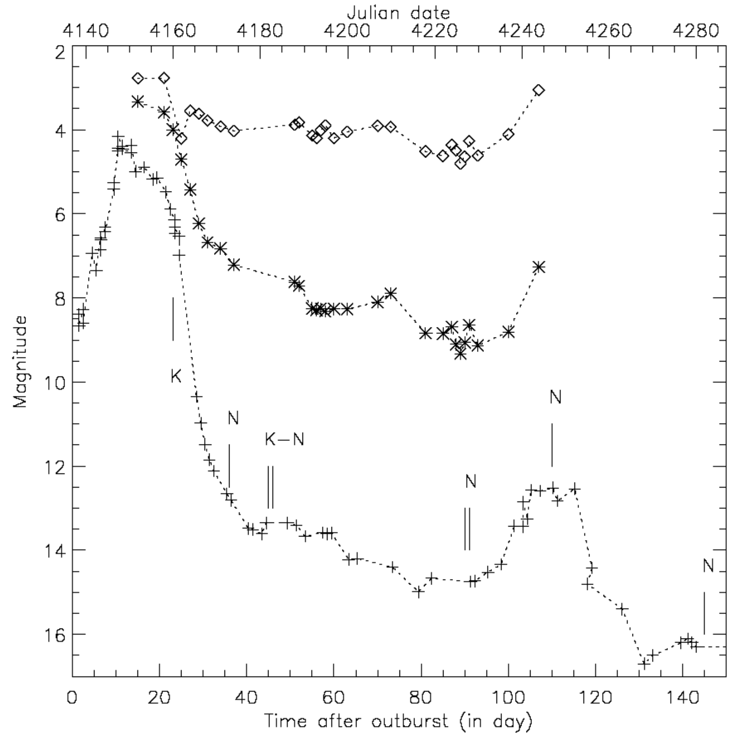


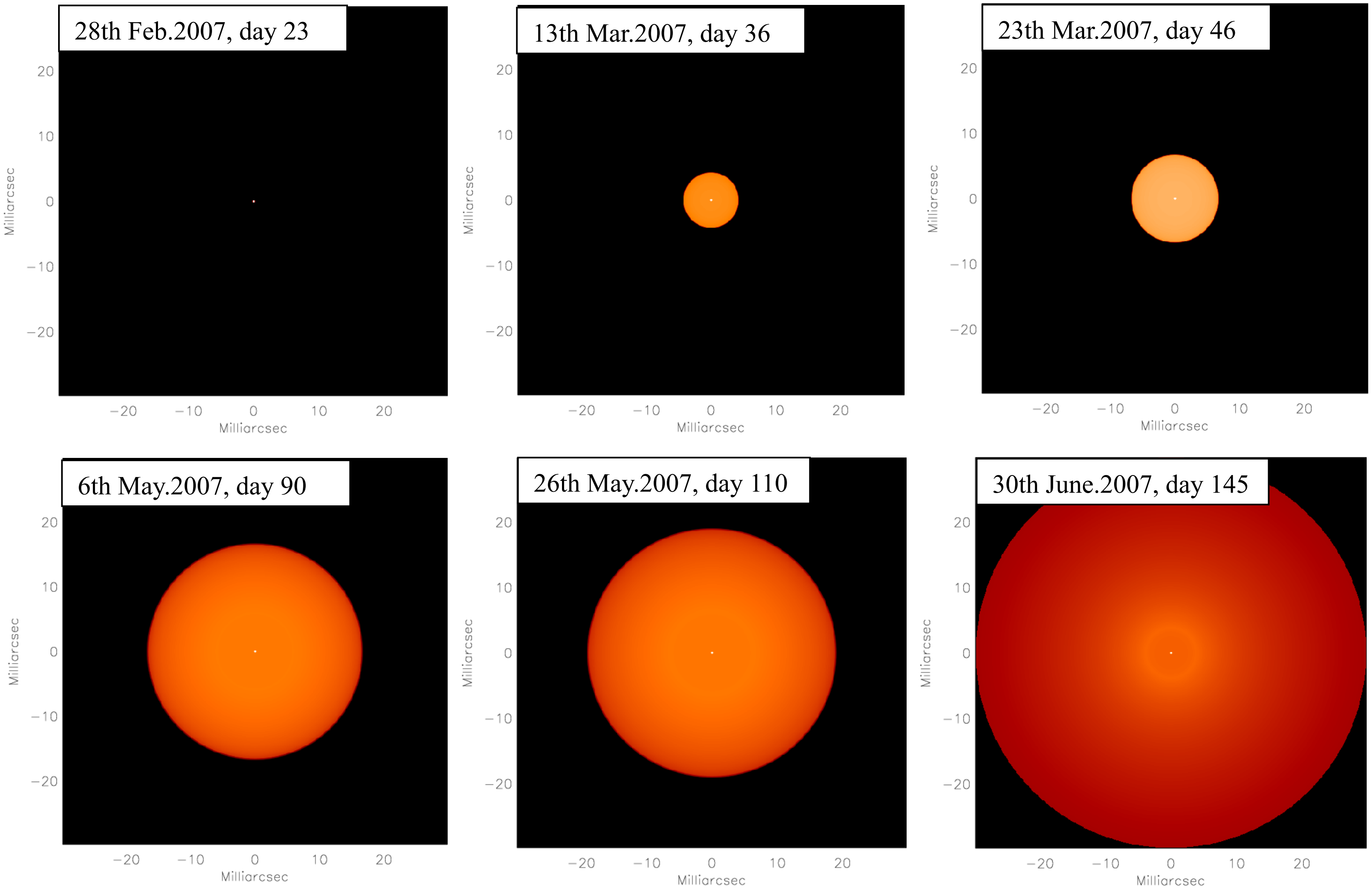
O'Brien et al. 2006, Nature;
Rupen et al. 2008, ApJ)

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

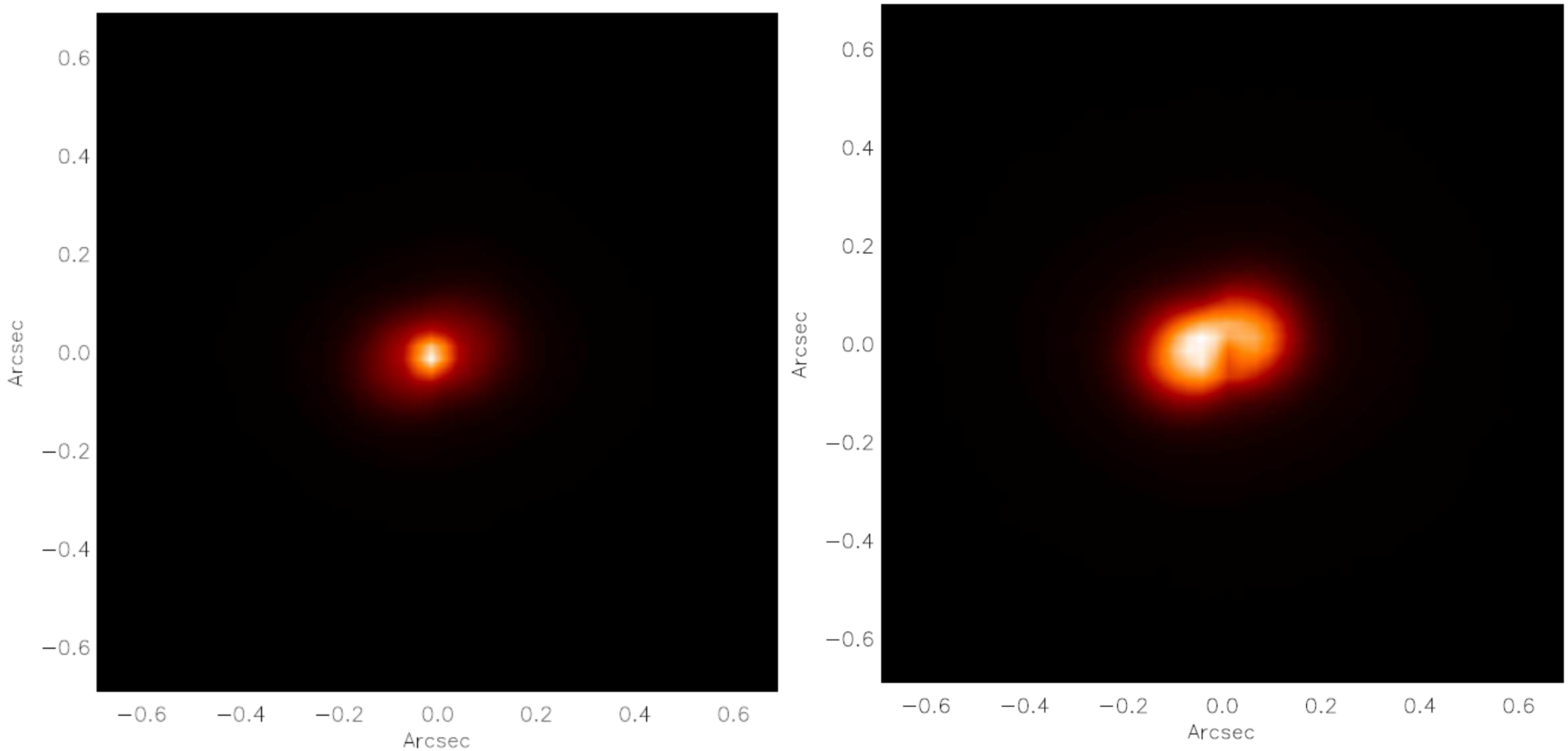






Chesneau, O., Banerjee, D., Millour F., Nardetto N. et al., 2008, A&A
Use of the DUSTY code for the interpretation.

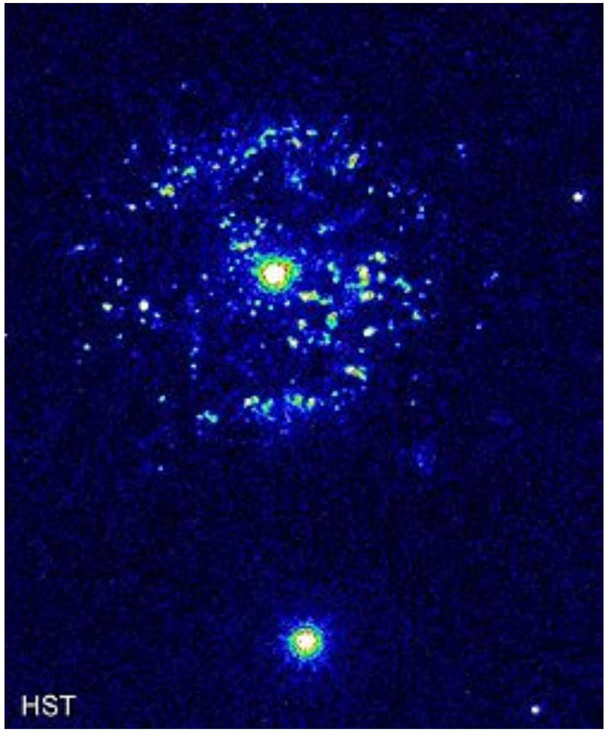
July 2009: NACO, 2.2μm: A BIPOLAR NEBULA…again



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

Dust velocity field (fully???) decoupled with the gas. Clumping?

The recurrent T Pyx: a long awaited event.



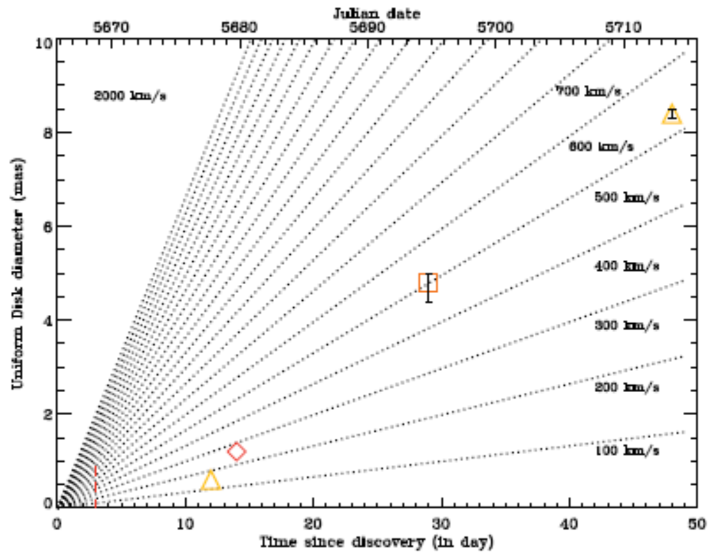
CV of T Pyx

- Discovered by H. Leavitt in 1913,
- First ‘recurrent’ nova, oubursts in 1890 and 1902,
- Then 1920, 1944, 1966…then April 2011

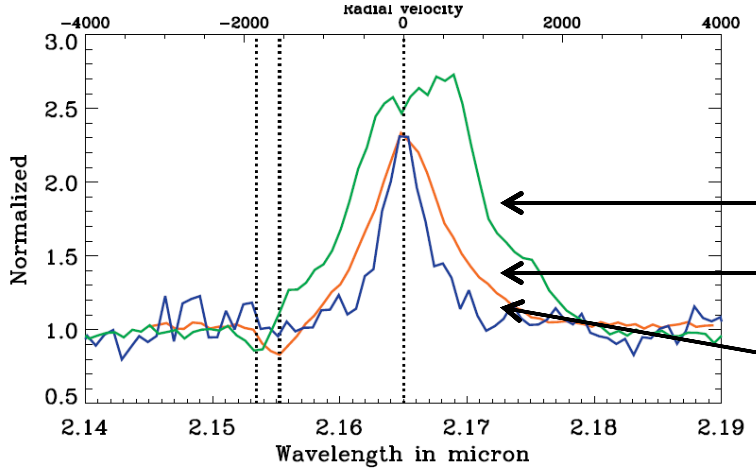
- Nebula deeply studied by the HST (Shara et al. 1997),
- ‘Slow motions’ measured (v~600km/s, Schaefer et al. 2010)
- Binary spectrocopic signal resolved, q=0.2, i= (Utas et al. 2010)

2011 T Pyx outburst: as seen by optical interferometry

- 2 *CHARA/CLASSIC* at Mt Wilson (1st: t=2.7d, t_0=14th April)
- 3 *VLTI/AMBER* and 2 *VLTI/PIONIER* obs. (until t=48d)
- Results
  - A slow expansion (v<700 km/s) measured assuming D=3.5kpc (but Shore et al. 2011→ D>3.5 kpc)
  - The source appears circular (r=1+/-0.07),
  - Extended Complex phase signal in the Brγ line,



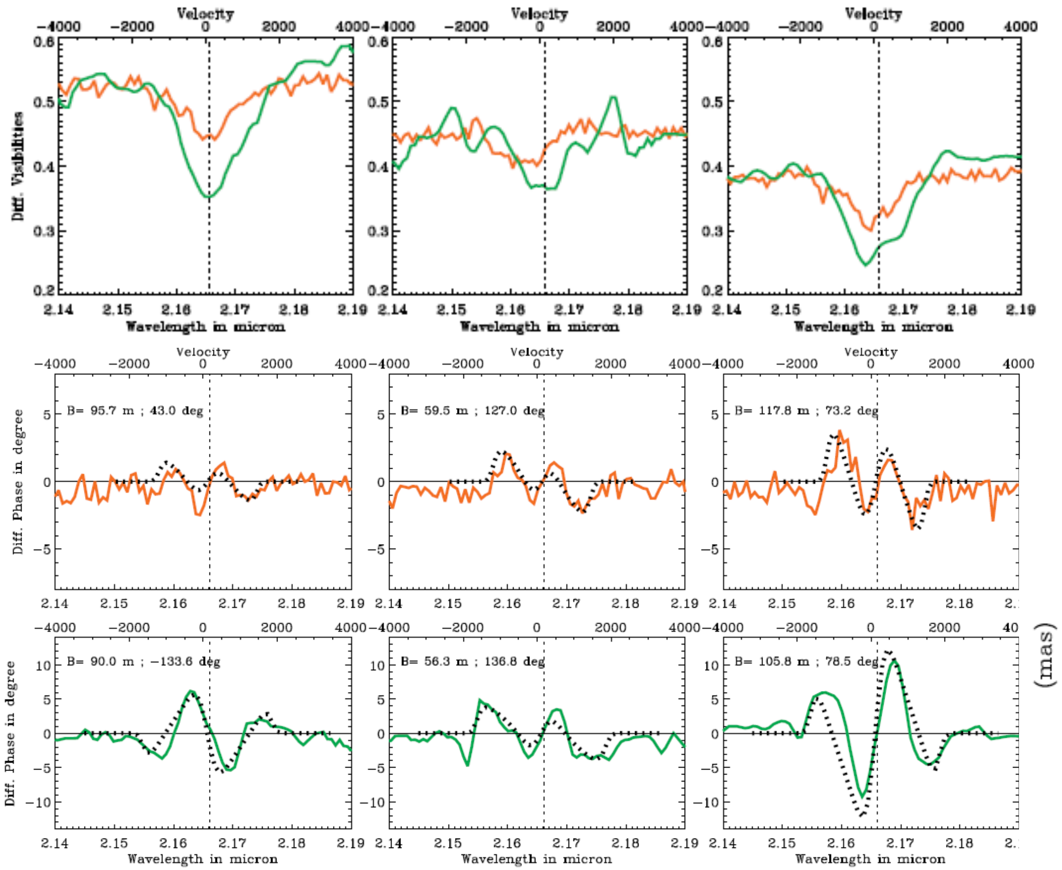
AMBER / VLTI obs.



Green: **t=36 d, FWHM=1600, P Cyg=-1800 km/s**

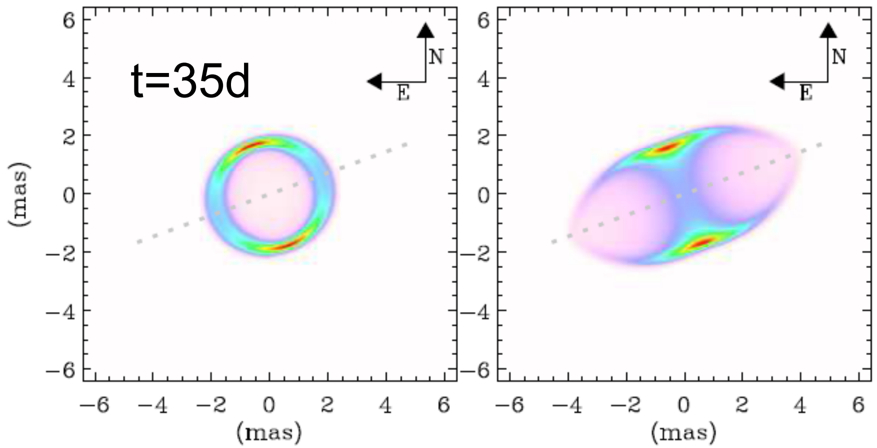
Red: **t=28 d, FWHM=1050, P Cyg=-1450 km/s**

Blue: **t=13 d, FWHM=590 km/s,**



Observations best interpreted in the frame of a nearly pole-on, accelerating bipolar model, i~15°, P.A.~110°

- t=28d: Vpol=1200 km/s, Veq=600 km/s
- t=36d: Vpol=1600 km/s, Veq=700 km/s



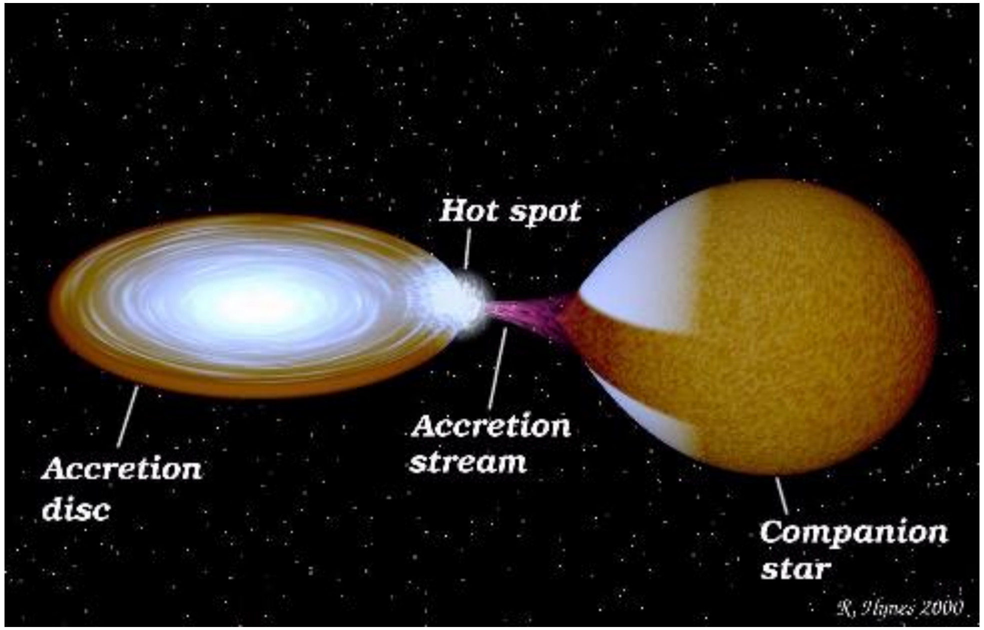
Origin of bipolarity?

Three hypotheses:

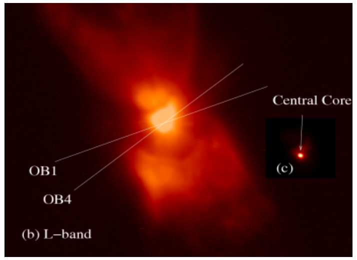
1. An explosion channeled by a circumbinary environment,
2. An intrinsically asymmetrical eruption (spun-up WD? Accretion disks? Magnetic fields? Jets/MHD effects?
3. A common envelop phase,
    1. Slow novae are statistically more bipolar that fast one,

Many connections with:

- strongly bipolar PNs (short term events),
- Symbiotic stars,
- ILOT (Intermediate Luminosity Optical Transcient) → mergers, close-encounters

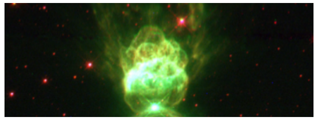


QX Pup, the 'rotten egg'



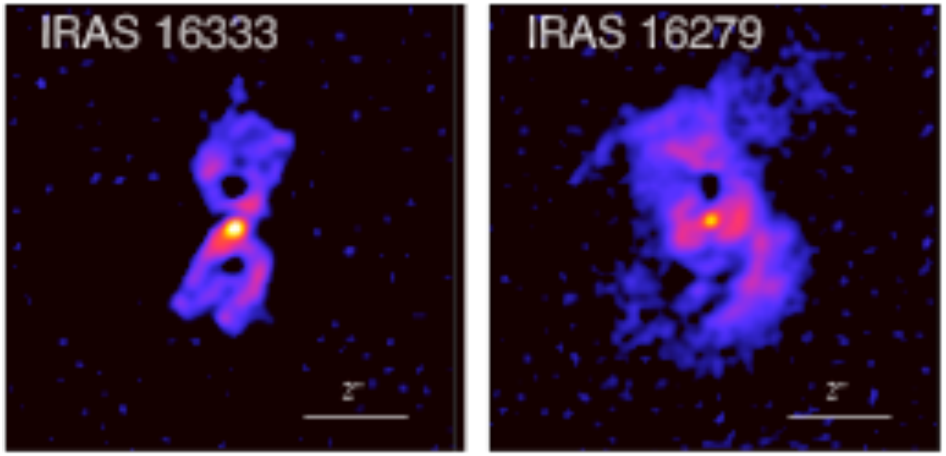
QX Pup/OH231.8: equatorial overdensity, no stratified disk, disk in formation? Detection of a companion in uv
High potential: good target for ALMA/VLTI joint studies
Spherical shell opened by jet
Matsuura, Chesneau et al. 2006,

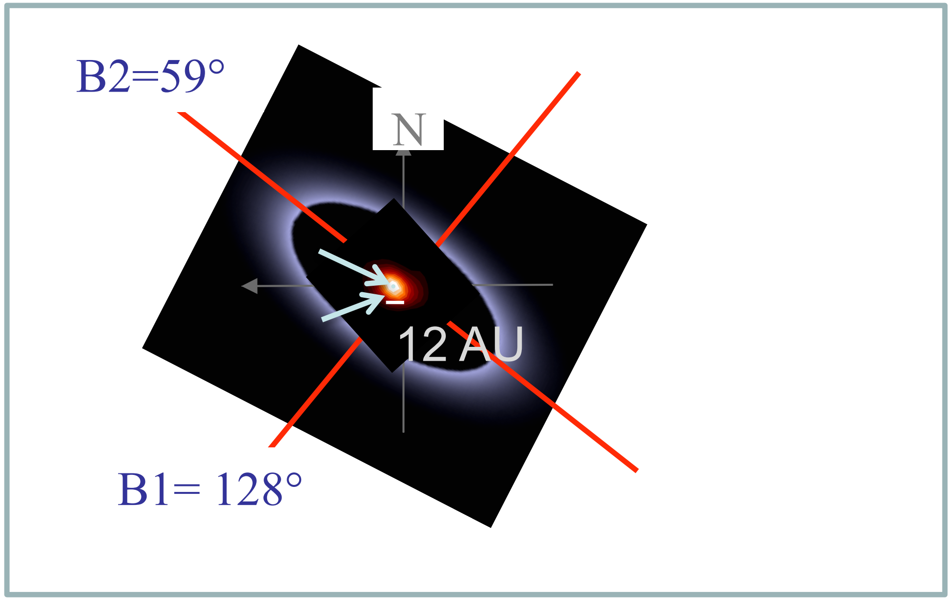
Menzel 3, the ant



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

Period 87 (Observations partially completed)





Conclusions

- Binary interaction is in the core of many of the physical processes in action to eject bipolar nebulae and create decretion disks (except for the fast rotating Be stars),
- The common envelop phenomenon is universal and lead to profond consequences, deeply affecting the fate of the stars in frequent cases,
- Due to the low density material involved, even massive planets can have a significant implact on the ejecta,
- There is growing evidence that the most bipolar Planetary Nebulae are formed in short events, and that PNs are deeply related to binarity,

The outburst of V838 Mon: a merger in a young stage!!!
From triple to double system…
The prototype of ILOT: intermediate luminosity optical transient