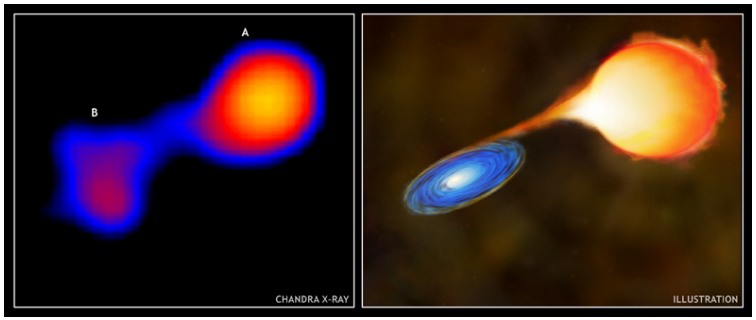
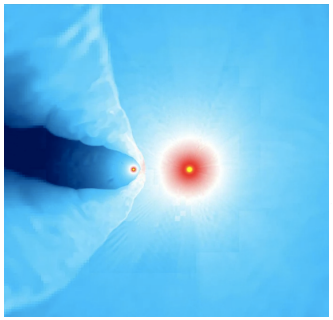
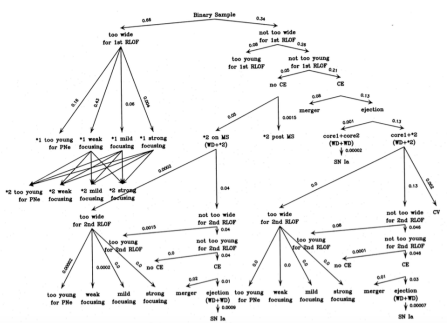
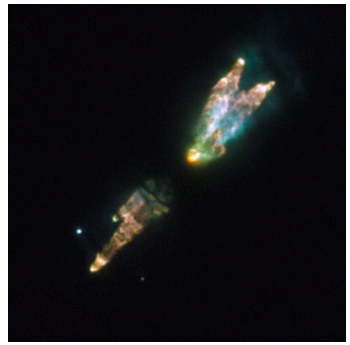


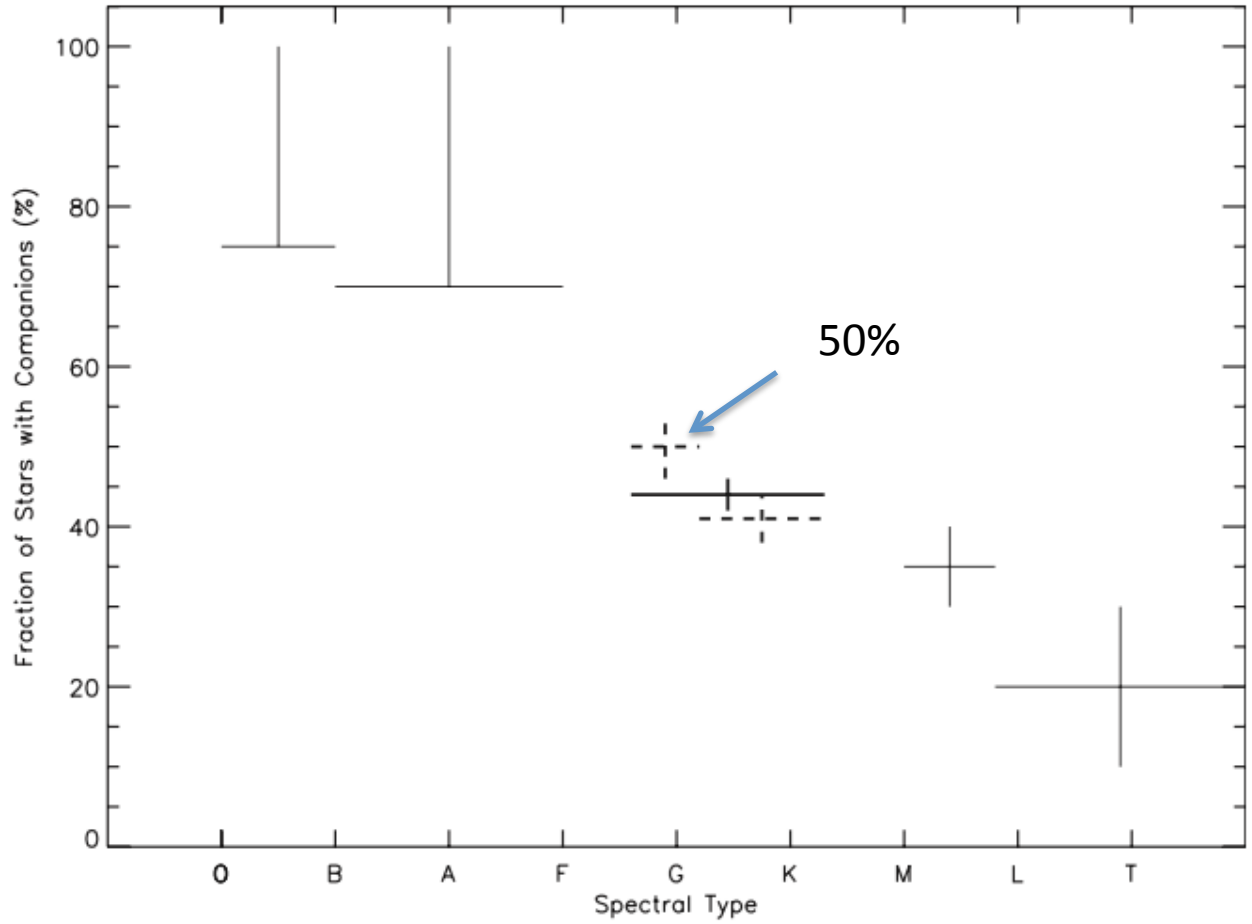
Binaries across the mass spectrum from theory to observations

Orsola De Marco
Macquarie University
Sydney

Outline

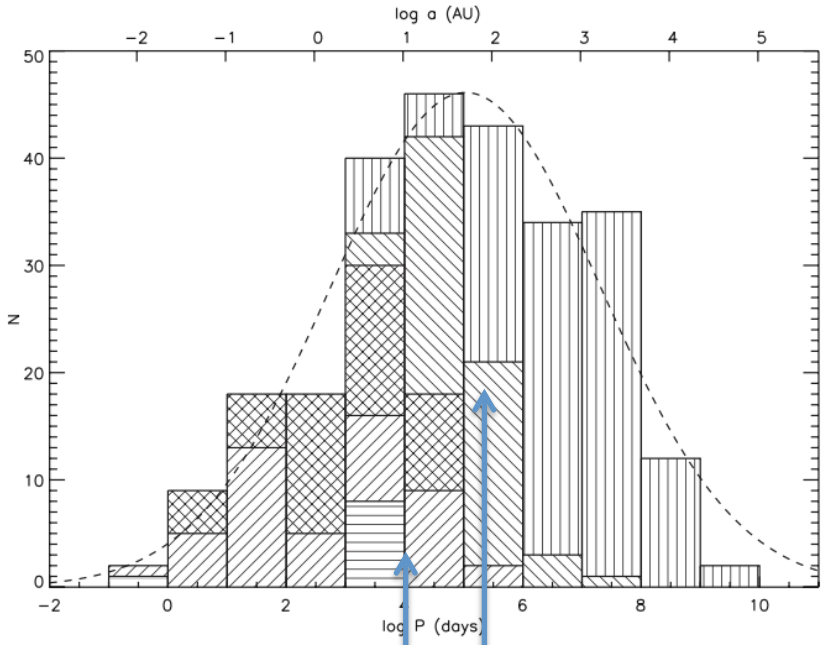
- How many binaries?
- The classical binary and the new binary
- The binary astronomer toolkit, observations and theory
- A fast binary tour
- Conclusions

More massive stars, more binaries



Raghavan et al. (2010)

Period distribution of F and G main sequence stars



$R_{AGB} < 3$ AU

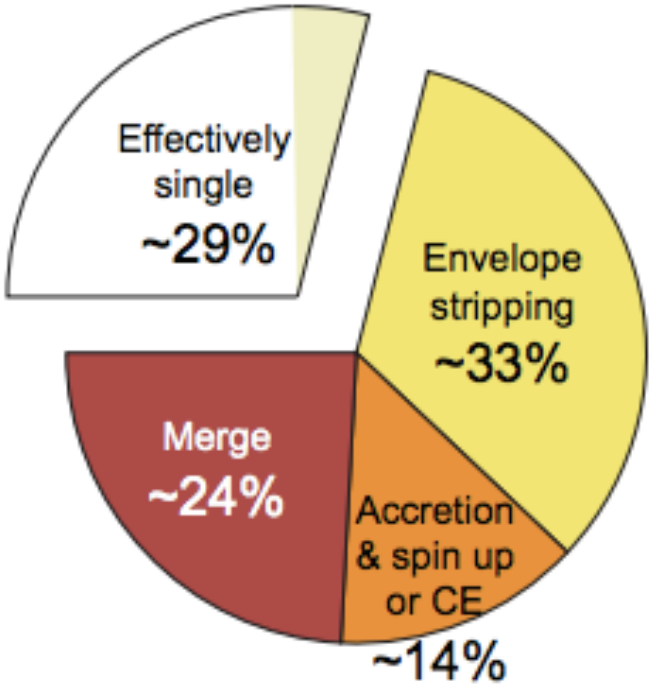
$a_{max} < 10$ AU

a_{max} wind < 100 AU

Raghavan et al. (2010)

Interacting binaries in massive stars

~70% interaction fraction upon evolution



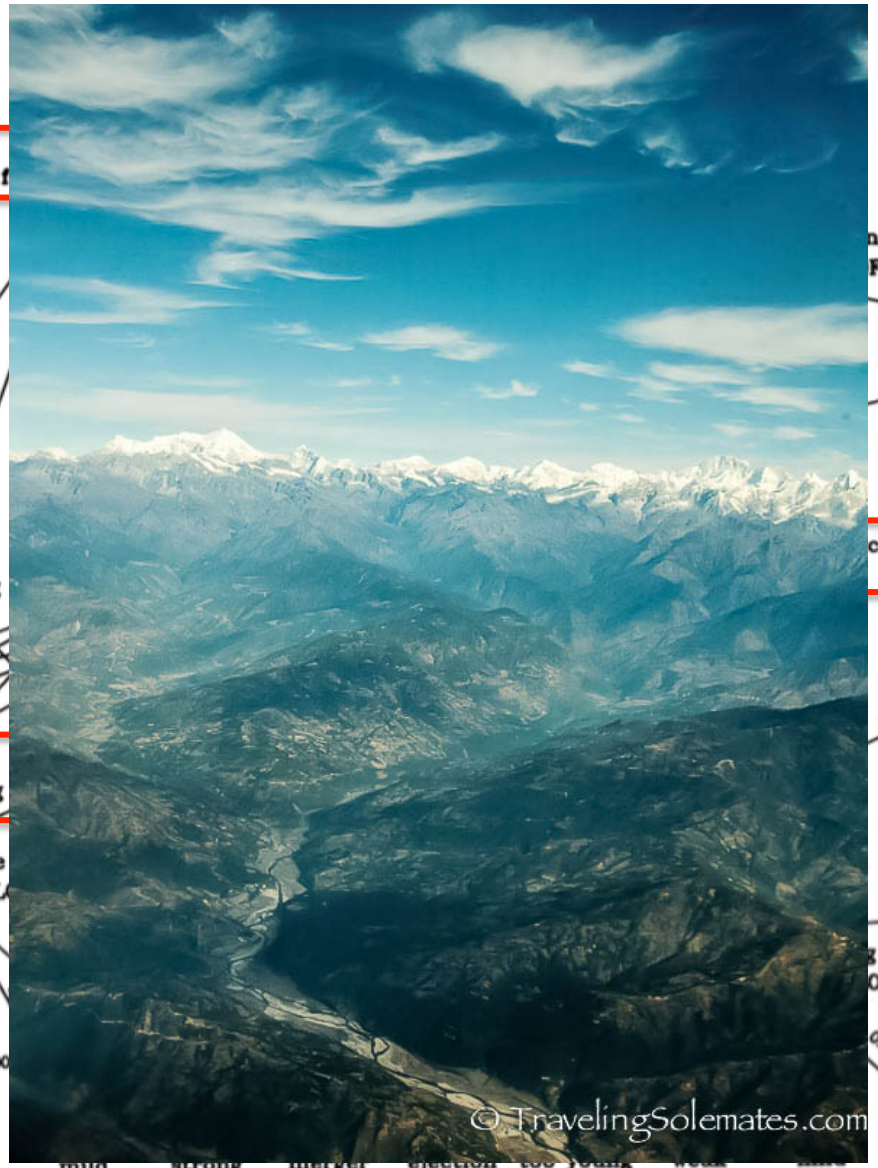
Sana et al. (2012)

These are (some) binary classes

- Novae, dwarf novae, recurrent novae
- Symbiotics
- Algols (W Serpentis, e.g., β Lyrae)
- Spectroscopic
- FS CMa
- Post-CE central stars of PN
- postAGB and postRGB close and not so close binares
- AMCVn
- Visual
- Eclipsing
- WR+O pinwheel LBV binaries
- Contact, over-contact
- Sequence-E stars
- Ellipsoidal variable, irradiated variable
- …

Connecting binary classes

e.g., L2 Pup or WRLOF binaries (Kervella+15; Mohamed+Podsi-adlowski12)



From Han et al. (1995) Example of binary channels for 1-8Mo stars

Symbiotics e.g., Mikola-jewska's papers

Close binary CSPN e.g., Miszalski+09

The questions

- *Classical* questions about binary evolution, e.g., the evolutionary path to symbiotics, or the progenitors of Type Ia SN.
- *Cross-field* questions: binaries as laboratories, e.g., how does accretion work, or jets...
- The *new* question: how often is a phenomenology better explained by binarity (or the presence of a planet)?

Observational Toolkit

- All the old tools!!!!
- High contrast and high angular resolution
- ALMA
- *Kepler* (and in t… future, TESS…
- Time-d…
- Mult… …senger

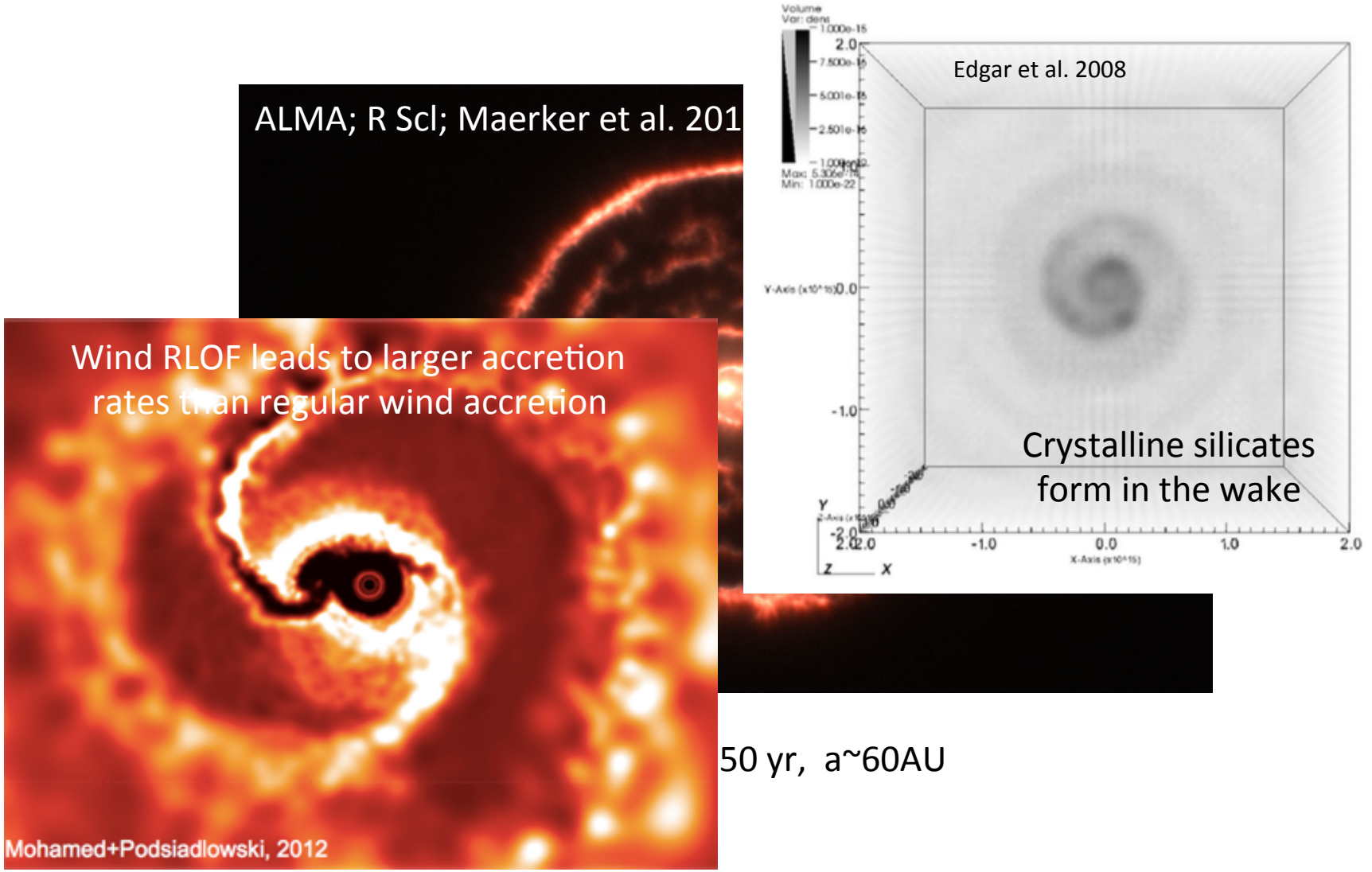
Theoretical Toolkit

- 1D stell… structure
- Ana… models of …ansfer and …es
- Semi-analytical (hydro + analytical)
- Population synthesis
- 3D hydro of details
- 3D hydro of the entire interaction

More observations than explanations

(Anita Richards)

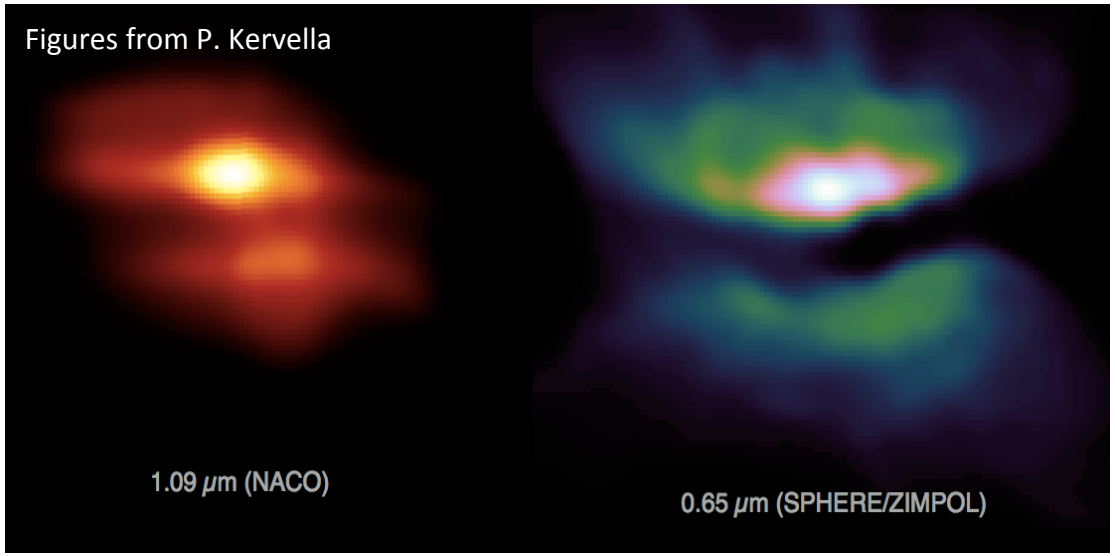
The widest interacting binaries

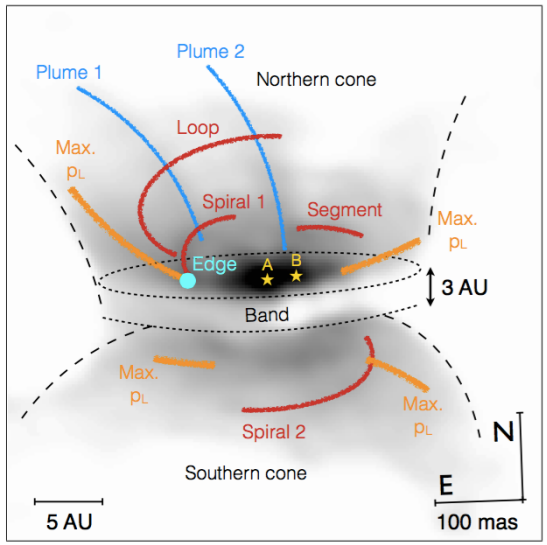


50 yr, a~60AU

Pretty wide interacting binaries

SPHERE+ZIMPLO@VLT view of L2 Pup

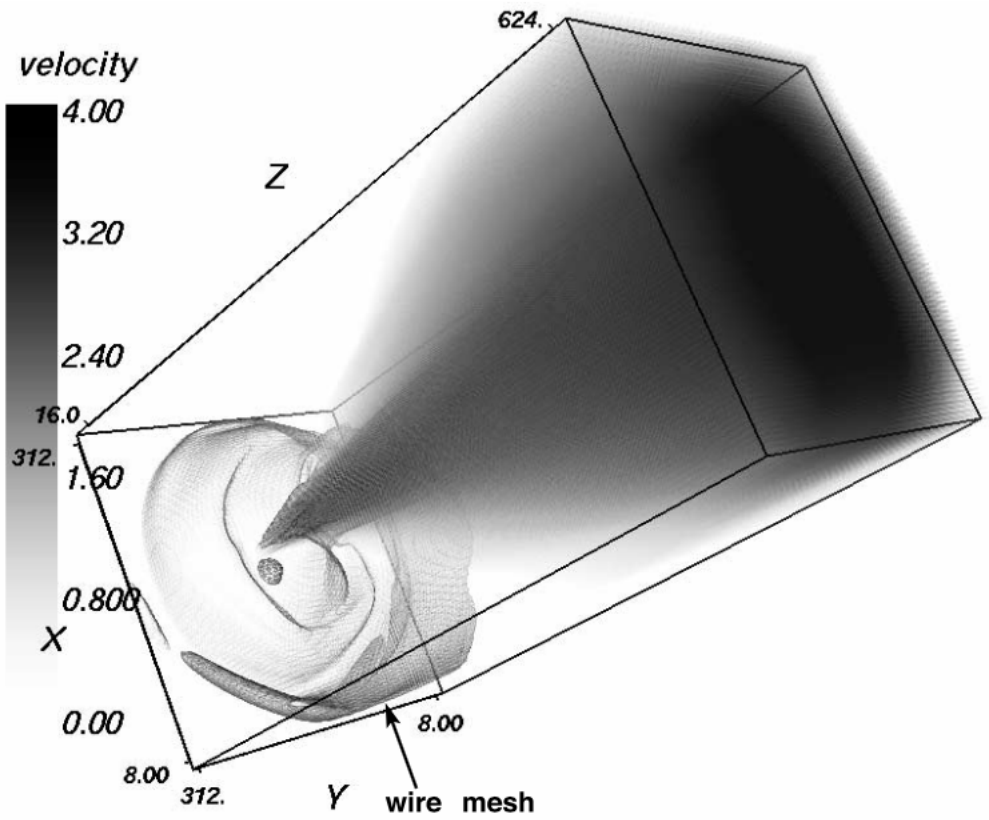




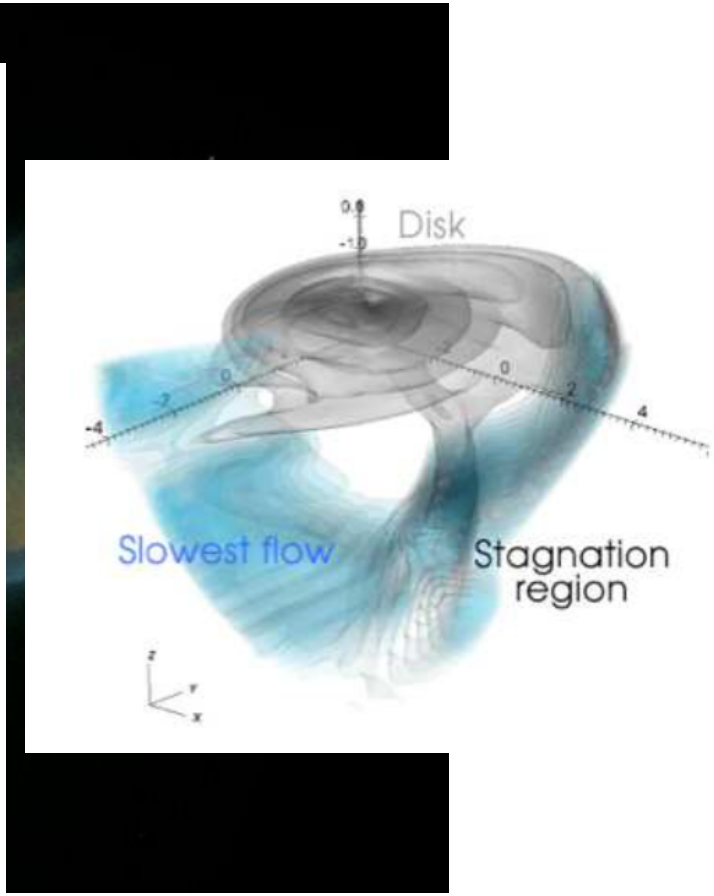
2Mo + comp. a = 2 AU;
Disk 6-13 AU

Kervella et al. 2015

Disks and jets from wide-ish binaries



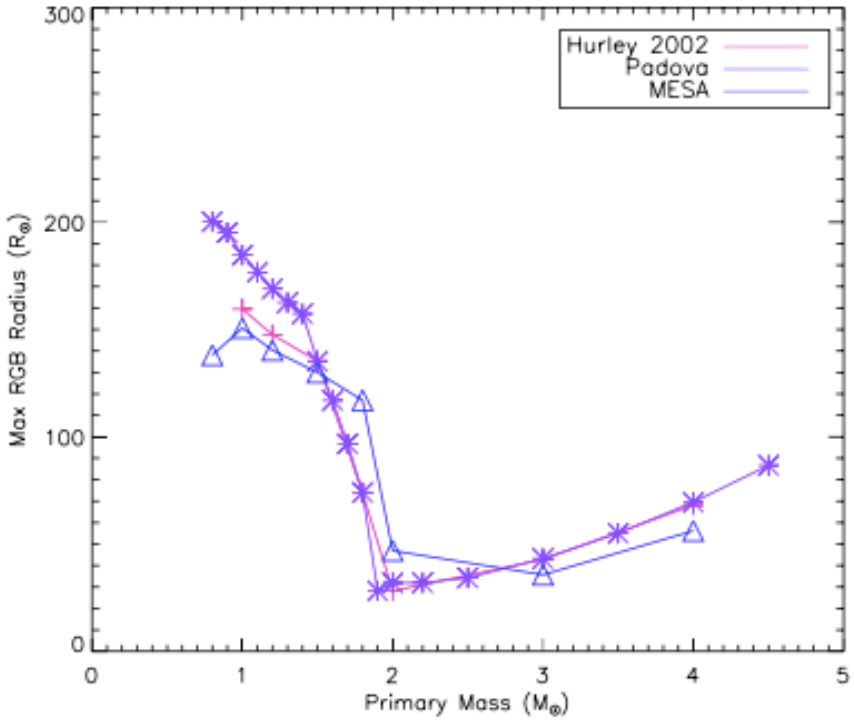
Giant + companion; a~10AU + jet;
(Garcia-Arredondo & Frank 2004)

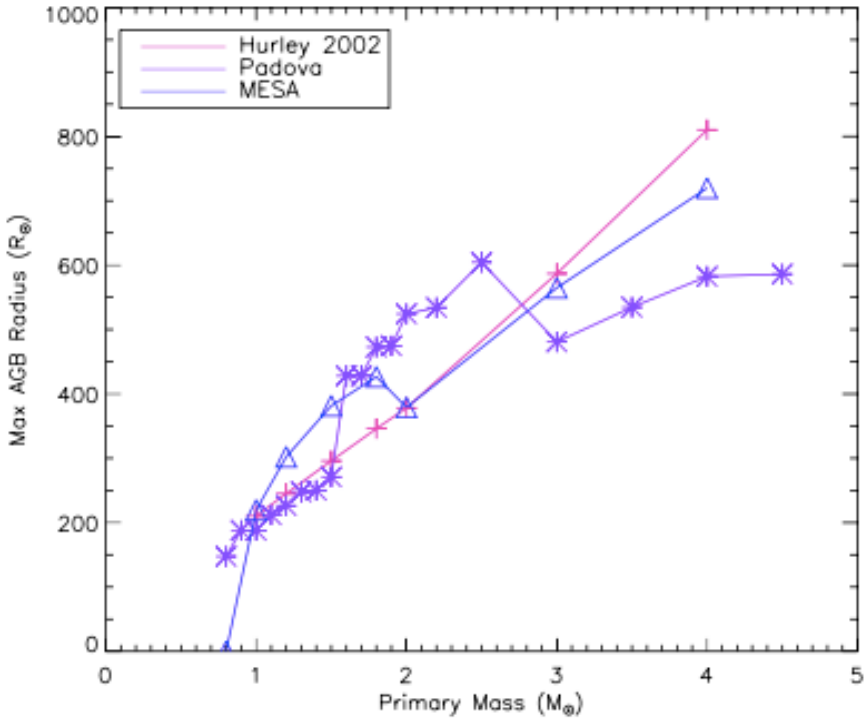


Disk formed from wind accretion from AGB star has mass-accretion rates too low to do much; (Huarte-Espinosa et al. 2012)

Can you do “two” with one-D?

- MESA binary module (Paxton et al. 2015)
- Good old fashioned stellar structures:

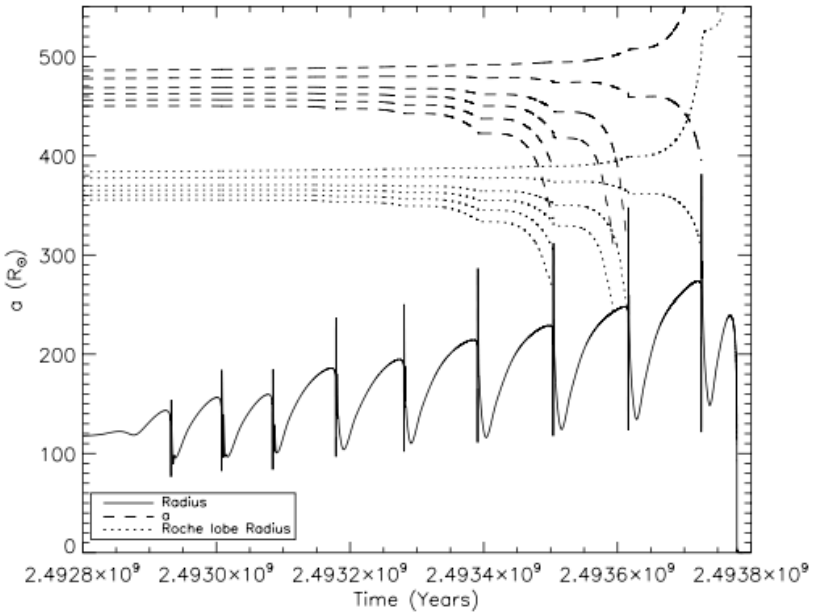




Madappatt, De Marco, Villaver 2015 (in review)

Analytical techniques: tides

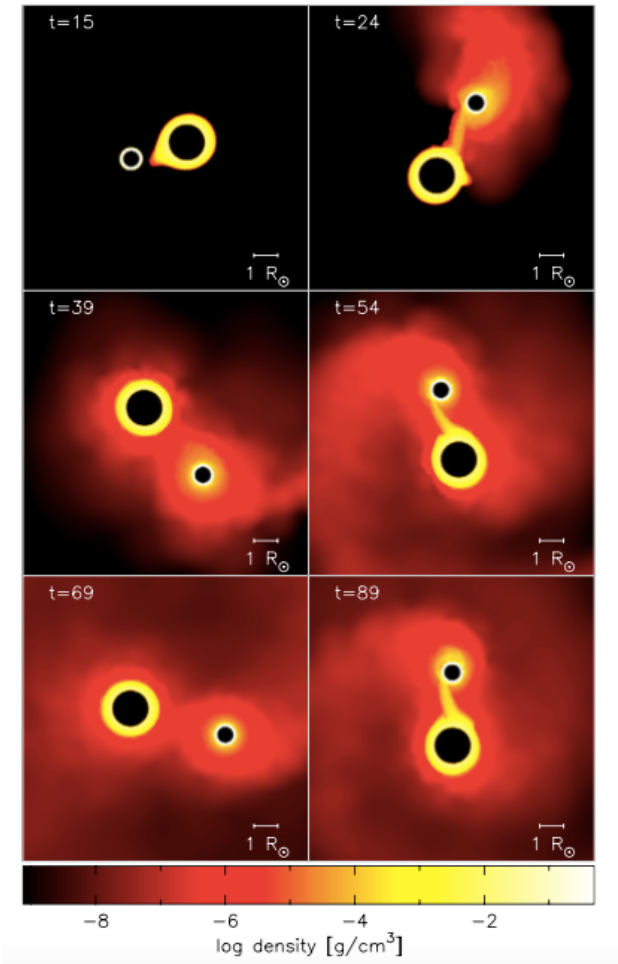
- How far out can a star capture a companion into an interaction?
- Star-planet tidal interactions: Villaver and Livio (2007, 2009), Nordhaus et al. (2010, 2013), POET.
- For star-star tidal interaction: Hurley et al. (2002)



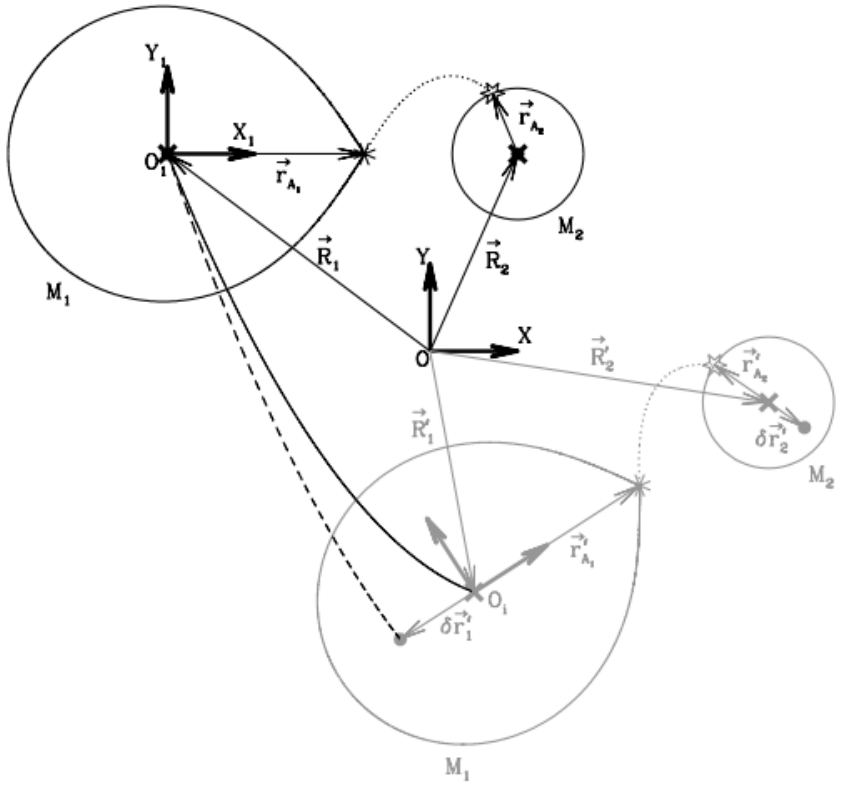
Madappatt, De Marco, Villaver 2015 (in review)

3D hydro + analytical

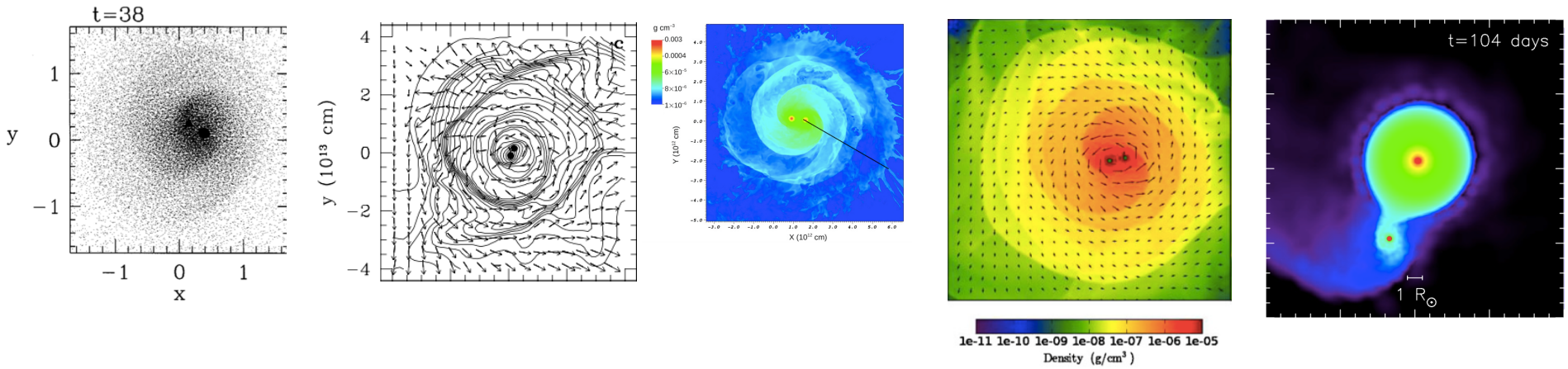
Eccentric interactions
0.5+0.8Mo main sequence stars;
4Ro at periastron (Lajoie & Sills 2011)



Conservative and non-conservative mass transfer:
prediction of accretions and orbital elements
(Sepinski et al. 2007)



3D hydro and the common envelope interaction

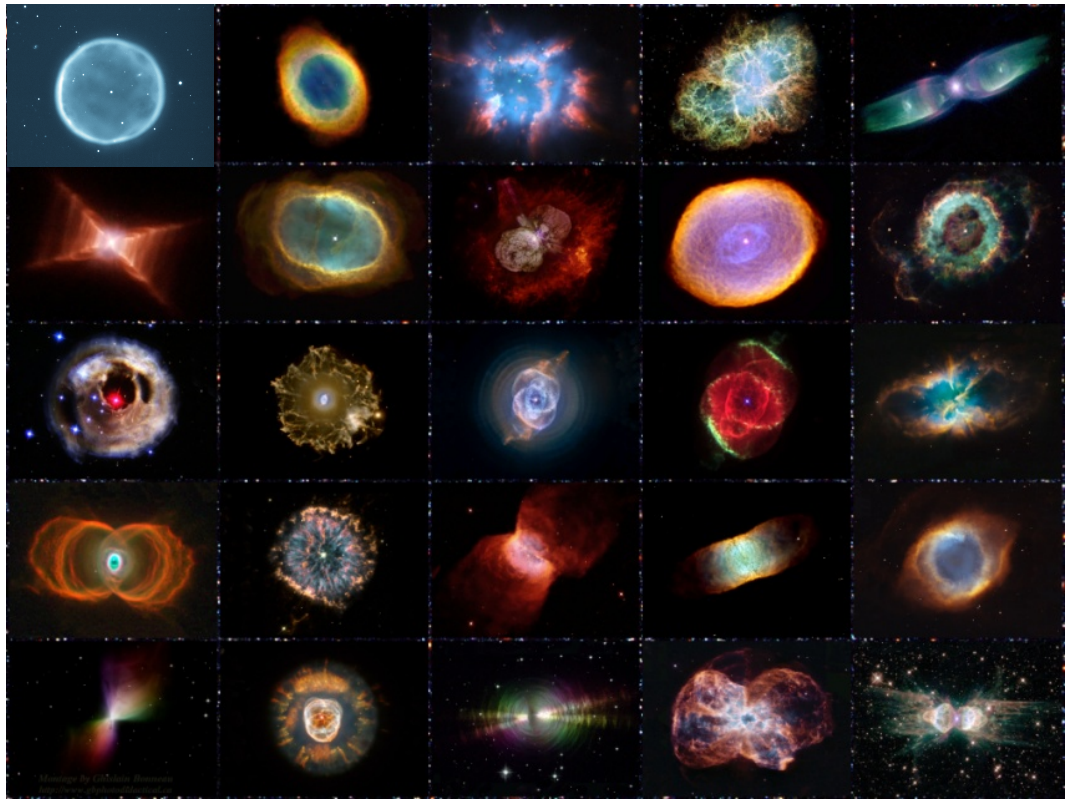


	Rasio & Livio 96 (SPH)	Sandquist et al.98 (static nexted grid)	Ricker & Taam 12 (AMR)	Passy et al. 12 (unigid +SPH)	Nandez et al. 14 (SPH)
M_1 (Mo)	4 (RGB)	3,5 (AGB)	1.05 (RGB)	0.9 (RGB)	1.5 MS
M_2 (Mo)	0.7	0.4, 0.6	0.6	0.15-0.9	0.16
R_1 (Ro)	63	200, 356	32	90	~3.5
a_0 (Ro)	100	289, 536	61	90	~6.5
a_f (Ro)	2	4-9	9	~20	merge
M_{unb}	8-14%	30%	26%	~10%	~2%

What are the combined effects of binary interactions, mass transfer, common envelopes and jet in those cases when it is hard to observe them?

What is their influence on mass-loss, dust formation, chemistry, geometry, all readily observed?

Are planetary nebulae preferentially a binary phenomenon?

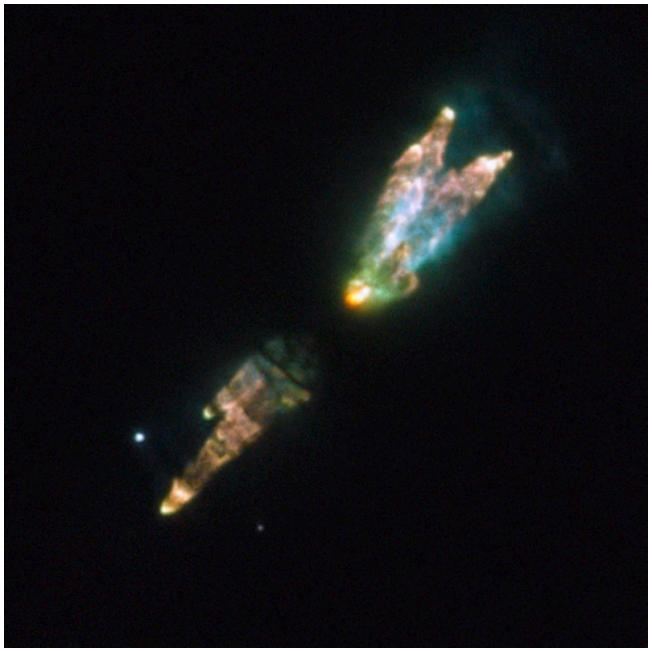


~80% of PN are not spherical

and there is no comprehensive theory to explain their shapes

(Park+06; Mellema+94; Icke+92; Icke03; Garcia-Segura+99,14; Soker06, Nordhaus+06)

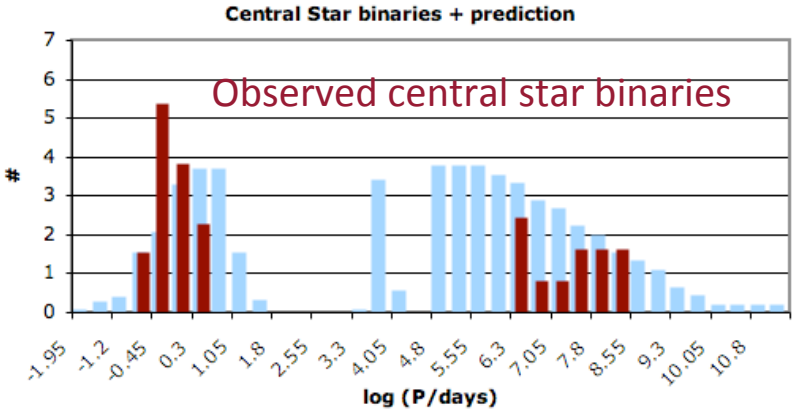
Are planetary nebulae preferentially a binary phenomenon?



Pre-PN always collimated; linear momenta in excess of what is provided by radiation (Bujarrabal et al. 2001; Blackman & Lucchini 2014)

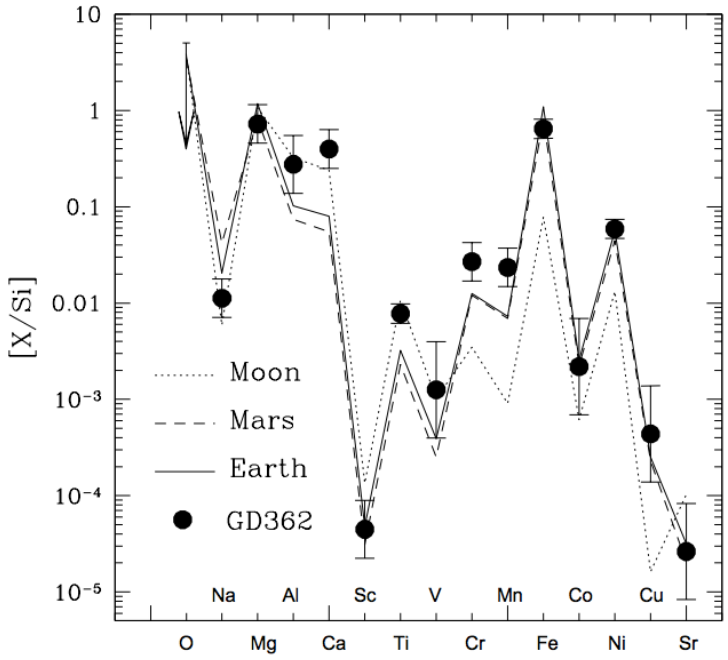
PN: the binaries we know

- ~15% are post-common envelope binaries; P<~3 days (Bond 2000; Miszalski et al. 2009; Jones et al. 2015)
- Fraction at all separations >35% (De Marco et al. 2013; Douchin et al. 2015)
- Wider binaries finally discovered P ~ few years (van Winckel et al. 2014)
- NB: if 80% of PN come from binary interactions, then some single stars/wide binaries make faint PN or no PN

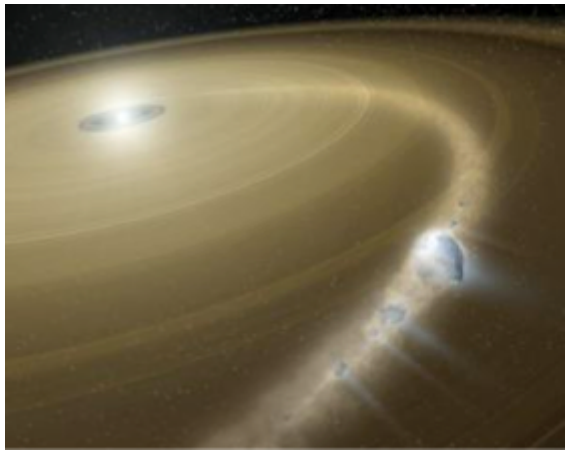


Polluted WDs

- ¼ of all WDs are of the DZ class, i.e. polluted by metals.
- Explanation used to be accretion from the ISM among others.
- Disks were found around some of these stars.
- Best explanation now is the accretion of planetesimals.



Zuckerman 2007; GD362

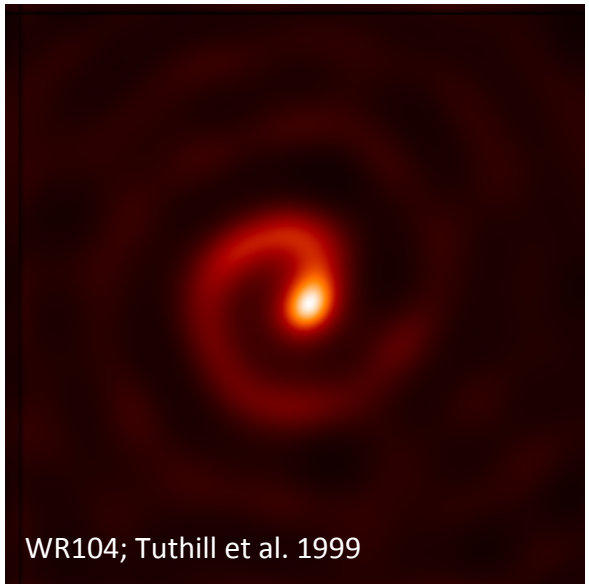


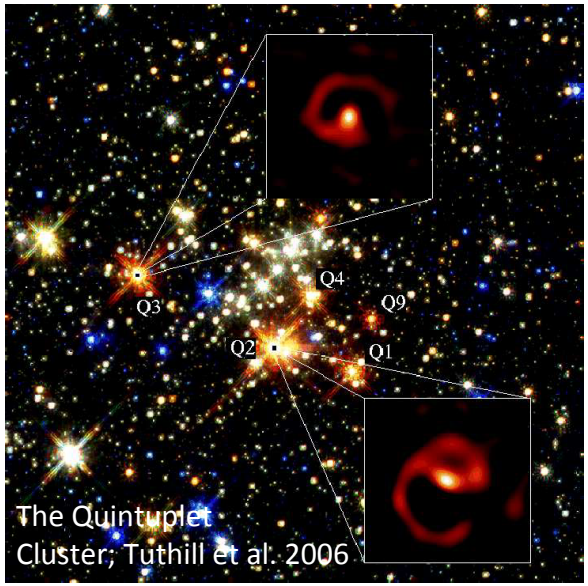
Veras et al. 2015

See talk by Hollands on Thursday

Pinwheels, LBVs, WRs and Type Ib,c SN

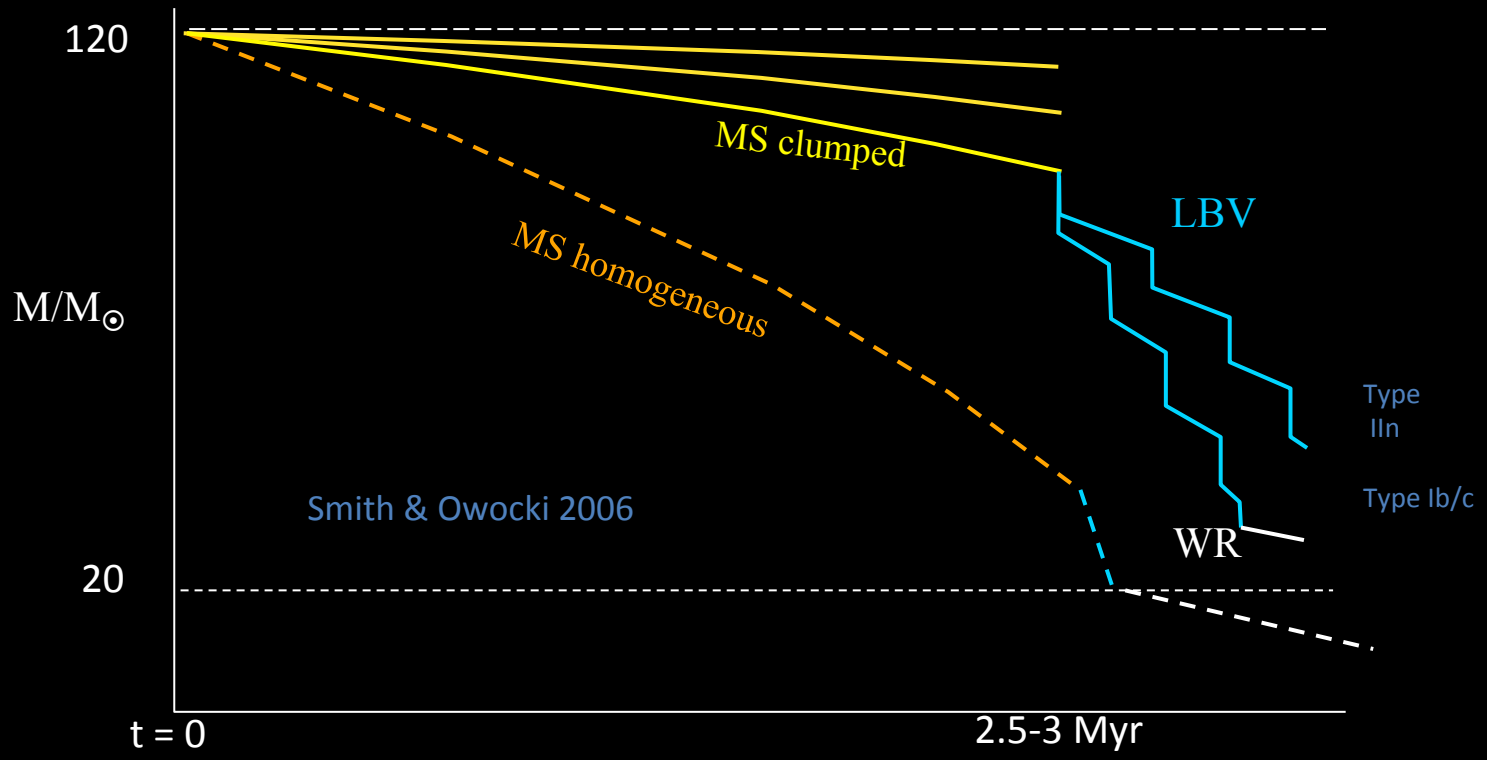
- WR+O binaries, reasonably close, spiral seen in thermal IR (Moffat papers, Tuthill papers).
- These "dustars" contribute to cosmic dust budget (Shara et al. 2009, 2012; Mauerhahn et al. 2009,2011)
- Binarity contributes to the formation of WR stars via mass-transfer stripping.


WR104; Tuthill et al. 1999



The Quintuplet Cluster; Tuthill et al. 2006

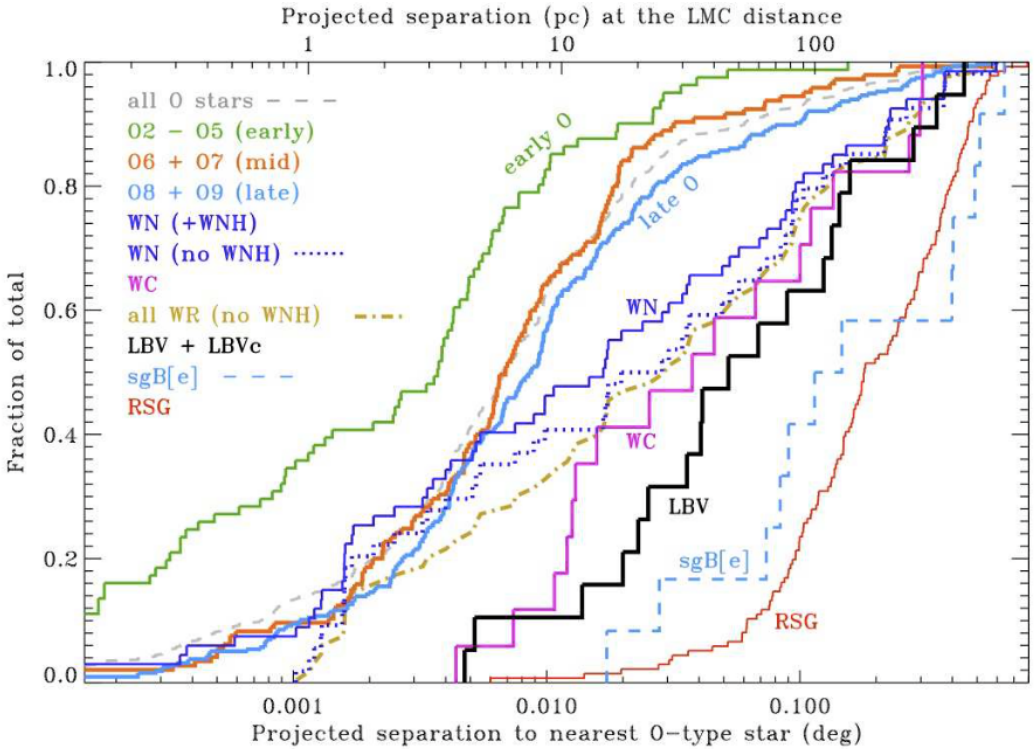
Pinwheels, LBVs, WRs and Type Ib,c SN



Massive stars classic view (e.g., Conti 1976, Humphreys & Davidson 1994)

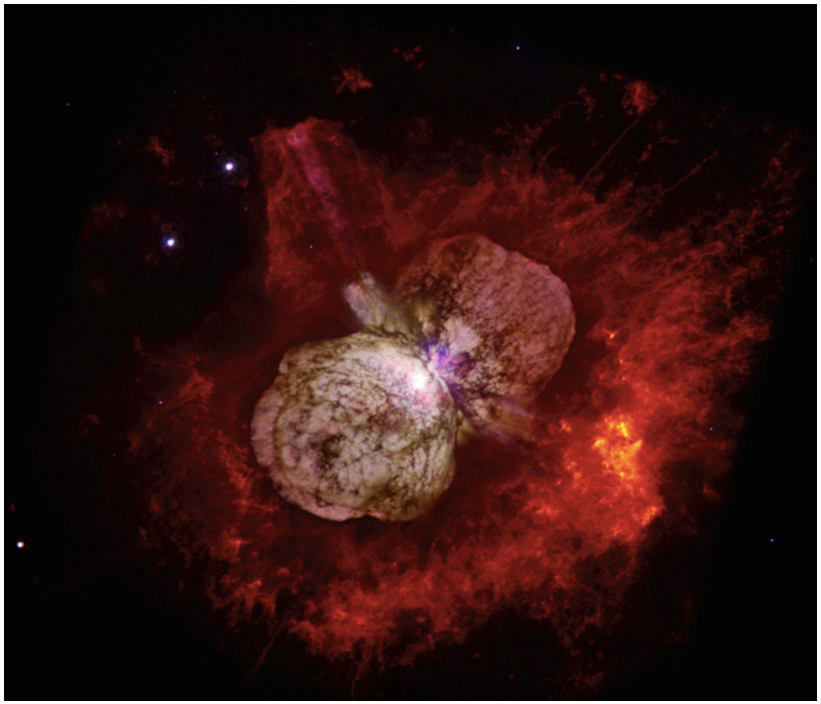
LBVs from ejected binaries?

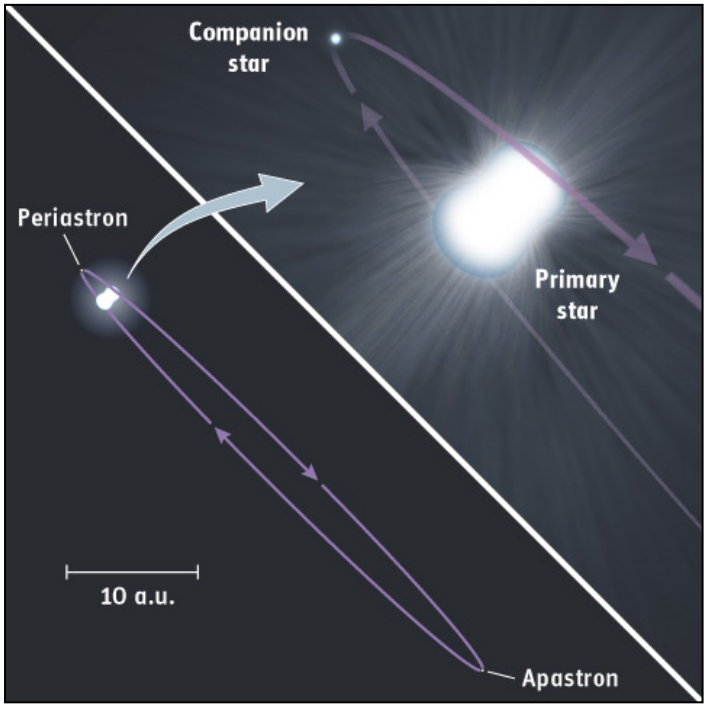
- LMC LBVs are not segregated in the centers of massive clusters, near the O stars that are thought to be their immediate predecessor
- In massive (but not too massive) binaries, mass transfers via RLOF
- Primary is stripped and becomes a Wolf-Rayet
- Secondary gains mass.
- Primary explodes as SN Ib,c
- The now-massive secondary is ejected.
- Due to the interaction (somehow) the ejected star goes through an LBV phase.



Smith & Tombleson 2015

What triggered η Car's LBV outburst?



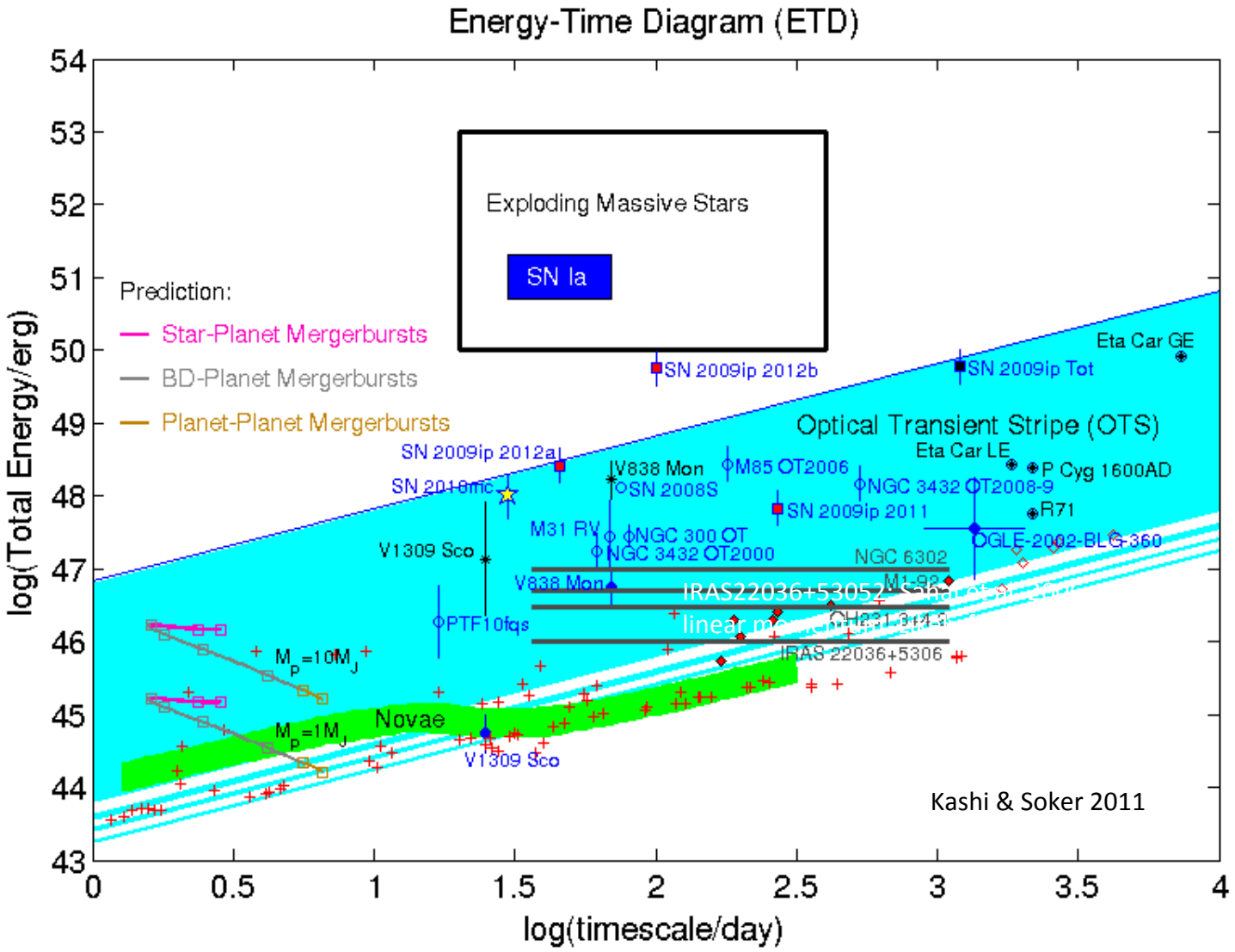


P~5 yr; e~0.9; peri-passage ~2 au

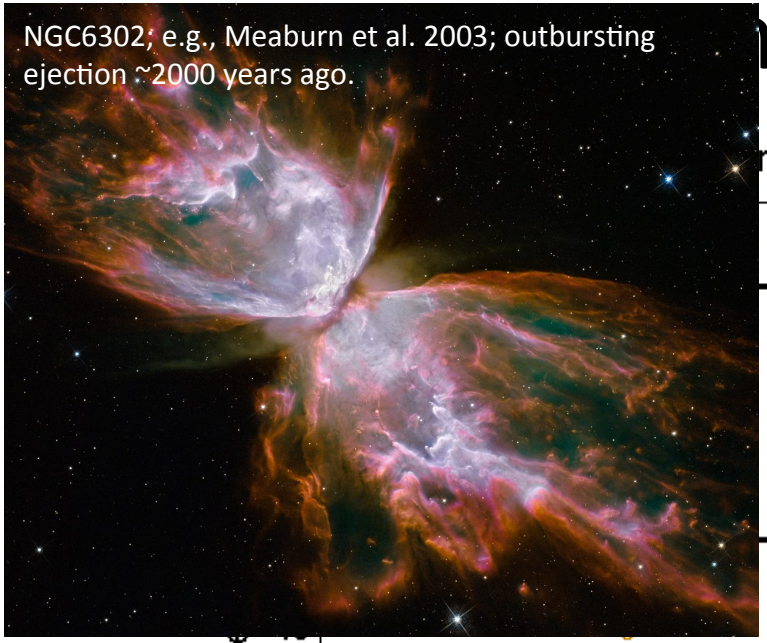
Damineli et al. (2008); Corcoran et al. (2001)

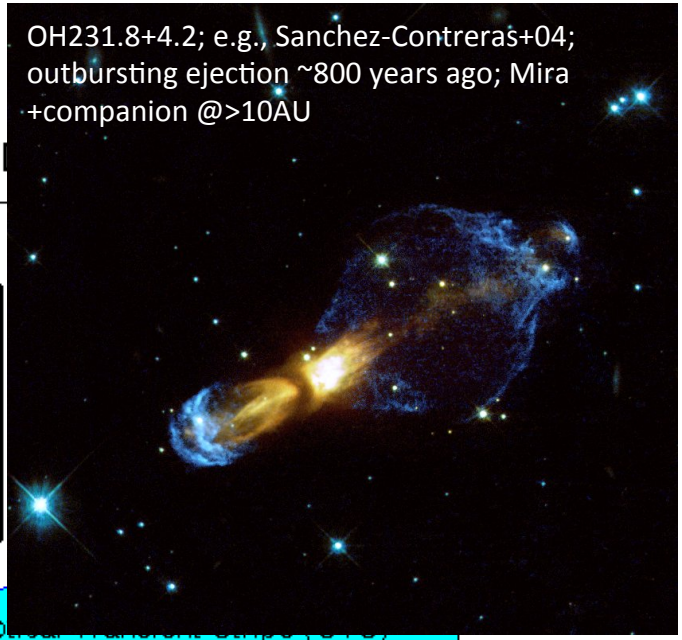
Kashi & Soker 2010: could LBV outbursts be triggered by periastron passages?

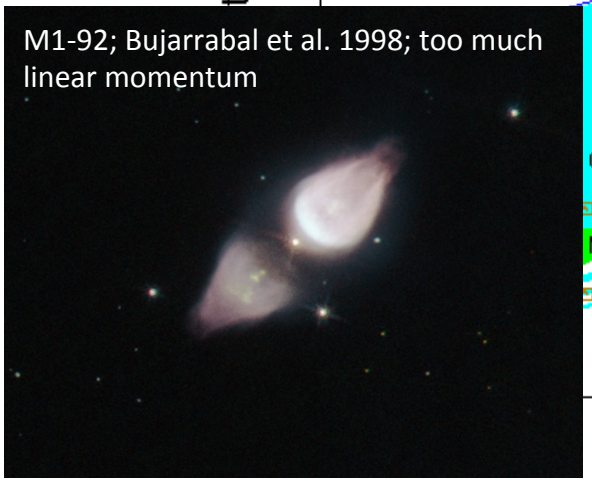
Intermediate luminosity optical transients: ILOTs

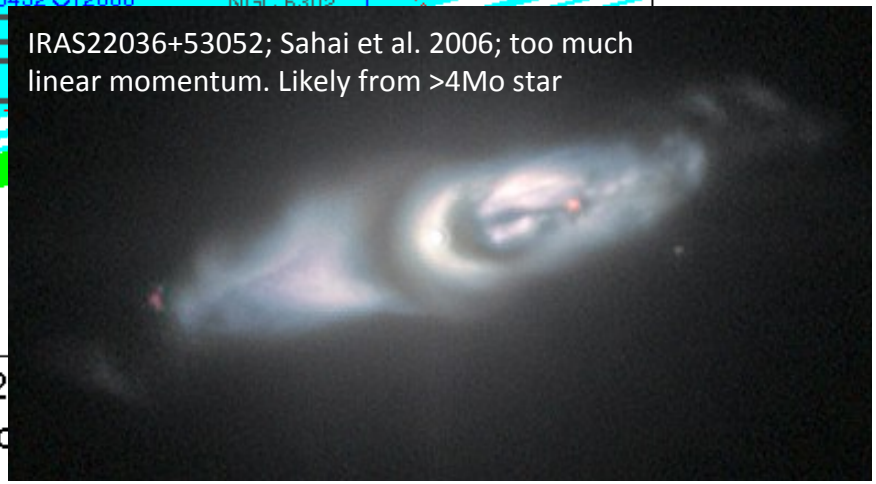


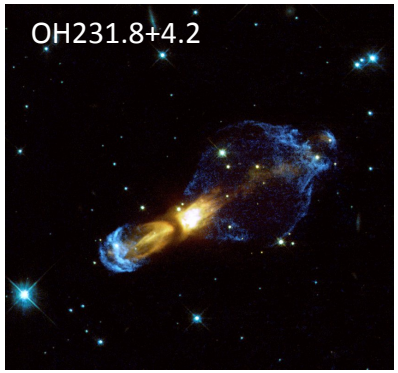
Eccentric interactions at the origin of the nebulae?



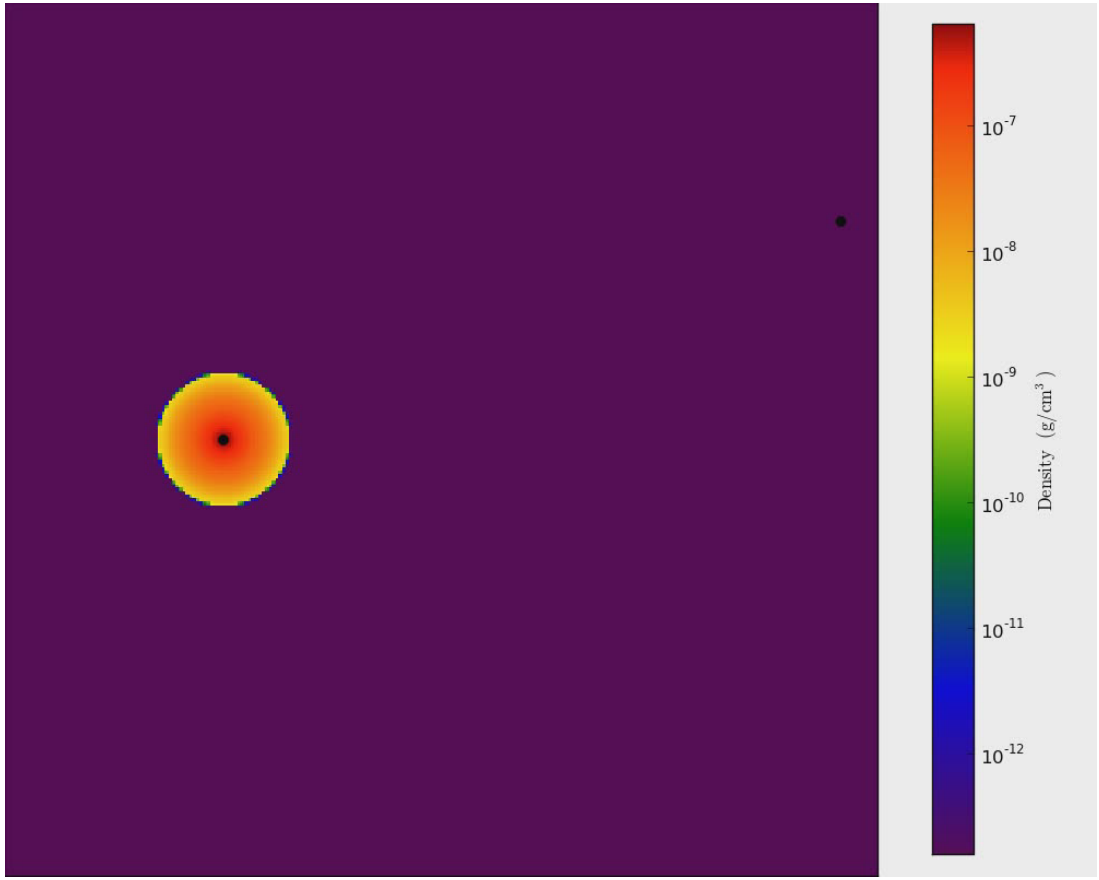




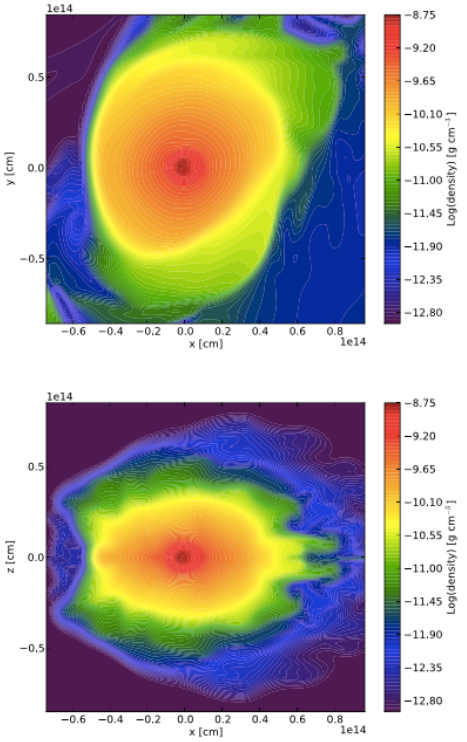




Interacting eccentric binary simulations to explain OH231 and ILOTS?

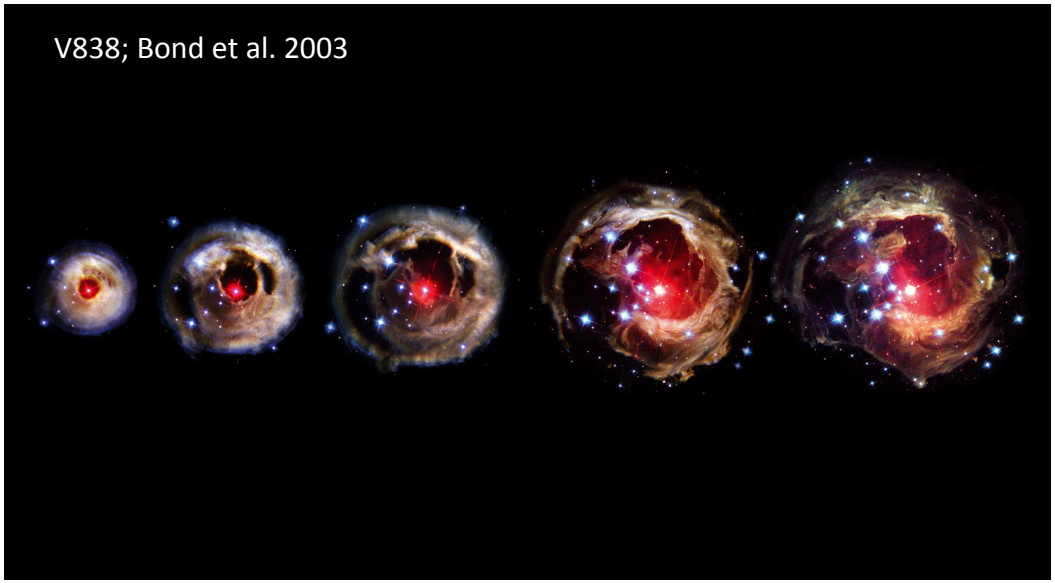


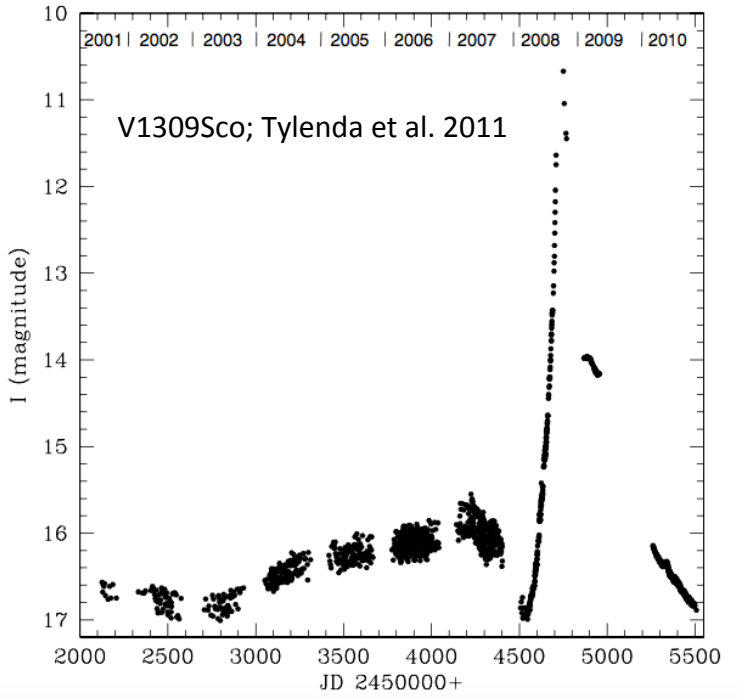
Staff,De Marco et al. 2015



Disk: 0.01-0.04 Mo
Lifetime: few x 10 years
Accretion onto the disk 0.01 Mo/yr
Jet could have the required characteristics

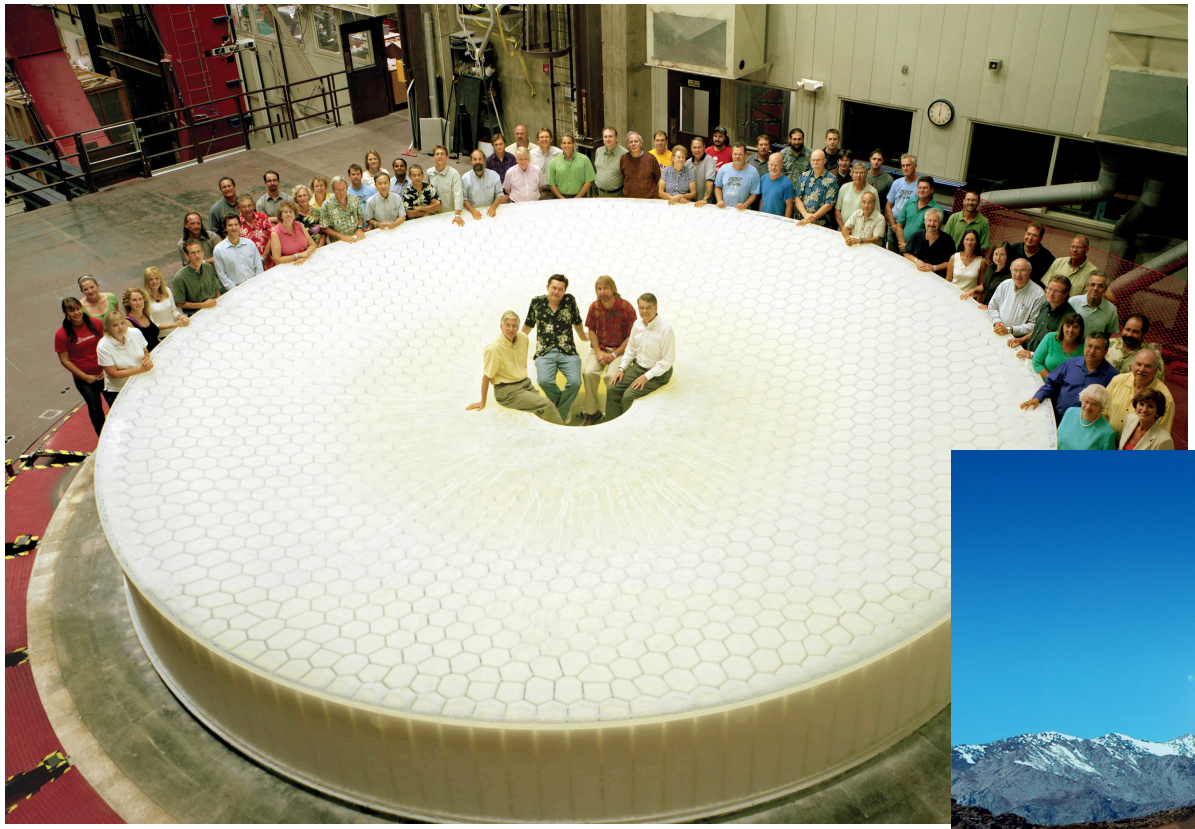
Other ILOTS are mergers: V838 Mon and other “mergerburst”



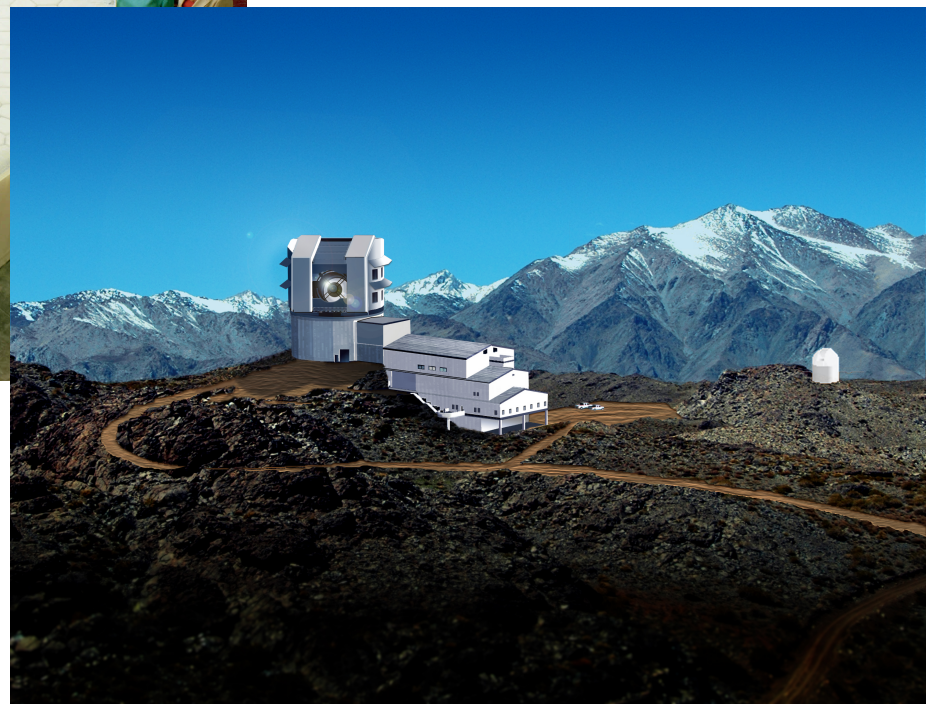


Other similar objects:
M31 RV Mould et al. 1990
NGC300 OT2008 Berger et al. 2009
V4334 Sgr Martini et al. 1999
Several tend to be on the massive side

The new time-domain: LSST



First light: 2018
30,000 sq. deg. of sky
every 3 nights
24th mag depth
Sloan filters
Forecast:
1,000,000 events per night!!

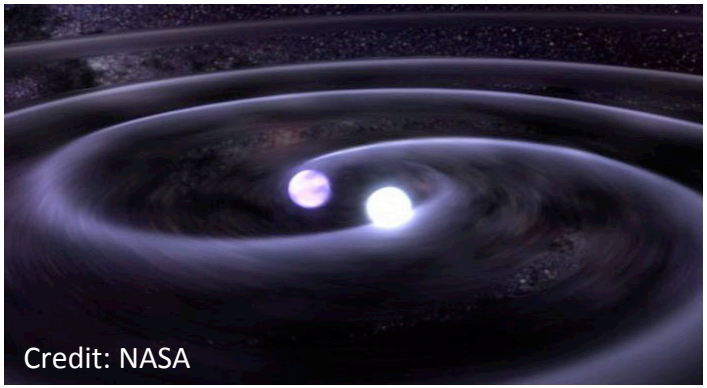


Current surveys

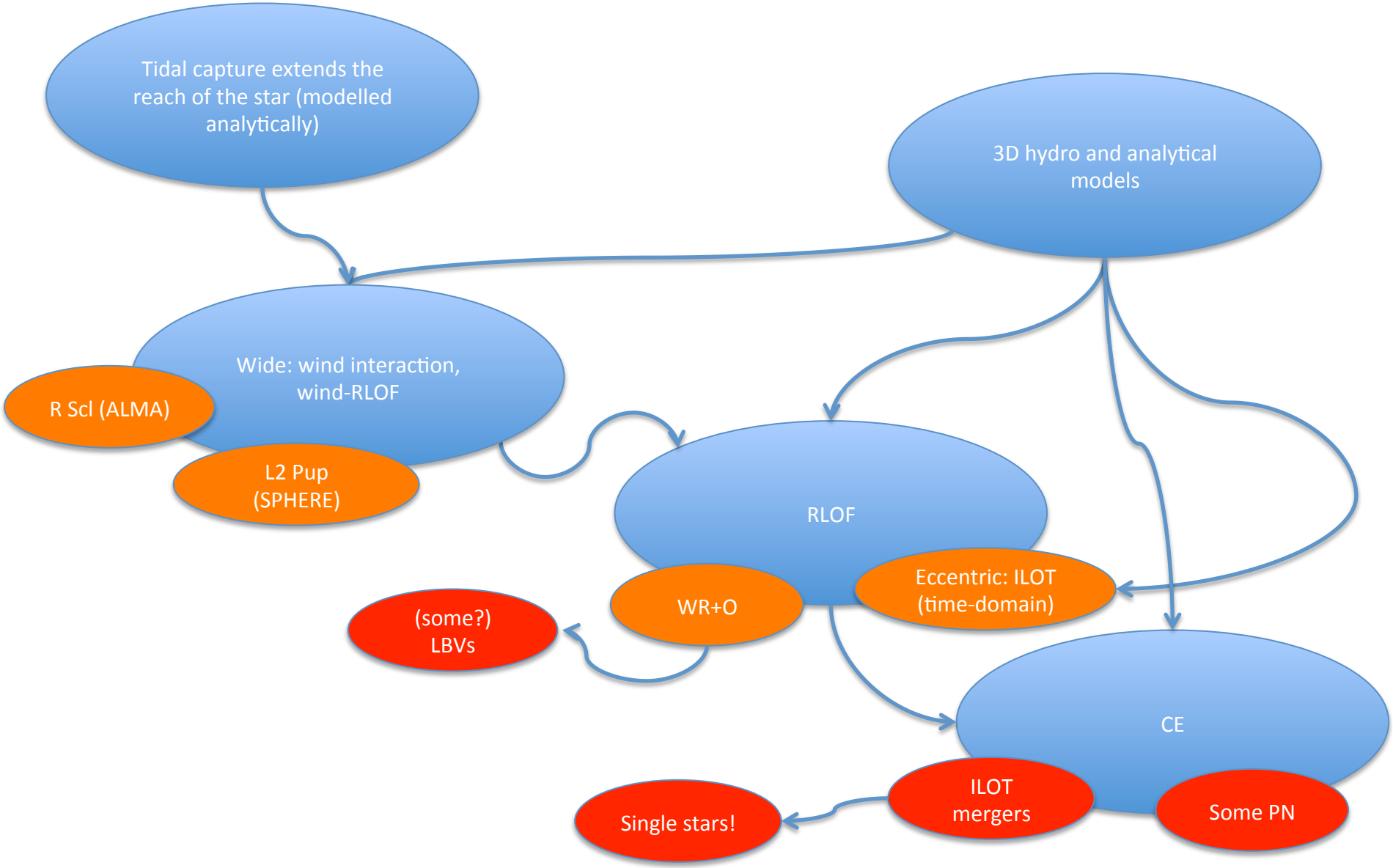
- Catalina Real Time Transient Survey
- Palomar Transient Factory,
- Zwicky Transient Facility,
- Pan-STARRS,
- Sky Mapper

Multi-messenger: Advanced LIGO

- What LIGO can see
  (Abadie et many many al. 2010)
- How many NS-NS mergers?
  (Kalogera et al. 2004; Fryer et al. 2015; de Mink & Belcinski 2015)
- How many BH-BH mergers?
  (Portegiest Zwart & McMillan 2000)



The summary “mind map”



Conclusions?

- Influence of binarity seen and unseen.
- Particular emphasis in high mass stars
- Lack of appropriate models

Send me suggestions

I will be writing this talk up as a review for Publications of the Astronomical Society of Australia.

Please send me any suggestions at orsola.demarco@mq.edu.au or orsola@gmail.com

Themes/Questions

- superAGB
- Nucleosynthesis
- Dust and organics manufacturing

People

- Langer
- Van Beveran
- Bildsten
- CK lists from Canada meeting

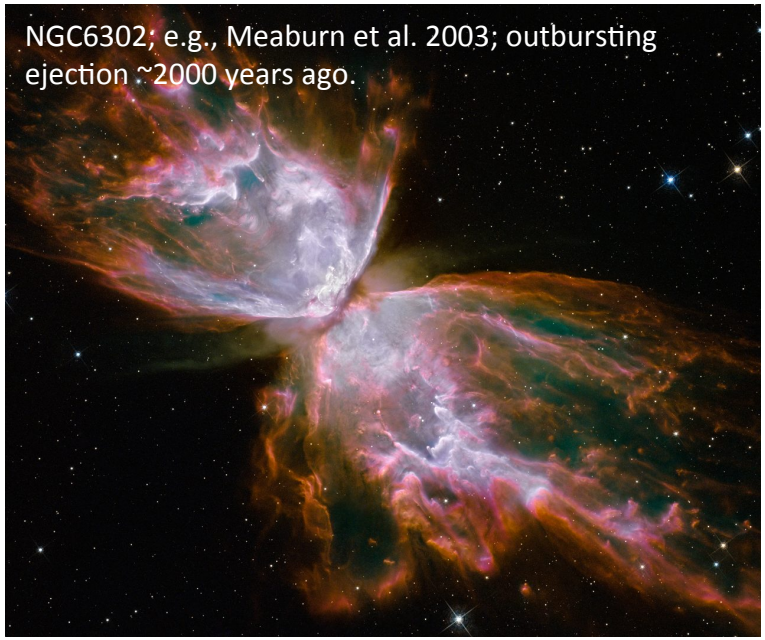
Remember

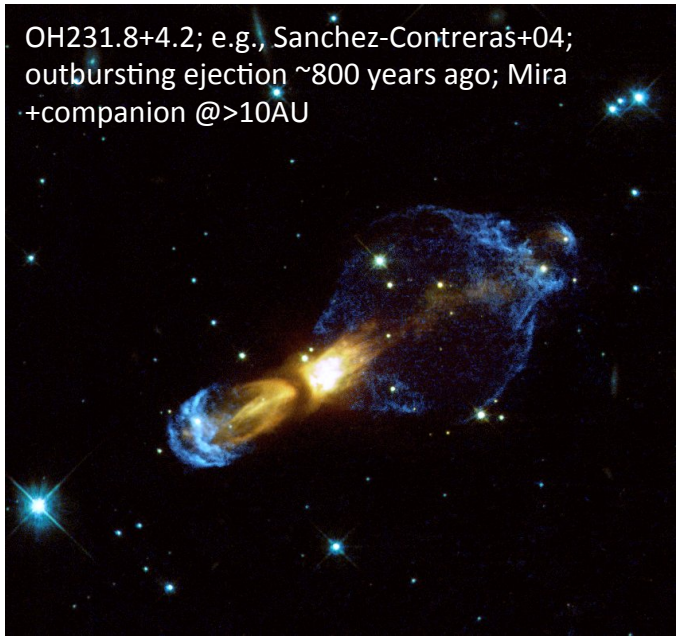
- Need to mention pulsars.
- Jets
- Formation of compounds in disks. PPN main source of organics in the Universe.
- Mention angular momentum explicitly.
- Ck R Aqr also from SPHERE
- Gaia
- W Ceph, Beteljuice, Antarest
- RCB

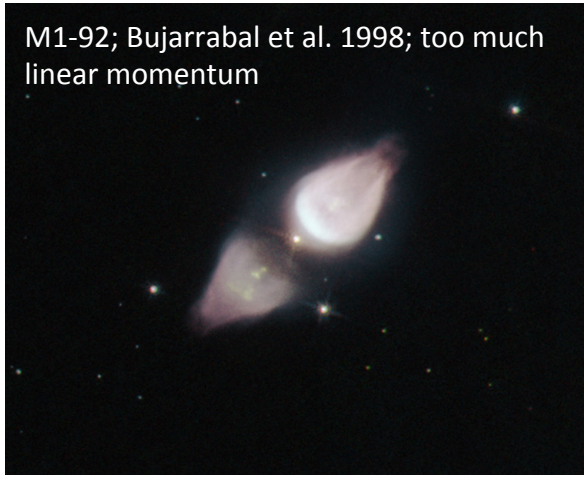
A classification should be observational

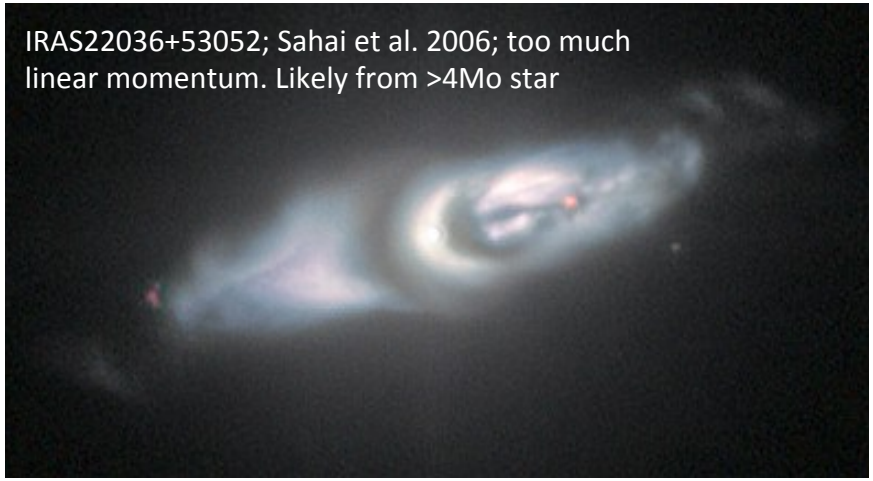
- Binaries defined by how they are observed/ detected: visual, eclipsing, spectroscopic.
- Even if the observation is a more complex set of spectra, light behaviour, e.g., symbiotics, W Serpentis.
- Some observational sets may not be inherently a binary, but the best interpretation might be binarity.
- Some observations not previously interpreted as binarity might at some point in time be reinterpreted.

Other “outburst” nebulae









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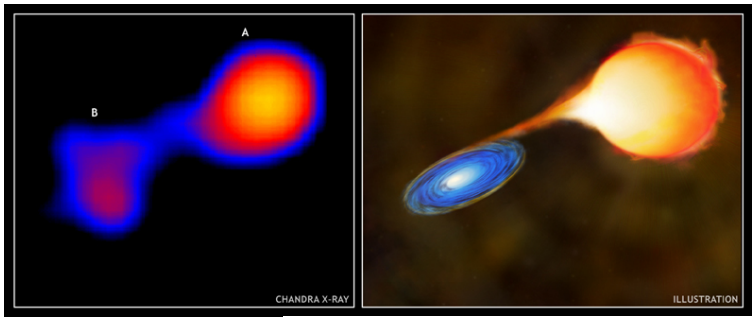

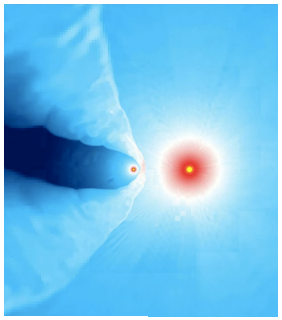

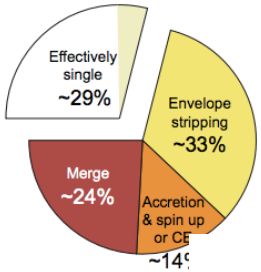

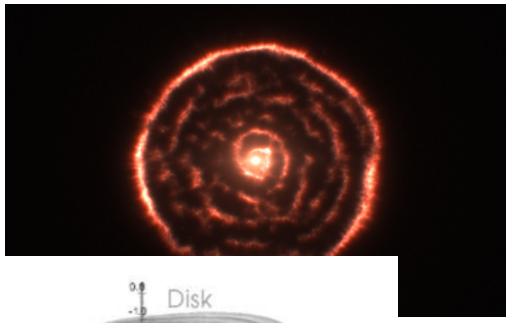

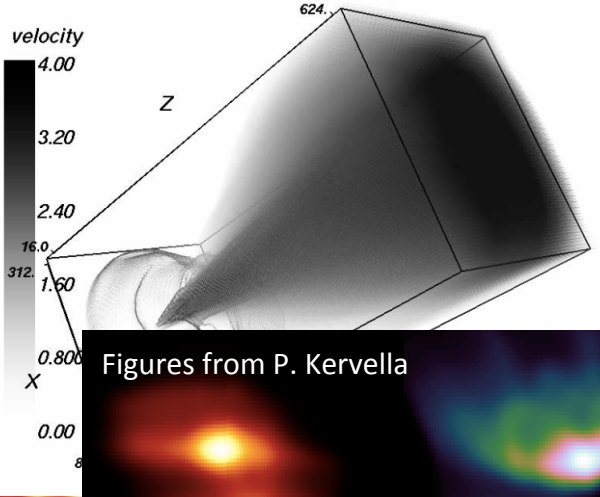

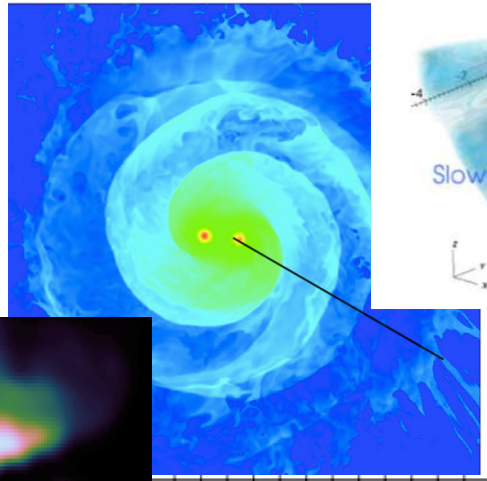

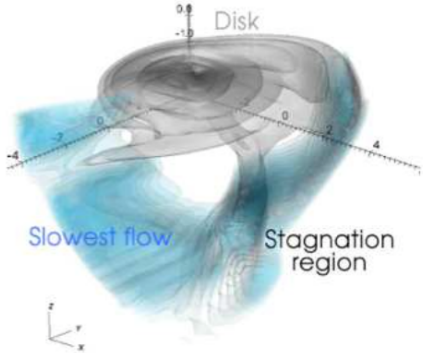

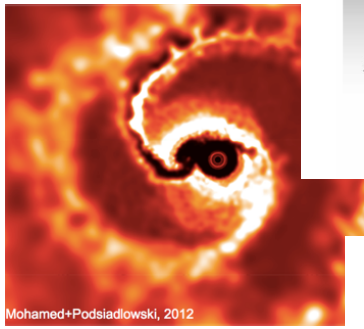

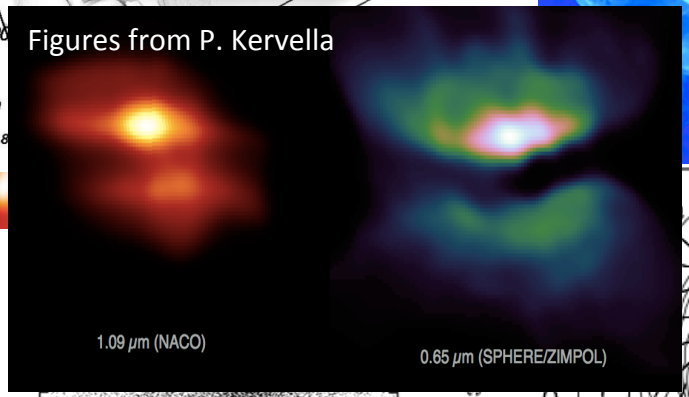

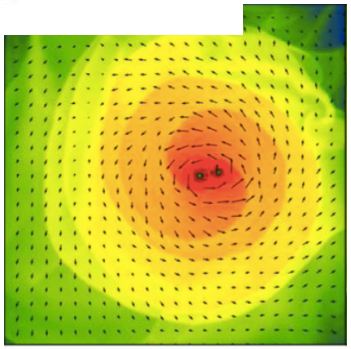

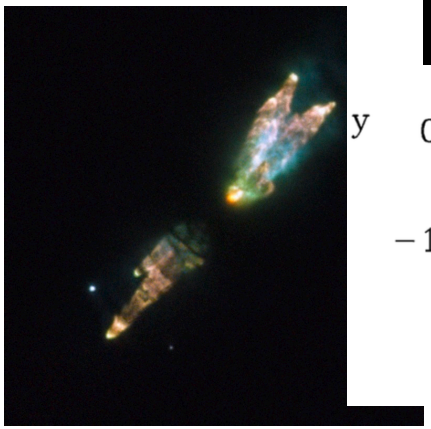

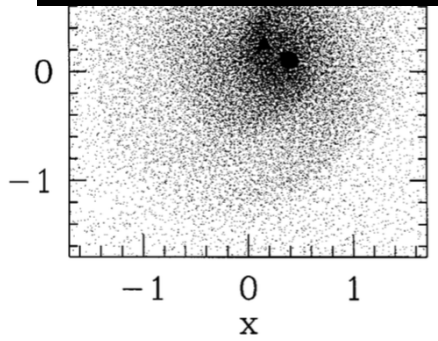

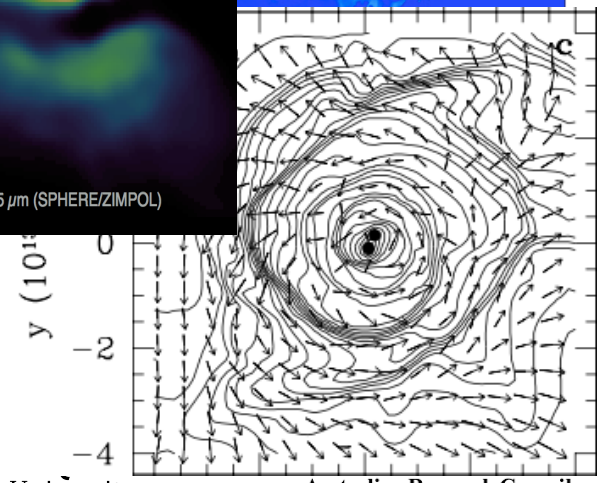

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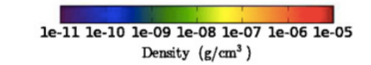
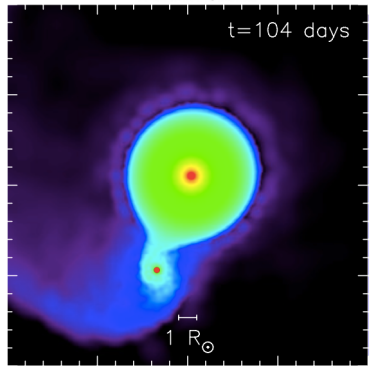
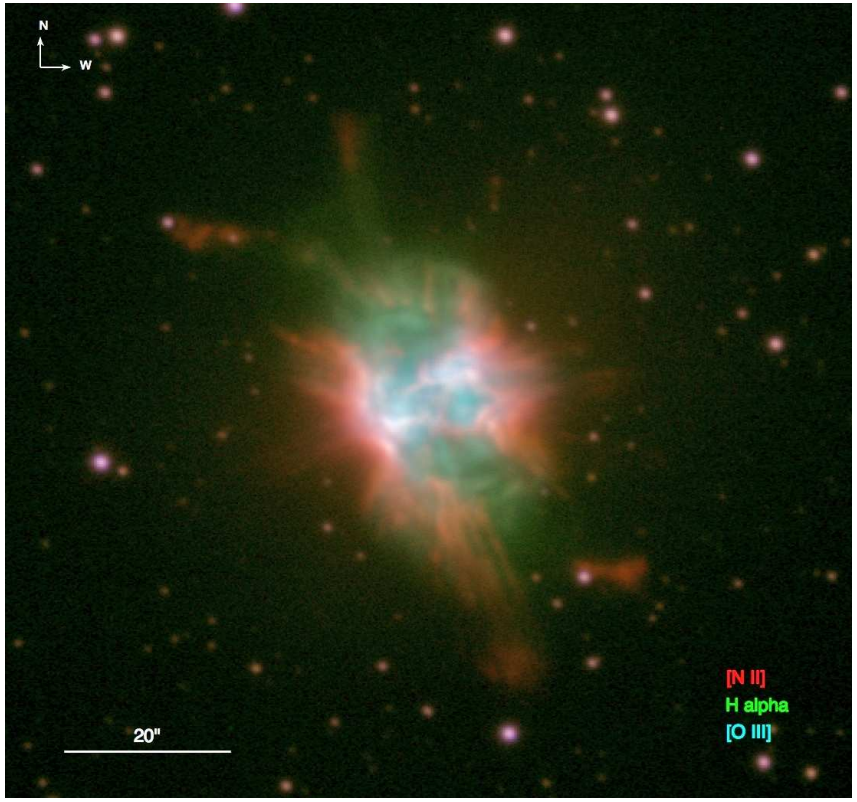


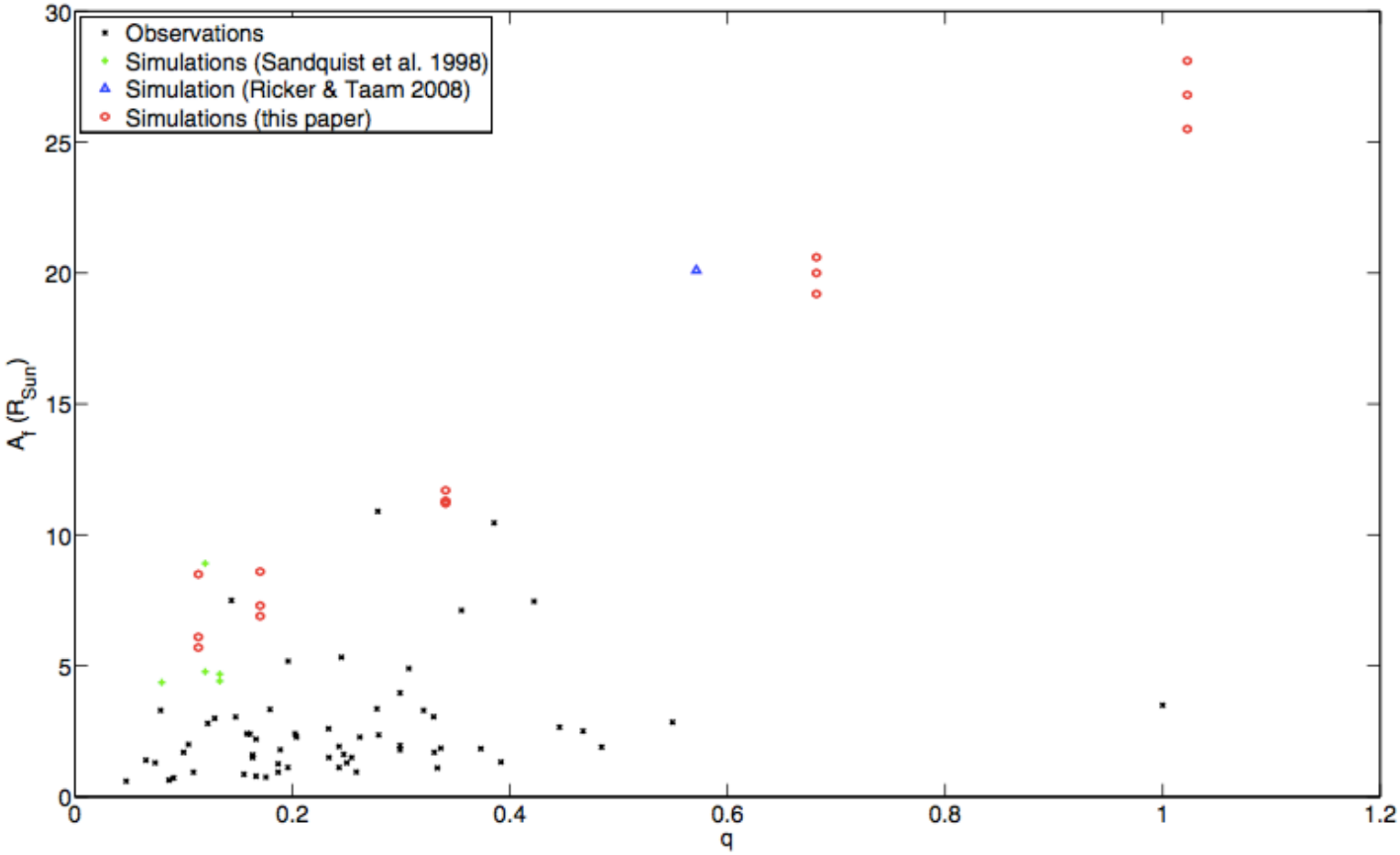


Using hybrid techniques



Tocknell, De Marco & Wardle 2014

3D hydro and the CE interaction



The excitement

- Binary time is now!