Star-planet interaction simulations with PHA NTOM

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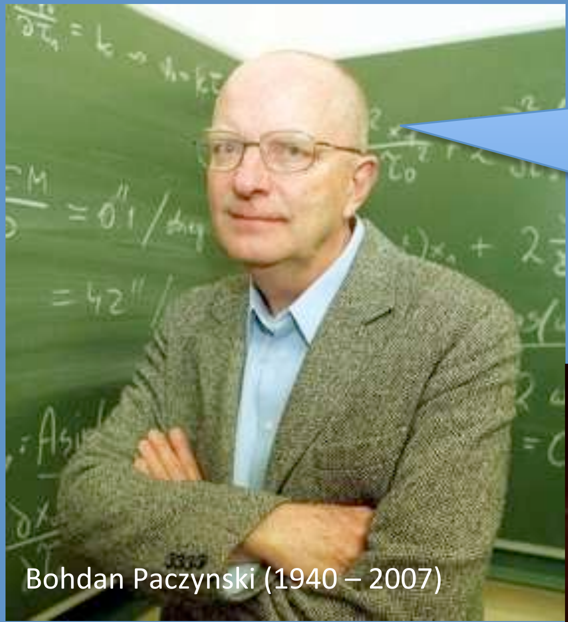
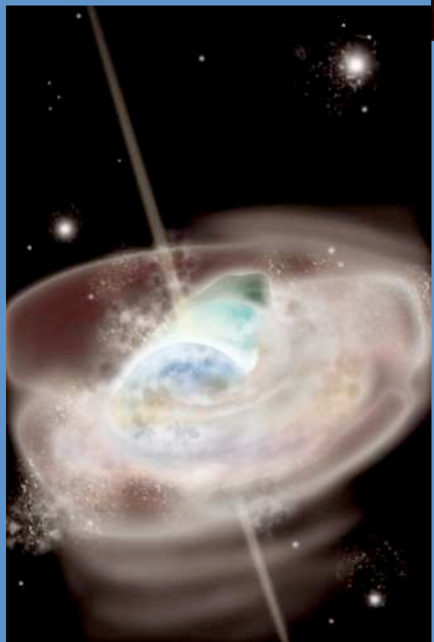
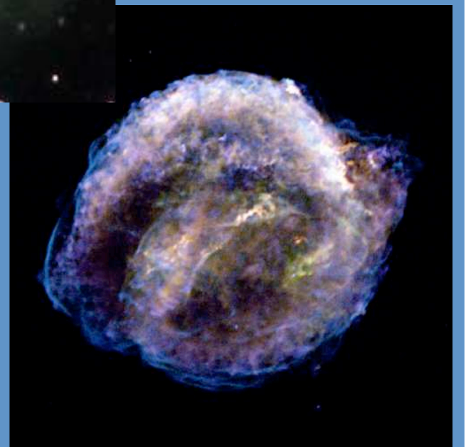
Outline

- Introduction to the CE interaction
- History of CE simulations
- Current simulation status
- What are simulations for?
- Planets inside stars, a project
- Issues we would like to address in simulations: the laundry list
- Simulation validation, an example

Common envelope interactions are at the origin of all compact evolved binaries

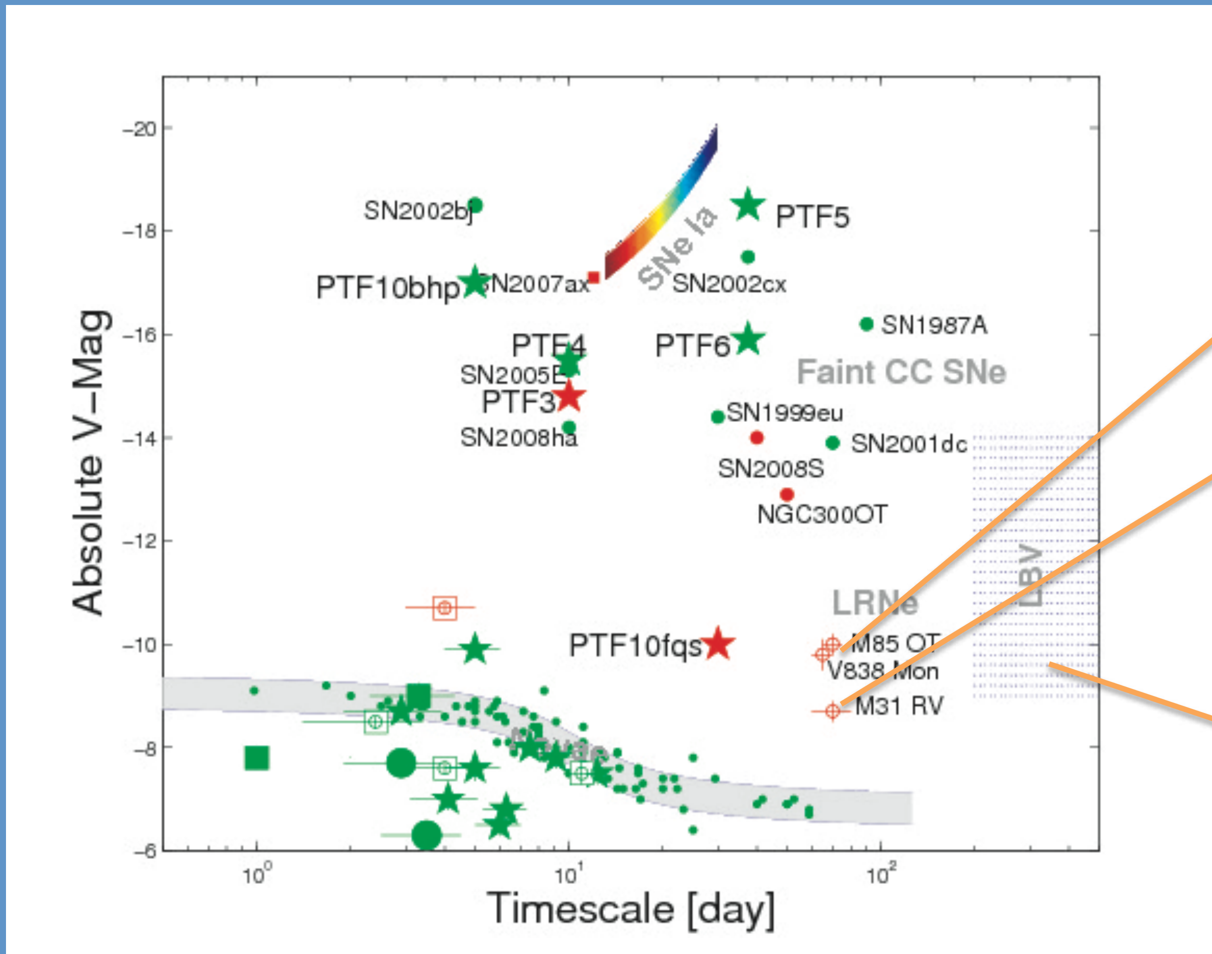

Bohdan Paczynski (1940 – 2007)

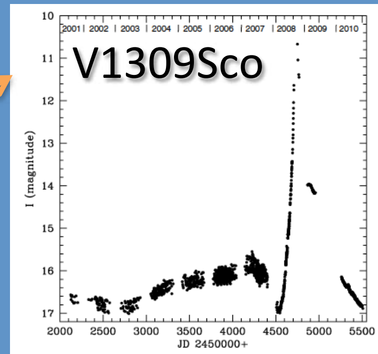


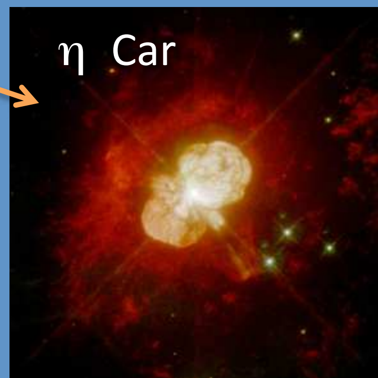


- Cataclysmic Variables
- Central stars of planetary nebula
- Type Ia Supernova progenitors
- Low and High mass X-ray binaries
- Mergers
- Short Gamma Ray Bursts & Gravitational Waves
- Brown Dwarf & Planet close to WD/HB

Intermediate Luminosity Optical Transients

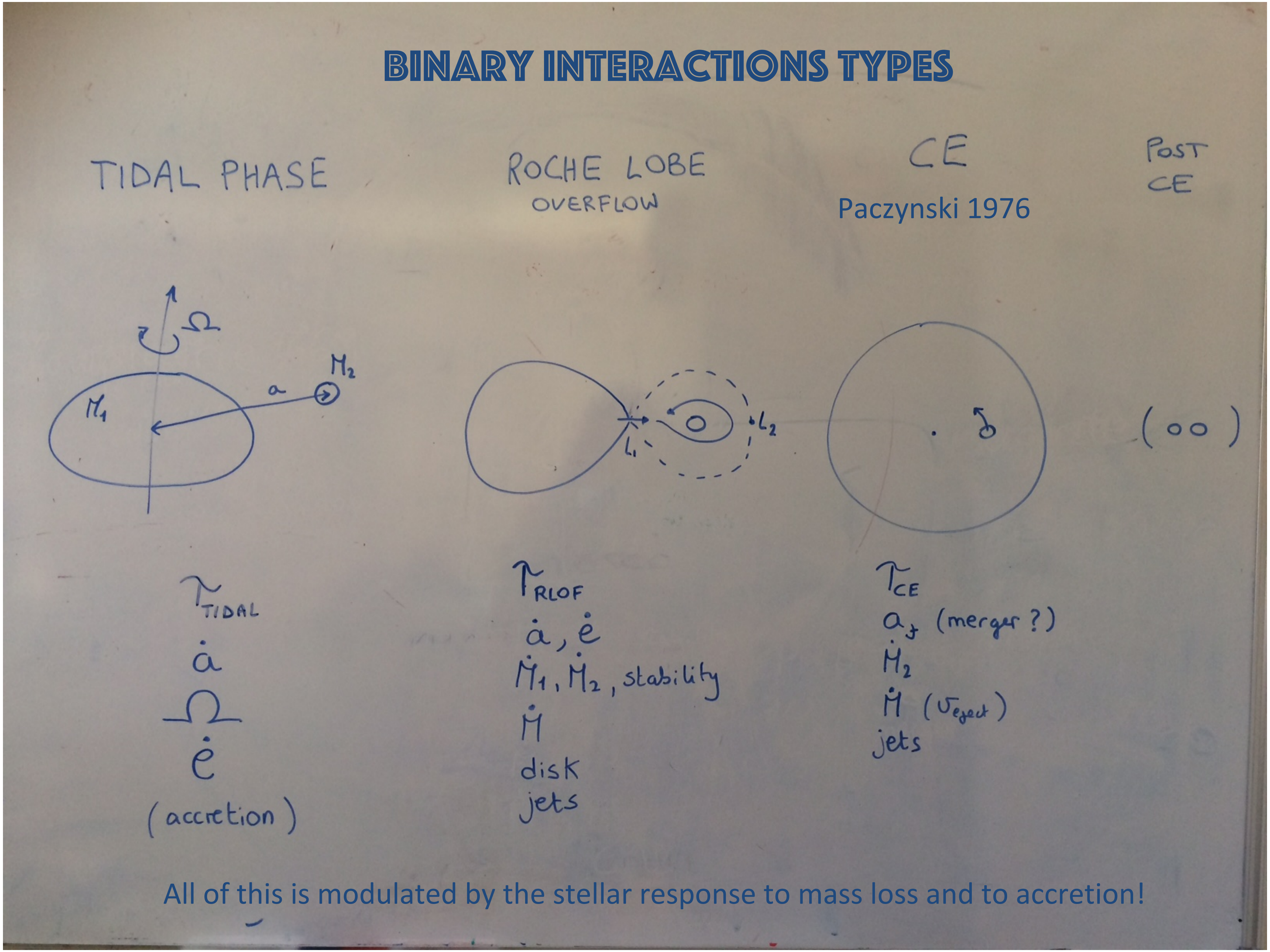






From Mansi Kasliwal

BINARY INTERACTIONS TYPES



Paczynski 1976

All of this is modulated by the stellar response to mass loss and to accretion!

CE simulations landscape

THE PAST: A cluster or simulations were carried out primarily by Ron Taam's group starting in 1978 (10 papers). 3D was found essential: Rasio and Livio 1996 & Sandqist et al. 1998, 2000

THE PRESENT: Efforts lulled (but for De Marco et al. 2003) but picked up again in the late 2000s with:

- USA: 1. Ricker and Taam (2008,2012); FLASH-AMR
  2. Chamandy & Frank (in prep.); AstroBEAR-AMR
- Australia: Passy et al. (2012; Enzo-Grid, SNSPH), Kuruwita et al. (2016; Enzo), Staff et al. (2016a,b, Enzo-AMR), Iaconi et al. (2017; Enzo, PHANTOM-SPH)
- Canada: Nandez et al. (2014,2015,2016), Ivanova et al. (2015,2016); Starsmasher-SPH
- Germany: Ohlmann et al. (2016a,b); AREPO

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NOTE: most simulations are low mass stars where the primary is an RGB

What are simulations for?

PRESCRIPTIONS: hydro simulations can provide simplified prescriptions to be used by binary population synthesis models. Population models' outputs are calibrated to known quantities (e.g., WD birthrate) and predict others (Type Ia SN and GW rates, e.g. Belczynski+16).

DIRECT COMPARISONS: synthetic lightcurves from hydro simulations can be compared with observations of individual systems (validation for hydro sims).

CURRENT SIMULATIONS: CE simulations are not yet prescriptive. Final separations and resulting merger rates uncertain (Ricker+Taam12,Iaconi+17,Nandez+16,Ohlmann+16).

Typical 3D hydro CE simulations

- 1D stellar calculation (e.g., MESA, evolved to the desired stage (RGB or AGB, usually 1-5 Mo)
- 1D -> 3D mapping (box few AU, resolution 256^3-512^3 unigrid or 128^3 with 4-6 levels of AMR refinement; 0.1-2.5 M SPH particles)
- Core mass is point mass particle (M~0.5Mo), with smoothed potential
- Structure stabilisation… then insertion of a point mass companion at RLOF or 2-3R* in Keplerian orbit
- Then press "Play"

Planets inside stars

(Staff et al. 2016b: ENZO-STAR-AMR)

- 3-Mo RGB and AGB stars + 10 Mj companon
- Motivation: Planets may be present in small orbits around post-RGB stars: how can they survive an in-spiral?

Planets inside stars

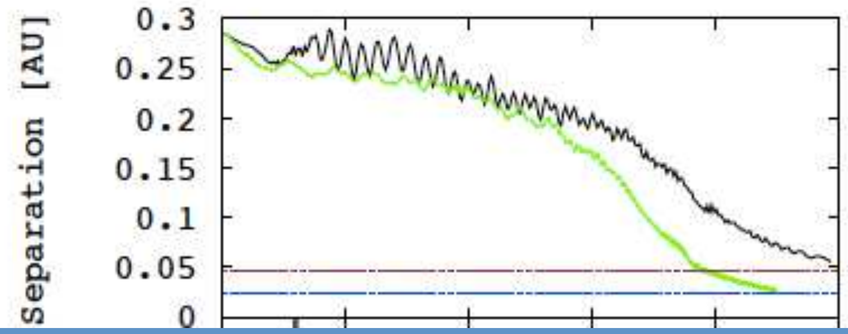
(Staff et al. 2016b: ENZO-STAR-AMR)

- 3-Mo RGB and AGB stars + 10 Mj companon
- Motivation: Planets may be present in small orbits around post-RGB stars: how can they survive an in-spiral?
- Results: in-spiral is “slow”. Both RGB and AGB planets in-spiral all the way – likely destroyed. Basically no unbinding of envelope, so no survival.

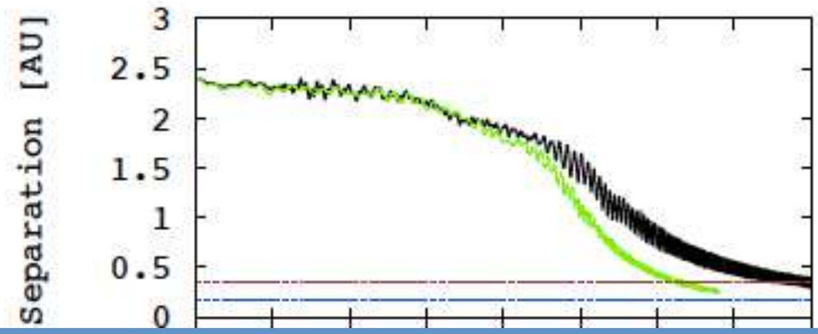
3 years

100 years

RGB star



AGB star

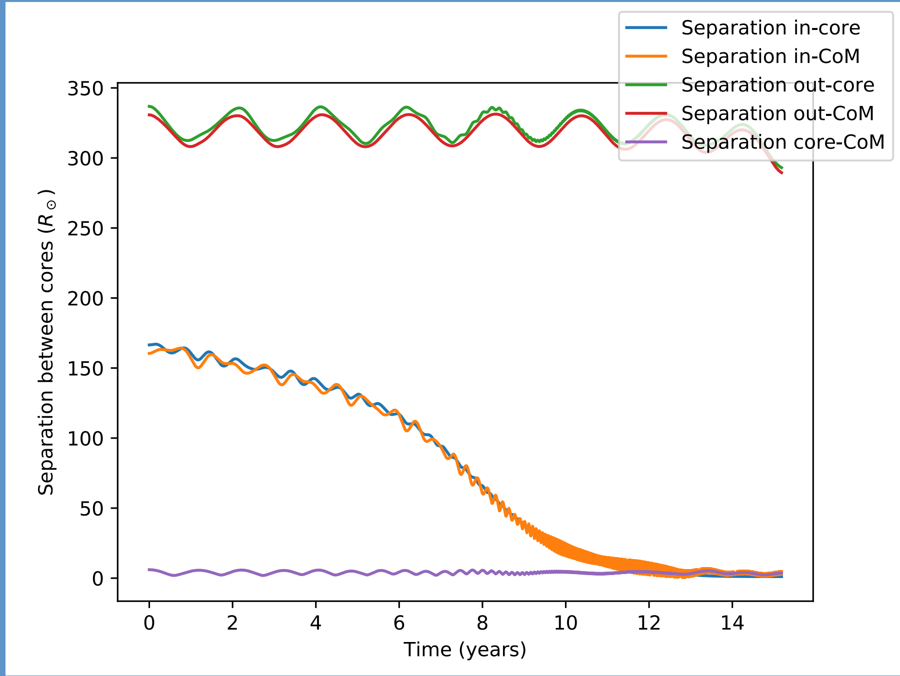


Two planets in a CE with a 0.8-Mo RGB star (PHANTOM)

- 0.8 Mo RGB star + 2 x 10 Mj planets
- Motivation: can a lighter star suffer more damage? Can two planets impart more damage?

Curious result?

- Results: in-spiral of outer planet is negligible for the first 15 years of the simulation



- Explanation (?) Gas surrounds both companions. Could the outflow promoted by the inner planet in-spiral push the outer planet out?

- Further: after ~15 yr the outer planet starts in-spiralling: why? What is the drag felt by the companion and is it accurate?

A side issue of fundamental importance: gravitational drag in CE simulations

- Gravo-drag is the only form of drag in simulations
- (Hydro-drag would matter only in the late in-spiral of planets).
- What should the drag force be?

$$F_{\mathrm{grav,drag}} \sim \zeta \rho v_{\mathrm{p}}^2 \, \pi R_{\mathrm{A}}^2 ,$$

$$R_{\mathrm{A}} = \frac{2GM_{\mathrm{p}}}{v_{\mathrm{p}}^2 + c_s^2} ,$$

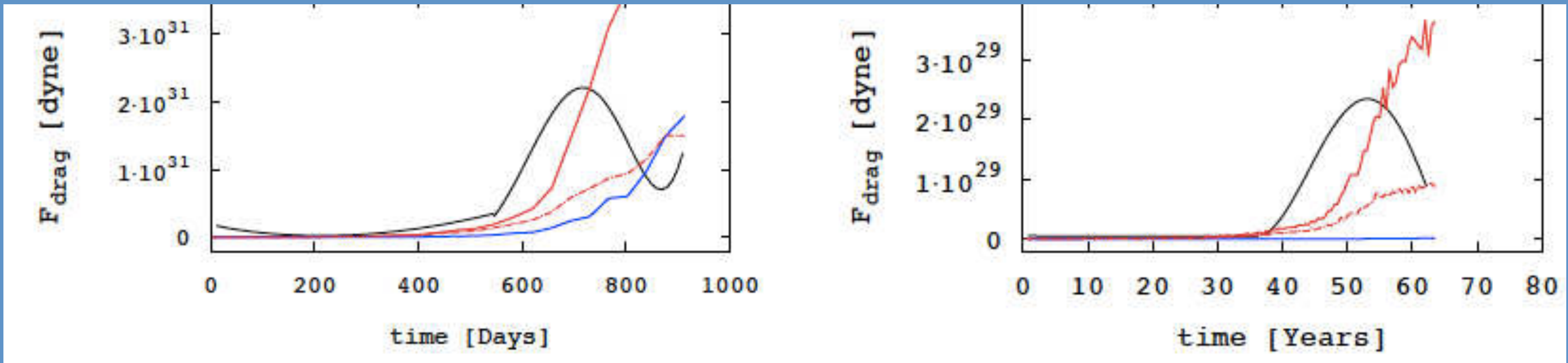
Subsonic

$$R_{\mathrm{A}} = \frac{2GM_{\mathrm{p}}}{v_{\mathrm{p}}^2} ,$$

Supersonic

A side issue of fundamental importance: gravitational drag in CE simulations

- Determining the drag felt in the code



Analytical gravo-drag supersonic

Analytical gravo-drag subsonic

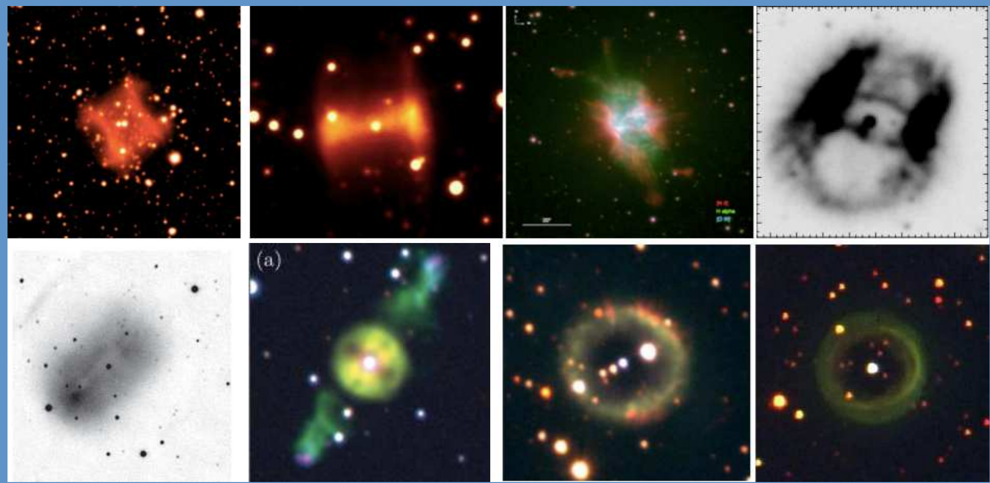
Analytical hydro-drag

Force in code

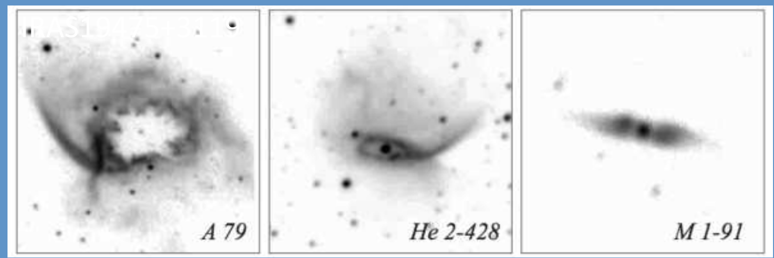
(A lot more) questions for CE simulations

- Gravity interaction particle-gas (low density near sinks)
- Energetics of the unbinding (recombination energy: Tom's talk)
- Jet launching from accretion disk around companion (Shiber et al., in prep.)
- Lightcurve of CE mergers (Galaviz, De Marco et al. 2017)
- Magnetic fields?

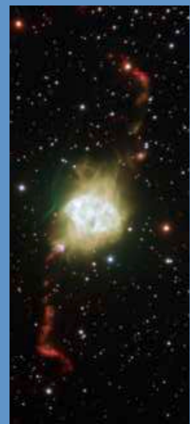
Validation: the shape of the CE



Hillwig+16, Huckvale+13; Jones+10, Santander-Garcia+15, Miszalski+11



Rodriguez et al. 2001

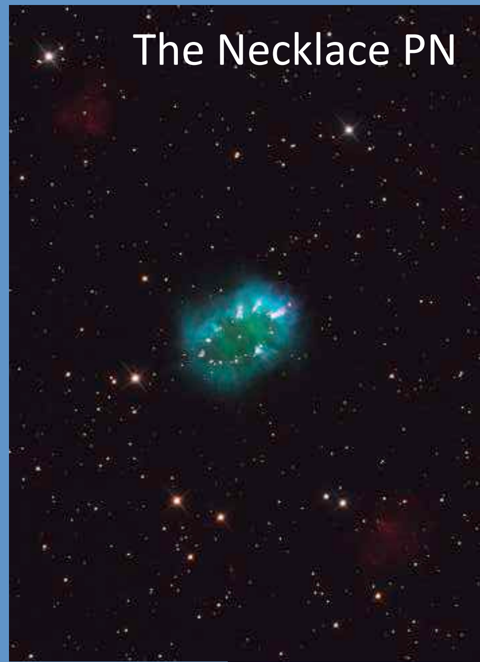


Fleming 1; credit: ESO/H. Boffin

Validation: B fields in CE?

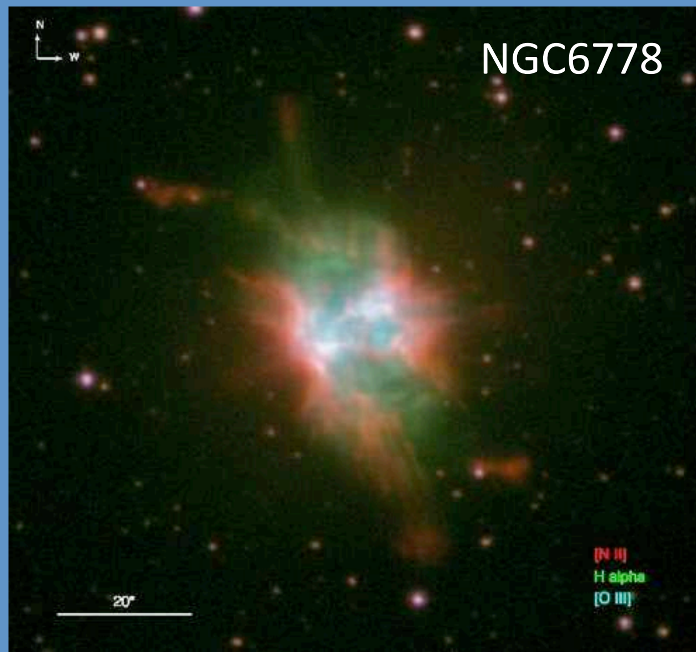
(Tocknell, De Marco & Wardle 2014)

- Pre-CE jets (2 objects) precede the CE by few x 1000 years.
- Jet speeds ~100 km/s
- Jet masses 1x10^{-3} Mo
- RL overflow or wind capture
- Accretion disk around companion
- B-perpendicular ~ 1 G



Validation: B fields in CE?

- Post-CE jets (2 objects) follow the CE by few x 1000 years
- Jet pairs, bent jets
- Speed ~100 or 300-500 km/s
- Fallback of gas onto binary: one or two accretion disks
- <u>B-perpendicular 100-1000 G</u>
- Consistent with wound-dynamo theory of Regos and Tout (1995) – B field dynamical effect on envelope ejection!!?



Thank you!

“Orsola De Marco, everyday superhero” by 12 yr old cartoonist Sasha Matthews