



The importance of binarity in the formation and evolution of planetary nebulae



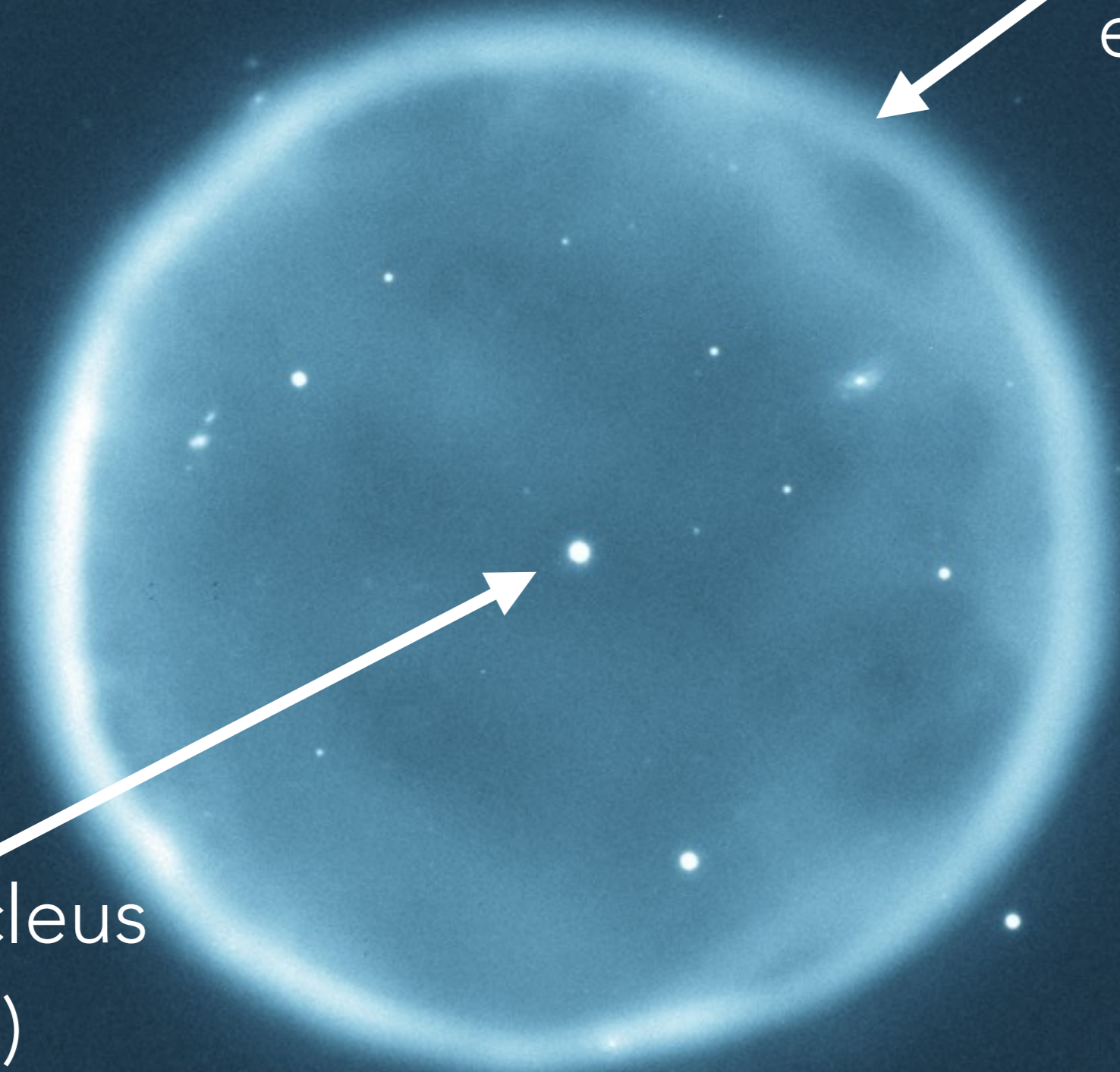
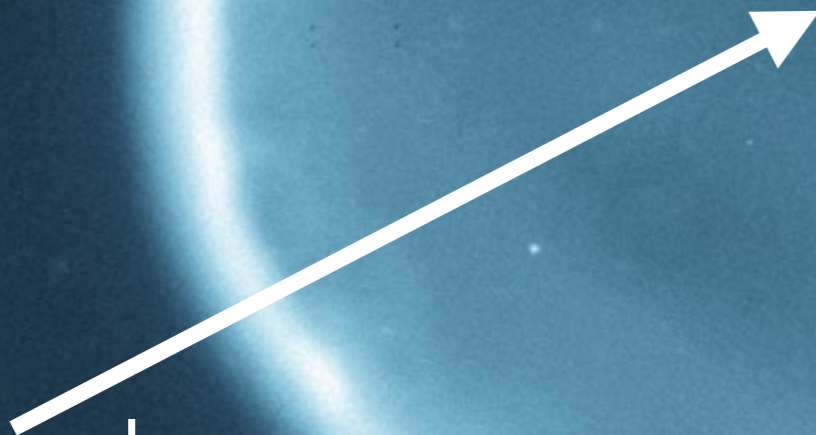


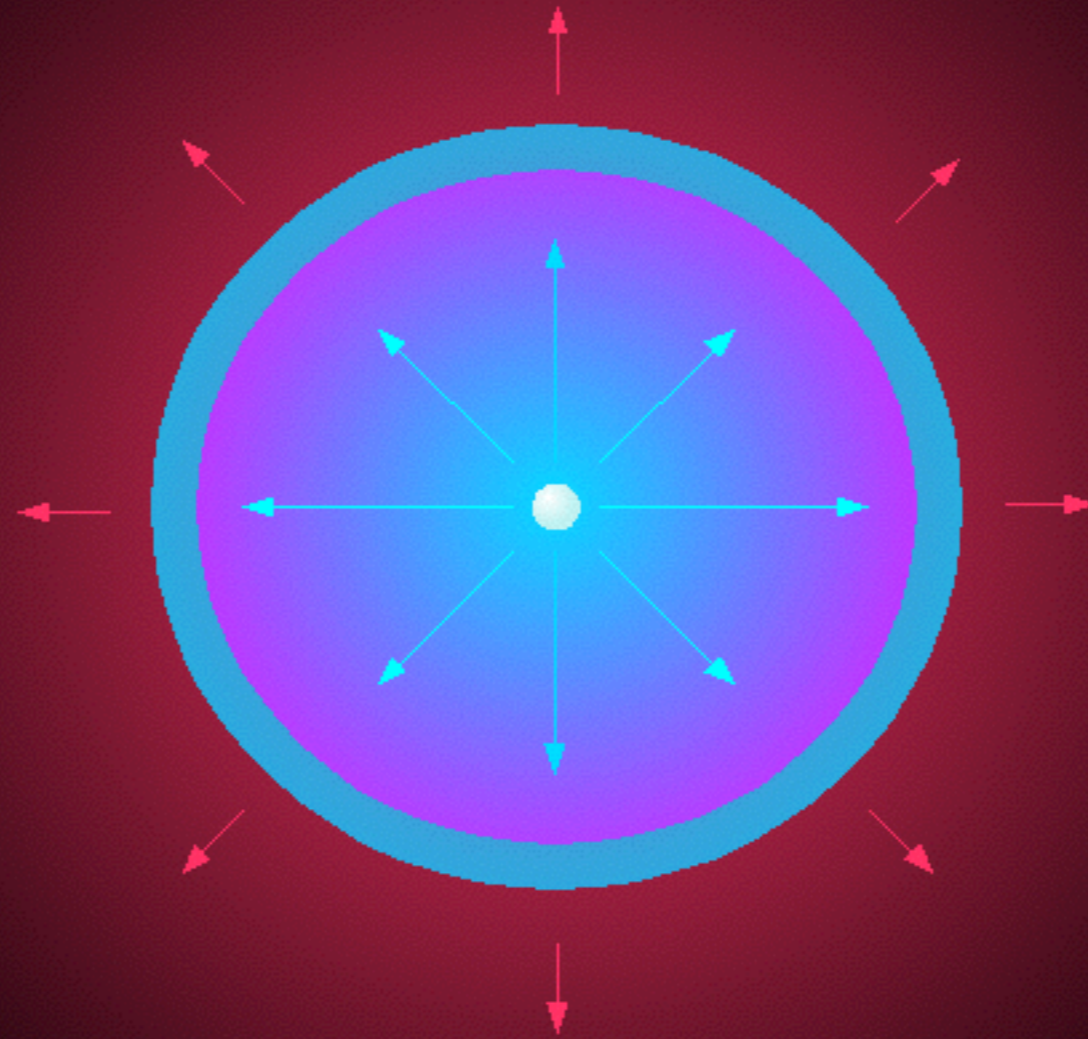
PLANETARY NEBULA

Ejected
envelope



Ionising nucleus
(pre-WD)







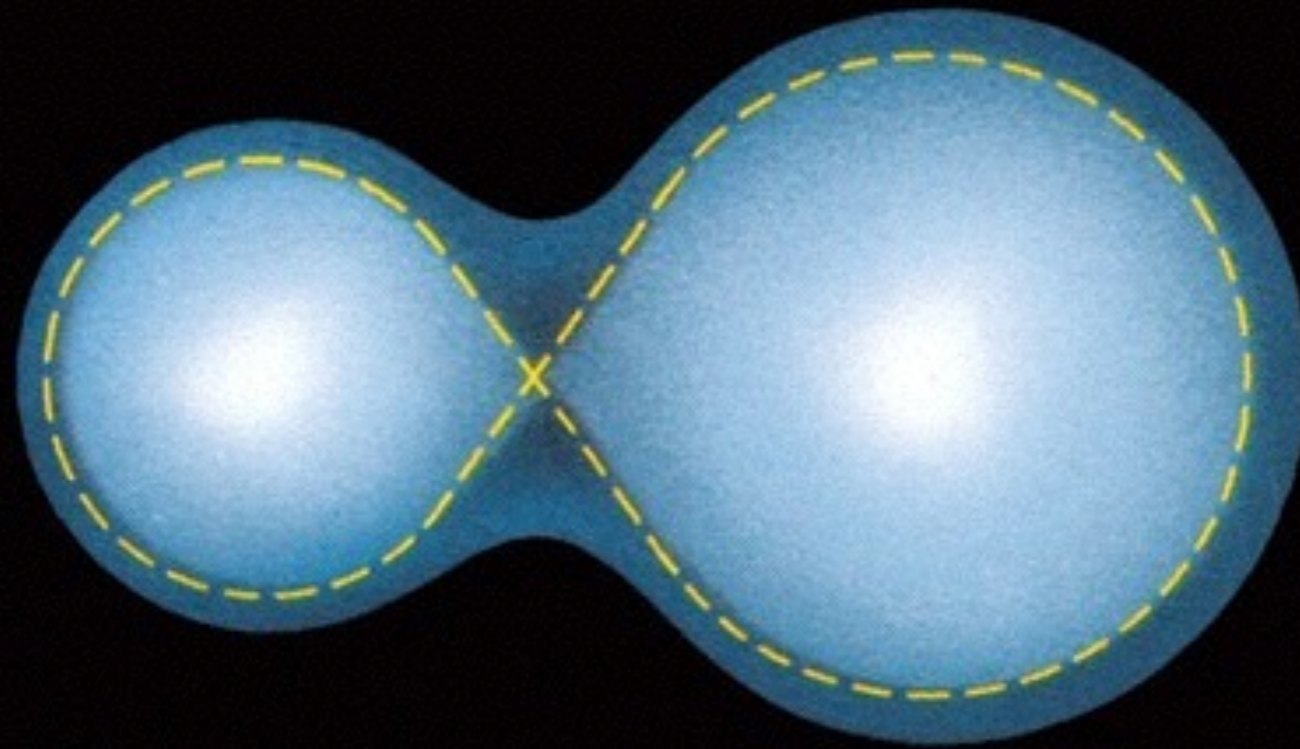


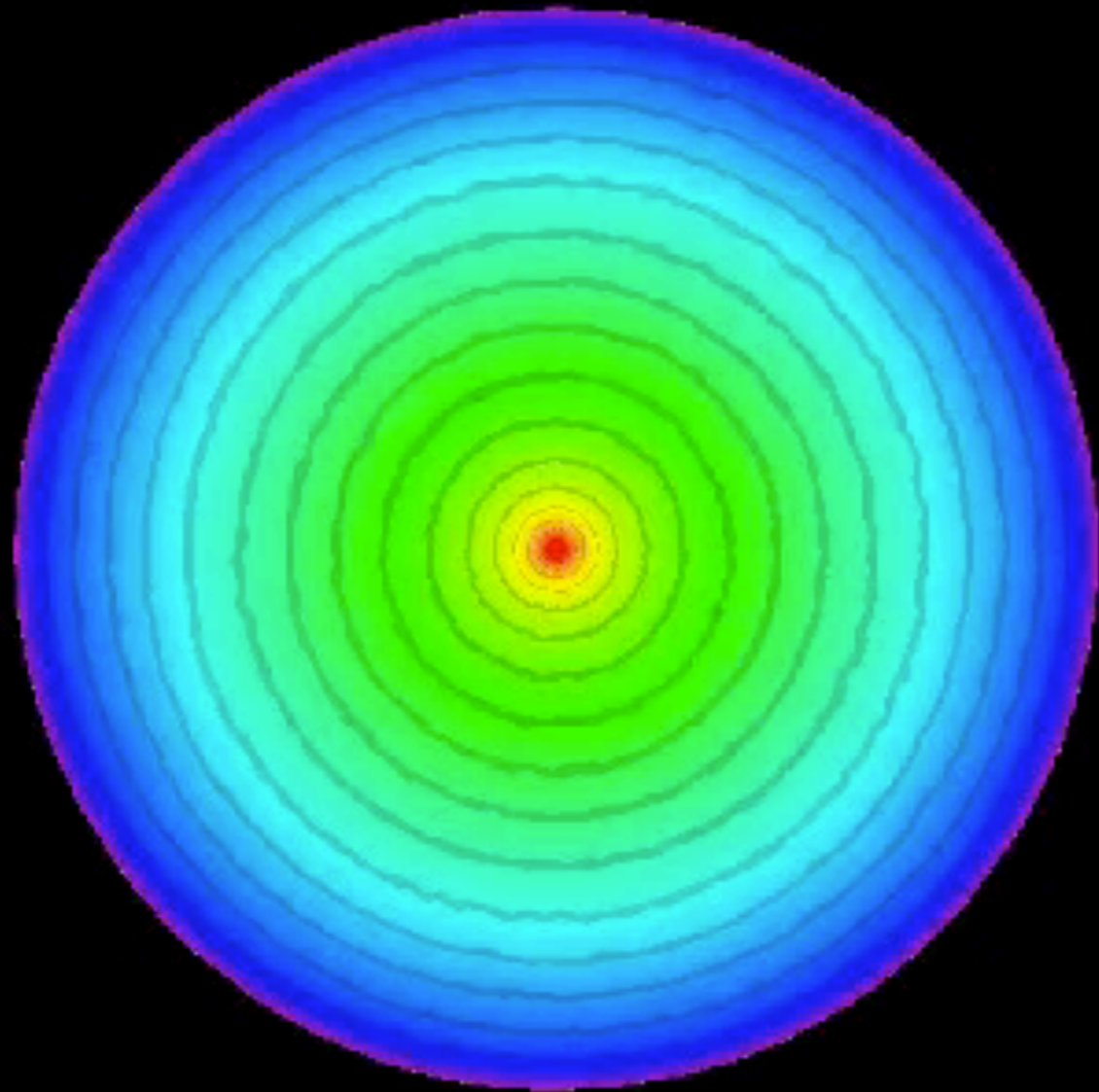
THERE IS NO PLAN B



COMMON ENVELOPE

BINARY EVOLUTION

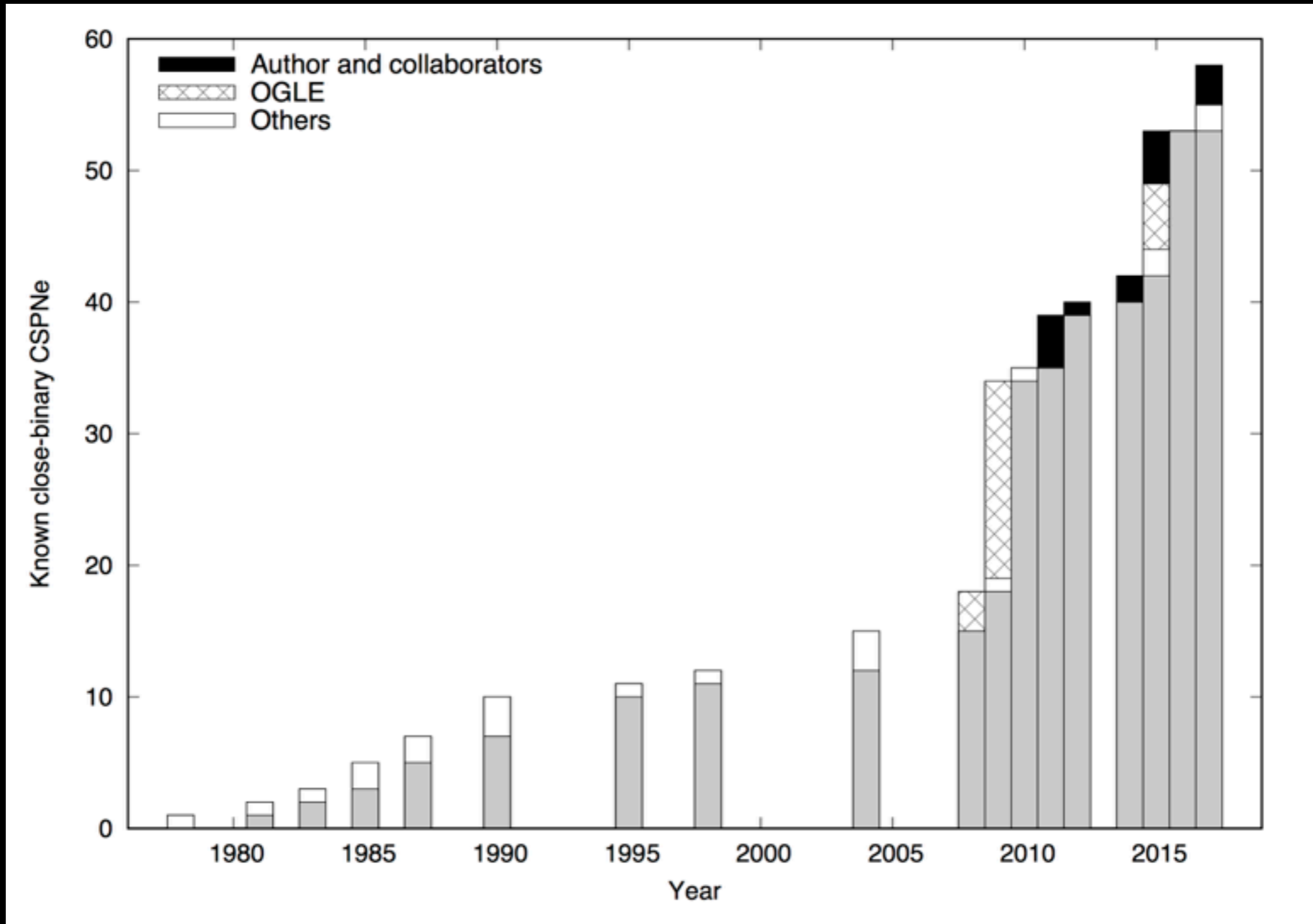




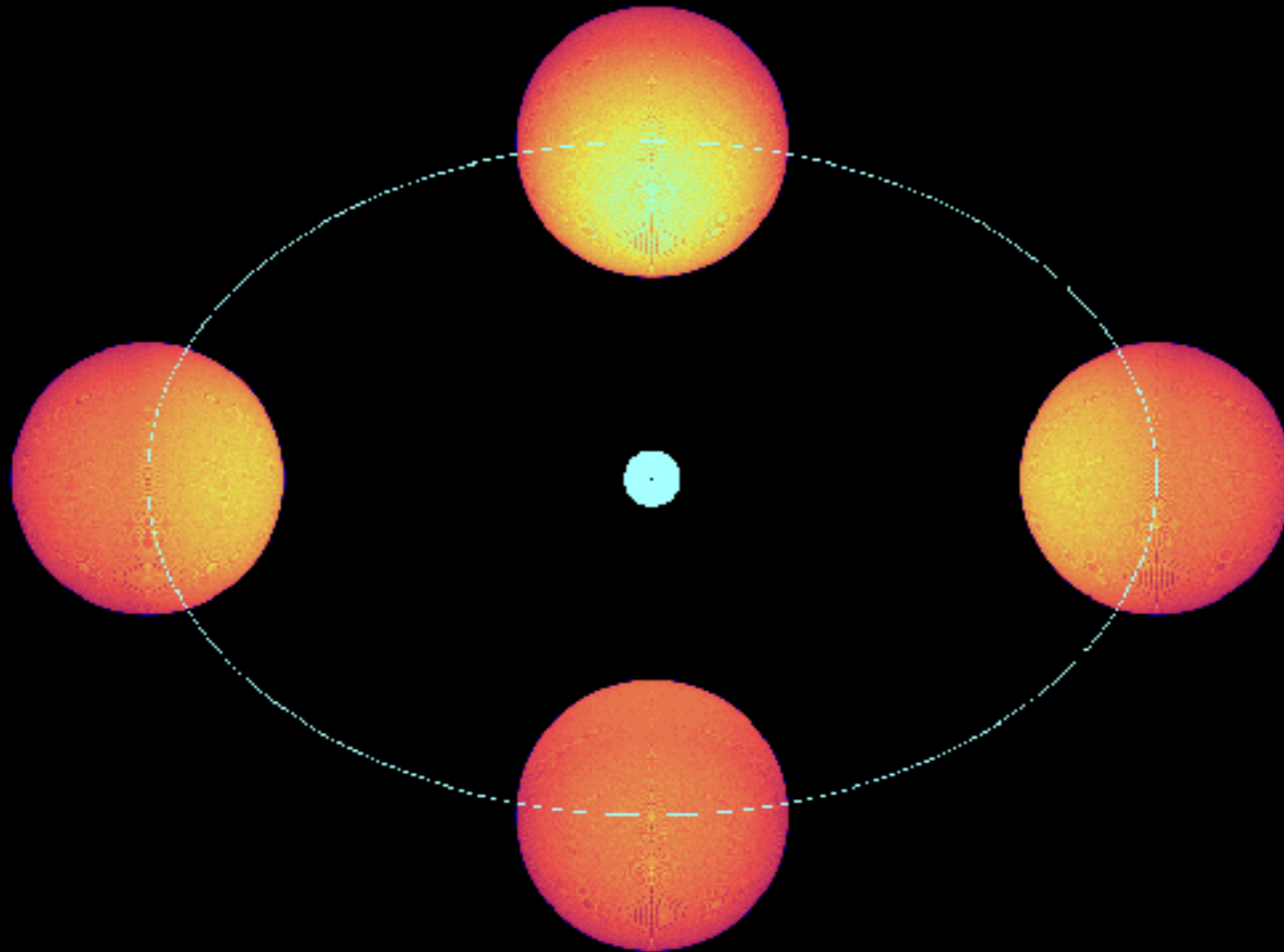
Initial separation

Passy et al. (2012)

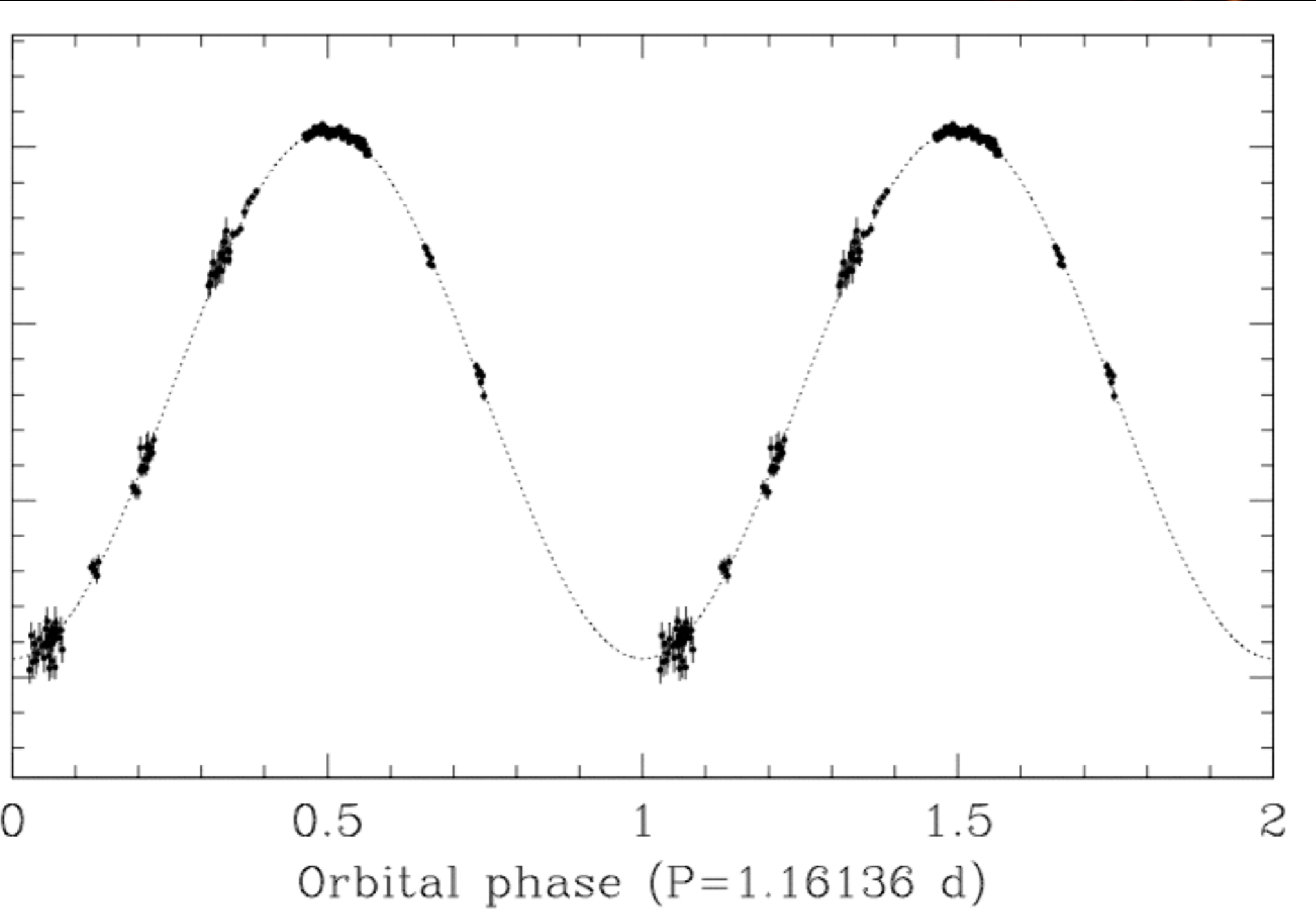
WHERE ARE THEY ALL THEN?

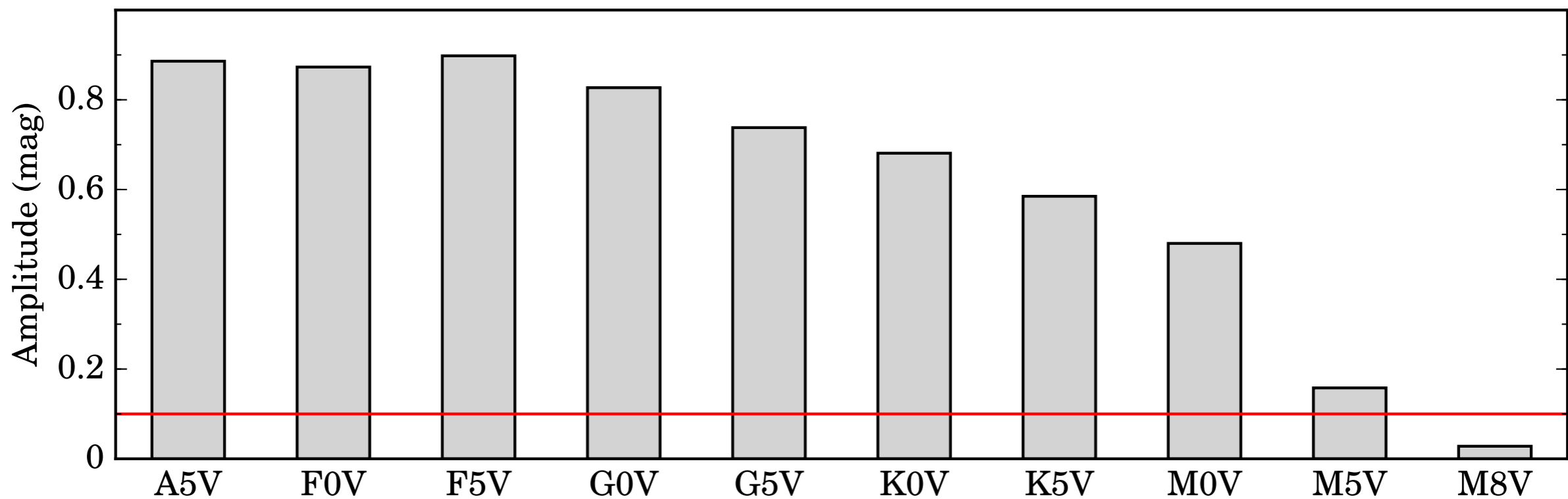
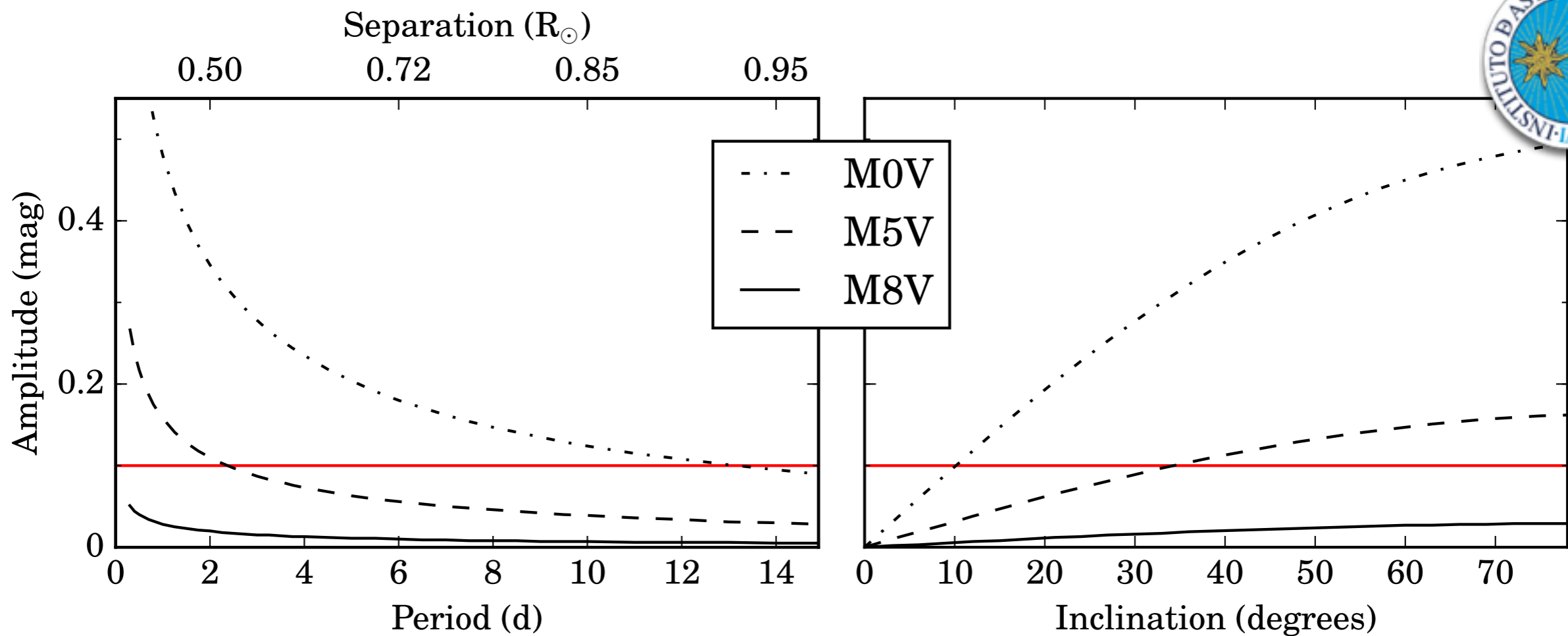


HOW DO YOU DETECT A POST-CE BINARY?



HOW DO YOU DETECT A BINARY?



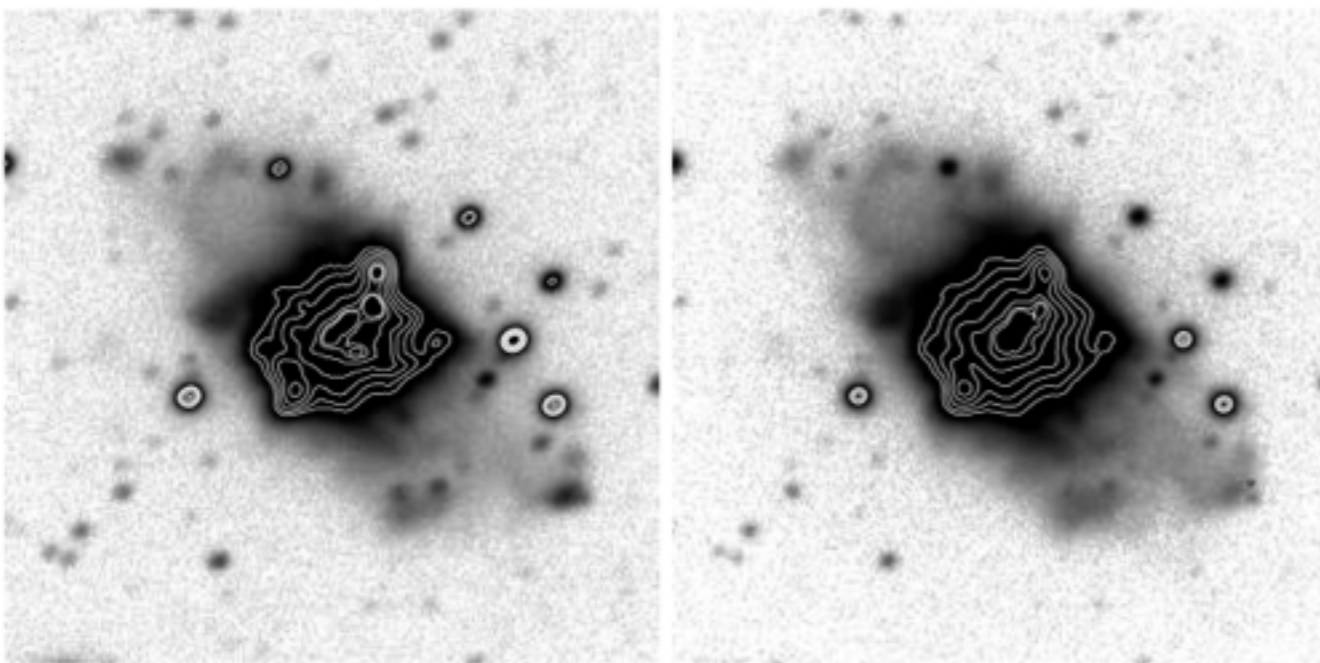




True binary fraction?

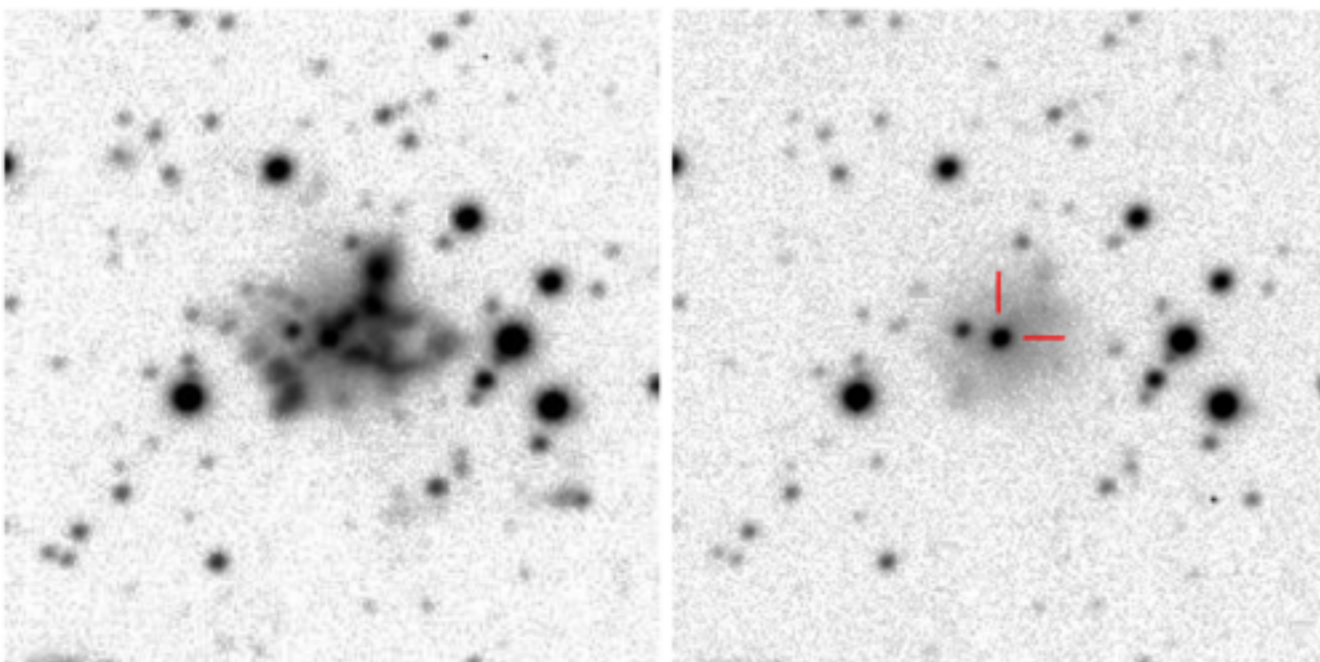
- (Photometrically) detectable fraction $\sim 20\%$ (Miszalski et al. 2009, *A&A*, 496, 813)
- Maybe as high as 80% based on other methodologies (De Marco et al. 2004, *ApJ*, 602, 93; Douchin et al. 2015, *MNRAS*, 448, 3132)

Simultaneous light curve & radial velocity modelling



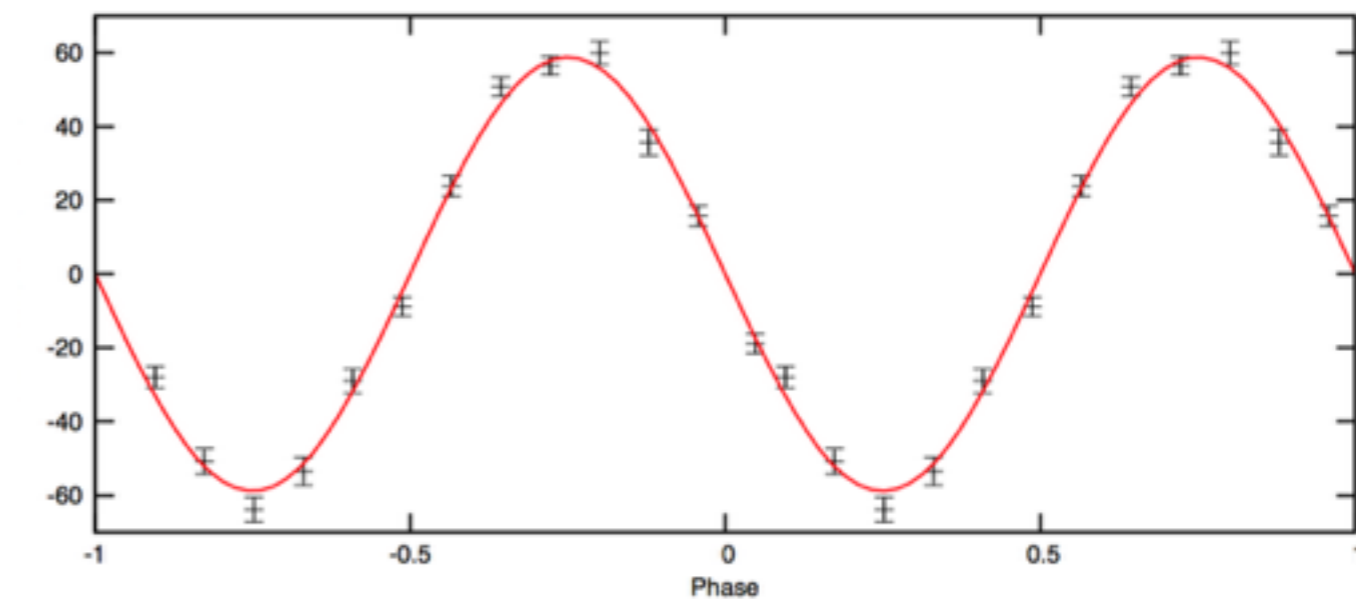
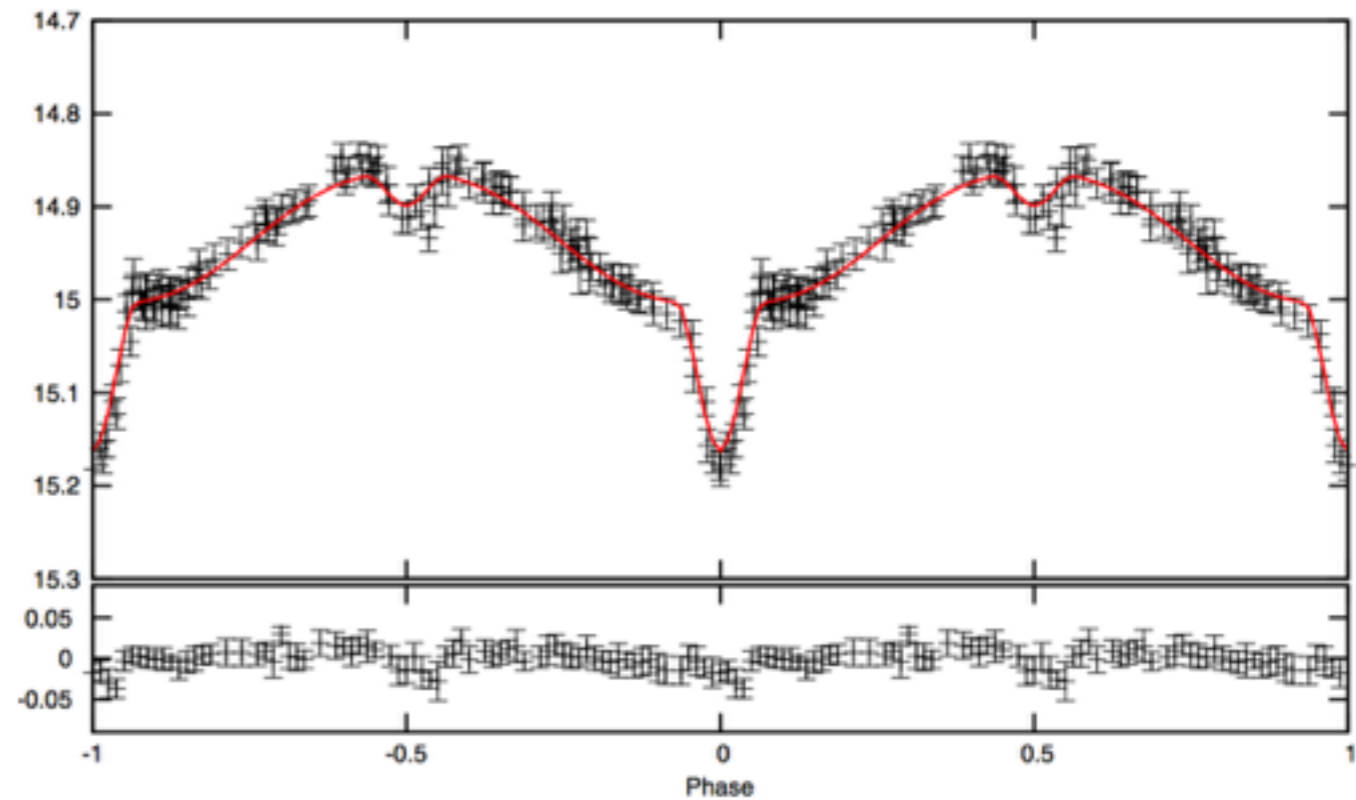
(a)

(b)

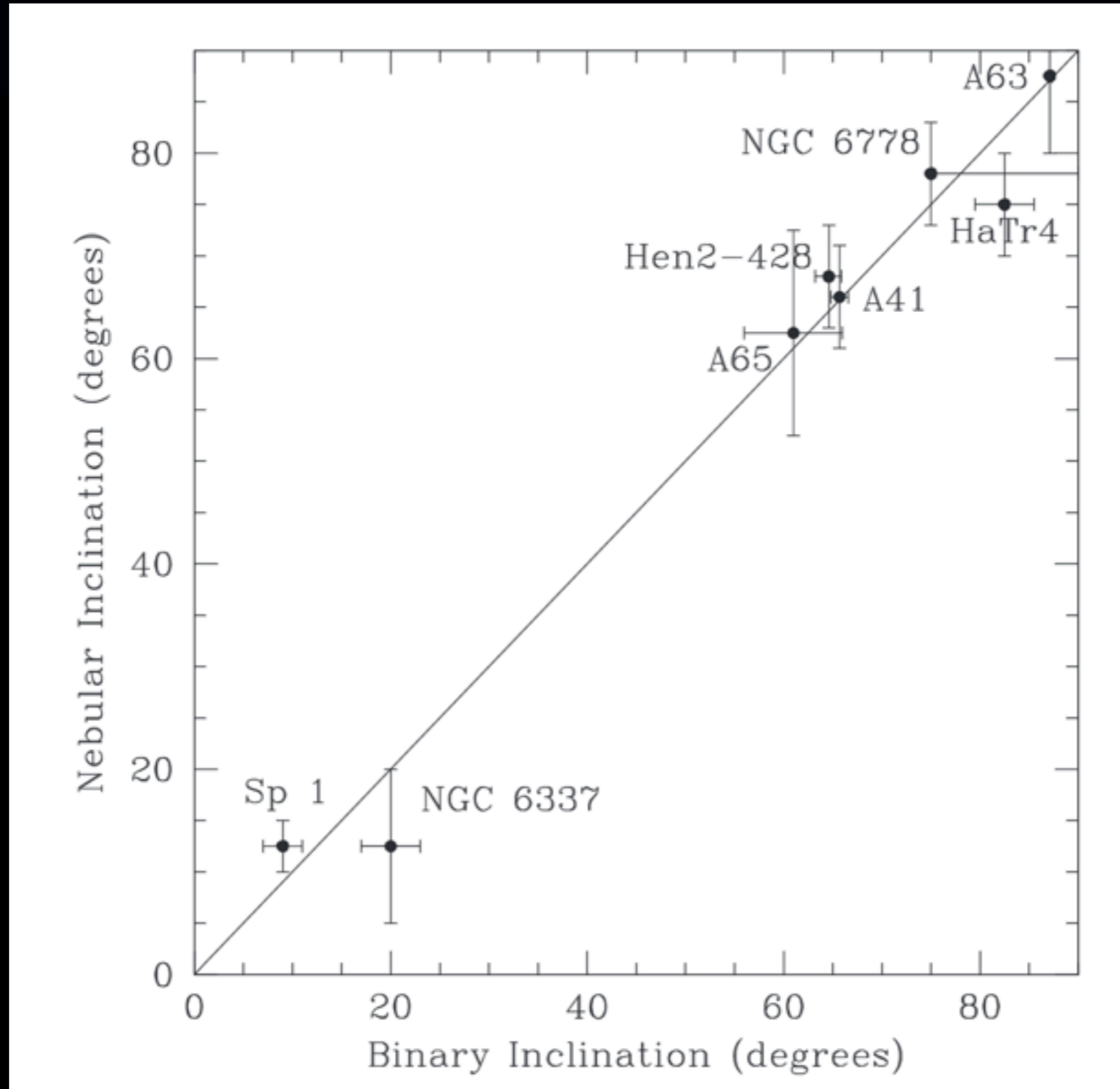


(c)

(d)



One in a million chance...



Inflated secondaries Evidence of mass transfer!



Abell 46

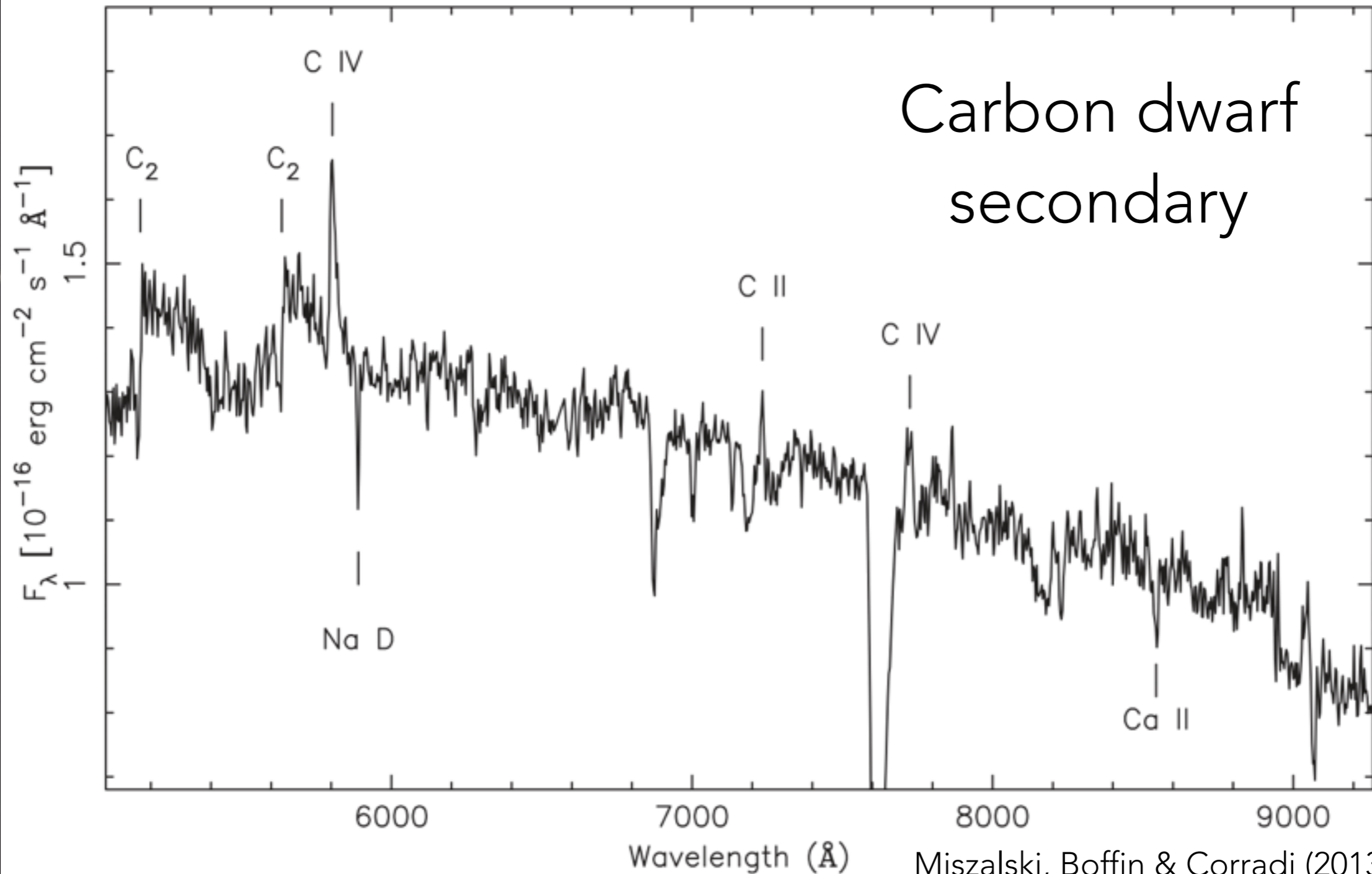


Hen 2-155

Every

well constrained main-sequence secondary is inflated!

More evidence of mass transfer!



More evidence of mass transfer!

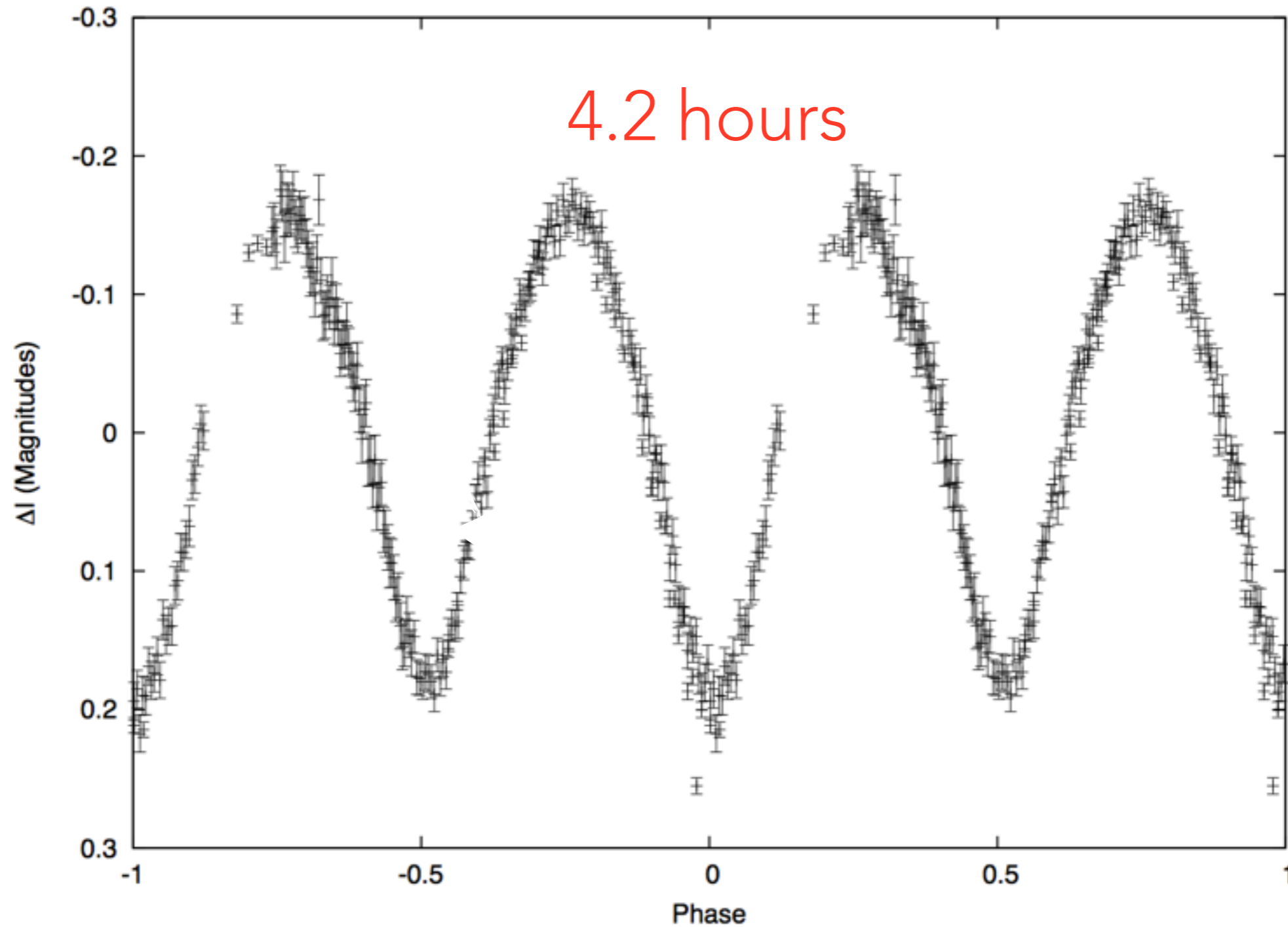




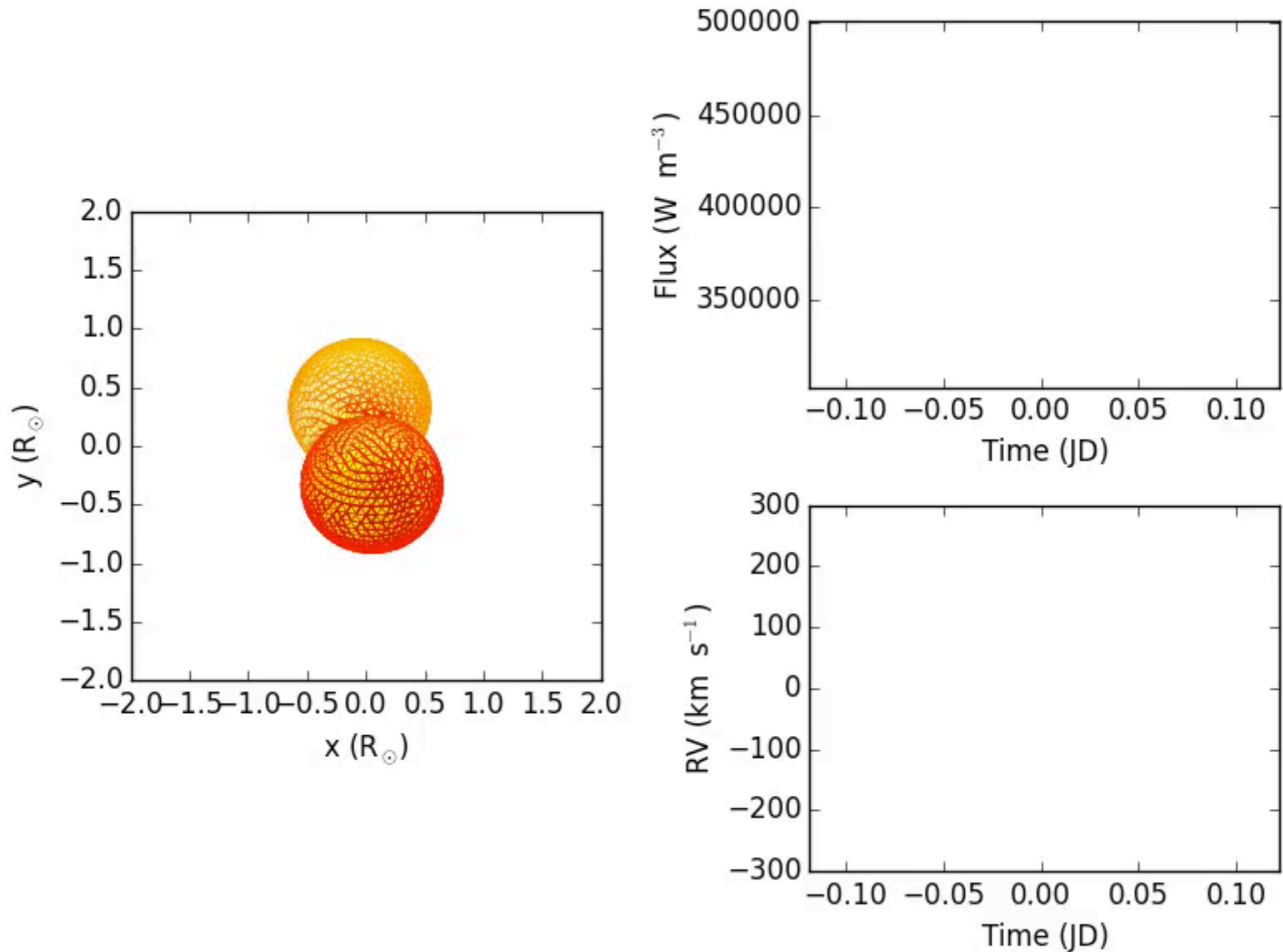
Hen 2-428: A perfect candidate



Mercator Observations



Modelling in PHOEBE





Hen 2-428

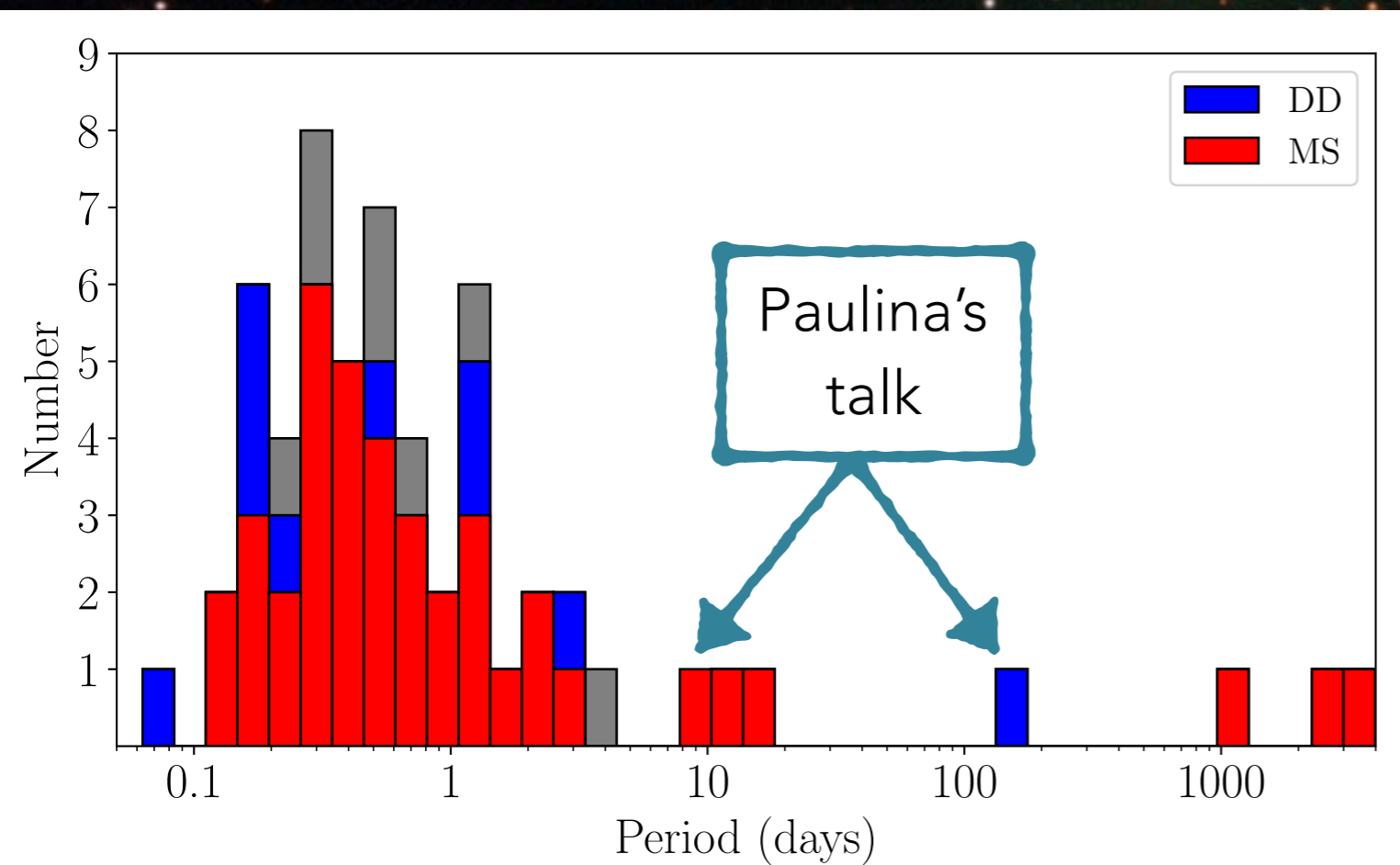
Total mass $>$ Chandrasekhar mass

Time to merger \sim 700Myr

\Rightarrow Supernova Type Ia progenitor!

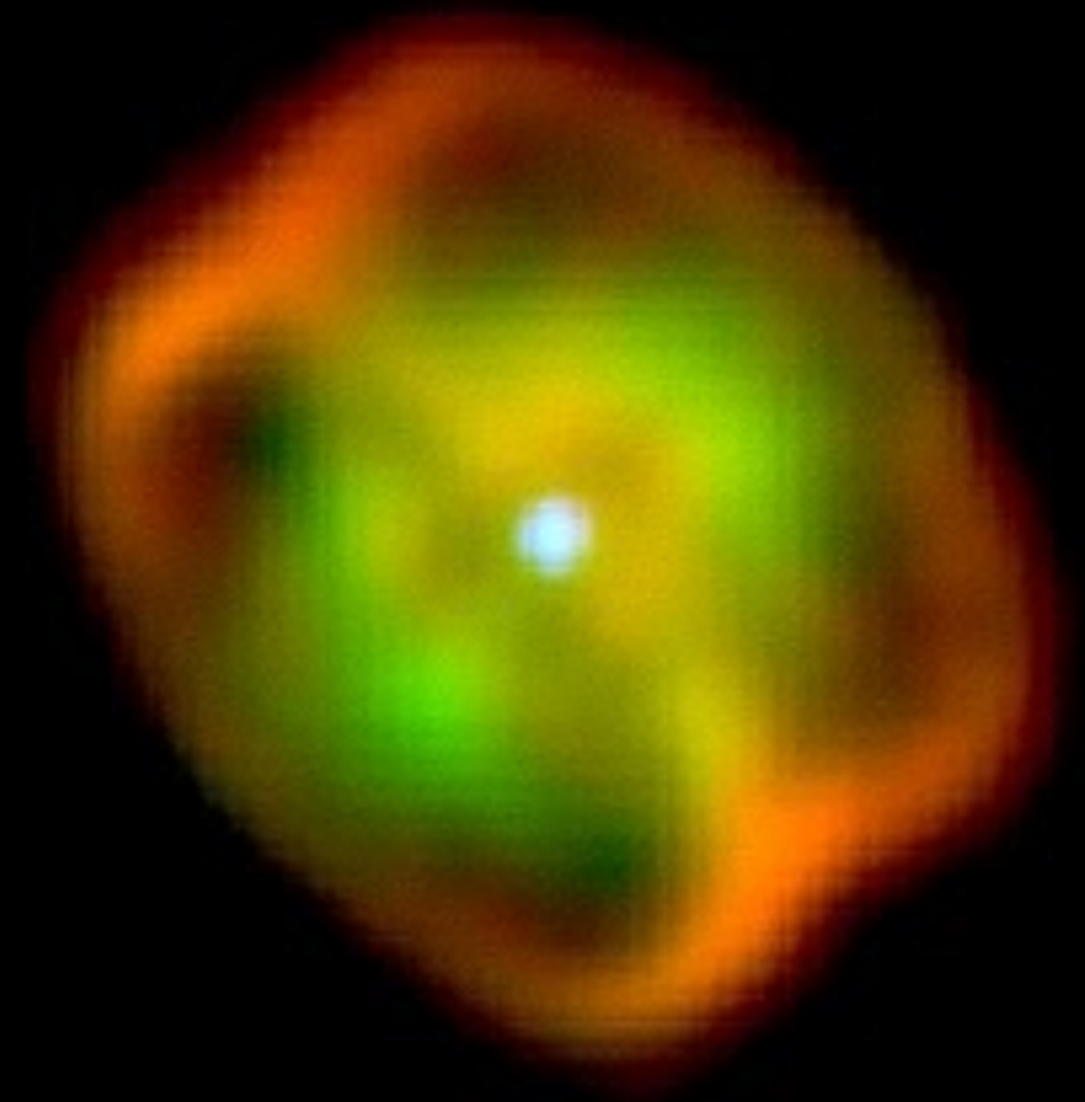
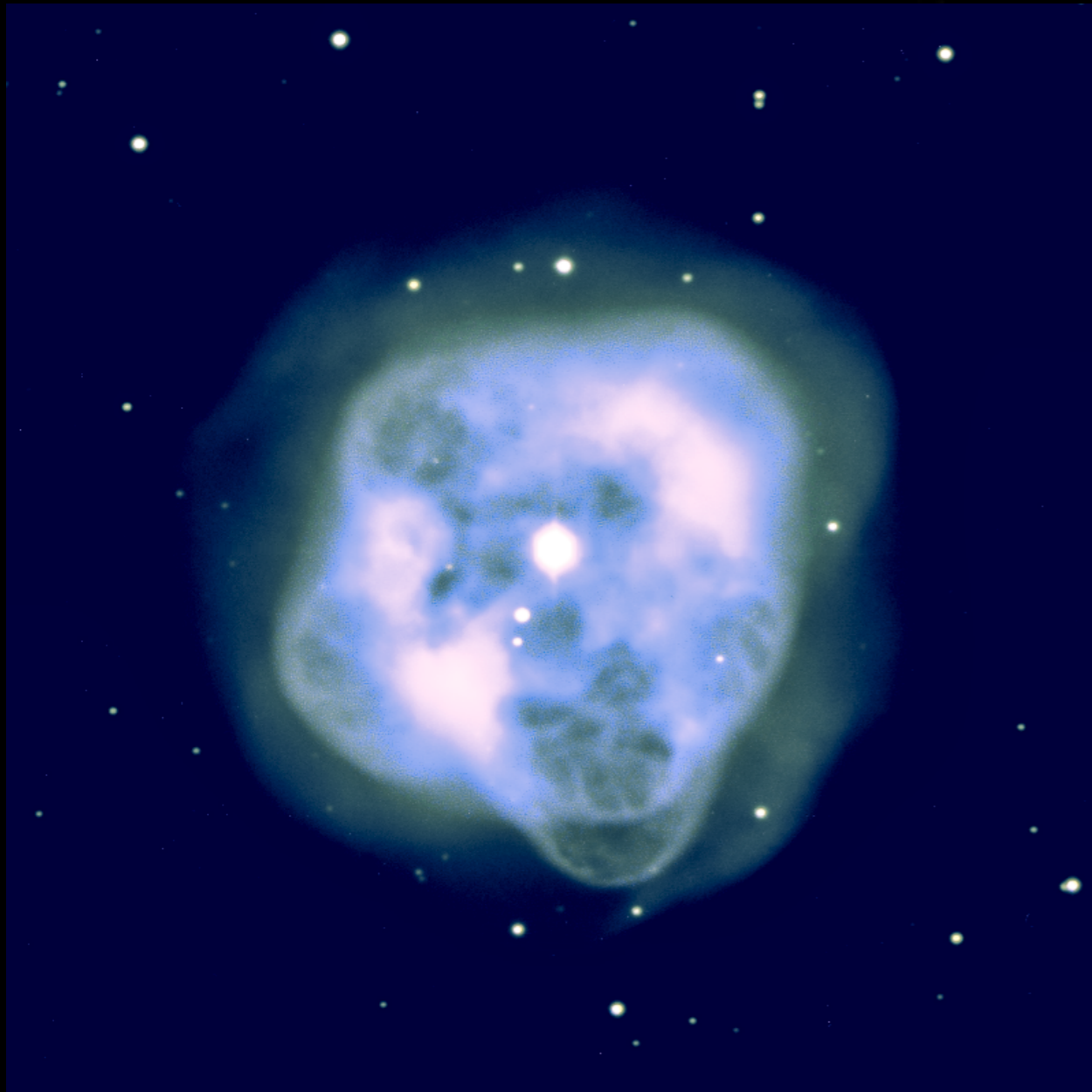
Santander-García et al. (2015)

Double-degenerates should be rare!

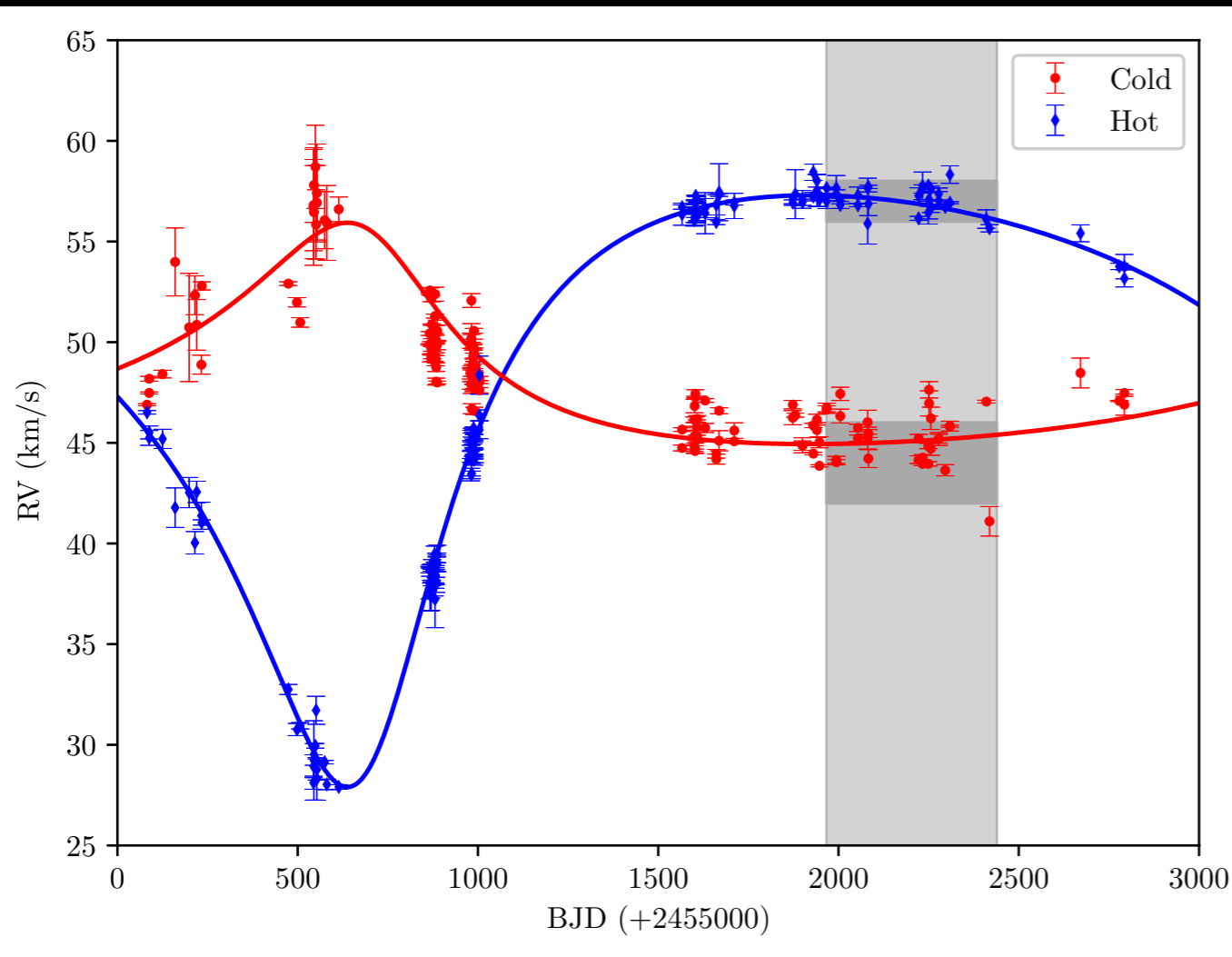


but they aren't ...

NOT ALL POST-CE...



Long periods: Radial Velocities

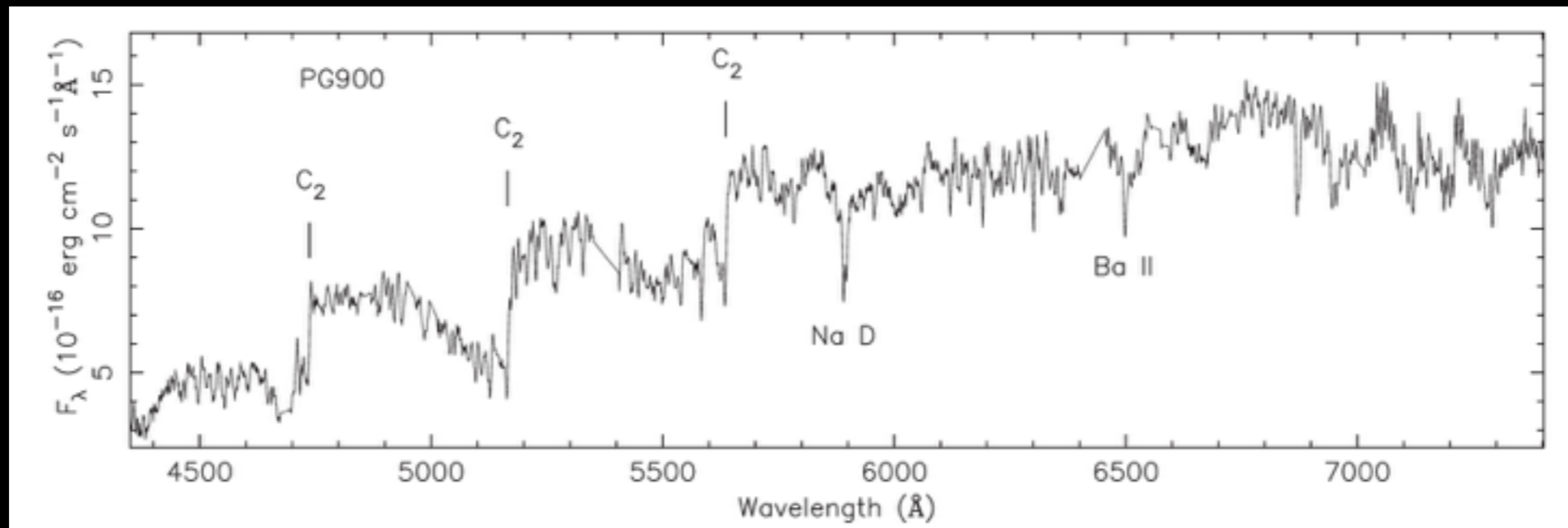


- Extremely difficult - everything is variable on some level (e.g De Marco et al. 2004)
- Needs high-resolution, high-stability spectrograph and lots of data.
- More in Paulina's talk

Van Winckel et al. (2014)

Jones et al. (2017)

Giant and/or chemically polluted secondaries

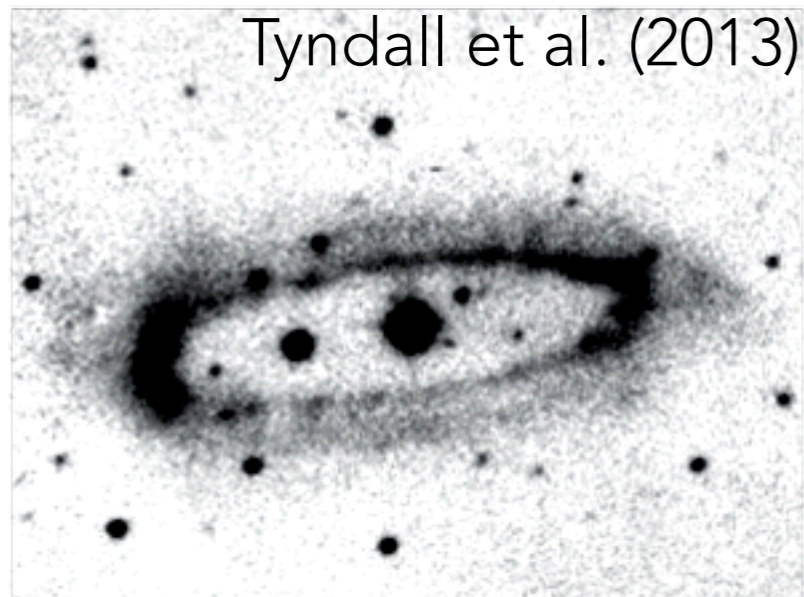


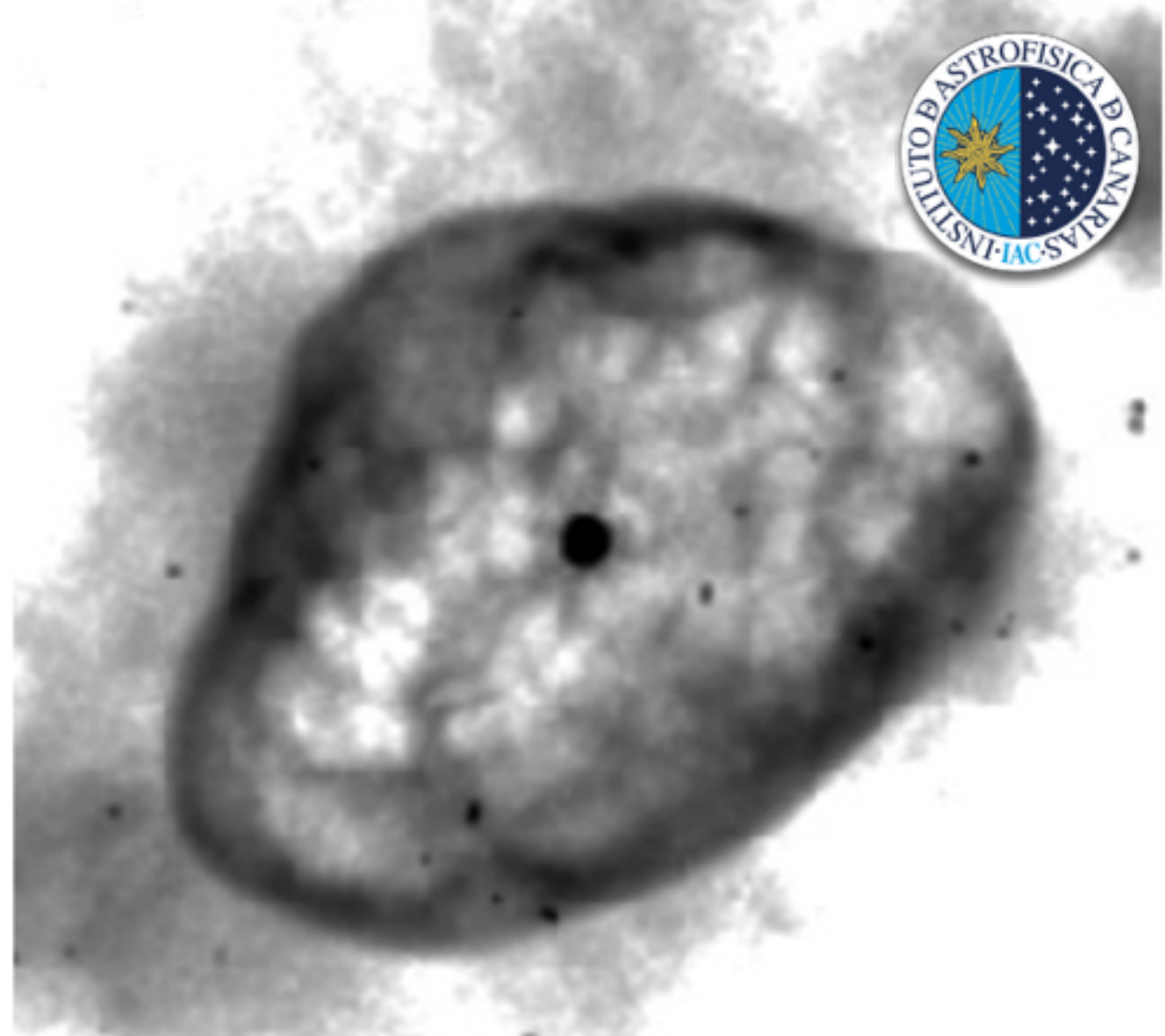
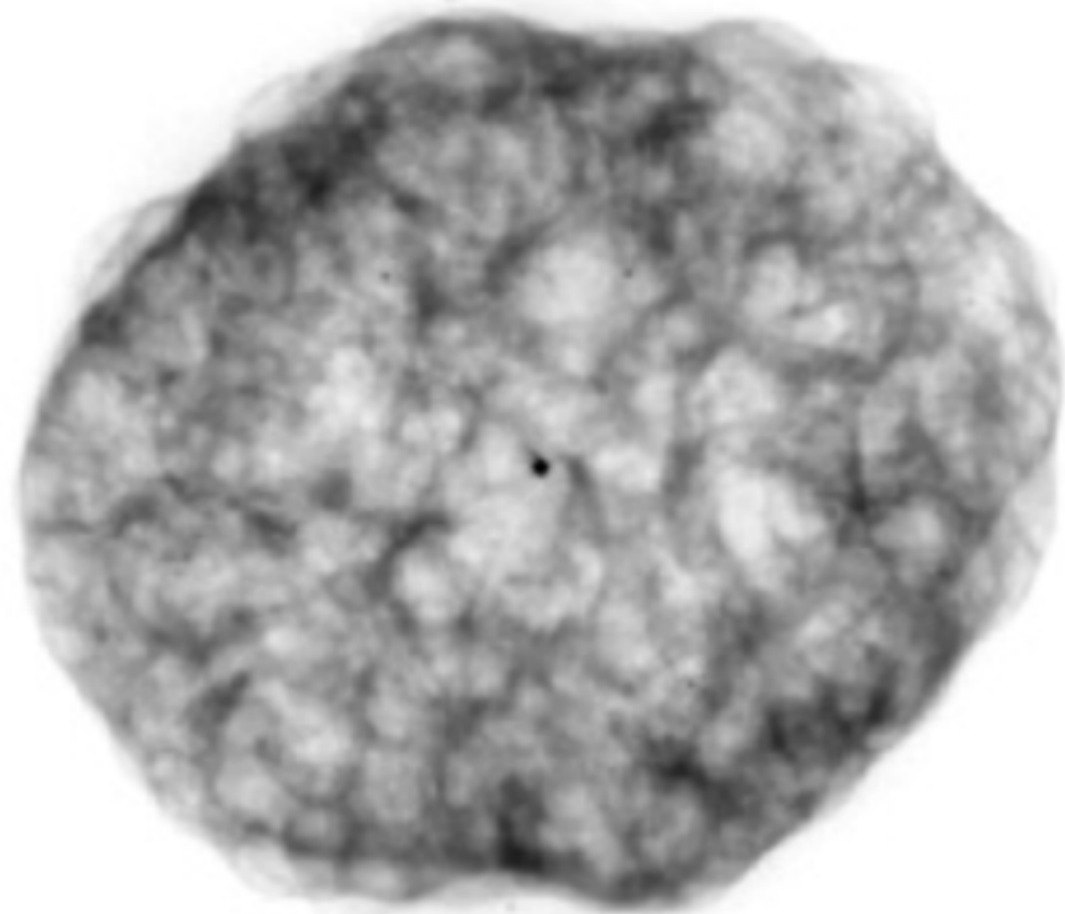
Miszalski et al. (2013)

Tyndall et al. (2013)

- Handful of systems with giant/sub-giant companions
- Chemical pollution is a pretty good evidence of connection to nebula

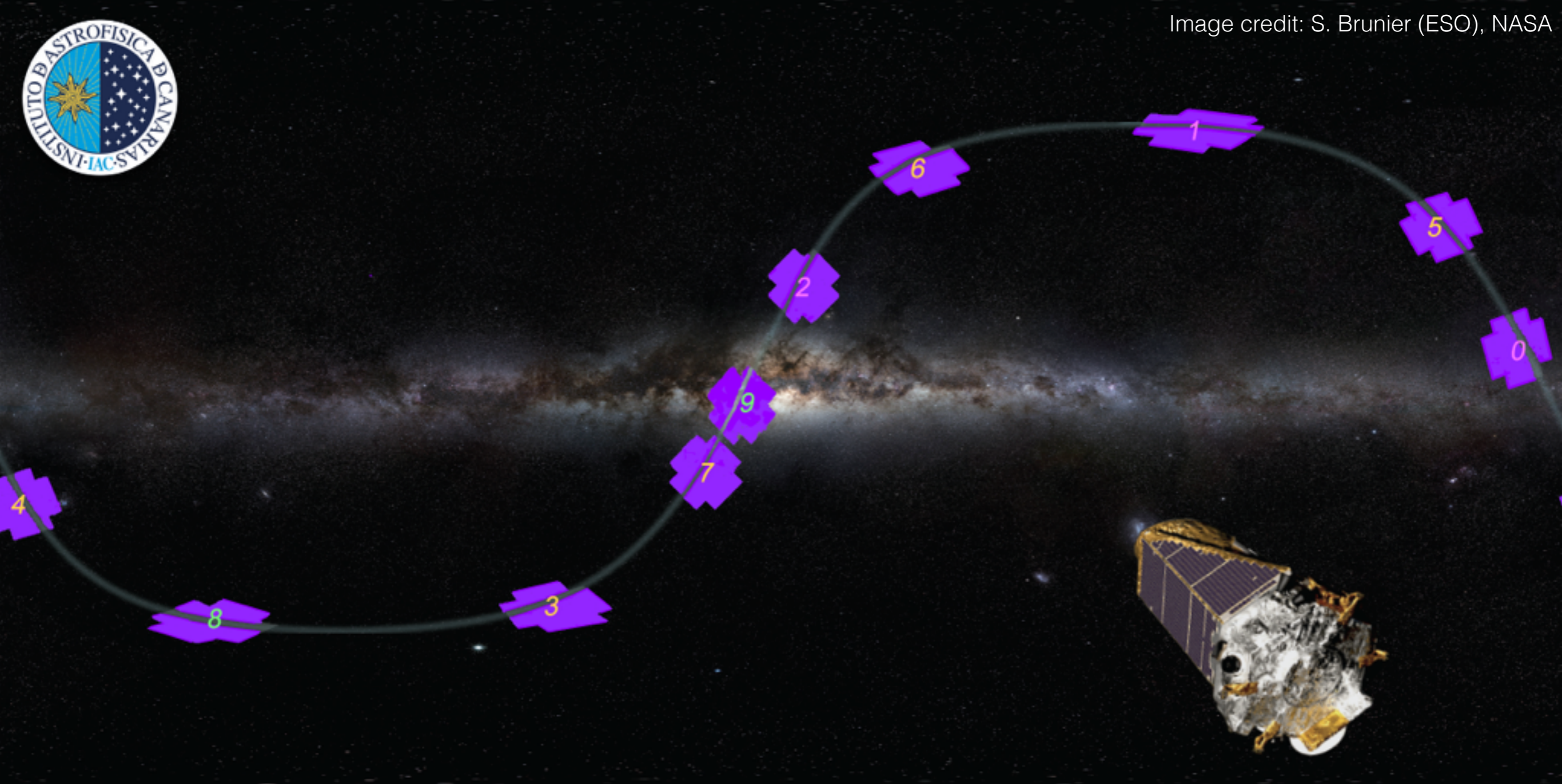
The Lord of the (Ba-)rings





The importance of mergers?

- Kepler can reveal rapid rotators (either via wind modulation or asteroseismology) which are likely merger products.
- Already one good example (NGC6826, Handler et al. 2013)
- Extensive ground-based campaigns can do this too (Sowicka et al., in prep)



- Already ~20 PN observed (~15 as part of K2)
- Another ~200 observed in campaign 11 (>30 “good” candidates)
- 4/5 CS observed in original Kepler field show variability consistent with binarity

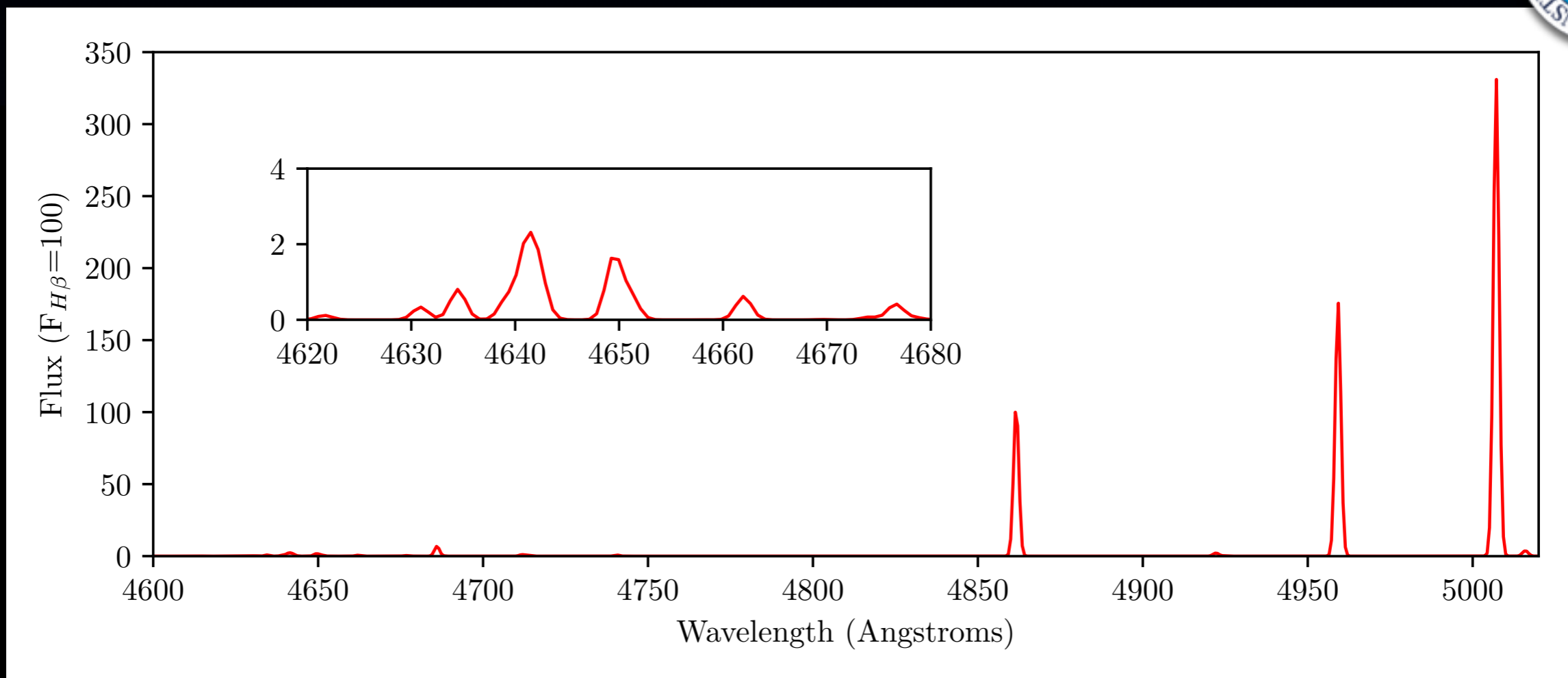
Handler et al. (2013)
De Marco et al. (2015)
Jacoby et al. (2016)



PROVISION

PRESENTS

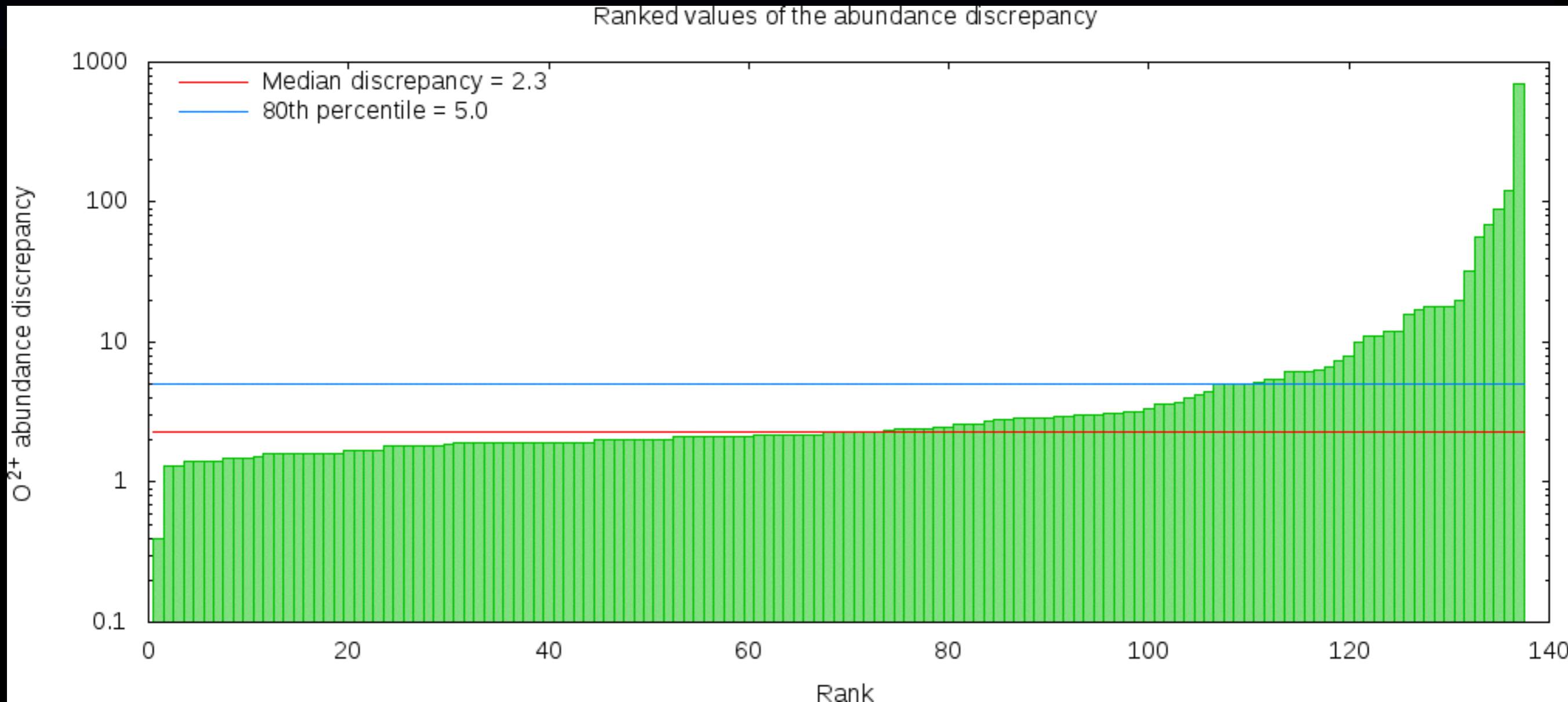
Nebular abundances



Abundances are calculated based on observed fluxes, but CEL fluxes are \gg than ORL fluxes.

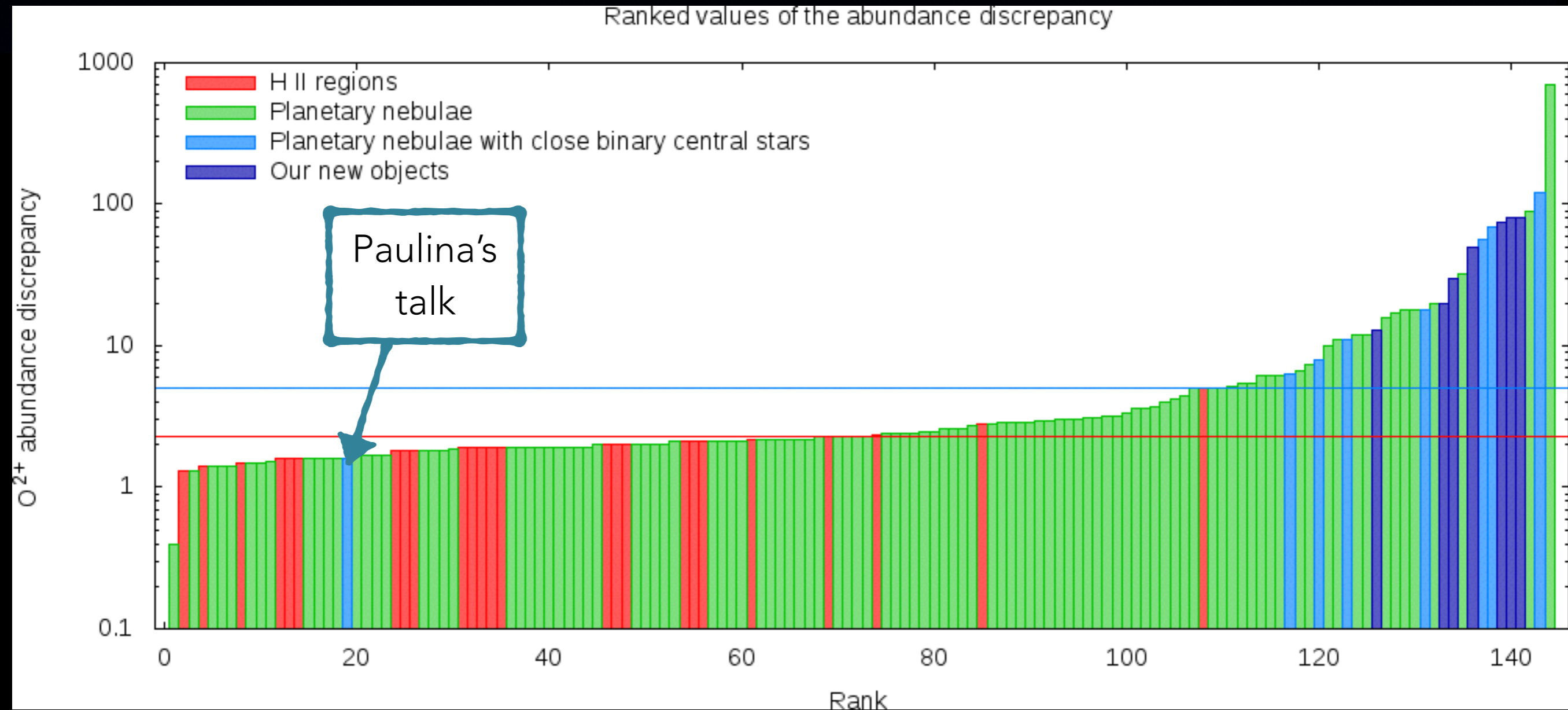
So, generally only CEL abundances are measured...

Abundance discrepancies



Abundances from ORLs > abundances from CELs

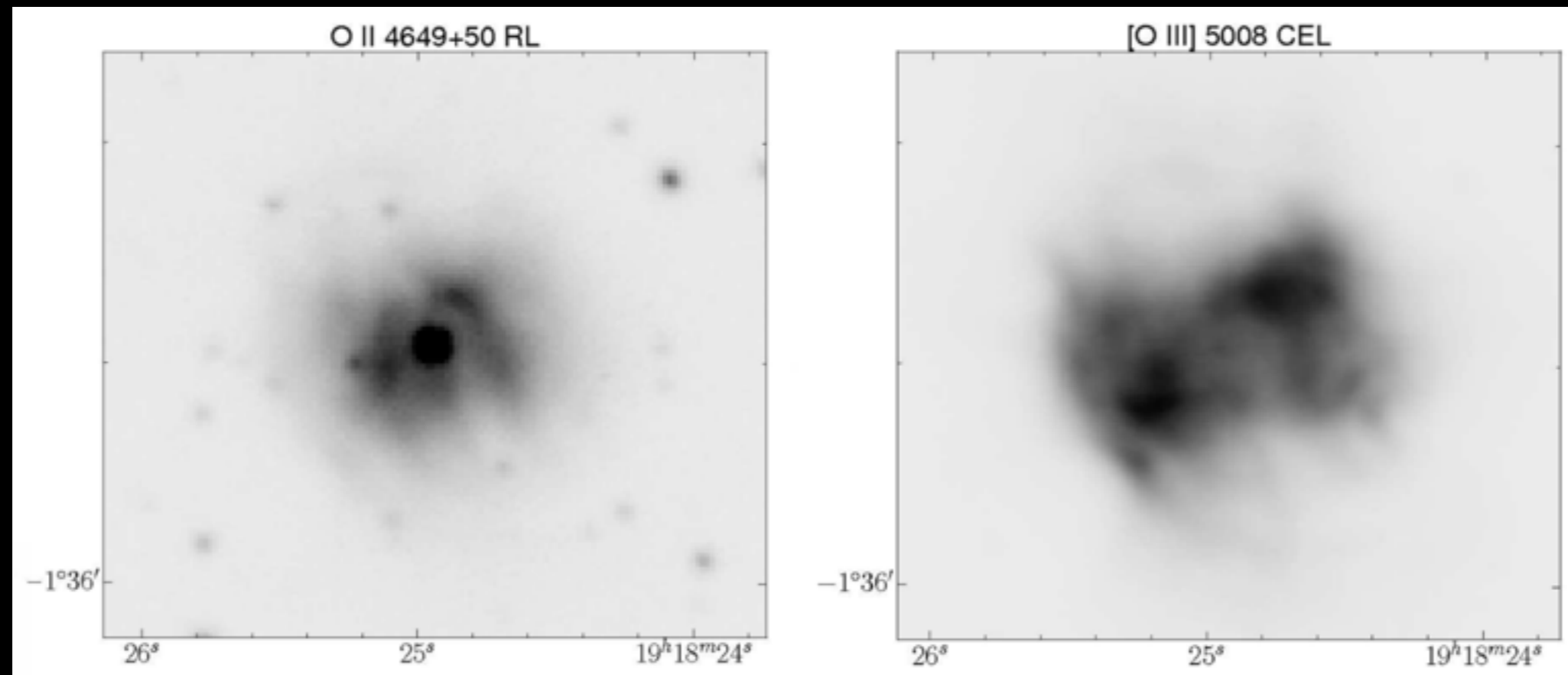
Abundance discrepancies



Abundances from ORLs $>$ abundances from CELs

A nebula within a nebula?

- High *adfs* imply a second metal-rich component to the nebula
 - Seems to be centrally concentrated

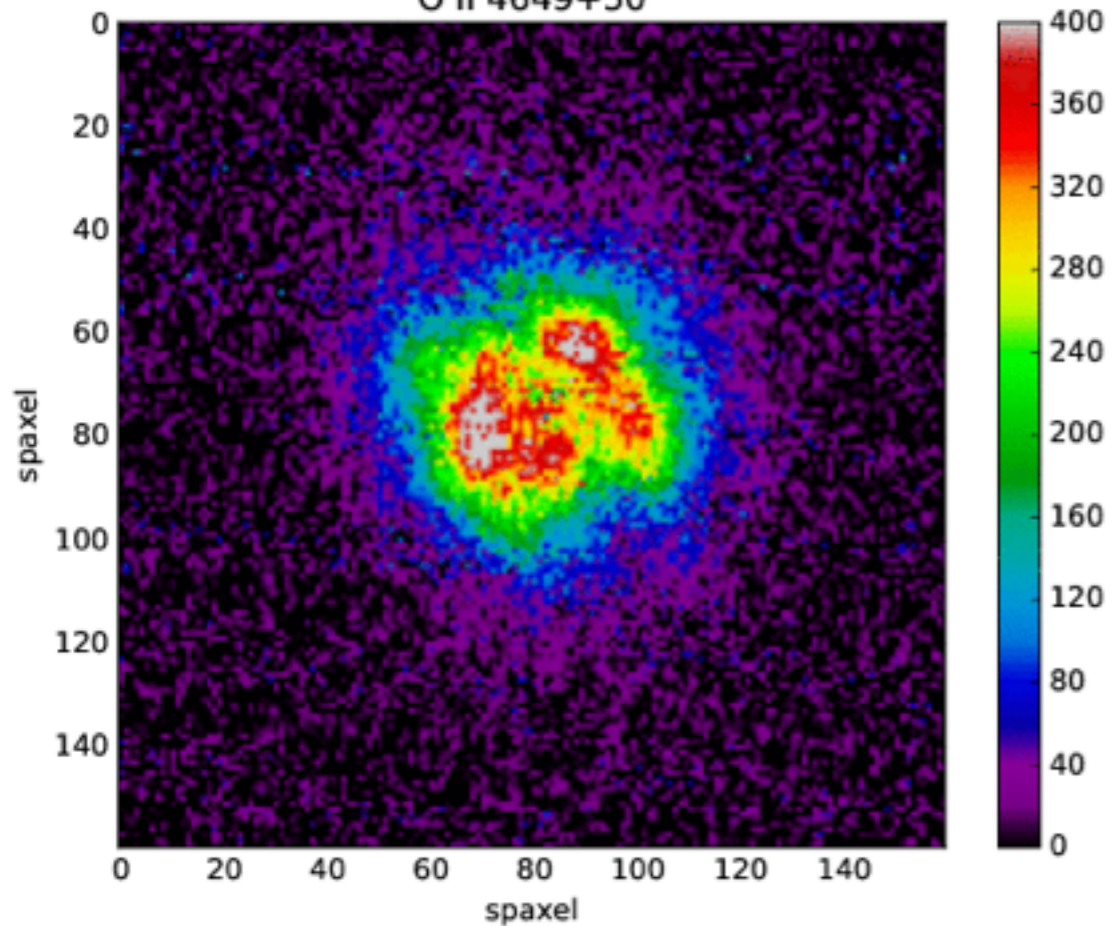


Corradi et al. (2015)

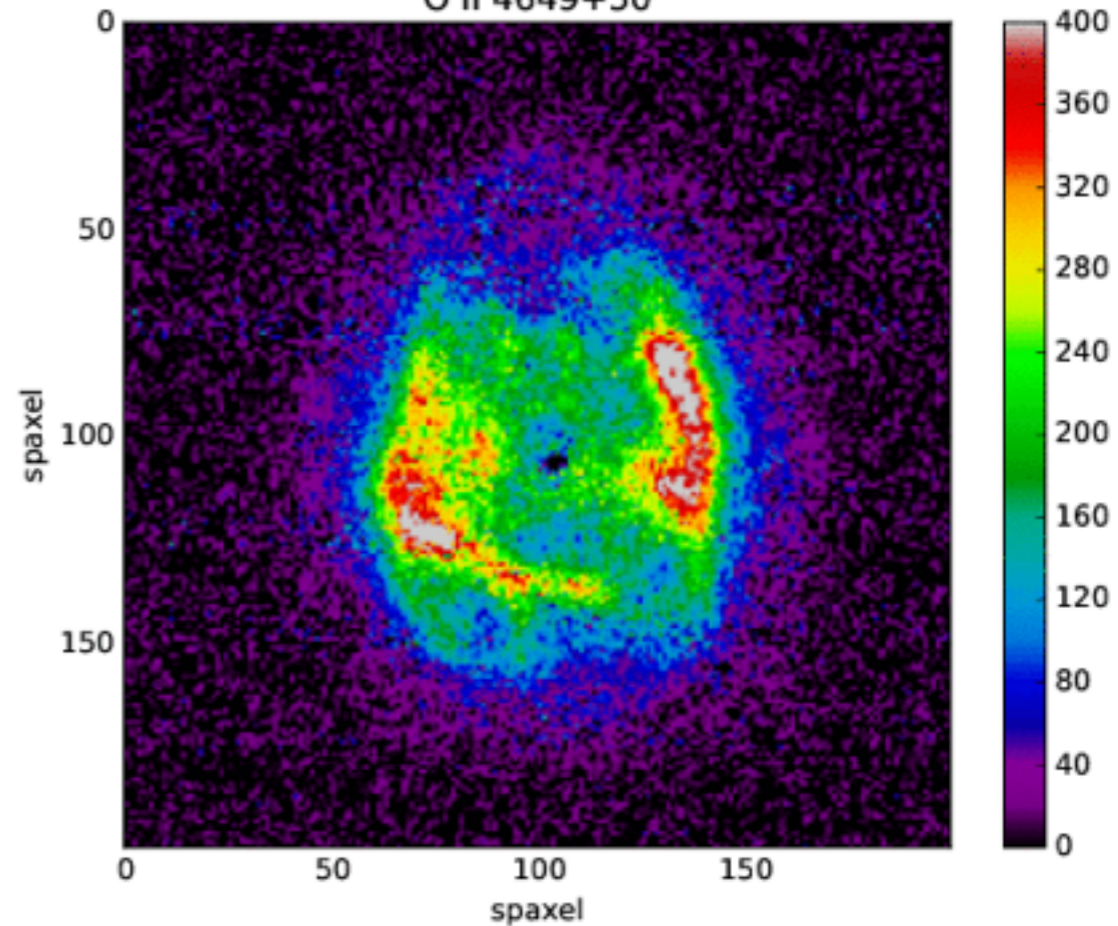
Jones et al. (2016)

García-Rojas et al. (2016)

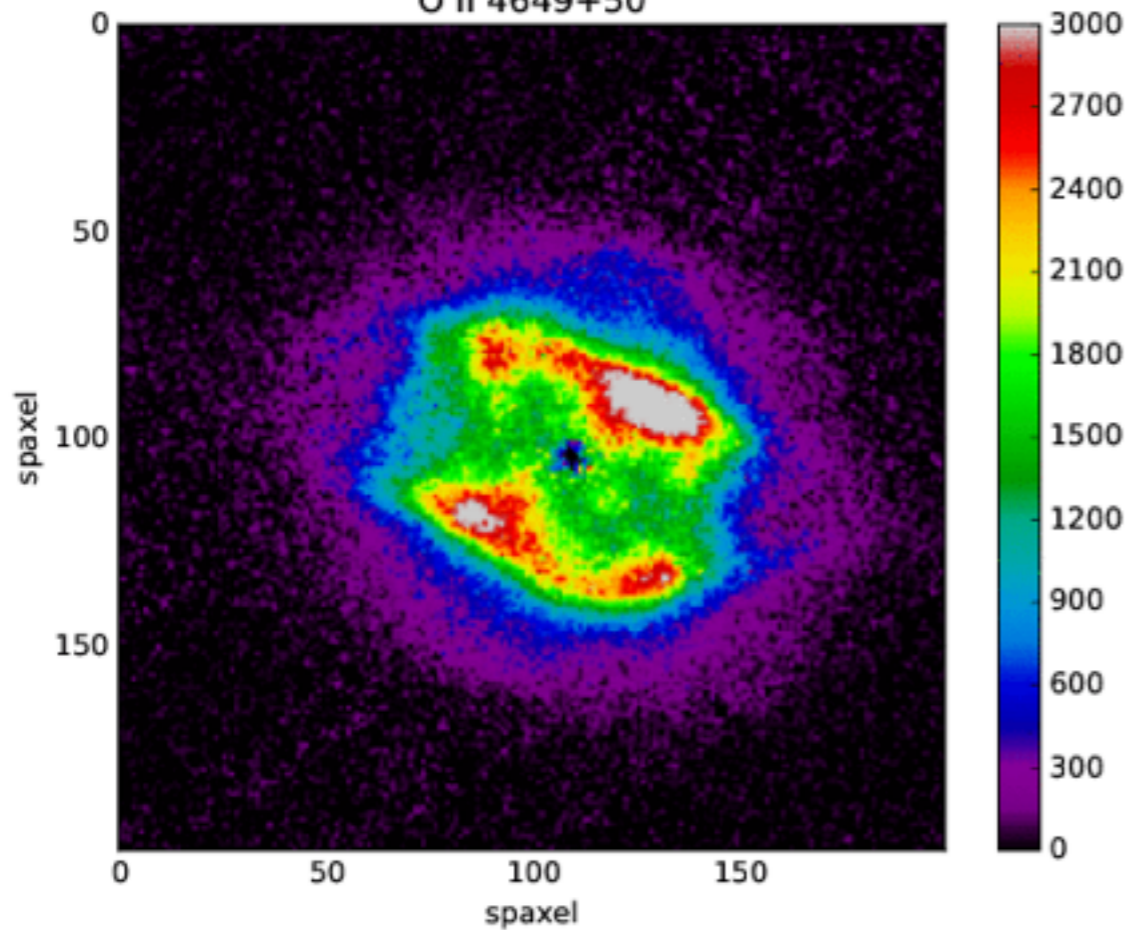
O II 4649+50



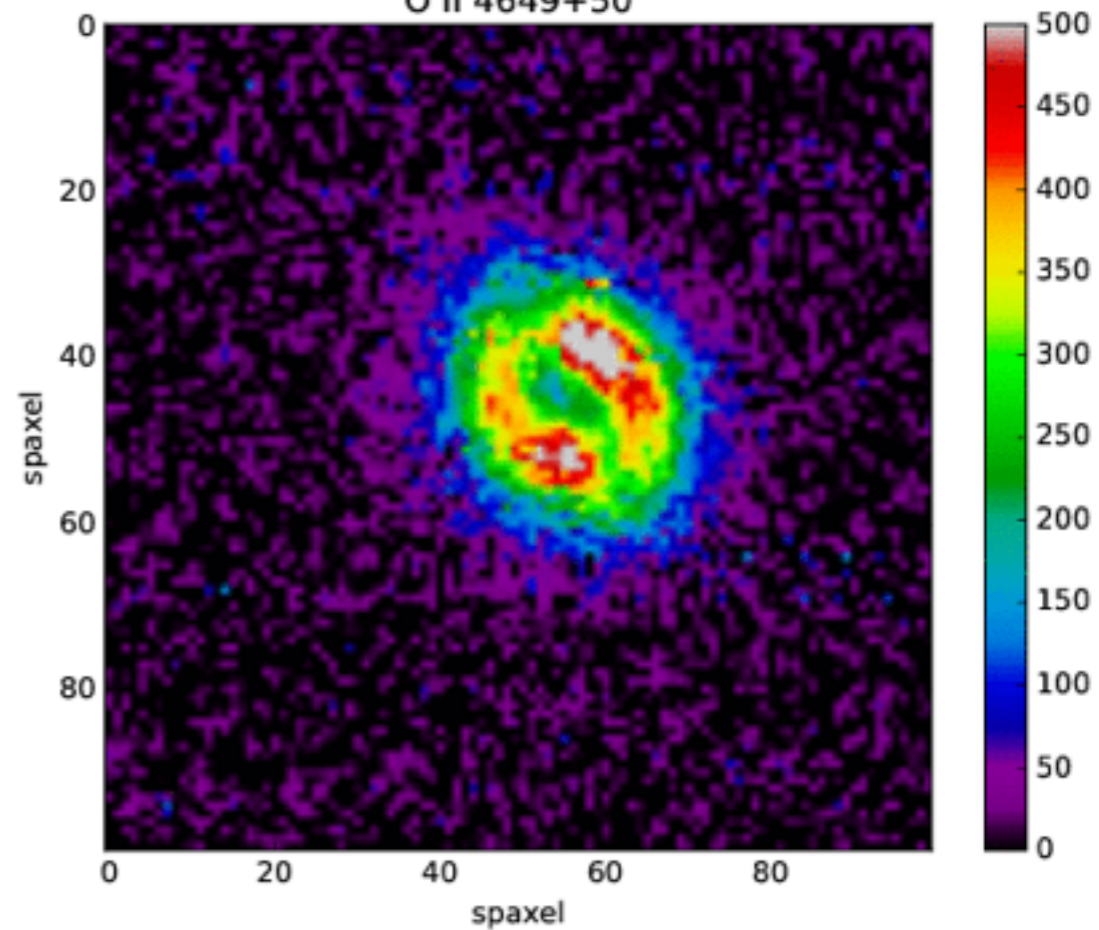
O II 4649+50



O II 4649+50



O II 4649+50





Summary

- Binaries are responsible for shaping (some/most/all) PNe
- Strong evidence for pre-CE mass transfer - and maybe repeated eruptive events?
- Good laboratories for ~~studying~~ *complicating* binary evolution
- Critical for understanding lots of other phenomena (CVs, SNe, Ba stars, dC stars...)

Planetary nebulae:
who cares?

I do!

And now so
should you!

***Boffin & Beccari
Binary Fest 2017***