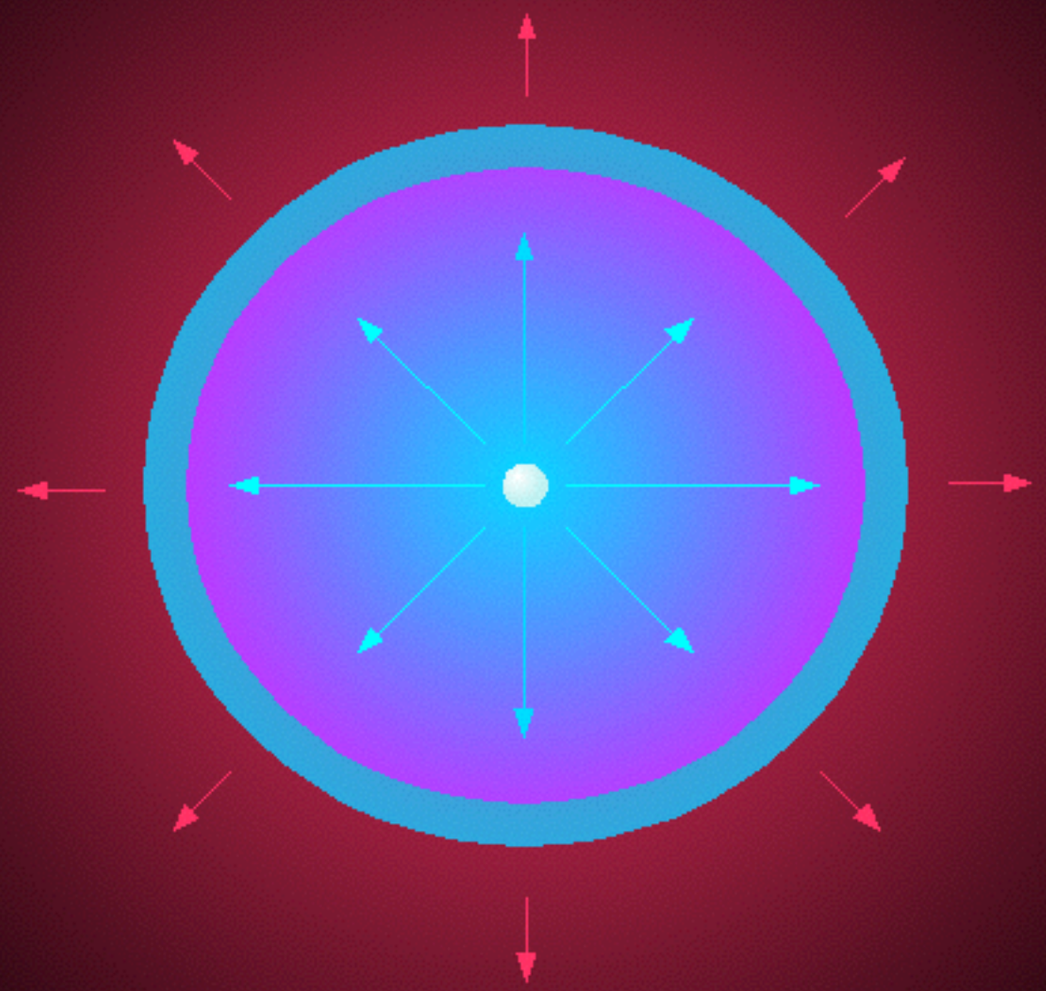
Cosmic Butterflies:
The product of tempestuous stellar marriages

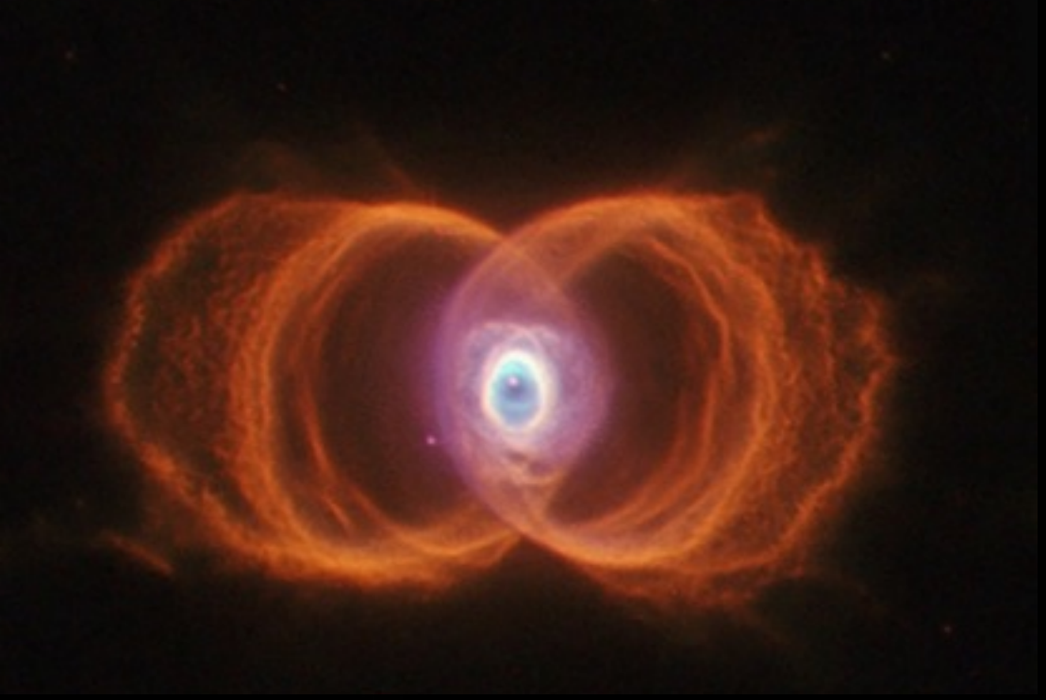
DR DAVID JONES

PLANETARY NEBULA

Ejected envelope

Ionising nucleus (pre-WD)

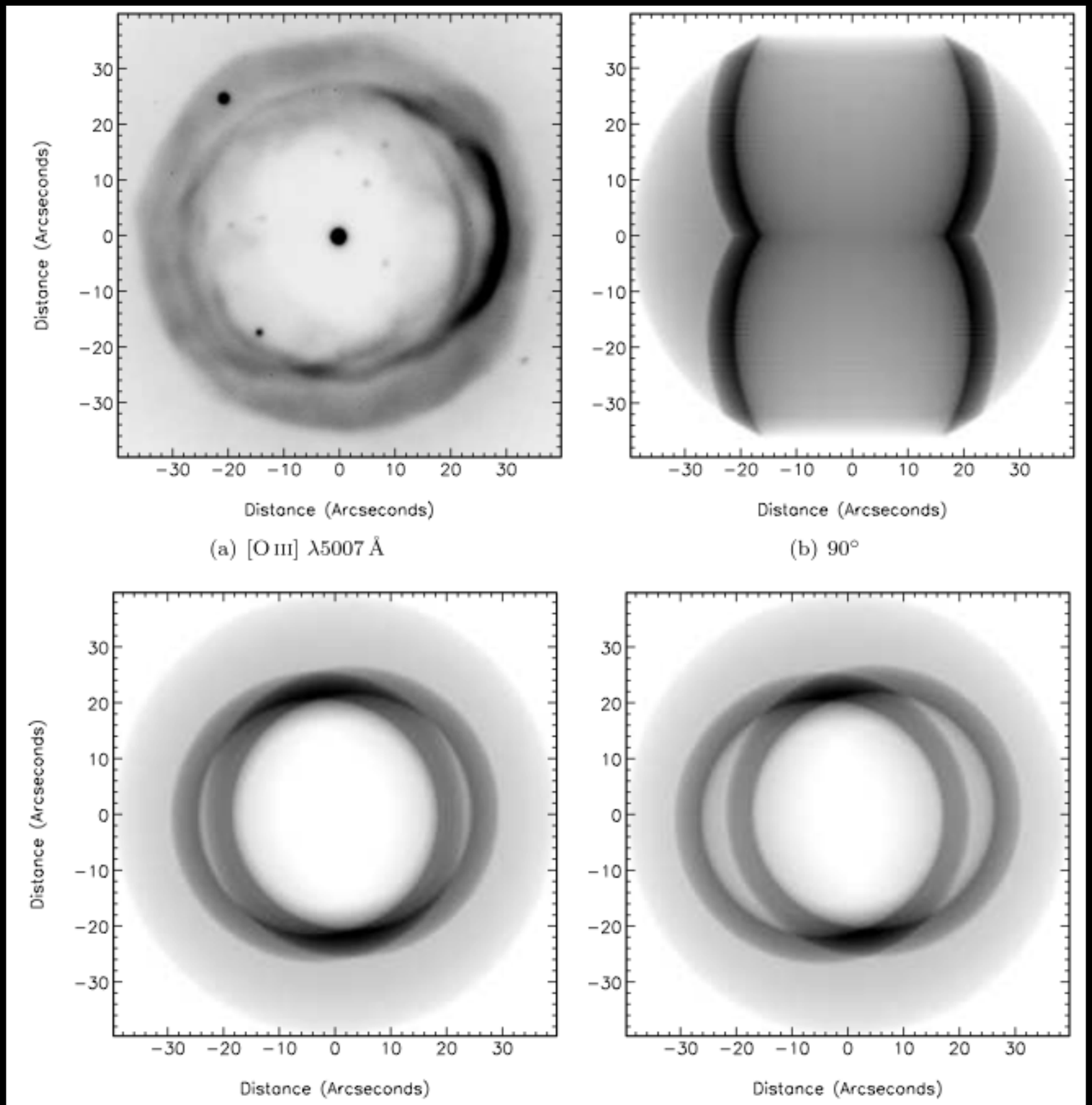




HOW DO YOU MAKE AN HOURGLASS?

- Rapid rotation?
- Magnetic fields?
- ¡Binaries!

An aside on morphologies

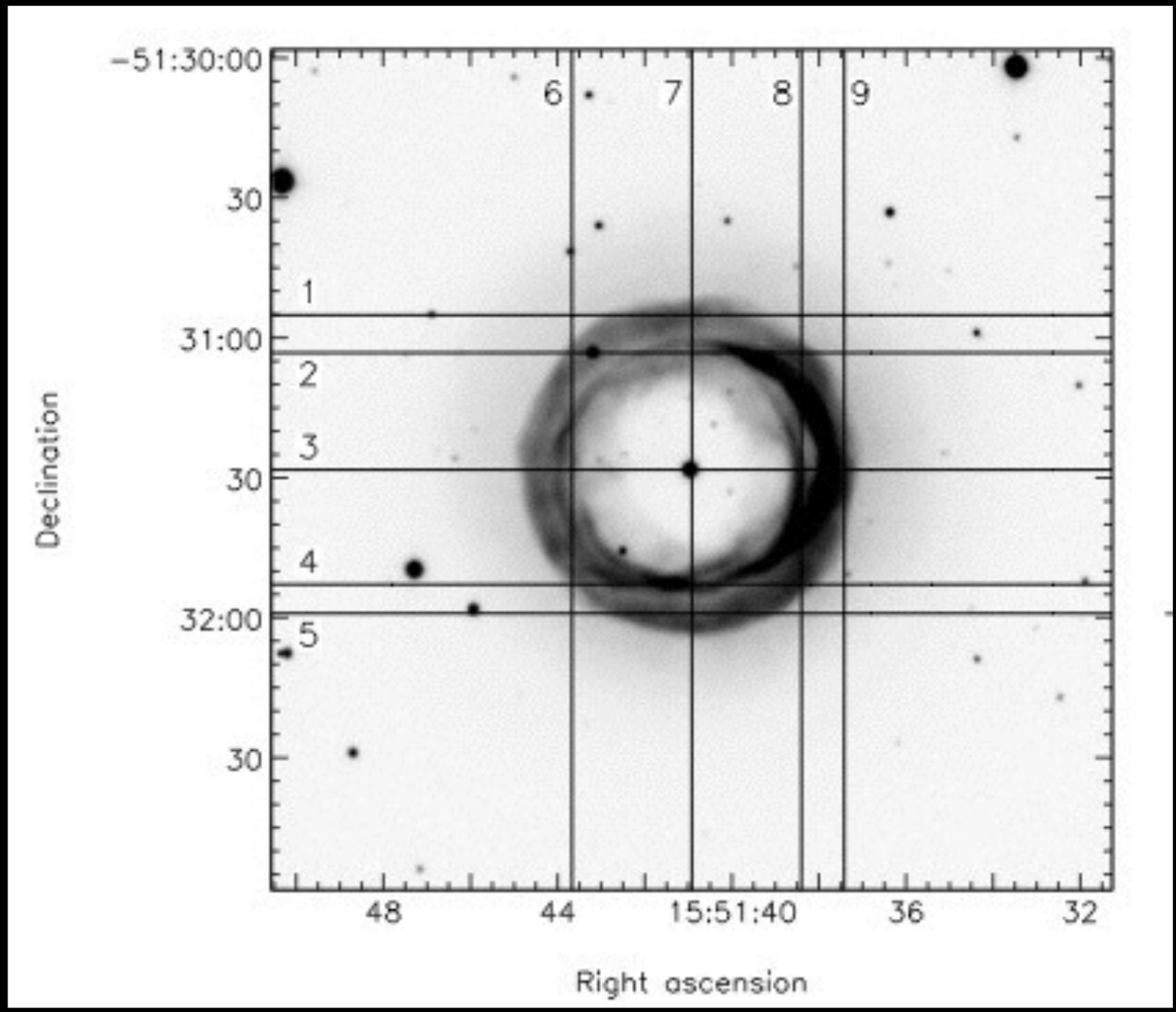


(a) [O III] λ5007 Å

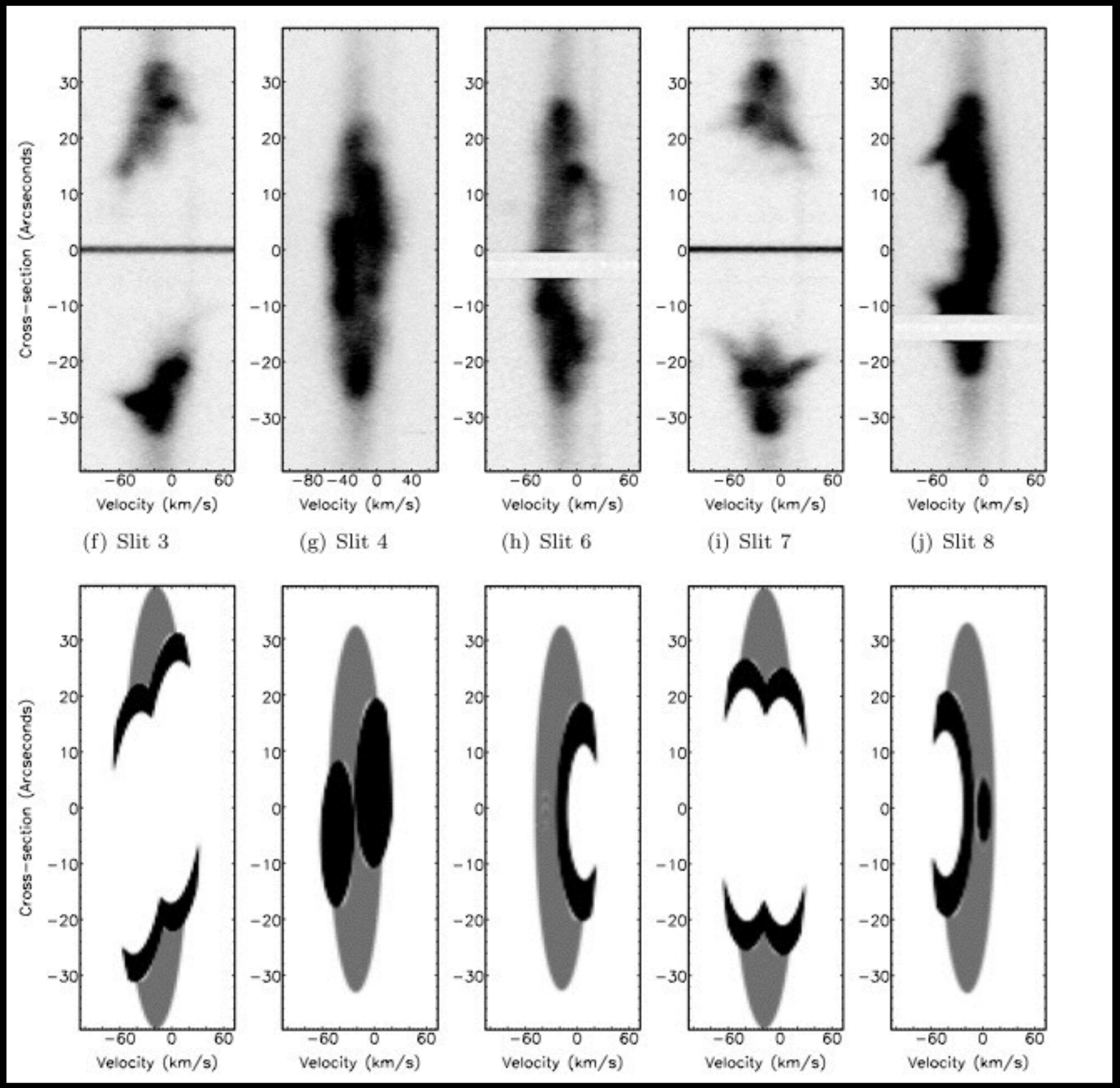
(b) 90°

(c) 10°

(d) 15°



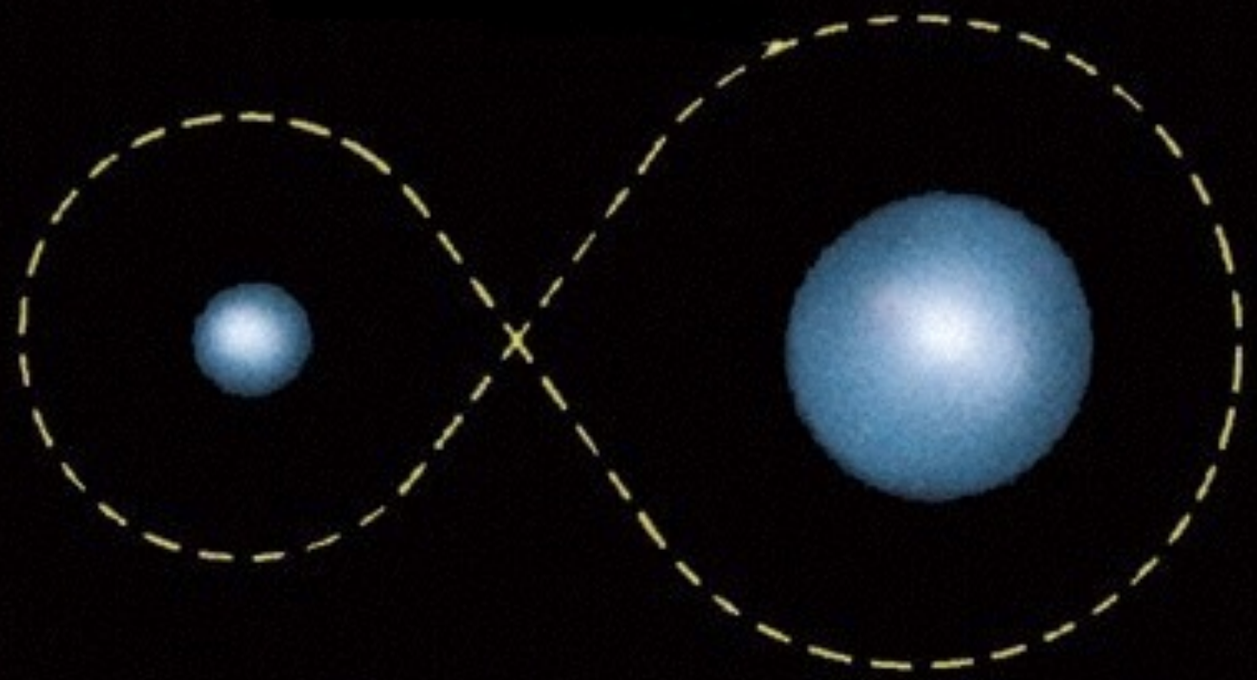
Jones et al. (2012)



Jones et al. (2012)

COMMON ENVELOPE

BINARY EVOLUTION



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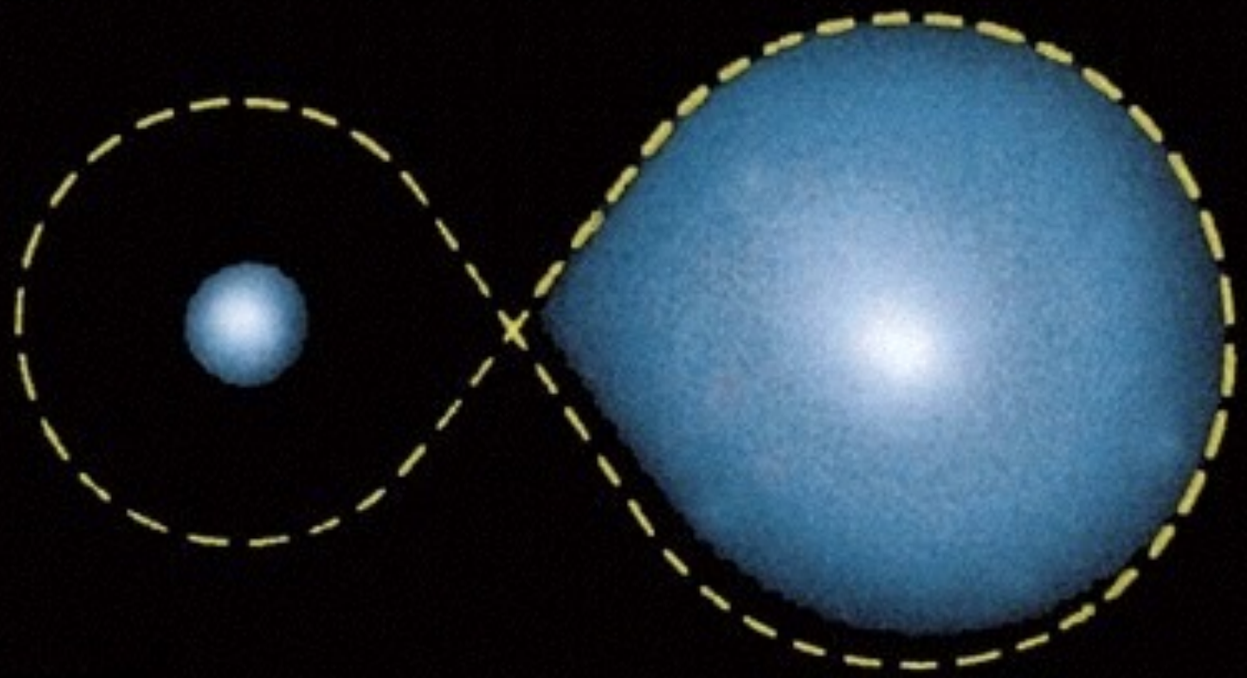

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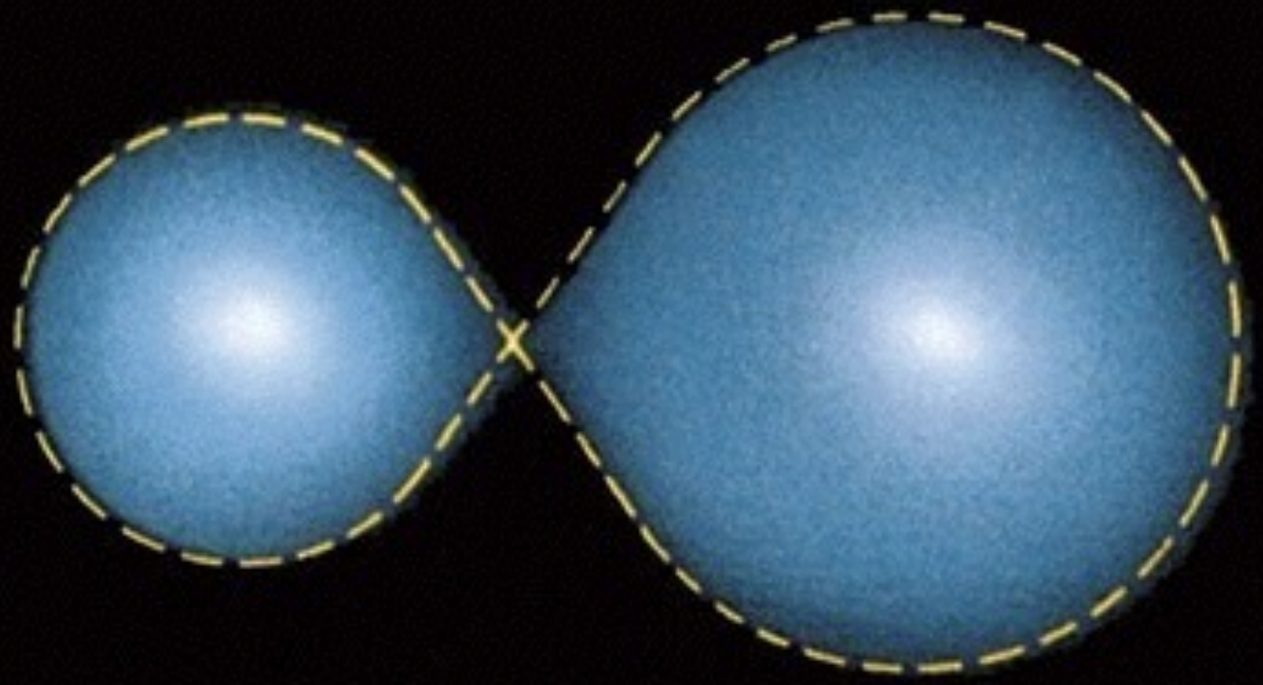

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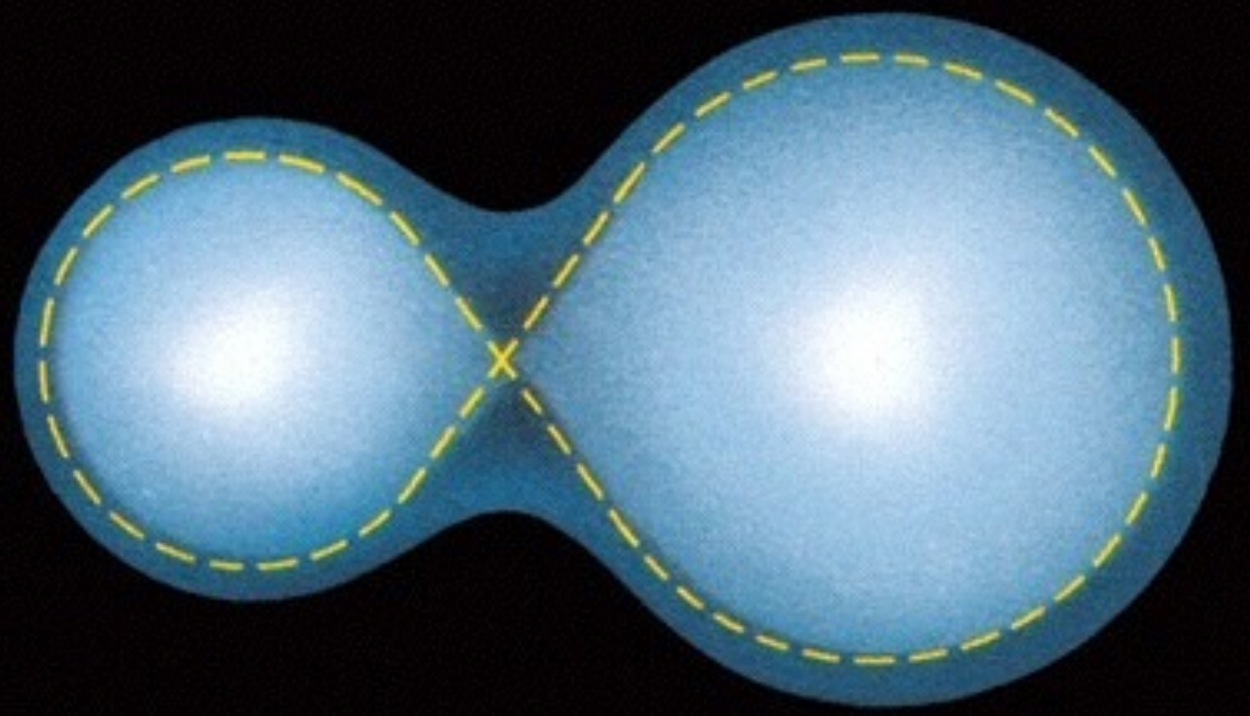
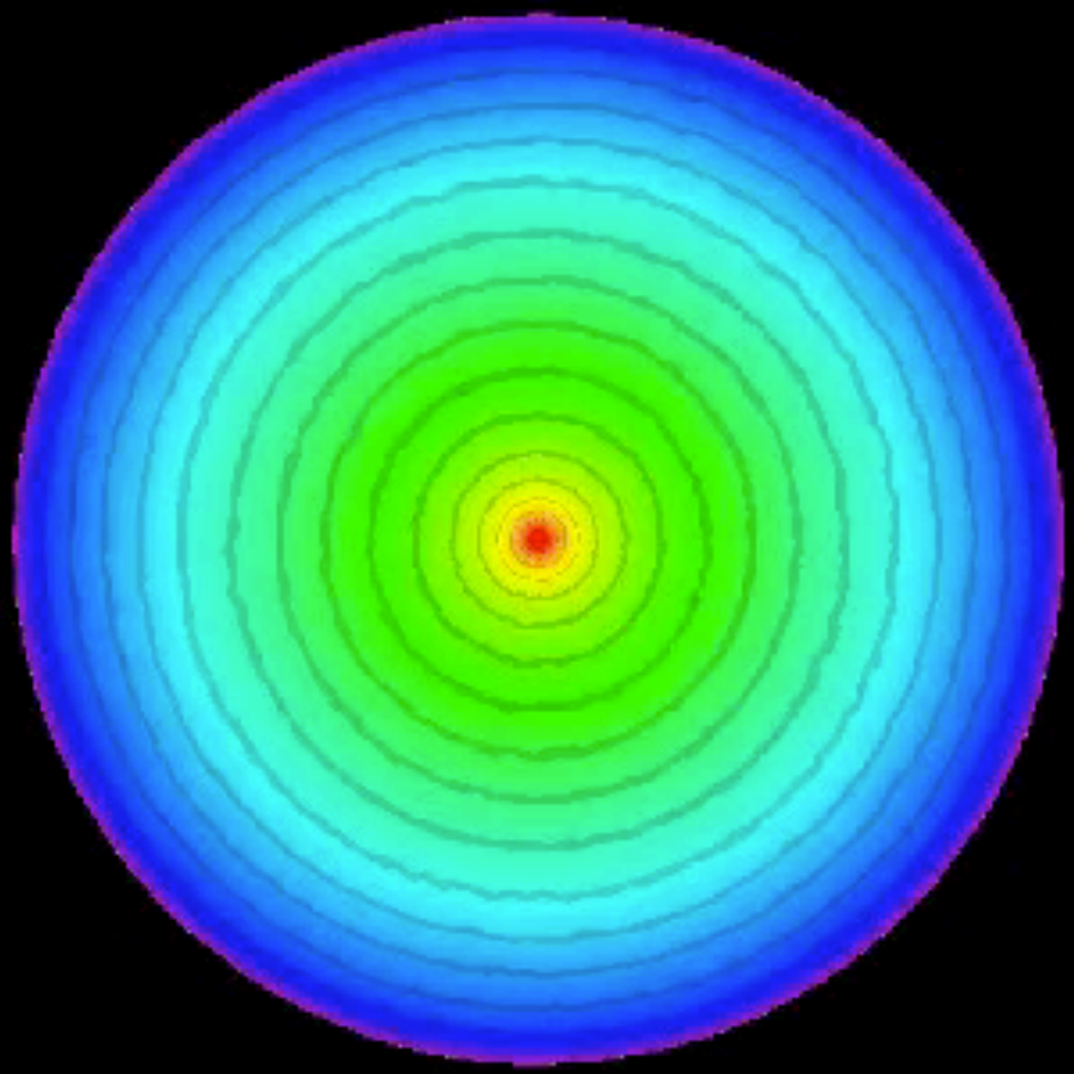
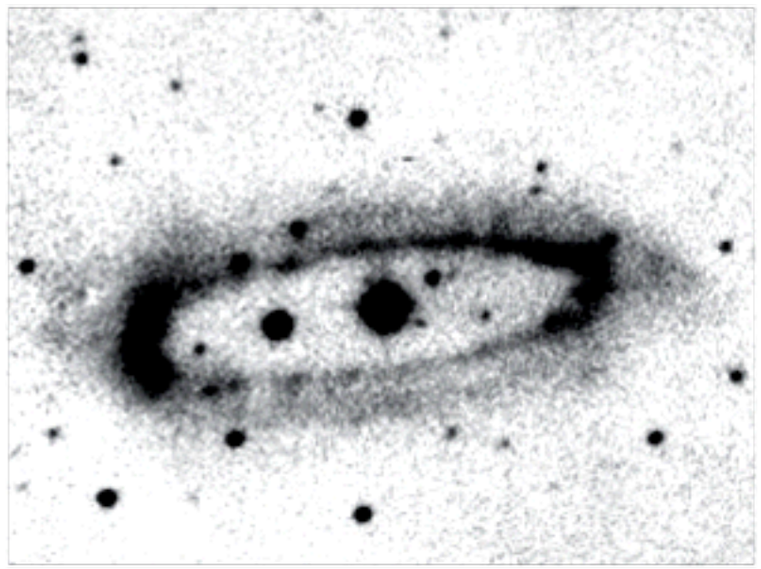




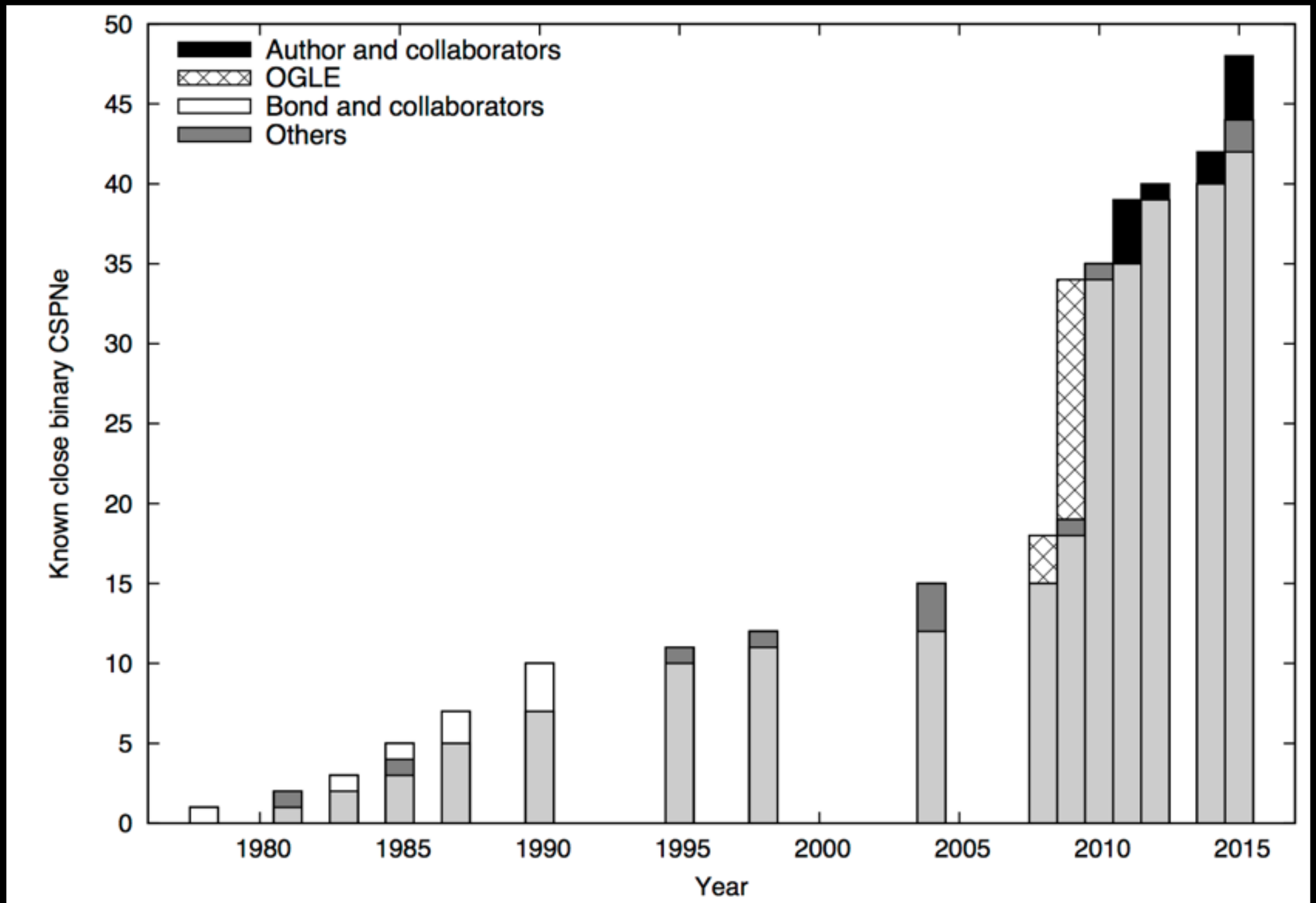
Initial separation

Passy et al. (2012)

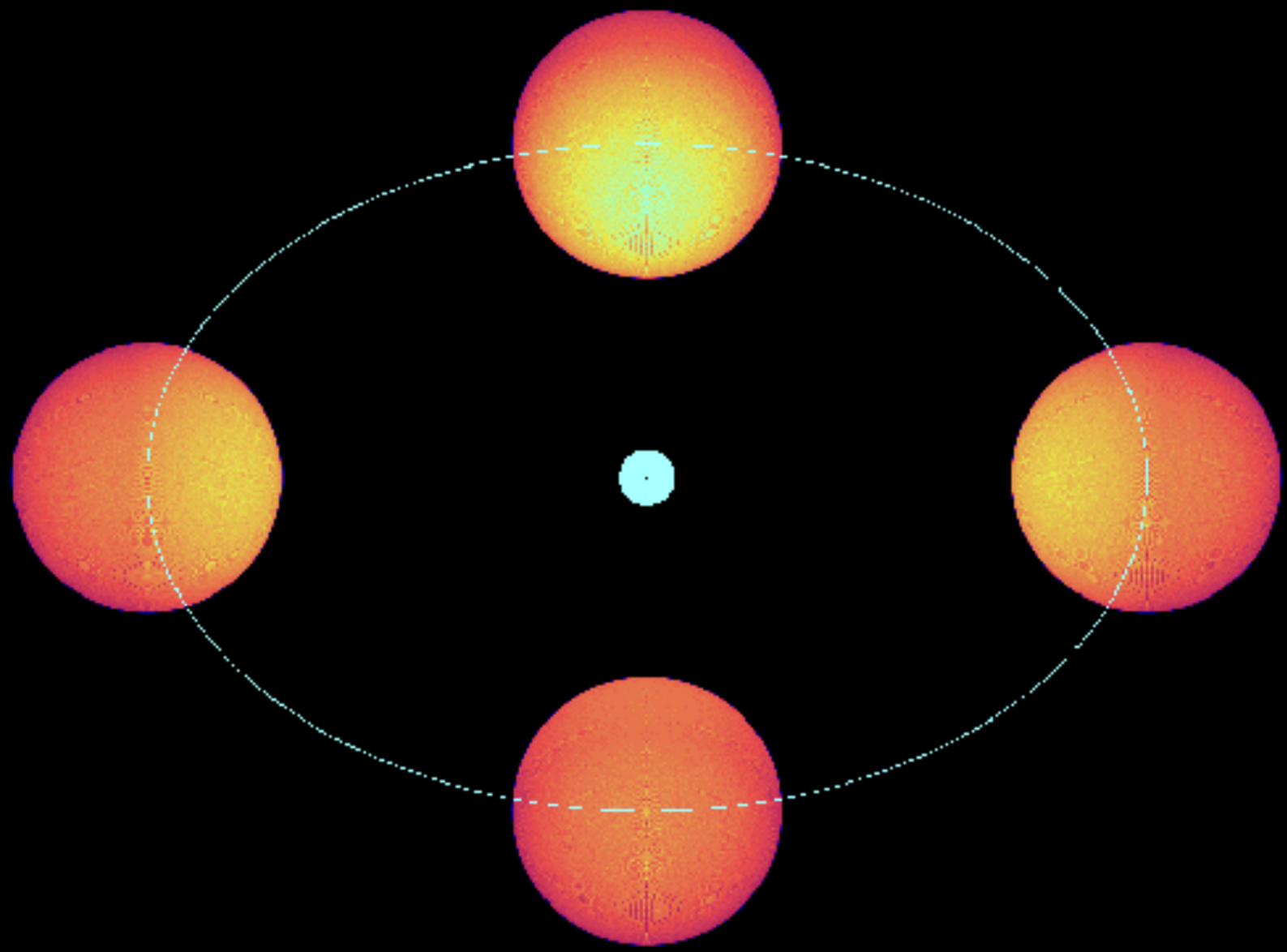
THE LORD OF THE RINGS



WHERE ARE THEY ALL THEN?



HOW DO YOU DETECT A BINARY?



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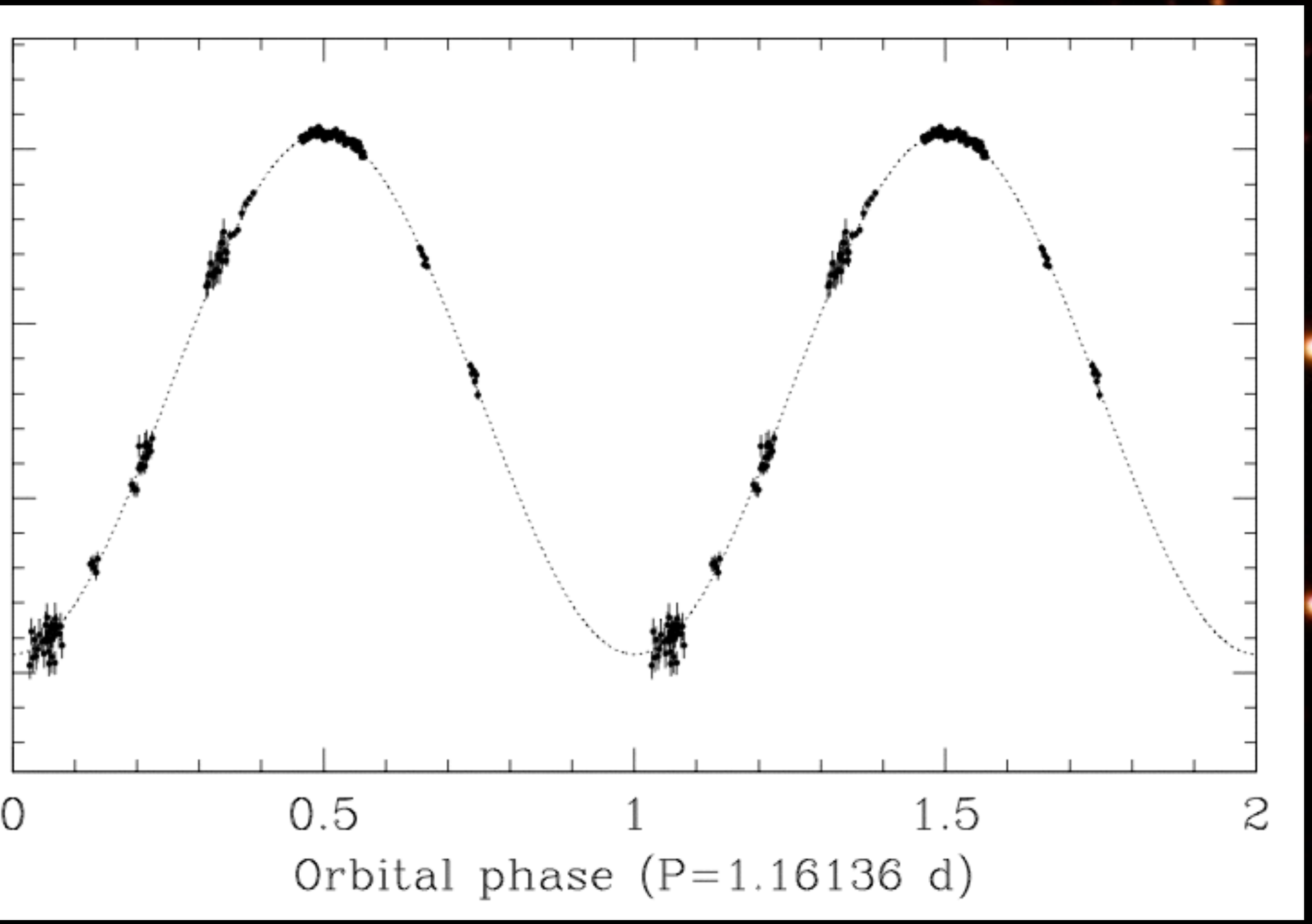
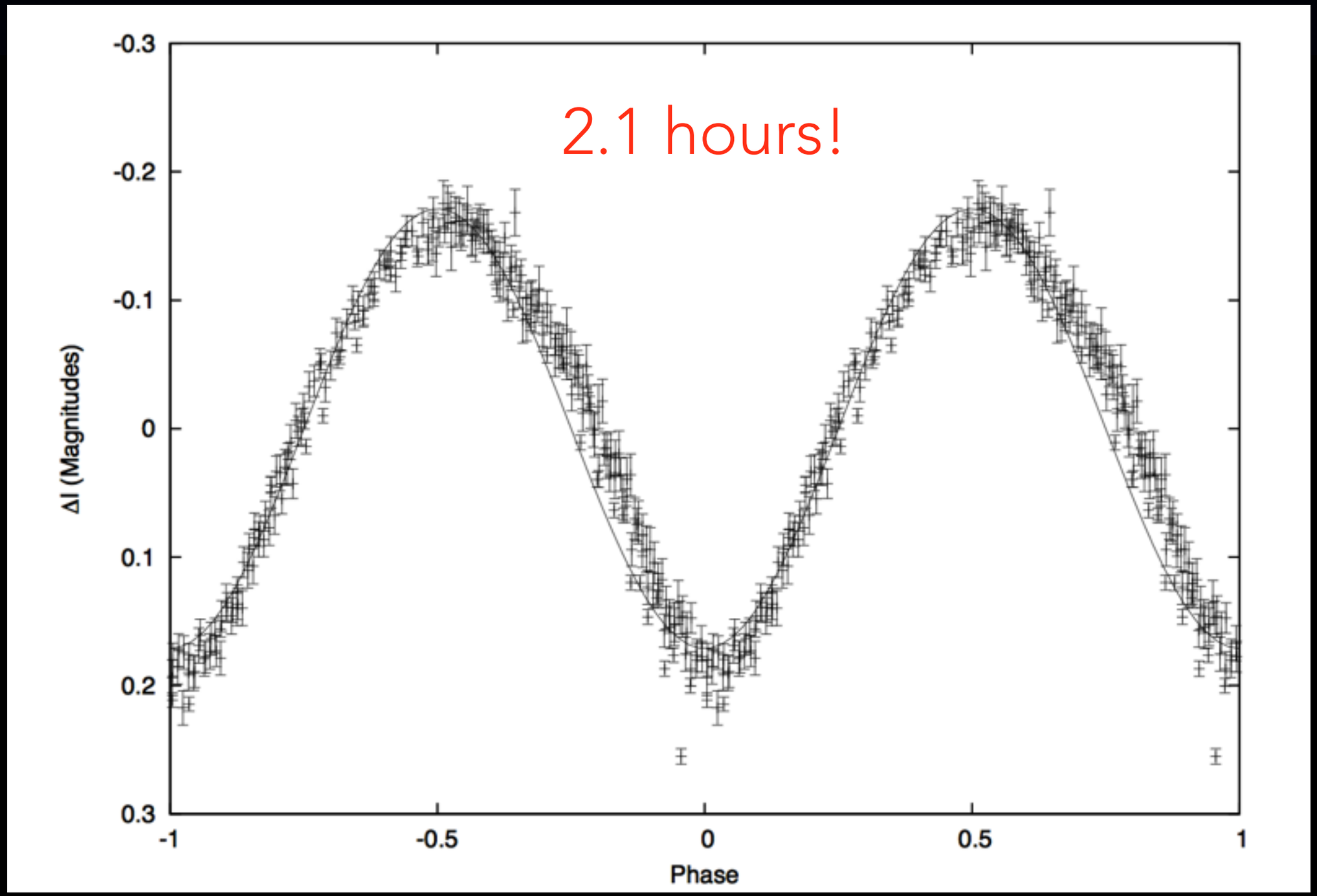


Hen 2-428: A perfect candidate

Mercator Observations



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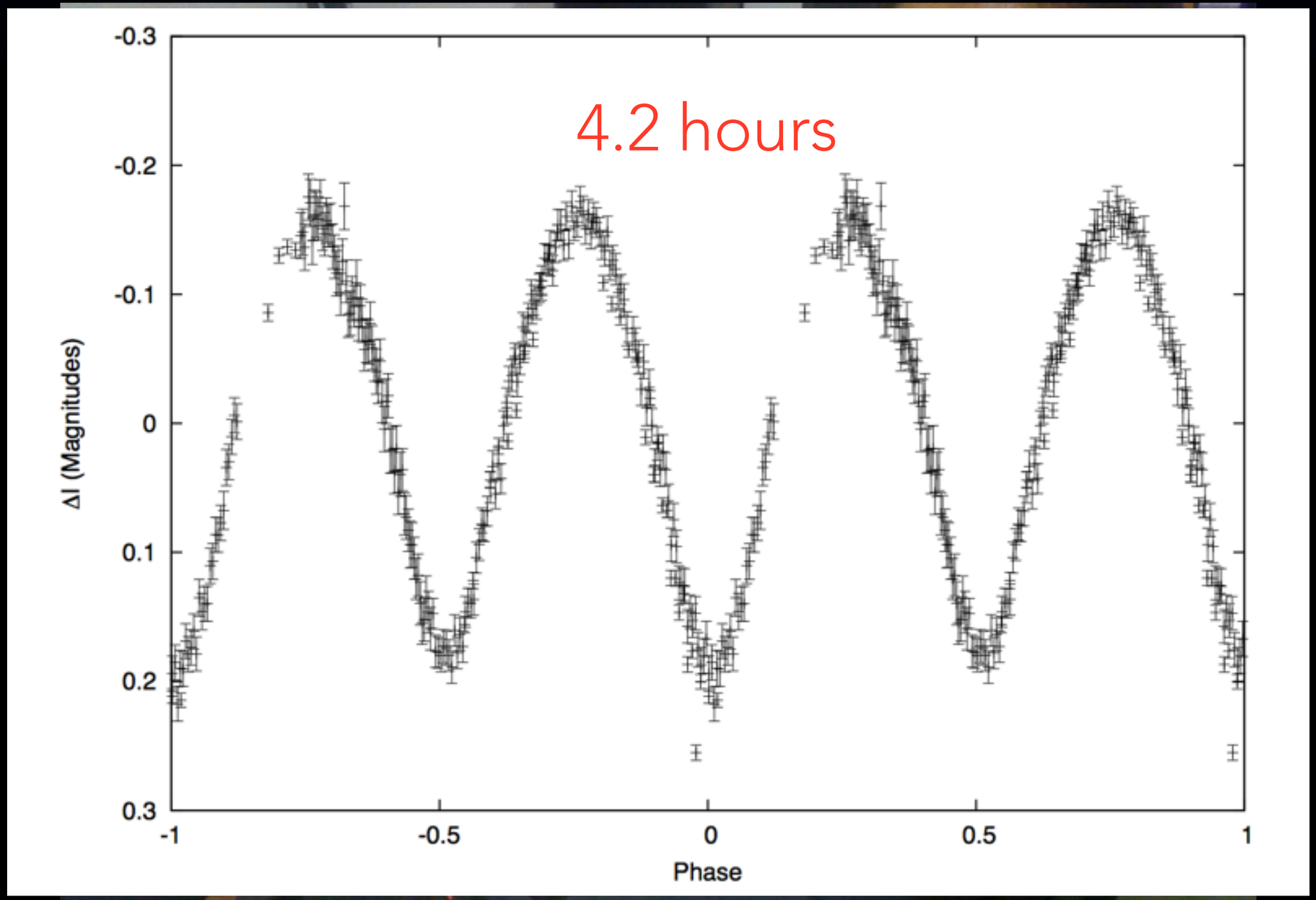
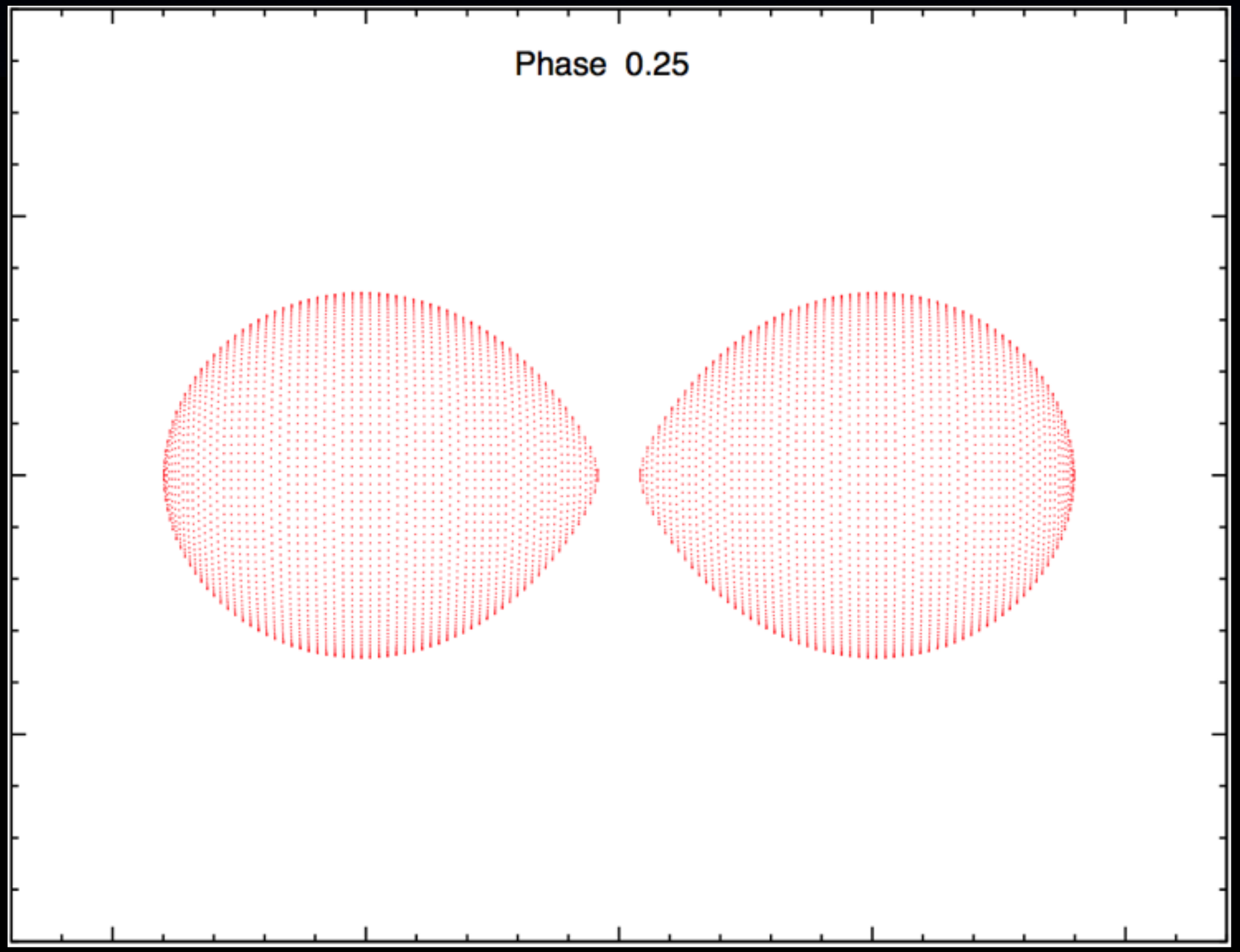


Ellipsoidal modulation (i=90°)



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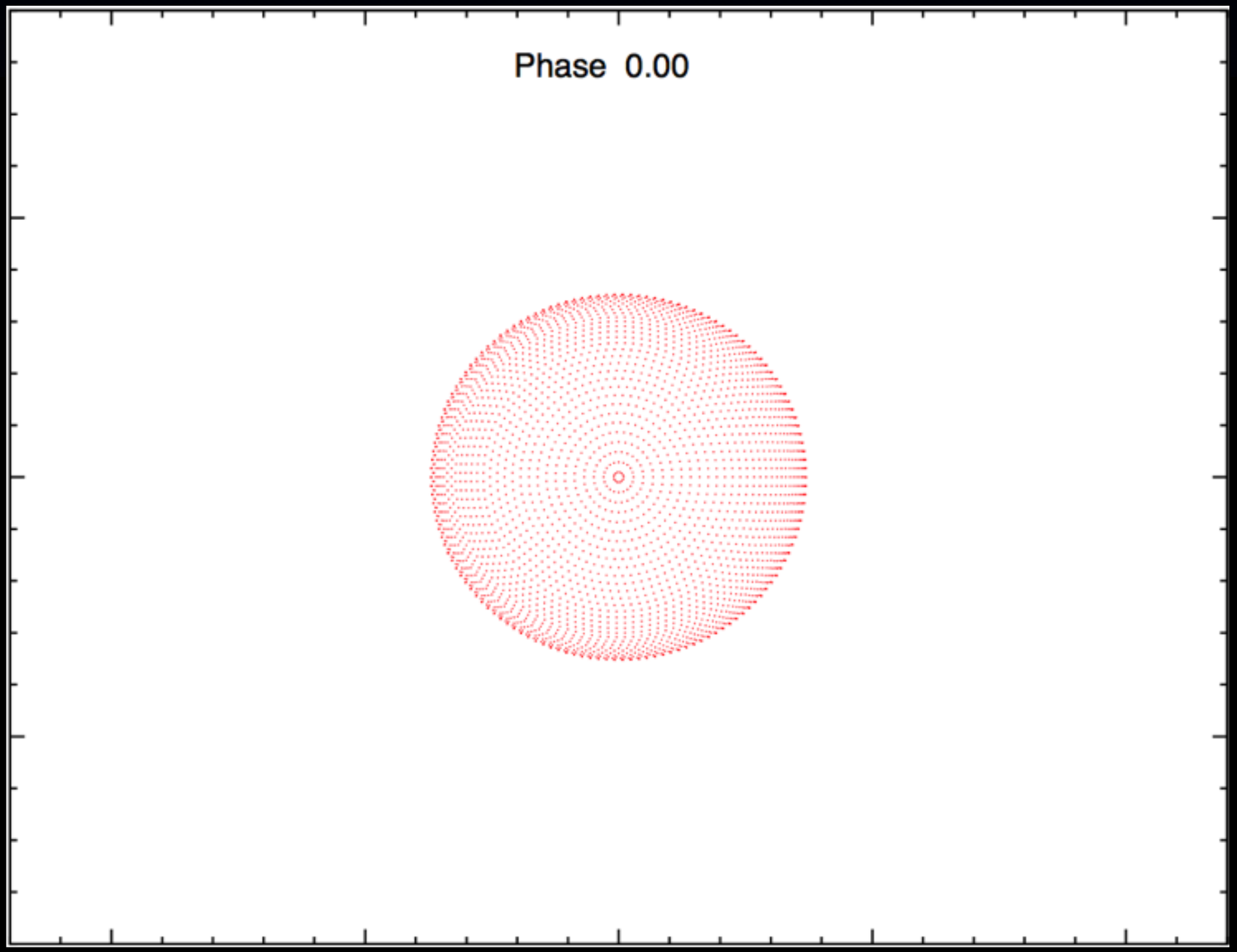
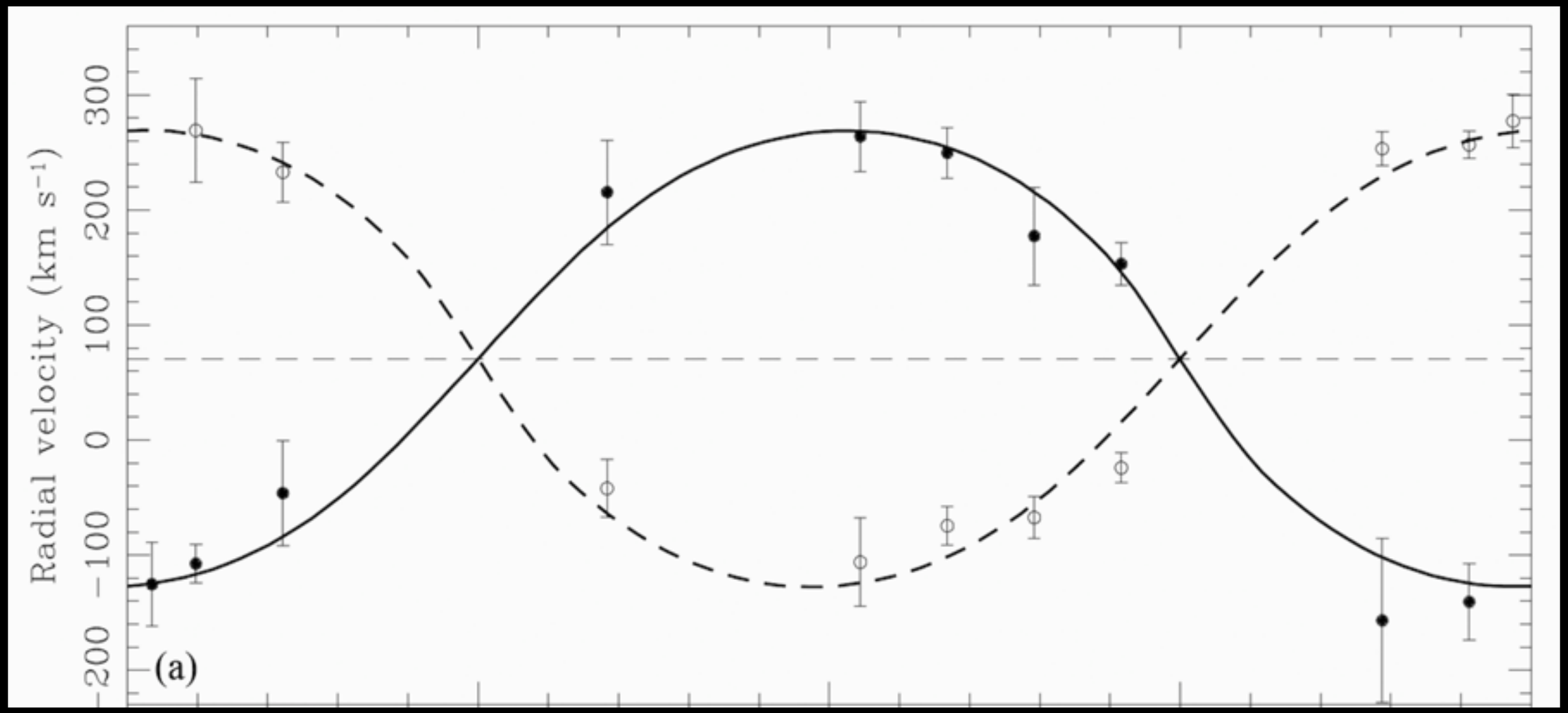
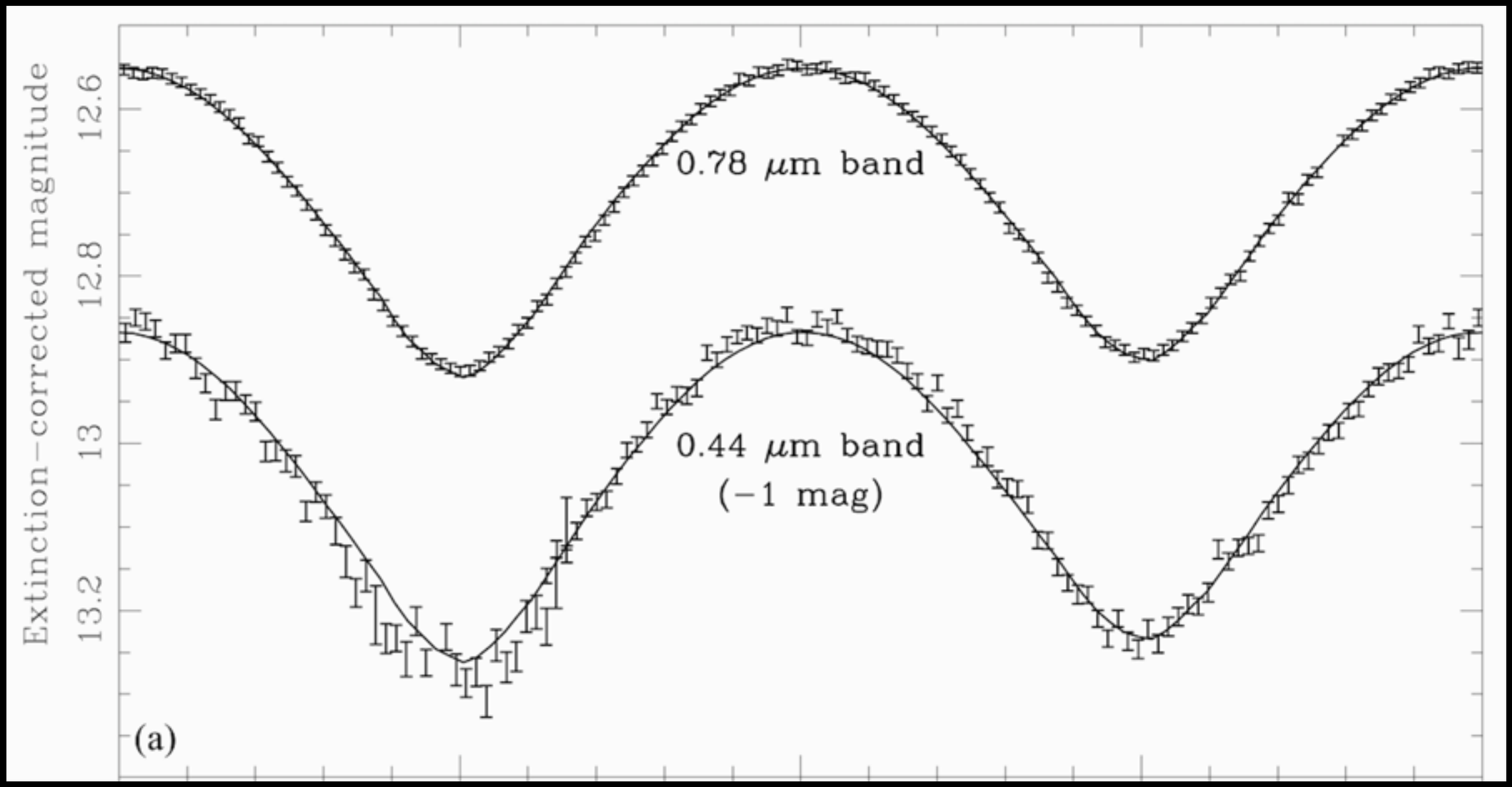


Radial Velocity analysis



Modelling in PHOEBE

PHysics Of Eclipsing BinariEs



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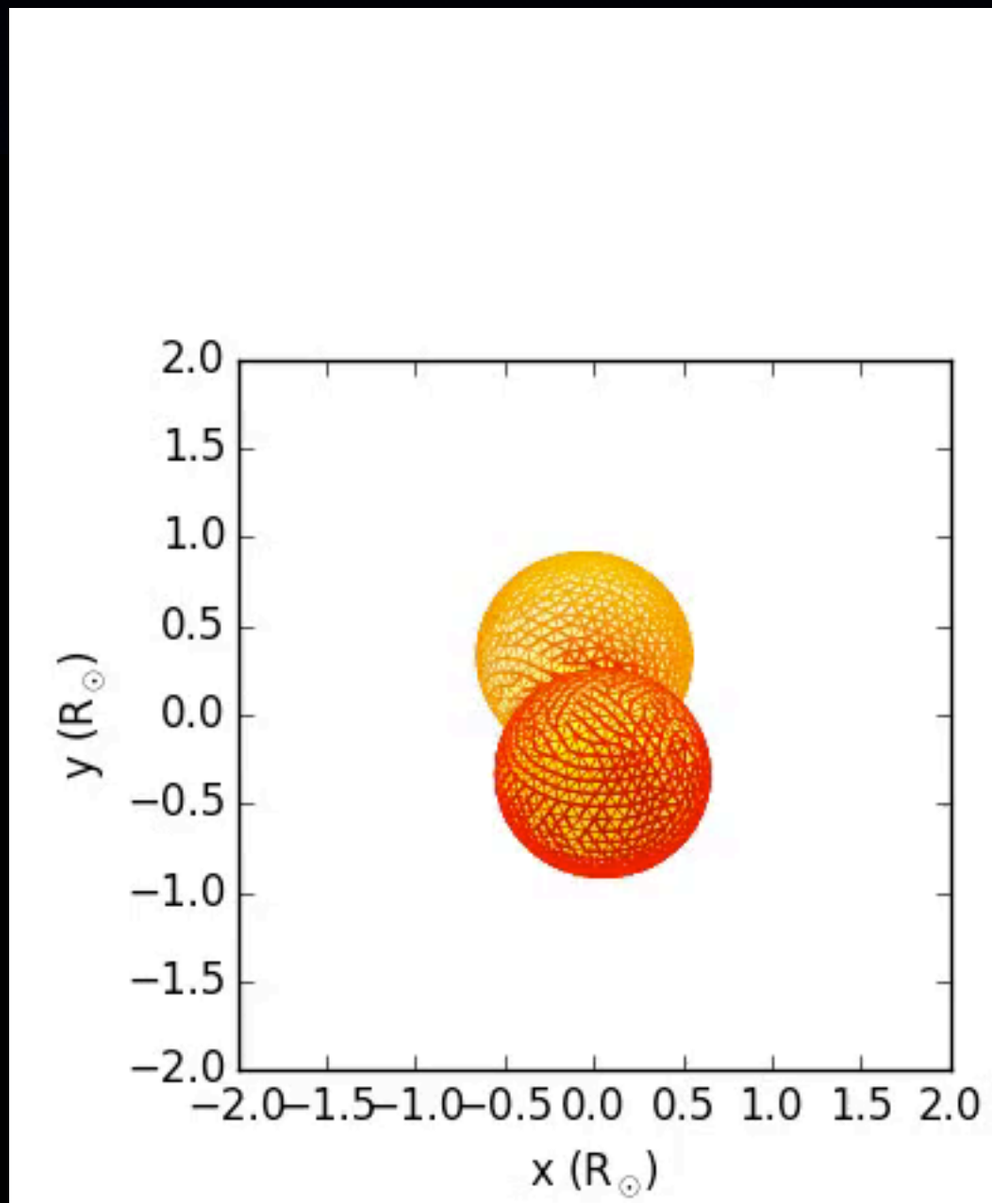
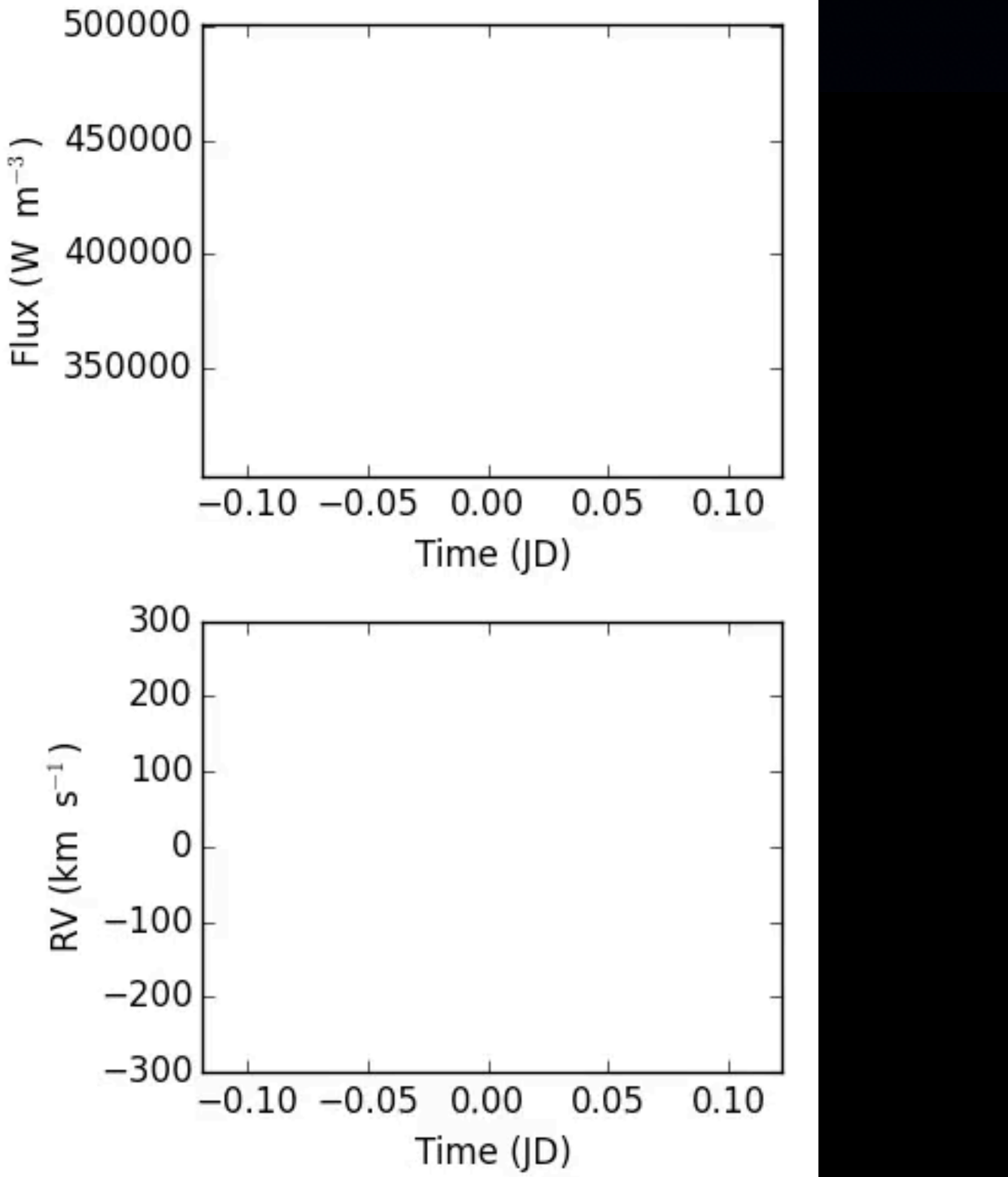




Hen 2-428

- Equal mass twins: M=0.88Msol, R=0.67Rsol, T~31kK
- Overcontact
- Binary inclination ~ Nebula inclination
- Separation = 1.59 Rsol

Hen 2-428

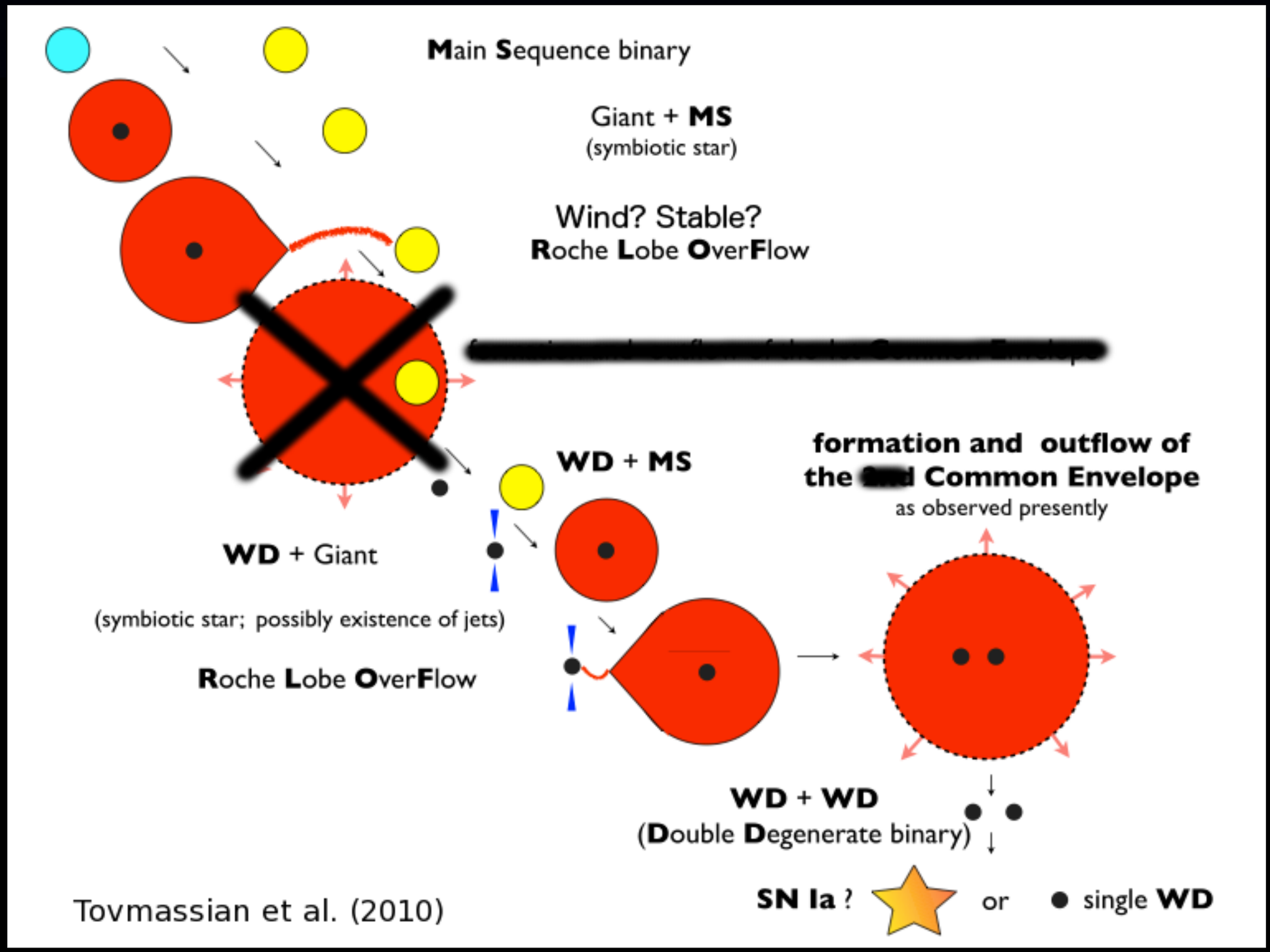
Total mass > Chandrasekhar mass (1.44 Msol)

Time to merger ~ 700Myr

=> Supernova Type Ia progenitor!

www.eso.org

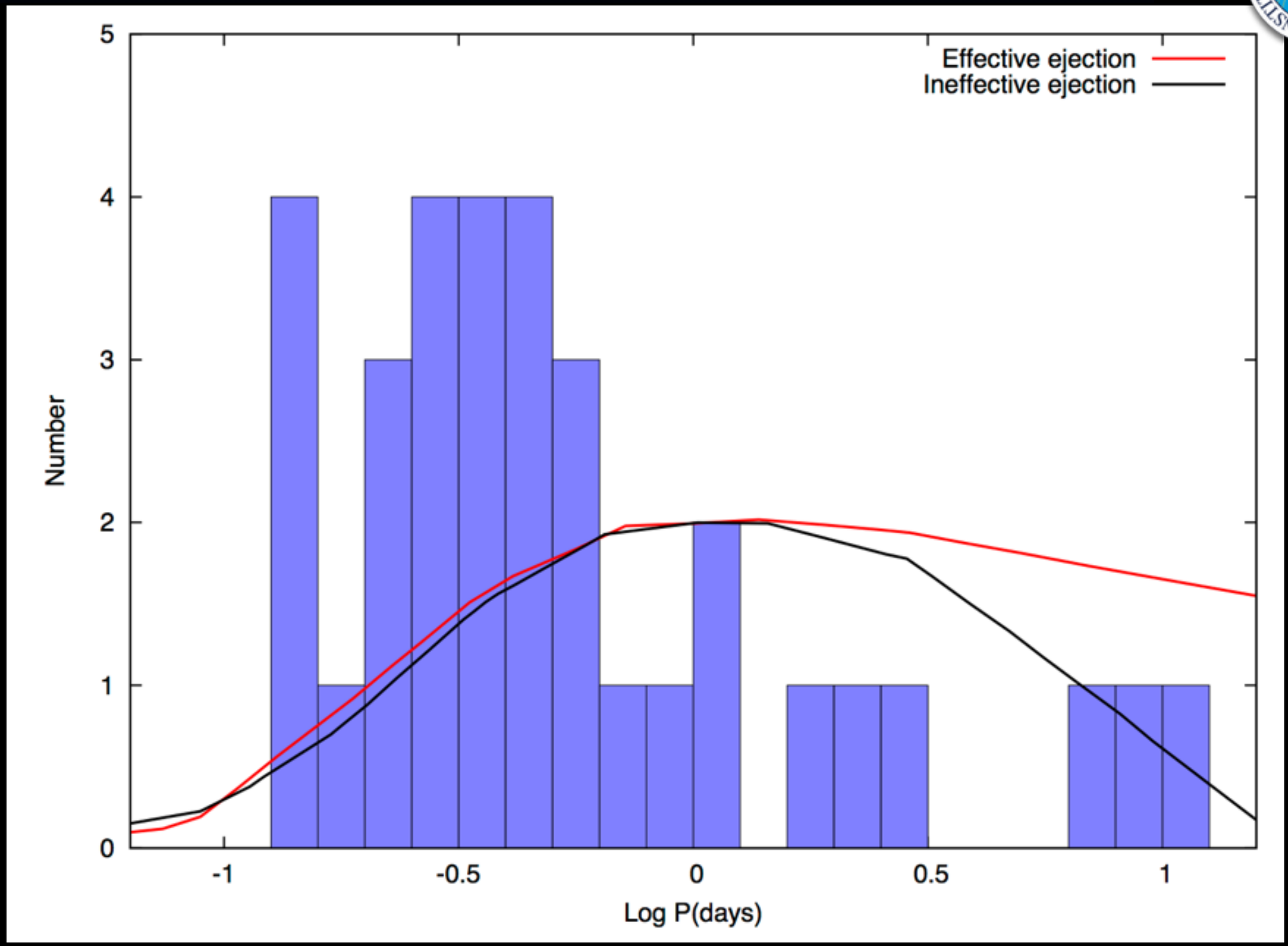
History?


Main Sequence binary
Giant + MS
(symbiotic star)
Wind? Stable?
Roche Lobe OverFlow
WD + MS
formation and outflow of
Common Envelope
as observed presently
WD + Giant
(symbiotic star; possibly existence of jets)
Roche Lobe OverFlow
WD + WD
(Double Degenerate binary)
SN Ia ?
or
single WD
Tovmassian et al. (2010)

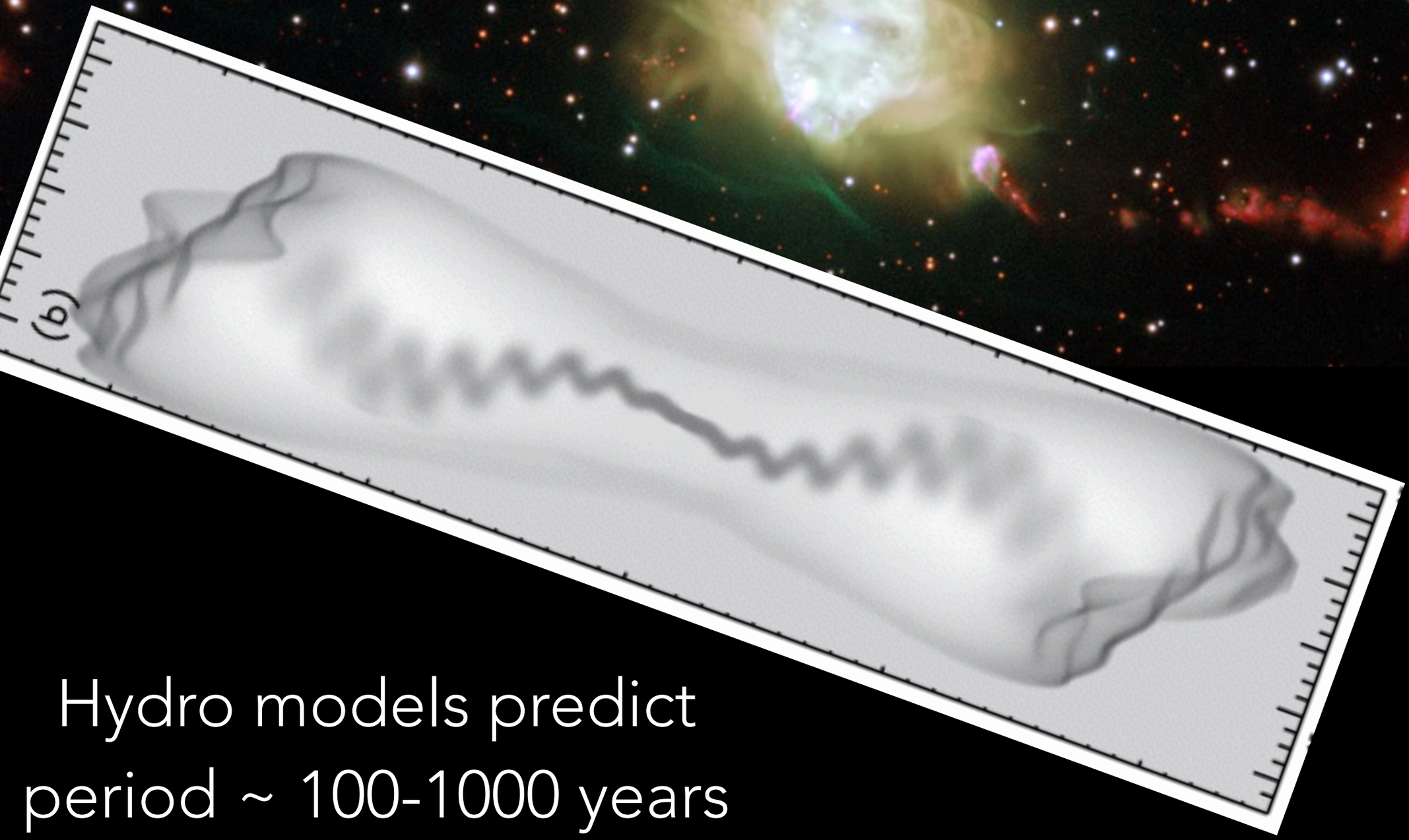
Double-degenerates should be rare!

but they aren’t …

Theorists have big problems…



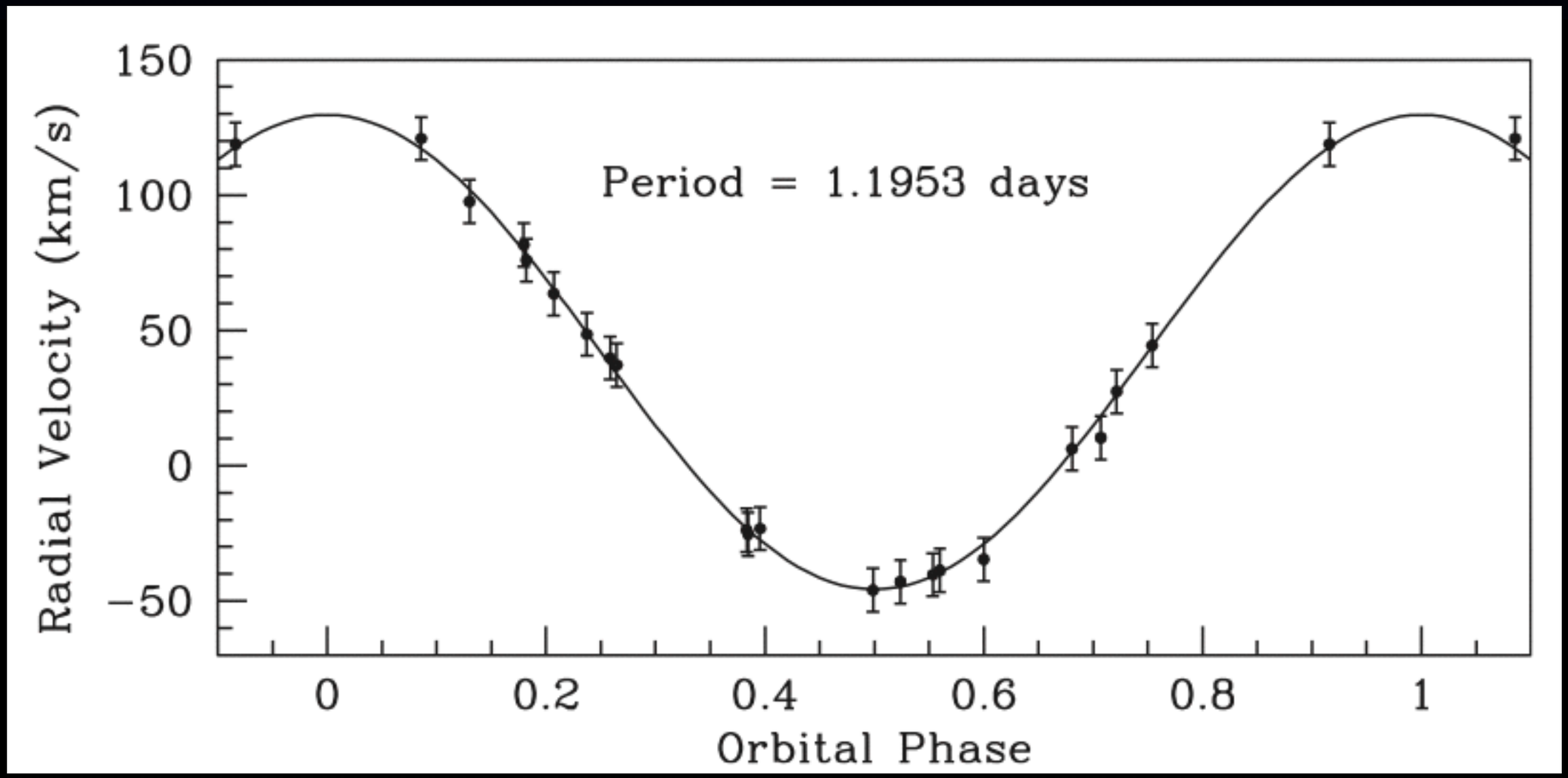
Han et al. (1995)



Hydro models predict
period ~ 100-1000 years

Raga et al. (2009)

Much shorter period!



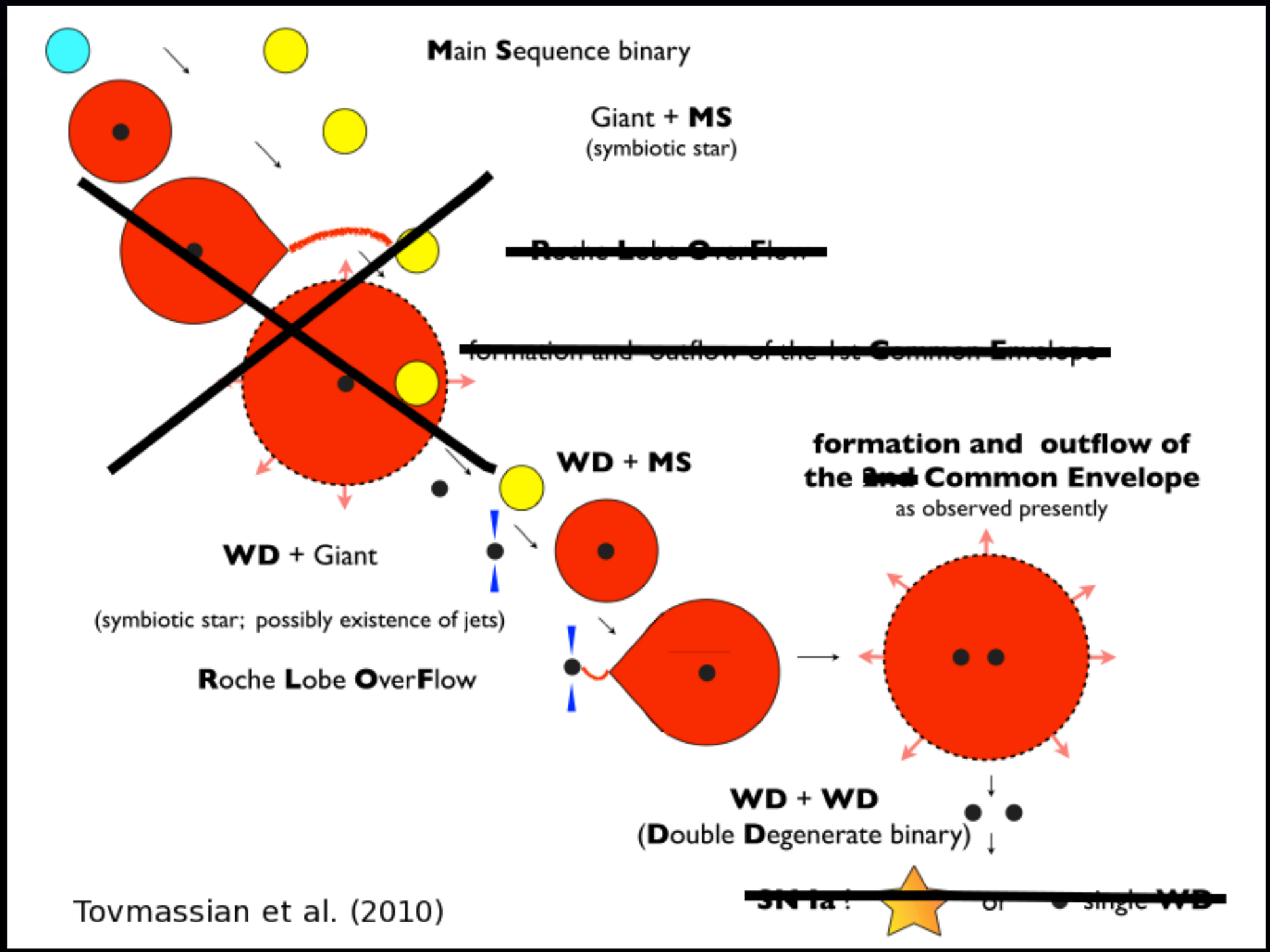
Boffin et al. (2012)

Jets were formed before orbital shrinkage!

PN	Neb. age (yrs)	Jet age (yrs)
Fg 1	2000	2500-7000
Necklace	1100	2400
Ethos 1	900	1800
Abell 63	3500	5200

Jones (2014)

History?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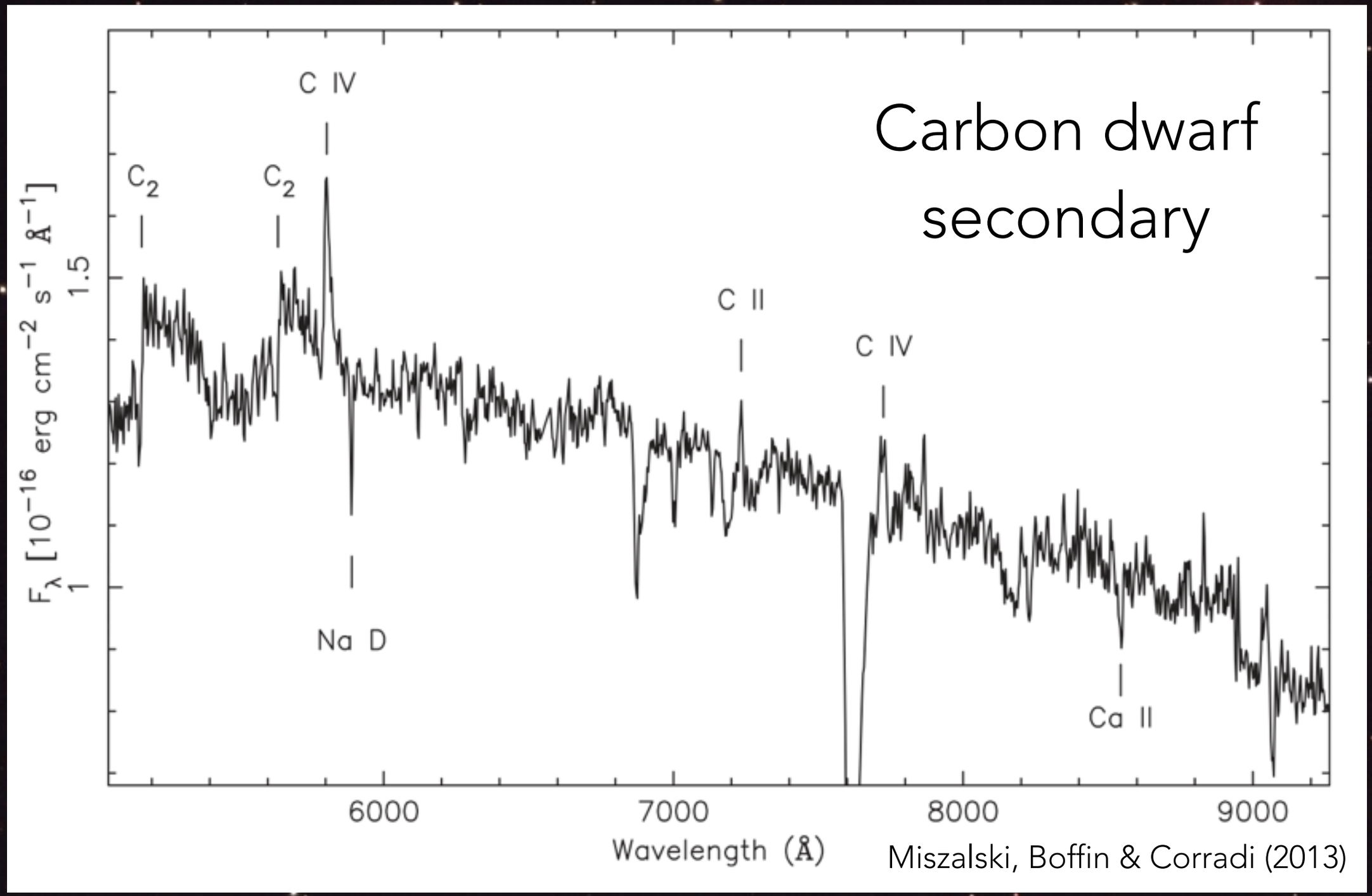
Younger jets = mass transfer

Younger jets = mass transfer



Miszalski, Boffin & Corradi (2013)

Inflated secondaries

More evidence of mass transfer!

Abell 46

Hen 2-155

Every

well constrained main-sequence secondary is inflated!

Jones et al. (2015a)

Nebular abundances

Abundances calculated from ORLs and CELs are discrepant, on average by a factor of 2-5

Some show much higher *adf*s, most of those are in binaries

Corradi et al. (2015)
Jones et al. (2015b)

PN	adf	Period (days)
A30	>>100	?
A46	120	0.47
A58	89	?
Hf 2-2	70	0.40
Ou 5	56	0.36
NGC 6778	18	0.15
Hen 2-161	11	~1
A63	8	0.46
Hen 2-155	6	0.15

“Real” planetary nebulae?

- Abundance are actually more nova-like
- High *adf*s imply a second metal-rich component to the nebula
  - Seems to be centrally concentrated
- Low nebular masses

Corradi et al. (2015)
Jones et al. (2015b)
Bear & Soker (2015)

Summary

- Binaries are responsible for shaping (some/most/all) PNe
- Strong evidence for pre-CE mass transfer
- Good laboratories for studying binary evolution
- Critical for understanding lots of other phenomena