Do we fully understand how

Cataclysmic Variables

form and evolve?

Diogo Belloni

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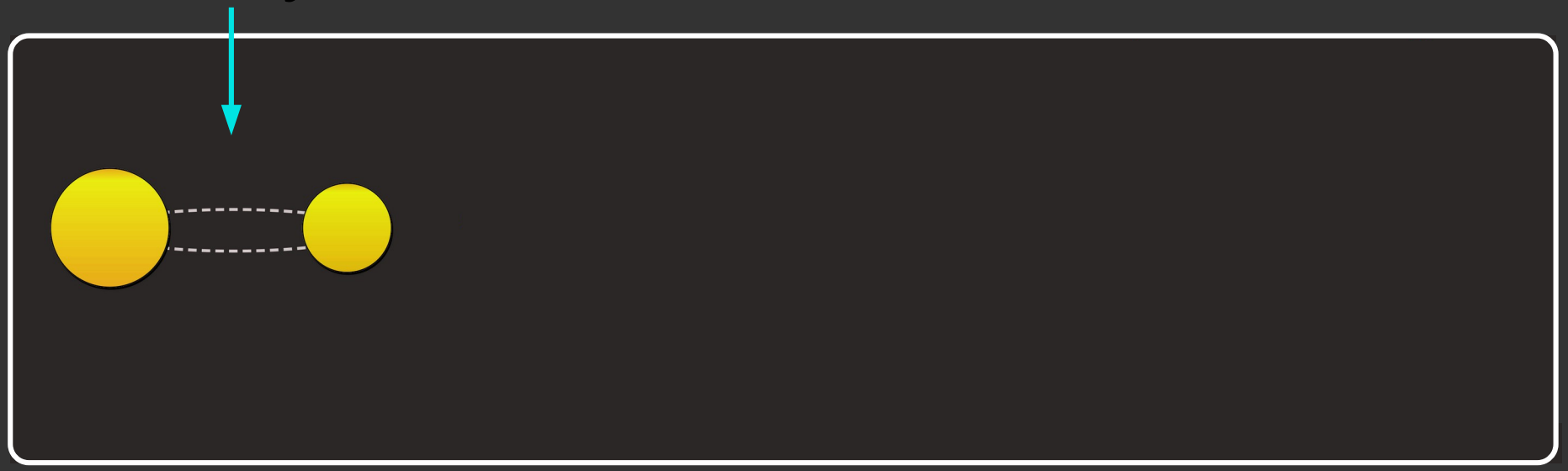
Científico y Tecnológico

CV FORMATION

CV FORMATION

main sequence

binary



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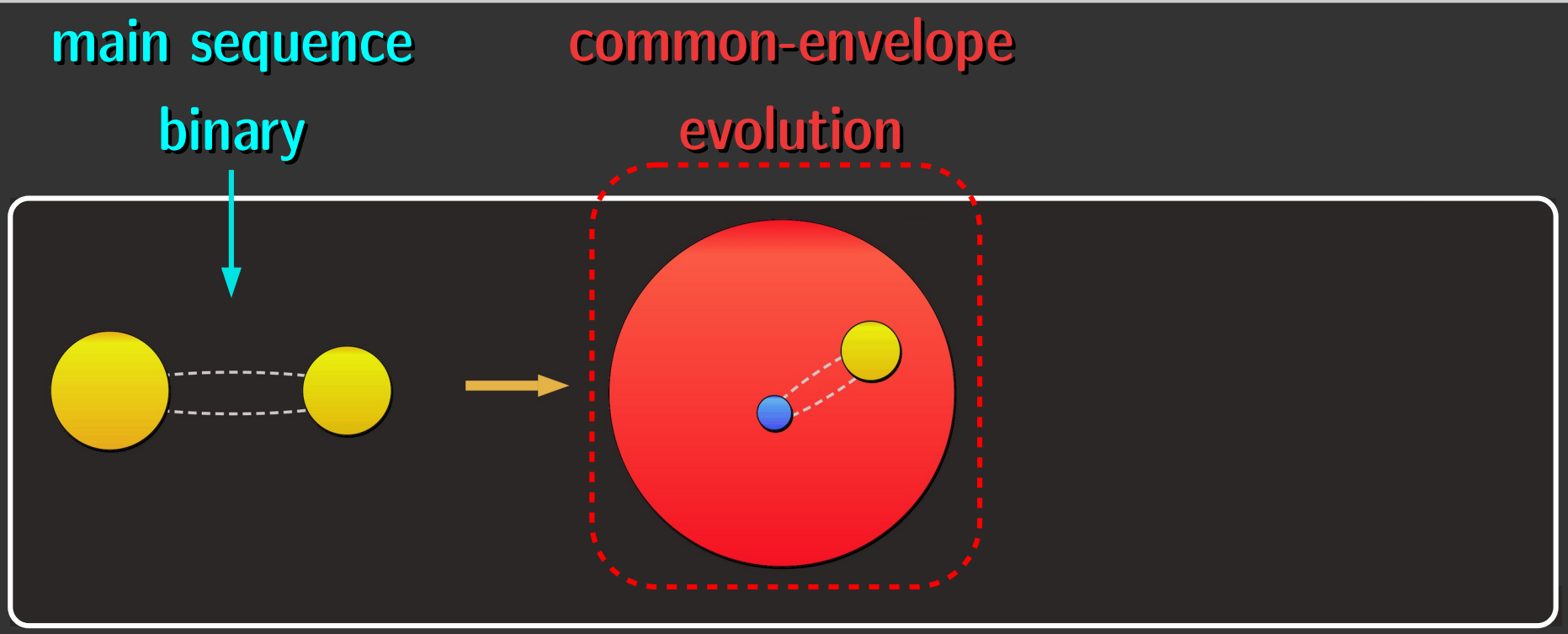

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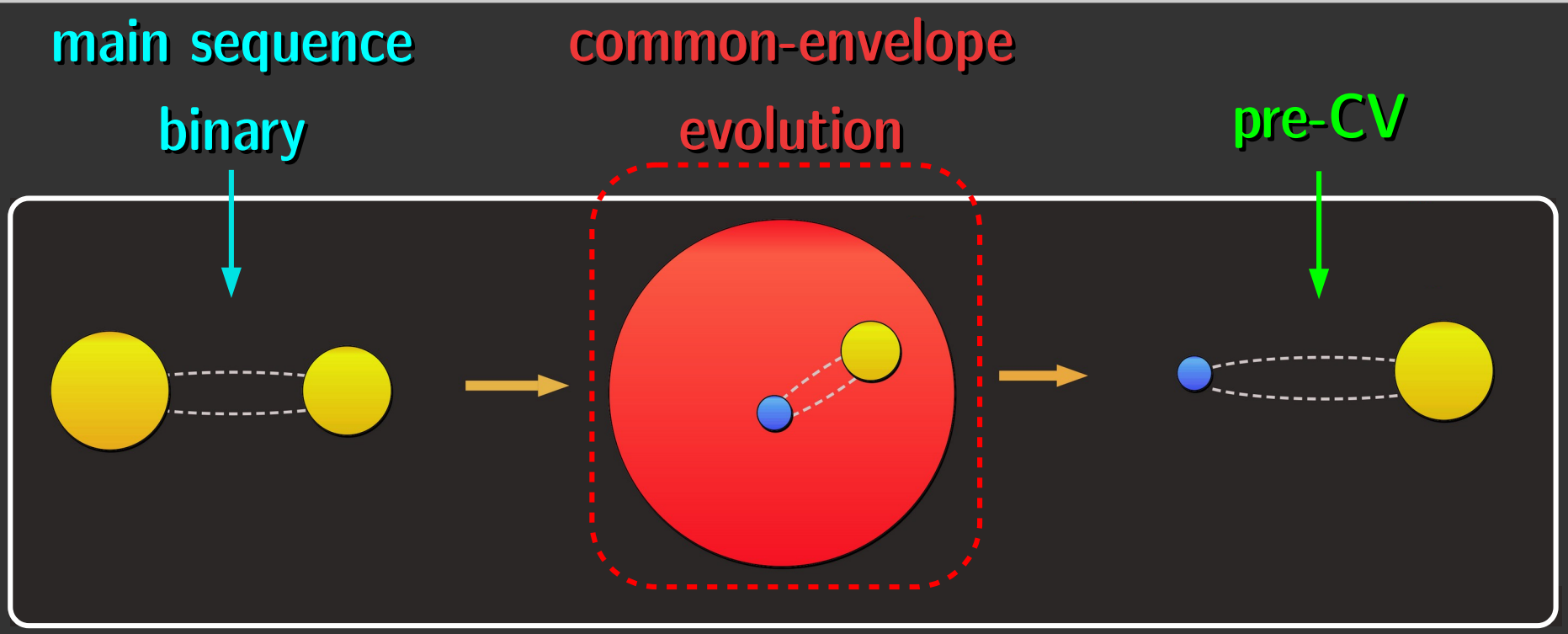

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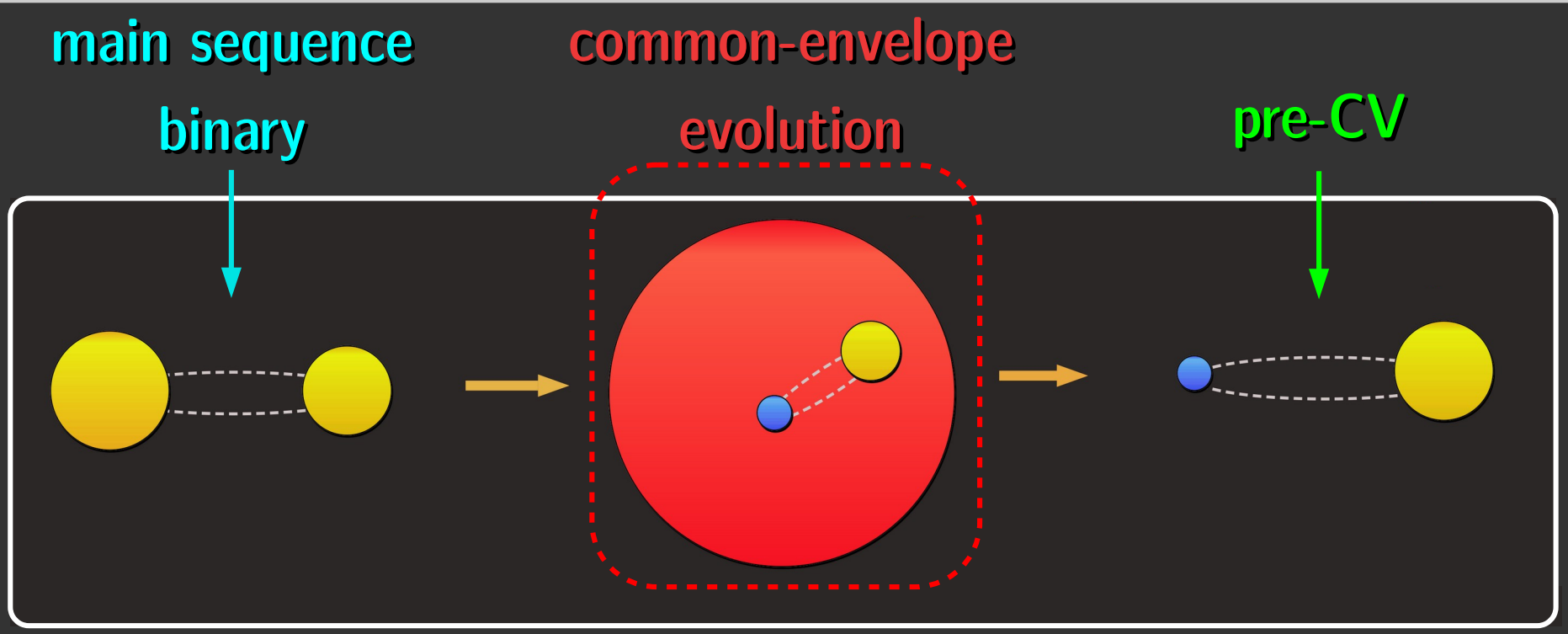
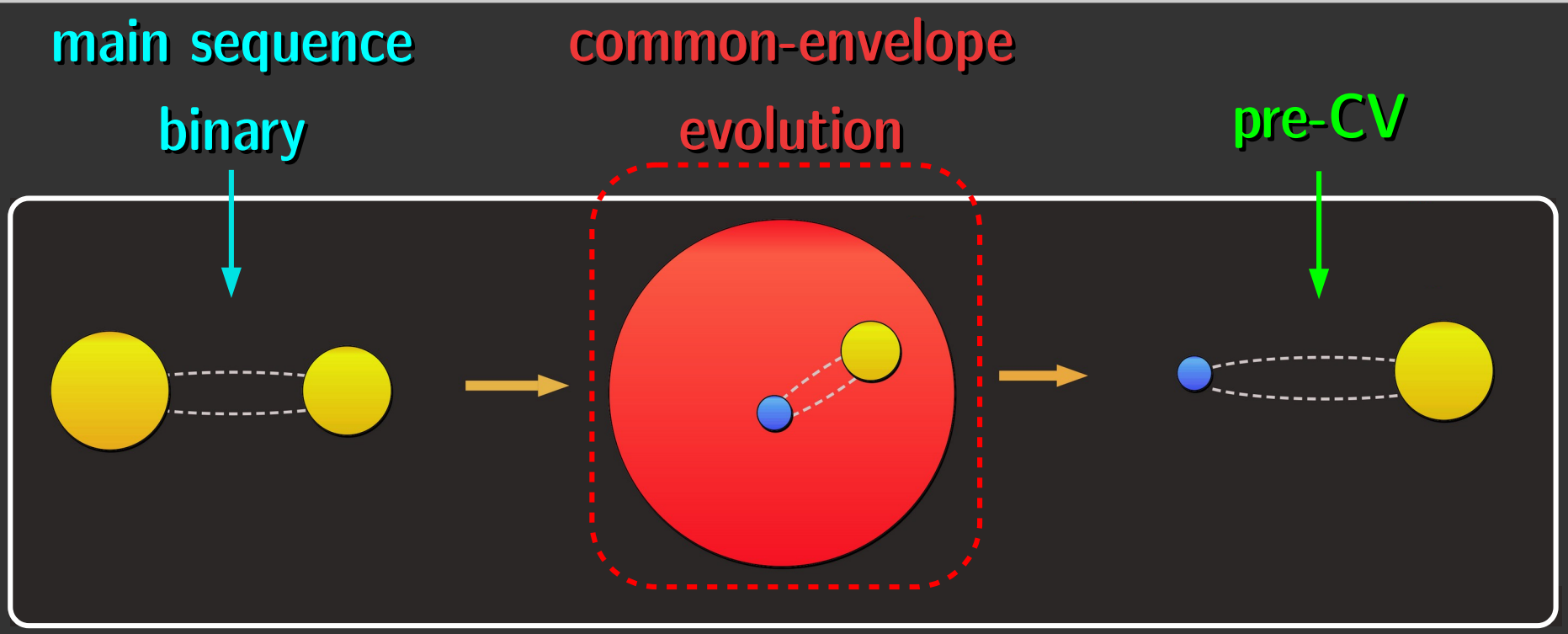


Main Problem: *common-envelope evolution*

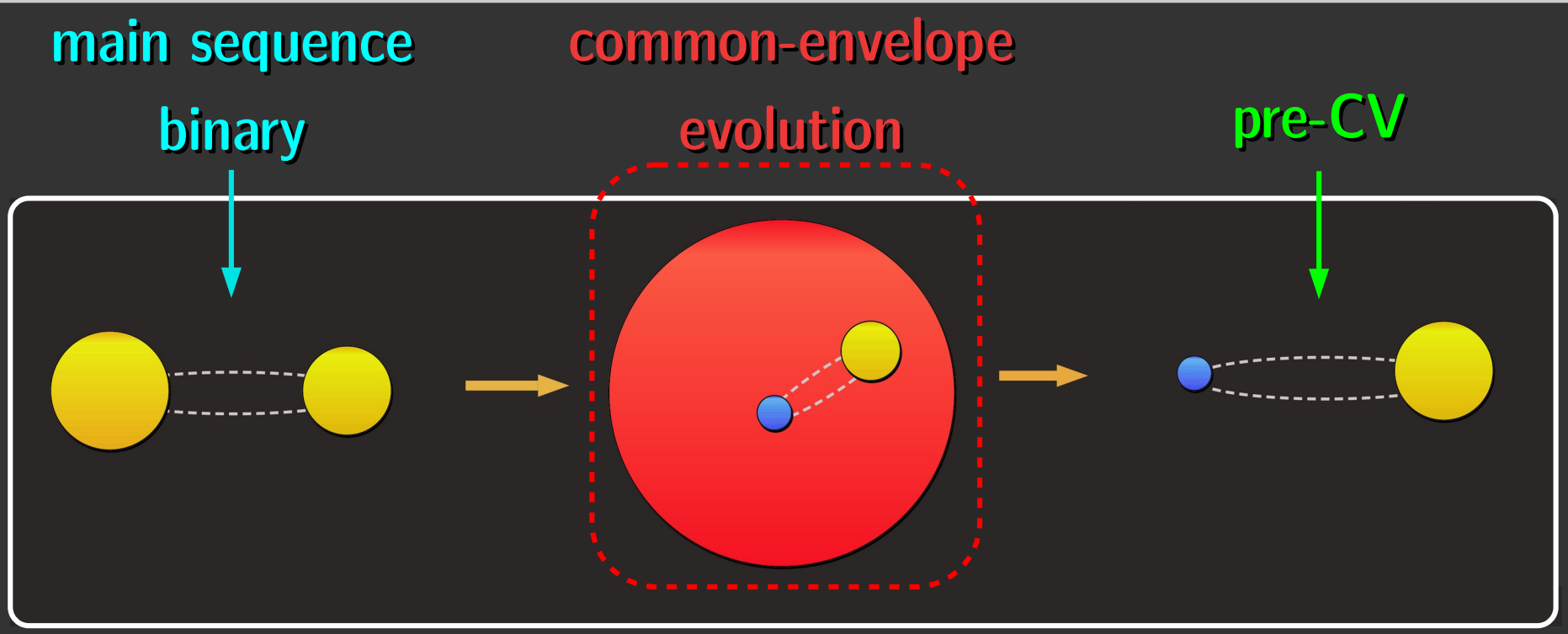
CV FORMATION



Main Problem: *common-envelope evolution*

→ *what is the efficiency?*

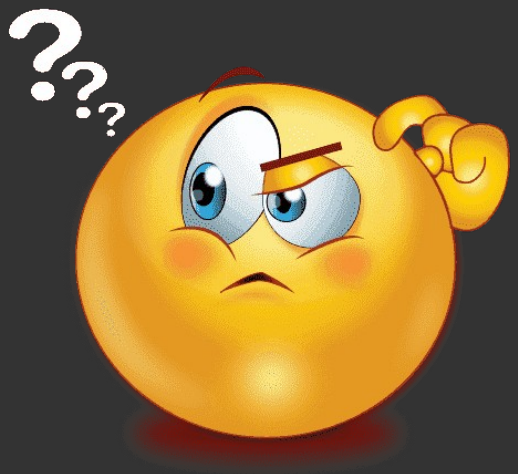
CV FORMATION



Main Problem: *common-envelope evolution*

→ *what is the efficiency?*

→ *are there other important energy sources?*



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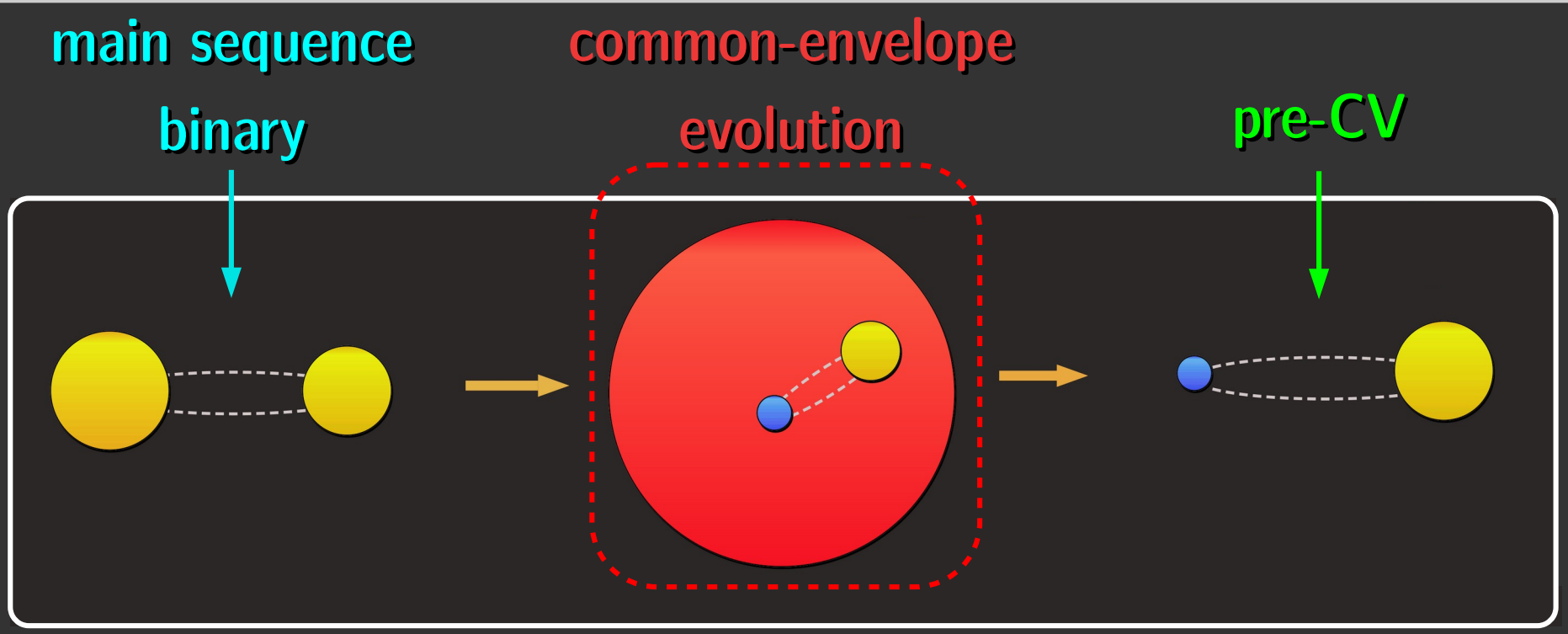
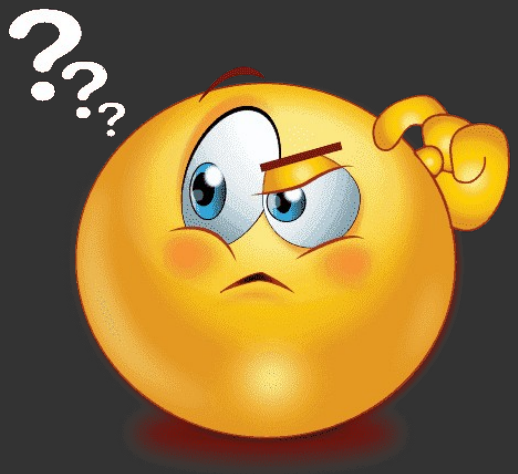


Main Problem: *common-envelope evolution*

→ *what is the efficiency?*

→ *are there other important energy sources?*

→ *what is needed to have a common-envelope event?*



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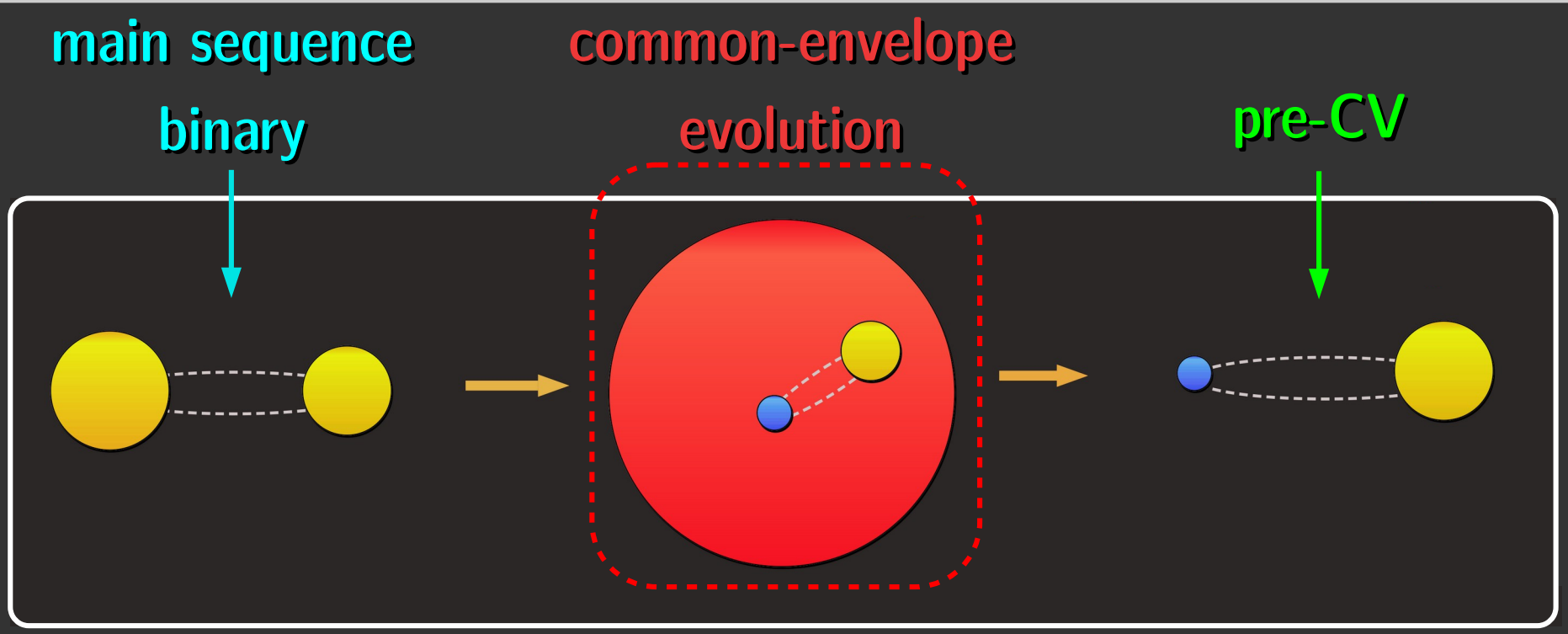

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→ *what is the efficiency?*

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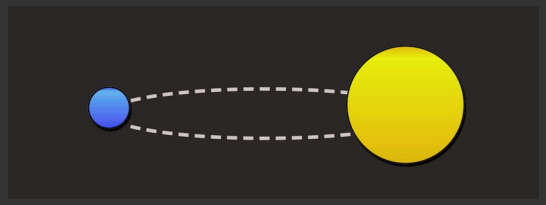
See talks by
Monica Zorotovic
and
Peter Scherbak

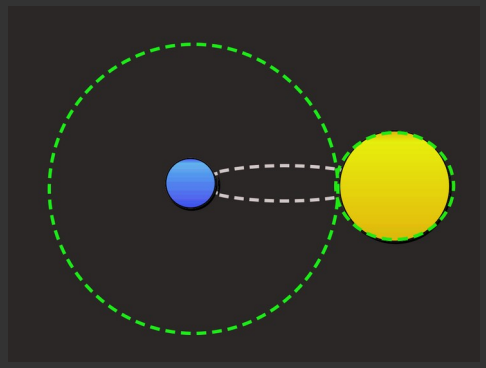
Remember Muk Kilic's talk yesterday

CV FORMATION



pre-CV

orbital angular momentum loss



CV

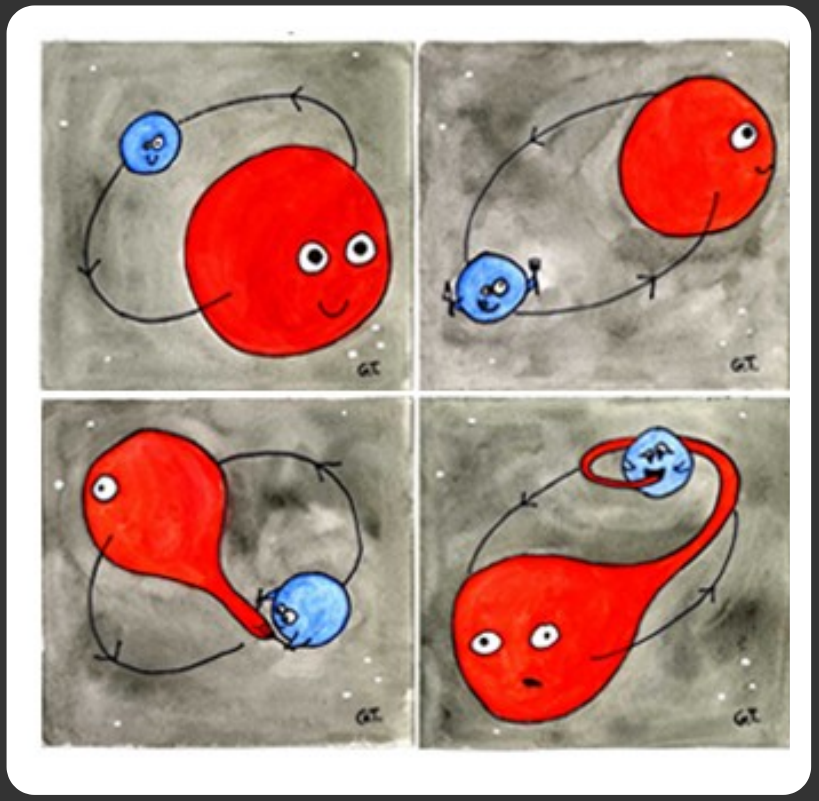
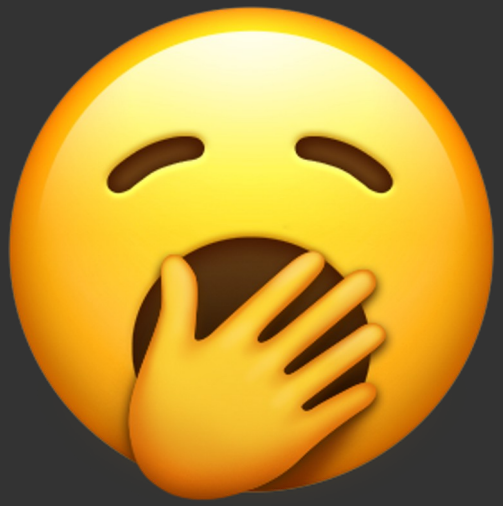


Image Credit: *Grace Treanor (Gaia UK team)*

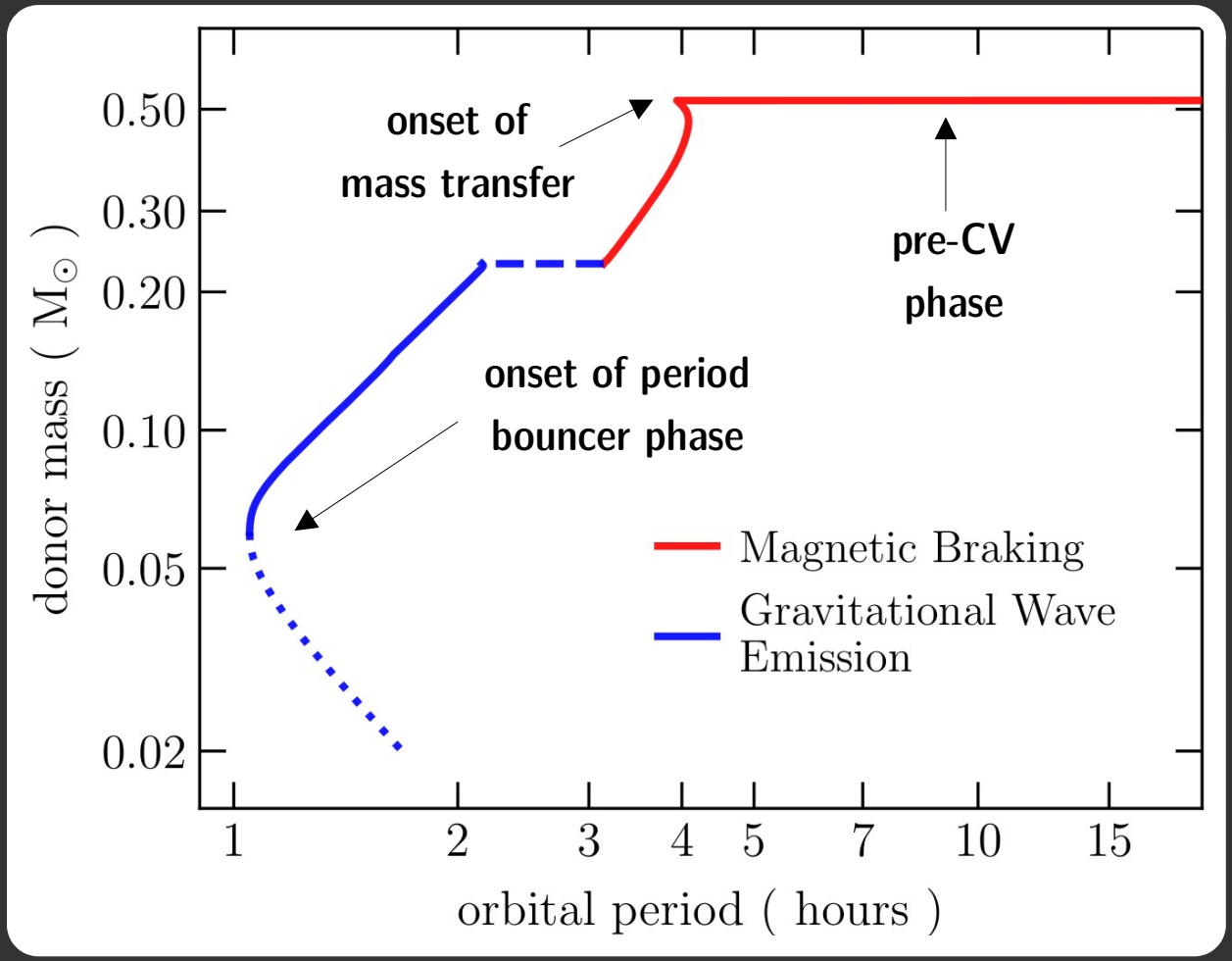
CV EVOLUTION

CV EVOLUTION

It seems we understand...



Rappaport et al. 1982; de Kool 1992; Kolb 1993; Politano 1996; Howell et al. 2001; Knigge et al. 2011; Goliasch & Nelson 2015; Kalomeni et al. 2016; AND MANY MORE...



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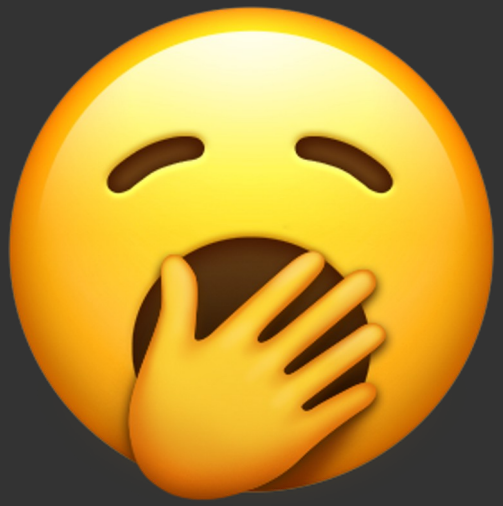

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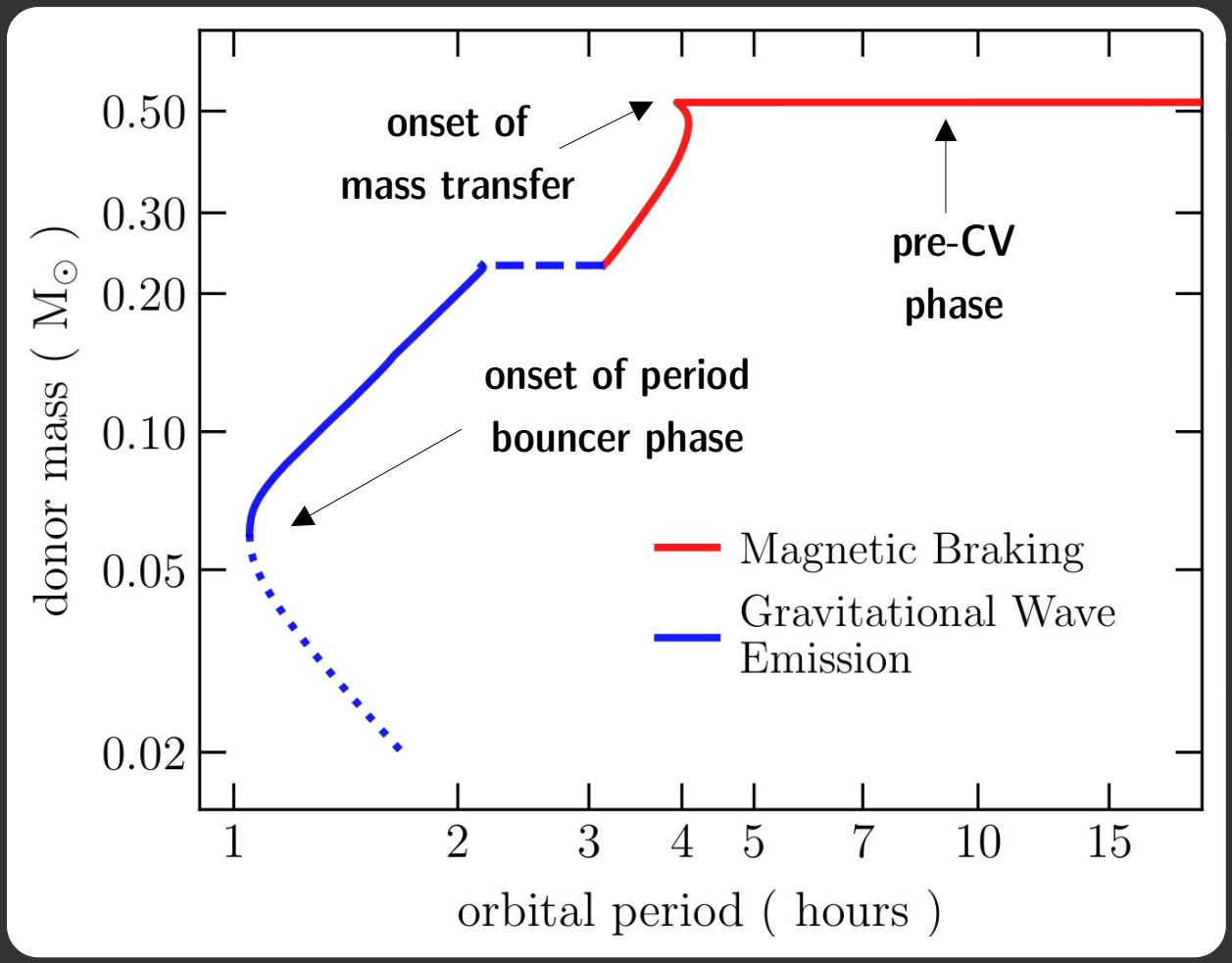
KEY

orbital angular momentum loss



CV EVOLUTION

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KEY

orbital angular momentum loss

CV PROBLEMS

1) *the observed space density is orders of magnitude smaller than predicted by population models*

(e.g. Hertz et al. 1990; de Kool 1992; Kolb 1993; Schreiber & Gänsicke 2003; Pretorius et al. 2007; Britt et al. 2015; Goliasch & Nelson 2015; Hernández Santisteban et al. 2018; Belloni et al. 2020; Pala et al. 2020)

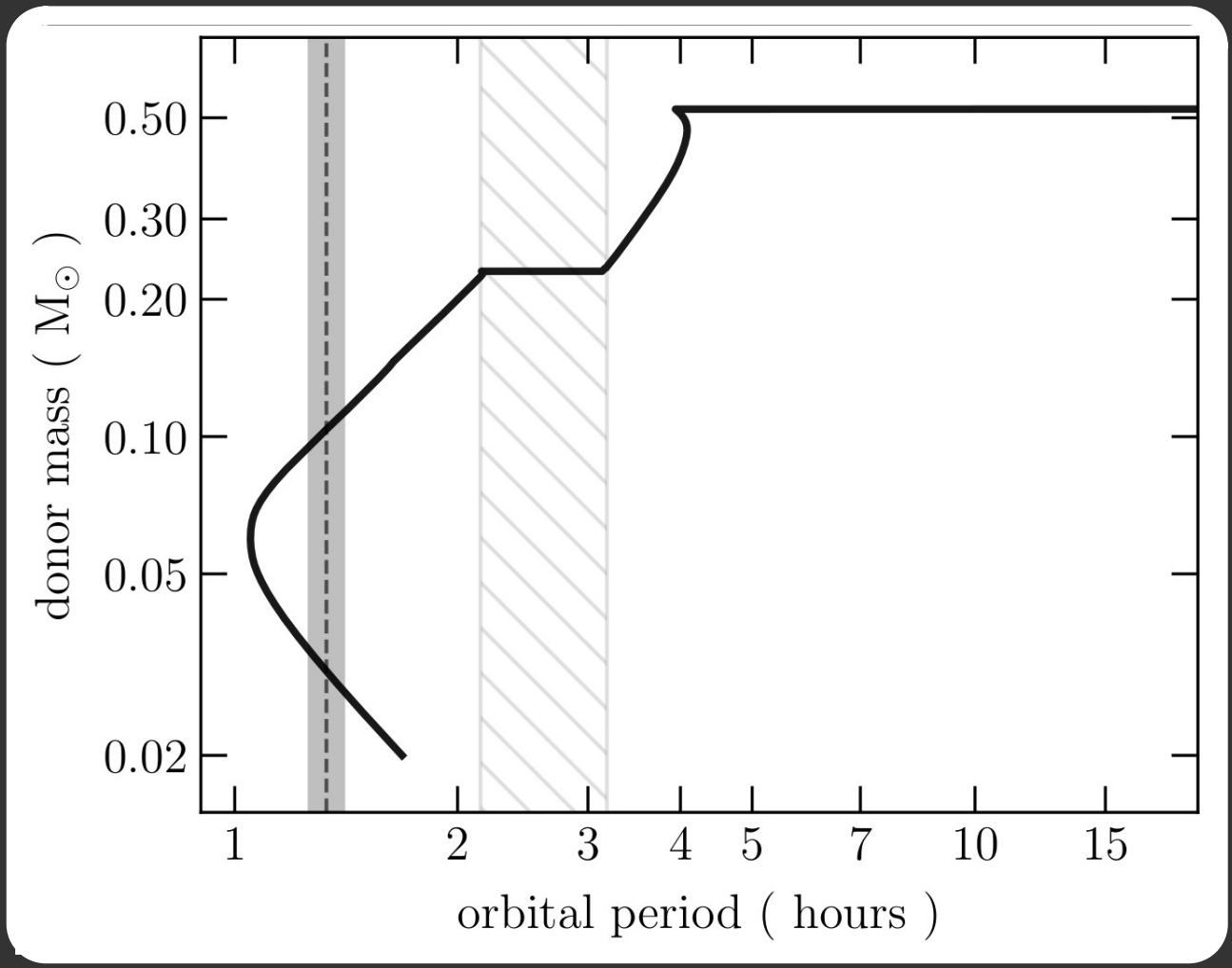
ρ (10^{-6} pc^{-3})

Observations	Simulations
$\simeq 4.8$	~ 890
Pala et al. 2020	Belloni et al. 2018

CV PROBLEMS

2) *the observed orbital period minimum is significantly longer than predicted*

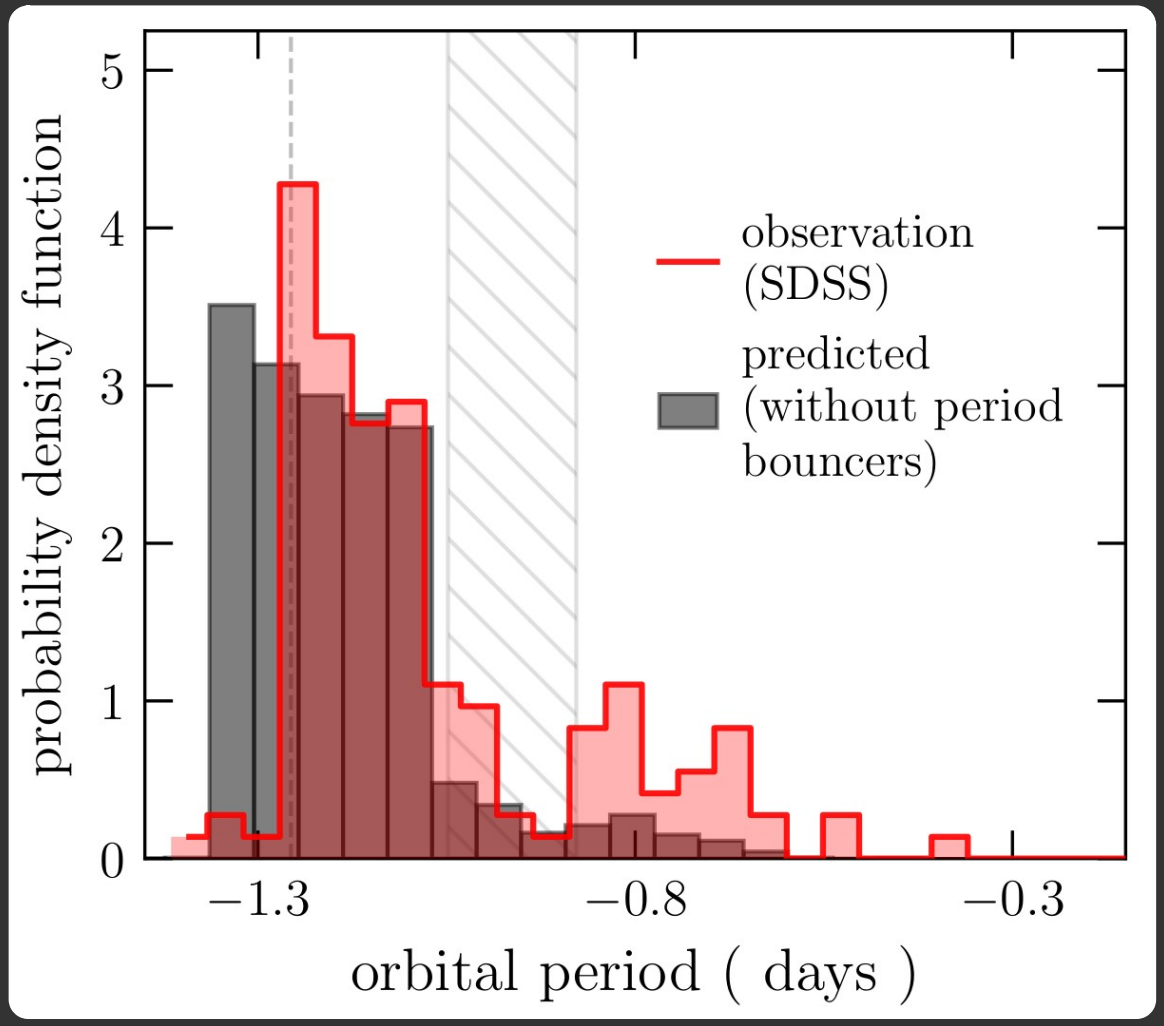
(e.g. Kolb & Baraffe 1999; Howell et al. 2001; Knigge 2006; Knigge et al. 2011; Gänsicke et al. 2009)



CV PROBLEMS

3) *the observed orbital period distribution is not well reproduced by population models*

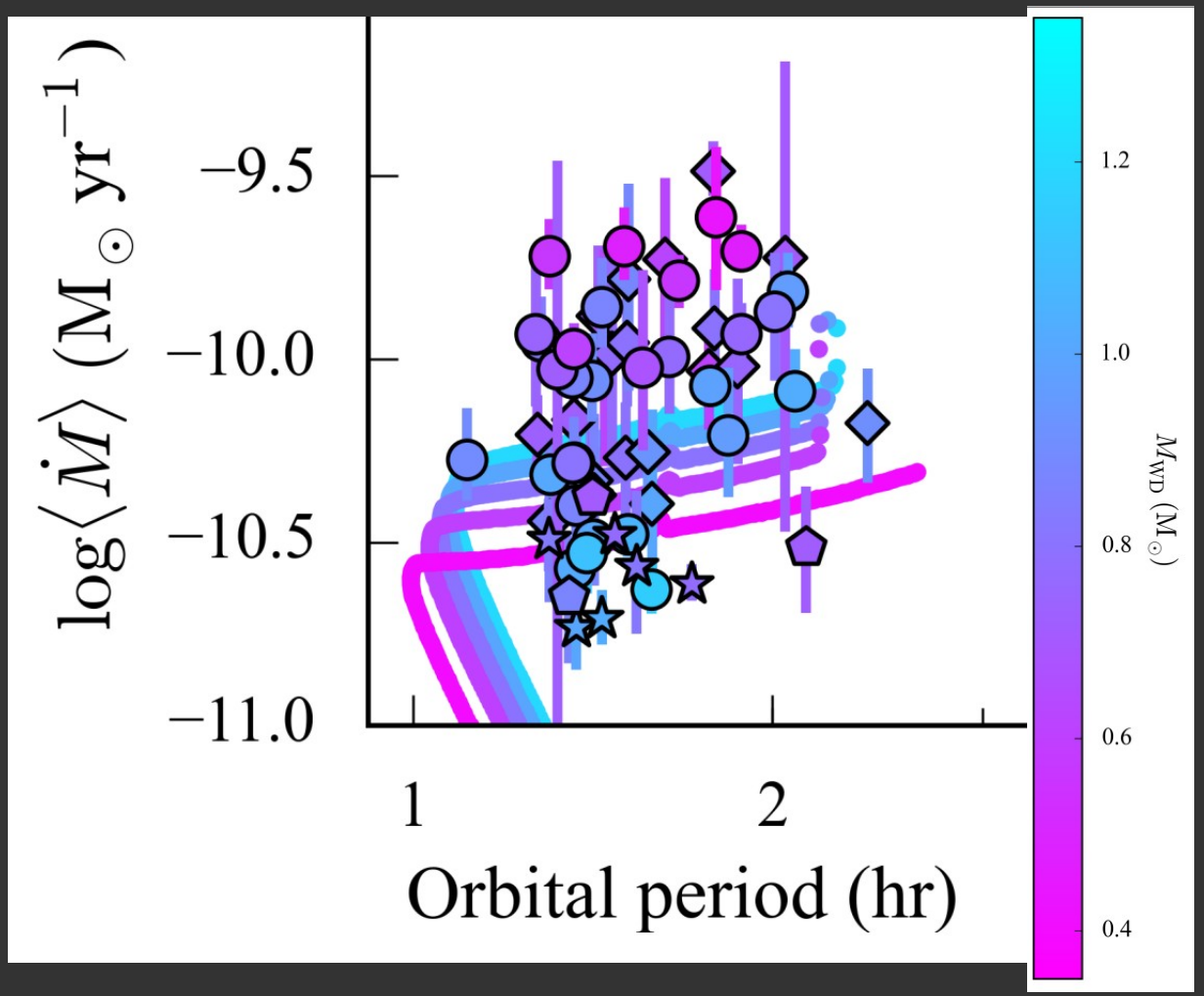
(e.g. Kolb & Baraffe 1999; Howell et al. 2001; Gänsicke et al. 2009)



CV PROBLEMS

4) *there is a spread of mass transfer rates in short-period CVs, which is not well reproduced in population models*

(e.g. Goliasch & Nelson 2015; Kalomeni et al. 2016; Pala et al. 2017; Dubus et al. 2018)

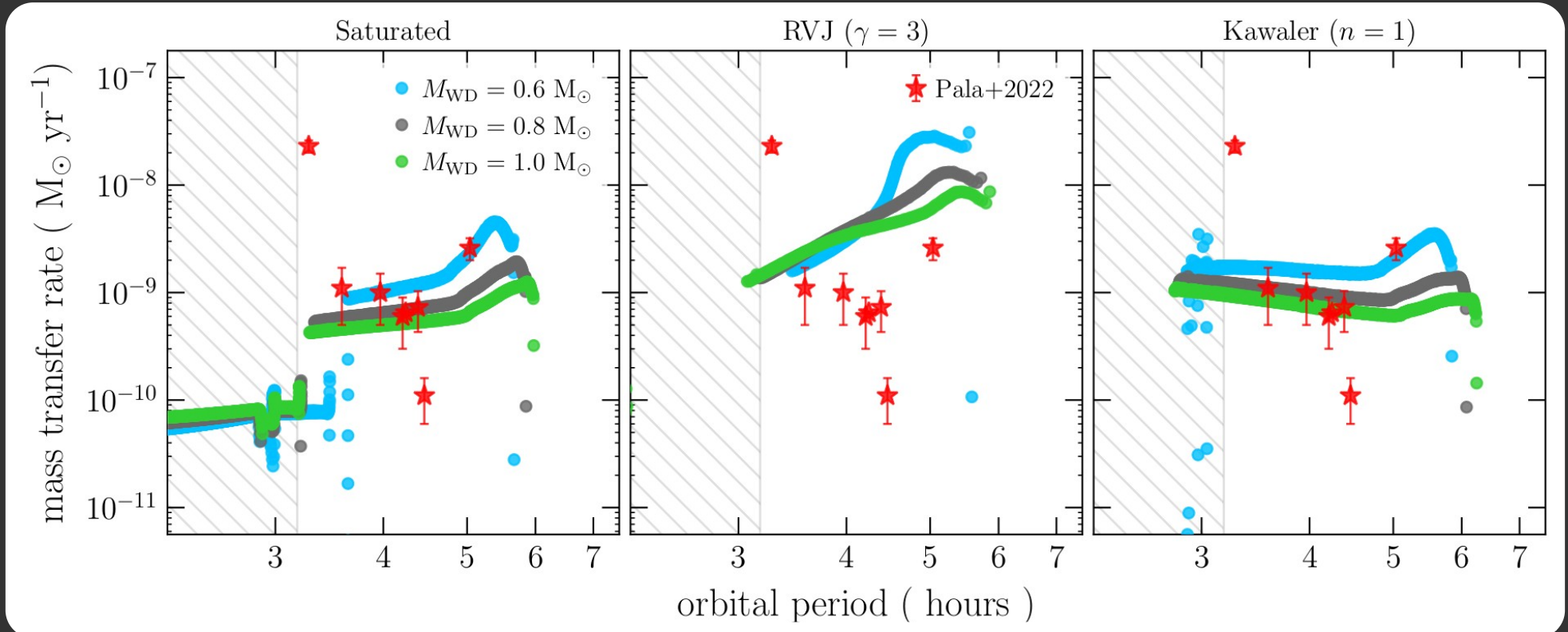


Pala et al. 2022

CV PROBLEMS

5) ***the observationally-inferred mass transfer rates of long-period CVs are very different from the predicted***

(e.g. Araujo-Betancor et al. 2005; Rodríguez-Gil et al. 2007; Townsley & Gänsicke 2009; Pala et al. 2017; Dubus et al. 2018)



CV PROBLEMS

6) ***the observational and predicted properties of period bouncers are very discrepant***

(e.g. Kolb 1993; Howell et al. 2001; Goliasch & Nelson 2015; Patterson 2011; Belloni et al. 2018, 2020; Pala et al. 2020, 2022)

Fraction (%)

Observations	Simulations
$\simeq 7-14$	$\gtrsim 80$

Belloni et al. 2018, 2020;
Pala et al. 2020, 2022

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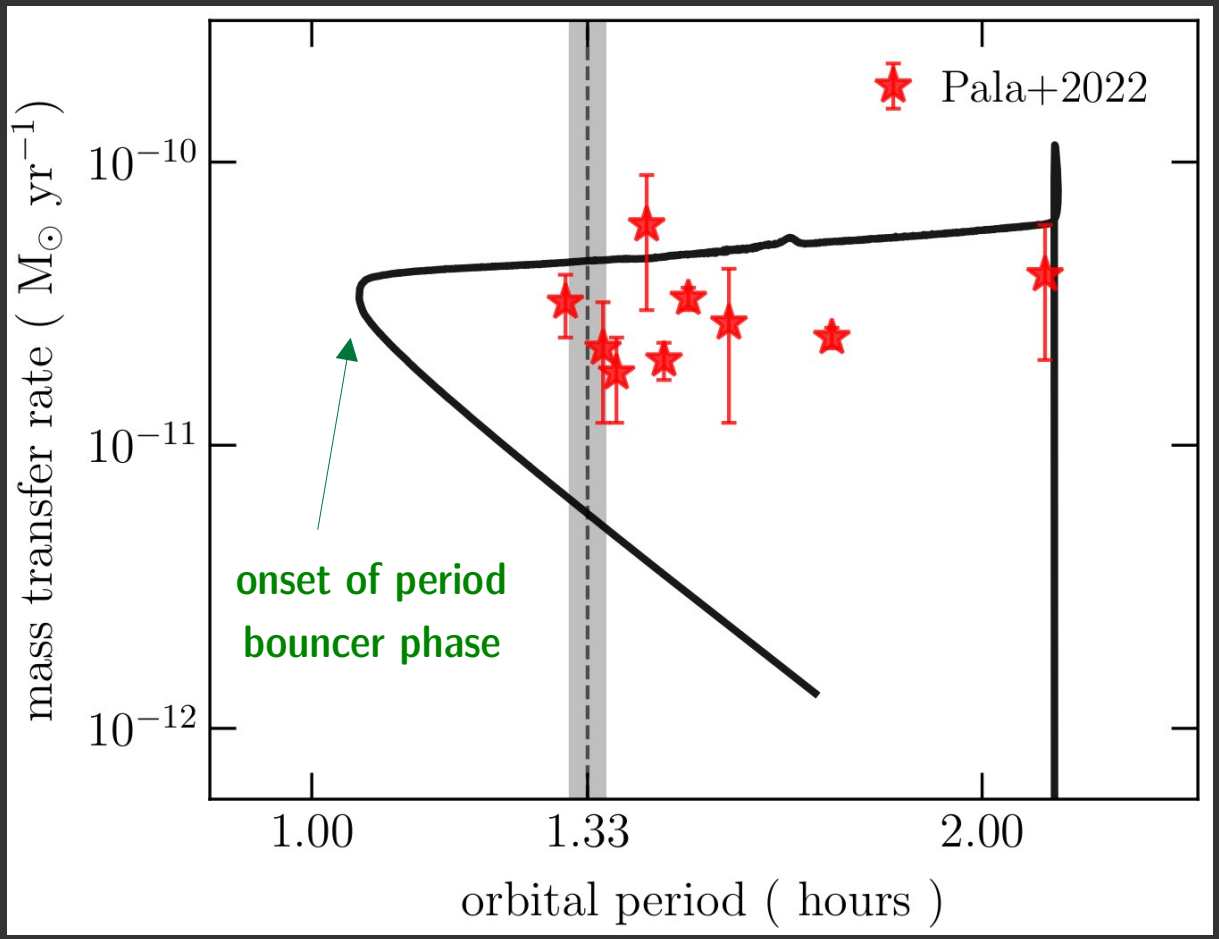
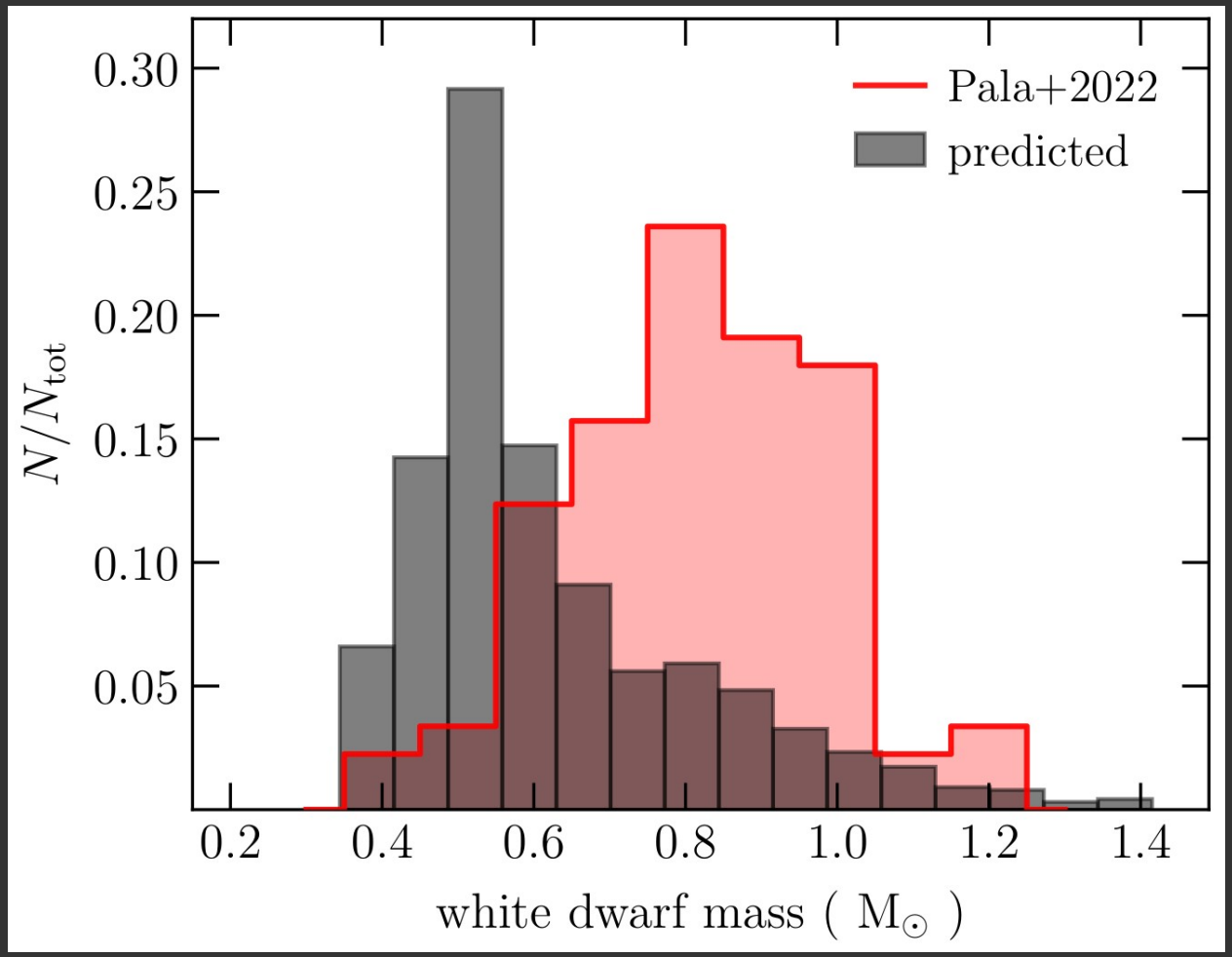


CV PROBLEMS

7) ***the white dwarf masses predicted by population models are, on average, considerably smaller than observed***

(e.g. de Kool 1992; Politano 1996; Zorotovic et al. 2011; McAllister et al. 2019; Pala et al. 2022)



CV PROBLEMS

What is needed to solve all these problems?

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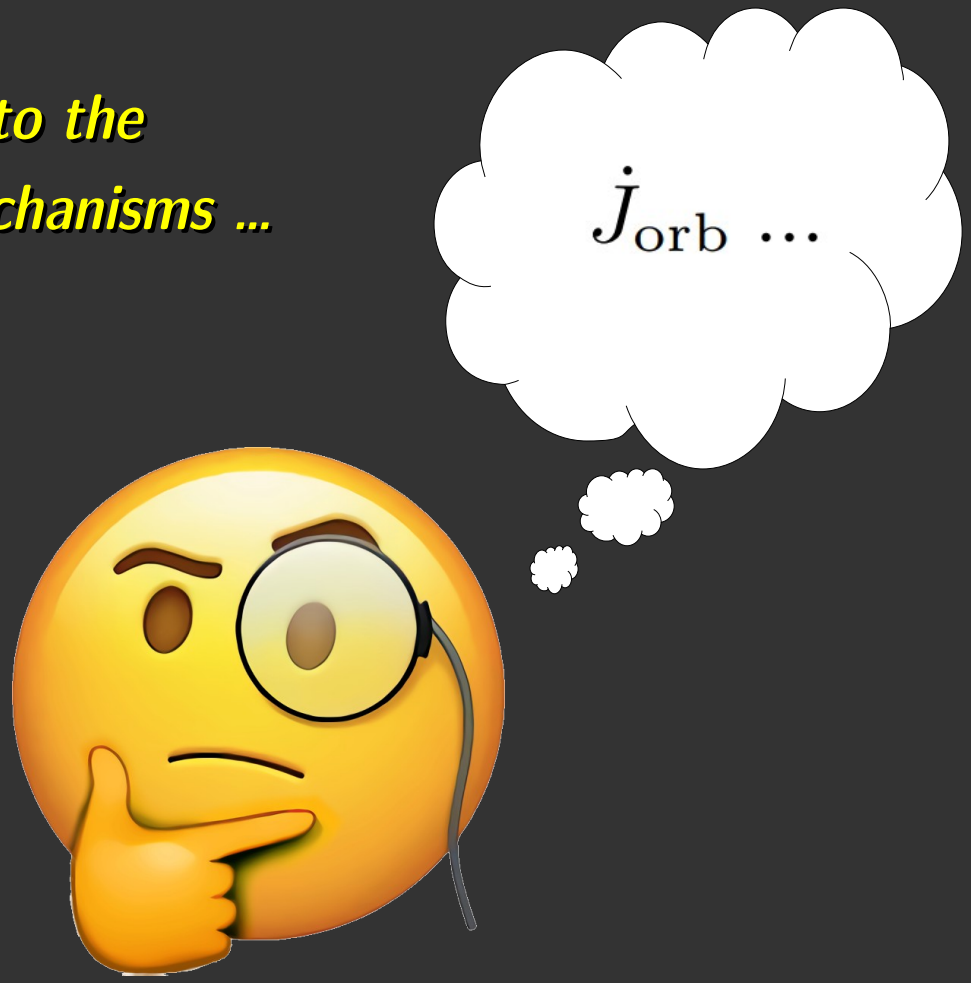
... they are most likely related to the orbital angular momentum loss mechanisms ...



CV PROBLEMS

What is needed to solve all these problems?

... they are most likely related to the orbital angular momentum loss mechanisms ...

We need to re-visit the mechanisms and the related physics !!!

(e.g. Knigge et al. 2011; Schreiber et al. 2016; Nelemans et al. 2016; Liu & Li 2019; Belloni et al. 2020; Pala et al. 2022)

Quick note before proceeding further...

→ We should not forget about observational selection effects...

→ We need an observational sample as large, complete, and unbiased as possible

See talk by
Anna Pala

Orbital Angular Momentum Loss Mechanisms

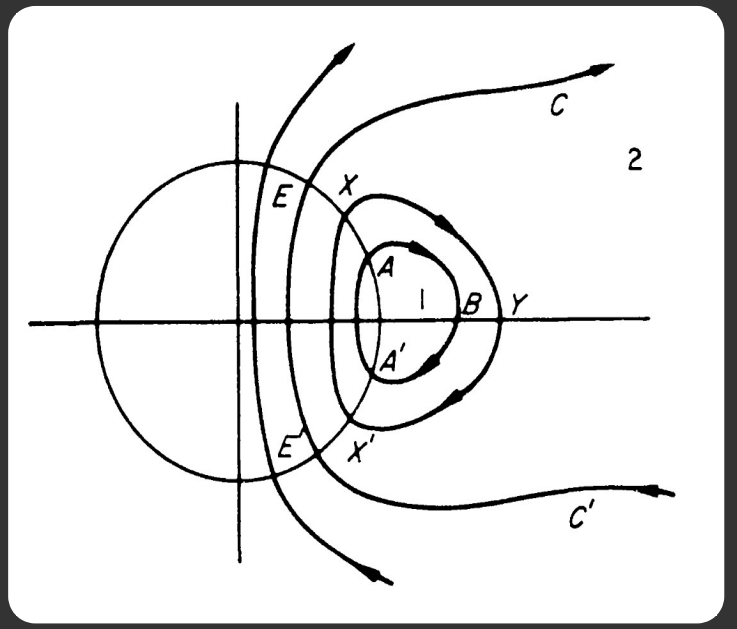
Orbital Angular Momentum Loss Mechanisms

Emission of Gravitational Waves

Orbital Angular Momentum Loss Mechanisms

Emission of Gravitational Waves

Magnetic Wind Braking



Mestel 1968

Orbital Angular Momentum Loss Mechanisms

Emission of Gravitational Waves

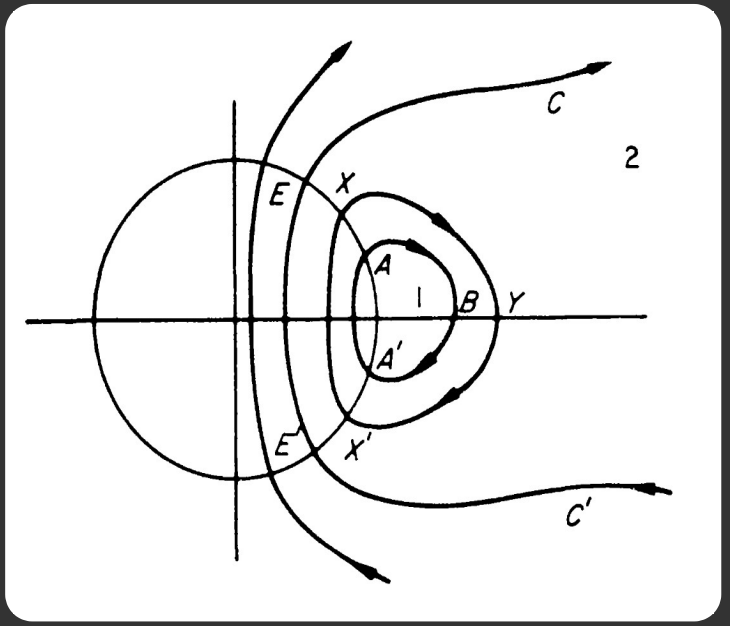
Magnetic Wind Braking

→ *What is the strength?*

→ *What is the dependence with mass, radius, spin?*

→ *Is it the same, irrespective of the evolutionary stage?*

→ *Does it change during the evolution?*



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Orbital Angular Momentum Loss Mechanisms

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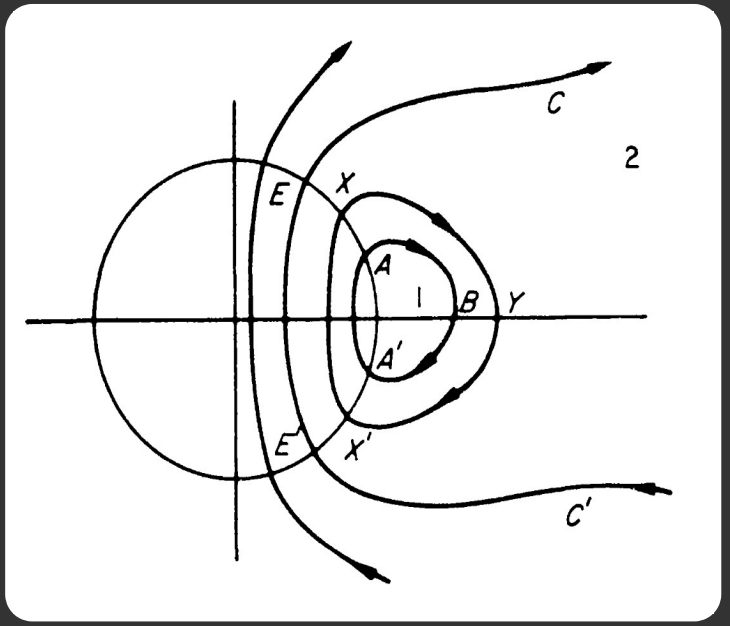
Consequential Angular Momentum Loss



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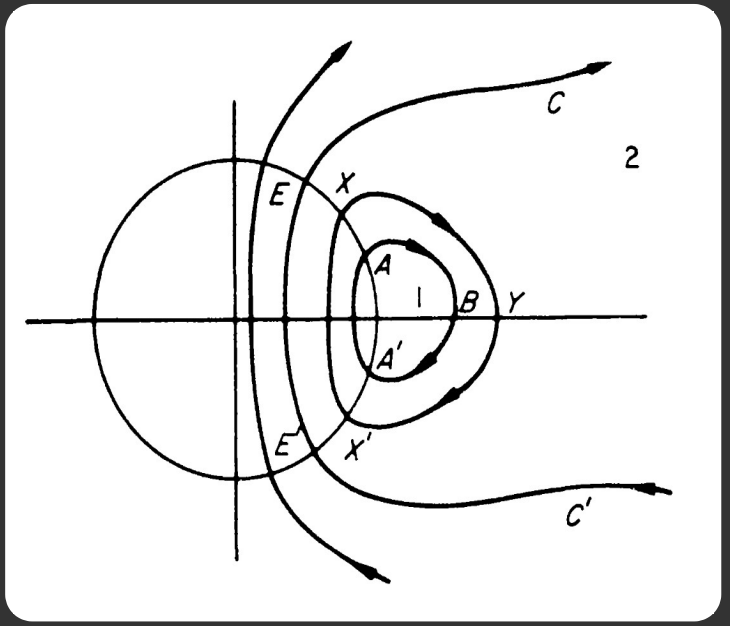

Mestel 1968

Consequential Angular Momentum Loss

→ *Is it important?*

→ *If so, what is the dominant mechanisms?*

+ circumbinary disk? *(e.g. Taam & Spruit 2001)*

+ frictional drag due to nova eruptions? *(e.g. Nelemans et al. 2016)*

+ accretion disk winds? *(e.g. Cannizzo & Pudritz 1988)*

Towards a solution to the problems...

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→ *orbital period minimum*

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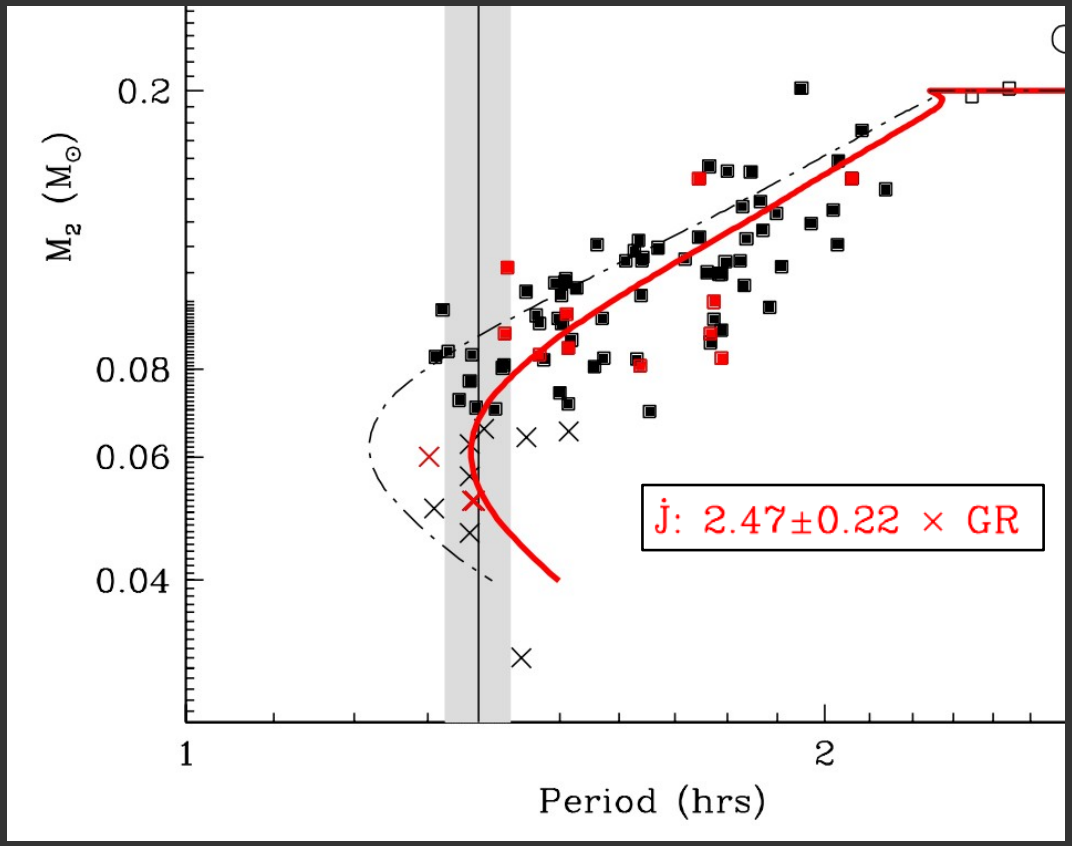

Knigge et al. 2011

CV PROBLEMS

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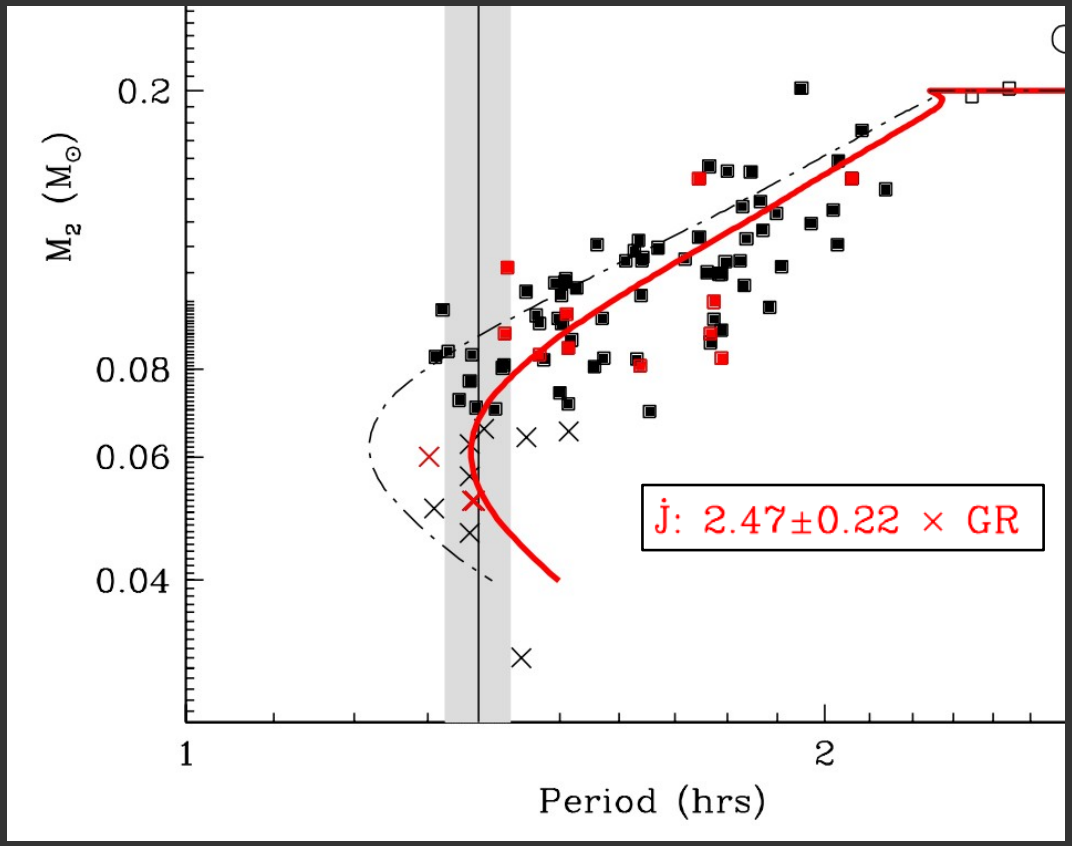
→ *orbital period minimum*



Knigge et al. 2011

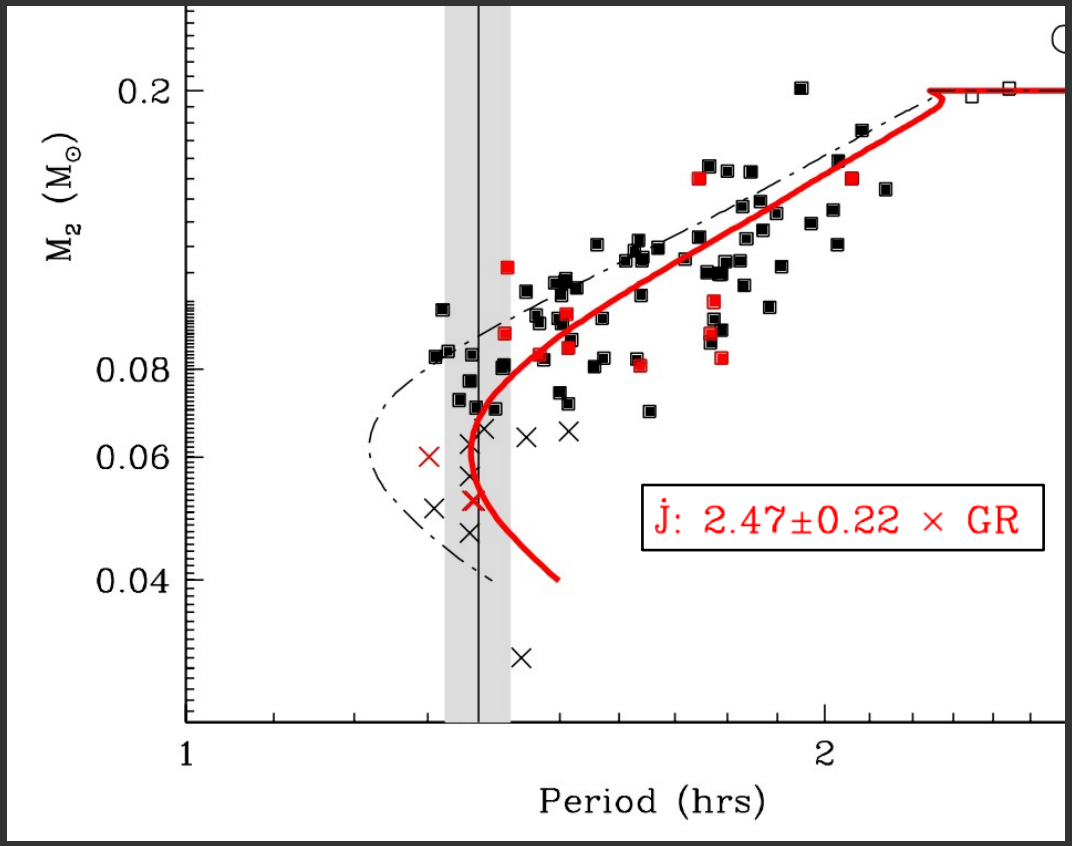
SOLUTION

Extra *Orbital Angular Momentum Loss*

CV PROBLEMS

Towards a solution to the problems...

→ orbital period minimum



Knigge et al. 2011

But, what is the mechanism?

- consequential angular momentum loss?
- magnetic braking?

Towards a solution to the problems...

→ *space density*

→ *white dwarf mass*

→ *orbital period*

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Consequential Angular Momentum Loss

$$\frac{\dot{J}_{\rm orb}}{J_{\rm orb}} = \left(\frac{0.35}{M_{\rm WD}}\right)\left(\frac{\dot{M}_{\rm donor}}{M_{\rm donor}}\right)$$

Schreiber et al. 2016

CV PROBLEMS

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→ *space density*

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ρ (10^{-6} pc^{-3})

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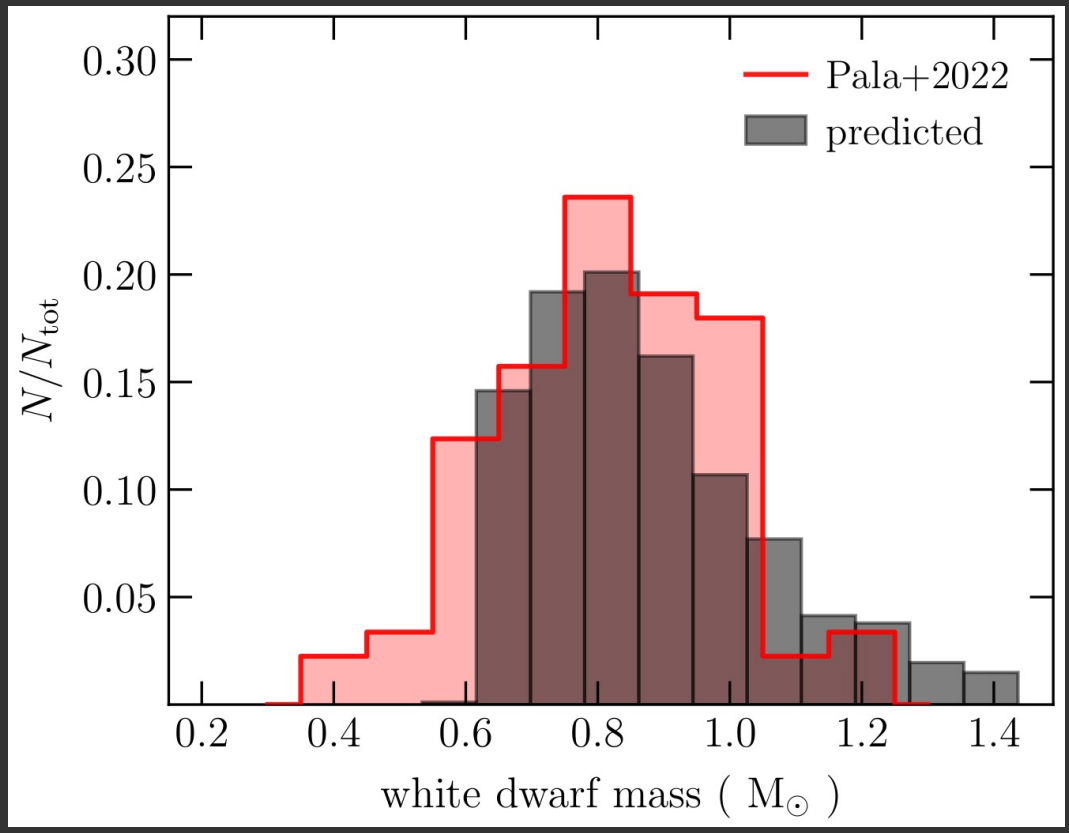

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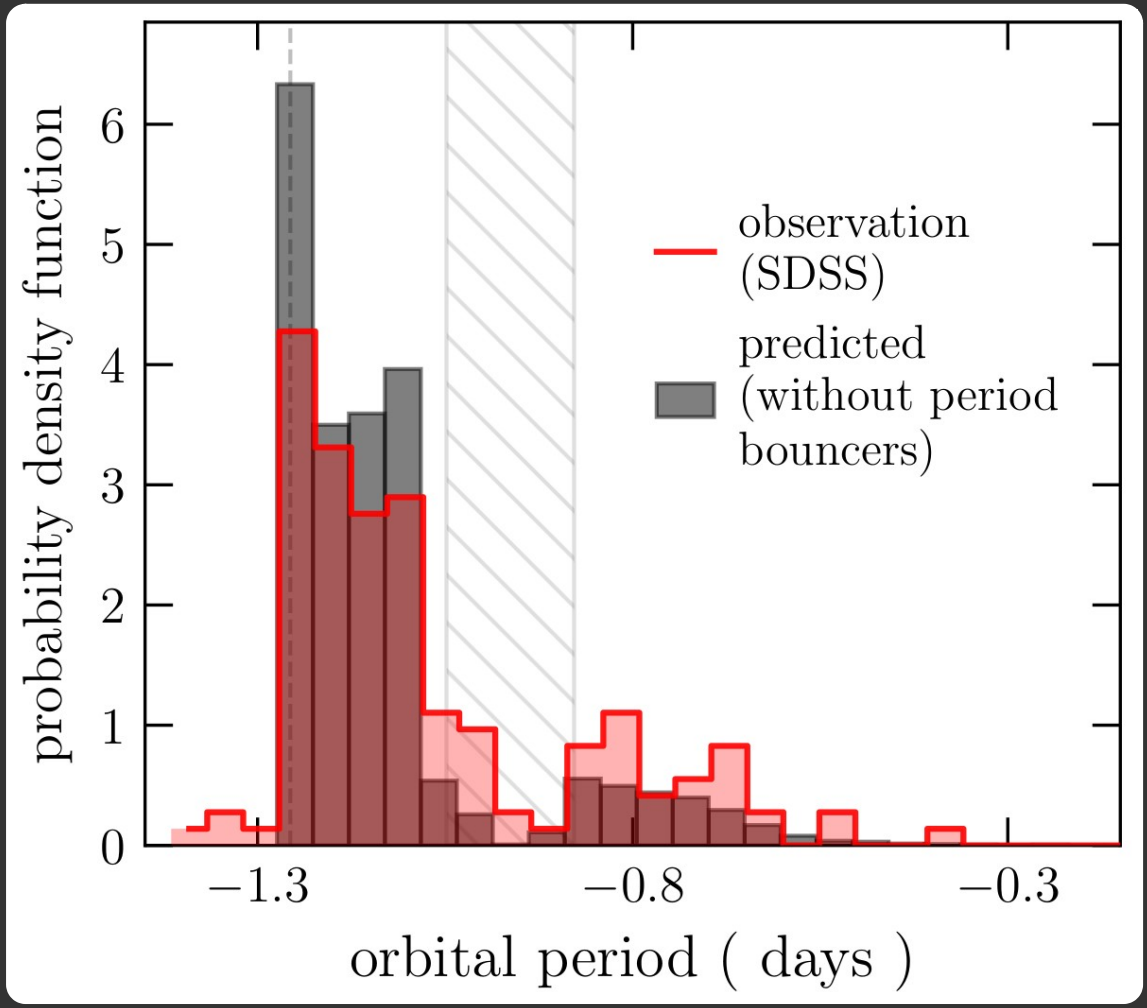

Belloni et al. 2020

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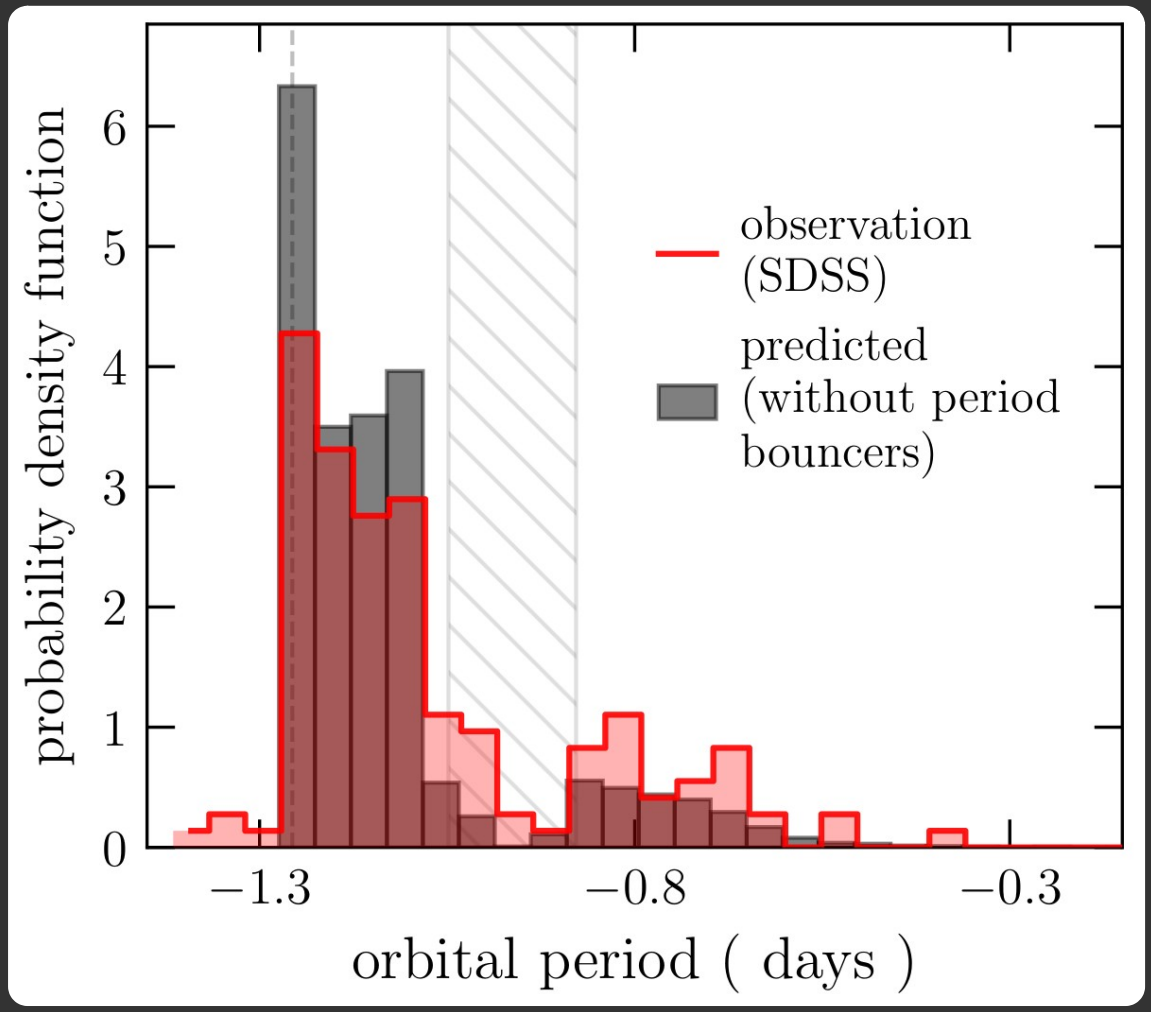

Belloni et al. 2020

See talk by Zhuofu Li

... maybe due to observational bias?

CV PROBLEMS

Towards a solution to the problems...

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Schreiber et al. 2016

The model helps,

but needs improvement...

Towards a solution to the problems...

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Schreiber et al. 2016

And what about the physics?

CV PROBLEMS

Towards a solution to the problems...

We do need to better understand

Magnetic Braking & Consequential Angular Momentum loss

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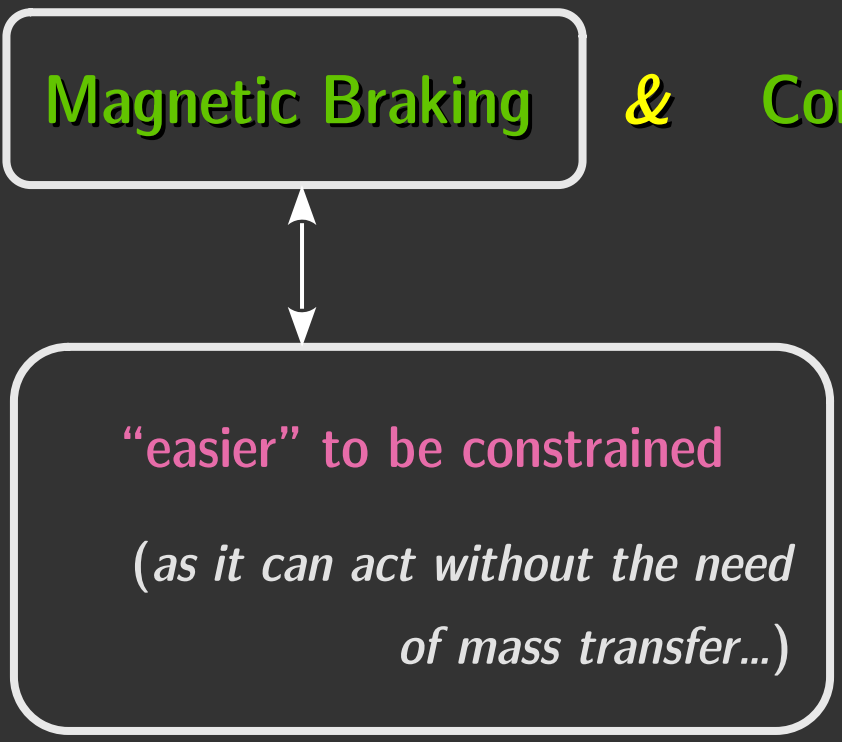
Magnetic Braking & Consequential Angular Momentum loss



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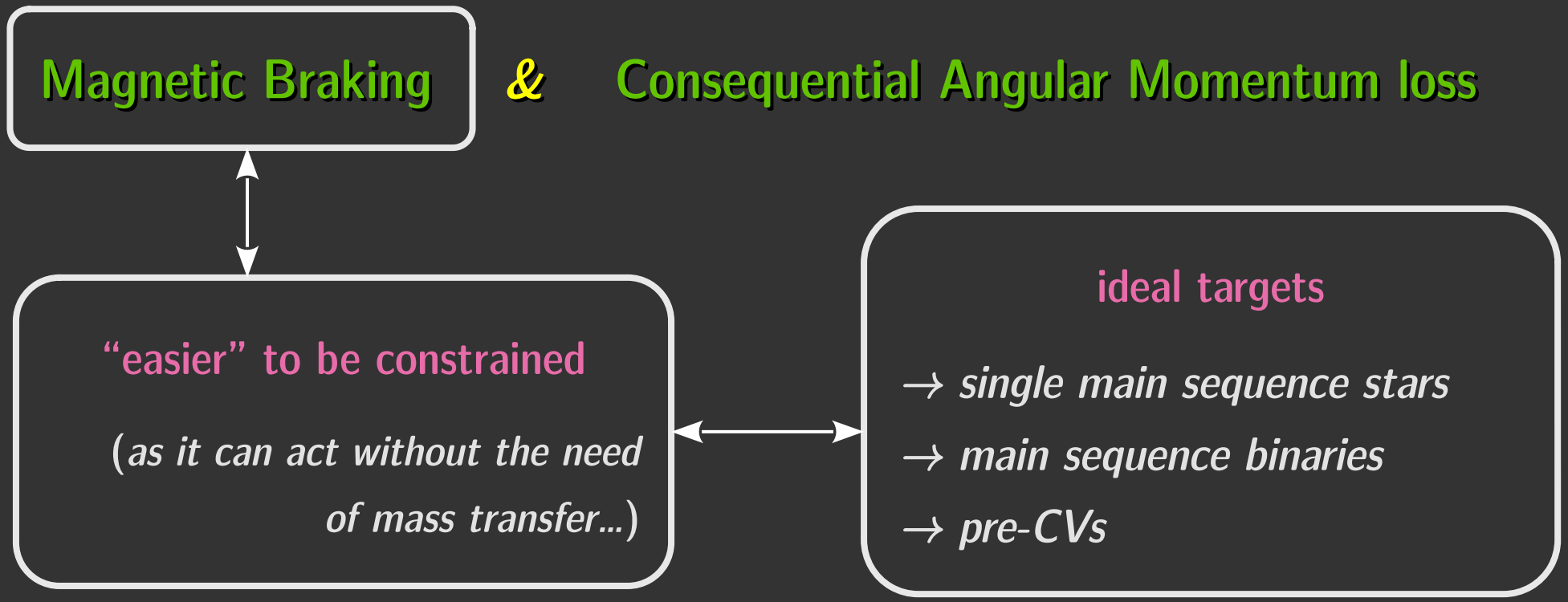


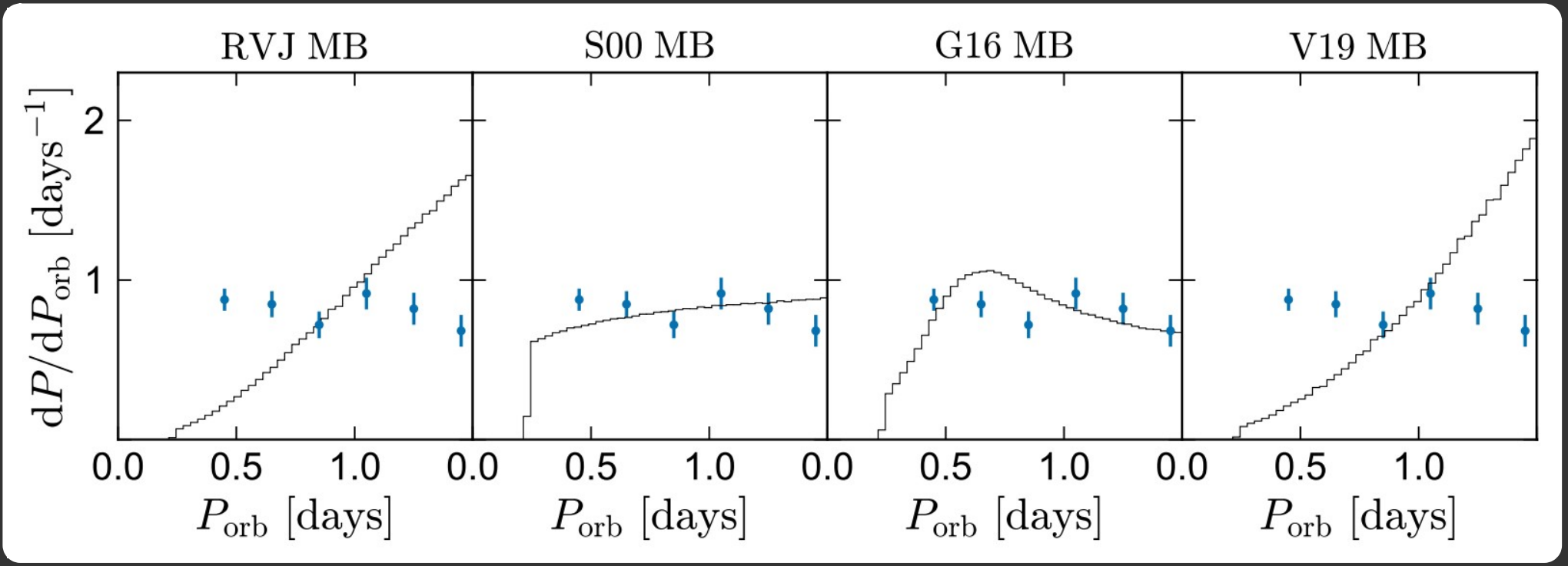
Magnetic Braking

Main Sequence Binaries

Magnetic Braking

Main Sequence Binaries

(El-Badry et al. 2022)



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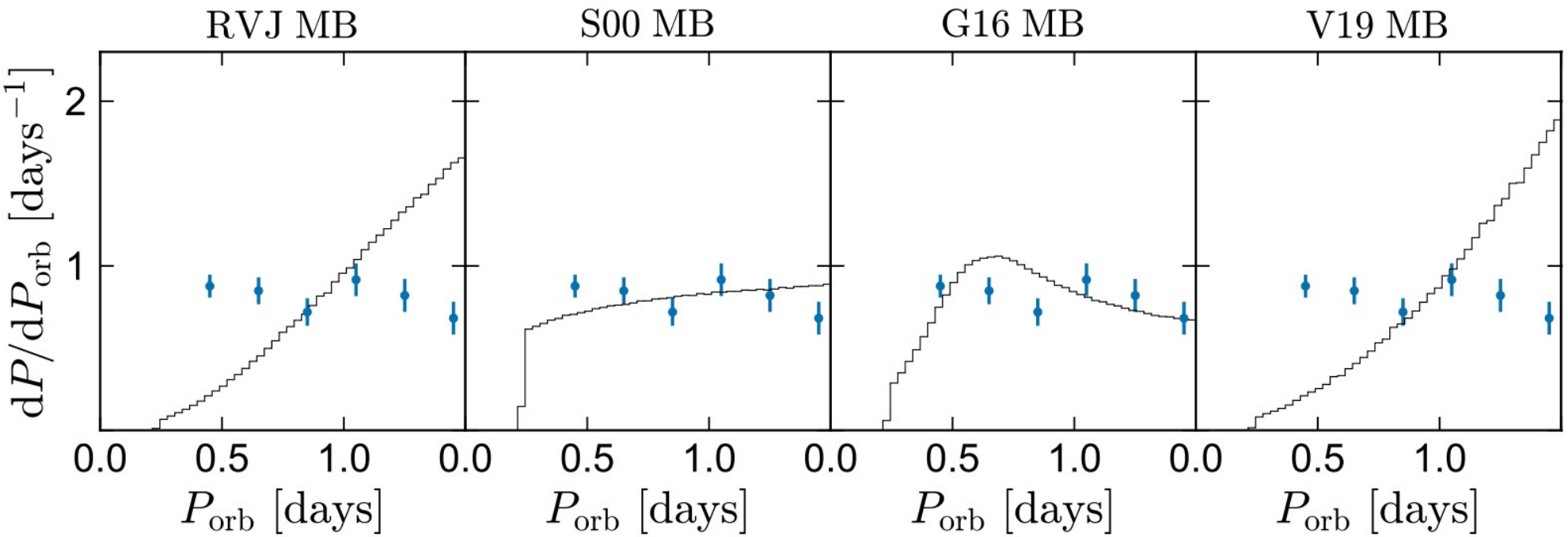
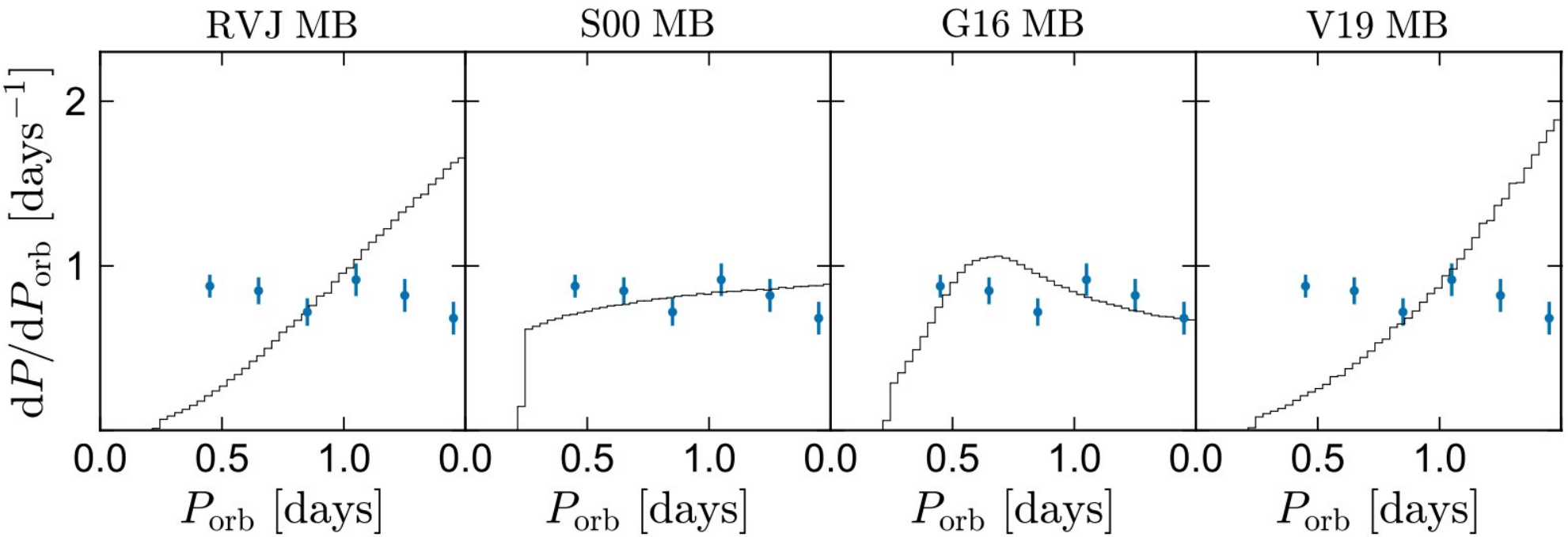


$$\dot{J}_{\mathrm{MB}} \propto \left(\frac{\Omega}{\mathrm{s}^{-1}}\right)$$

Magnetic Braking

Main Sequence Binaries

(El-Badry et al. 2022)



$$\dot{J}_{\mathrm{MB}} \propto \left(\frac{\Omega}{\mathrm{s}^{-1}}\right)$$

See talk by Kareem El-Badry

Magnetic Braking

Pre-CVs

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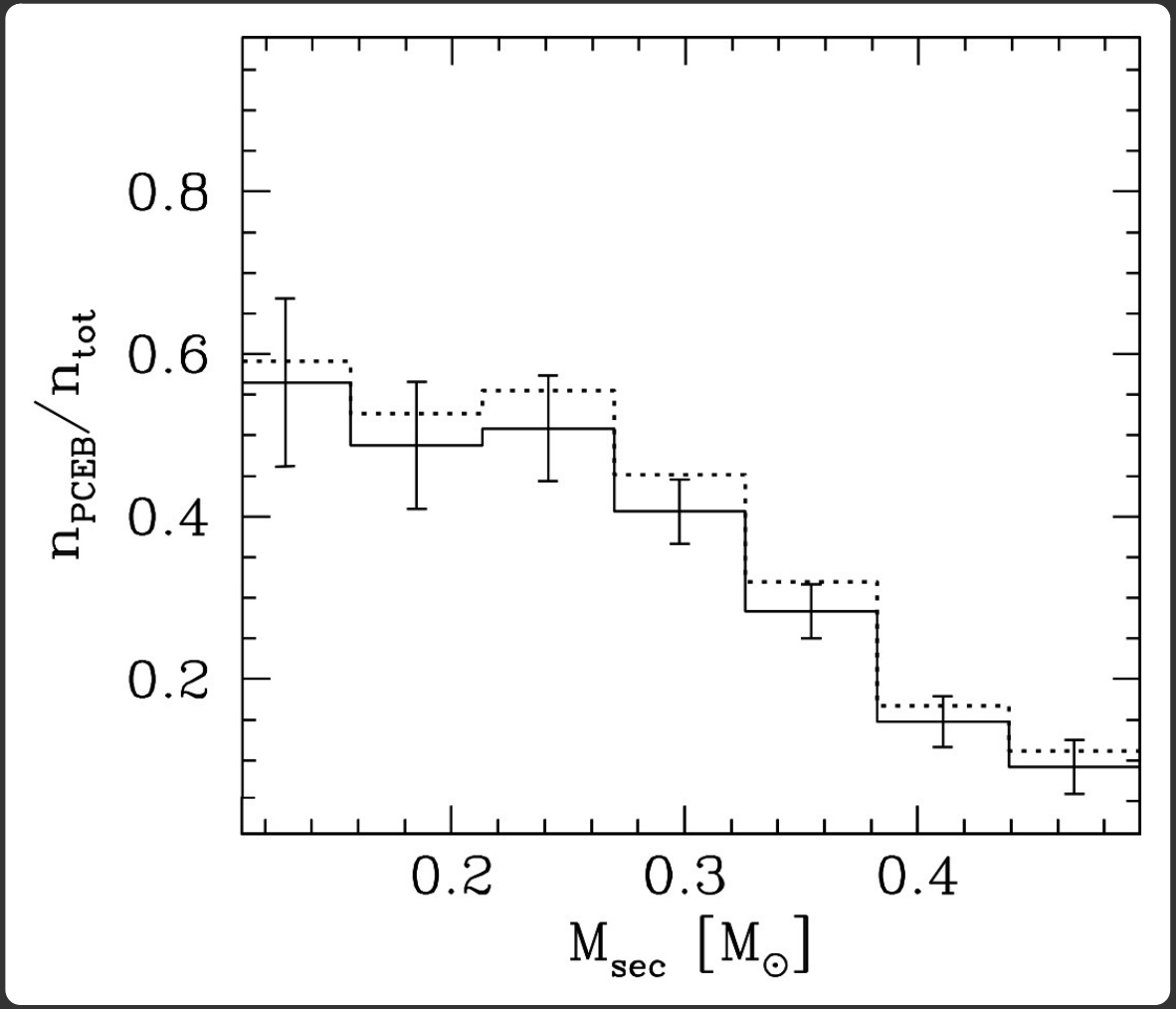
(Schreiber et al. 2010)

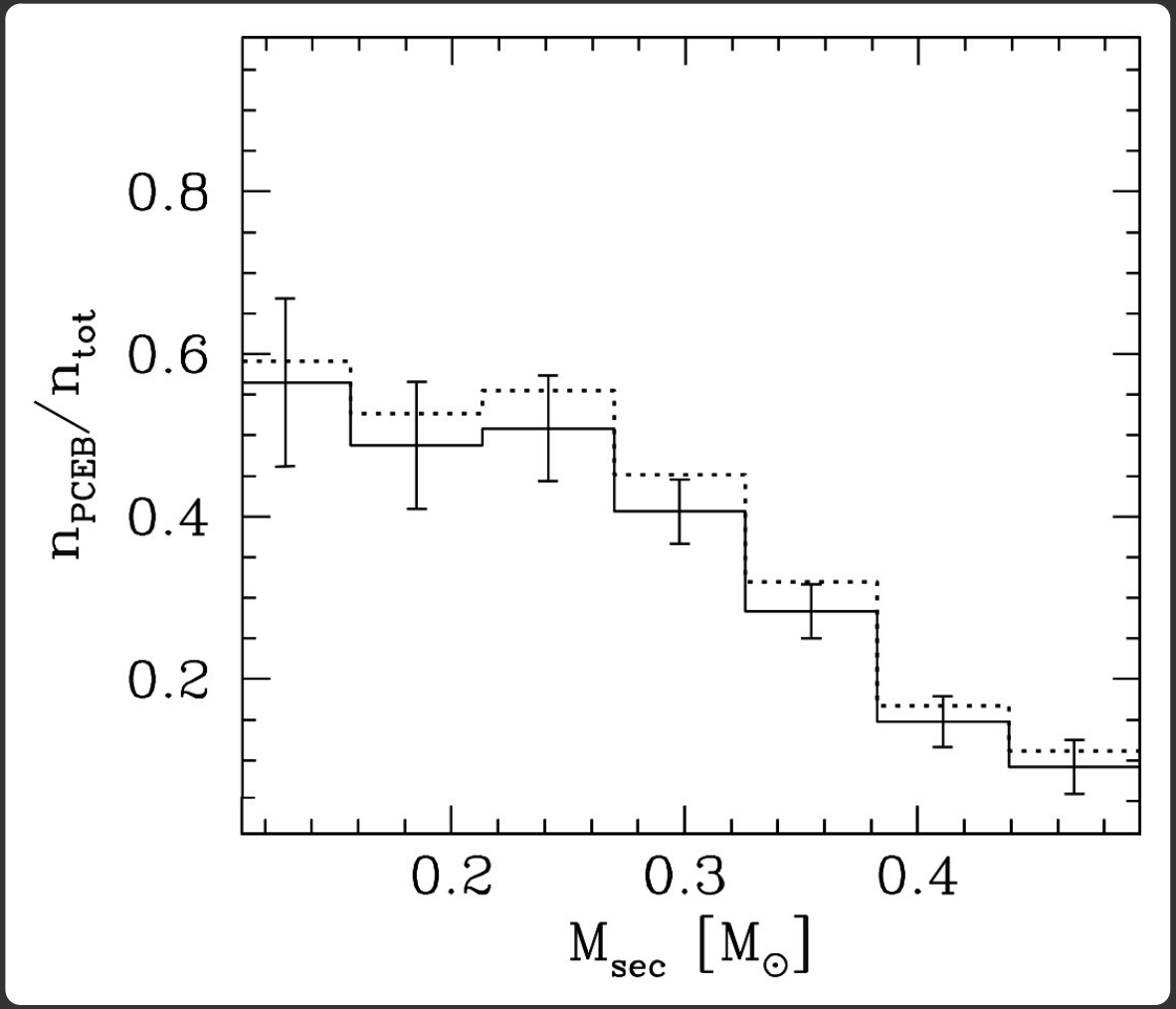


Magnetic Braking

Pre-CVs

(Schreiber et al. 2010)

→ the fraction of pre-CVs steeply decreases by
~ 80–90 % at 0.5 $M_\odot$



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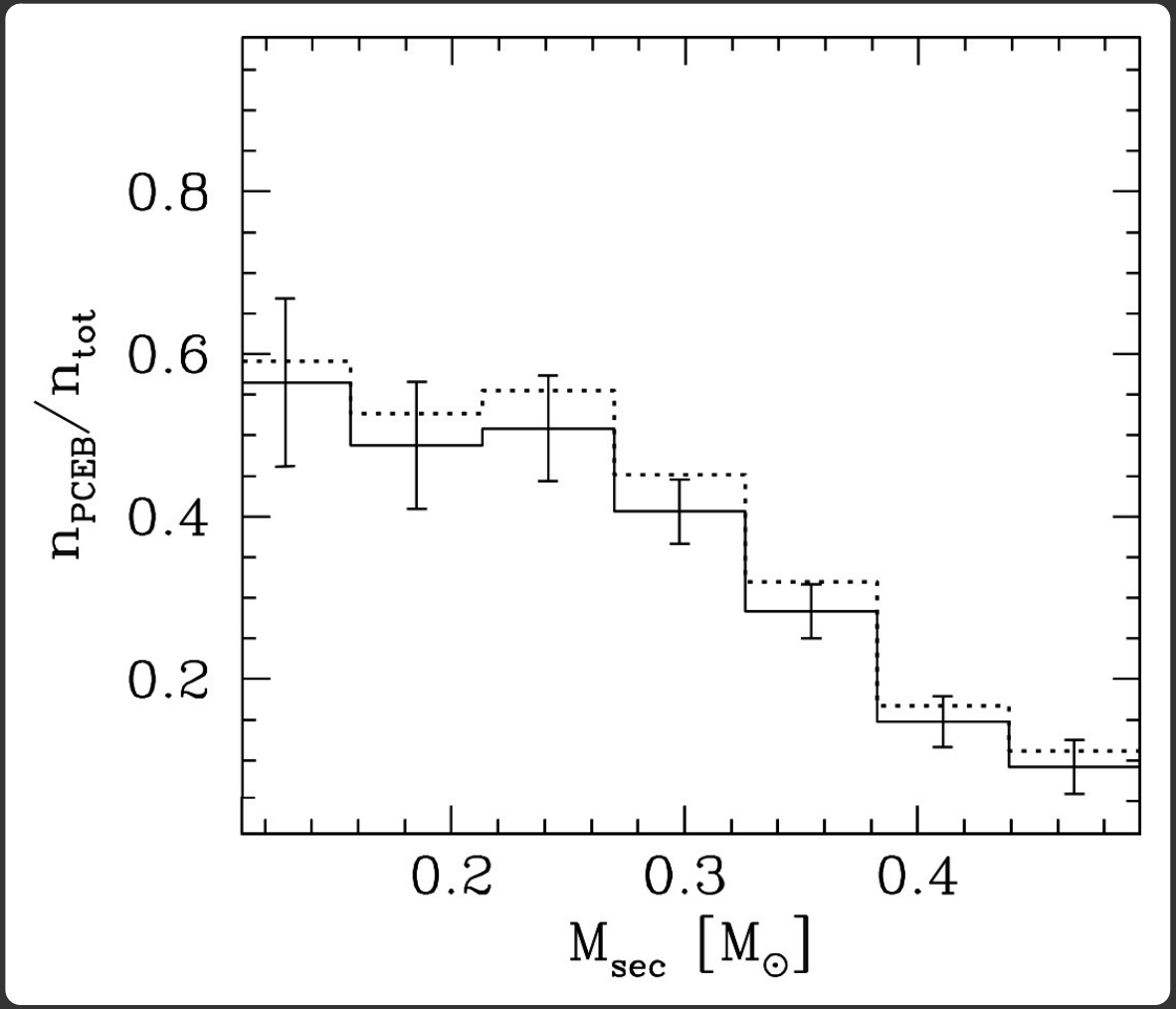
→ *magnetic braking is weaker in* fully convective stars



Magnetic Braking

Pre-CVs

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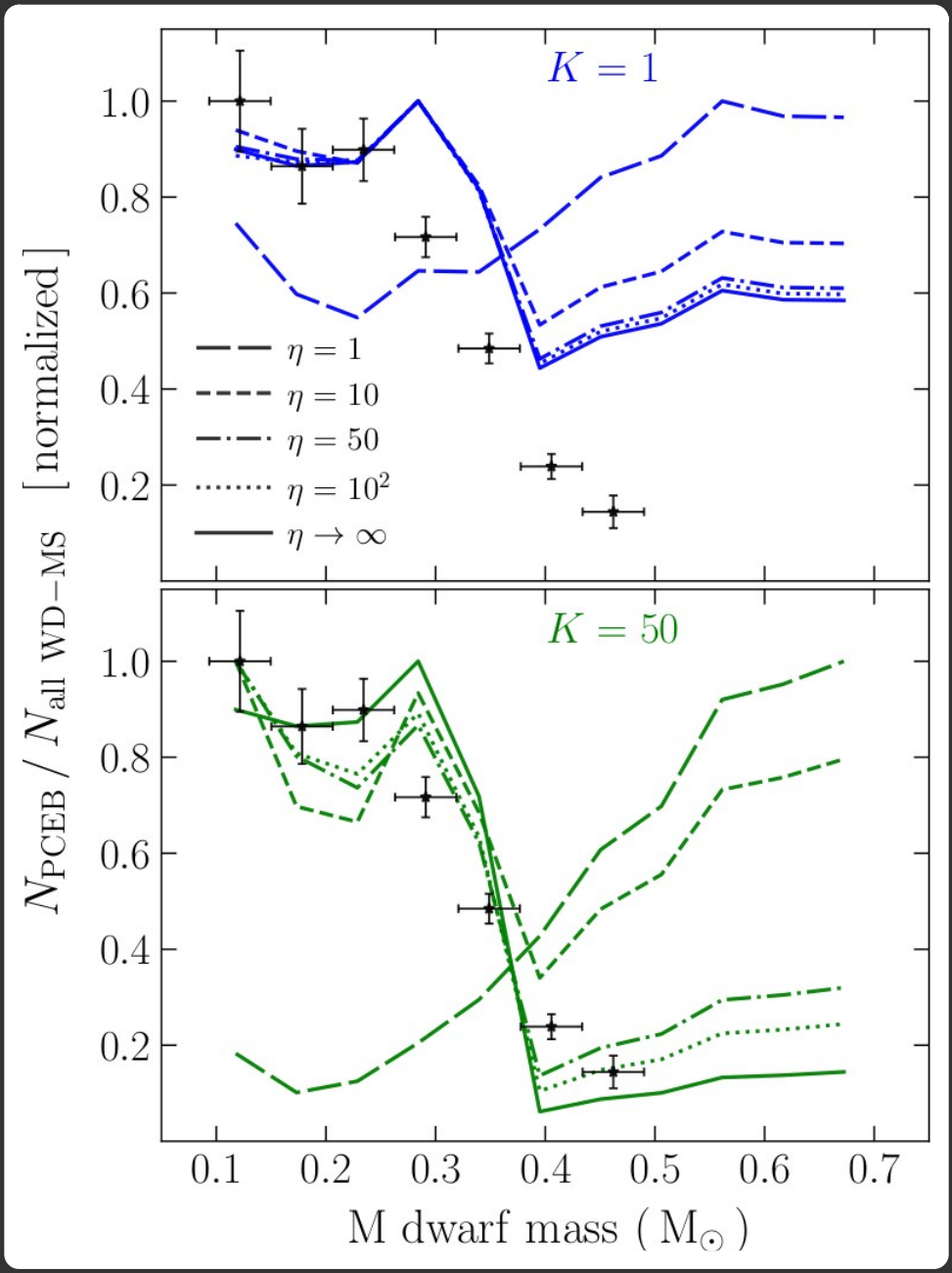

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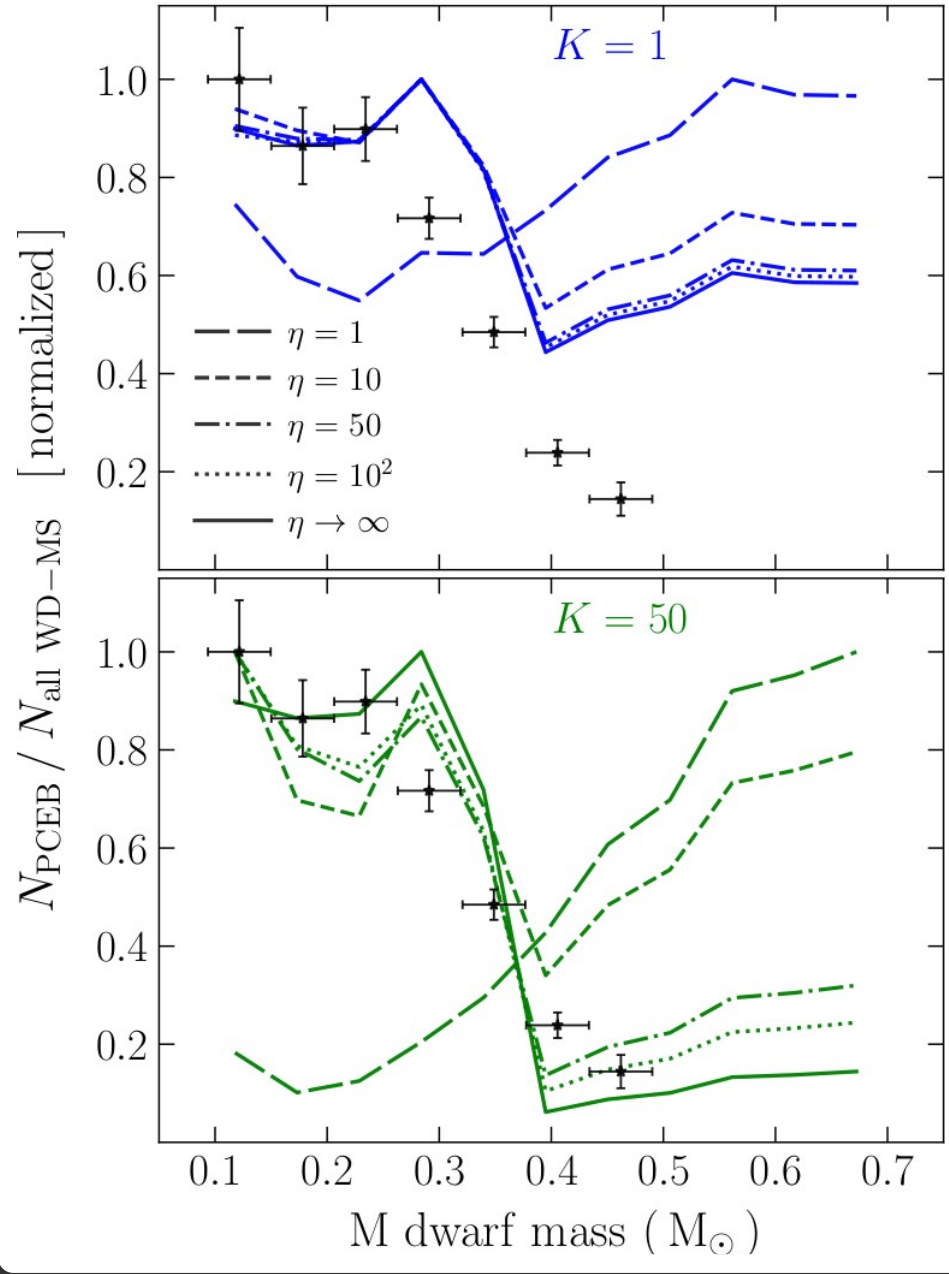
***K* ≳ 10 & *η* ≳ 50**
can reproduce the observational features



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