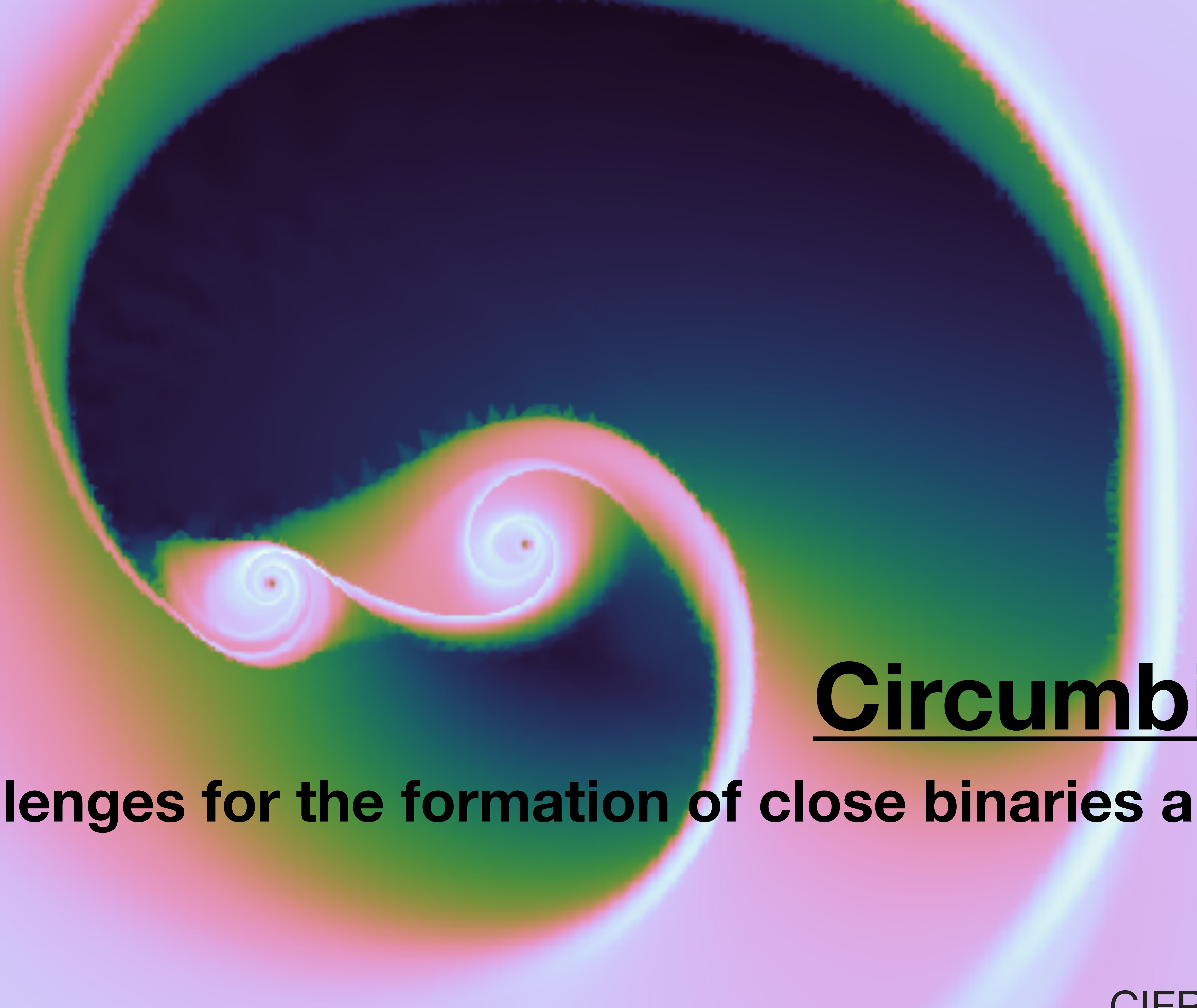


Circumbinary Accretion

Challenges for the formation of close binaries and circumbinary planets

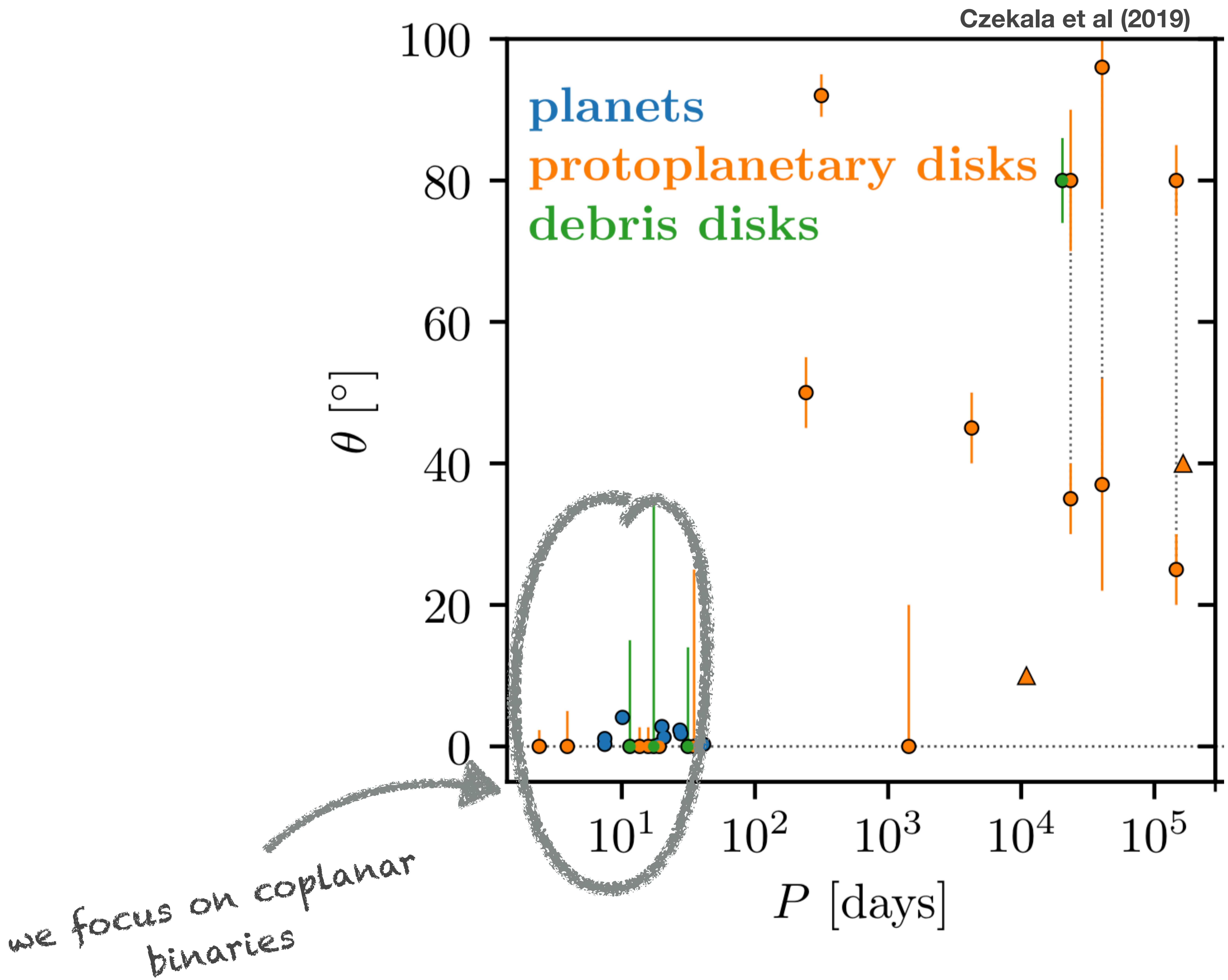
Diego J. Muñoz

CIERA Fellow, Northwestern University

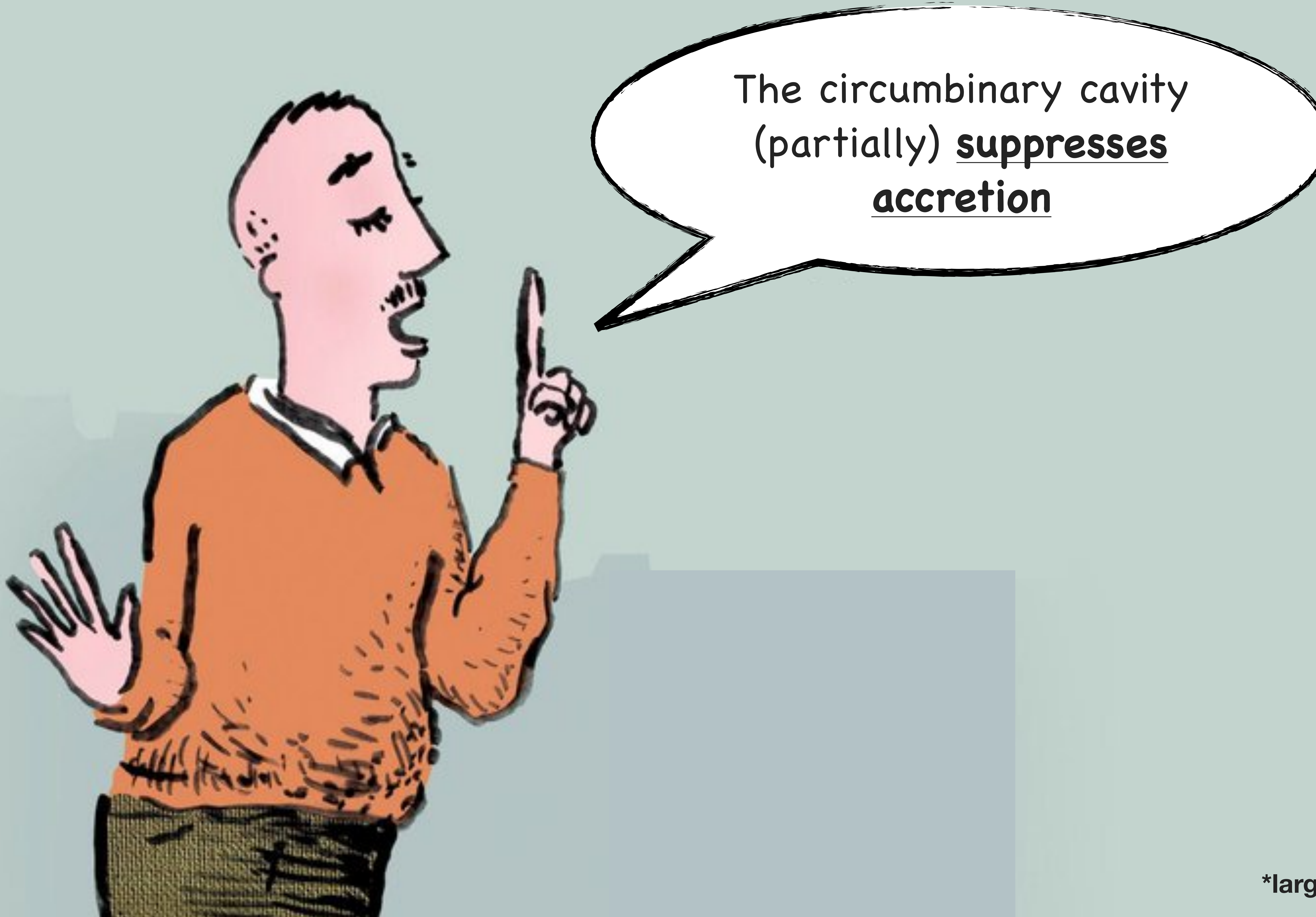
Collaborators: Dong Lai, Ryan Miranda

Also thanks to: Adam Dempsey, Yoram Lithwick, Kaitlin Kratter

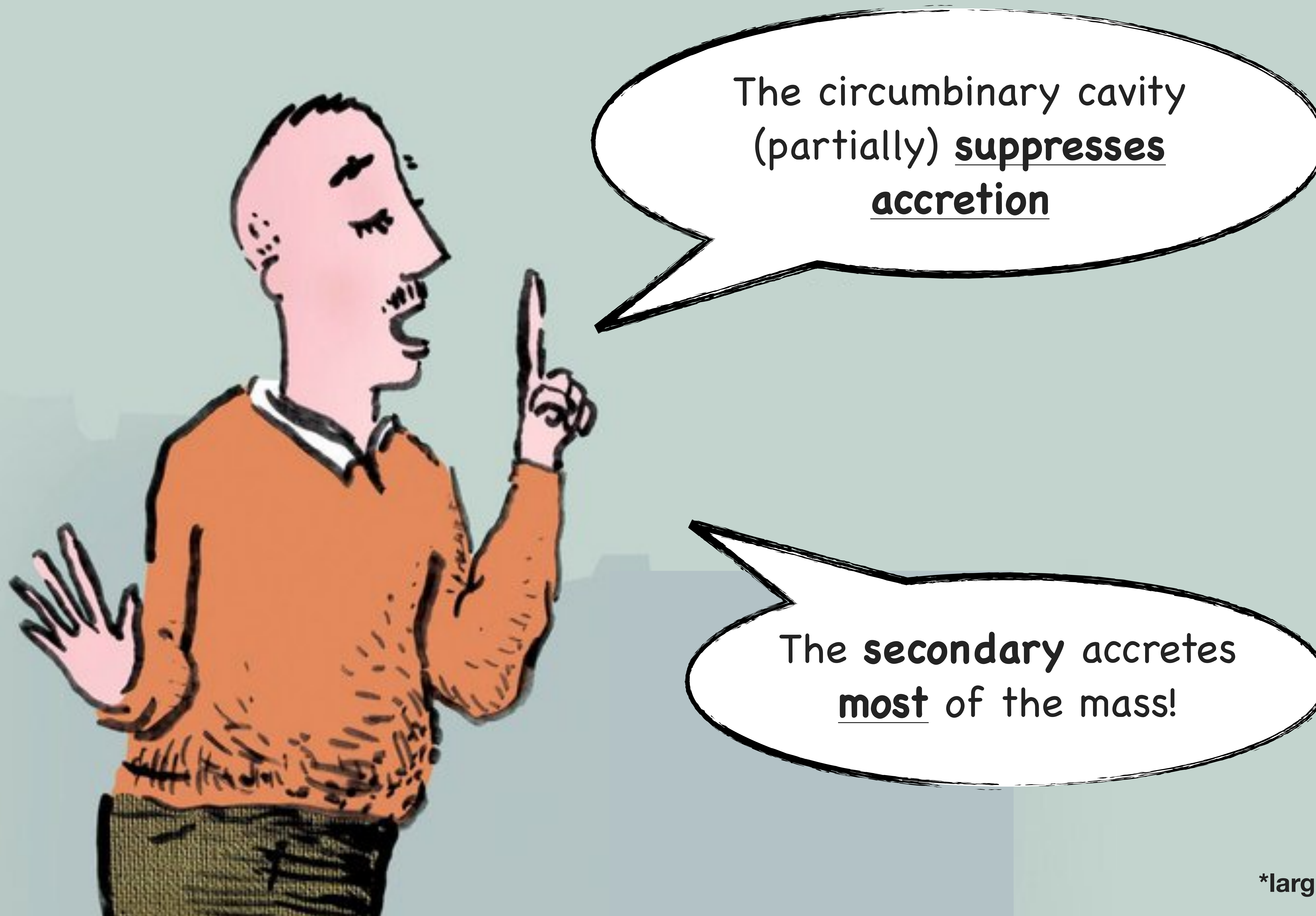
We observe these binaries in nature … Furthermore, they form planets.



e.g., Kennedy+(2012), Czekala et al (2015,16)



*large disks assumed



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Binary growth: equal or unequal masses?

Accreting binaries are expected/assumed to evolve toward mass ratios of unity

(Bate & Bonnell 1997; Dotti+ 2010; Nixon+ 2011,13; Dunhill+2014; Young+2015; Hanawa et al. 2010; de Val-Borro+ 2011; Farris+2014; Young & Clarke 2015).

Important for explaining mass ratios and overdensities of “twins”

Moe (2016)

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Important for explaining mass ratios and overdensities of “twins” Moe (2016)

Binary migration: coalescence or expansion?

Protostellar disks are unlikely to form binaries closer than 50 au via gravitational fragmentation

(e.g., Bate+1995; Matzner & Levin 2005; Rafikov 2005; Boley et al. 2006; Whitworth & Stamatellos 2006; Stamatellos & Whitworth 2008; Cossins et al. 2009; Kratter et al. 2010b; Krumholz et al. 2009; Kratter et al. 2010a; Zhu et al. 2012)

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Circumbinary disk behave differently

Circumbinary disks are eccentric

Miranda, Muñoz & Lai (2017), Ragusa+2018; Price+2018, (also Enrico Ragusa’s talk)

“planet formation is very resilient!” G. Duchene

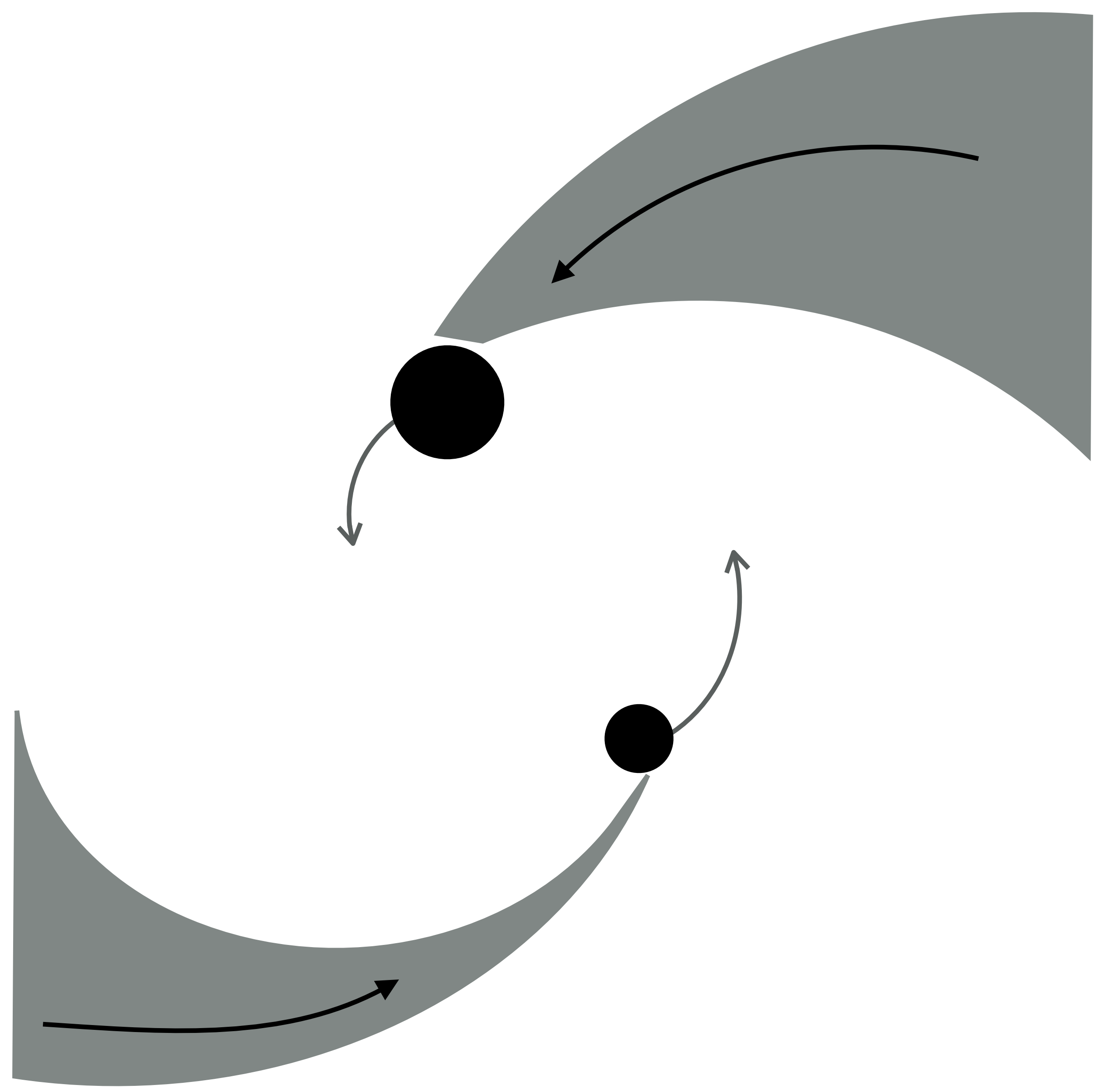
which might be critical to planet formation

Paardekooper+(2012); Rafikov (2013); Rafikov & Silsbee (2015)

Secular dynamics of circumbinary disks seldom probed/analyzed in hydro

e.g., Goodchild & Ogilvie (2006), Teyssandier+(2018);

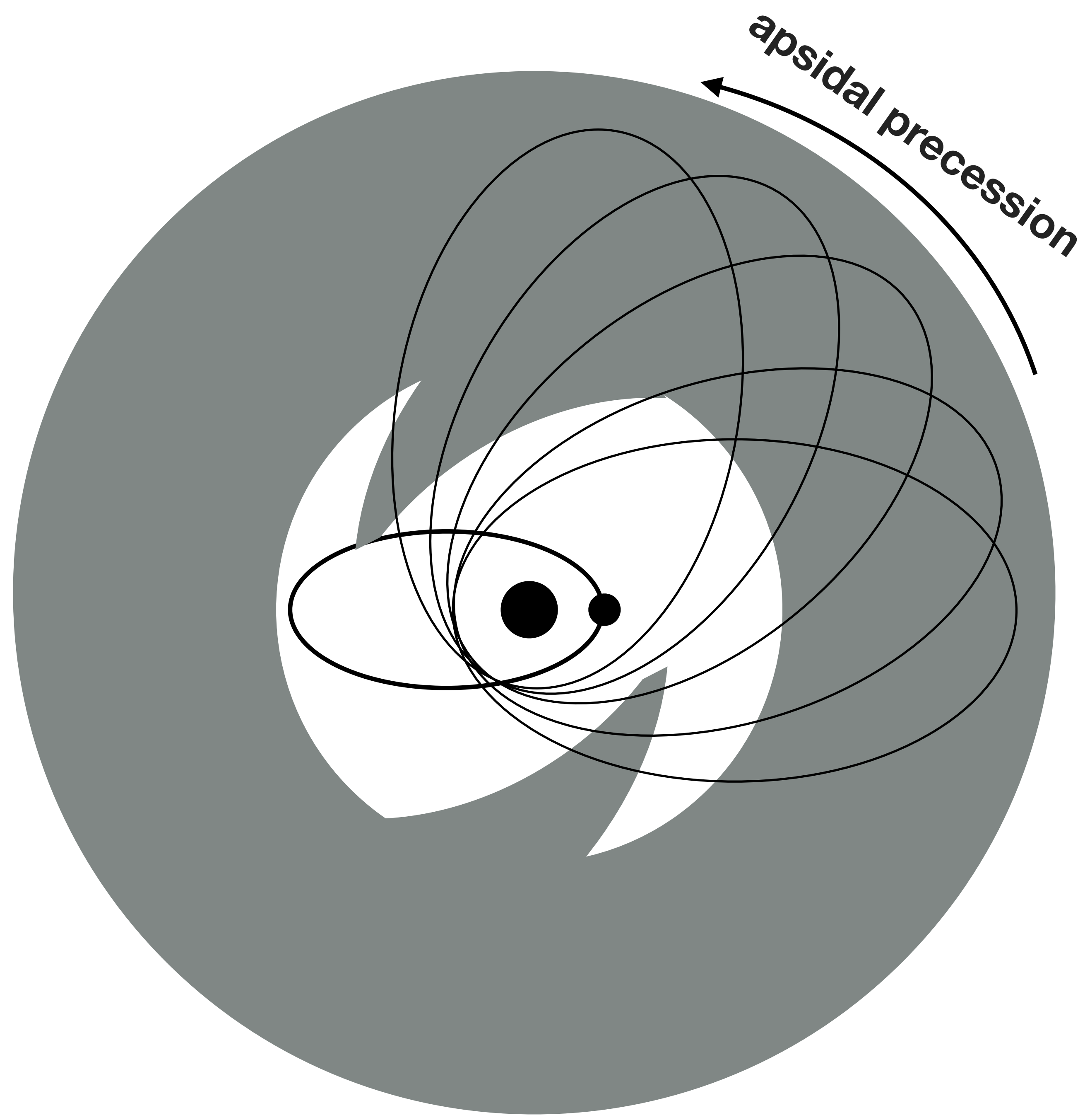
Binary accretion is a multiple-timescales problem.



dynamical timescales

$$\tau \sim \frac{1}{\Omega_{\rm b}}$$

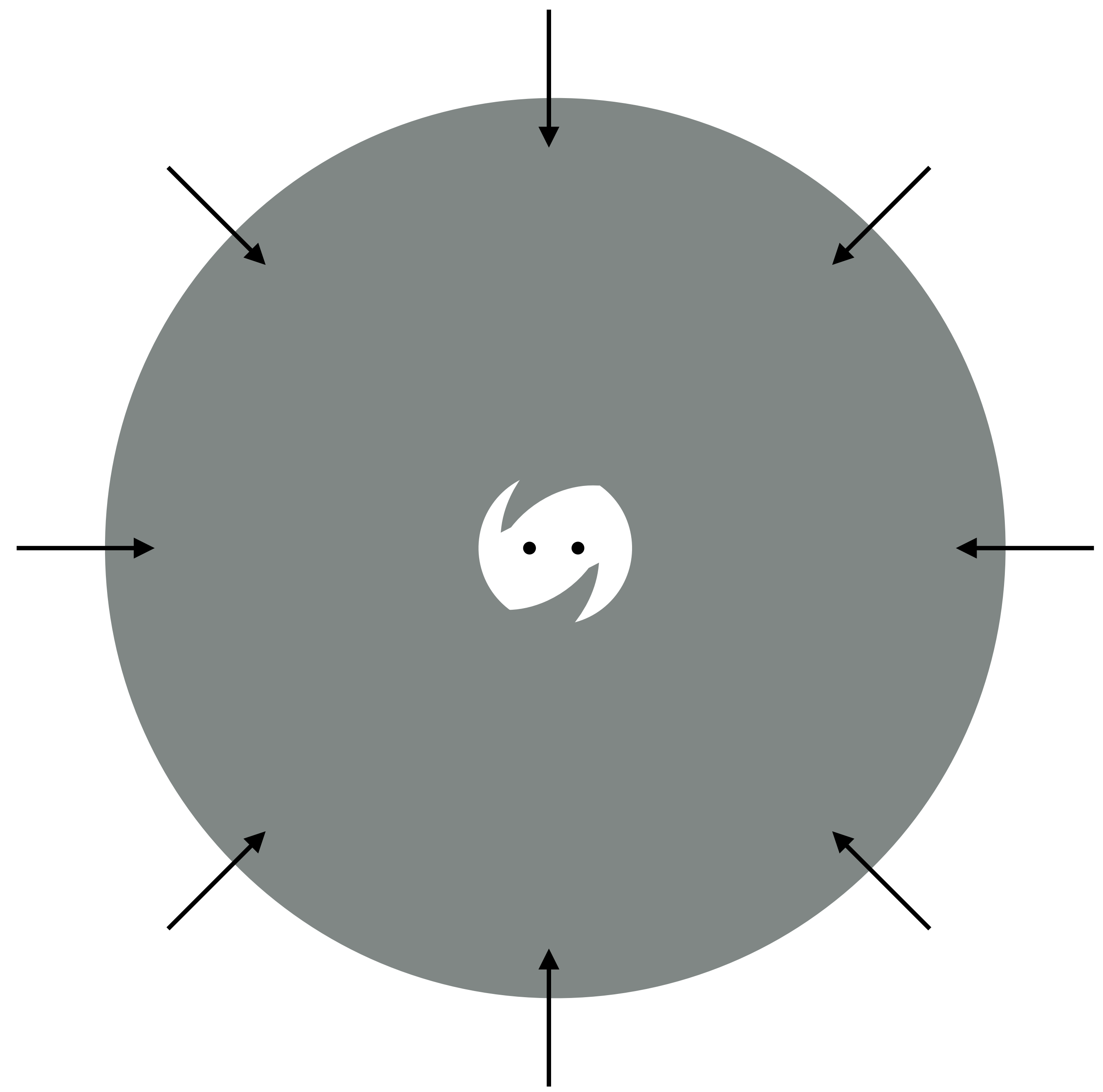
a few orbits



secular timescales

$$\tau \sim \frac{1}{\Omega_{\rm b}} \frac{(1+q_{\rm b})^2}{q_{\rm b}} \left(1+\frac{3}{2}e_{\rm b}^2\right)^{-1} \left(\frac{R}{a_{\rm b}}\right)^{7/2}$$

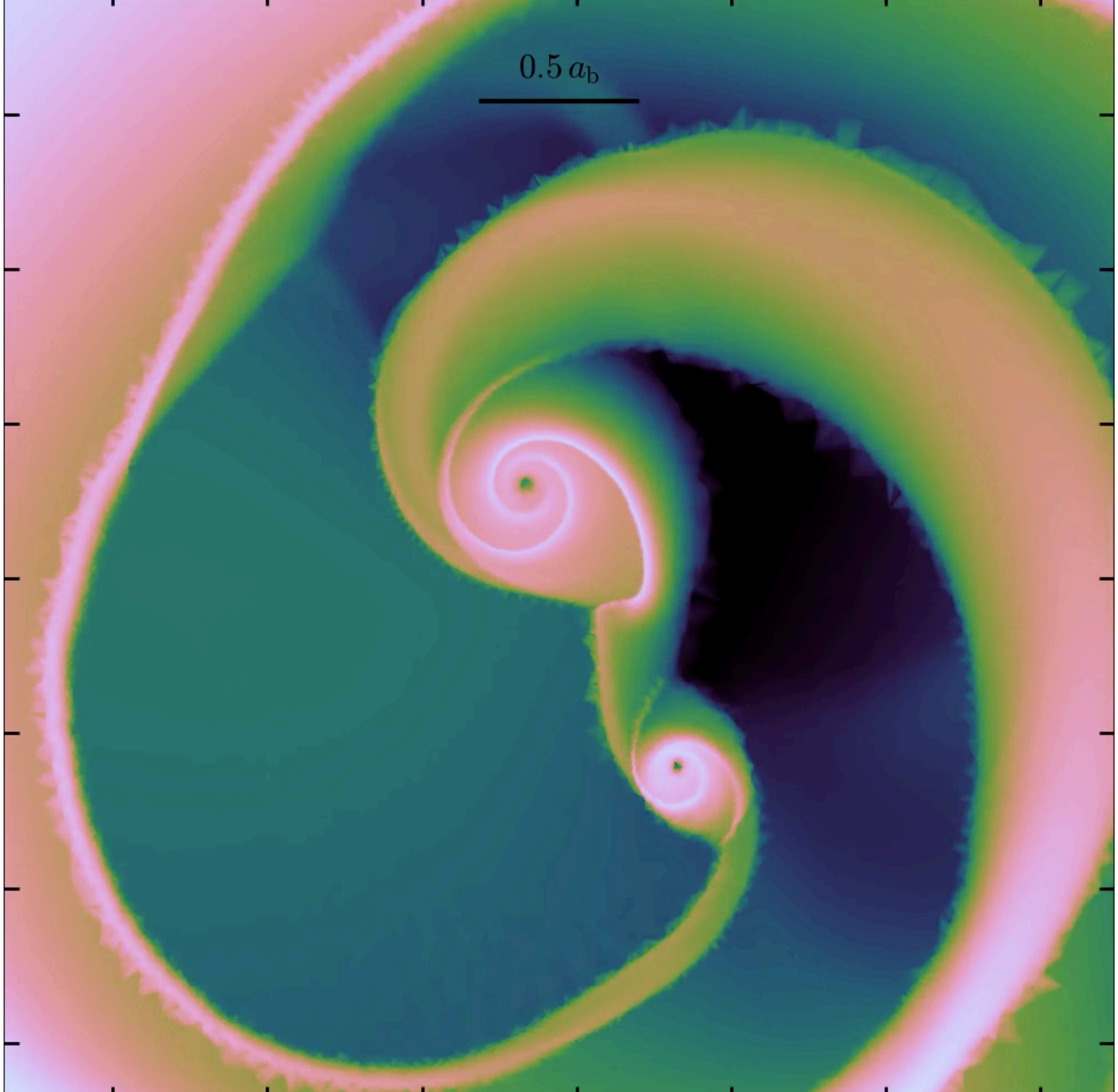
hundreds of orbits



viscous timescales

$$\tau \sim \frac{R^2}{\nu} \sim \frac{1}{\Omega_{\rm b}} \frac{1}{\alpha h_0^2} \left(\frac{R}{a_{\rm b}}\right)^{3/2}$$

thousands-to-millions of orbits



Moving-tessellation ALE Godunov method AREPO

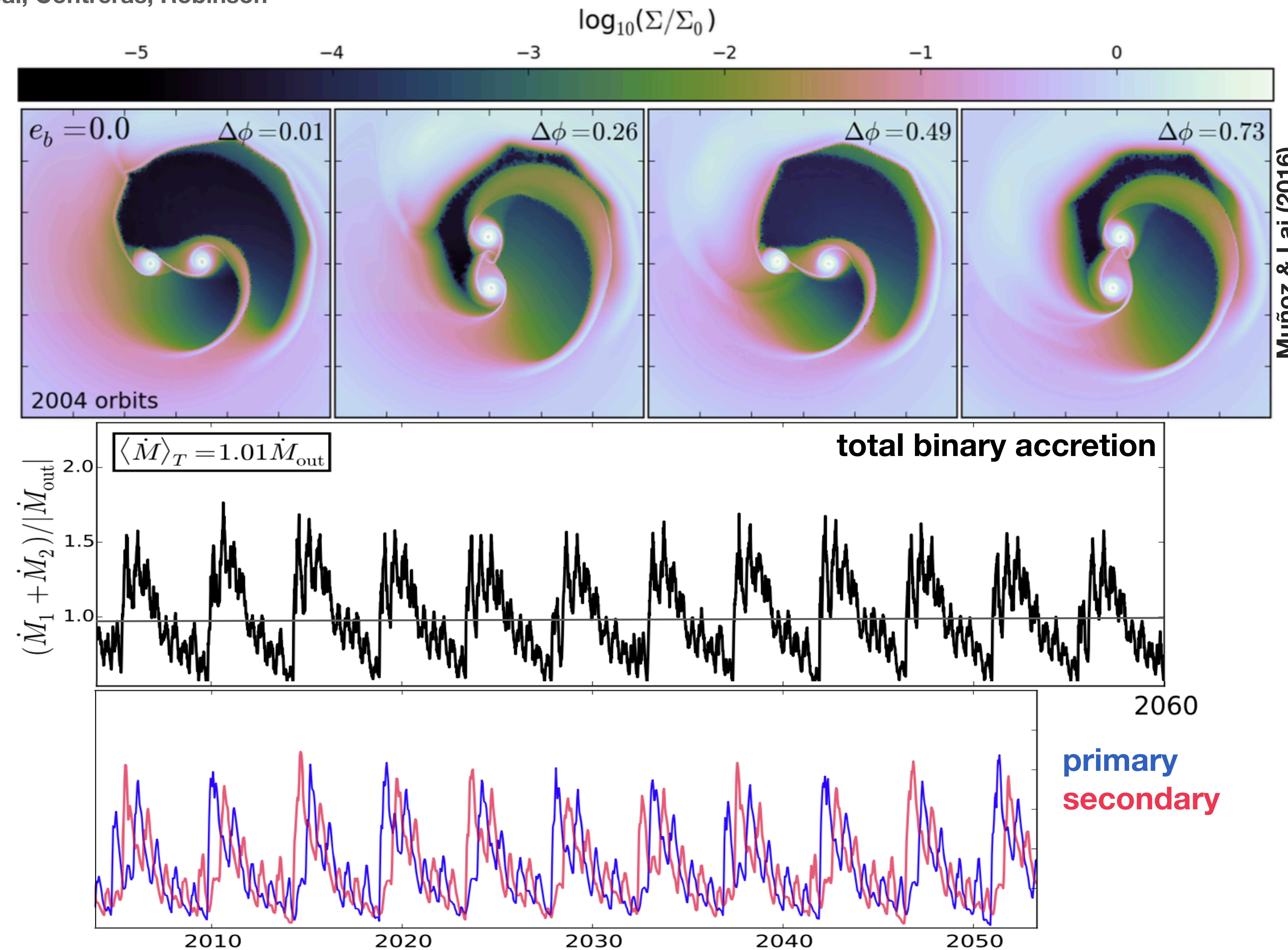
Springel (2010);
Muñoz+(2013,14);
Pakmor+(2016)

Circumbinary accretion is not suppressed but modulated.

Binarity is a well-known cause of periodic variabilty

e.g., talks by Agnes Kospal, Contreras, Robinson

circular



Muñoz & Lai (2016)

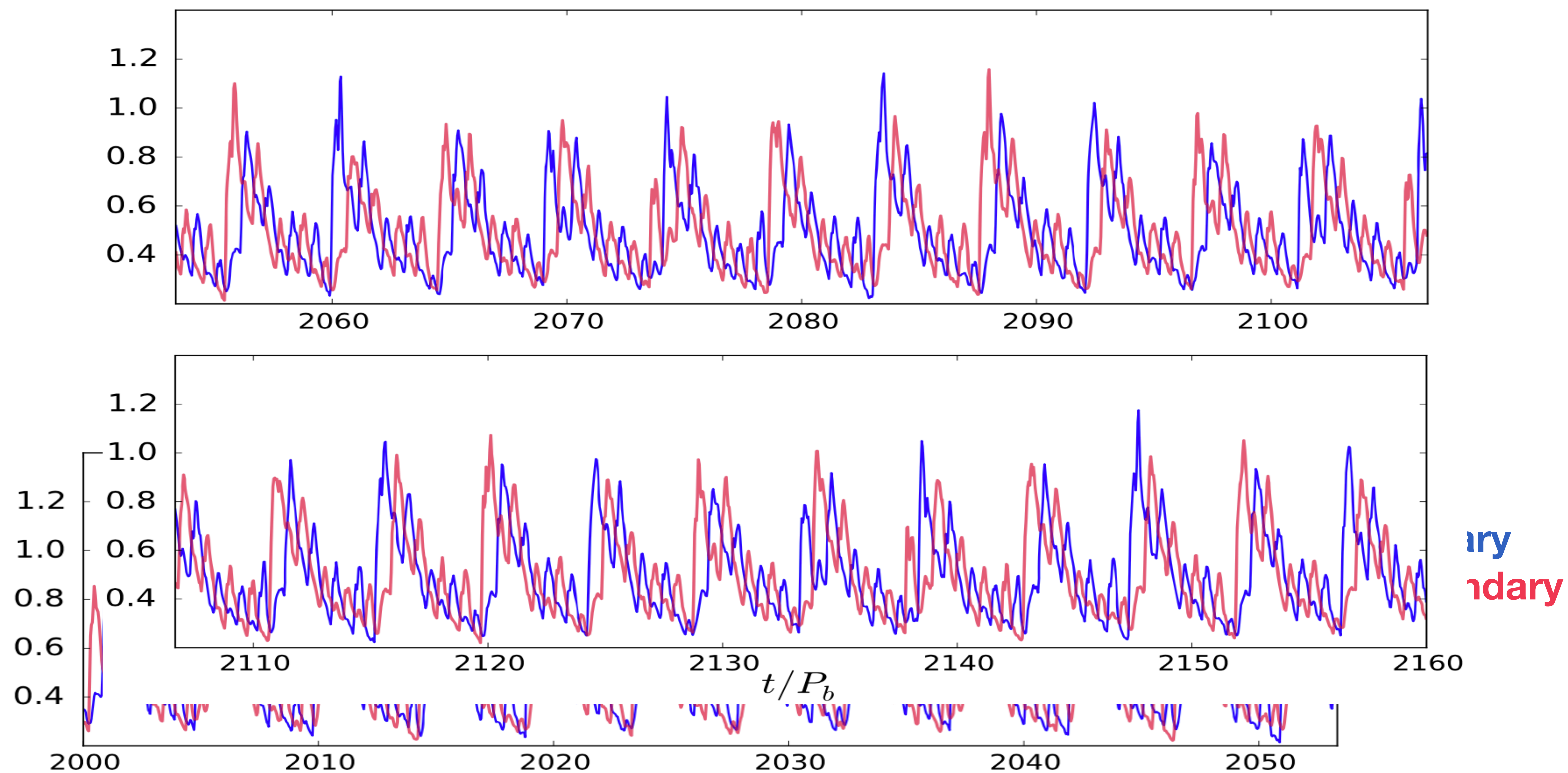
$h = \alpha = 0.1$

primary

secondary

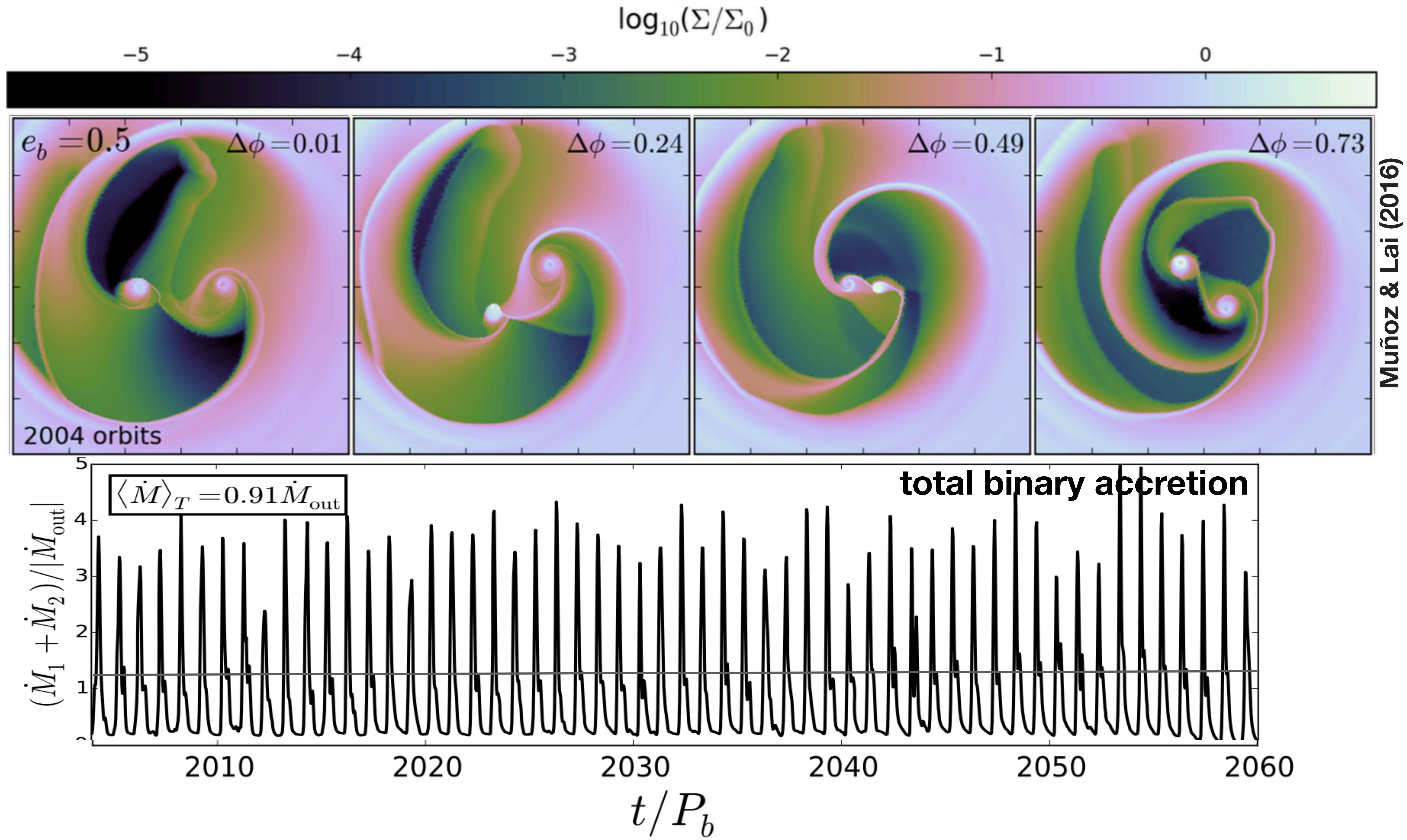
(also MacFadyen+Milisavljevic 2008, Shi+ 2012, Farri+2012)

Long-term accretion reaches a quasi-steady state in circular binaries.



Long-term accretion reaches a quasi-steady state in eccentric binaries.

eccentric



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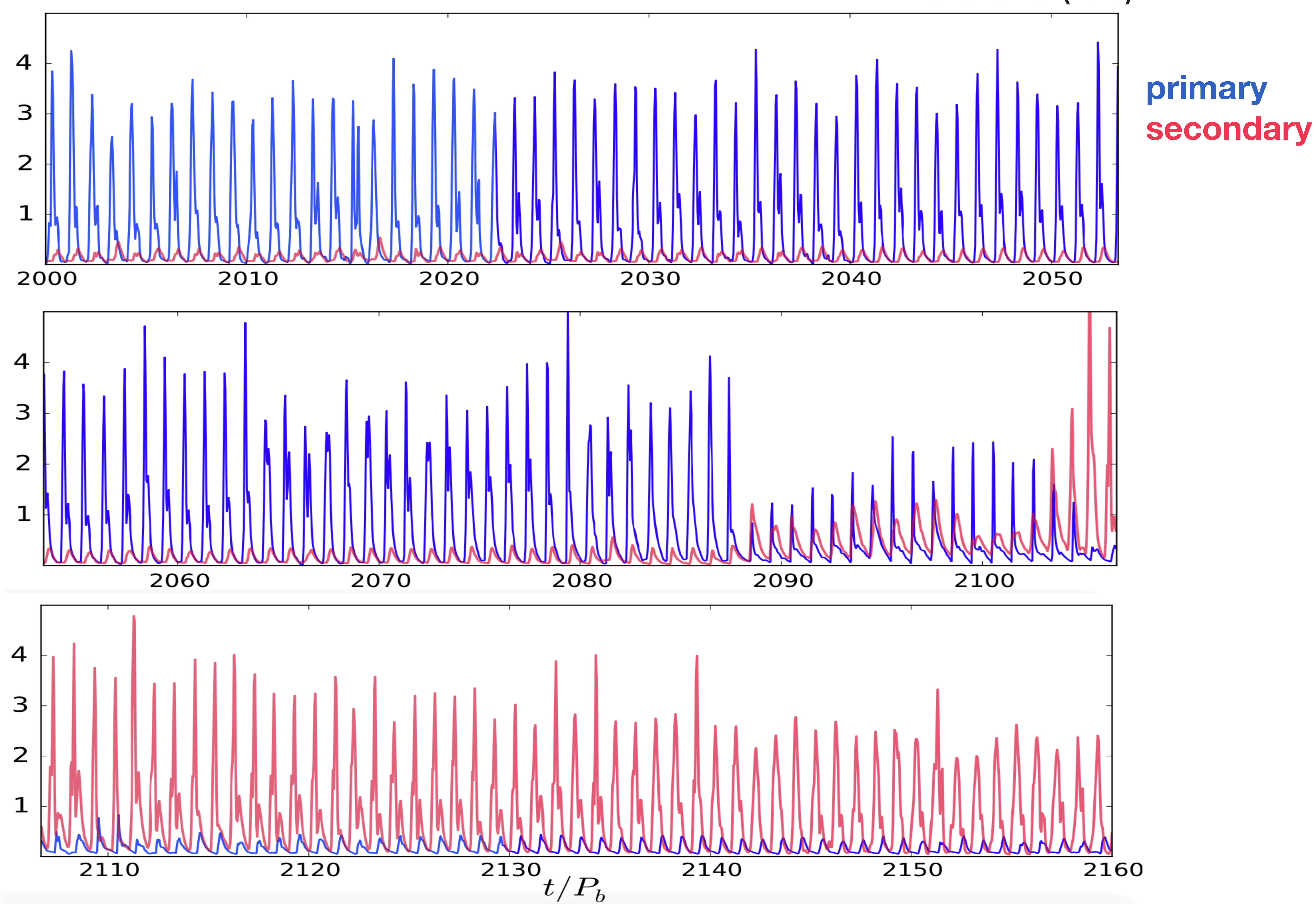
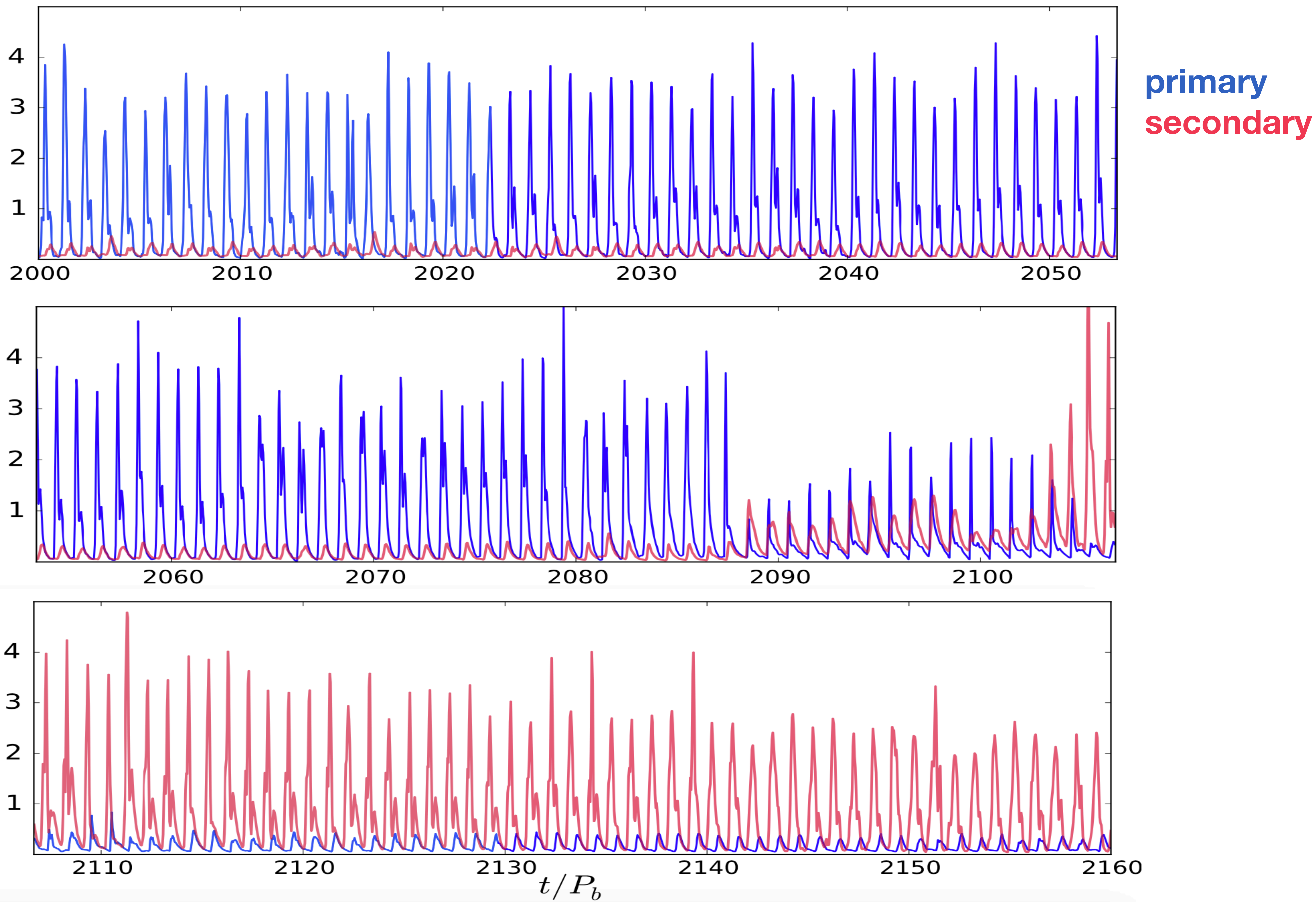
Accretion suffers a “symmetry breaking” in eccentric binaries.

Muñoz & Lai (2016)

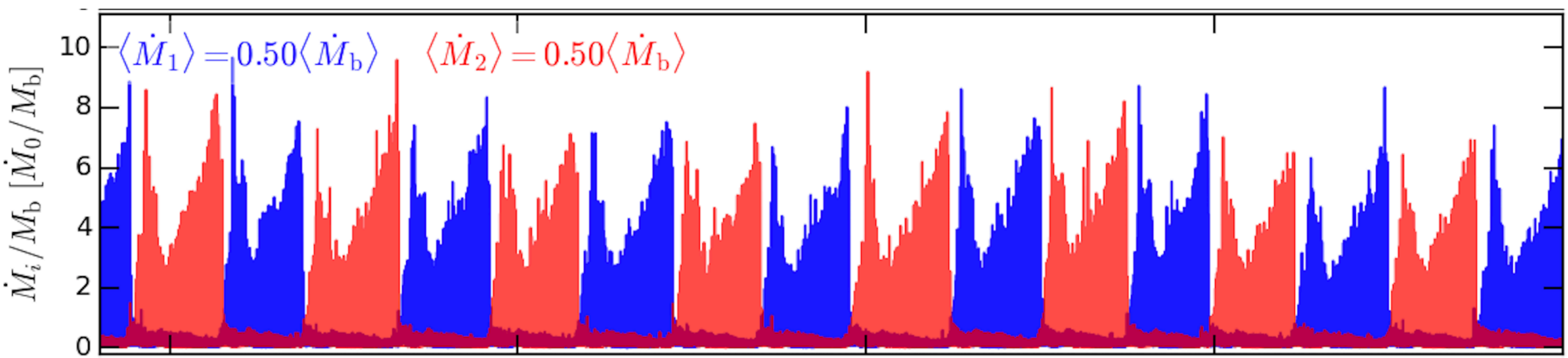


Accretion suffers a “symmetry breaking” in eccentric binaries.

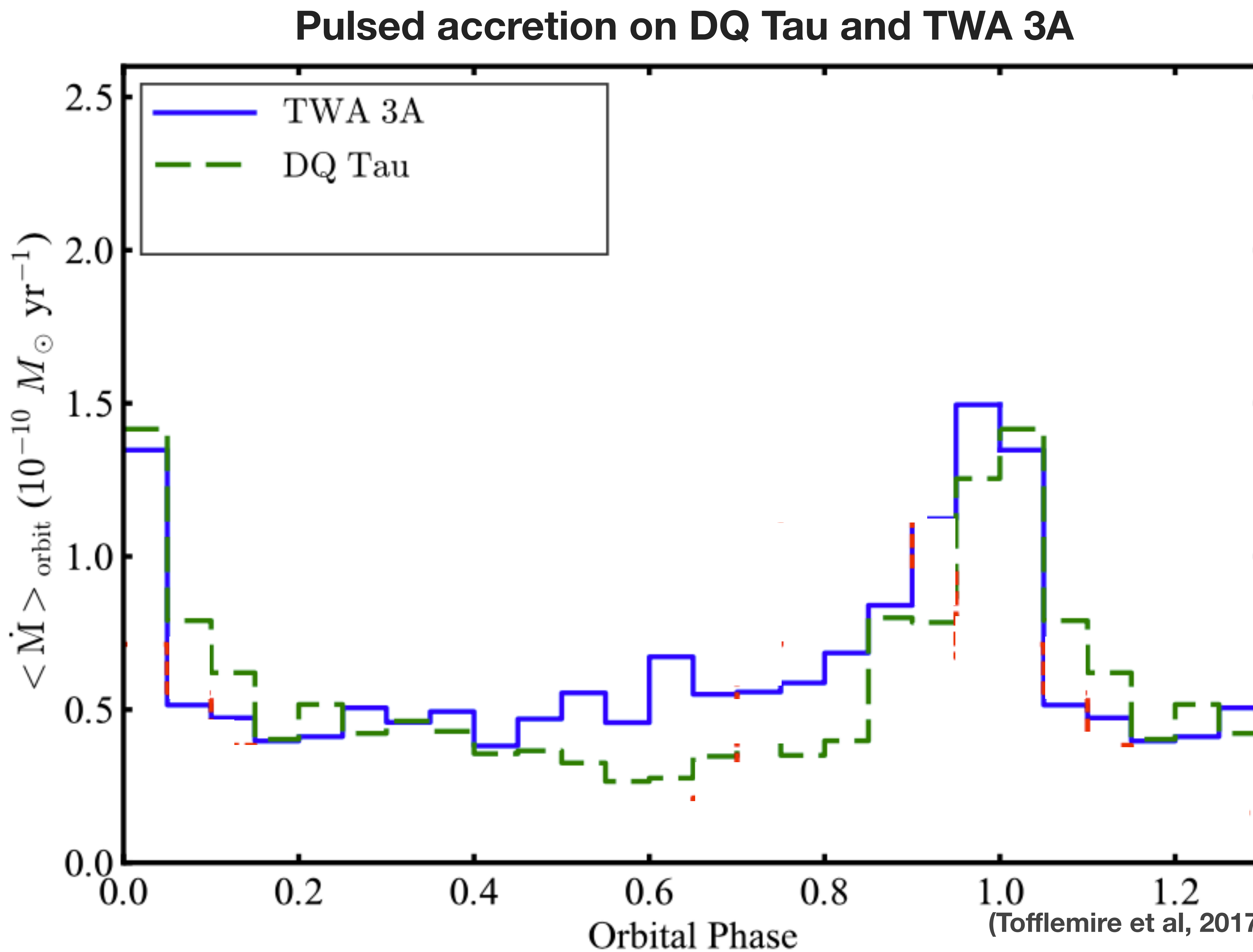
alternating-preferential accretion (Dunhill+2015; Muñoz & Lai, 2016)



Accretion onto high-mass ratio eccentric binaries is alternating-preferential



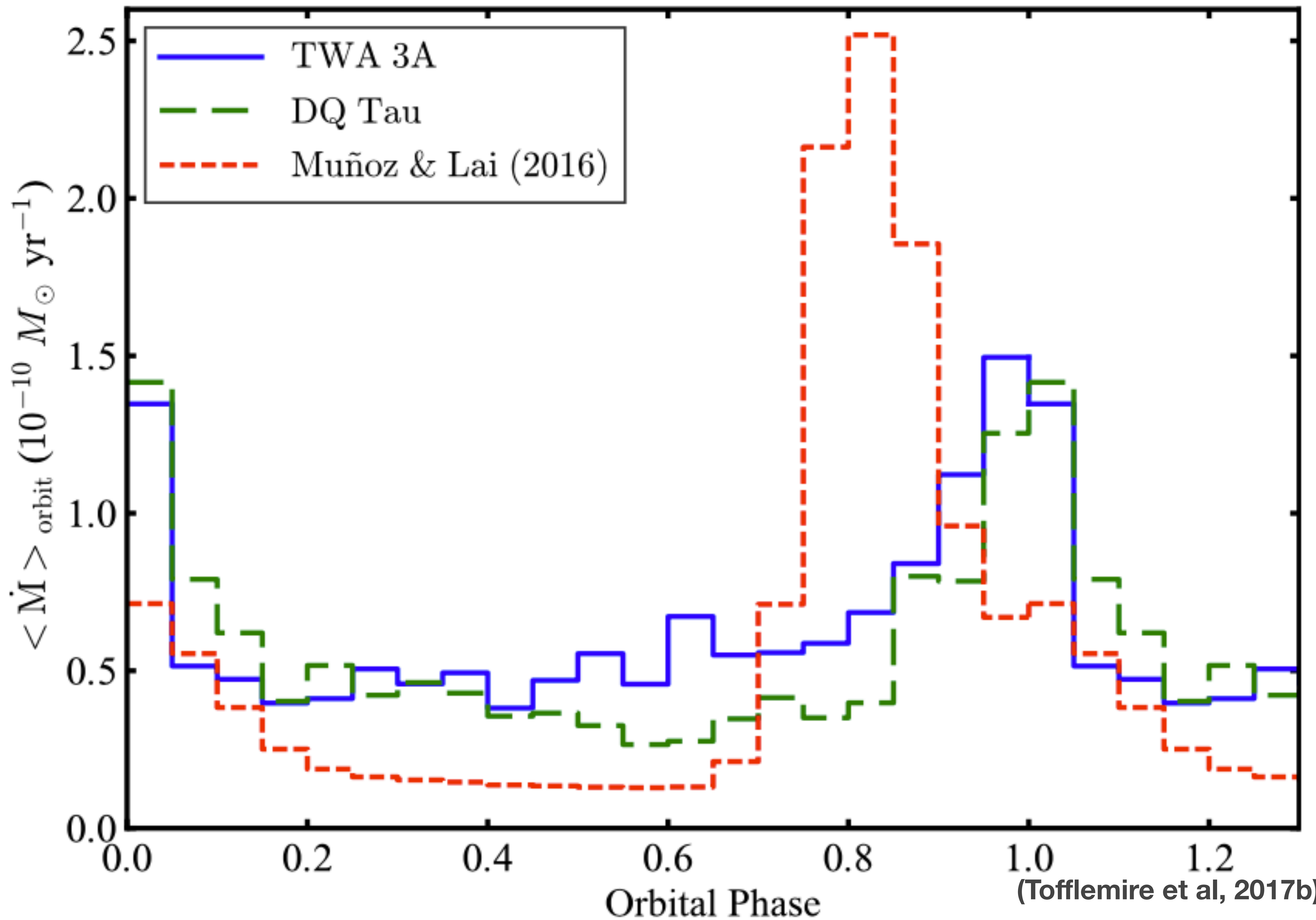
Binaries can modulate accretion, but not suppress it.



(Tofflemire et al, 2017b)

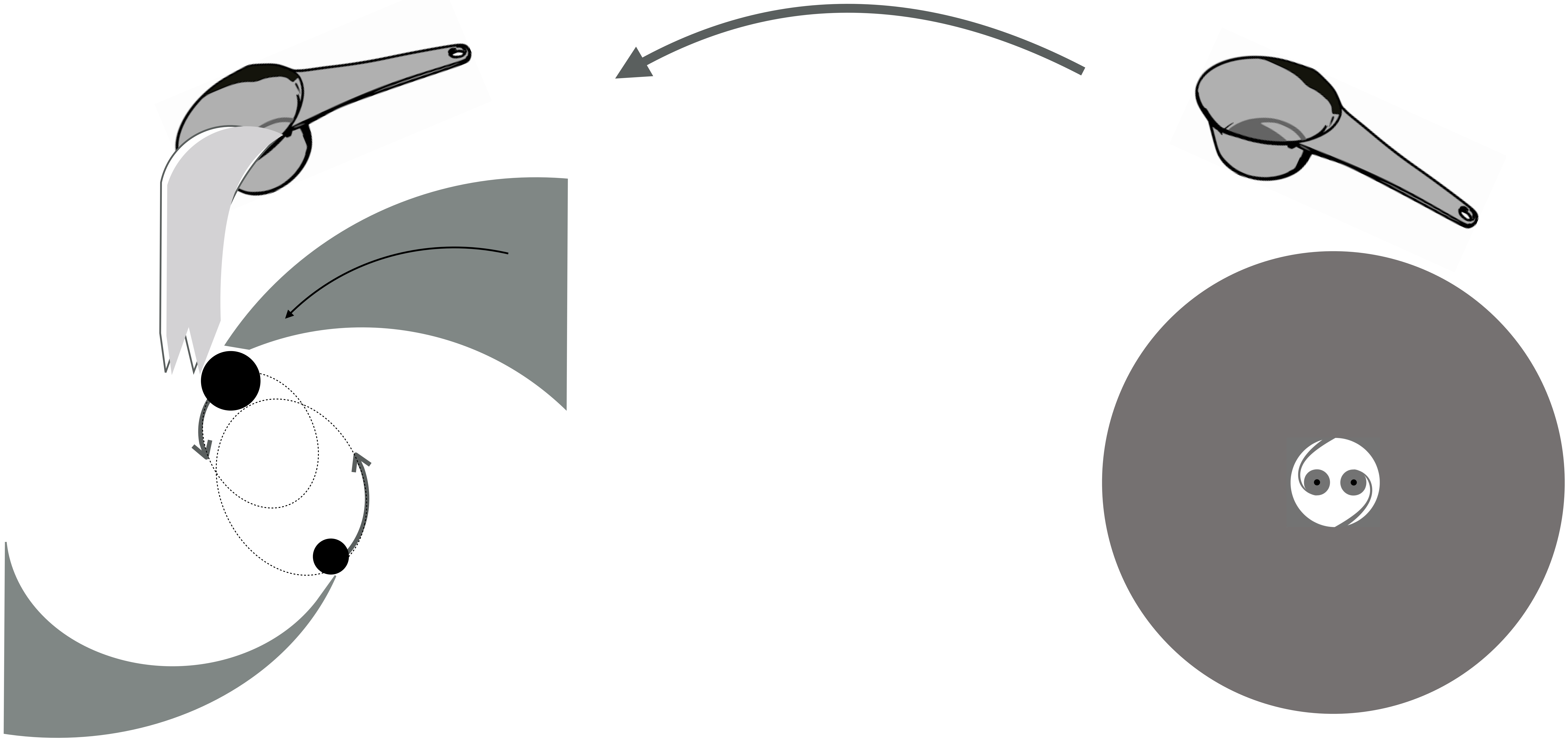
Binaries can modulate accretion, but not suppress it.

Pulsed accretion on DQ Tau and TWA 3A



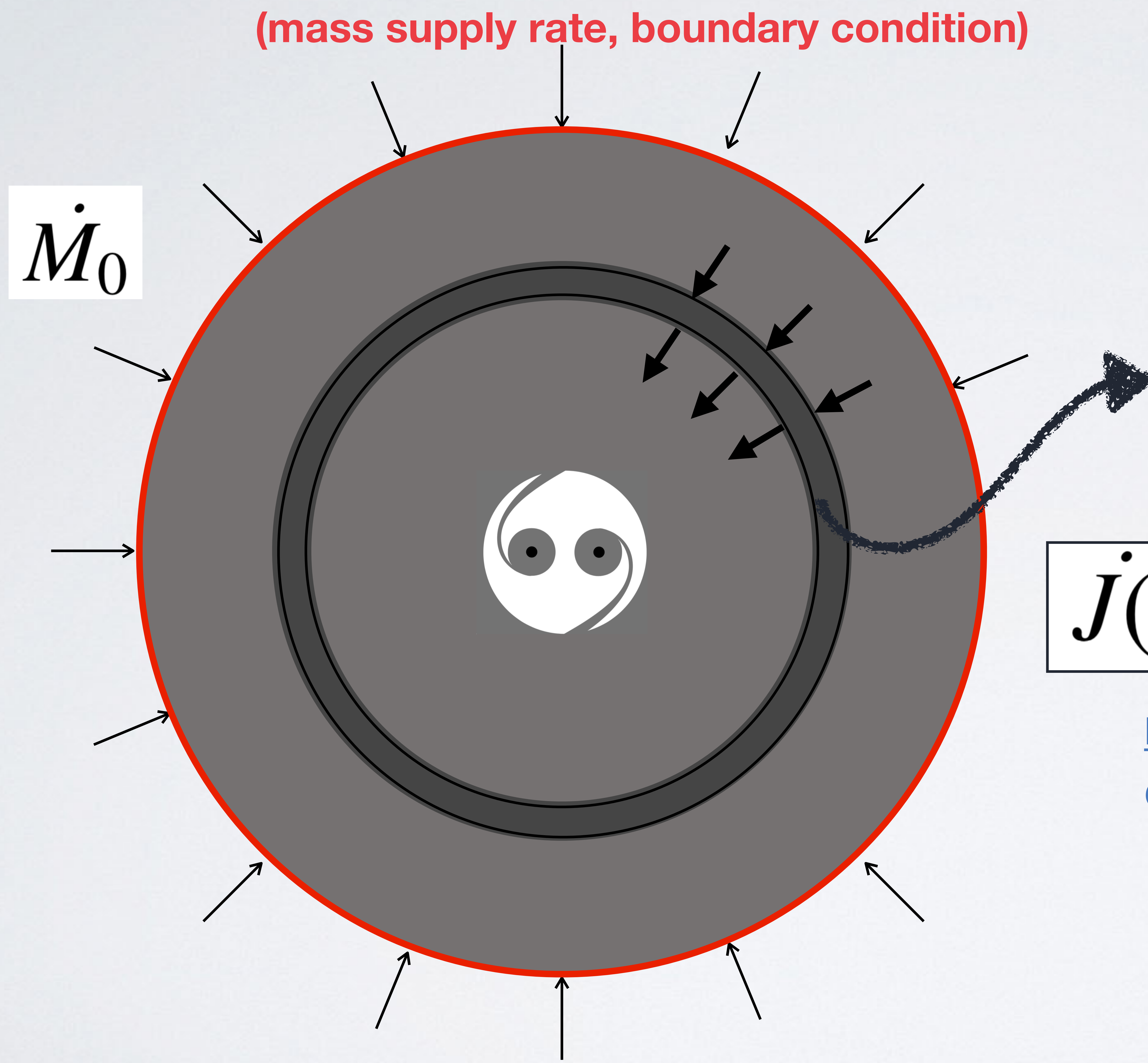
(Tofflemire et al, 2017b)

Binaries have no issue accreting mass… they also accrete momentum.



l_0 is the angular momentum per unit accreted mass

The first way is the "disk way"



at each annulus

$$\boxed{\dot{M}(R,t)}$$

$$\boxed{\dot{J}(R,t) = \dot{J}_{\rm adv} - \dot{J}_{\rm visc} - \dot{J}_{\rm grav}}$$

mass and angular momentum currents (transfer rates)

The first way is the "disk way"

Accretion disks transport angular momentum outward and advect angular momentum inward

angular momentum conservation

$$\boxed{\frac{\partial}{\partial t}(\Sigma l) + \frac{1}{R}\frac{\partial}{\partial R}\left[\underbrace{\dot{M}l}_{\text{advective term}} - \underbrace{F_\nu}_{\text{viscous term}}\right] = 0}$$

$$F_\nu = -2\pi\nu\Sigma R^3 \frac{d\Omega}{dR}$$

Angular momentum exchange can be computed in two ways.

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advective term

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viscous term

$$F_\nu=-2\pi\nu\Sigma R^3\frac{d\Omega}{dR}$$

in steady state:

$$\dot{M}l-F_\nu=\mathrm{constant}\equiv\dot{M}l_0$$

l_0 is the "accretion eigenvalue" (e.g. Paczynski 1991; Popham & Narayan 1991),

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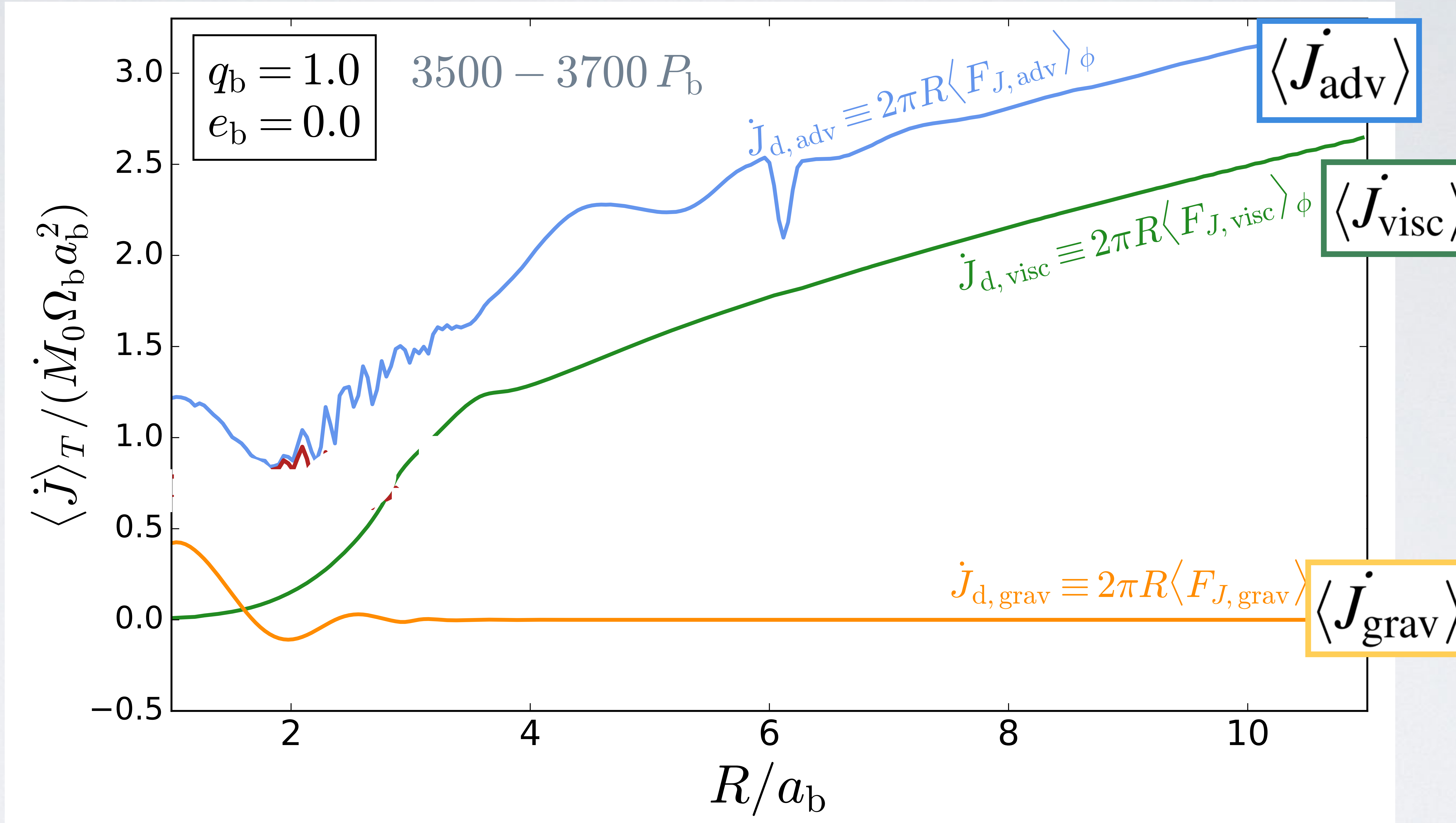
In simple models with accretion down to the stellar surface

$$\dot{M}l_0 = \dot{M}\sqrt{\mathcal{G}M_*R_*}$$

e.g., accretion boundary layers

Binary gains angular momentum from the disk

Miranda, Muñoz& Lai (2017); Muñoz, Miranda & Lai (2019), Moody+(2019)



$$\frac{\langle \dot{J}(R,t) \rangle}{\langle \dot{M}(R,t) \rangle} \approx 0.7 \Omega_b a_b^2$$

Muñoz, Miranda & Lai (2019)

(also Moody+2019)

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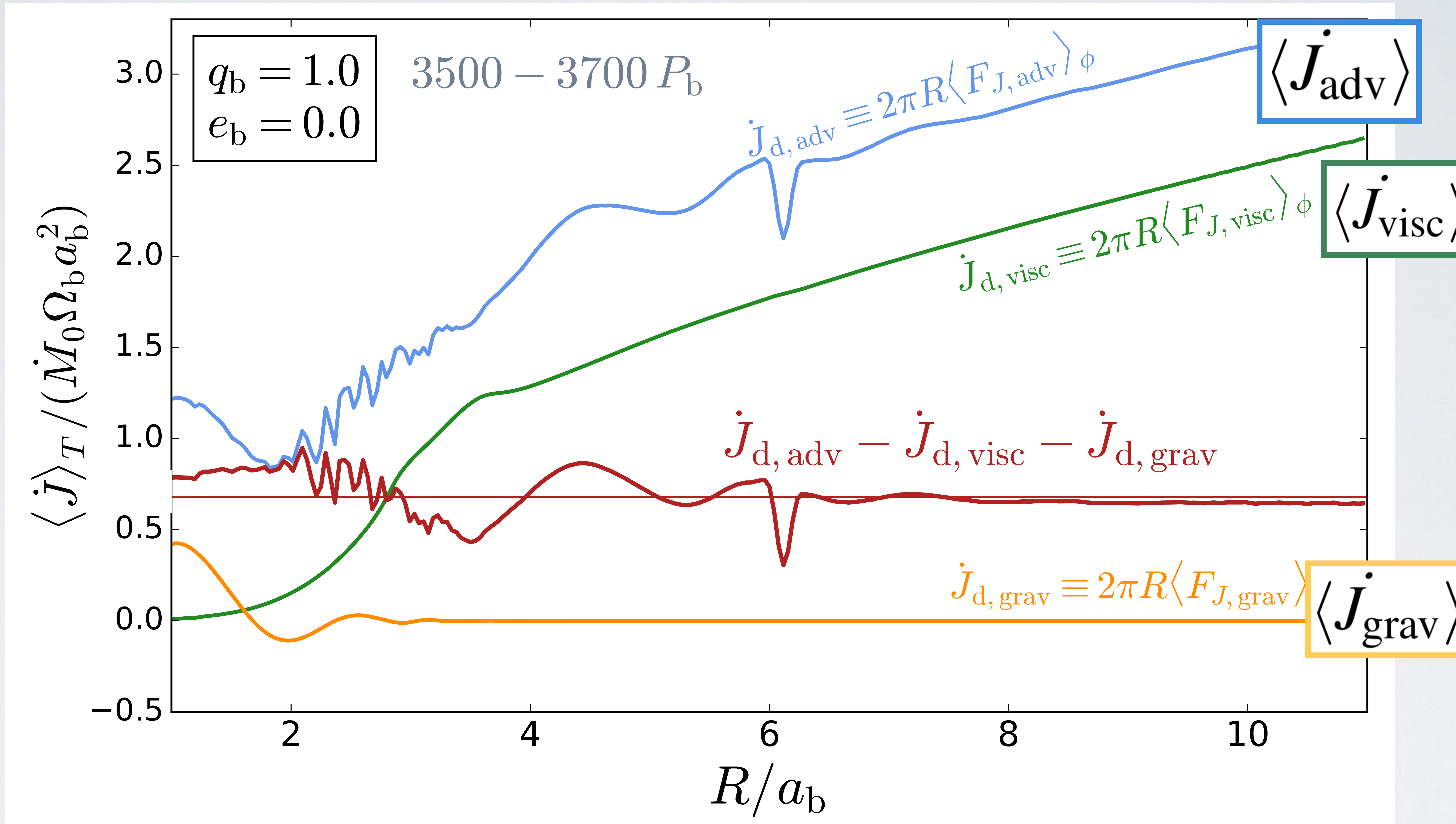

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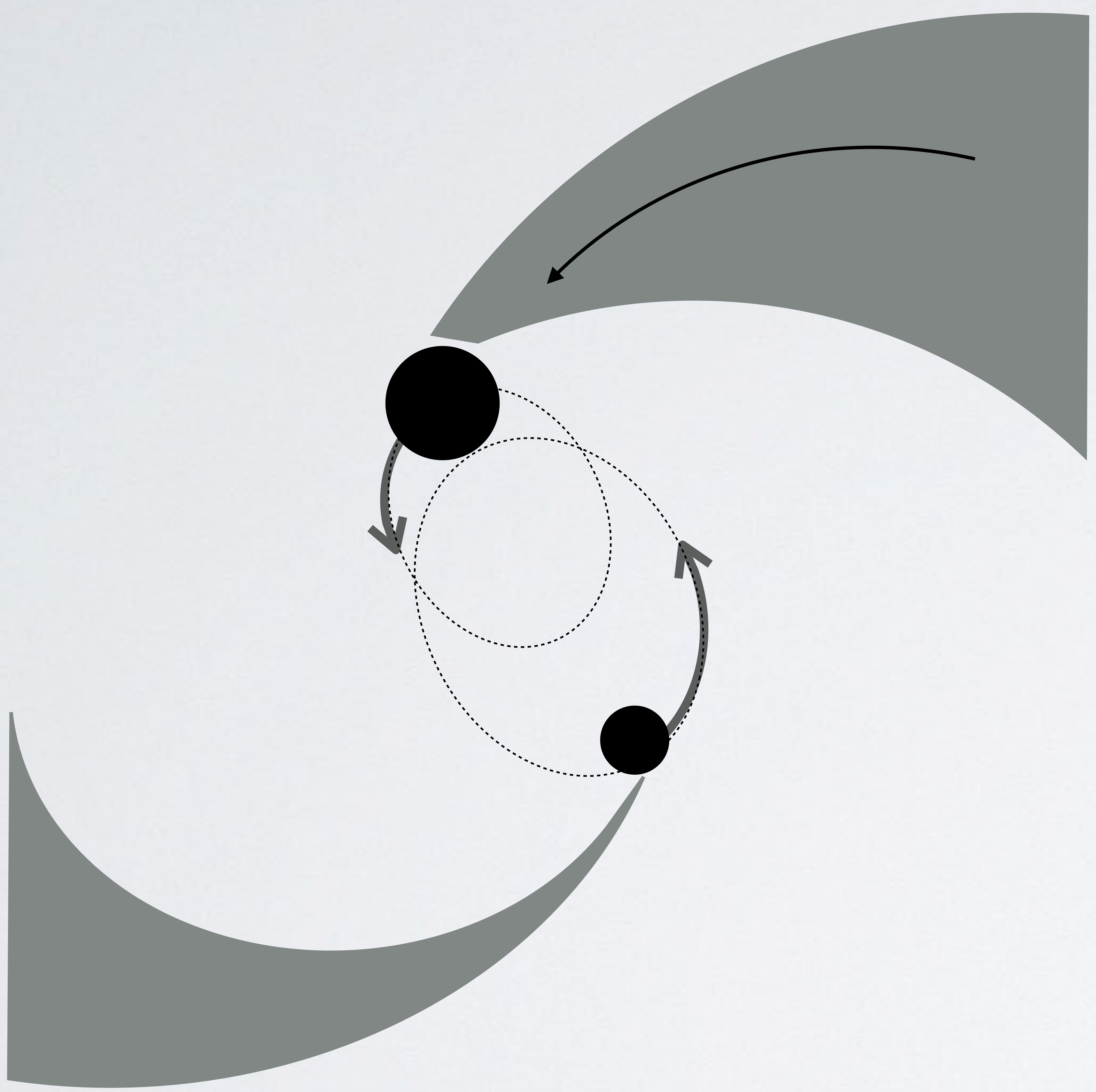
The second way is the "binary way"



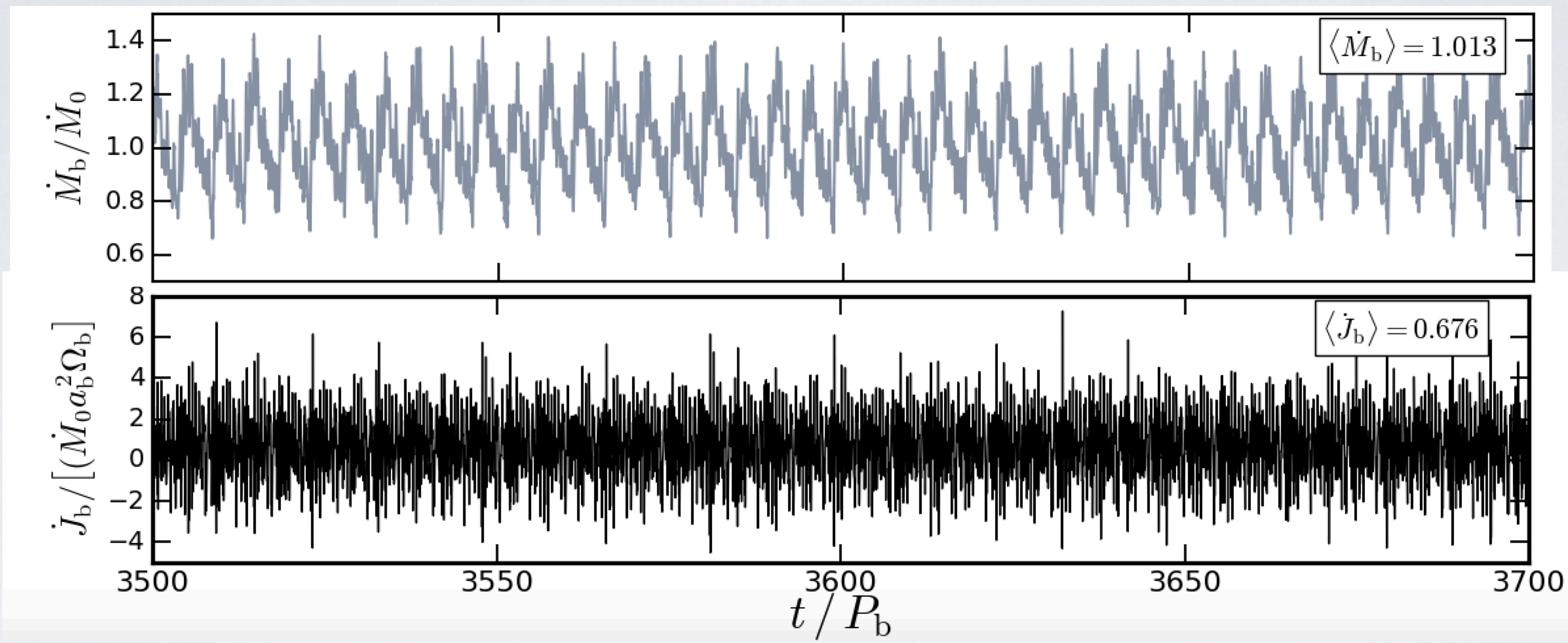
A binary exchanges angular momentum with the gas via gravitational torques, accretion and spin-up/down

$$\dot{J}_{\mathrm{b}} = \dot{L}_{\mathrm{grav}} + \dot{L}_{\mathrm{acc}} + \dot{S}_1 + \dot{S}_2$$

Angular momentum exchange can be computed in two ways.

Mass, angular momentum transfer rates onto the binary are quasi-steady.

$$\boxed{\langle \dot{J}_{\rm b} \rangle \approx \langle \dot{J}(R,t) \rangle \approx l_0 \langle \dot{M}_{\rm b} \rangle}$$



$$\boxed{\frac{\langle \dot{J}_{\rm b} \rangle}{\langle \dot{M}_{\rm b} \rangle} \approx 0.7 \Omega_{\rm b} a_{\rm b}^2}$$

SAME!!!

Binaries can expand if the transferred angular momentum per unit mass is large enough

if $\langle \dot{e}_{\mathrm{b}} \rangle \approx 0$

$$\frac{\dot{a}_{\mathrm{b}}}{a_{\mathrm{b}}} = 8\left(\frac{l_0}{l_{\mathrm{b}}} - \frac{3}{8}\right)\frac{\dot{M}_{\mathrm{b}}}{M_{\mathrm{b}}}$$

with $l_{\mathrm{b}} = \Omega_{\mathrm{b}} a_{\mathrm{b}}^2$

$$\frac{\dot{a}_{\mathrm{b}}}{a_{\mathrm{b}}} > 0 \quad \text{if} \quad l_0 > 0.38\Omega_{\mathrm{b}} a_{\mathrm{b}}^2$$

Miranda, Muñoz & Lai (2017)

Accreting binaries can expand.

for different binary eccentricities

e_b	r_{acc} $[a_b]$	$\langle \dot{J}_b \rangle / \langle \dot{M}_b \rangle$ $[\dot{M}_0 \Omega_b a_b^2]$	$\langle \dot{a}_b \rangle$ $[a_b \dot{M}_0 / M_b]$	$\langle \dot{e}_b \rangle$ $[\dot{M}_0 / M_b]$
0	0.02	0.68	2.15	-0.004
	0.04	0.68	2.05	-0.008
	0.06	0.69	2.00	-0.025
0.1	0.02	0.43	0.75	2.42
0.5	0.02	0.78	0.95	-0.20
0.6	0.02	0.81	0.38	-2.34

always positive

Muñoz, Miranda & Lai (2018)

High-mass ratio accreting binaries **EXPAND**

Muñoz , Miranda, & Lai (2019)
Moody, Shi & Stone (2019)
Muñoz et al (in prep)

Summary and Conclusions

- “Paradigms” in circumbinary accretion need a reassessment
- Accreting binaries (q_b~1) gain angular momentum at a quasi-steady rate l_0 consistent with transport within the disk: accreting binaries expand
- Circular binaries at different (moderate) mass ratios also expand
- Alternating-preferential accretion can be explained by disk precession. It can happen for unequal mass binaries