Migration in selfgravitating discs

Evolution of supermassive black hole binaries at centi pc scale

Retrograde versus prograde

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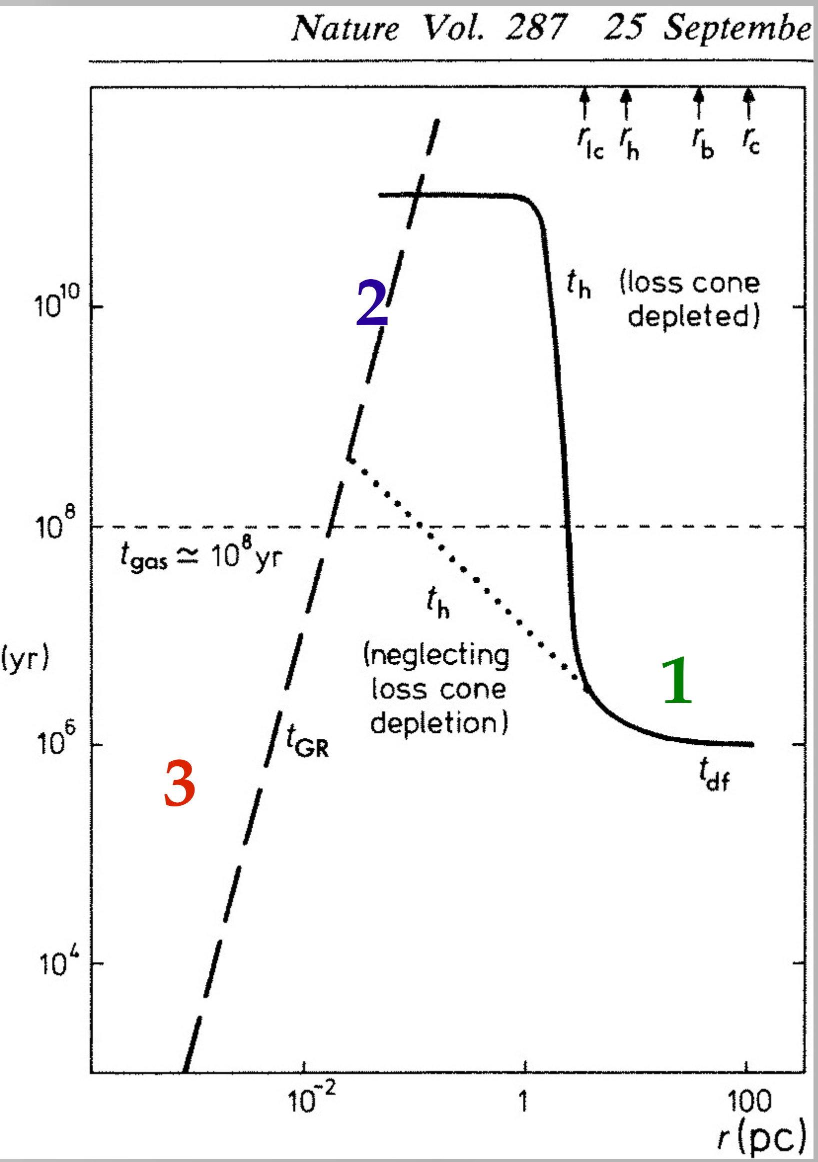
Outline:

- Introducing...
  ...the physical problem: SMBHB in circumbinary discs
  ...what we've learnt previously
- Flipping the Sign: retrograde migration in a selfgravitating disc
  insights from comparisons && analytical explanations
- The final fate: Introducing the tilting instability for high e
- Summary

the BH merger paradigm

(Begelman, Blandford, Rees 1980)



(1) dynamical friction regime

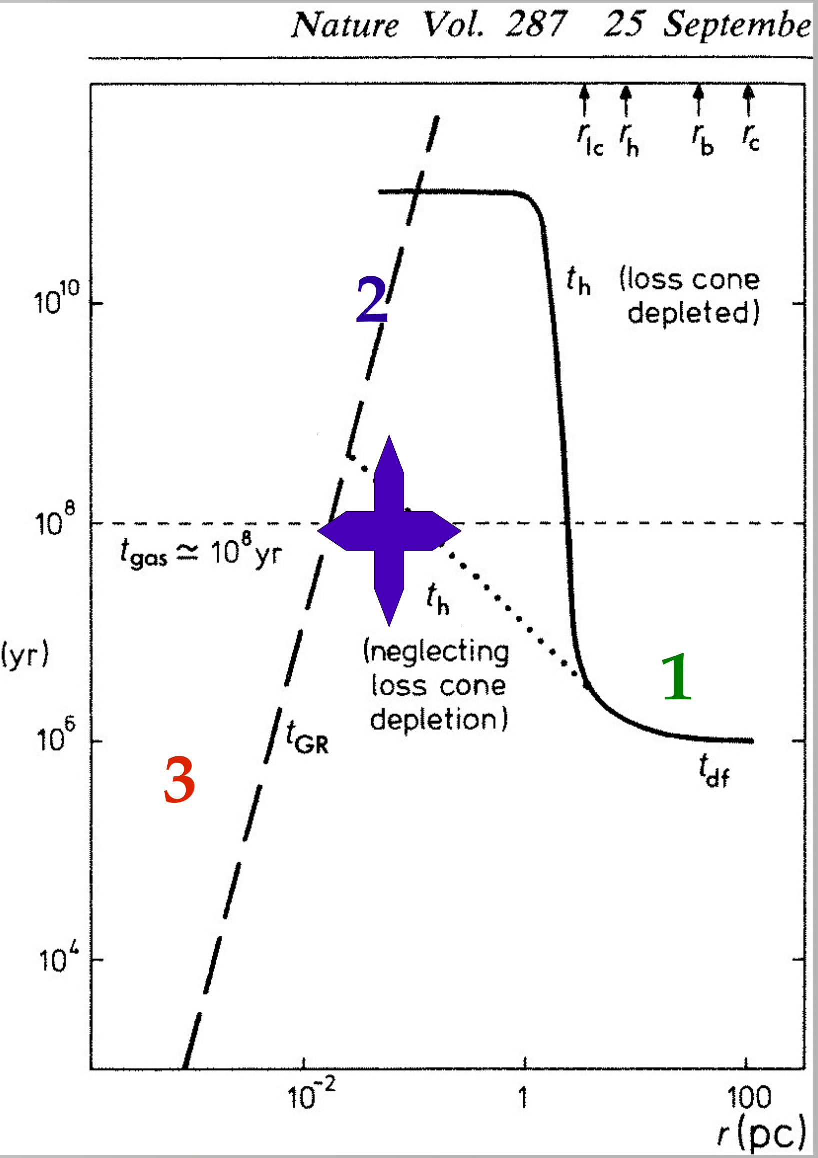
(2) binary hardening regime

by interaction with gas and/or stars

(3) emission of GWs inspiral/merger/ringdown

Focussing on centi-parsec scale

(Begelman, Blandford, Rees 1980)



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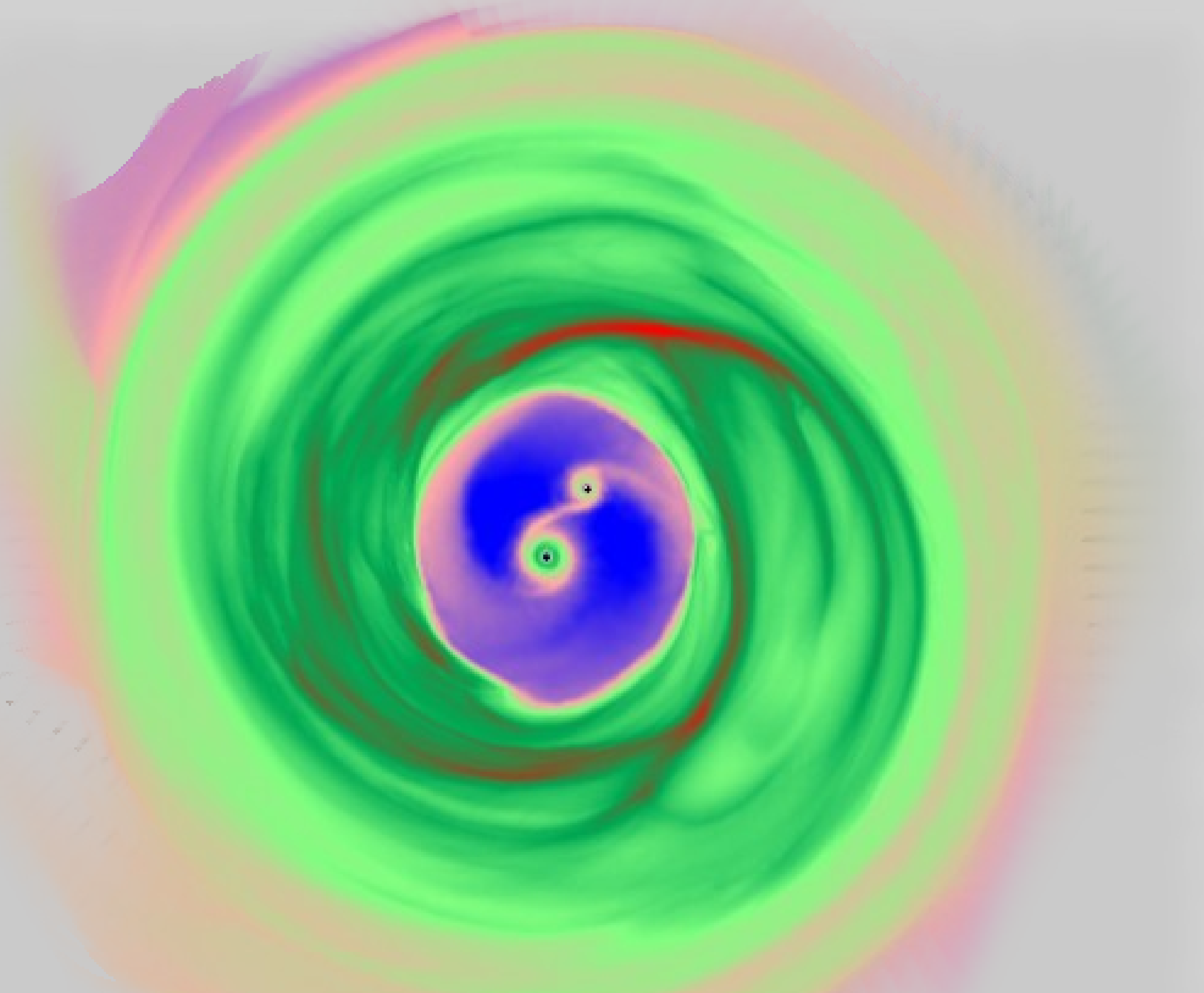

Secular evolution of binaries in self-gravitating discs

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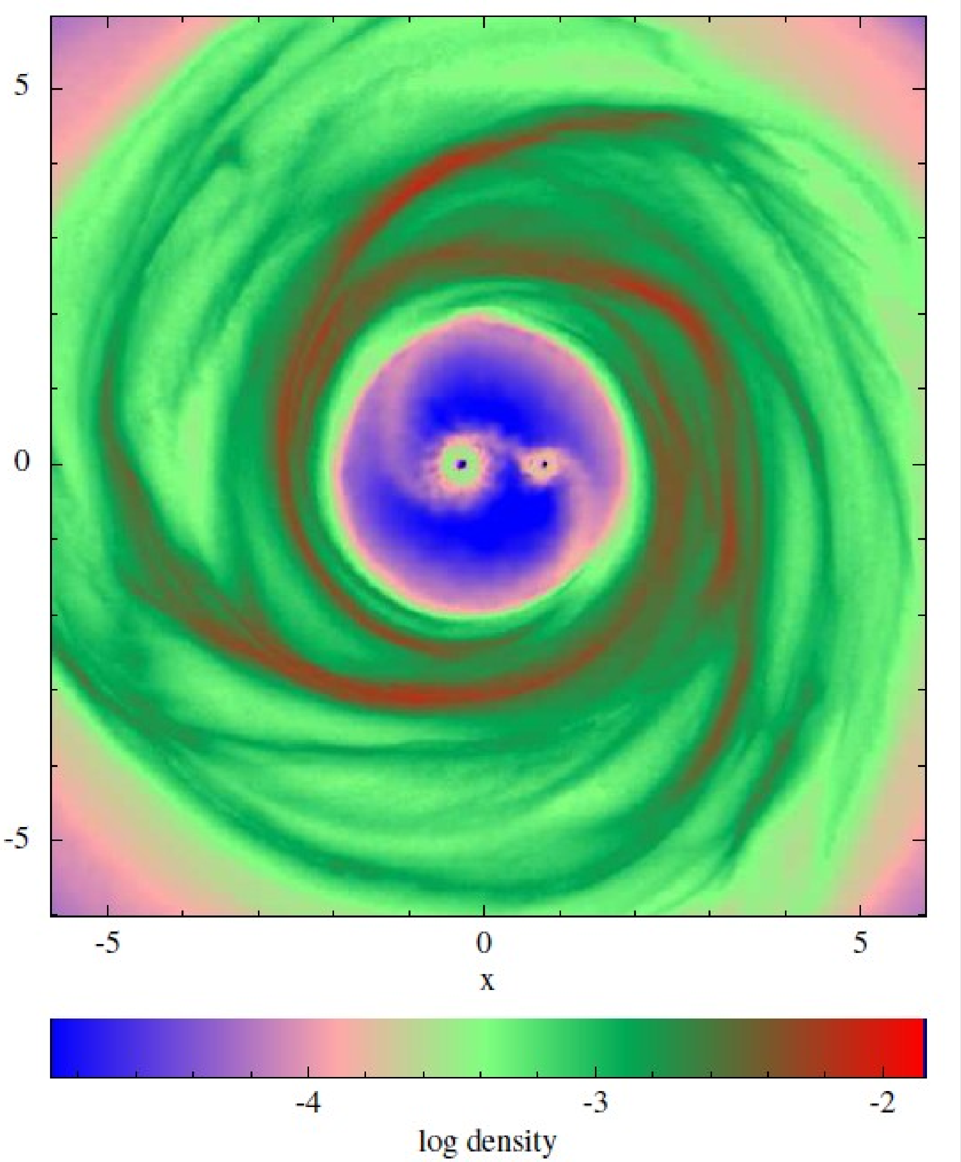
Secular evolution using GADGET-2

Disc needed to redistribute Energy E and Angular momentum L

- Selfgravity as "viscosity"
- $\beta = t_{\rm cool}/t_{\rm dyn} = 10$
- "life" binary
- Accretion transfers mass + momentum
- Cavity of size 2a sustained
- Formation of minidiscs on t_{dyn}
- Mean motion resonances not applicable

kinematic streams & "stream-bending"

dynamically important



Secular evolution using GADGET-2

Gravitational and accretion torques change a and e

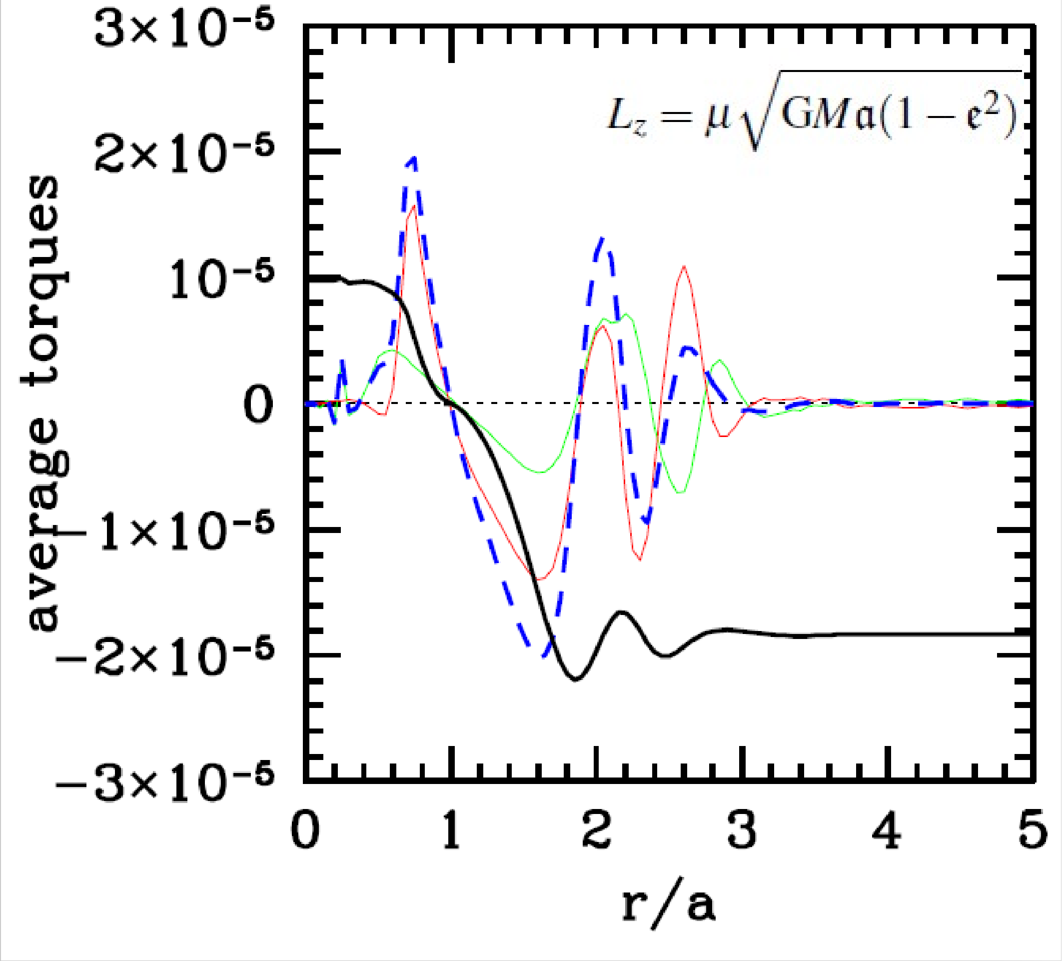
- Prograde disc:
- Strongest torque inside cavity
- Opposite sign torque at minidisc
- Total torque of disc onto binary:

Negative --> a shrinks

--> e grows

cavity expands to 2a (1+e)

- Balance reached at e ~ 0.6
- Shrinkage adot~Mdot (!!)



(Roedig et al, 2011, 2012, 2013)

Secular evolution using GADGET-2

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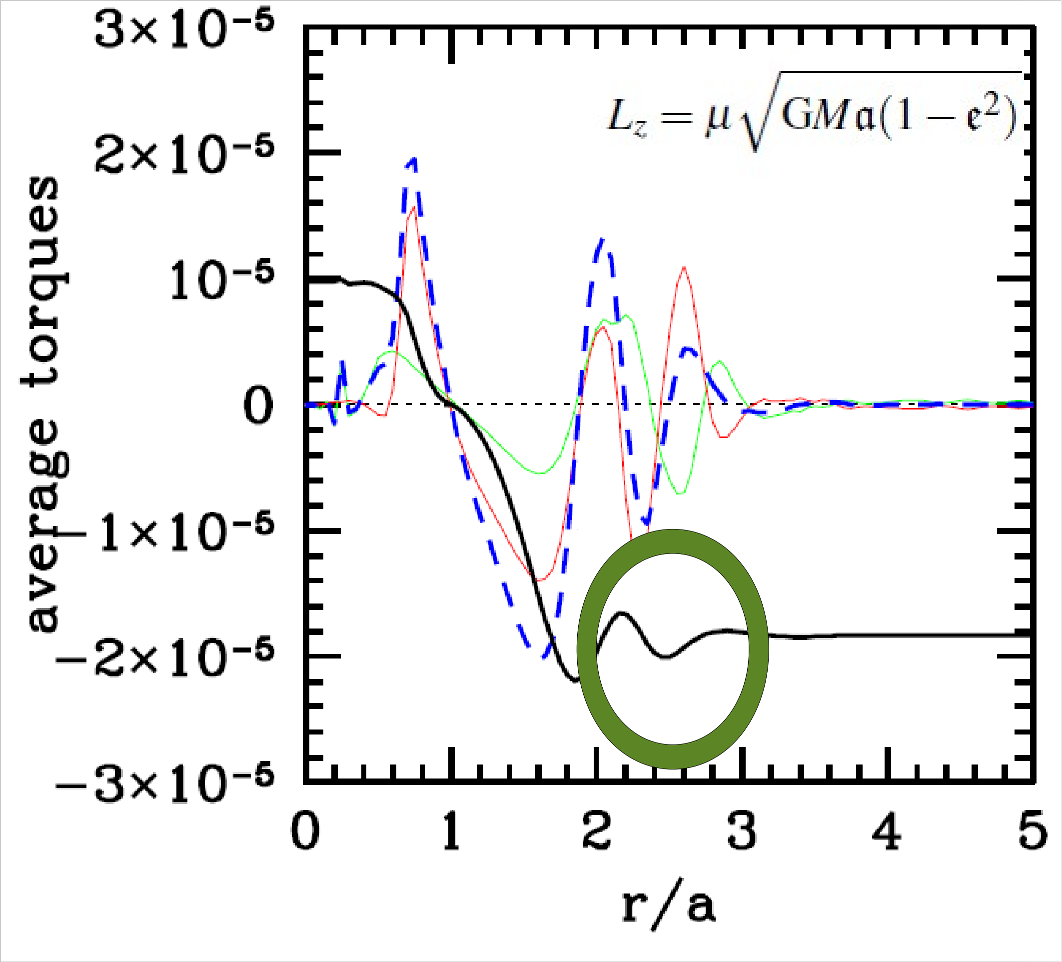
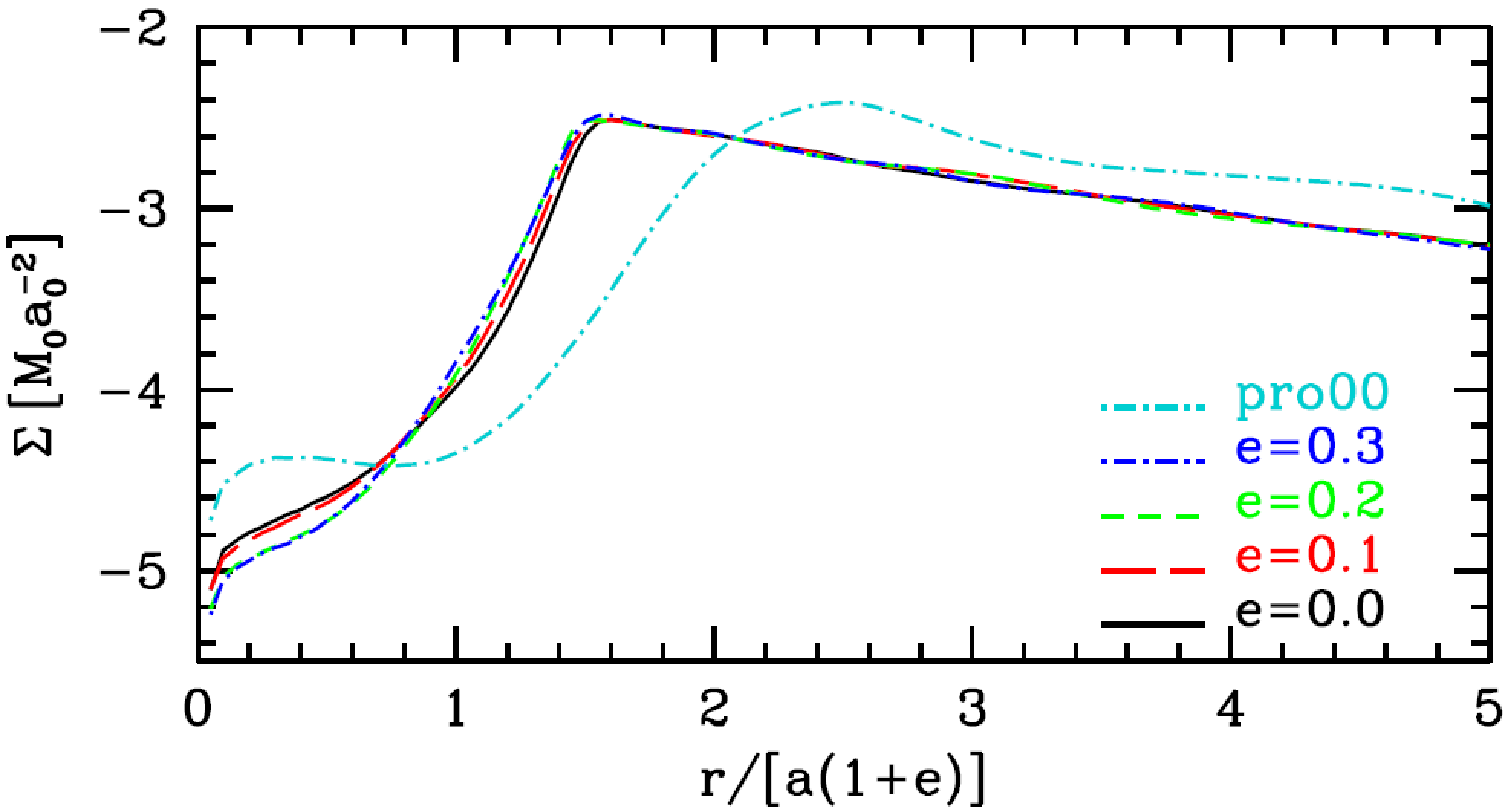
- Shrinkage adot~Mdot (given by Σ)



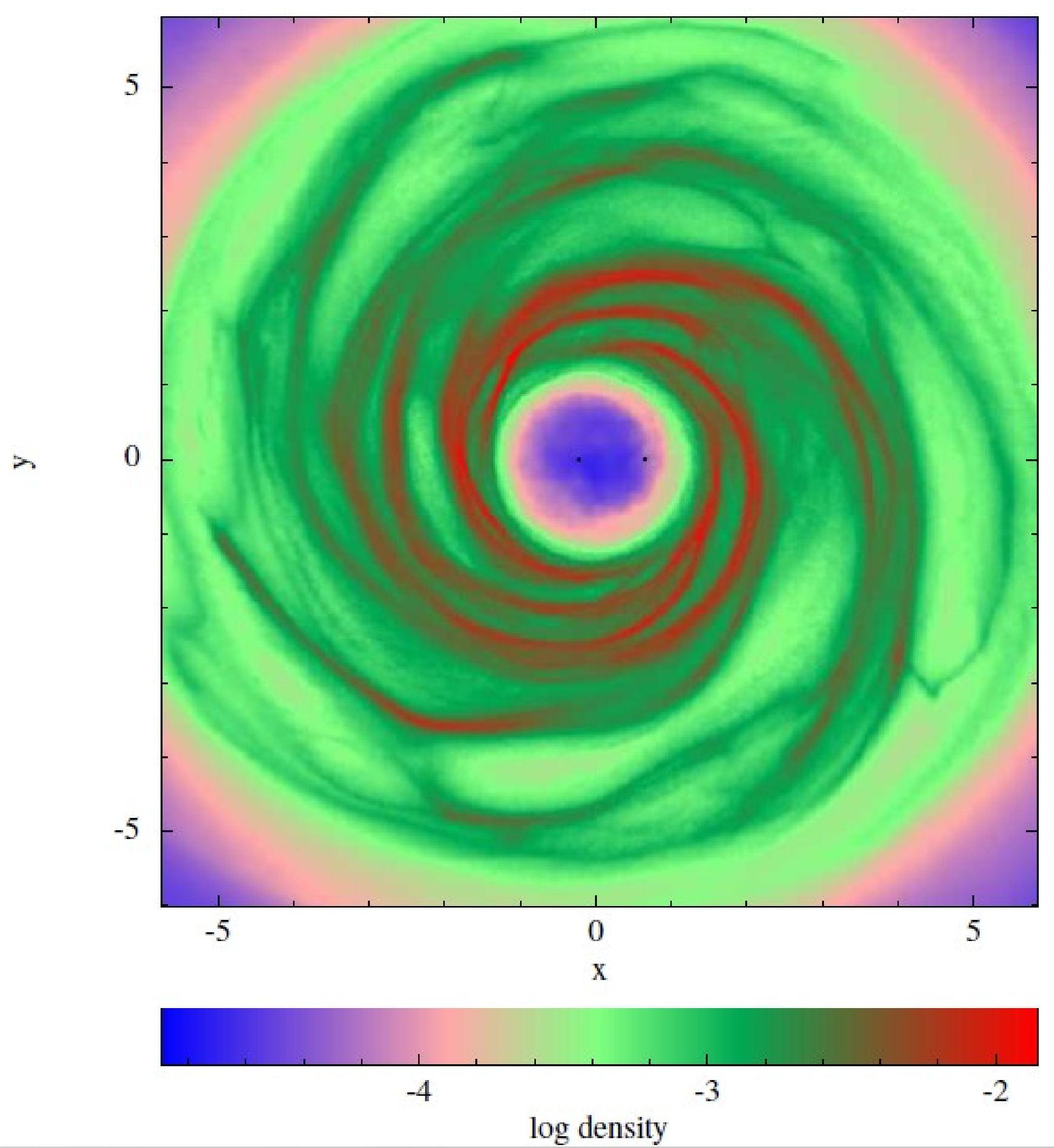
(Roedig et al, 2011, 2012, 2013)

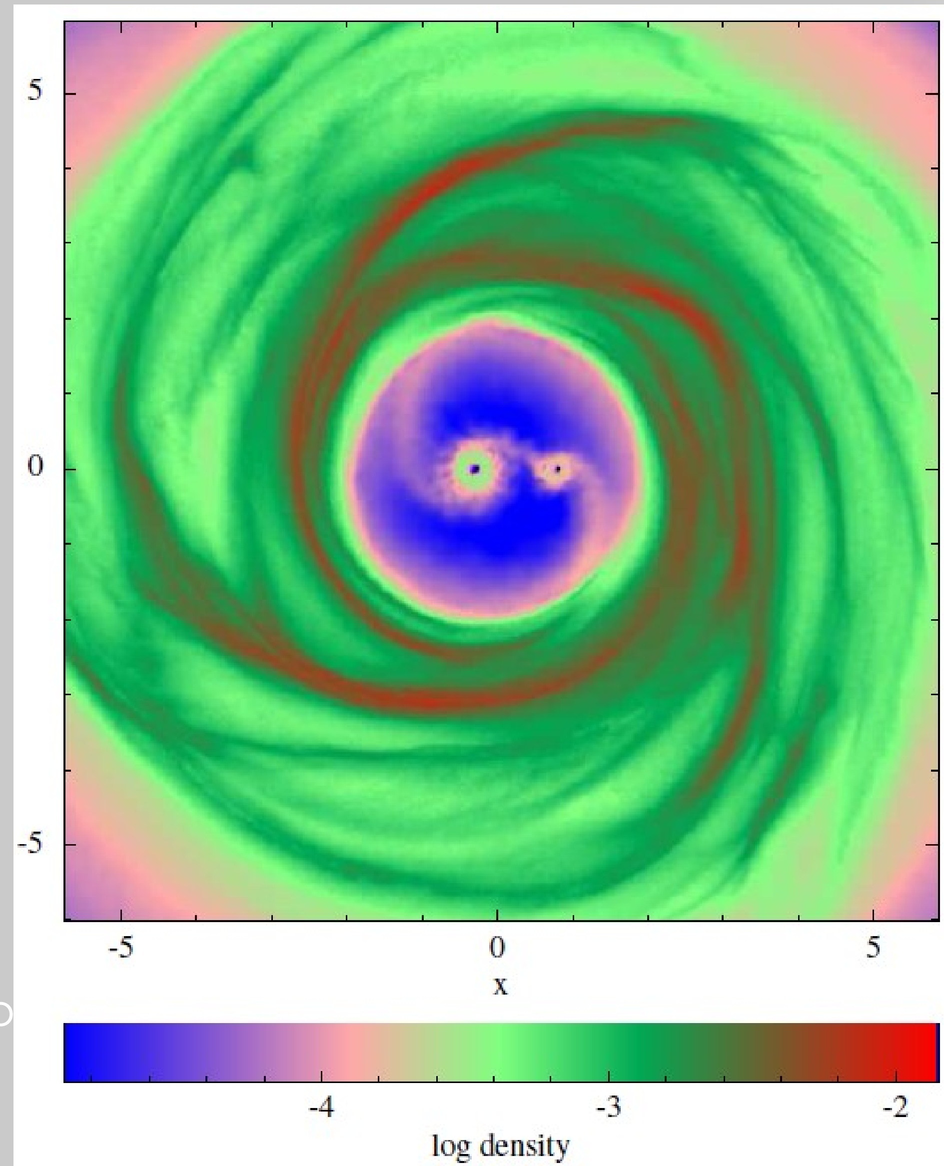
Retrograde versus prograde

Surface density self similar to a (1+e) $\Sigma \sim r^{-4/3}$



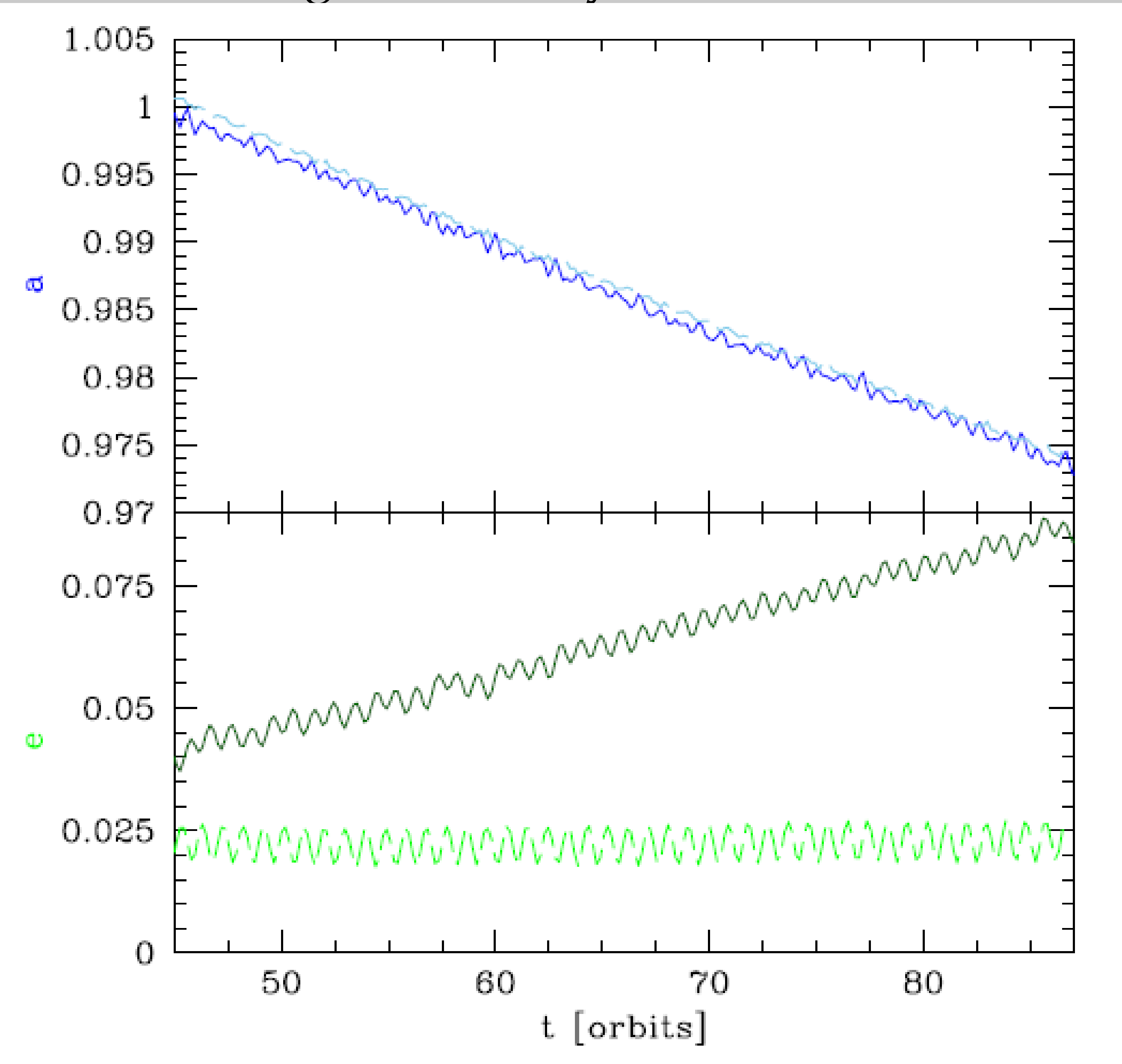
Retrograde versus prograde





Retrograde versus prograde: 1. Circular BHBs

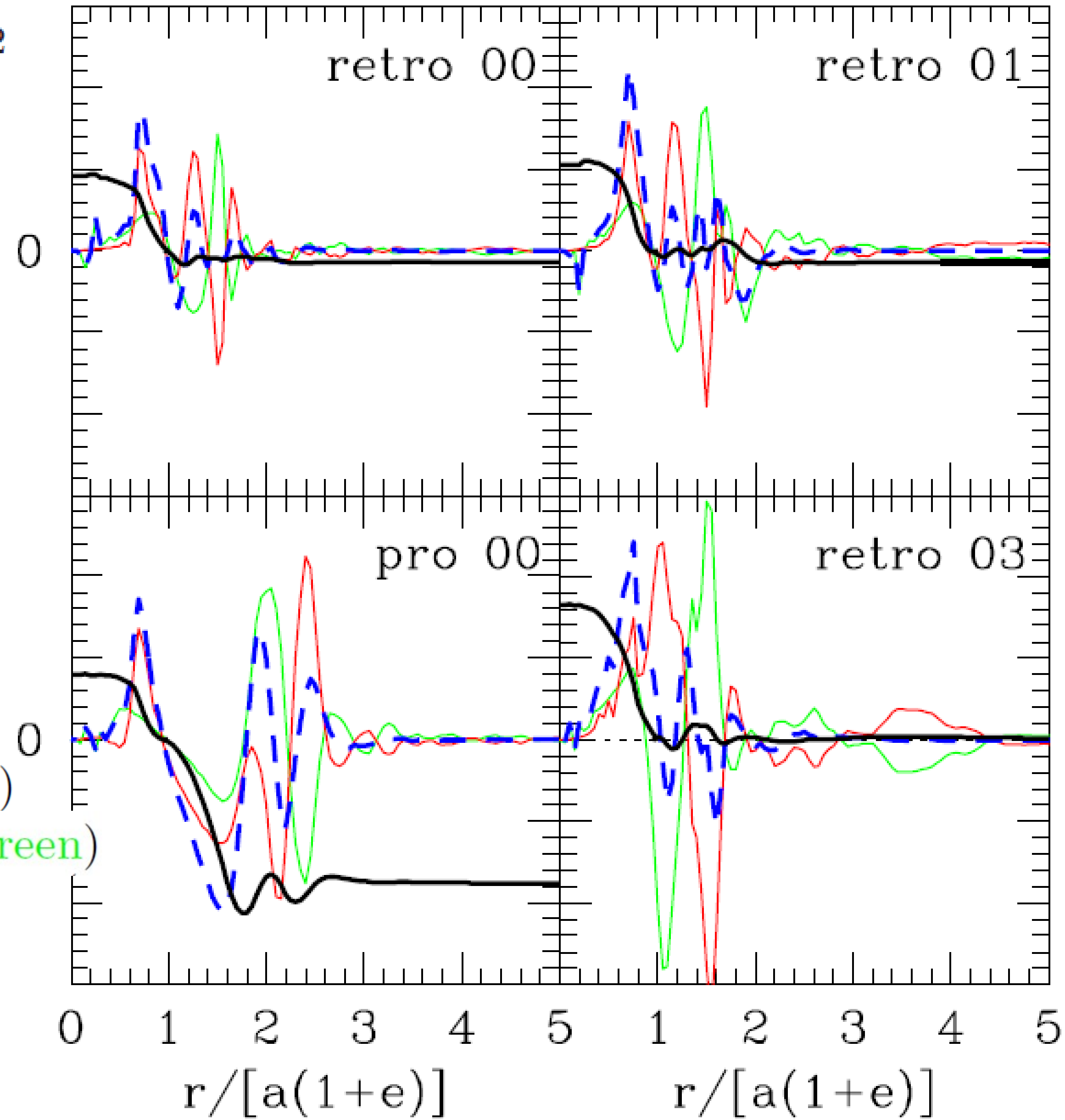
Shrinkage identical, retrograde binary remains circular



(Roedig & Sesana submitted)

Retrograde torques: no stream-component

$$T_{\rm in}(e) \approx T_{\rm in}(e=0) + 10 \cdot T_{\rm in}(e=0)\, e^2$$



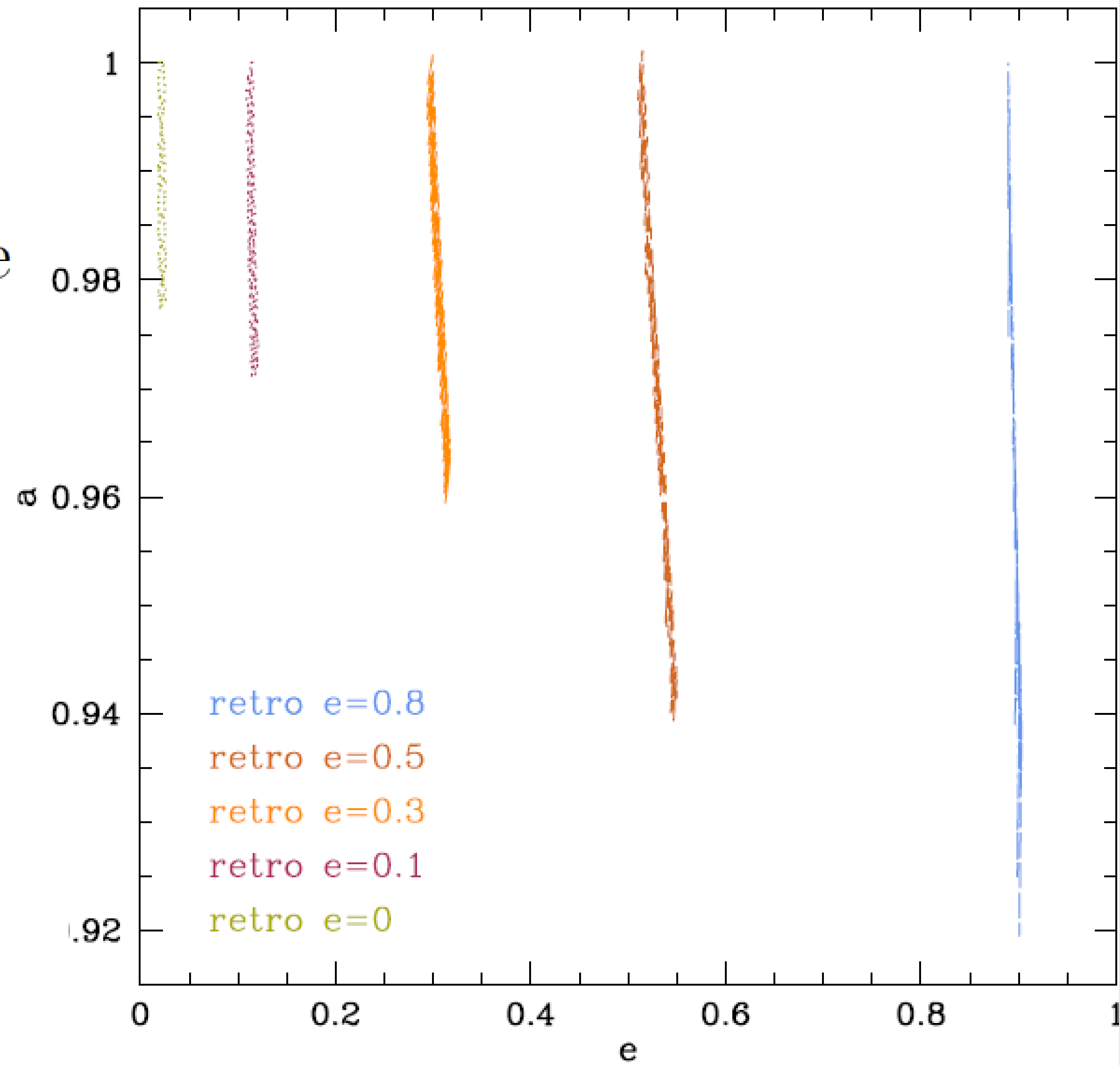
differential torque on the primary (red)
differential torque on the secondary (green)
the sum of the two (dashed–blue)
integrated torque (black)

Retrograde decay exponential

$$\dot{\mathfrak{e}}(\mathfrak{e}) \approx -0.0034 + 0.09\,\mathfrak{e}$$

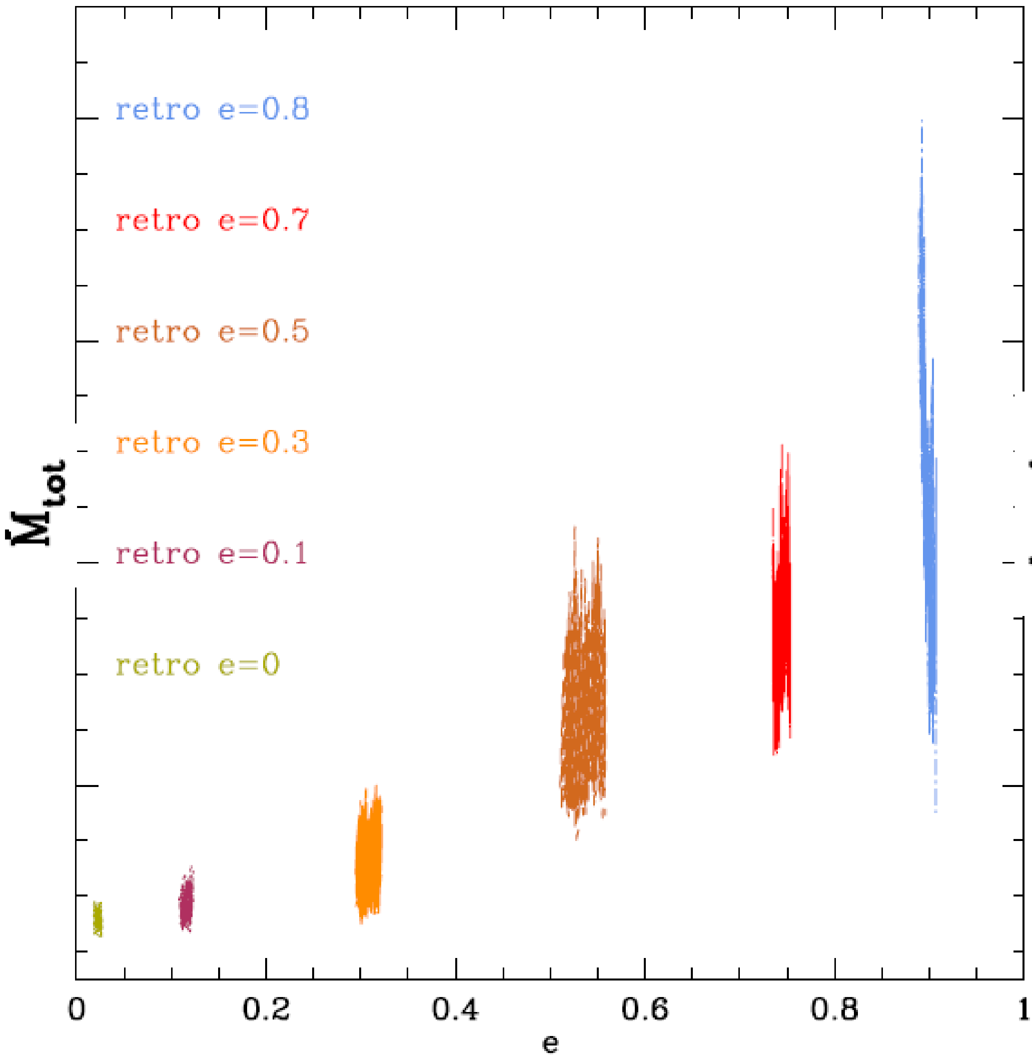
$\dot{\mathfrak{a}}(\mathfrak{e})$ is linear and negative

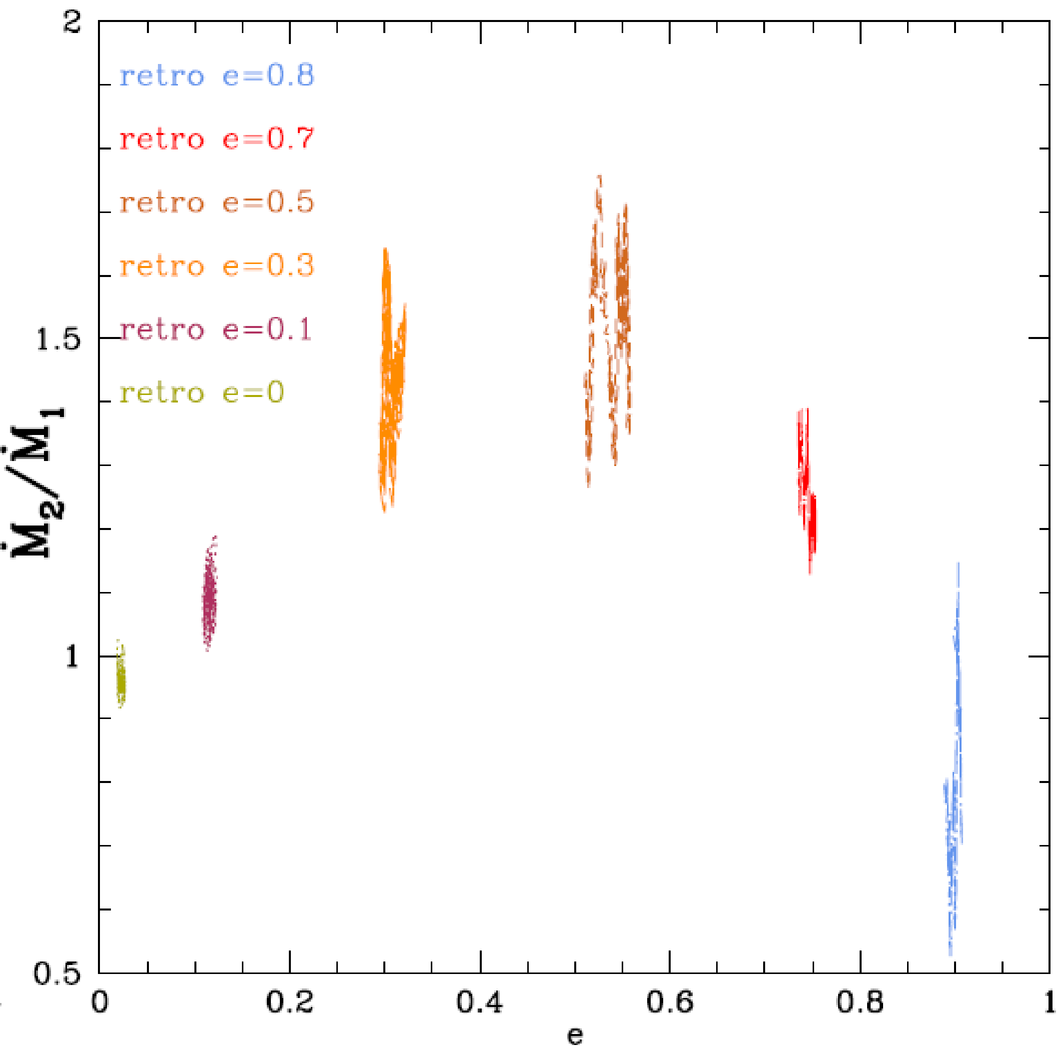
$$\frac{\dot{\mathfrak{a}}(t)}{\mathfrak{a}} = -\frac{2}{M_2}(\dot{\mu} + \dot{M}_{\rm BHB})$$



Impact on both BHs once eccentricity high

Accretion rates and ratio depends on eccentricity
Turnover when primary Bondi-radius large at apocentre





Analytical understanding: M2-impact model

Purely kinematic interaction between secondary BH and gas at apocenter with fraction α of accreted gas

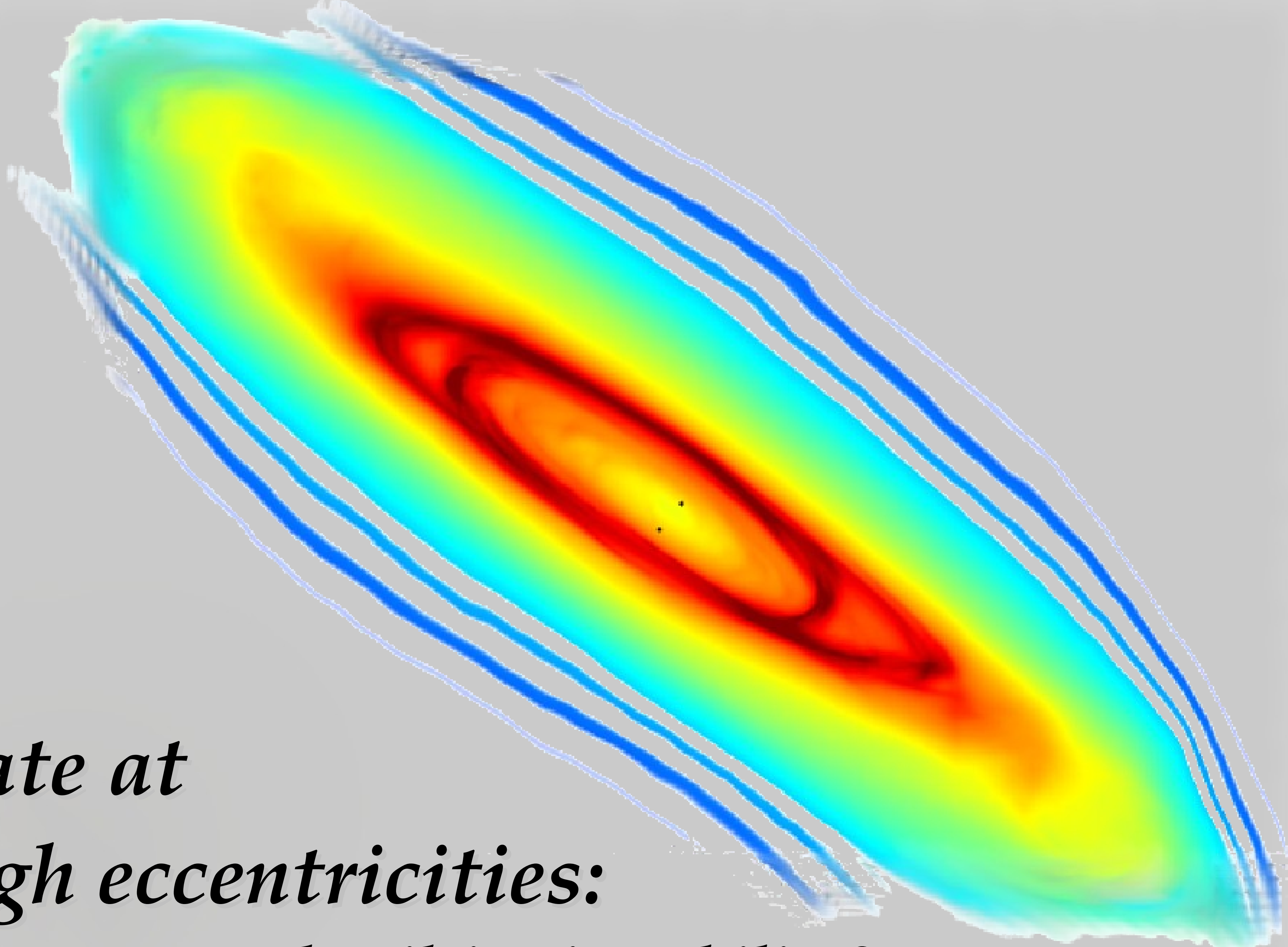
Ignoring CoM motion

(compare with Nixon etal 2011)

$$\frac{\Delta \mathfrak{a}}{\mathfrak{a}} = -\frac{2\Delta M}{M_2(1+\mathfrak{e})}\mathcal{F}(\mathfrak{e},\mathfrak{q},\alpha),$$

$$\Delta \mathfrak{e} = \frac{2\Delta M}{M_2}\mathcal{F}(\mathfrak{e},\mathfrak{q},\alpha),$$

$$\mathcal{F}(\mathfrak{e},\mathfrak{q},\alpha) = (1-\mathfrak{e})^{1/2}(1+\mathfrak{q})^{1/2} + \alpha\frac{1-\mathfrak{e}}{1+\mathfrak{q}}$$



fate at
high eccentricities:
The tilting instability?

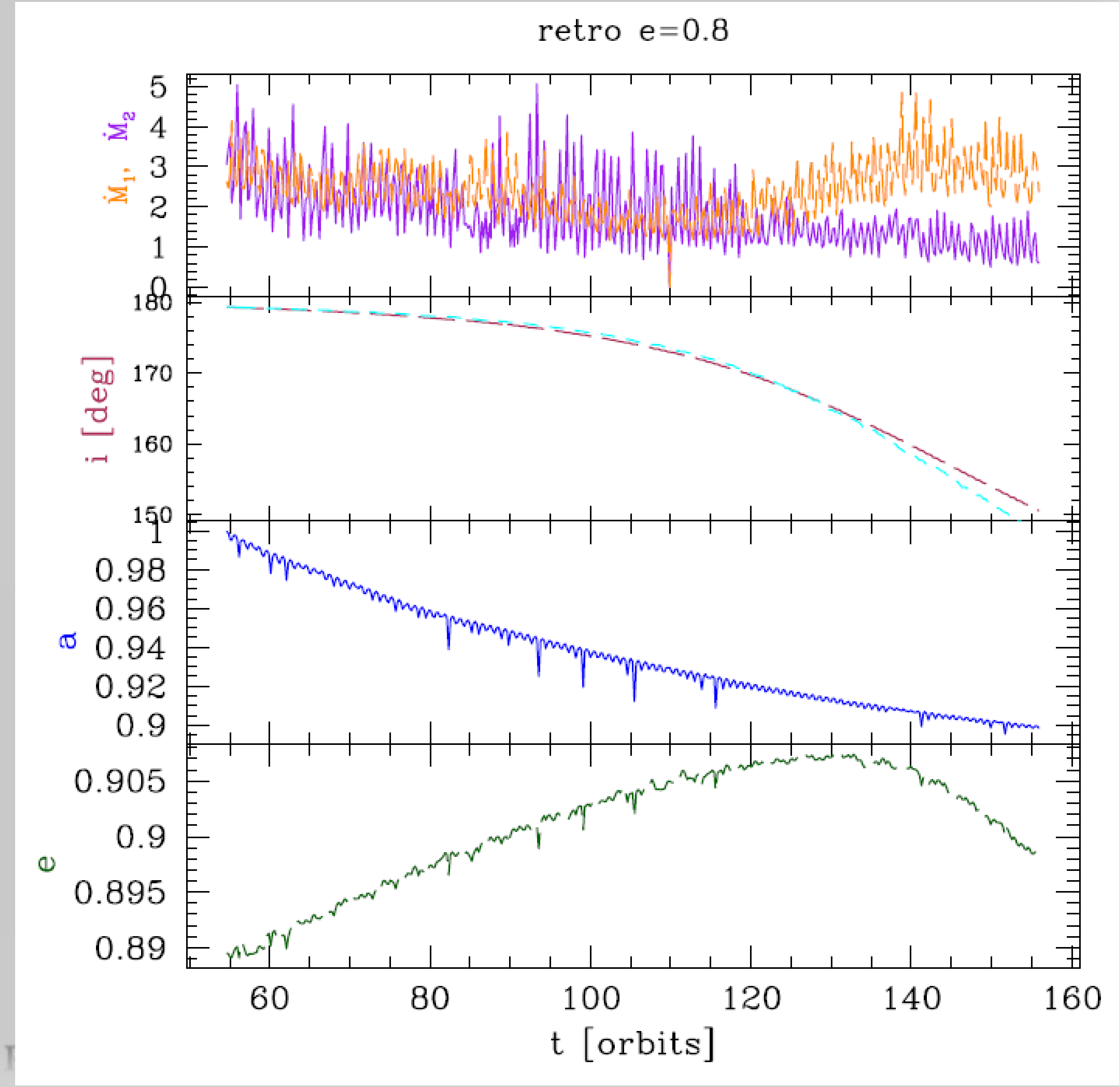
Out-of-plane perturbations at high eccentricity

mass accretion rates
M1 and M2

$$i = \arccos\left(\frac{\langle \mathbf{L}_{\mathrm{BHB}} | \mathbf{L}_{\mathrm{Disc}} \rangle}{|\mathbf{L}_{\mathrm{BHB}}||\mathbf{L}_{\mathrm{Disc}}|}\right)$$

Semi-major axis a

Eccentricity e



Constanze I

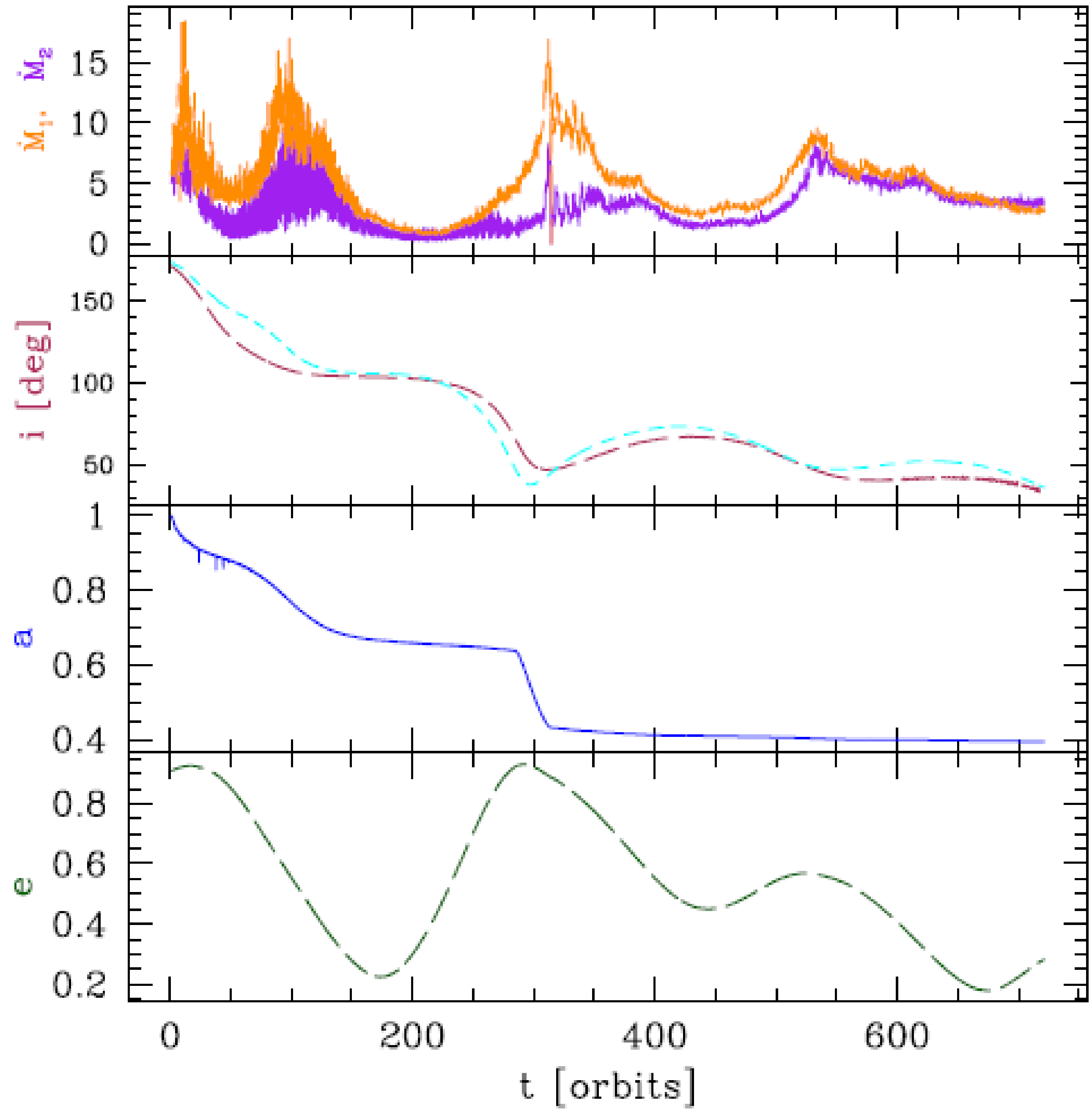
Kozai-like exchange of inclination & eccenticity

mass accretion rates
M1 and M2

Inclination i

Semi-major axis a

Eccentricity e



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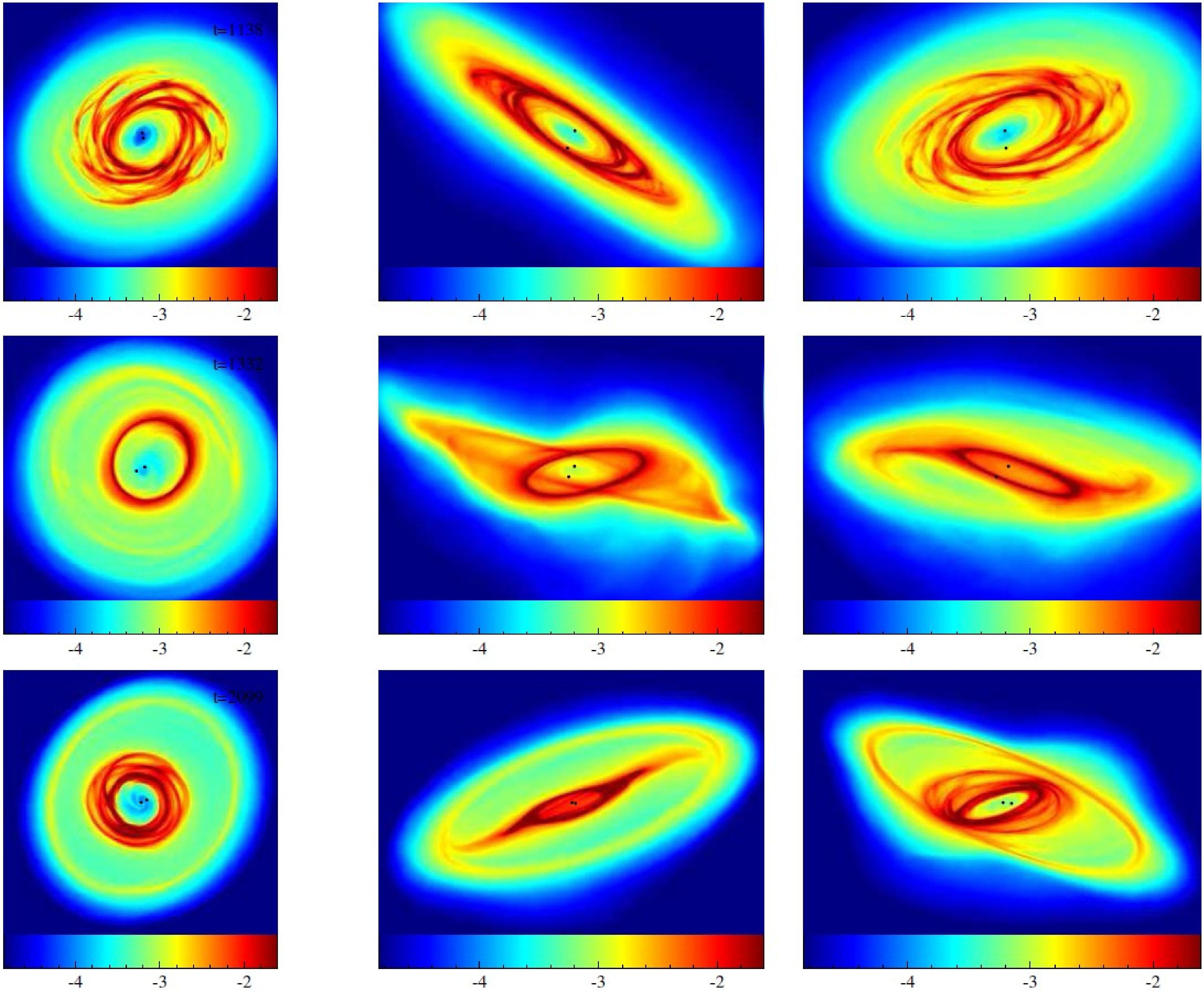
t=1138
t=1332
t=2099
-4
-3
-2

Summary:

- Circular retrograde discs shrink similar to prograde ones
- They remain circular

- If eccentricity excited, retrograde BHB shrinks exponentially
- Torques ~ Accretion rates ~ eccentricity
- Ballistic impact-model
- Ratio of accretion rates M2/M1 turnover at e~ 0.45
- Increasing movement of BHB-Centre of Mass

- At high ecc: stochastic perturbations from clumpy disc destabilize binary : it leaves the plane
- Kozai like exchange of inclination and eccentricity
- Final stage: prograde and eccentric
  OR: plunge-like merger if GW important

Thank you for your attention !

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