The Bardeen-Petterson Effect in accreting supermassive black hole binaries

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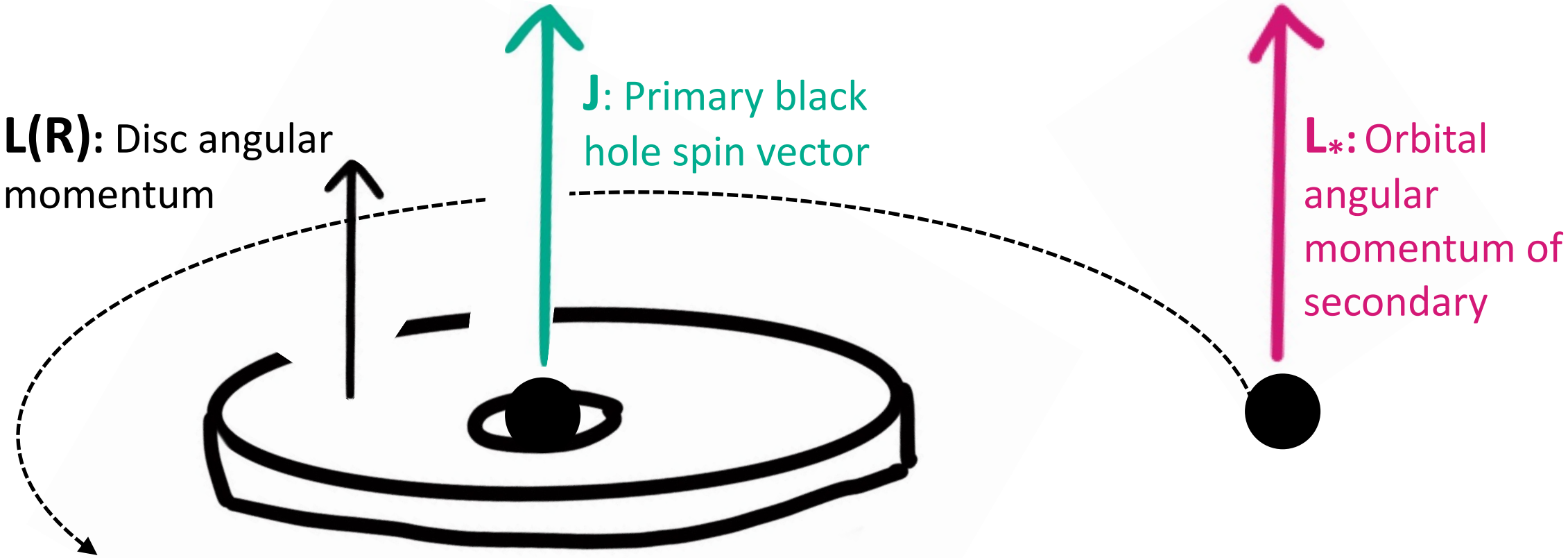
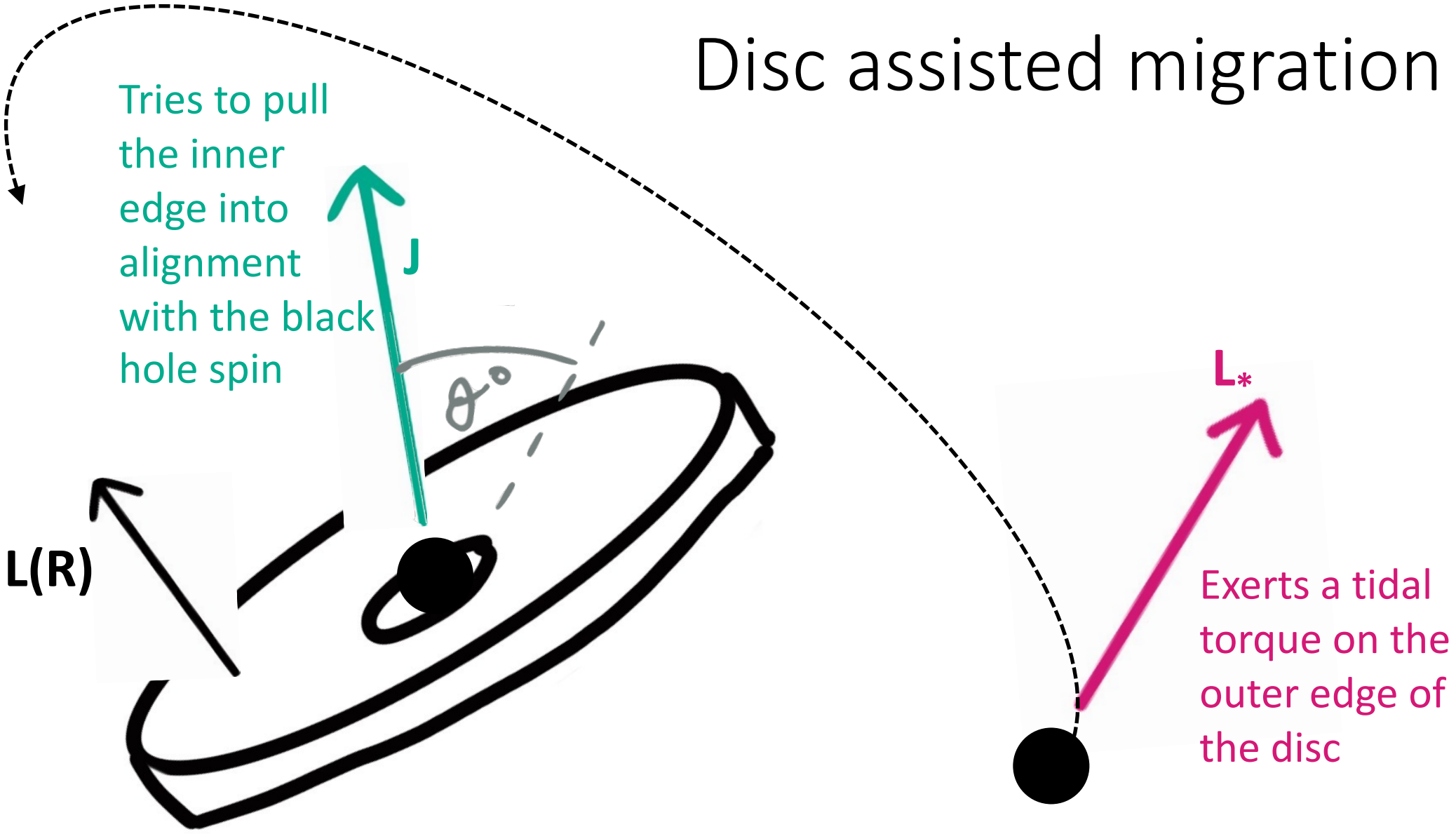
Disc assisted migration



Disc assisted migration



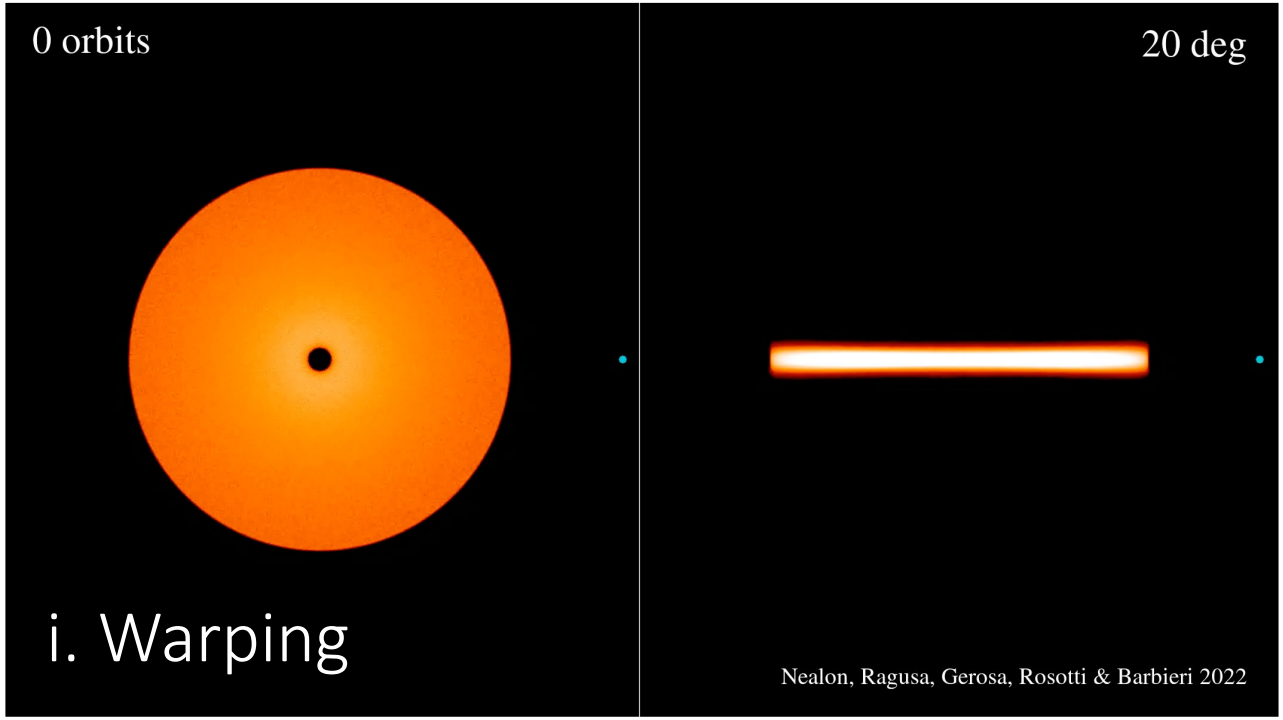
1. What shape does the disc take?
2. How does this affect the alignment of the black holes?

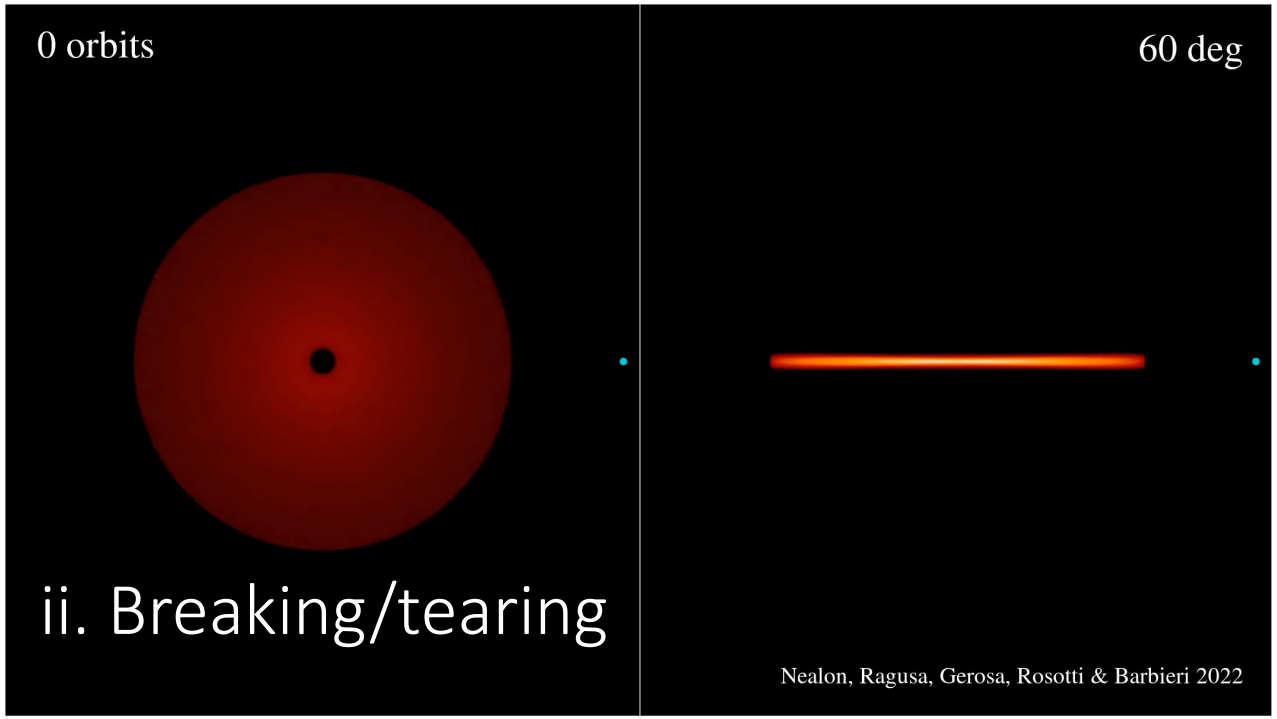
Paper I: *The BP Effect in accreting SMBHBs, a systematic approach*
Gerosa, Rosotti, Barbieri and Riccardo (2020)

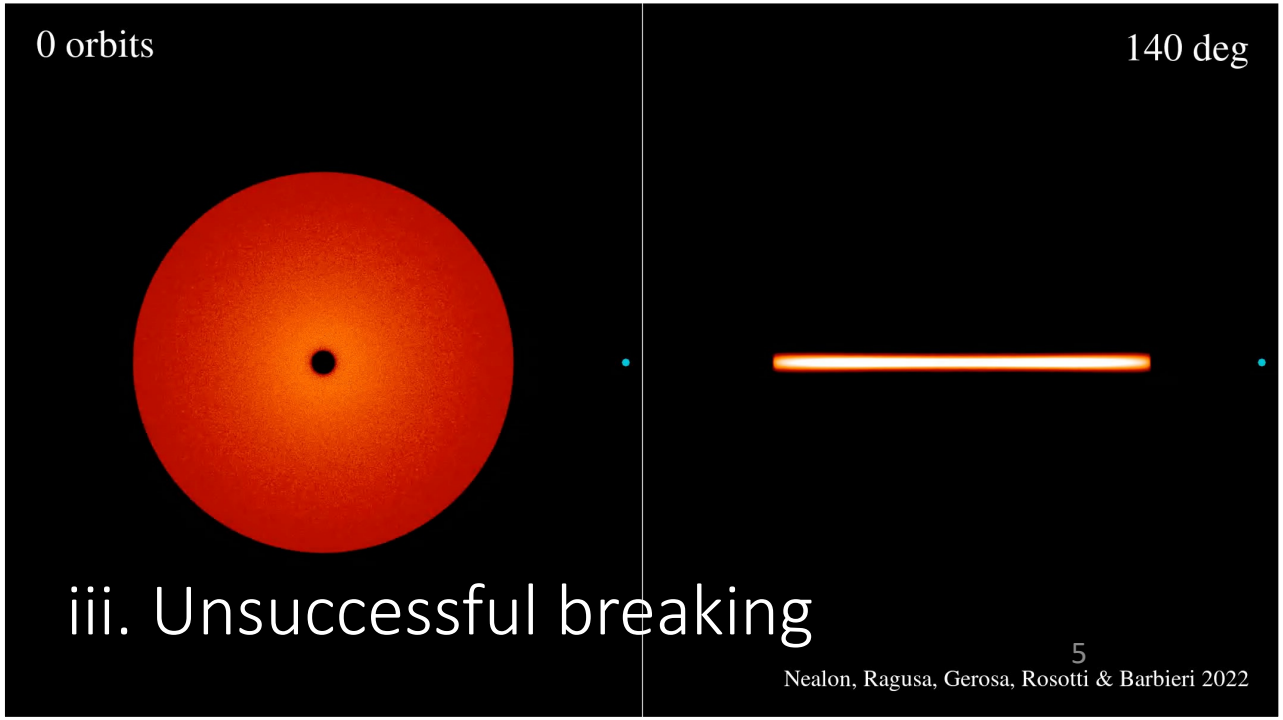
Paper II: *Disc breaking and the critical obliquity*
Nealon, Ragusa, Gerosa and Barbieri (2022)

Paper III: *The BP Effect, disc breaking, and the spin orientations of SMBHBs*
Steinle and Gerosa (2023)

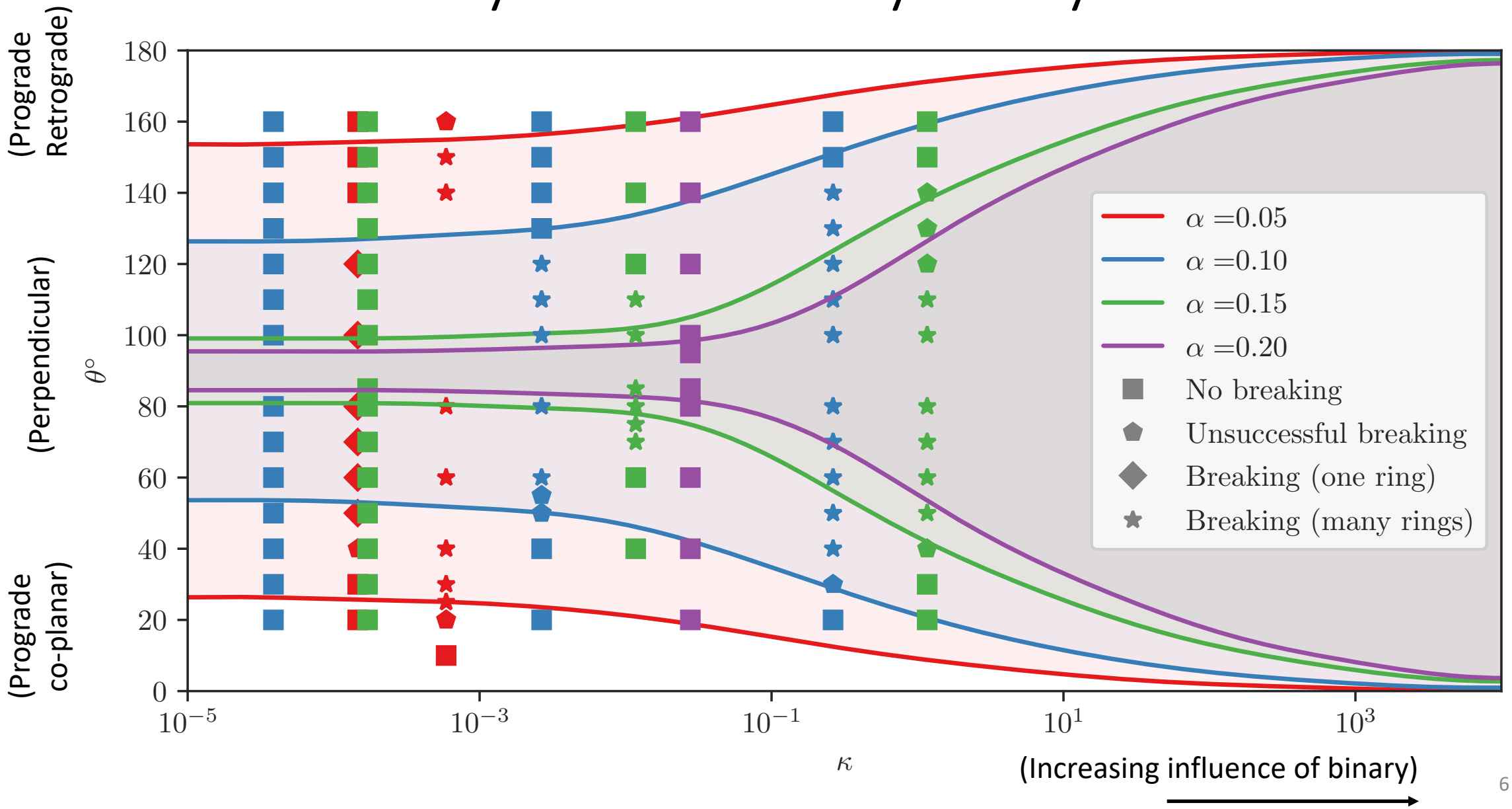
1. What shape does the disc take?





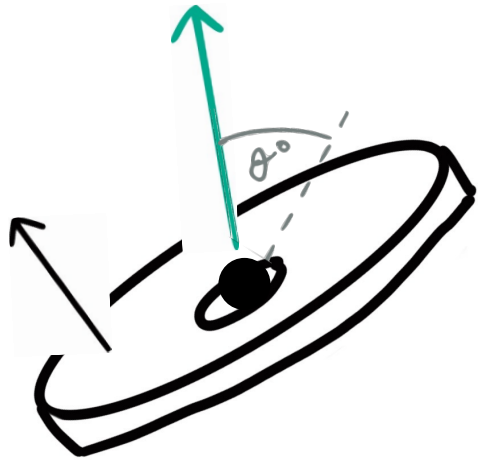


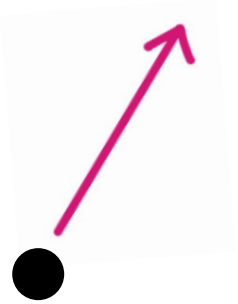
1D semi-analytics vs. 3D hydrodynamics



On the alignment timescale

The disc and black hole align on ….



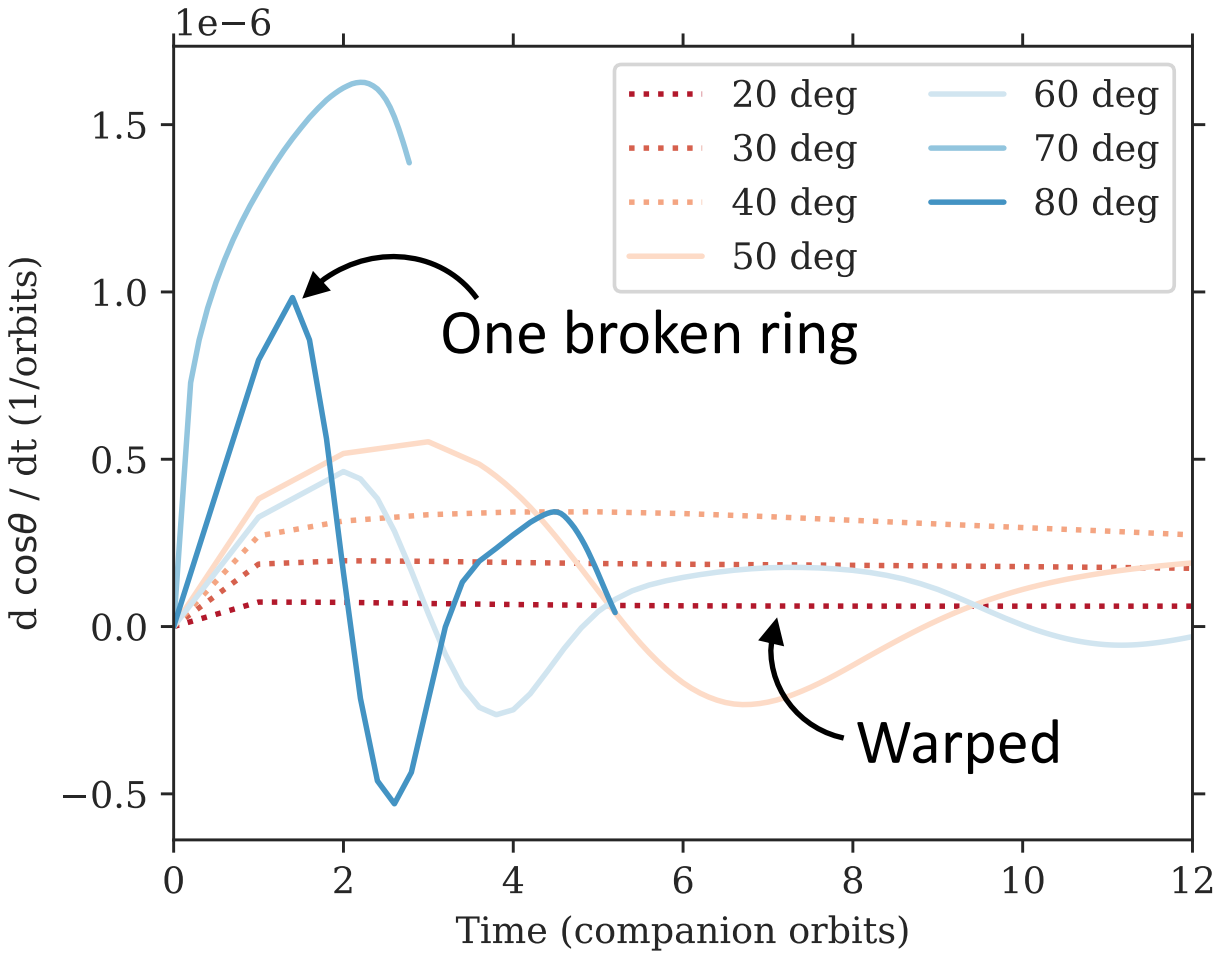


$$\frac{\mathrm{d}\cos\theta}{\mathrm{dt}} = \frac{\mathrm{d}\hat{\mathbf{J}}}{\mathrm{dt}} \cdot \hat{\mathbf{L}}_*$$

$$\frac{\mathrm{d}\mathbf{J}}{\mathrm{dt}} = -\int_{R_{\mathrm{min}}}^{R_{\mathrm{max}}} \frac{2G}{c^2} \frac{\mathbf{J} \times \mathbf{L}}{R^3} 2\pi R \mathrm{dR}$$

Our simulations are too short-lived to measure this on relevant time-scales. But we can show how **changing the disc structure can alter this summation**.

On the alignment timescale



- For warped and continuous discs (dotted lines), find that this timescale settles to a roughly constant value quickly
- If the disc breaks into two sections (solid lines), the inner disc precesses such that regions of the disc have opposing angular momentum
- This causes variations in the alignment time-scale that correlate to the precession of the inner disc

The BP Effect in accreting SMBHBs

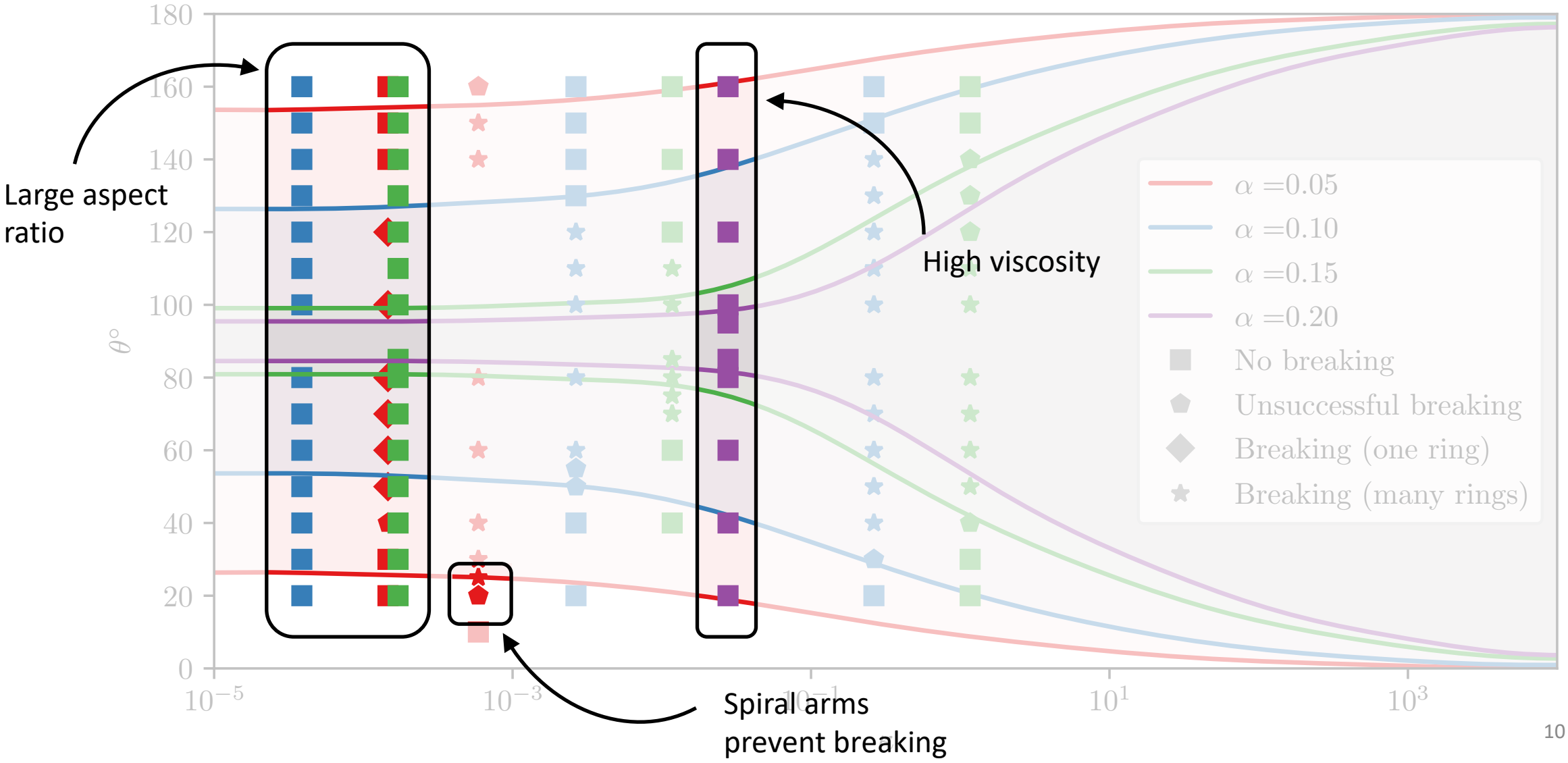
1. Discs in accreting SMBHBs may be warped or broken depending on the disc properties and relative misalignment of the BHs

2. This prediction is found in both semi-analytic models and 3D hydrodynamic simulations

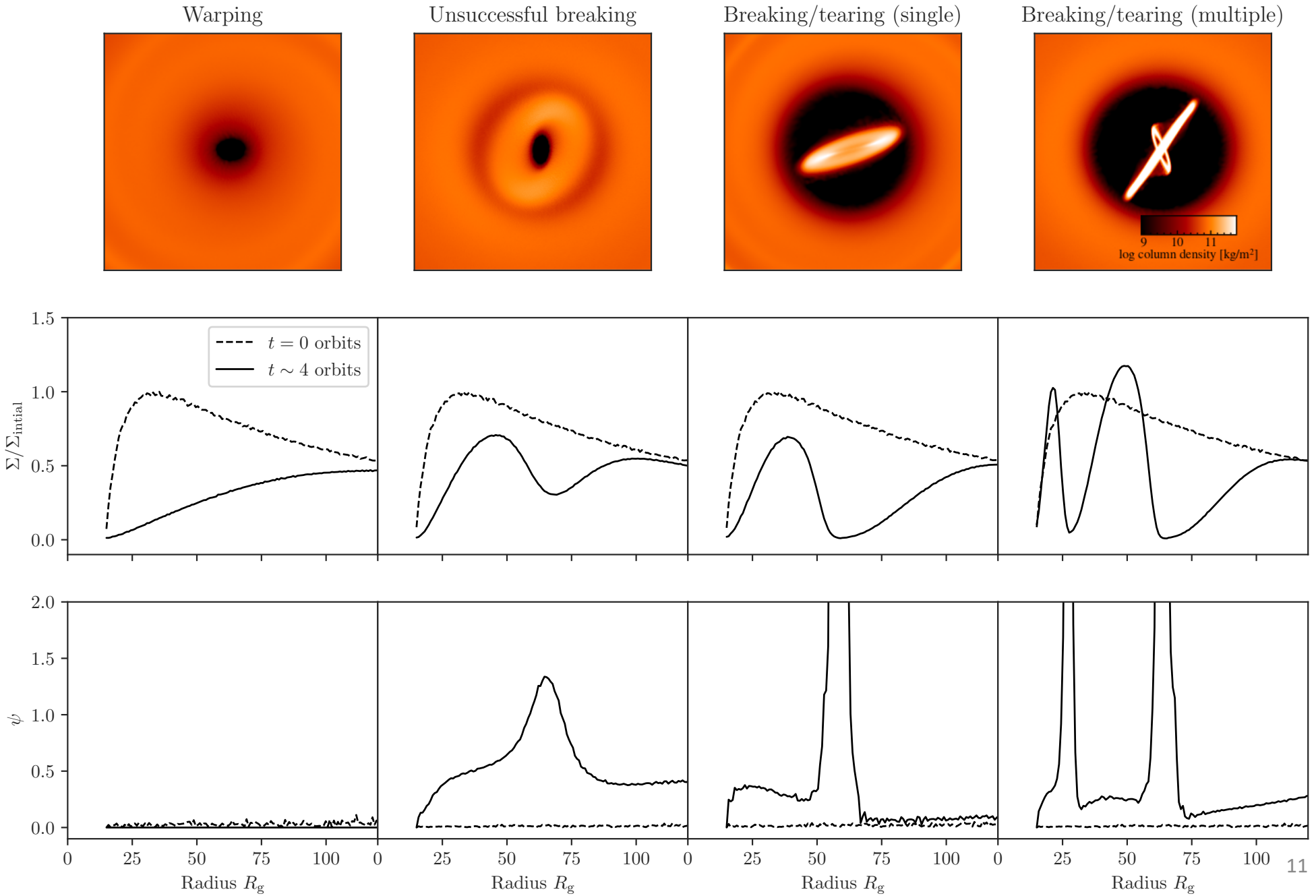
3. Breaking the disc compromises the ability of the disc and the black hole to align on short time-scales

4. Steinle and Gerosa (2023) used this to predict distinct populations of SMBHBs that are likely to be observable by LISA

What about the simulations that don't match?



How do you define the different disc geometries?



Wait, say what about the alignment time-scale?

- Warping (and continuous) results in alignment

- Breaking with one ring results in oscillations, with occasional anti-alignment

- Breaking with multiple rings results in unpredictable oscillations