



# Binary tidal evolution as a sculptor of circumbinary planet architectures

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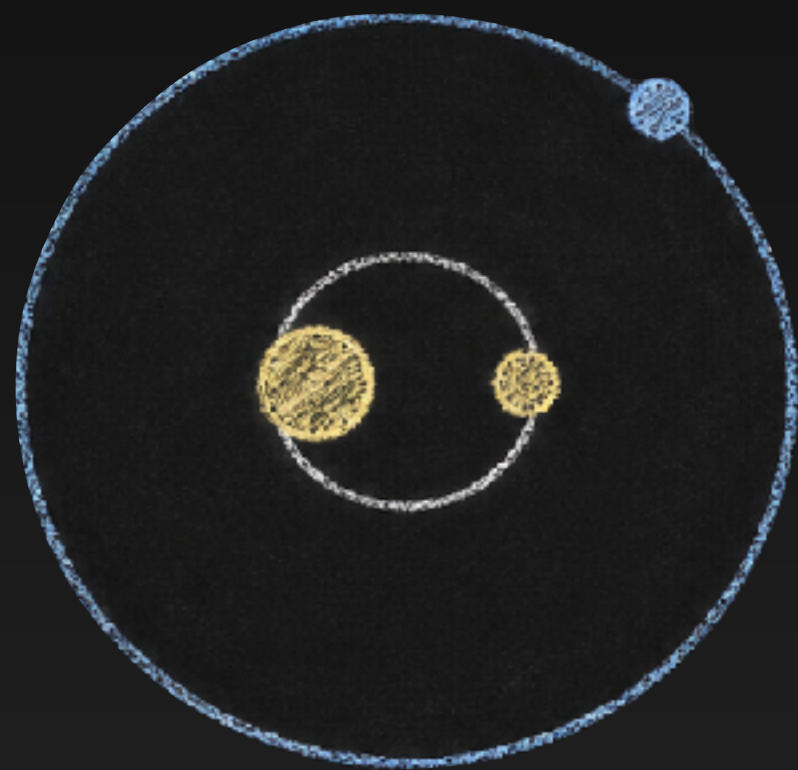
Institut de Planétologie et  
d'Astrophysique de Grenoble



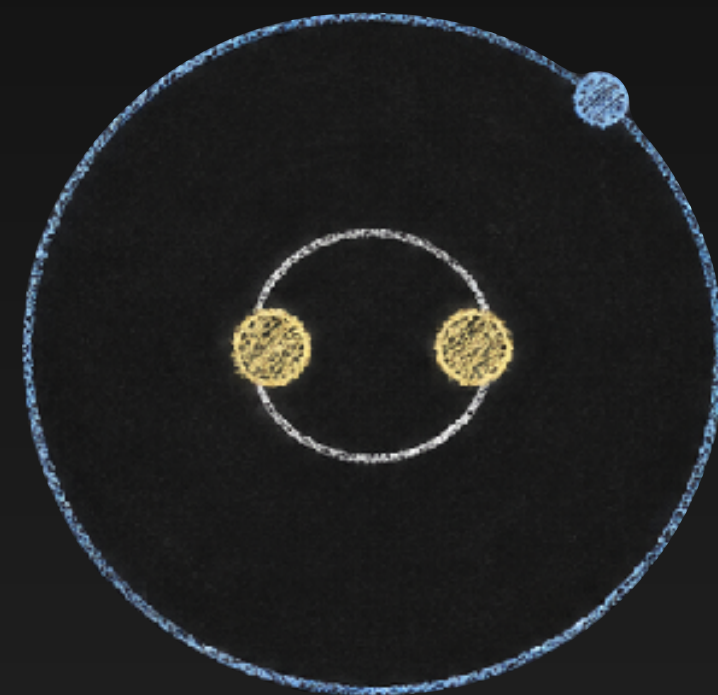
# Which binaries should we target for CBPs?

*A first observational guess*

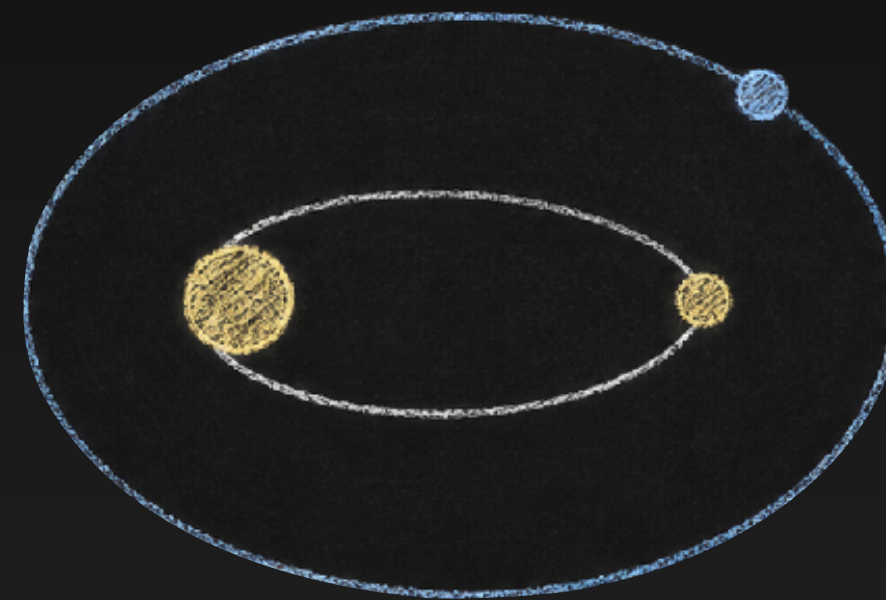
1. Compact binaries



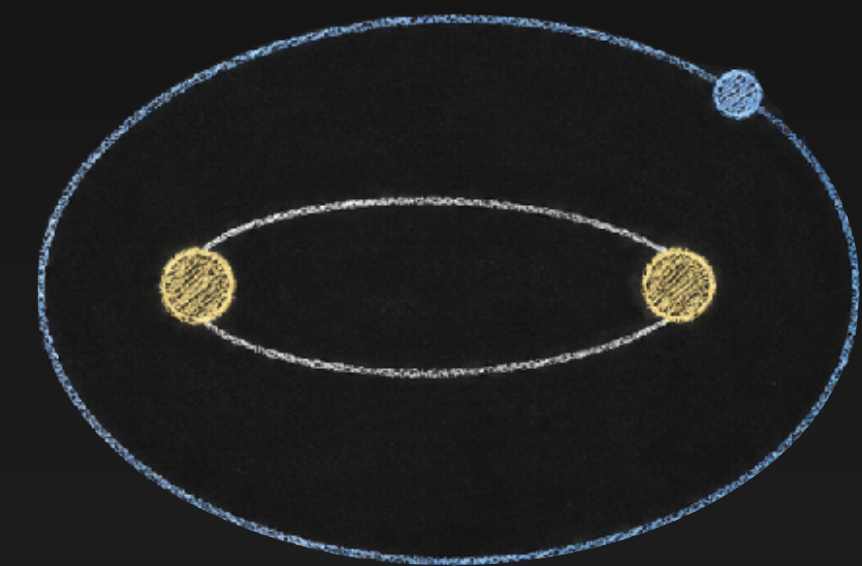
2. Compact and circular binaries



3. eccentric, low  $q_B$  binaries



4. eccentric, near-equal-mass binaries



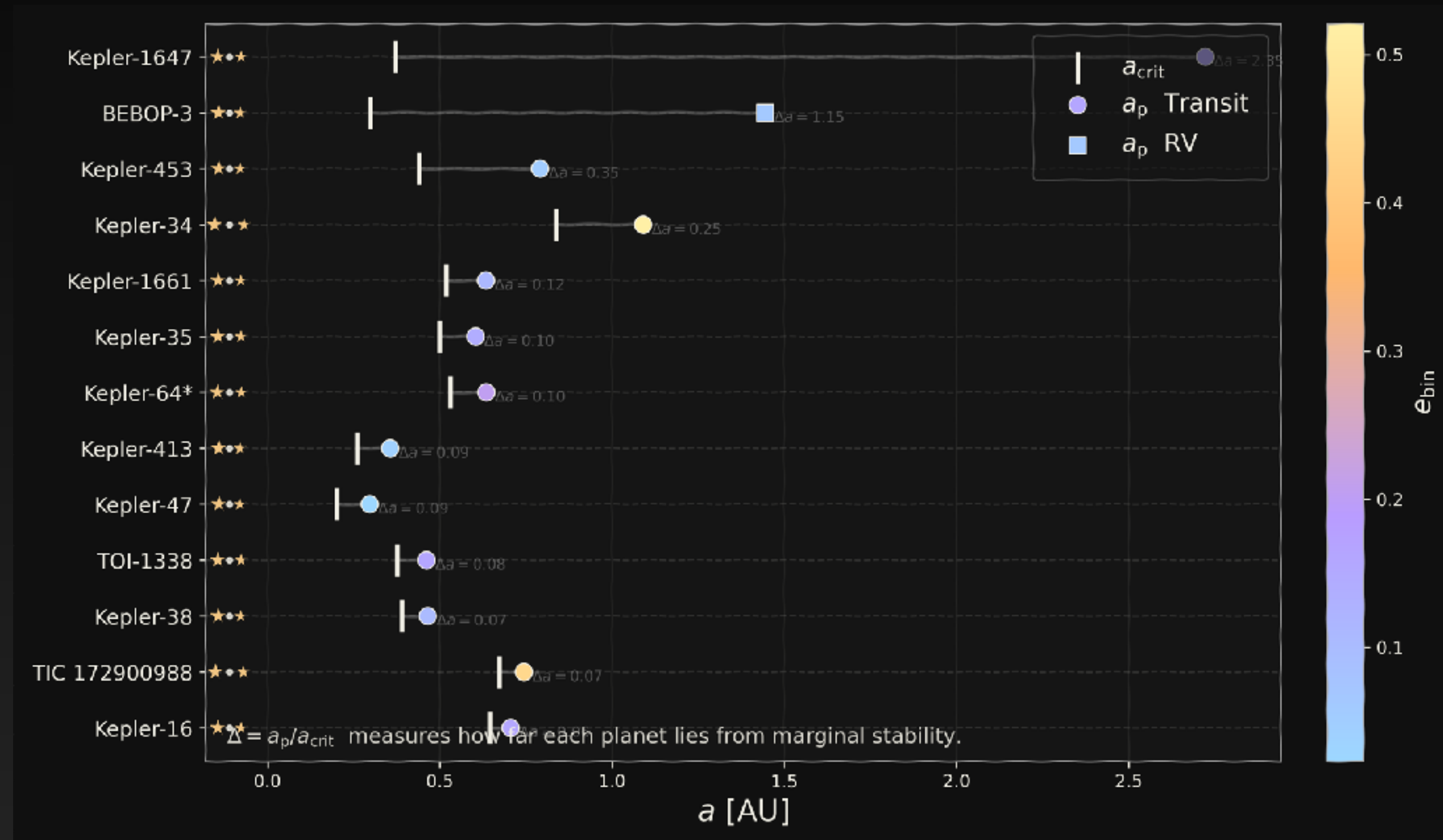
At first sight, the best targets seem to be compact, circular, well-characterised binaries.

Tidal history may decide which planets are still there and where.

# CBPs live near a dynamical edge — but not exactly on it

*CBPs migrate inward, but stability sets the inner edge.*

- Disc migration may park CBPs near the inner cavity.
- Long-term stability requires  $a_p > a_{crit}$
- Observed CBPs lie close to this boundary, but they do not pile up exactly at marginal stability.
- Why close to the edge, but not on the edge?



One possibility: the edge itself has moved.



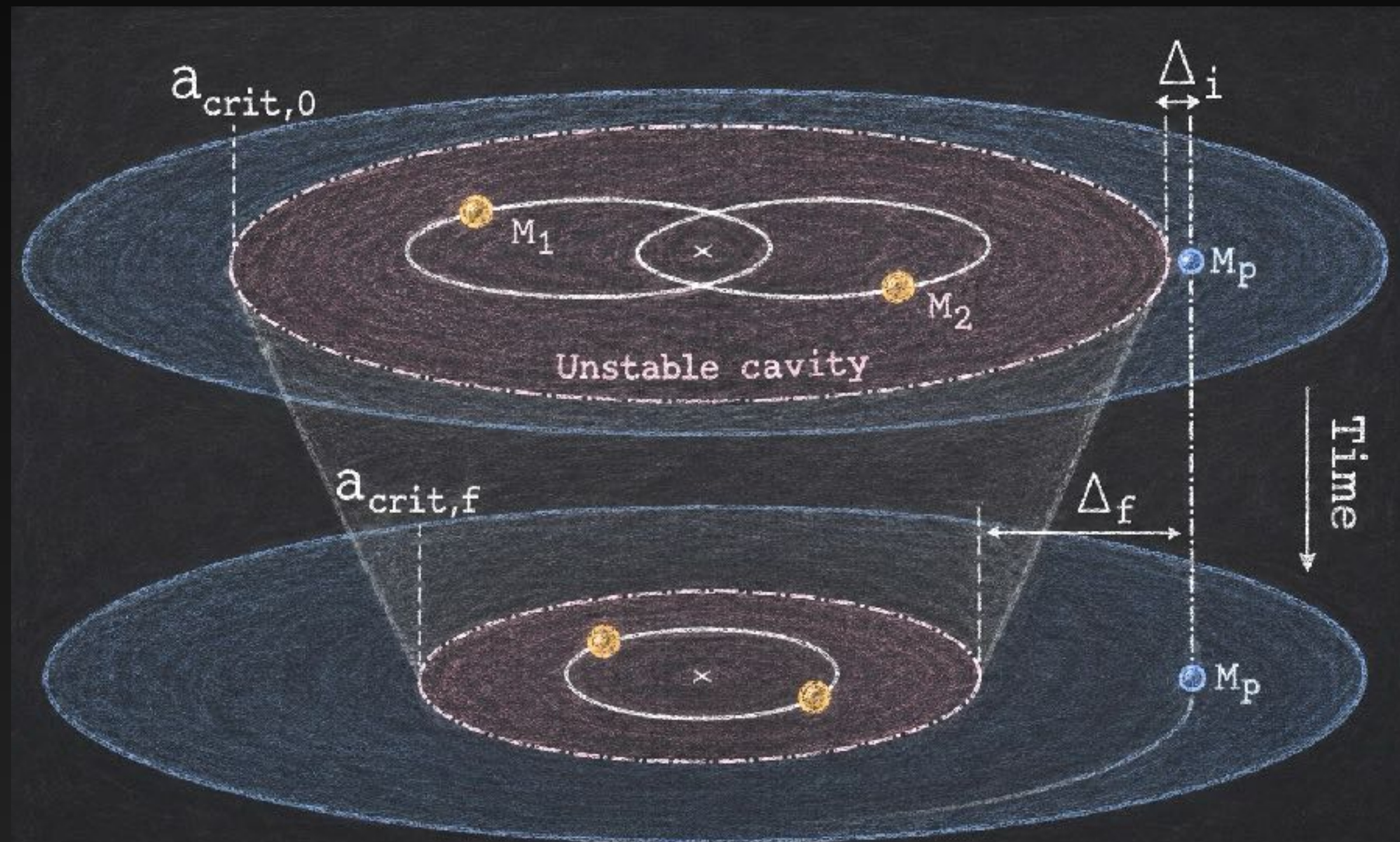
# The stability edge is not fixed

$$a_{crit} = a_{crit}(a_{bin}, e_{bin}, q_B)_1$$

1Holman & Wiegert 1999

$$a_{bin} \downarrow, \quad e_{bin} \downarrow$$

$$a_{crit}(t) \downarrow$$



The observed offset can grow without outward planetary migration.



# A controlled experiment

## Separating planetary motion from boundary motion

- Initial planet near the stability edge:

$$f = \frac{a_{p,0}}{a_{crit,0}}$$

- Two matched integrations:

*fixed binary & evolving binary*

In the evolving run:

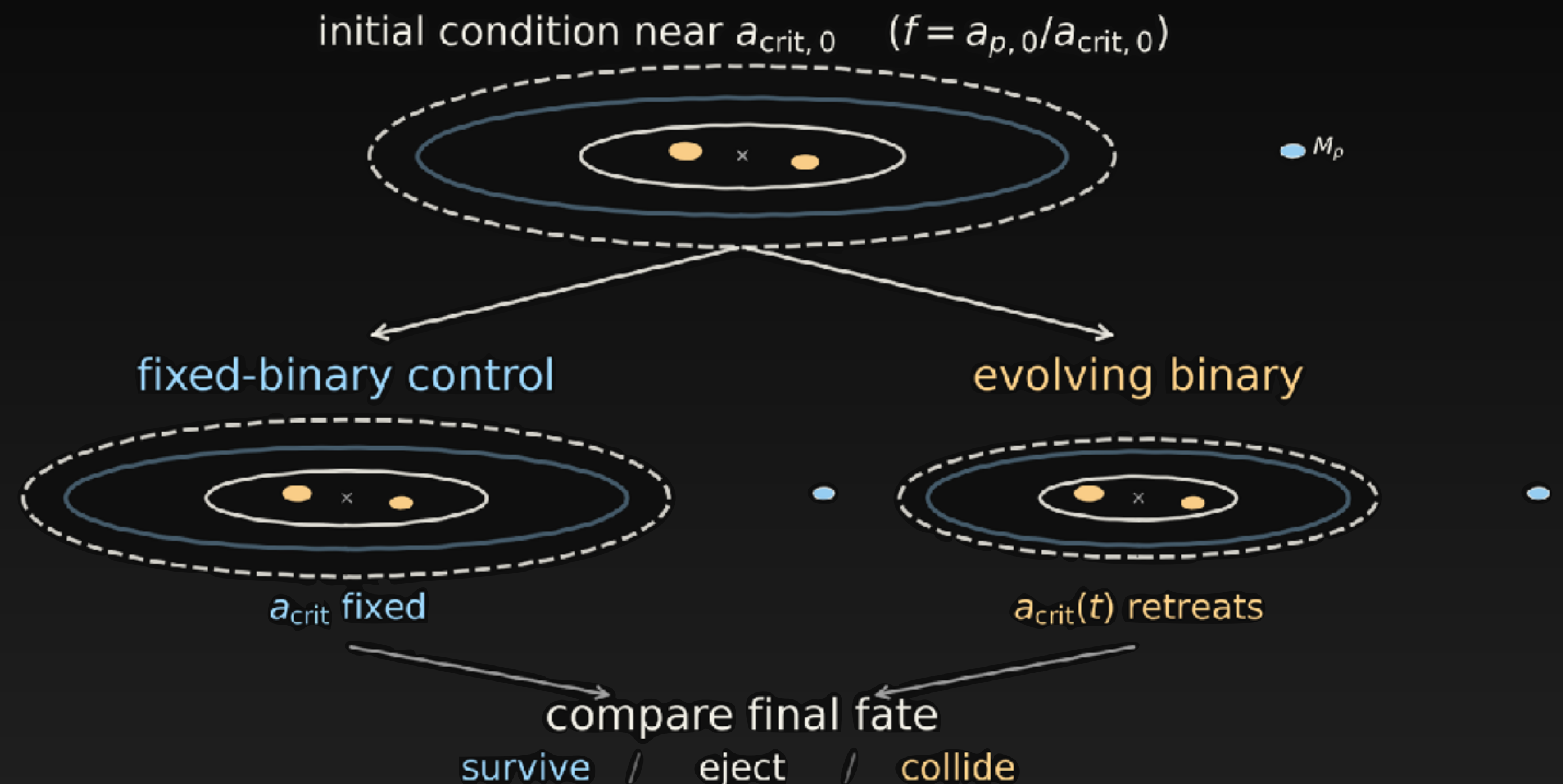
$$e_{bin}(t) \downarrow, \quad a_{bin}(1 - e_{bin}^2) \simeq const.$$

We compare

$$a_p(t) \quad \text{vs.} \quad a_{crit}(t)$$

- And the final fate,

survive / eject / collide

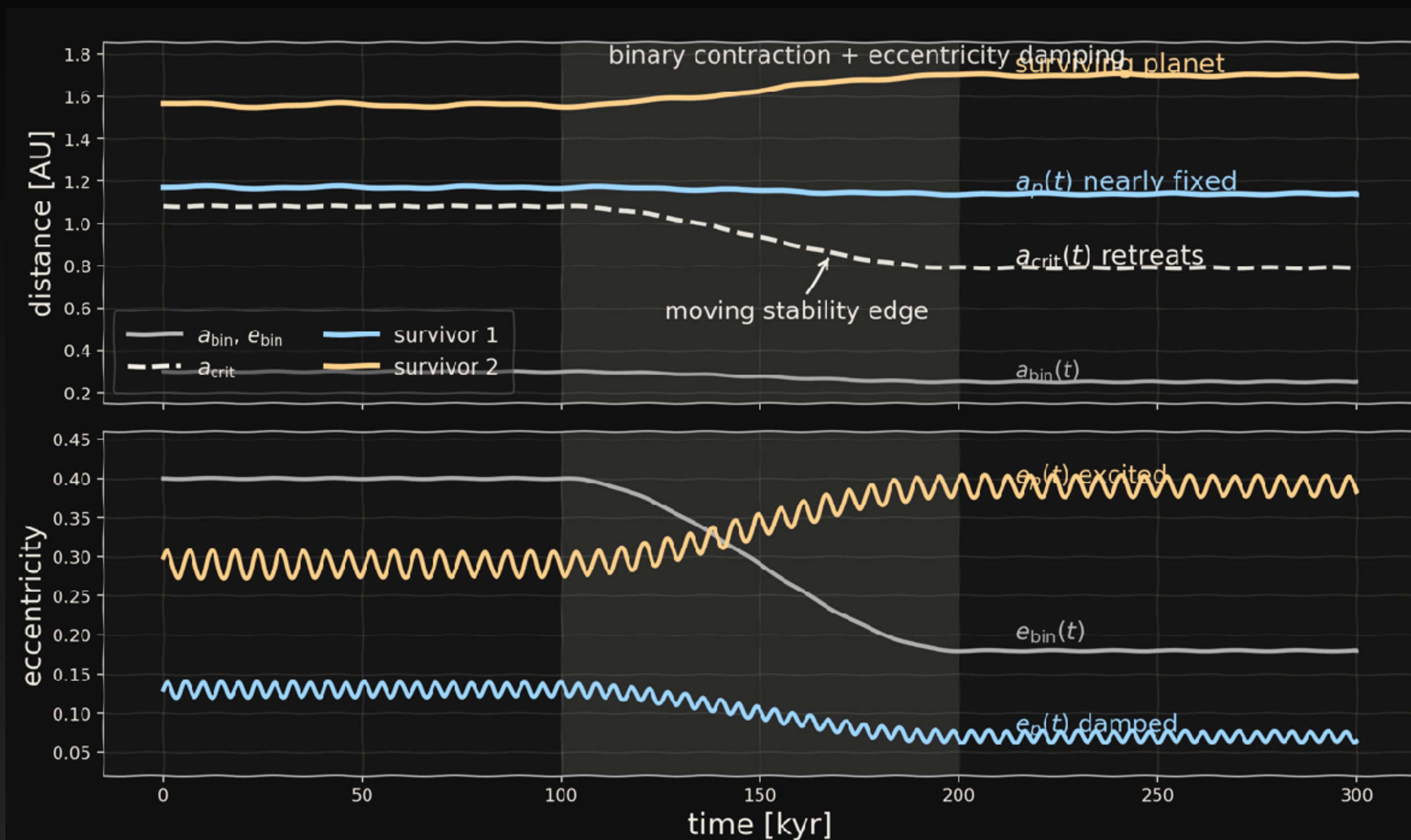


Do planets follow the edge, or are they left behind?



# Representative evolution

The edge retreats, but surviving planets barely move



A surviving planet can be left behind as the stability boundary retreats.



# Population-level response

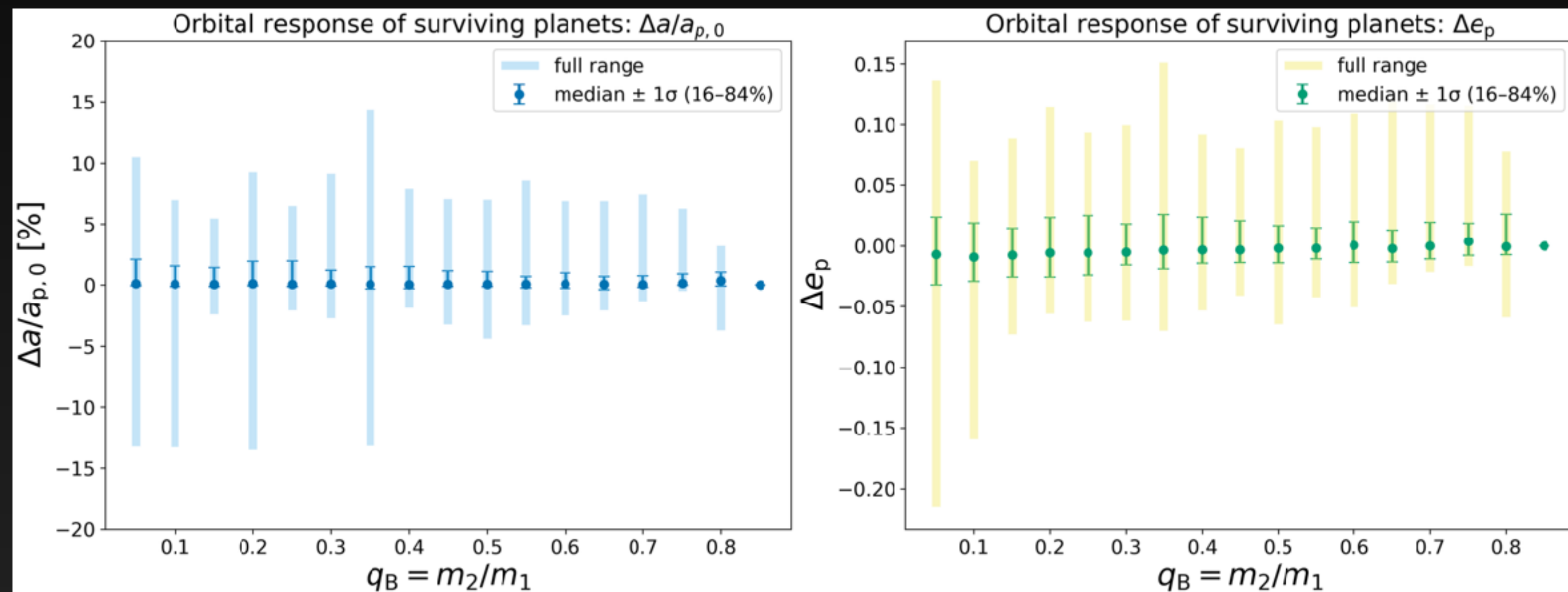
## Surviving planets remain nearly fossilised

- Survivors show little orbital displacement:

$$\Delta a_p / a_{p,0} \approx 0$$

$$\Delta e_p \approx 0$$

- The offset grows because  $a_{crit}(t)$  retreats inward.

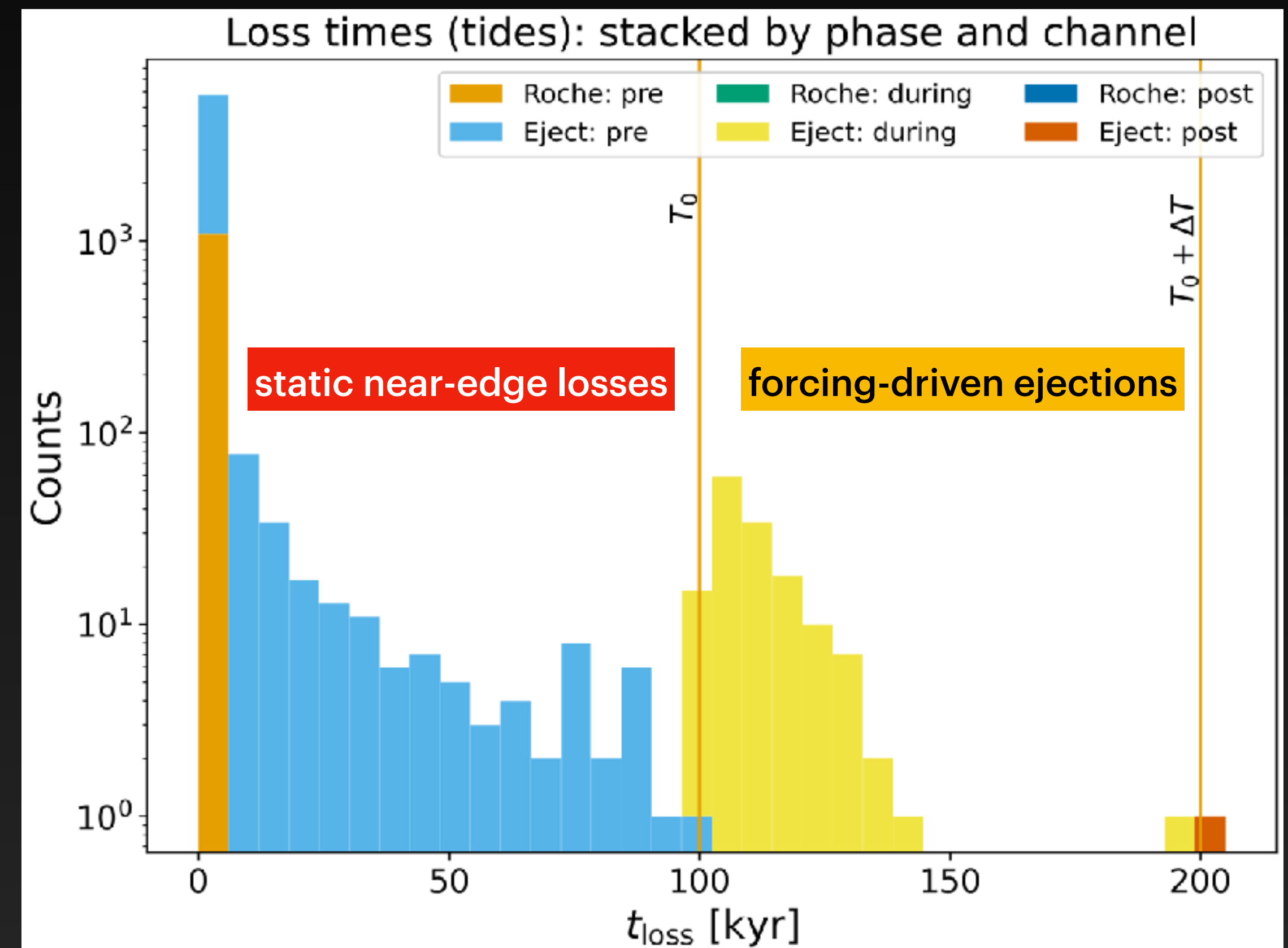


The planets barely move; the stability boundary does.

# Binary evolution opens an additional loss channel

Static near-edge losses and forcing-driven ejections occur at different times

- Near-boundary planets can be lost even before the binary evolves.
- But during the imposed tidal evolution, a second loss component appears.
- These forcing-driven losses are dominated by ejections.



Boundary retreat can leave fossil survivors — and remove unstable neighbours.

# Near-equal-mass binaries are stronger dynamical filters

The fate budget changes with  $q_B$

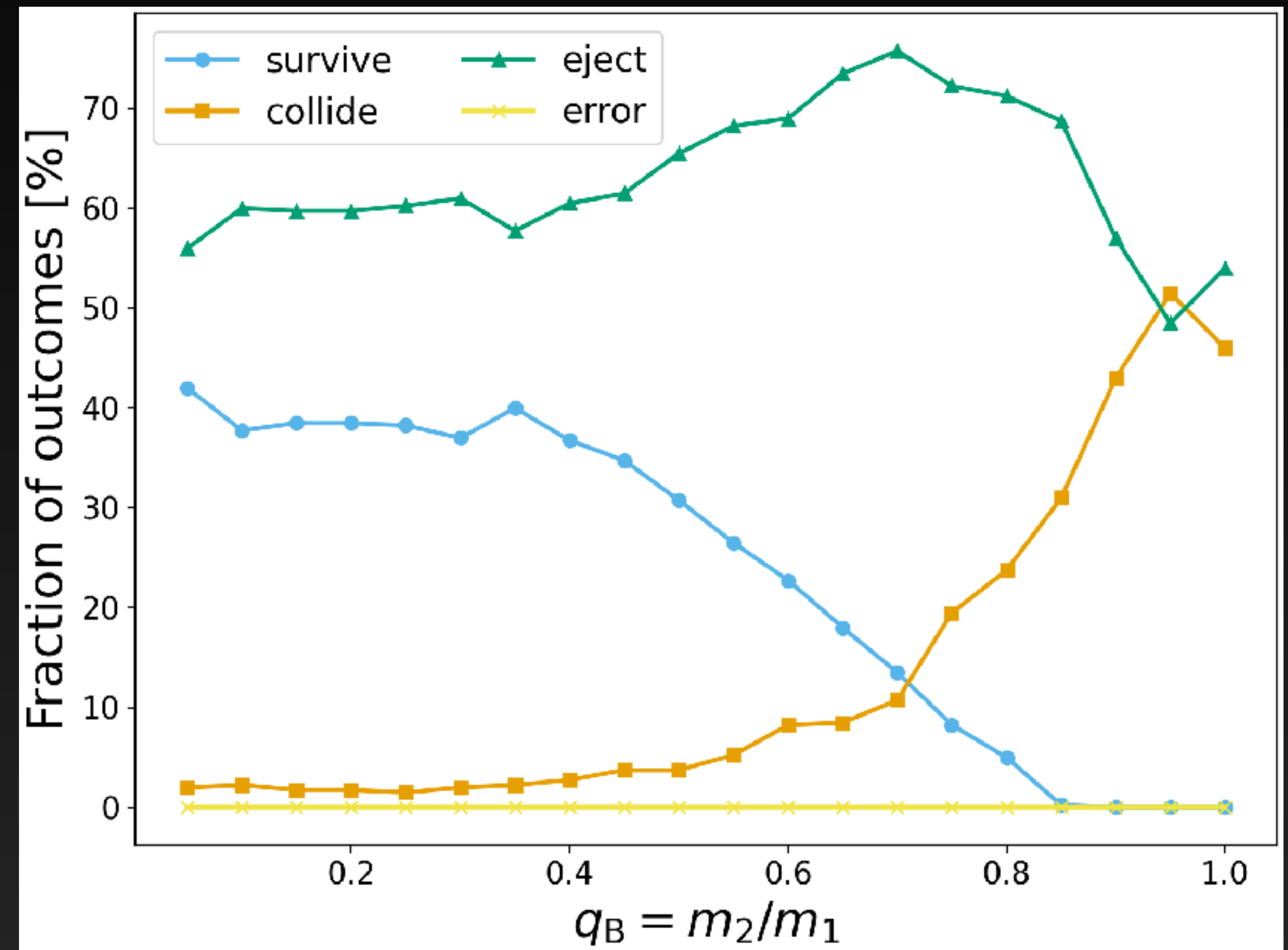
- The final fate budget depends on the binary mass ratio:  $q_B = \frac{m_2}{m_1}$

- For low-to-intermediate  $q_B$ , survival remains common.

- As  $q_B \rightarrow 1$ :

*survival* ↓      *ejections, collisions* ↑

- Near-equal-mass binaries host a more strongly filtered survivor population.



The near-boundary population is filtered before we observe it.

# A fossil-orbit test on observed CBPs

Do observed systems shift as expected if the boundary retreats?

- For each observed CBP we keep

$$a_p = \text{constant}$$

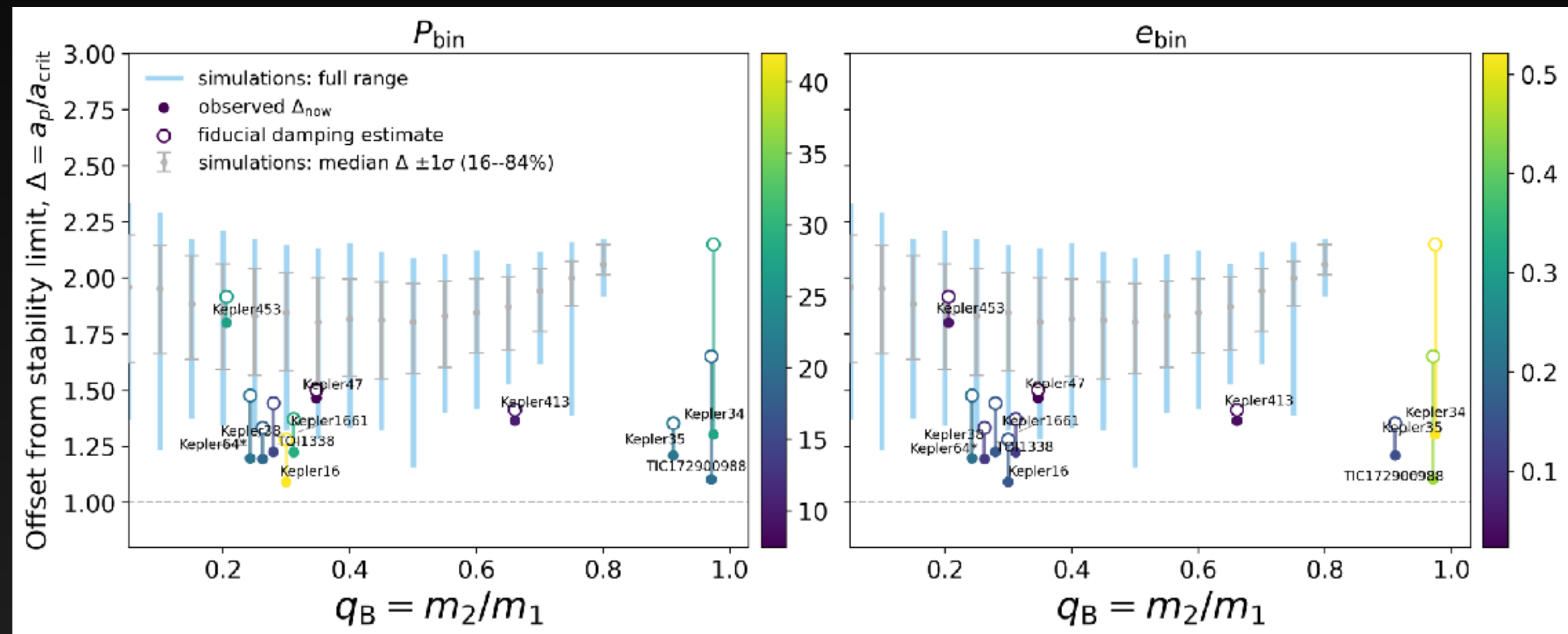
- and apply the same fiducial binary damping:

$$e_{bin} \downarrow, \quad a_{crit}(t) \downarrow$$

so the offset increases:

$$\Delta_{now} = \frac{a_p}{a_{crit,now}} \rightarrow \Delta_{damp} = \frac{a_p}{a_{crit,damp}}$$

Observed systems shift toward the simulated fossil population.



This is a fossil-orbit diagnostic, not a reconstruction of individual histories.



# Back to the opening question

For an observing campaign, I would prioritise:



## COMPACT

Shorter periods,  
Better detectability



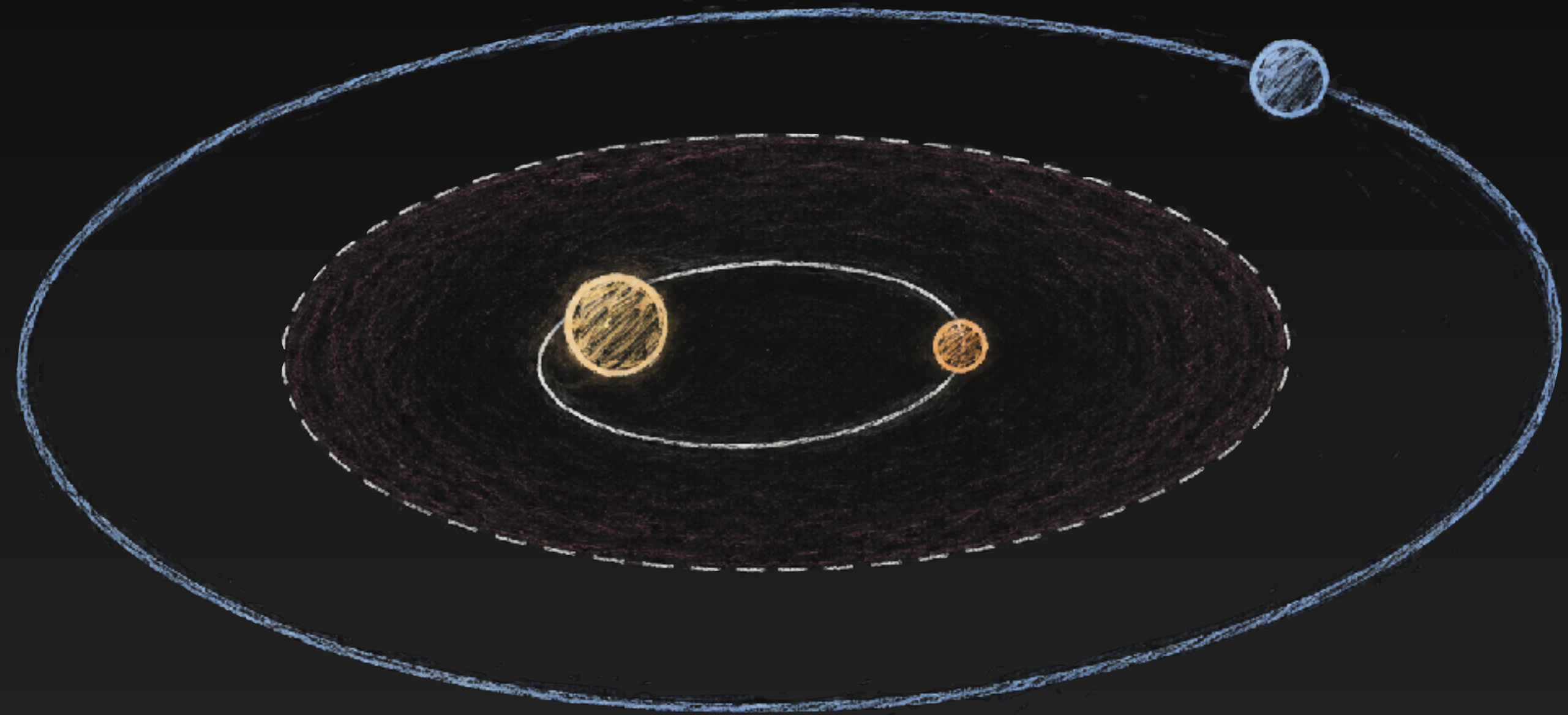
## STILL ECCENTRIC

Not yet fully  
Tidally processed



## LOW-TO-MODERATE $q_B$

Weaker dynamical filtering,  
More near-boundary survivors



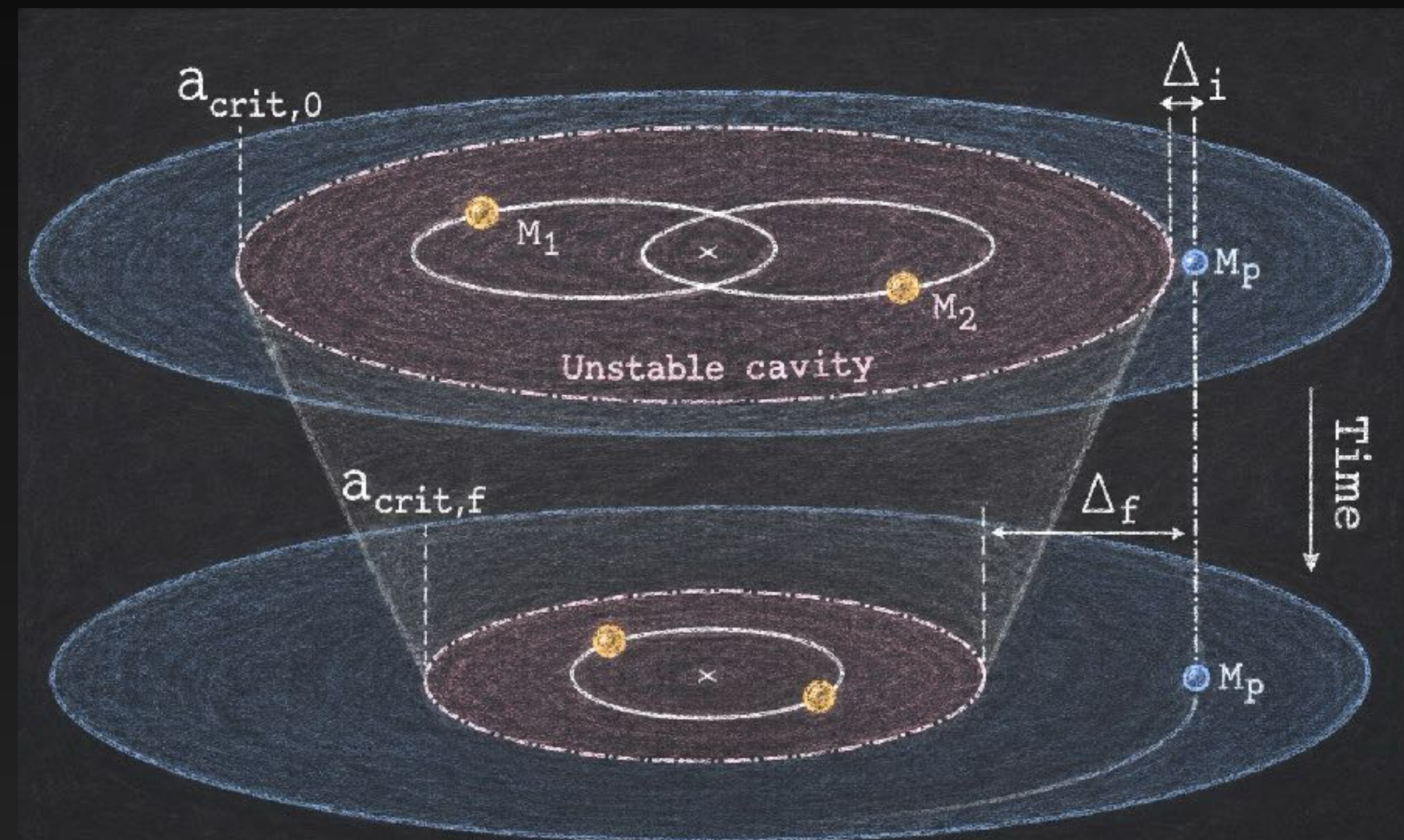
They may offer the best compromise between detectability and dynamical survival.



# Take home message

The stability edge is not fixed.

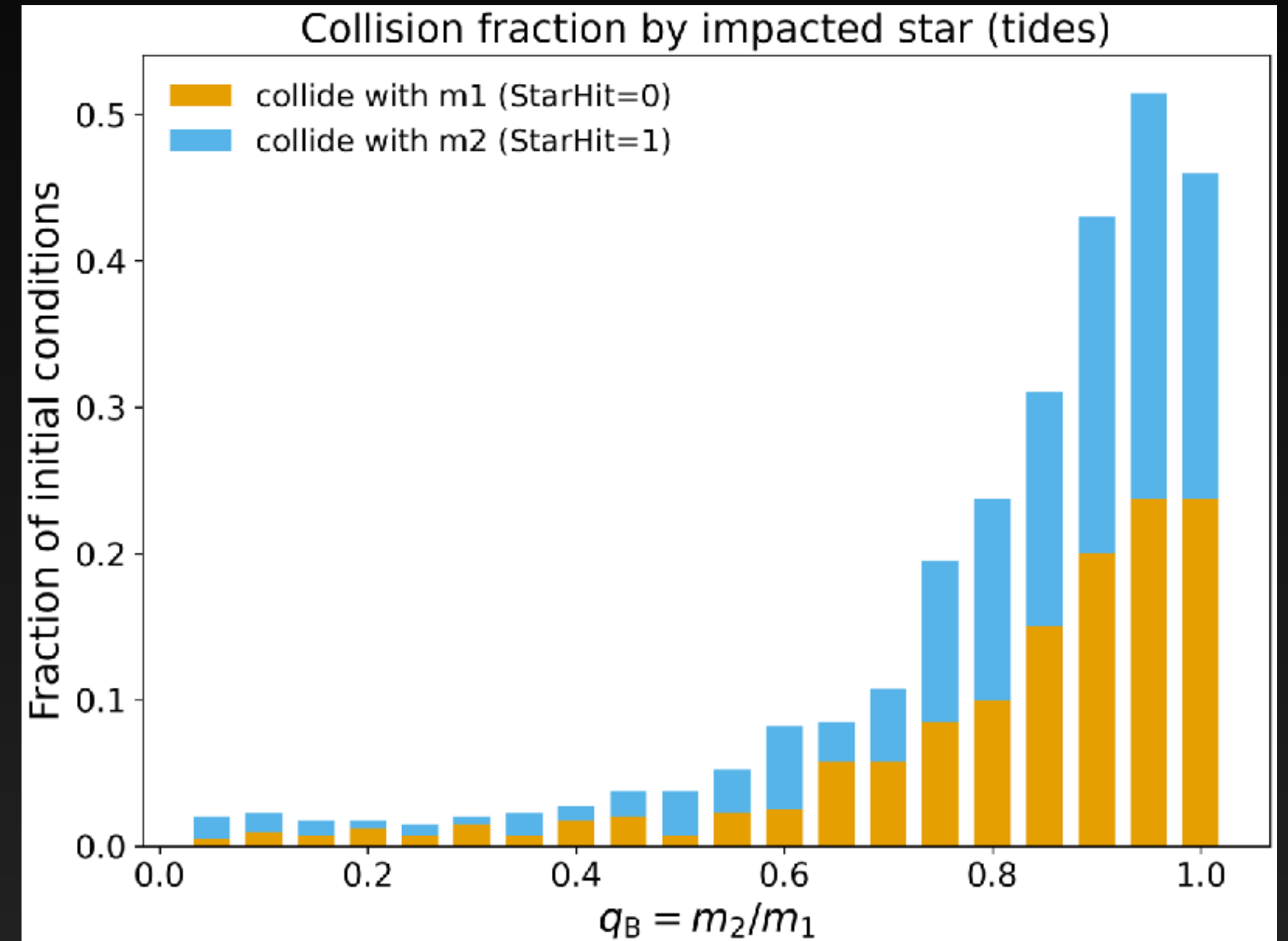
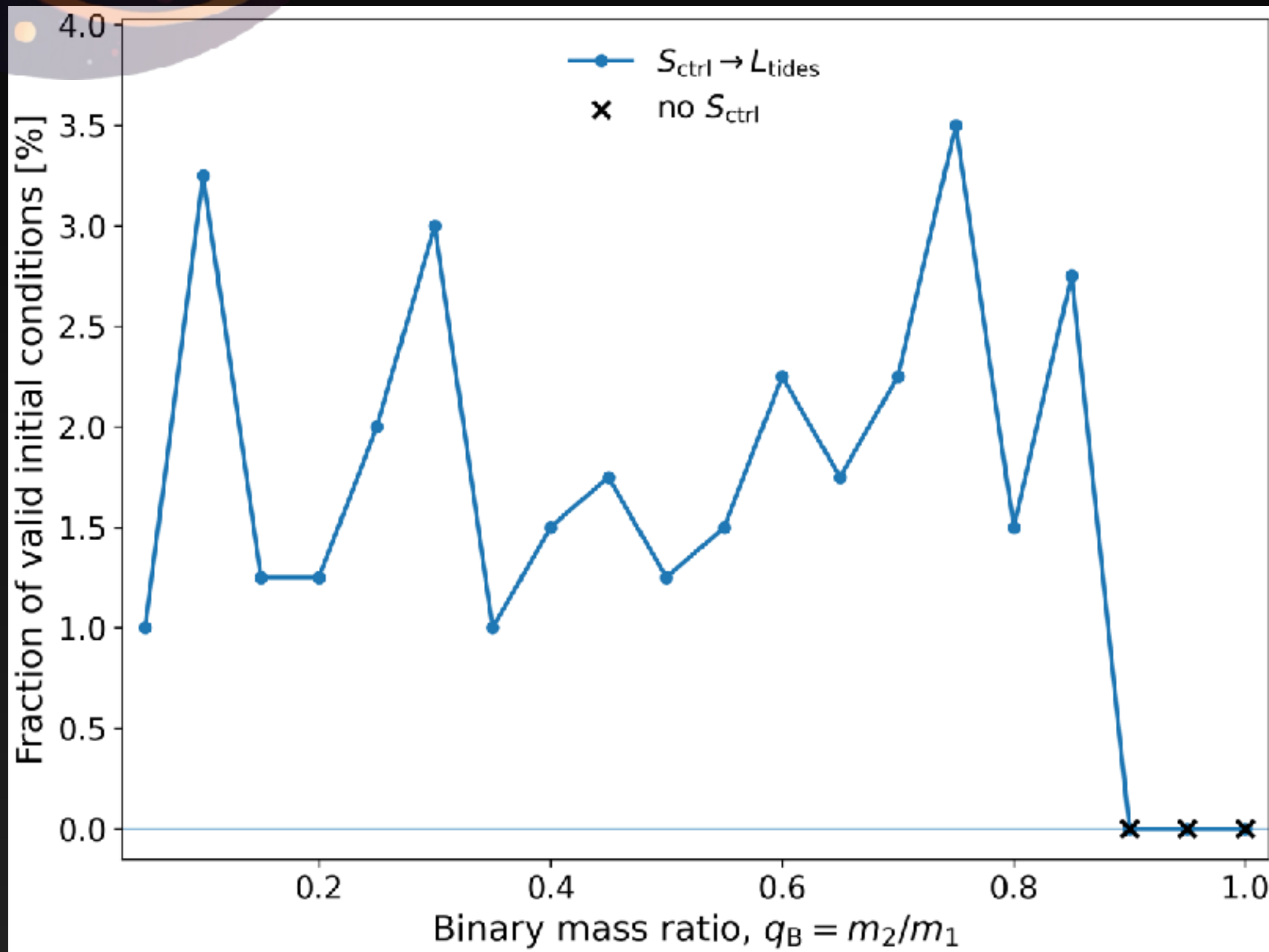
- Binary tidal evolution can move  $a_{crit}$  inward, leaving surviving CBPs as fossil orbits farther from marginal stability.
- Near-equal-mass binaries are stronger dynamical filters, removing more near-boundary planets.
- As the CBP sample grows, the offset from marginal stability may become a tracer of binary tidal evolution.





# Outcomes

## Additional material



# Circumbinary planets live near a dynamical edge

## Additional material

- Circumbinary planets are expected to form in circumbinary discs and migrate inward towards the disc inner cavity.

- But their final location is constrained by the binary:

$$a_p > a_{crit}(a_{bin}, e_{bin}, q_B)$$

- where  $a_{crit}$  marks the inner boundary for long-term stability.

- Observed circumbinary planets are close to this limit,

- but they are not exactly marginally stable.

- $\Delta \equiv \frac{a_p}{a_{crit}} > 1$

Two edges around a binary: disc cavity and dynamical stability

