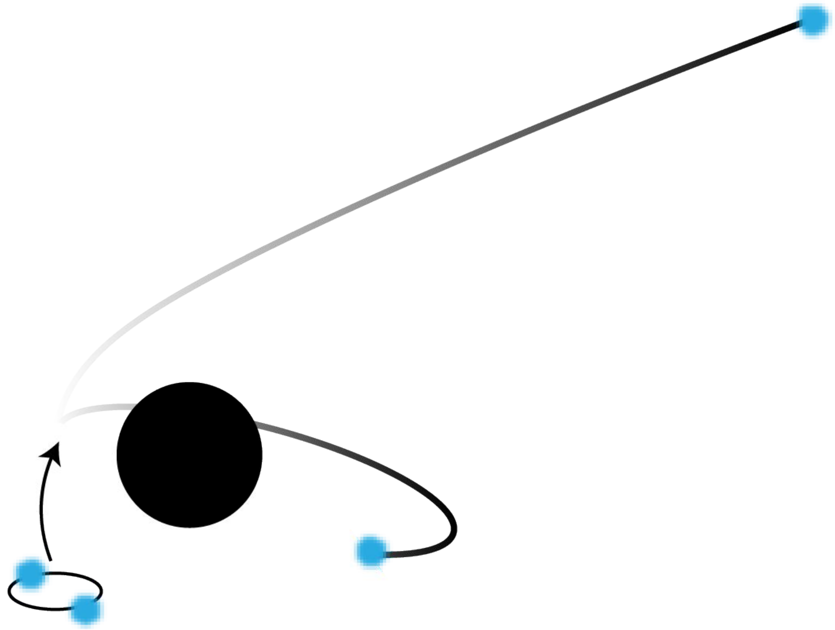
Dynamics of stellar binaries in the Galactic Center

Mark Dodici University of Toronto
mdodici.github.io
mark.dodici@astro.utoronto.ca

Binaries near Sagittarius A* may be related to several observables…



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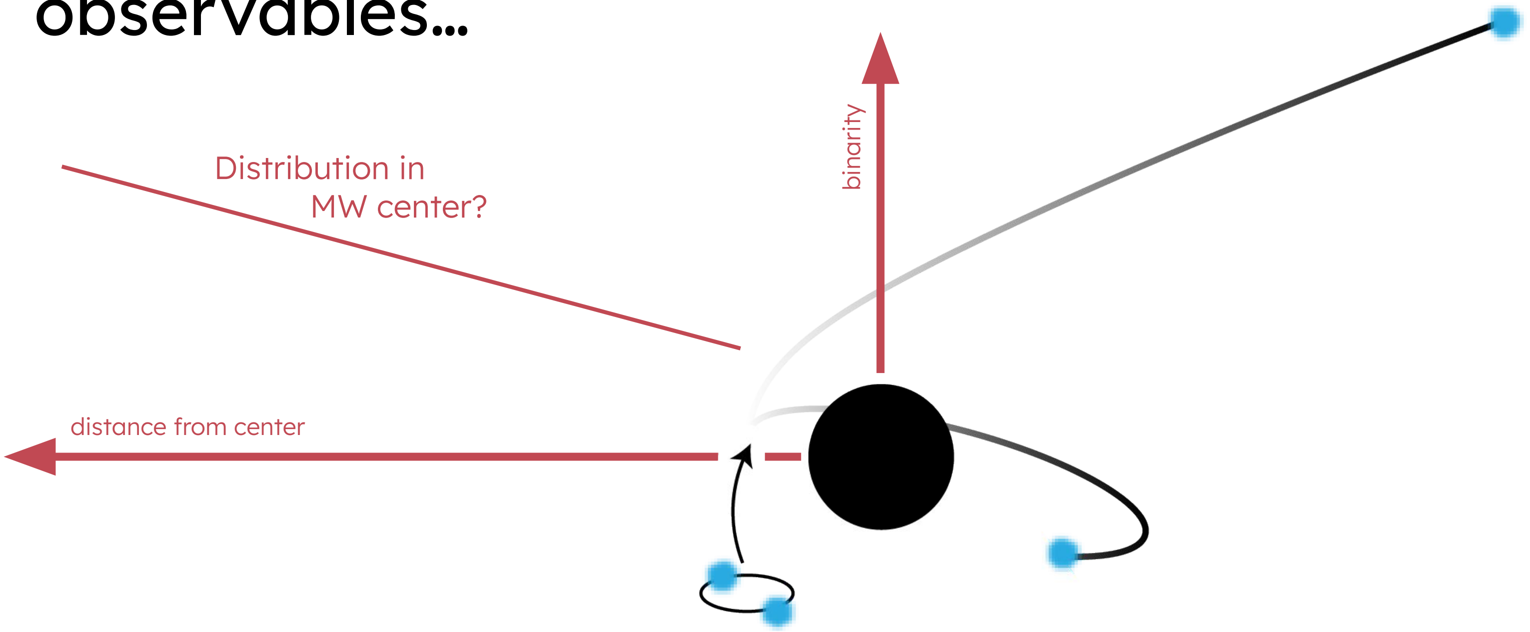

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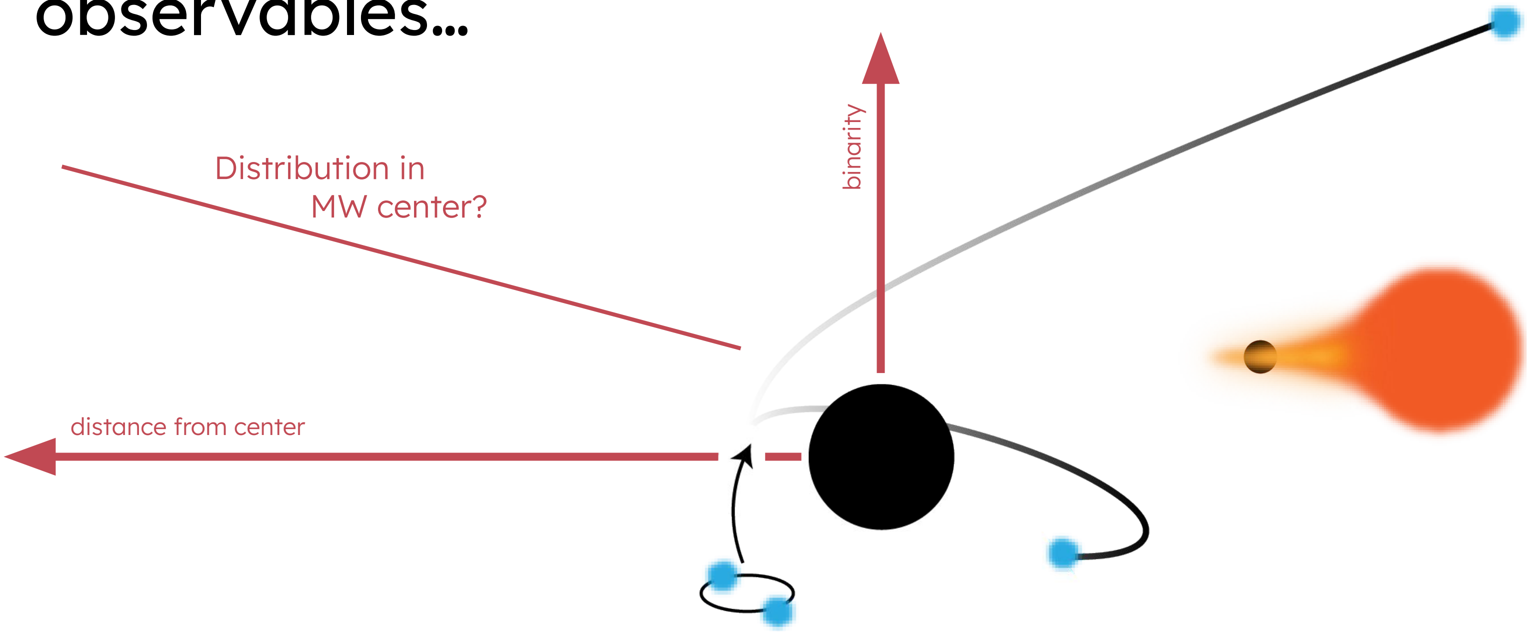

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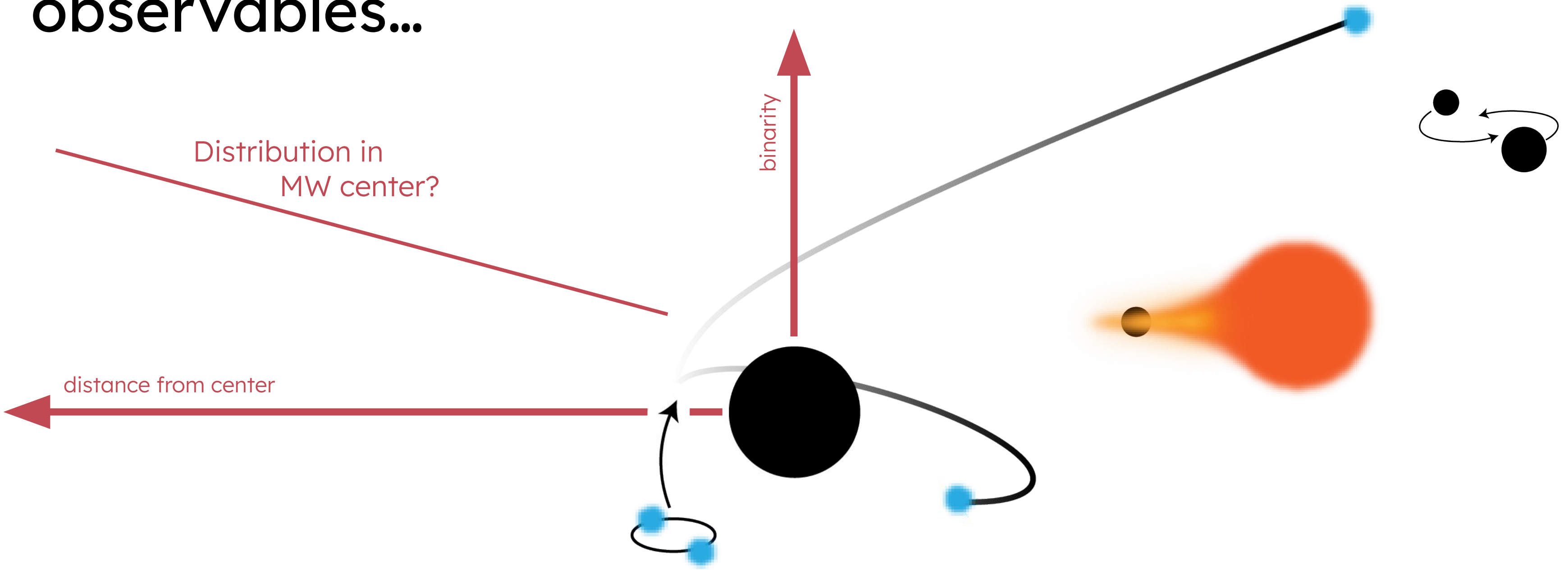

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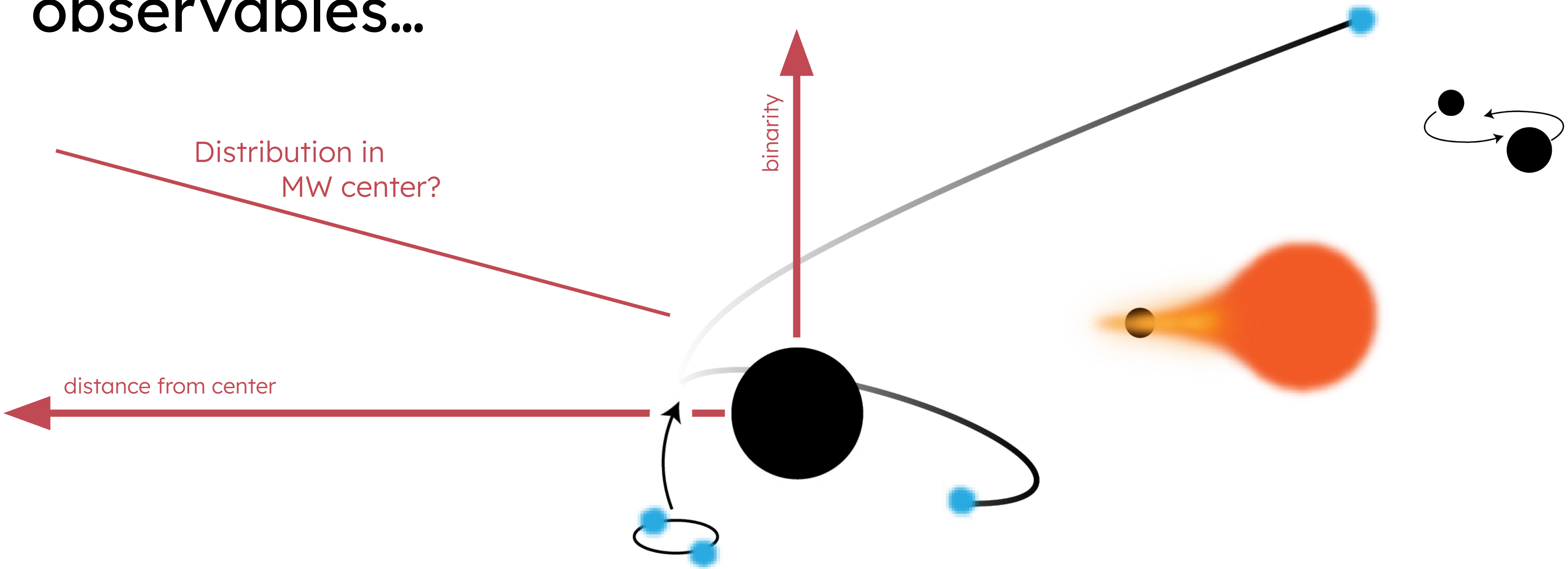
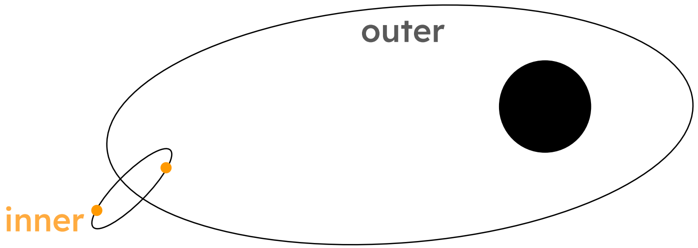


to constrain the observables, we need to understand how the binaries evolve result #1

2 in 5 stellar binaries orbiting Sgr A* should shrink before they die

M. Dodici, S. Tremaine, & Y. Wu (2026)
ApJ 1000 (2) 226
arXiv:2511.02905

Two broad steps to shrinking



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↓

2. Tides raised on the binary members shrink orbits to ~ 6 stellar radii

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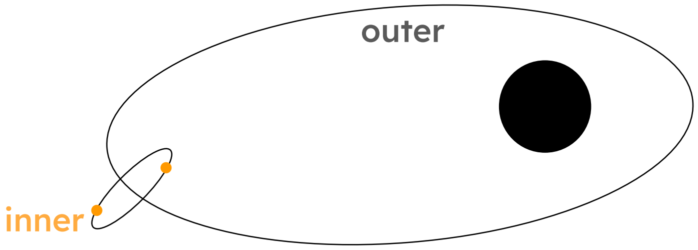

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primarily cf. Stephan et al. (2016, 2019)

Compared to past results:

- ~4x more small pericenters
- Shrinking instead of mergers

Two broad steps to shrinking

ZLK

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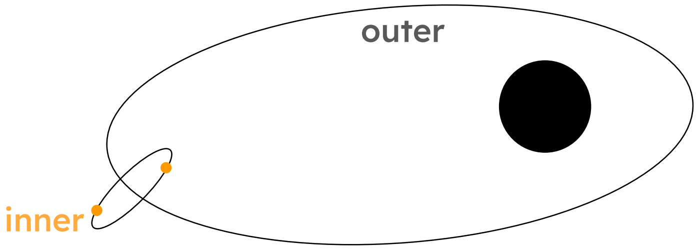

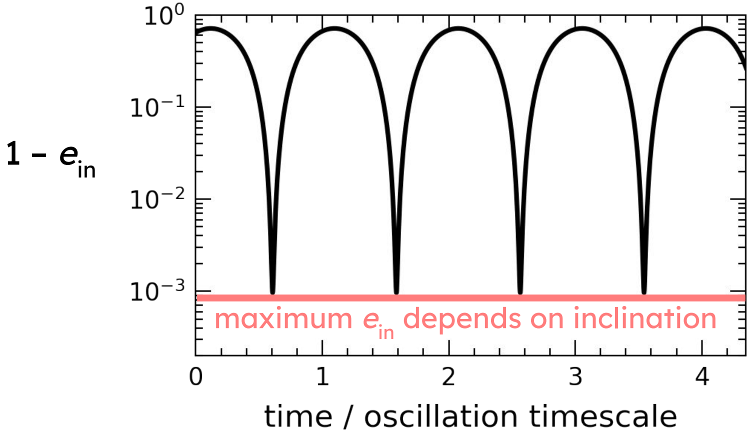

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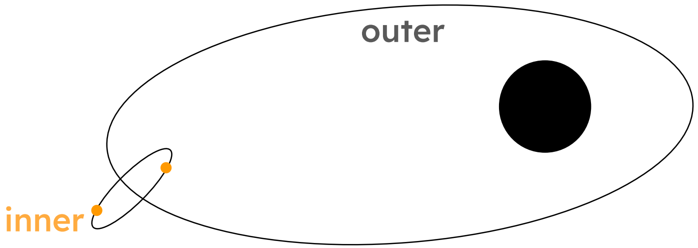

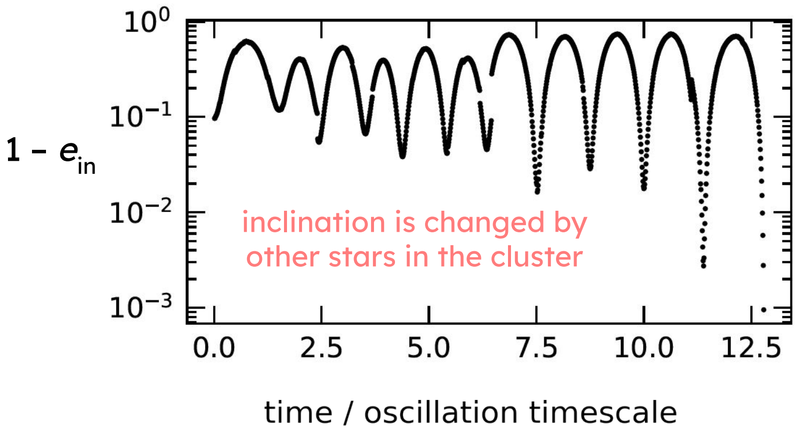

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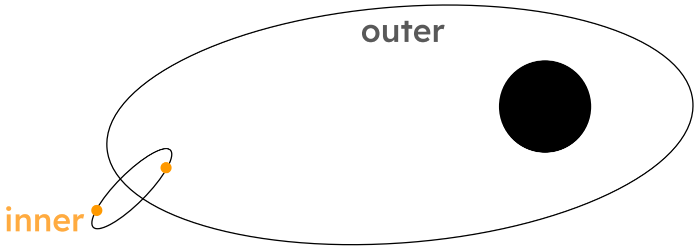

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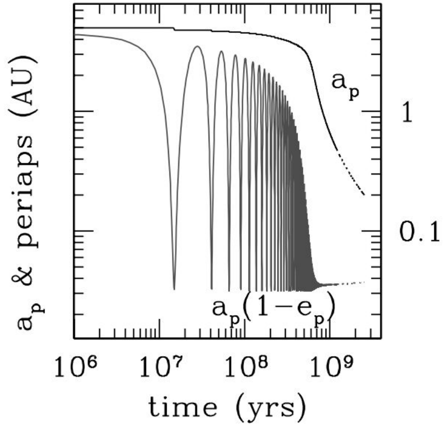
Diffusive tides → **rapid shrinking**

"Classic" tidal friction

ex. from Wu & Murray (2003)



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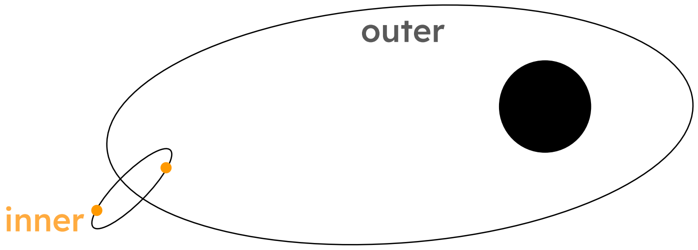

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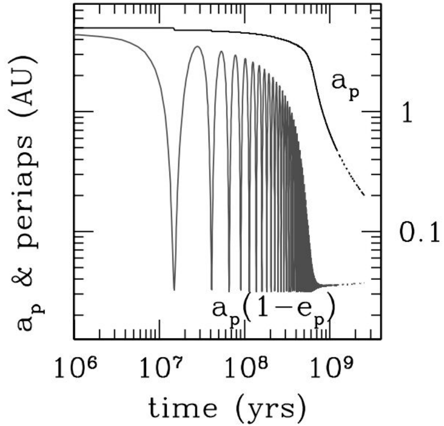

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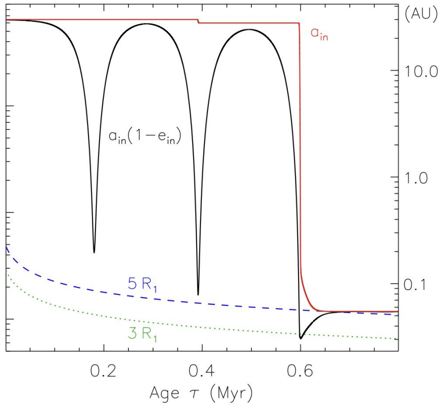

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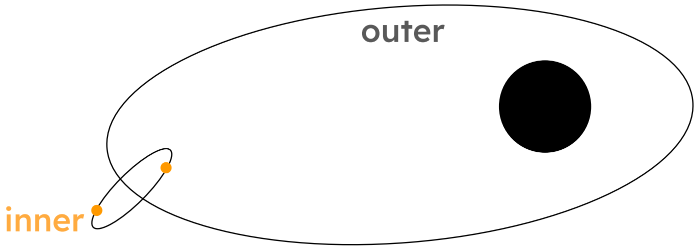

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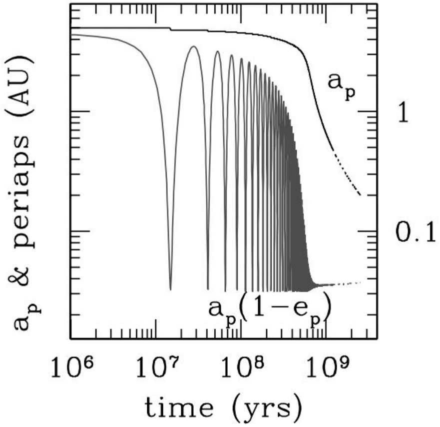

mergers likely

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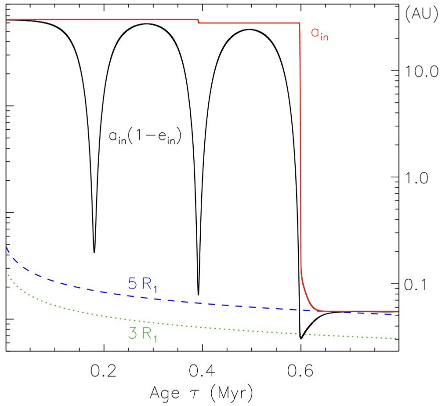

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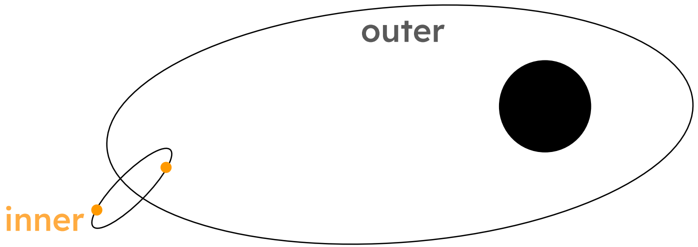

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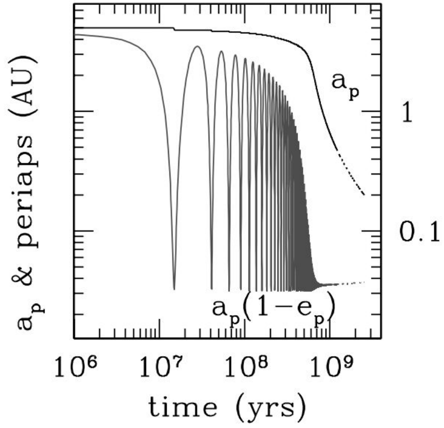

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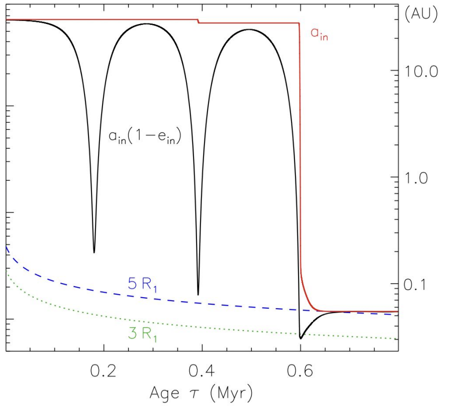

mergers strongly suppressed

arXiv:2511.02905

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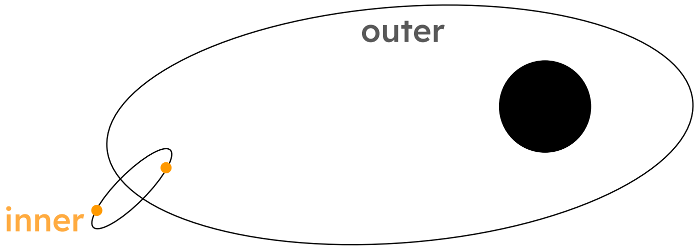

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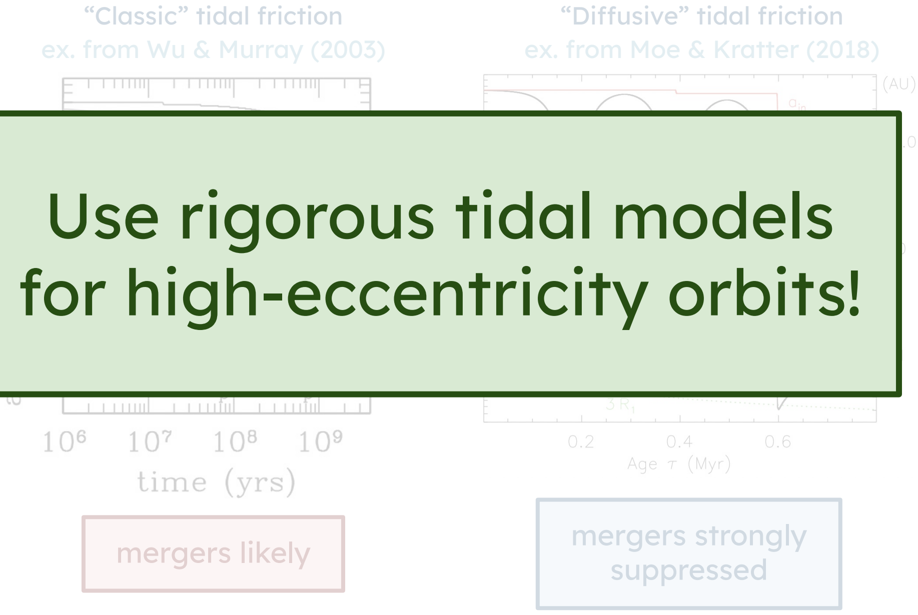
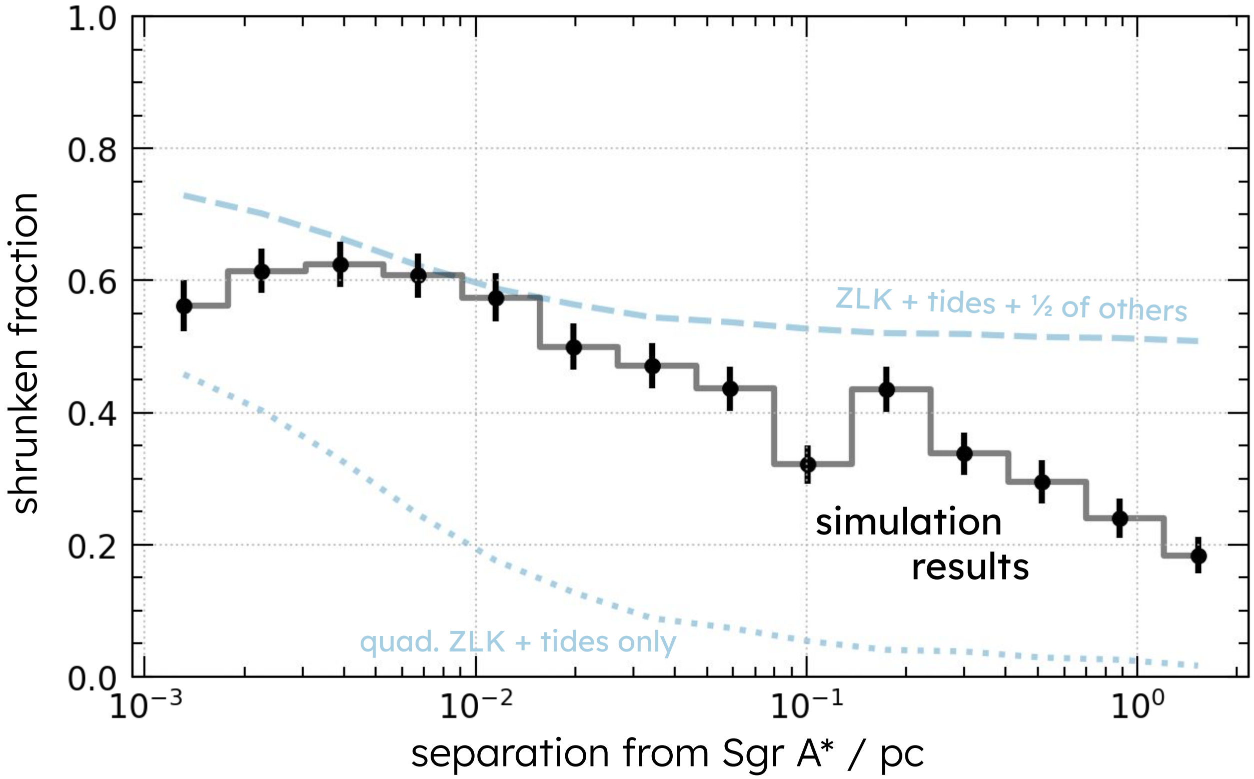


Use rigorous tidal models for high-eccentricity orbits!

arXiv:2511.02905

~2 in 5 binaries shrink via diffusive tidal friction



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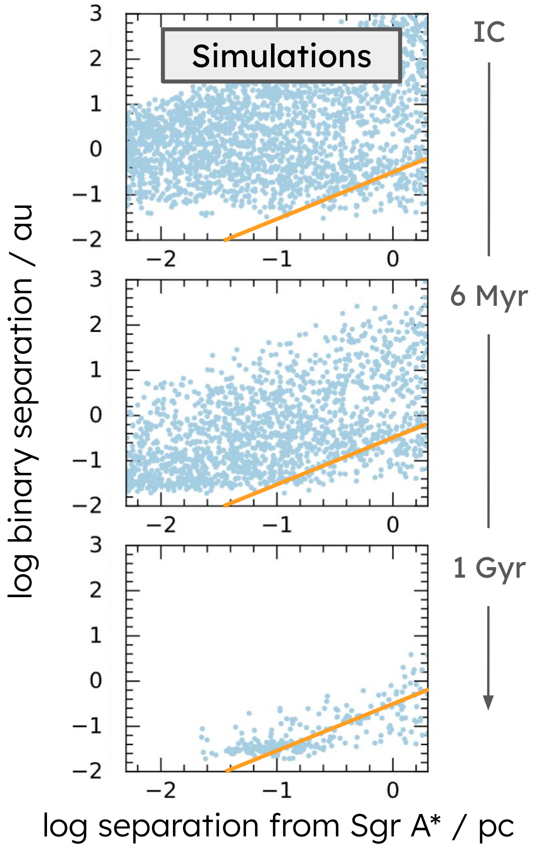
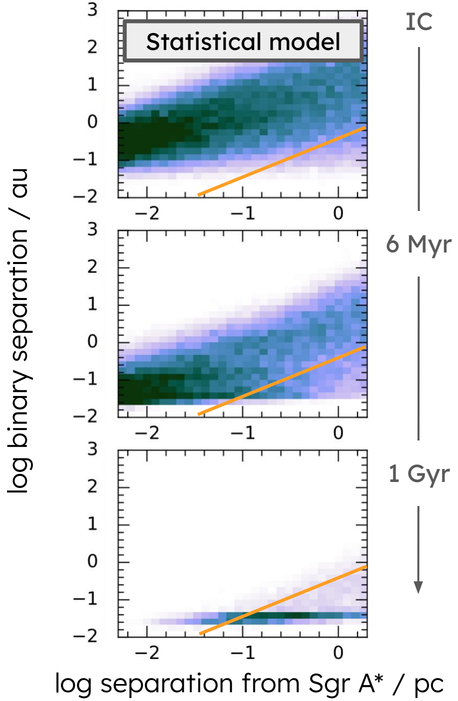
Persistent spike in binary semimajor axis distribution



One can replicate this distribution with a simple, statistical model



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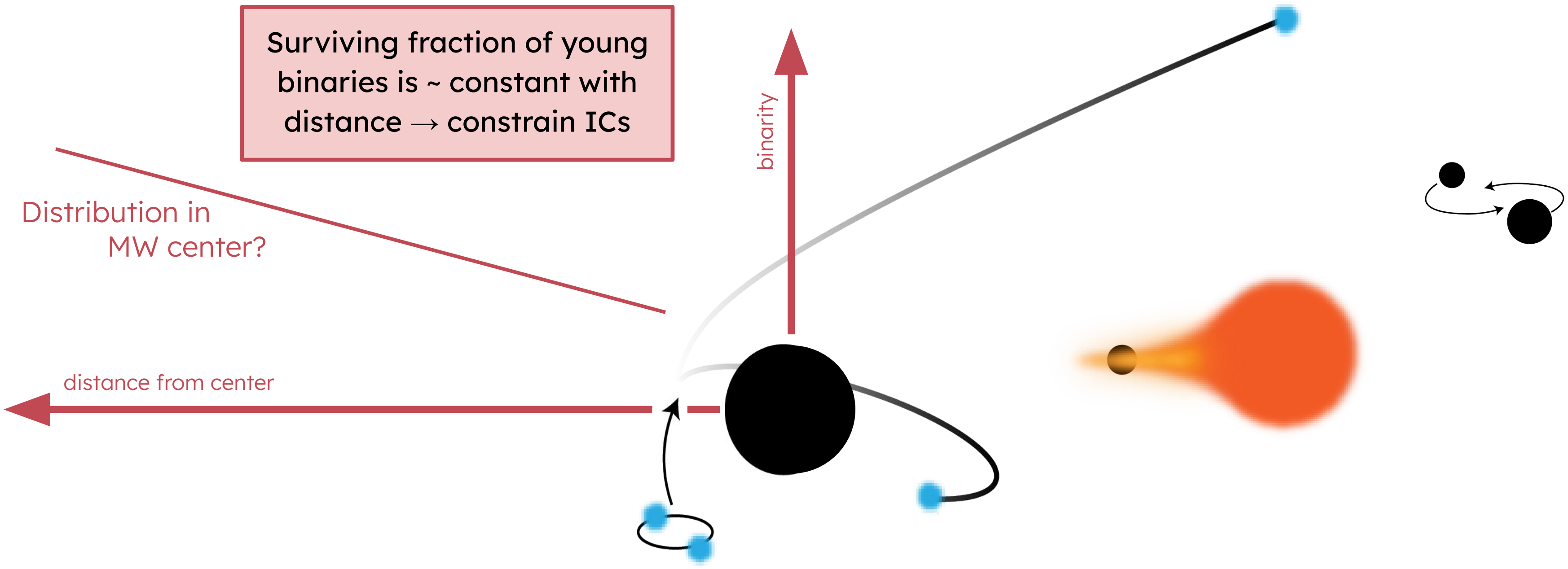
What can we say about our observables?

Surviving fraction of young binaries is ~ constant with distance → constrain ICs



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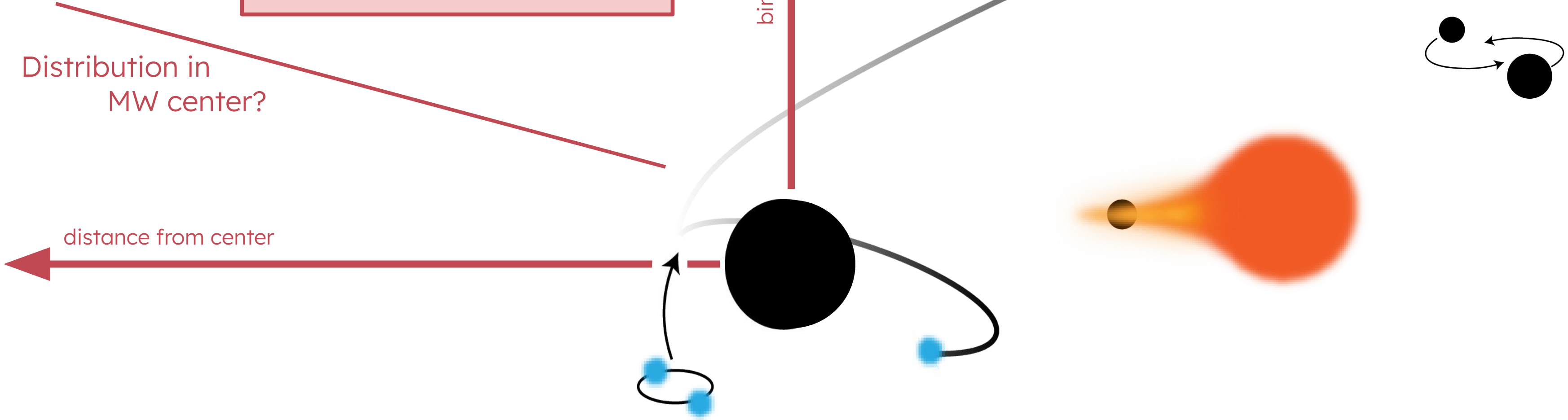

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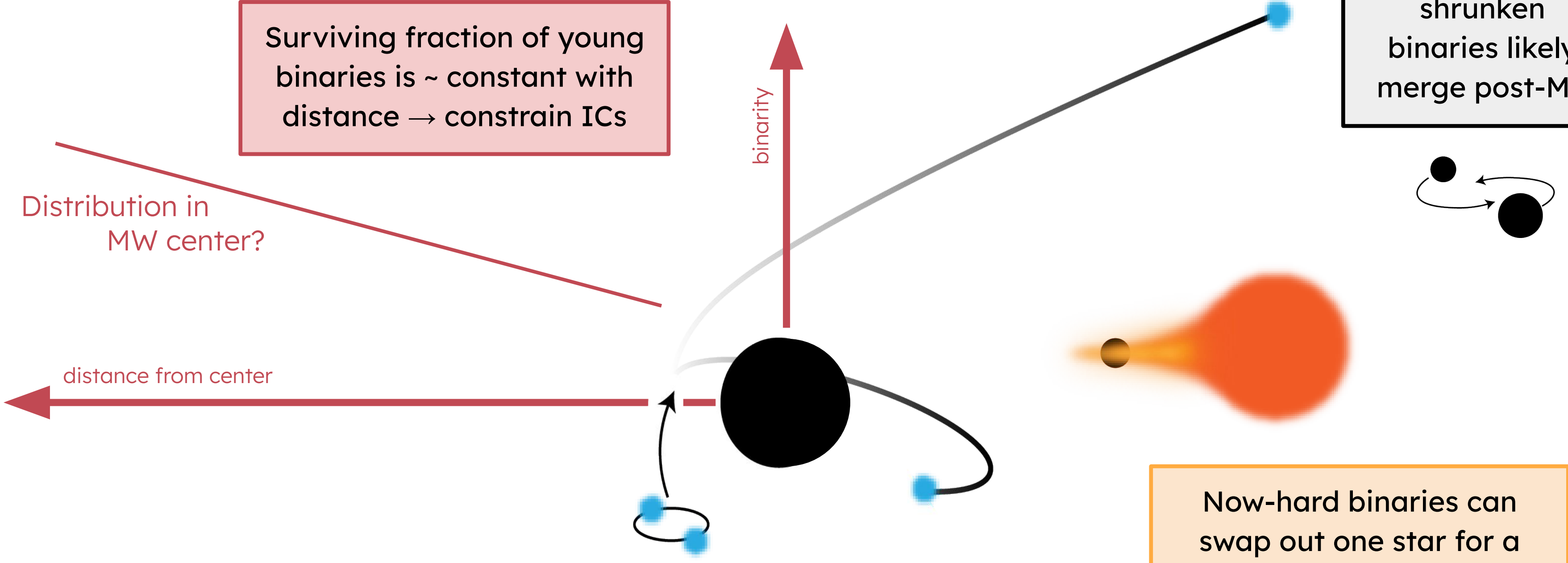

Now-hard binaries can swap out one star for a compact object → boost to X-ray binary formation

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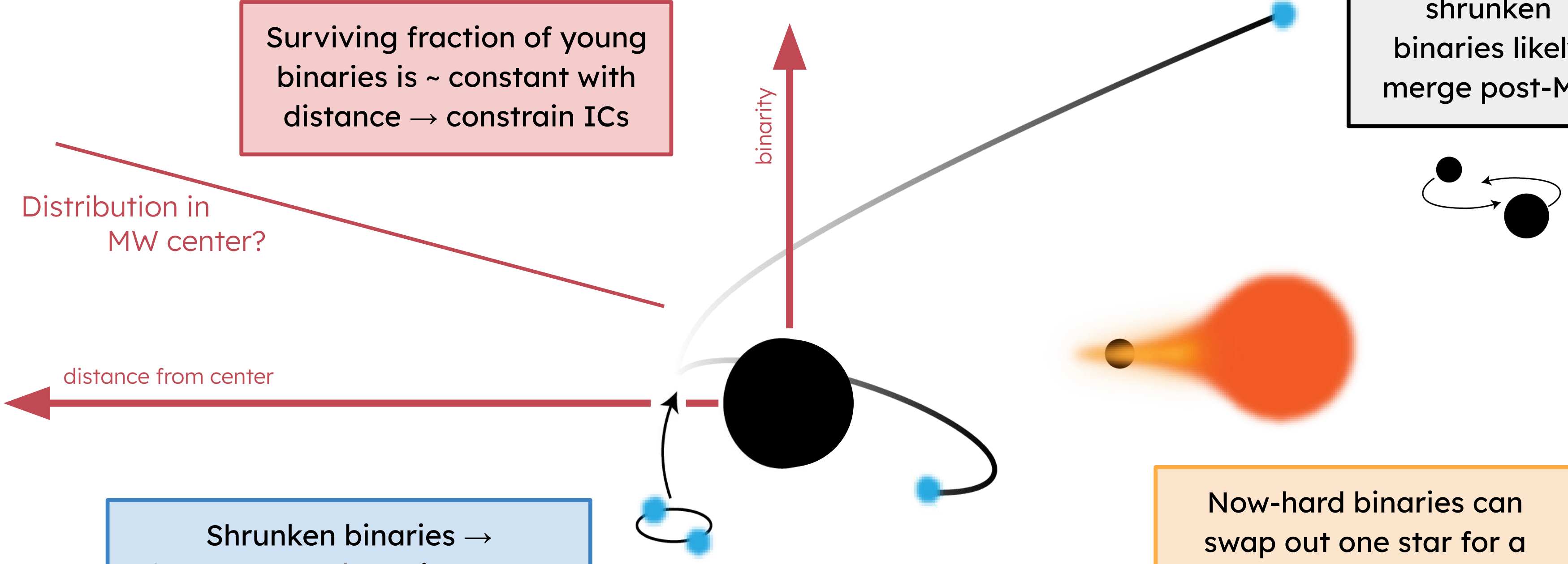

Shrunken binaries → faster HVSs, closer-in S-stars

Now-hard binaries can swap out one star for a compact object → boost to X-ray binary formation

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result #2

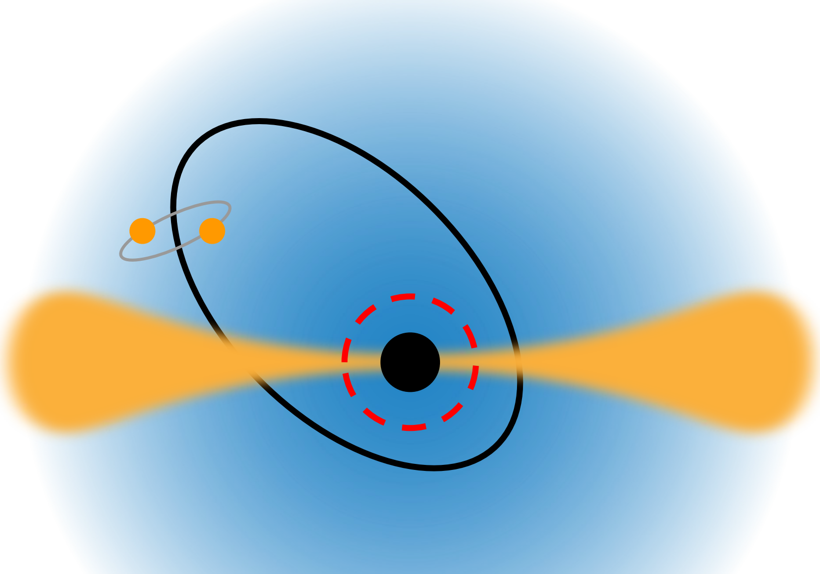
Massive accretion disks drive bursts of binary star disruptions

| in preparation — arXiv in the next few weeks, hopefully

Axisymmetric potentials drive Hills-style disruptions

Accretion disks present significant axisymmetric potentials

(Kaur & Stone, 2025)



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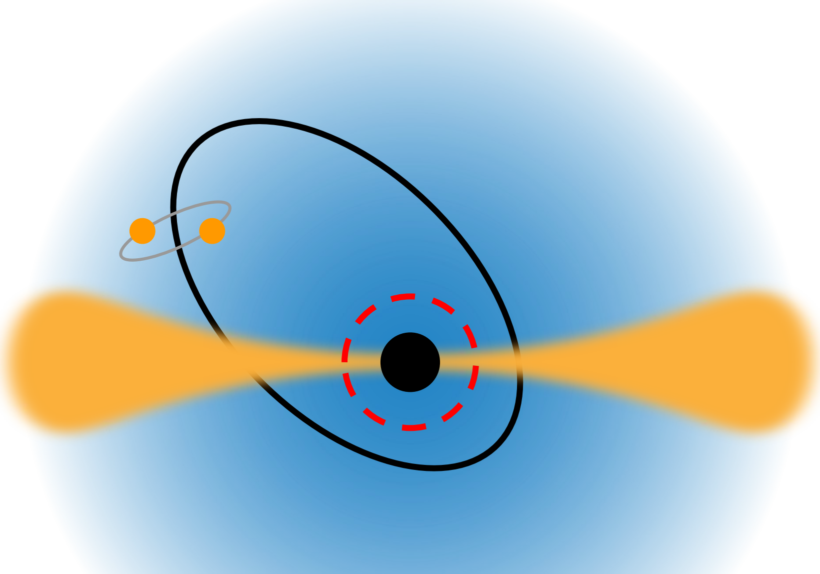

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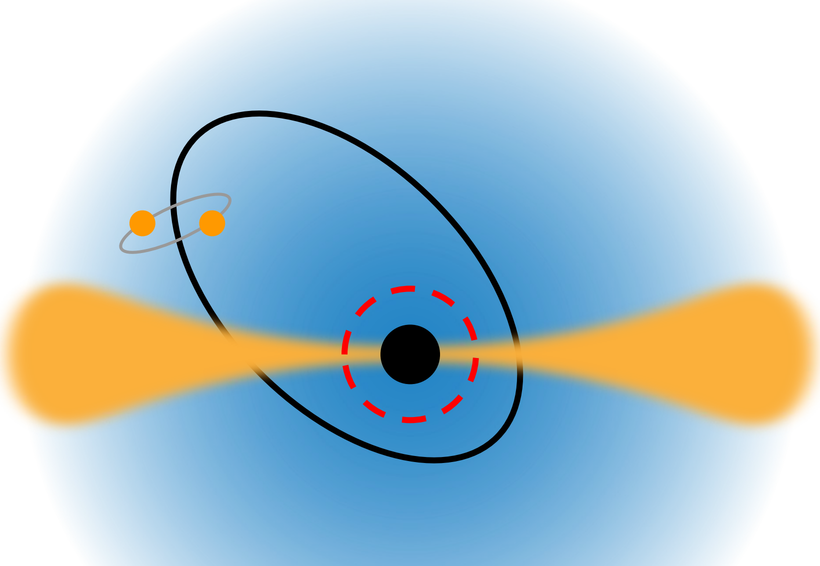

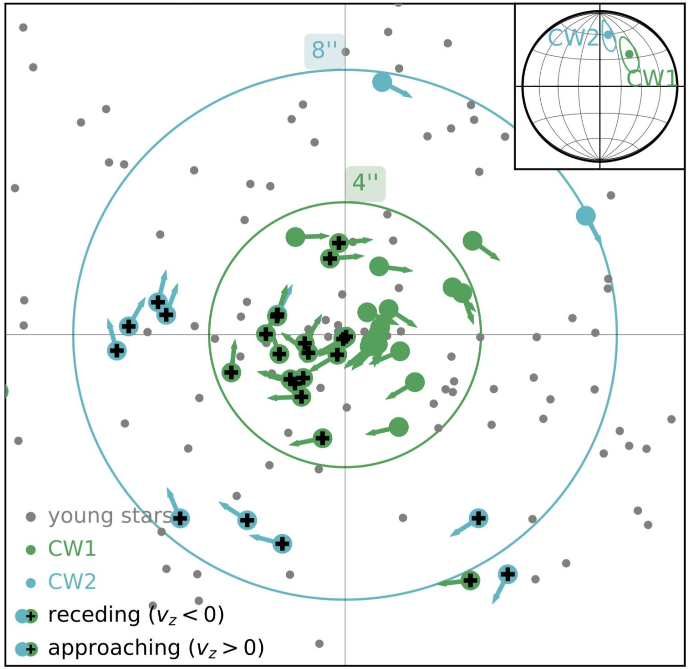

von Fellenberg et al. (2022)

With CWD formation, disrupt ~100 10^8-yr-old binaries

As an example, consider a population:

- 10^5 solar masses, formed 100 Myr ago
- Binary fraction ~ unity
- Log-uniform binary period distribution
- Isotropic orbits

Introduce a disk 10x the mass of the CWD

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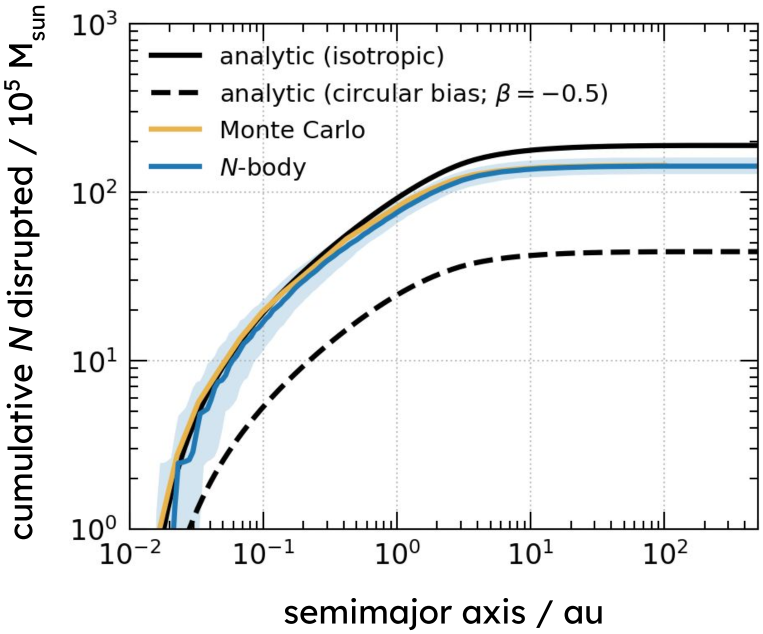

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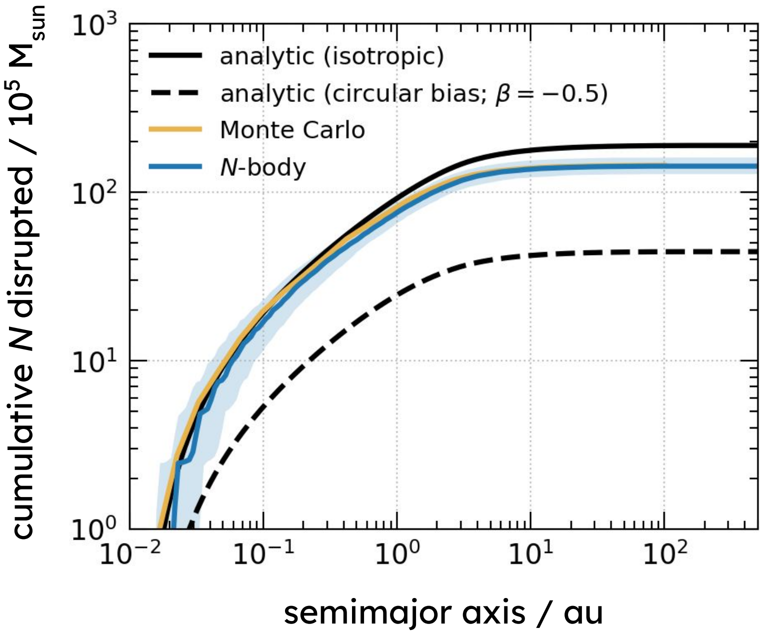

These disruptions yield hypervelocity stars and S-stars

Differs from other disk-driven disruption mechanisms

cf. Madigan et al. (2009), Šubr & Haas (2016), Generozov & Madigan (2020), Rantala & Naab (2024), Akiba et al. (2025)

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Differs from other disk-driven disruption mechanisms

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3. Does *not* require a highly eccentric disk

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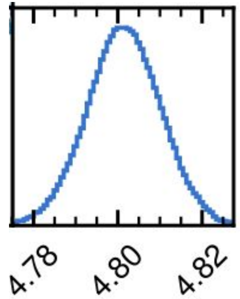
S5-HVS1 could be ejected in a disk-driven disruption

S5-HVS1

Koposov et al. (2020)

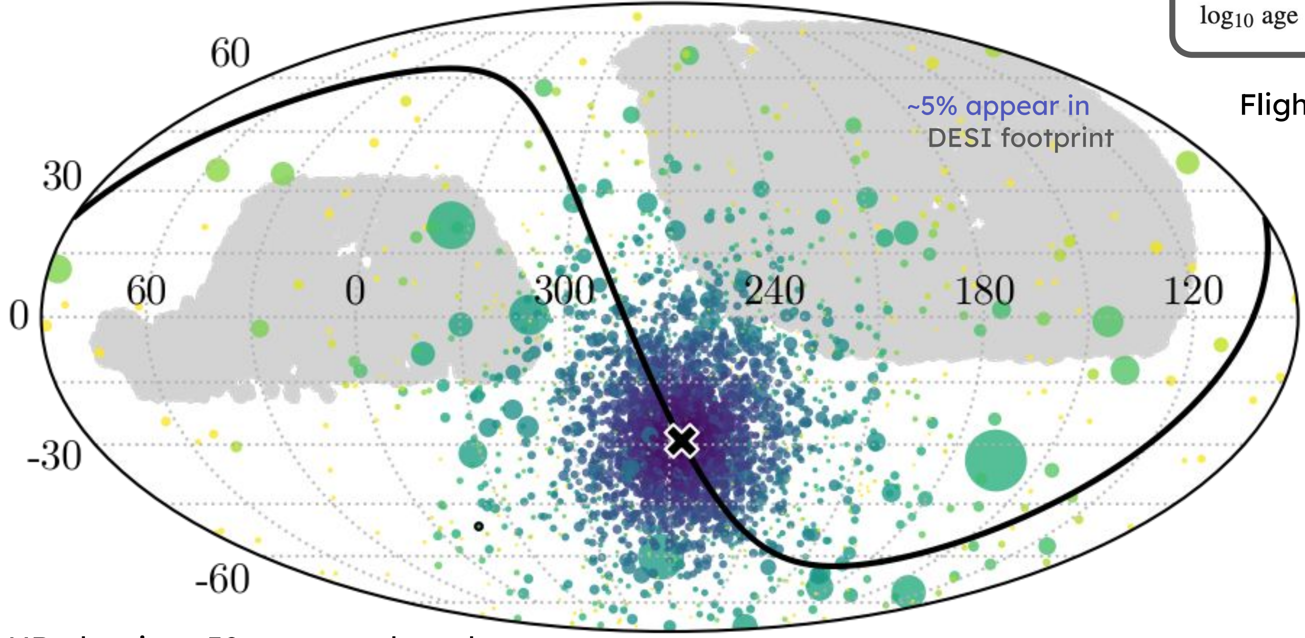
Mass	$2.35^{+0.06}_{-0.06}$	$M_\odot$
$\log_{10}$ age	$7.72^{+0.25}_{-0.33}$	dex

Flight time posterior (Myr)



S5-HVS1 could be ejected in a disk-driven disruption

on-sky positions of stars after 5 Myr,
colored by speed, sized by distance



NB: showing ~50x expected number

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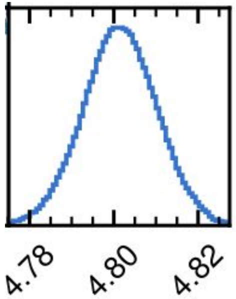

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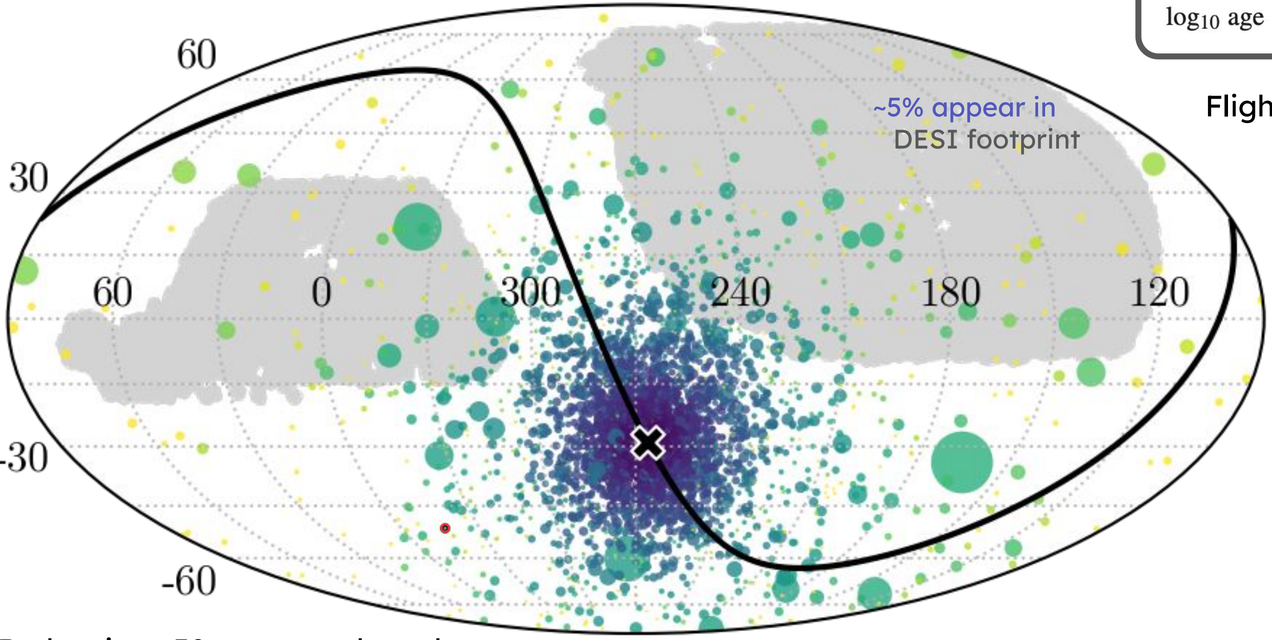

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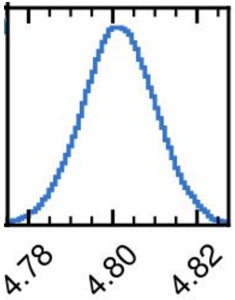

Contribute to S-stars, but can’t explain all of them

Should have deposited ~100 S-stars, generally low-mass, on highly eccentric orbits

Properties depend on star formation history (different colored lines)

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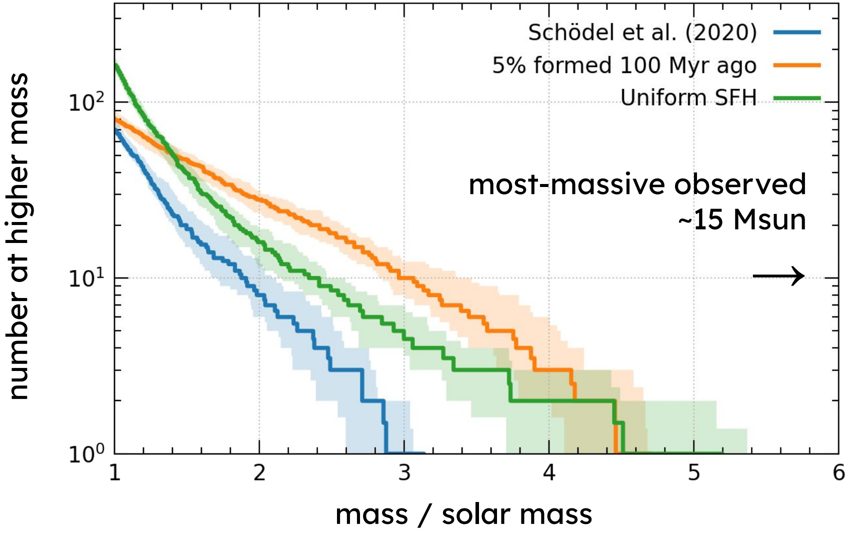

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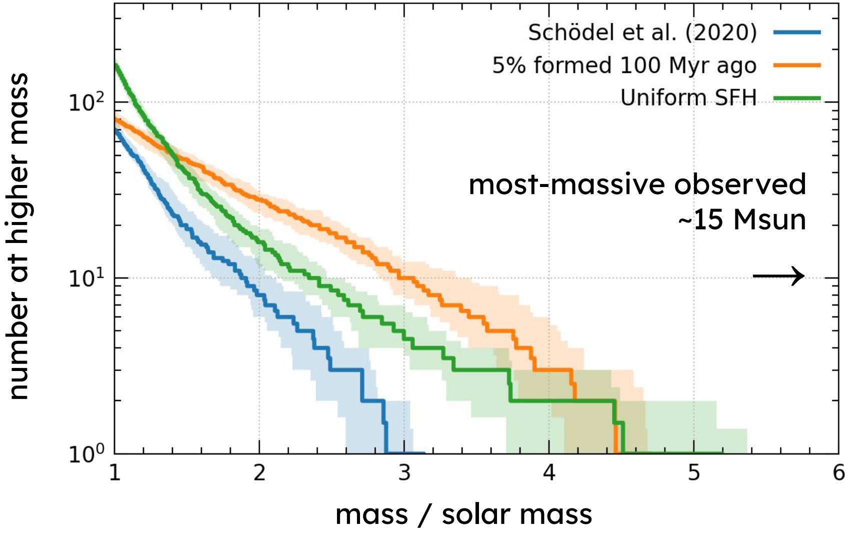

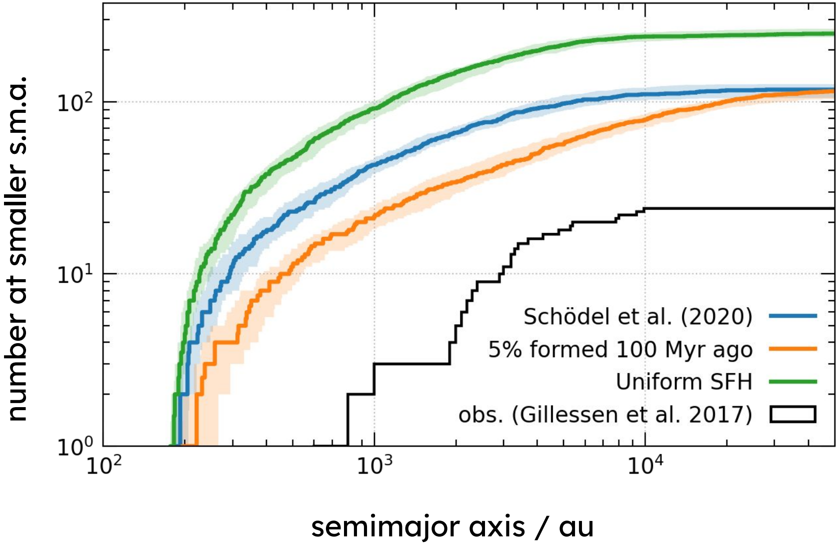

Conclusions

- Many binaries orbiting Sgr A* should shrink to near-contact separations
    - Dodici et al. (2026), arXiv:2511.02905
- Massive accretion disks drive binary disruptions via outer-orbit torques
    - Dodici (in prep.), arXiv soon
- Large uncertainties remain, particularly in initial conditions

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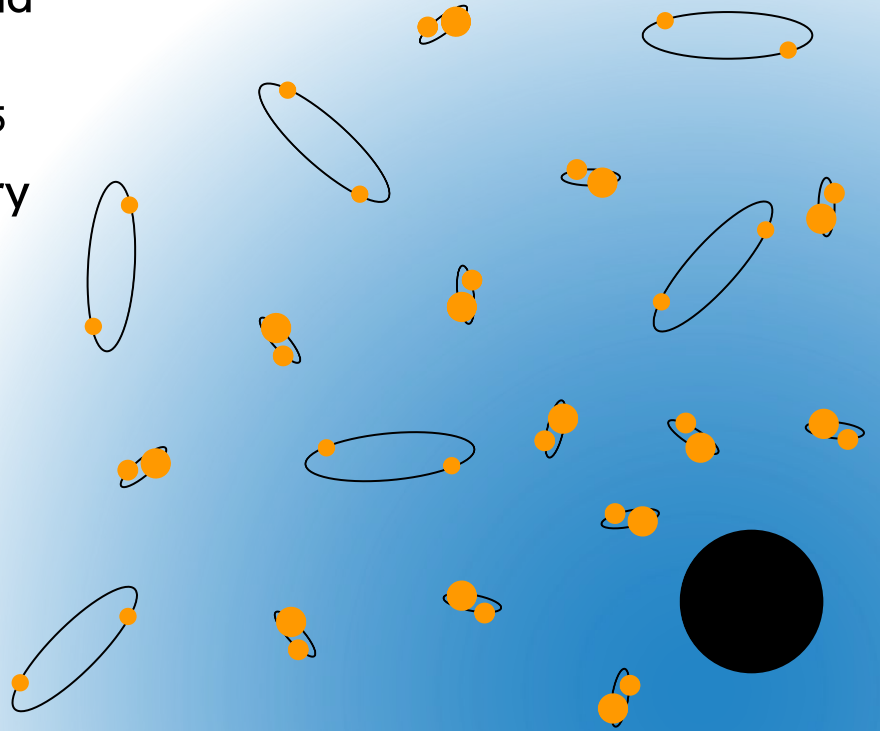


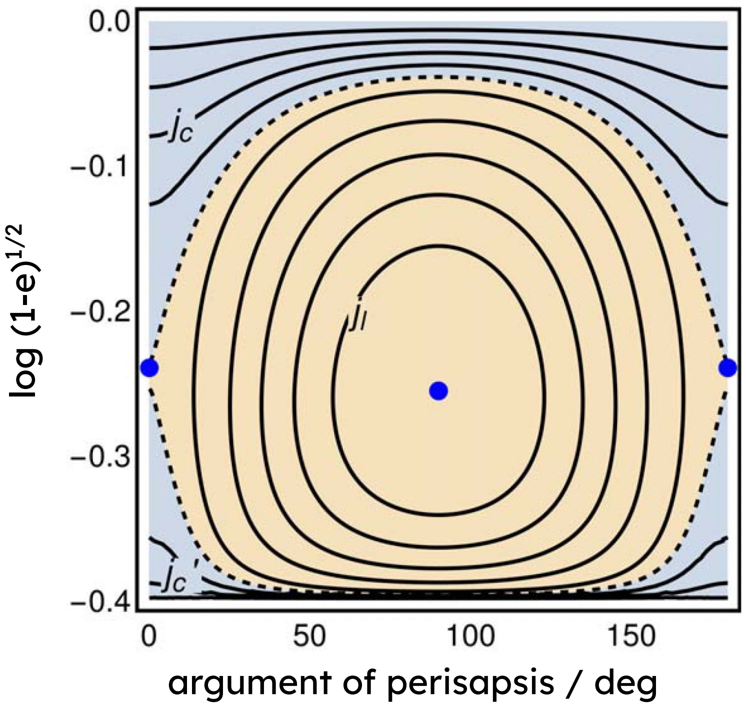
Extra Slides

Disk *potential* causes outer eccentricity oscillations

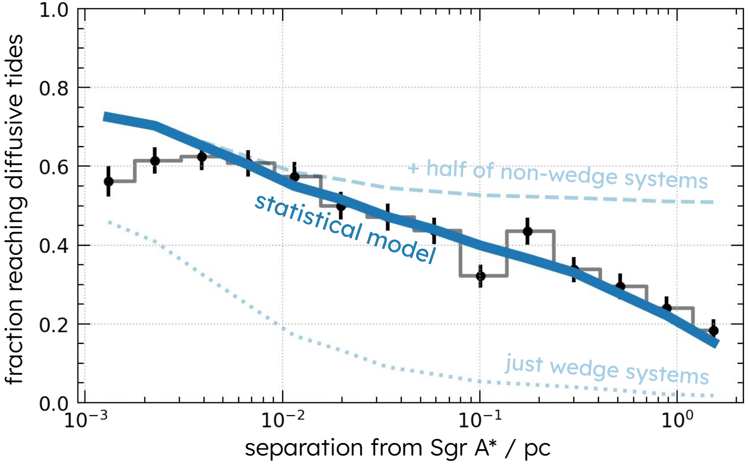
- Standard AGN disk models can reach ~ the mass of the MBH they surround
- Disk presents axisymmetric potential
    - Outer-orbital angular momentum is not conserved
    - Total L can become as small as L_z

Reducing outer-orbit pericenter separations may cause Hills mechanism disruptions

Fig. 1, Kaur & Stone (2025)



Very simple statistical model matches results



Model:

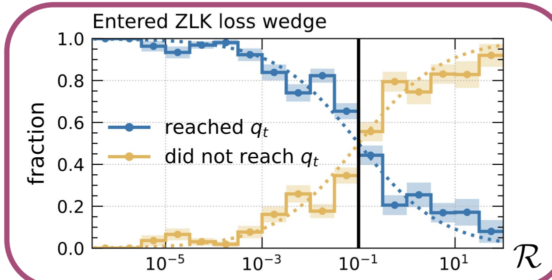
- Shrinking treated as random variable
- Probability of entering loss wedge is 0.5
- In loss wedge, probability of reaching critical pericenter is

$$p = \frac{1}{1 + \mathcal{R}/\mathcal{R}_0}$$

with

$$\mathcal{R} \equiv t_{\rm ZLK} / \min(t_{\rm VRR},\, t_{\rm evap})$$

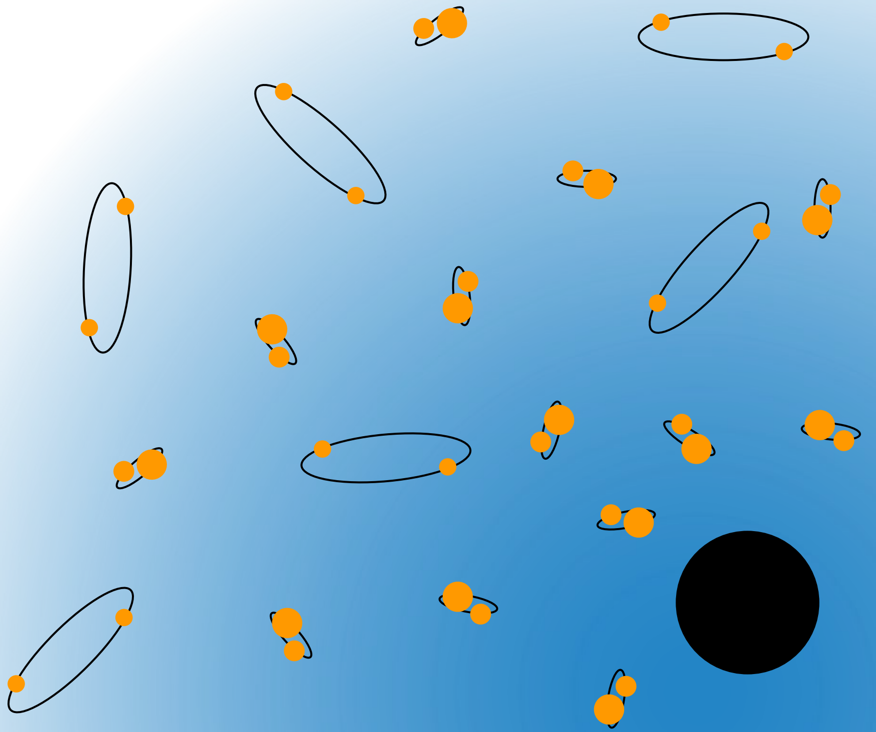
$\mathcal{R}_0 = 0.1$ (tuned to simulations)



Simulations of binary stars orbiting Sgr A*

Double-averaged, quadrupole ZLK
+ vector resonant relaxation
+ binary–single interactions

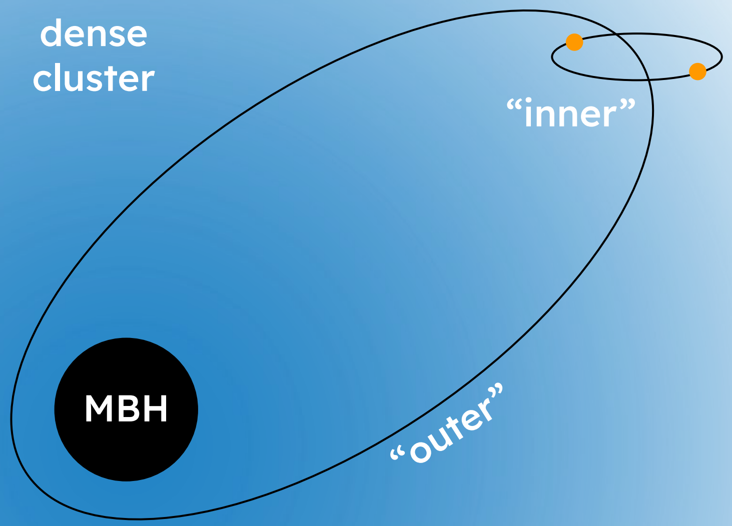
Ending in
shrinking*,
disruption, or
leaving the main sequence.

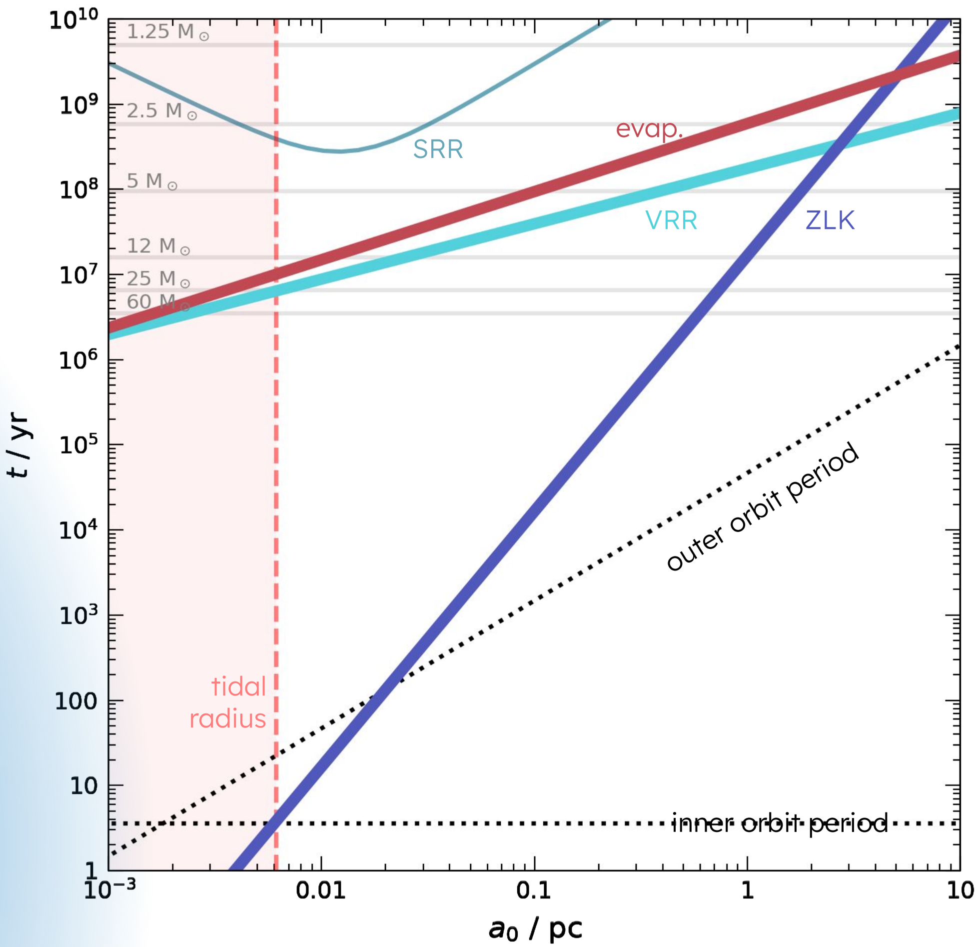


arXiv:2511.02905

Concurrent dynamics

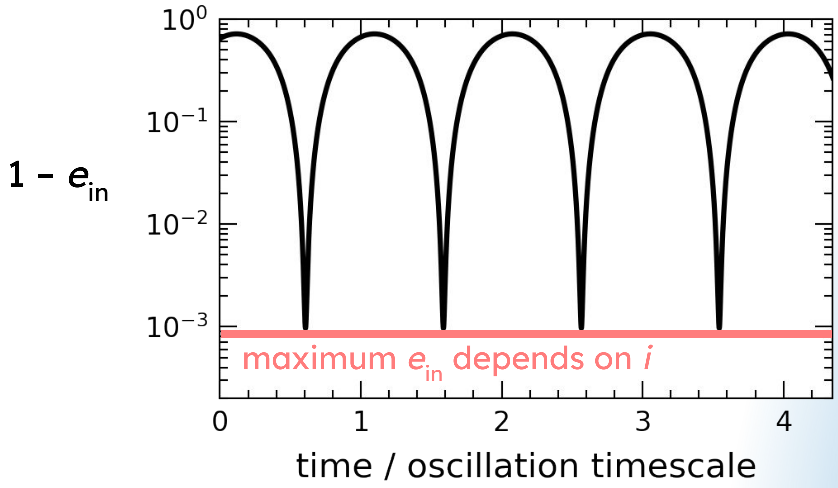
Example timescales
for a_{in} = 10 au, m_* = M_{sun},
MW-like nucleus



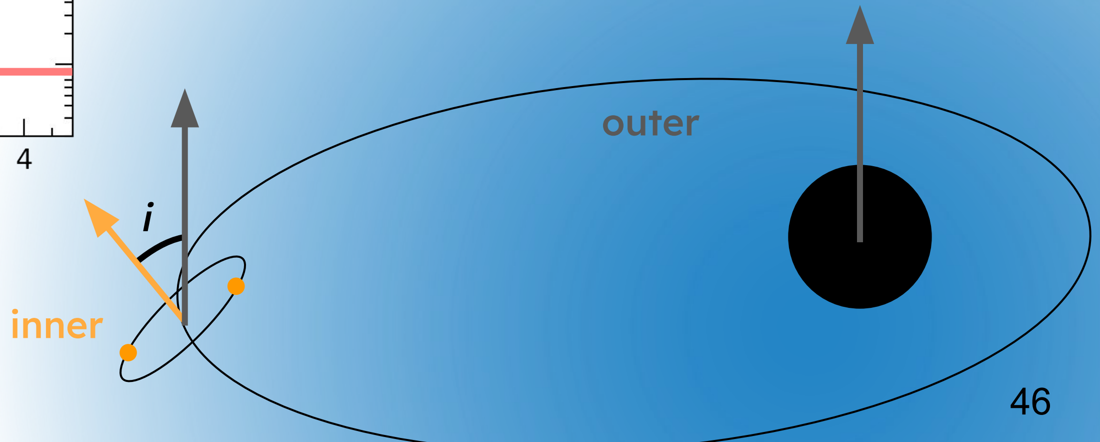


1. Reducing pericenter to a few stellar radii

ZLK cycles: reduce inner-orbit pericenter separation; minimum depends on *i*



$$e_{\max} = \sqrt{1 - (5/3)\cos^2 i}$$



arXiv:2511.02905

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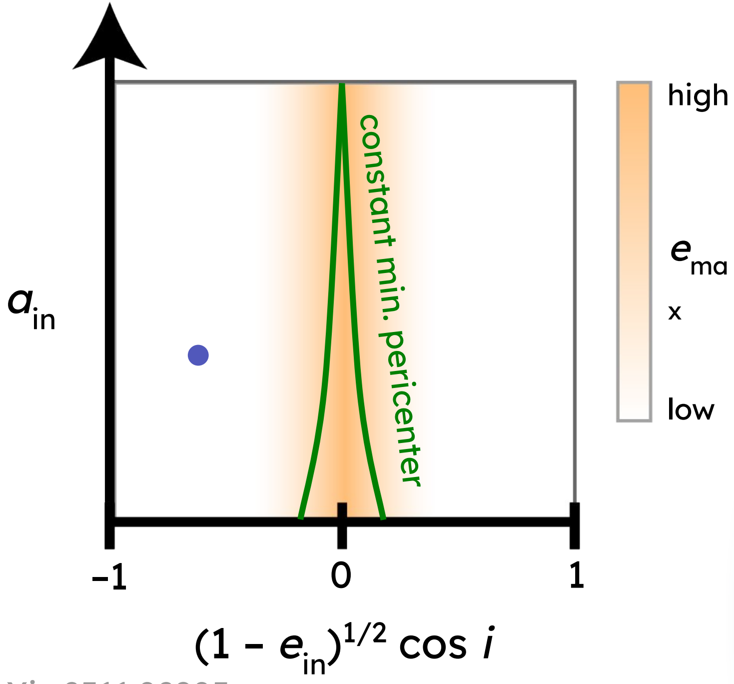
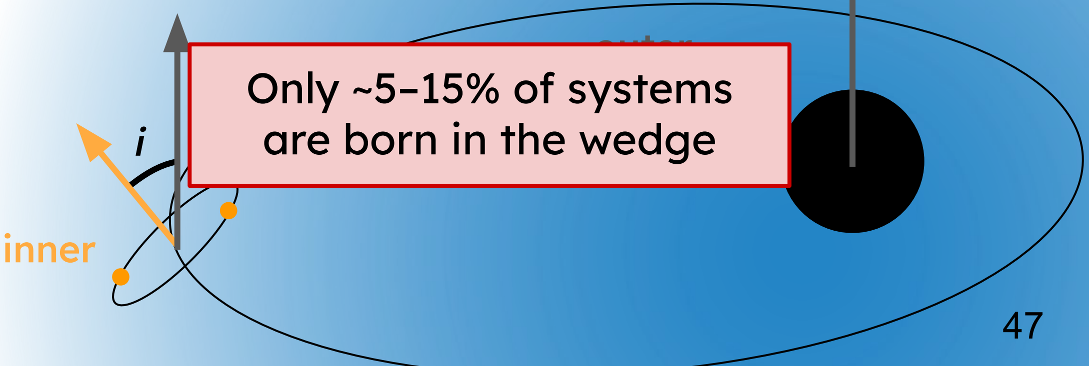


- Parameter space of properties conserved during ZLK cycles
- "Wedge" of space where cycles can reach some critical pericenter

For isolated triple, only systems born in the wedge can reach that pericenter

Only ~5–15% of systems are born in the wedge



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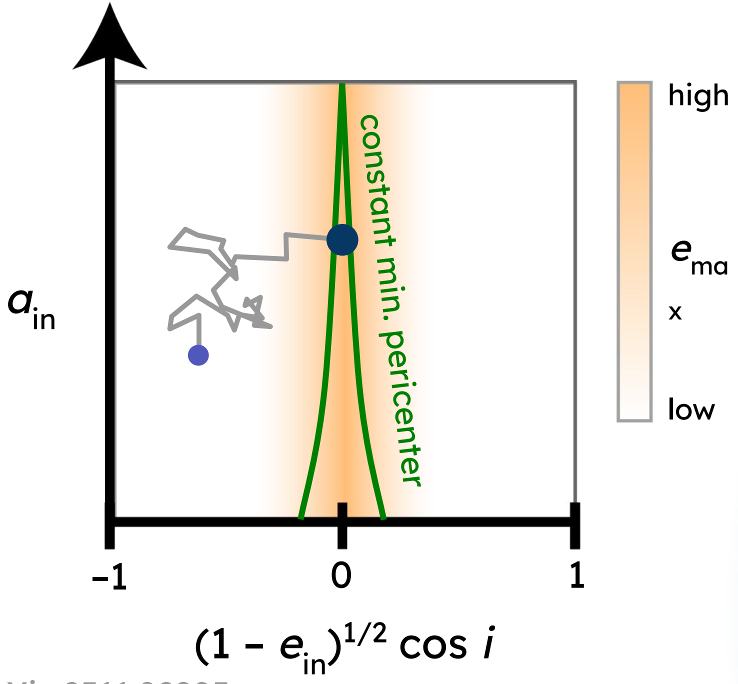
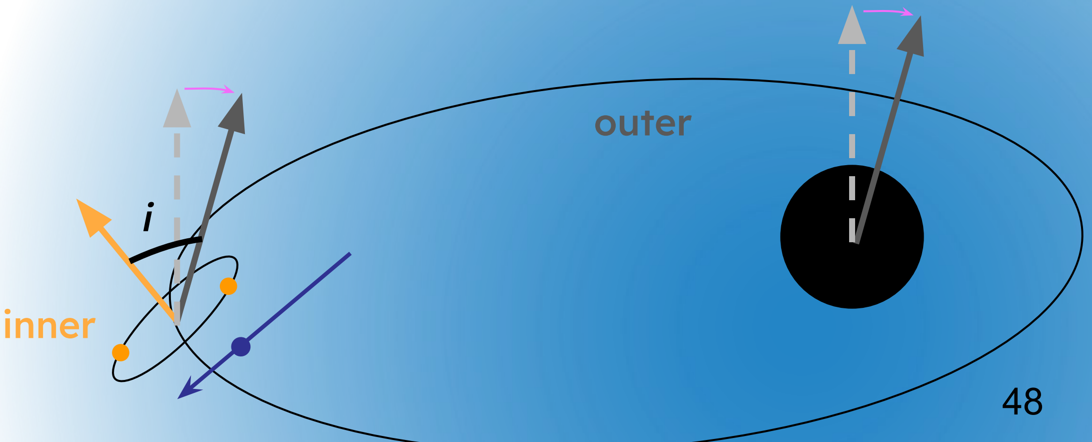


Perturbations to the triple system can refill the wedge



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2. What happens at such small pericenters?

Our “critical pericenter” is the onset of the *diffusive-tide* regime

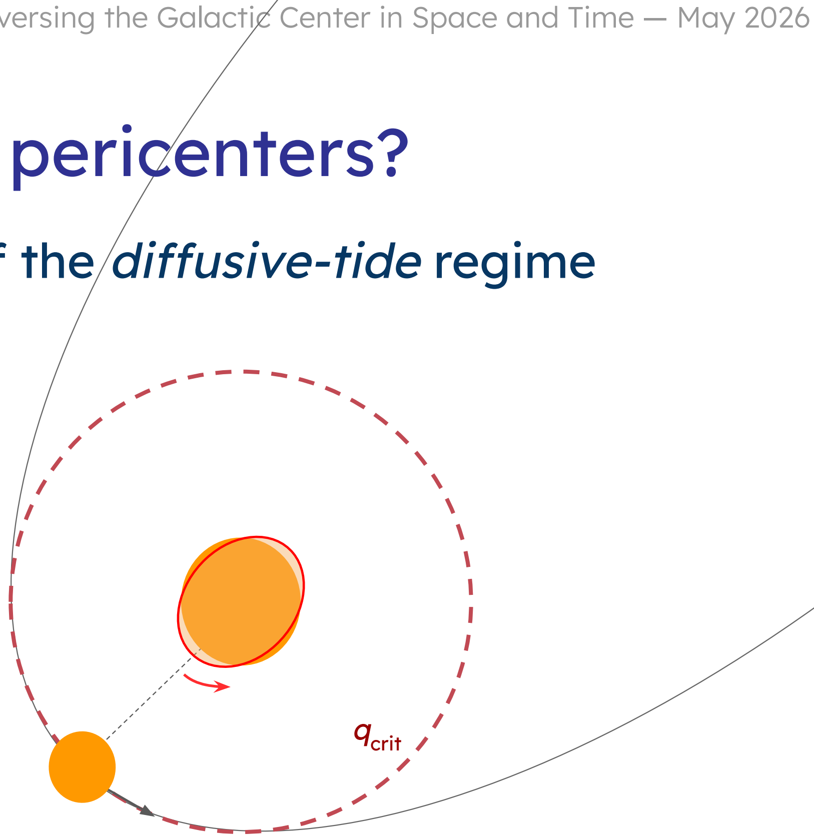
kinetic energy of tide

⇕

orbital binding energy $\propto$ $1/a_{in}$

In diffusive regime, tidal energy grows linearly with number of orbits

Numerical: Kochanek (1992), Mardling (1995a,b)
Analytical: Ivanov & Papaloizou (2004), Vick & Lai (2018), Wu (2018)

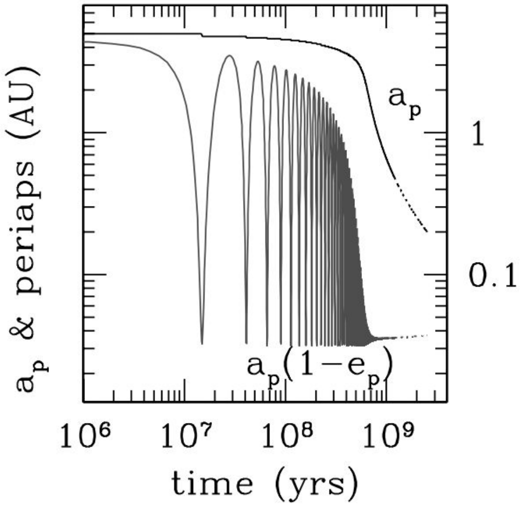


→ orbital energy reduced *quickly*

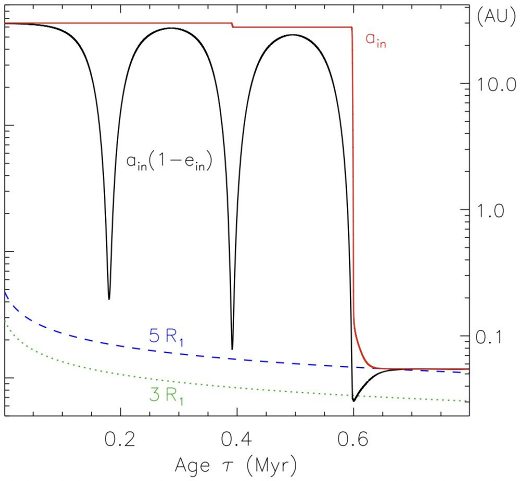
2. What happens at small pericenter separations?

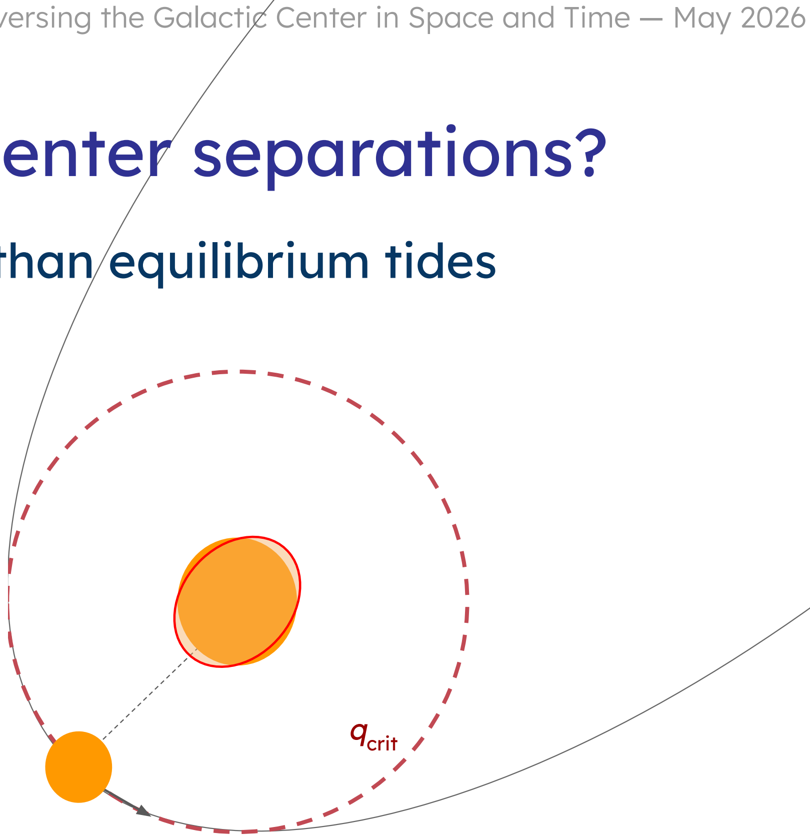
Diffusive tides → faster shrinking than equilibrium tides

Wu & Murray (2003)
ZLK + equilibrium tides



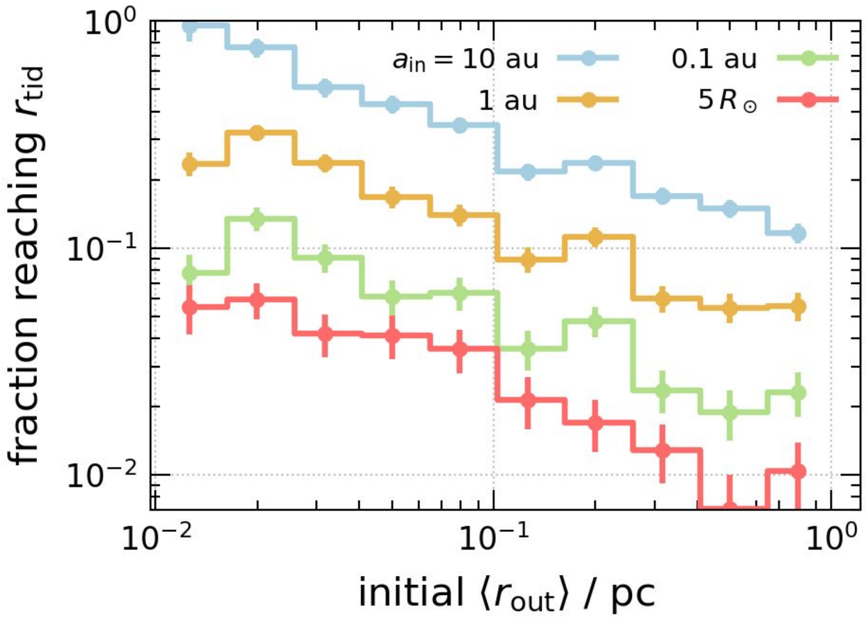
Moe & Kratter (2018)
ZLK + diffusive tides





Excess Hills' mechanism disruptions → Excess HVSs

From orbit integrations with Sgr A* + NSC potential + disk (10% of MBH mass)



1 au — 470 km/s

0.1 au — 1500 km/s

5 solar radii — 3100 km/s

Excess Hills' mechanism disruptions → Excess HVSs