Planet-disk interaction in circumbinary disks

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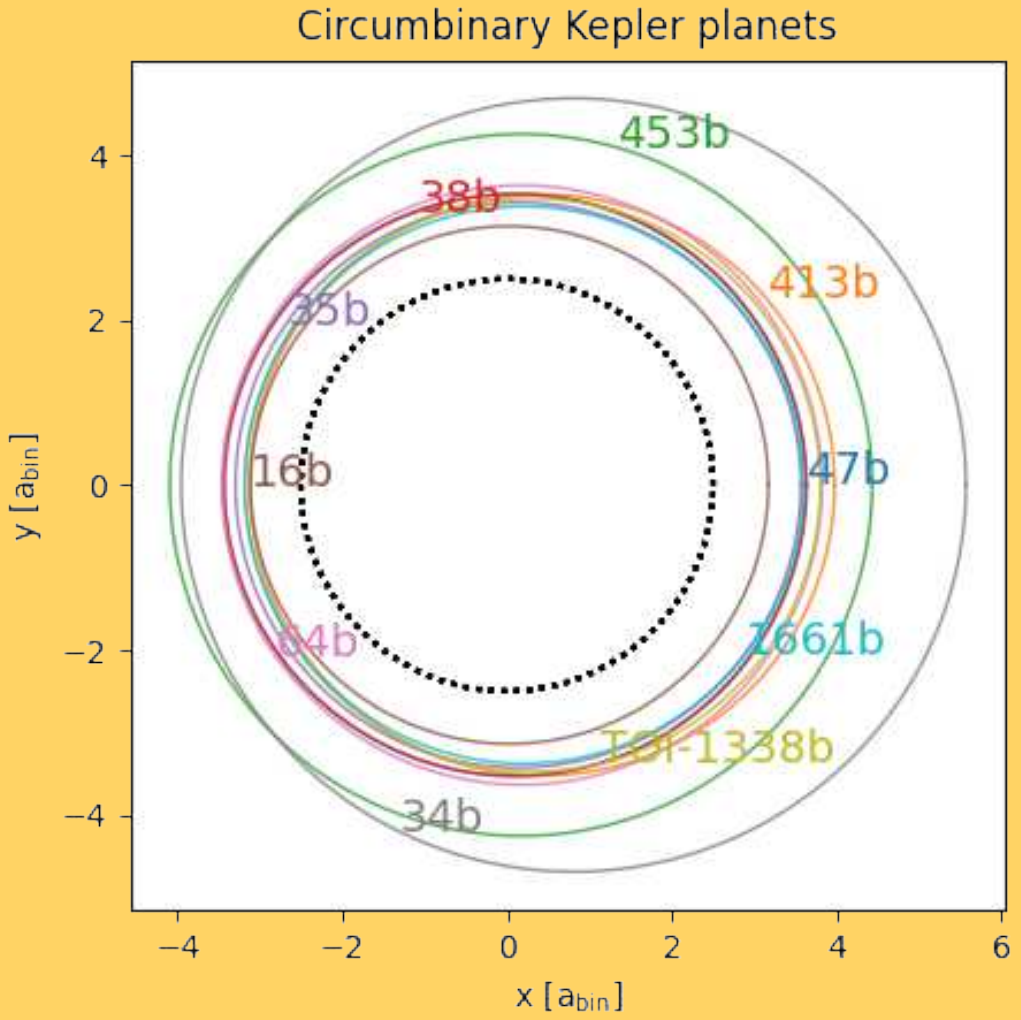
IMPERIAL

RELAX ON

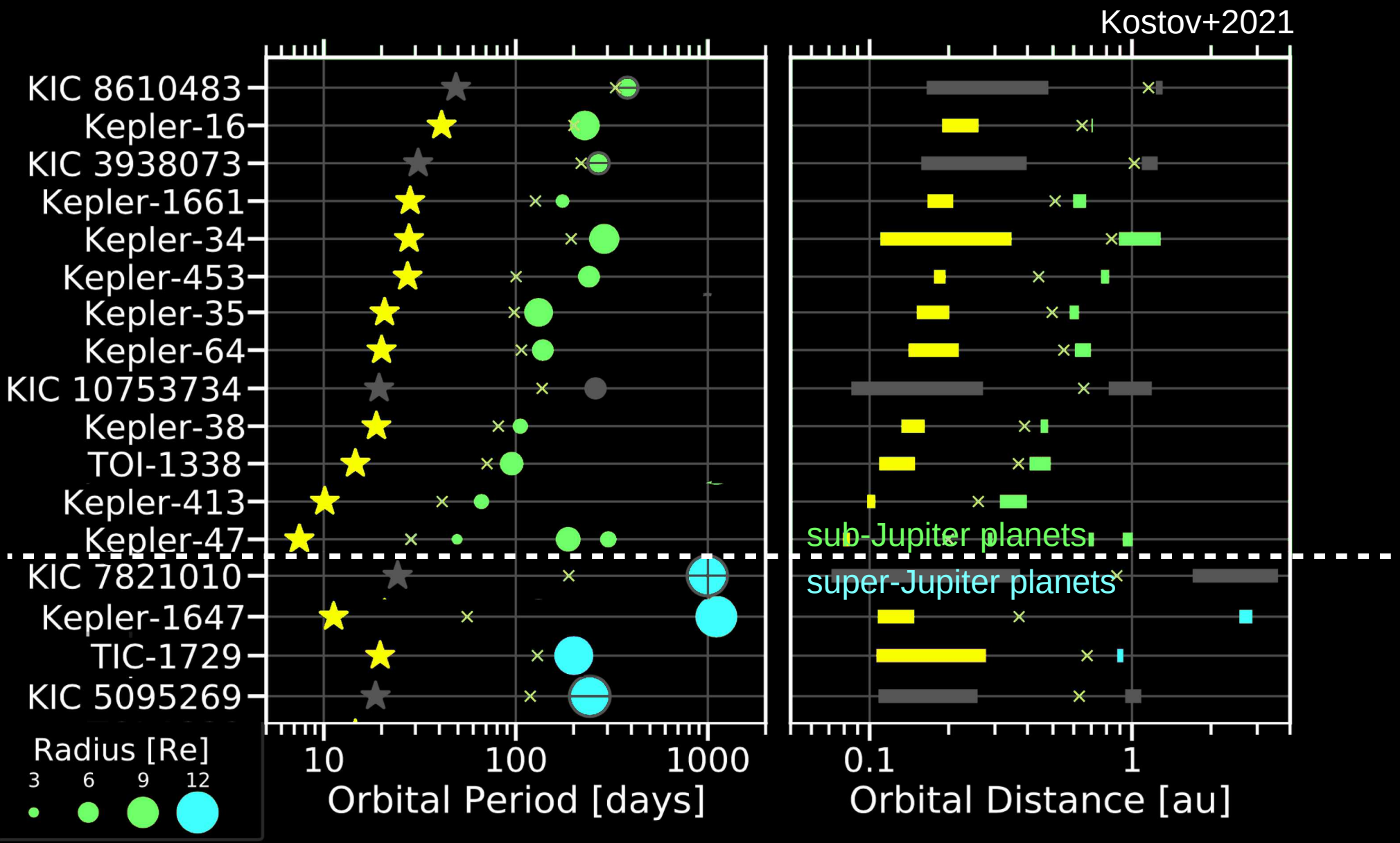
KEPLER-16b

THE LAND OF TWO SUNS

WHERE YOUR SHADOW ALWAYS HAS COMPANY



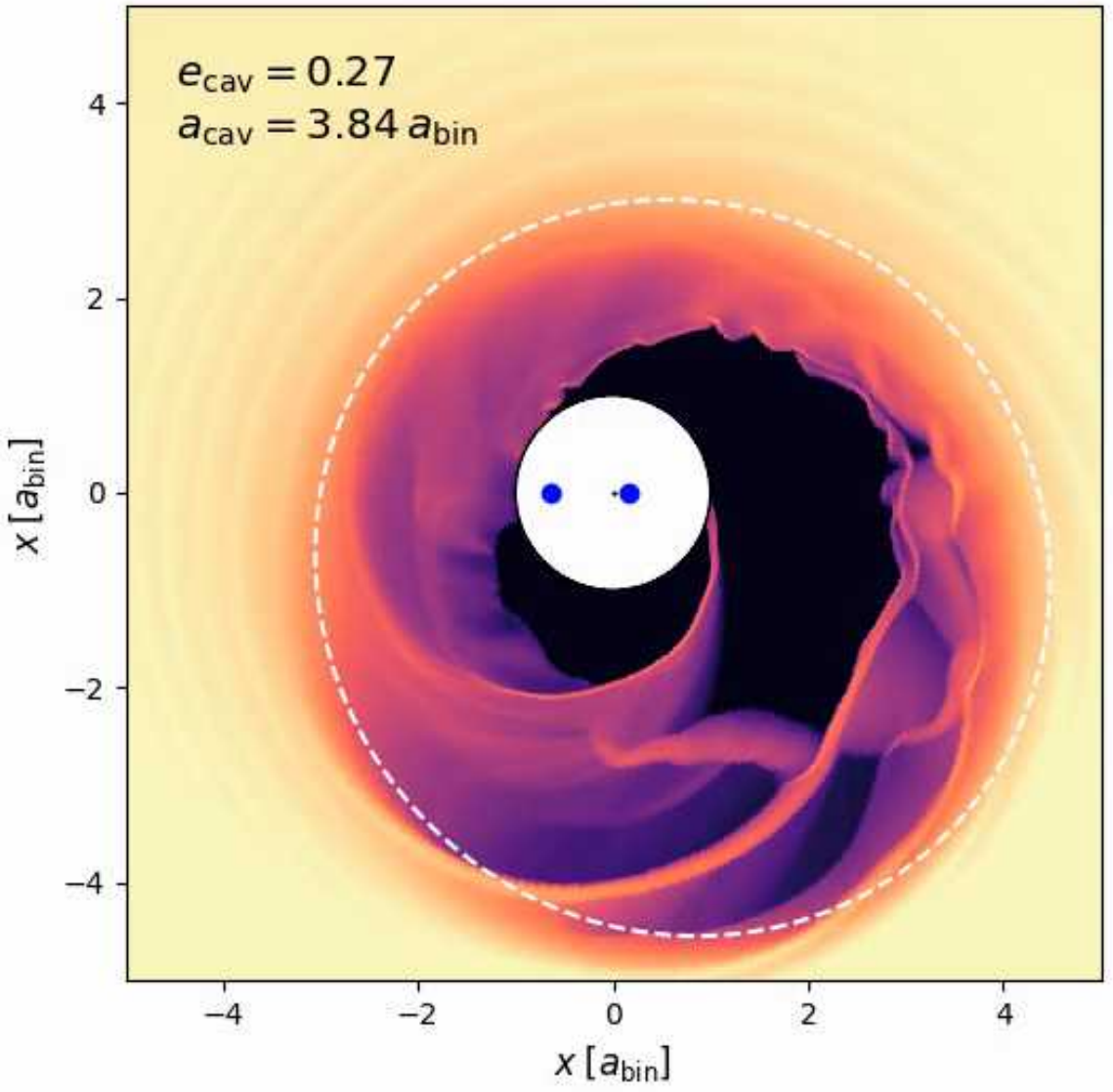
Circumbinary planets through observations



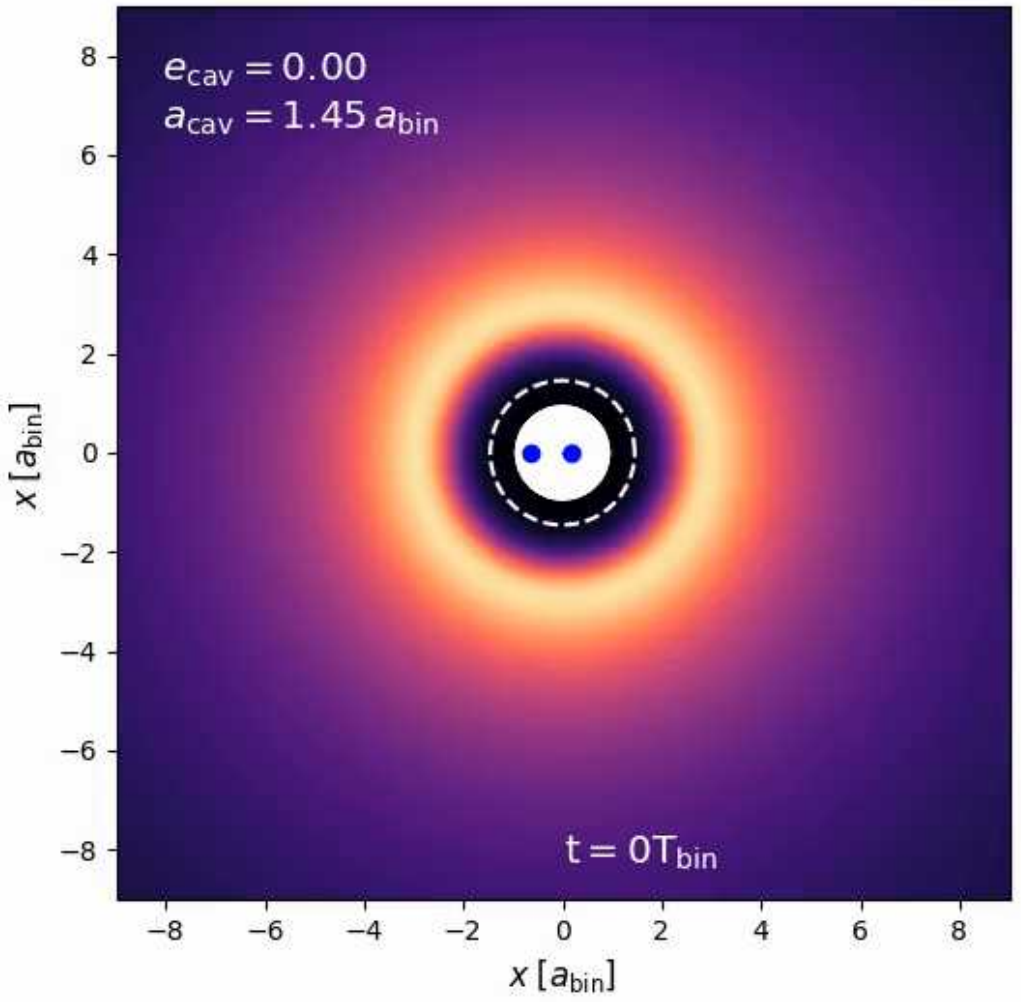
Circumbinary planets through observations

- Why are sub-Jupiter planets cluster at ~3 – 4 a_{bin}?
- Why do the sub-Jupiter planets have low eccentricities?
- Why are larger planets further out?

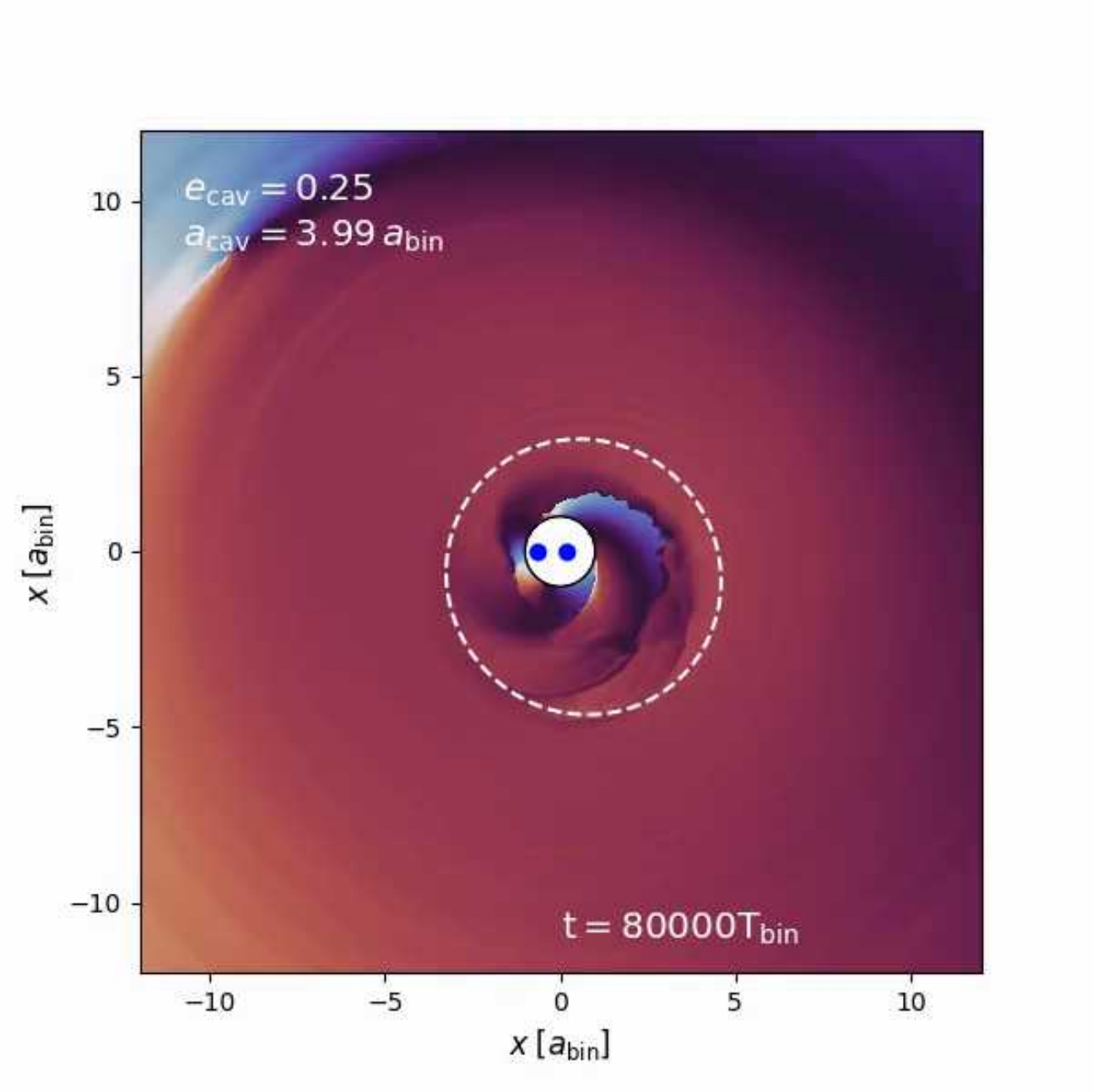
Dynamics of the CBD in orbits



Dynamics of the CBD in precession time



Dynamics of the CBD in precession time



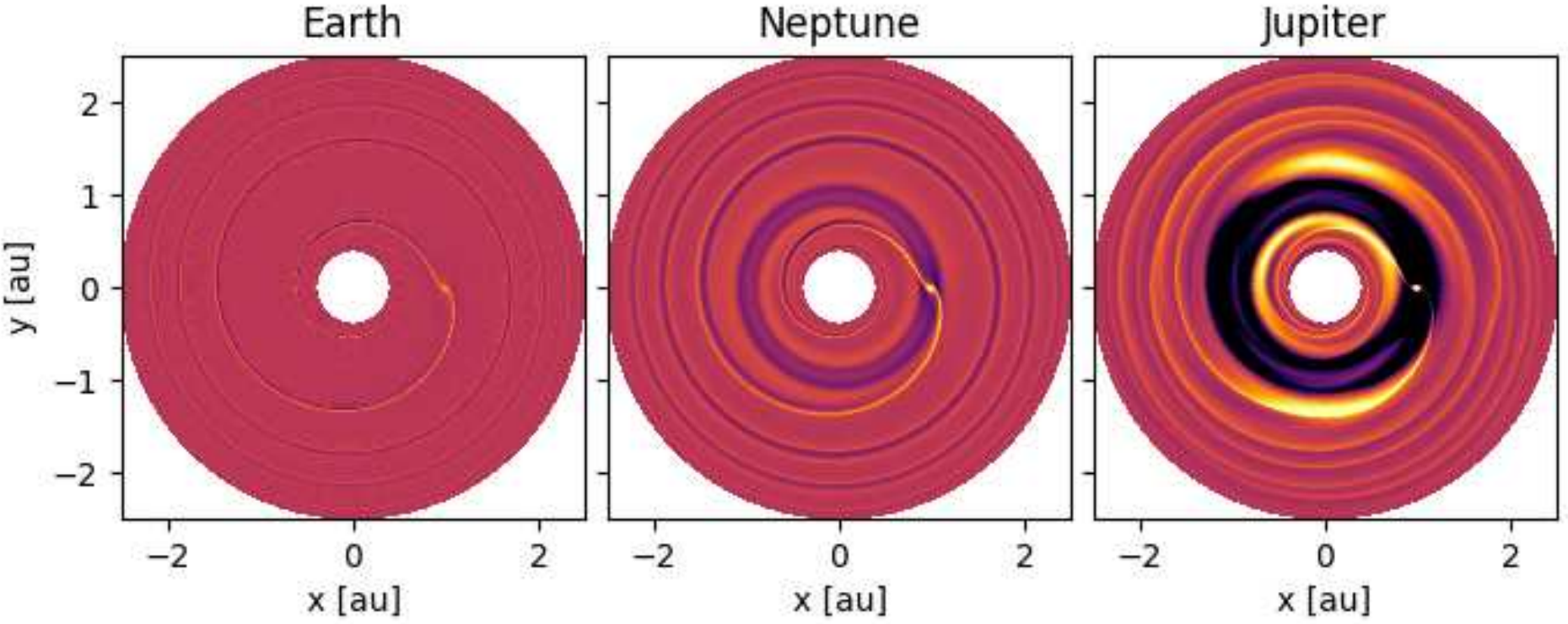
Dynamics of the CBD

- Resonant interaction creates an inner unstable region ~2.5 – 3.5 a_{bin} (Holman&Wiegert1999).
- The binary motion drives eccentricity excitation in the inner disc (e.g. Muñoz+2020) and expands the inner cavity a_{cav}= 3.5 – 5 a_{bin}.
- The inner disc becomes eccentric and precesses around the binary orbit.
  (Miranda+2017, Mutter+2017, Muñoz+2019, Ragusa+2020, Tiede+2021, Dittmann+2022, Siwek+2023,...
  KITP-code-comparison2024)

Planet migration in a disc

Type I: No gap, viscous momentum transfer to gas in the horseshoe

Type II: Full gap, tidal momentum transfer to the gas at the gap rim

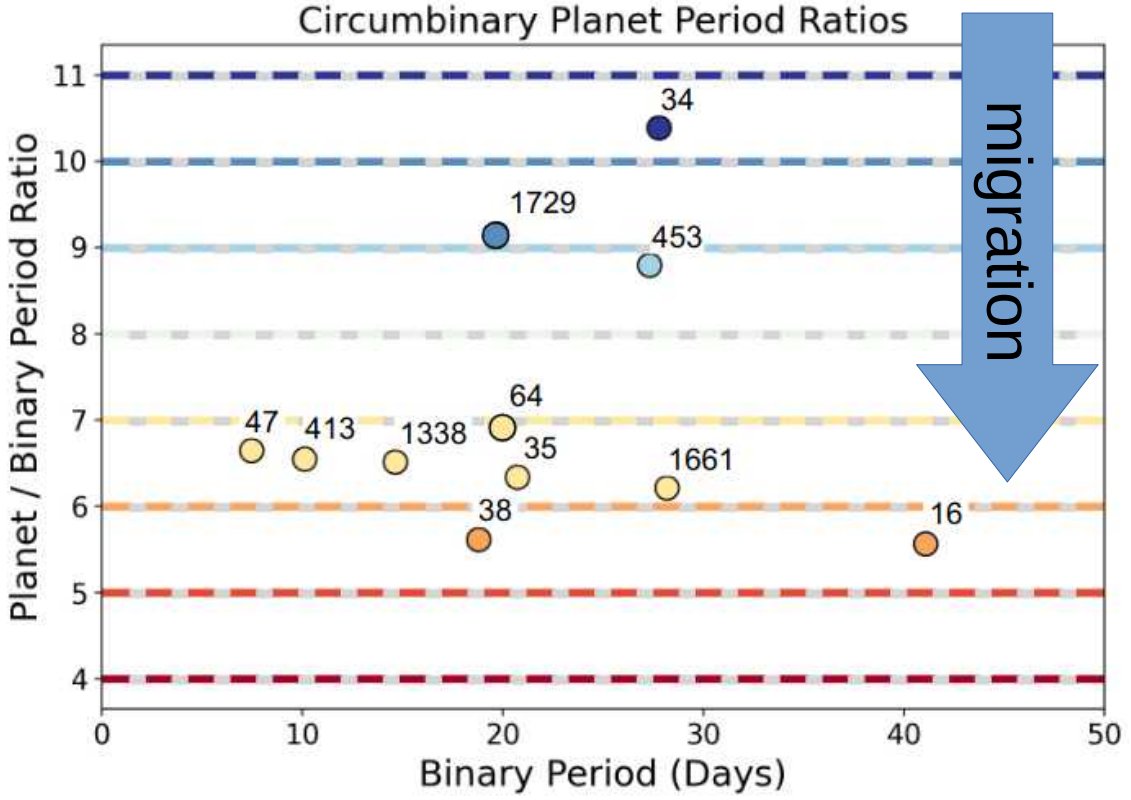


Planets stop, when gas has higher density on outer disc sides or when they reach the rim of the disc

Resonant interaction of binary and planets

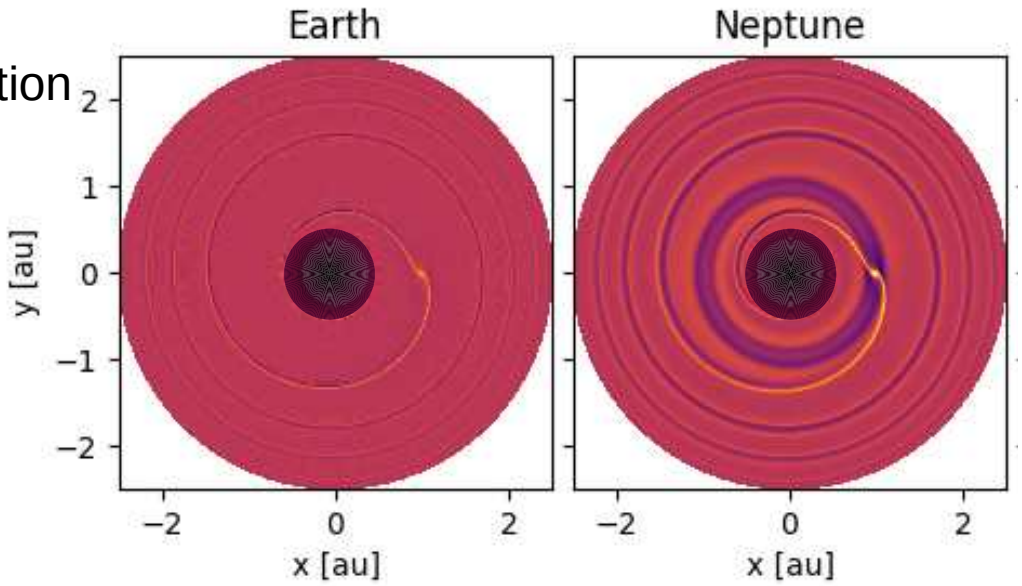
Planets interact the with binary resonances within the disc

Martin&Fitzmaurice 2022 found that planet smaller than 3 Earth radii are likely to be destabilised through resonance.

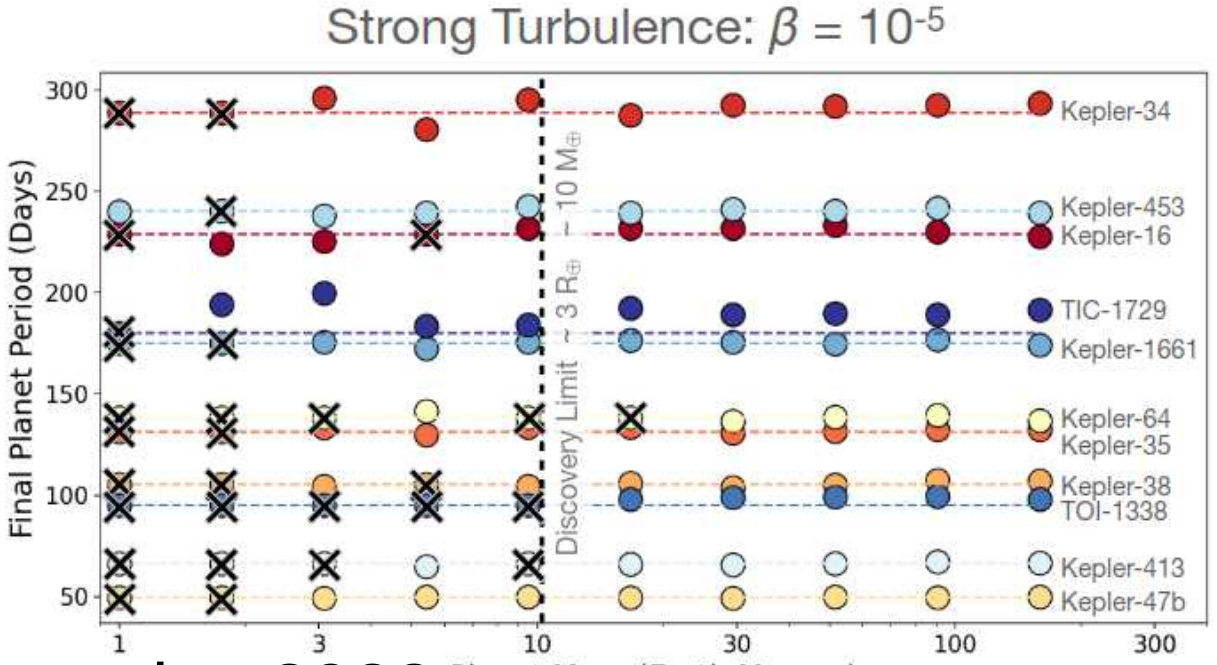


Resonant interaction of binary and planets

slow migration



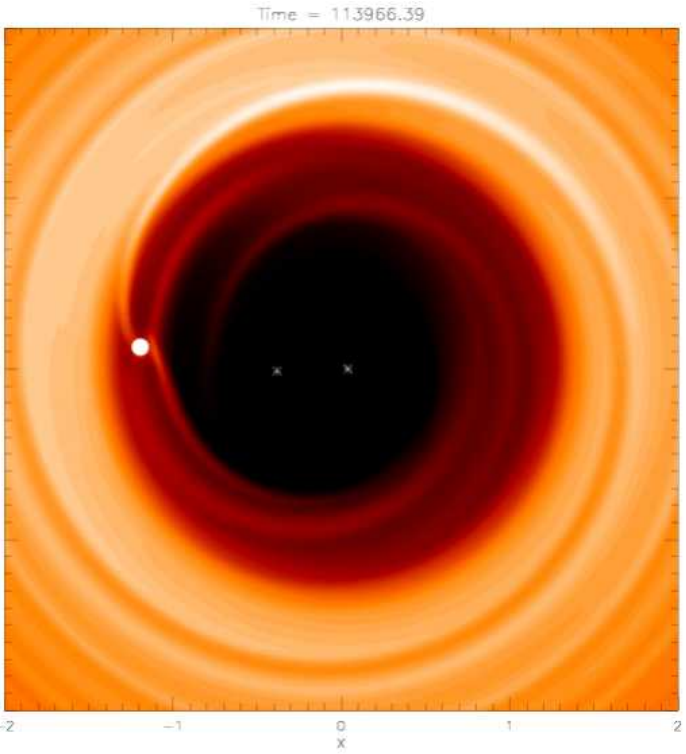
fast migration



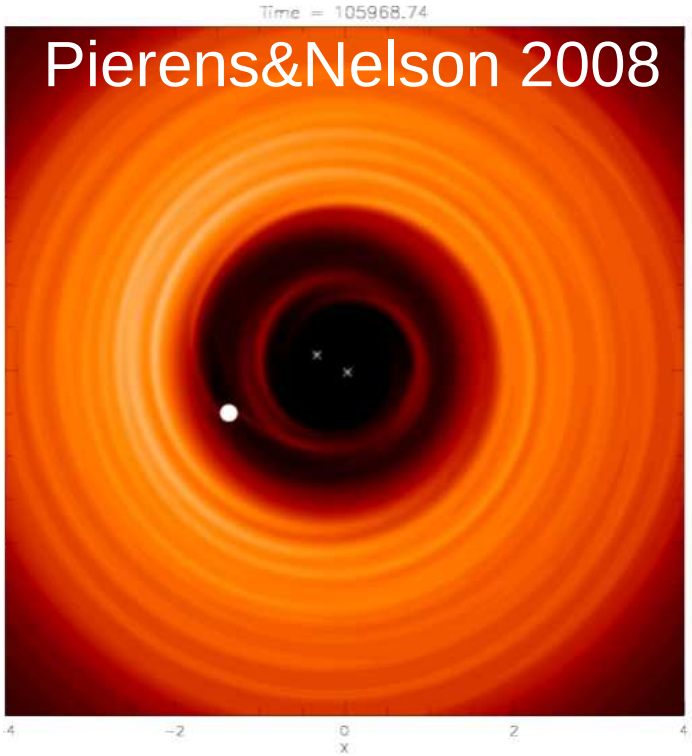
Martin&Fitzmaurice 2022

Hydrodynamic interaction of planets and CBD

Saturn mass



Jupiter mass



super-Jupiter mass

< Jupiter migrate to the inner cavity and park

~ Jupiter migrate slowly inwards and don’t stop

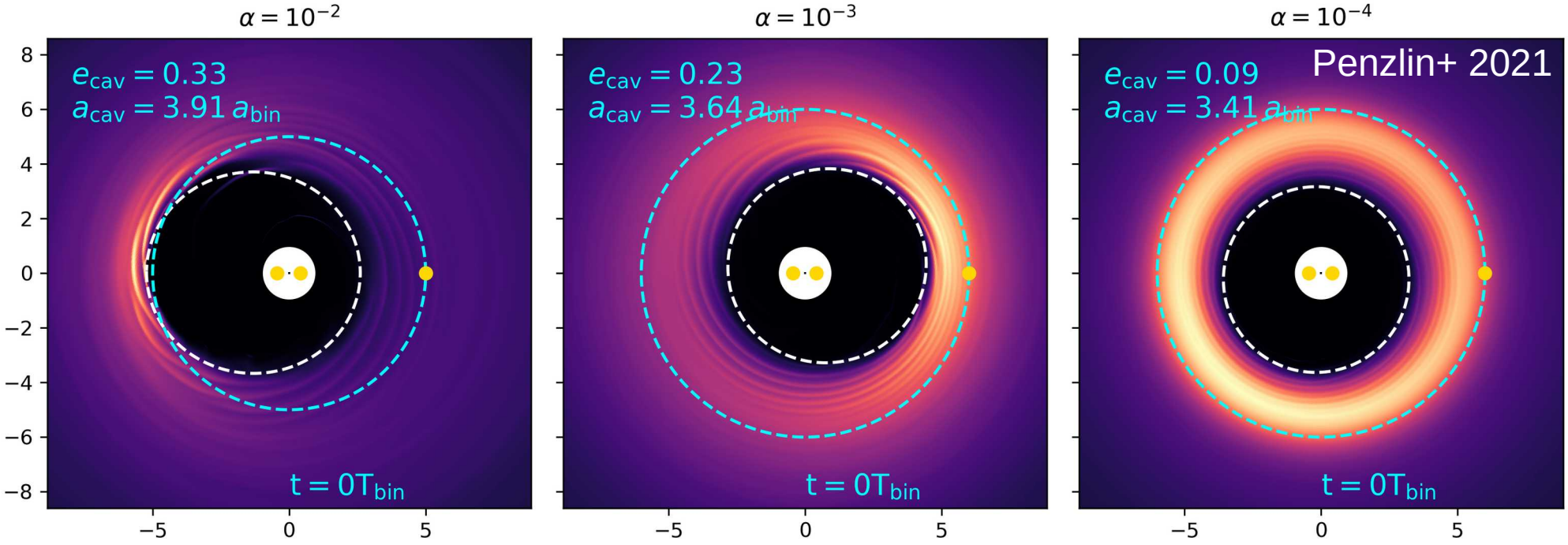
> Jupiter migrate outward in a deep gap

Viscous migration of small planets in CBD

Viscosity changes the interactions between binary and disc.

Viscosity with max. disc excitation is at $\alpha \sim 10^{-2.5}$, H/R~0.06

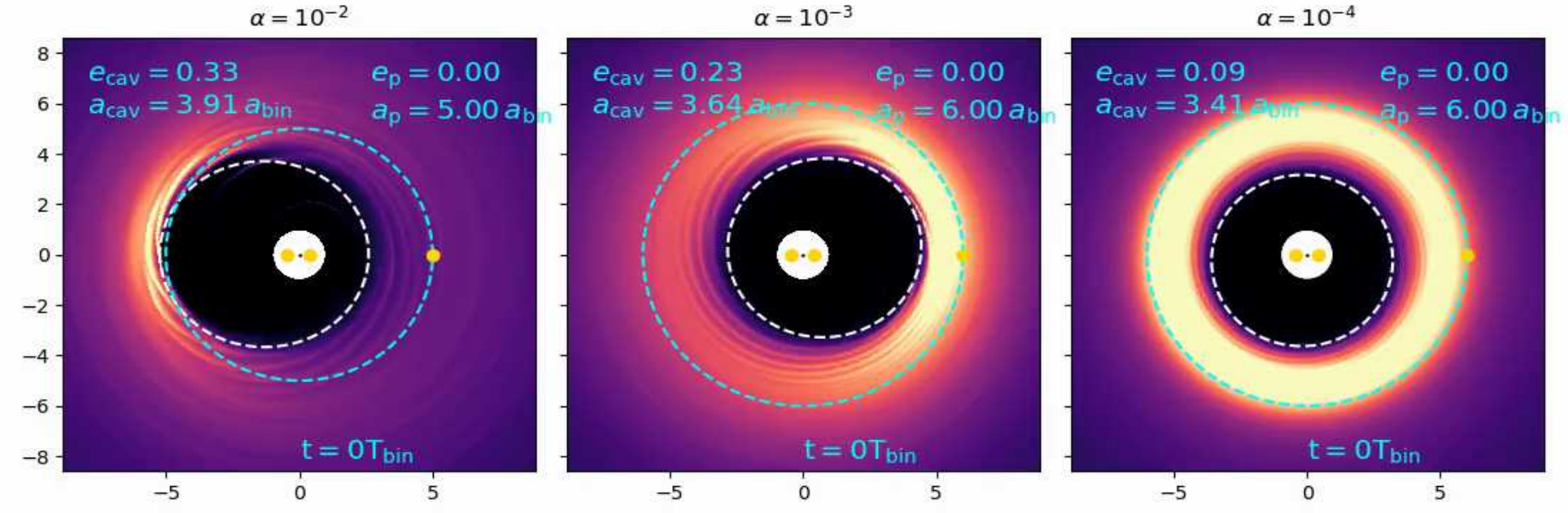
Above and below the cavity becomes smaller and less eccentric(Penzlin+2024, Penzlin subm.)



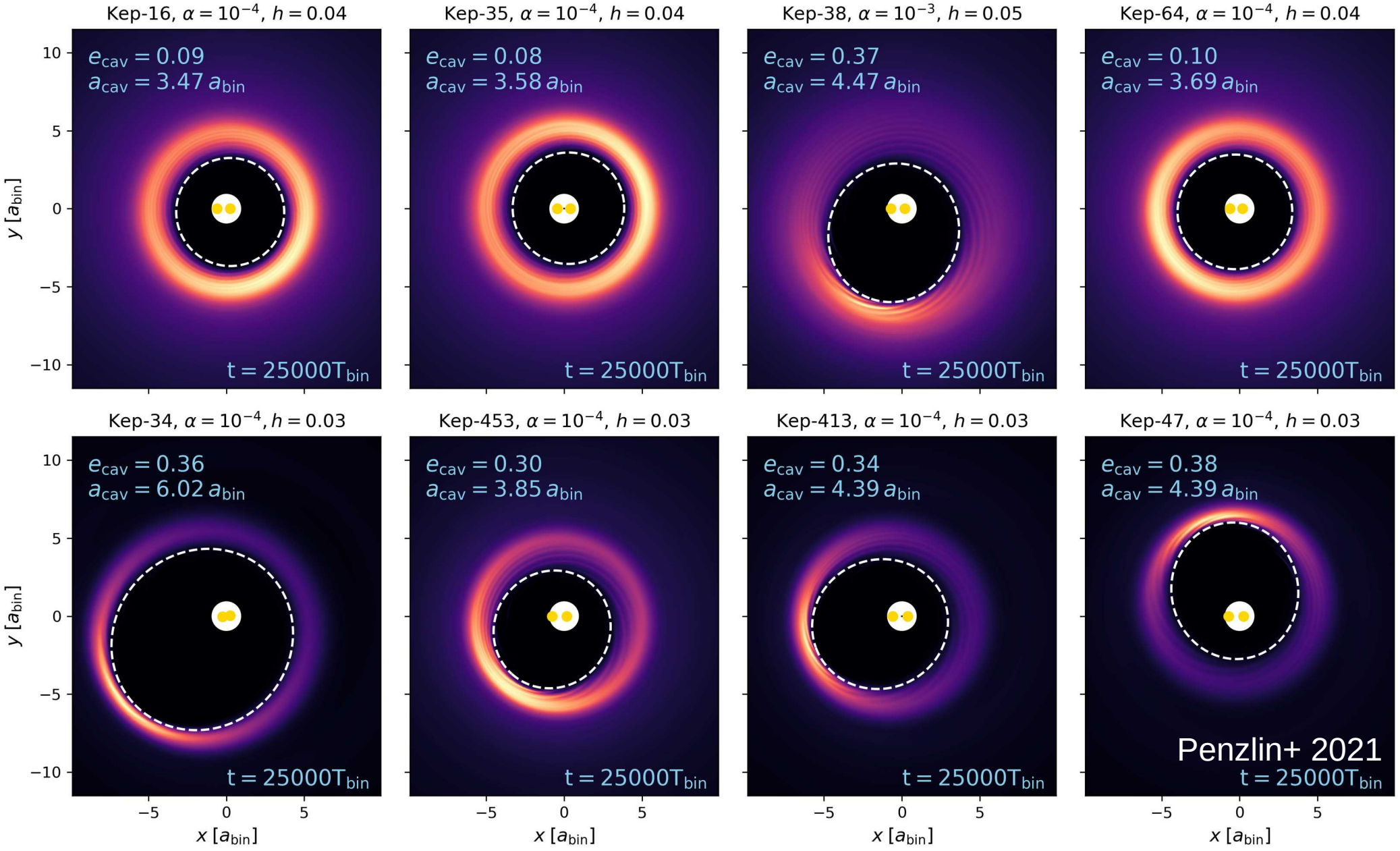
Viscous migration of small planets in CBD

Viscosity also influences gap opening.

Lower viscosity ⟺ lower thermal masses ⟺ deeper gaps
(Crida+2006)



Migration of observed planets in CBD



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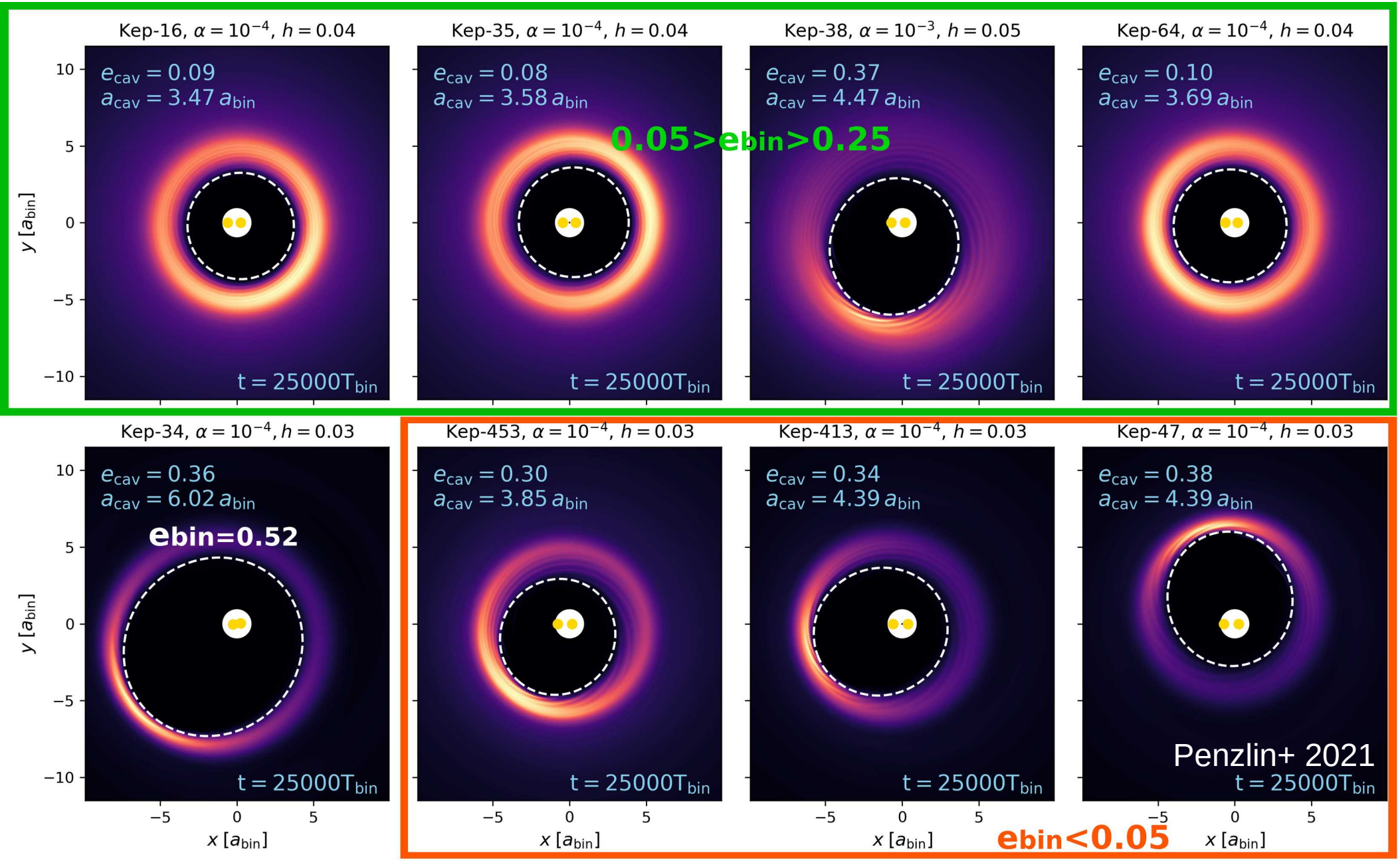

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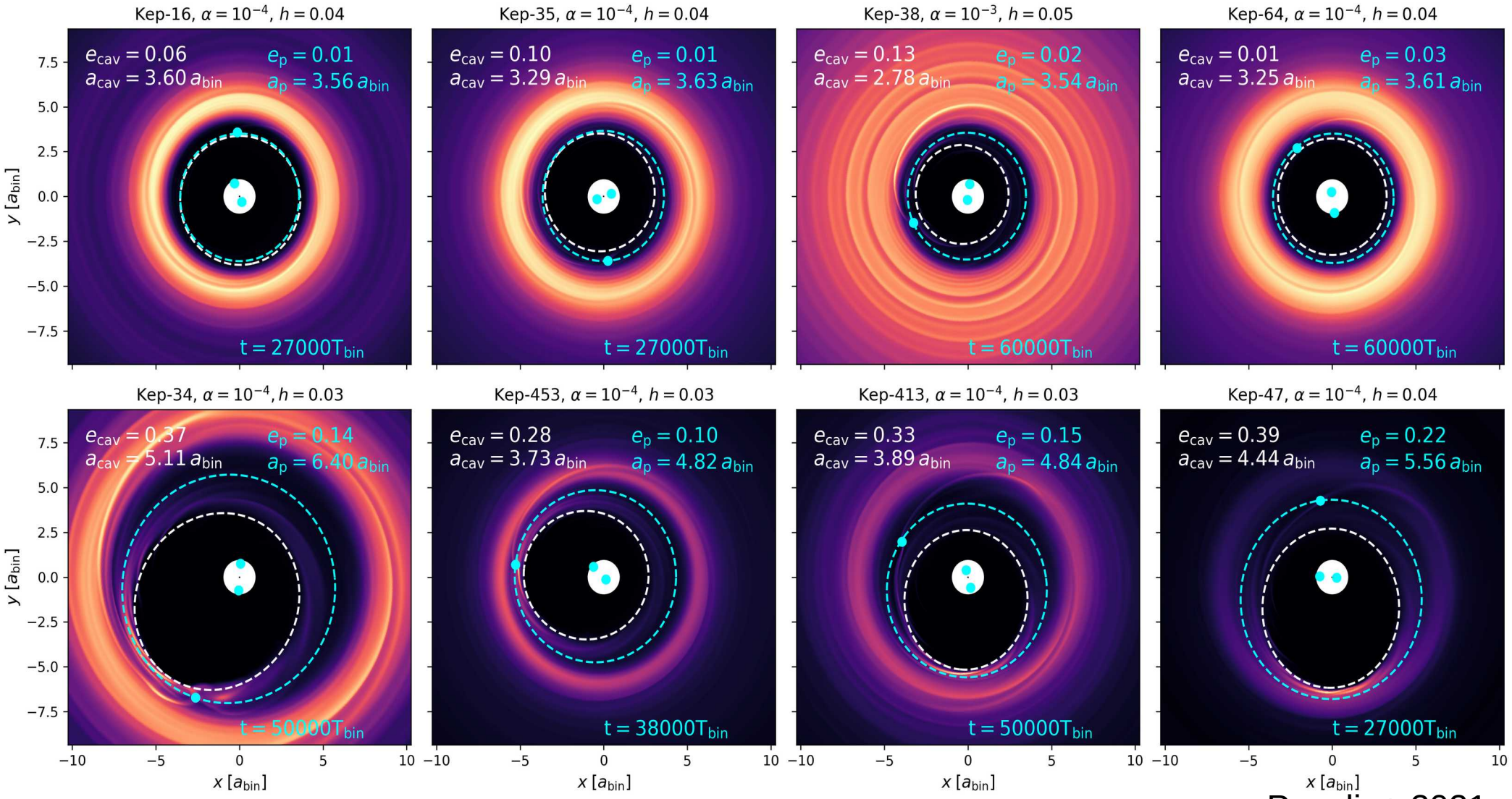
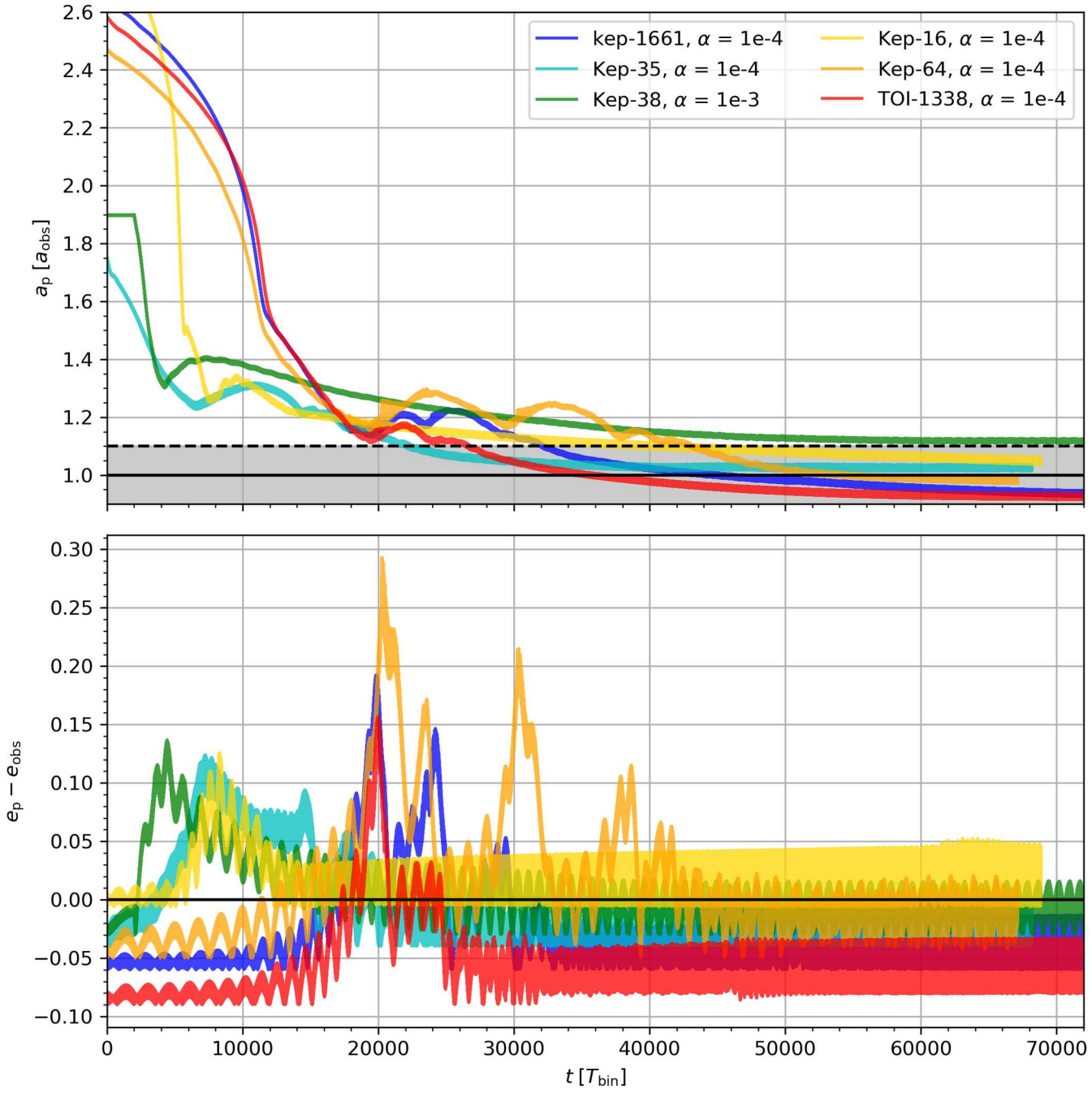


Penzlin+ 2021

Highly eccentric disc block the planets from reaching the cavity

Migration of observed planets in CBD



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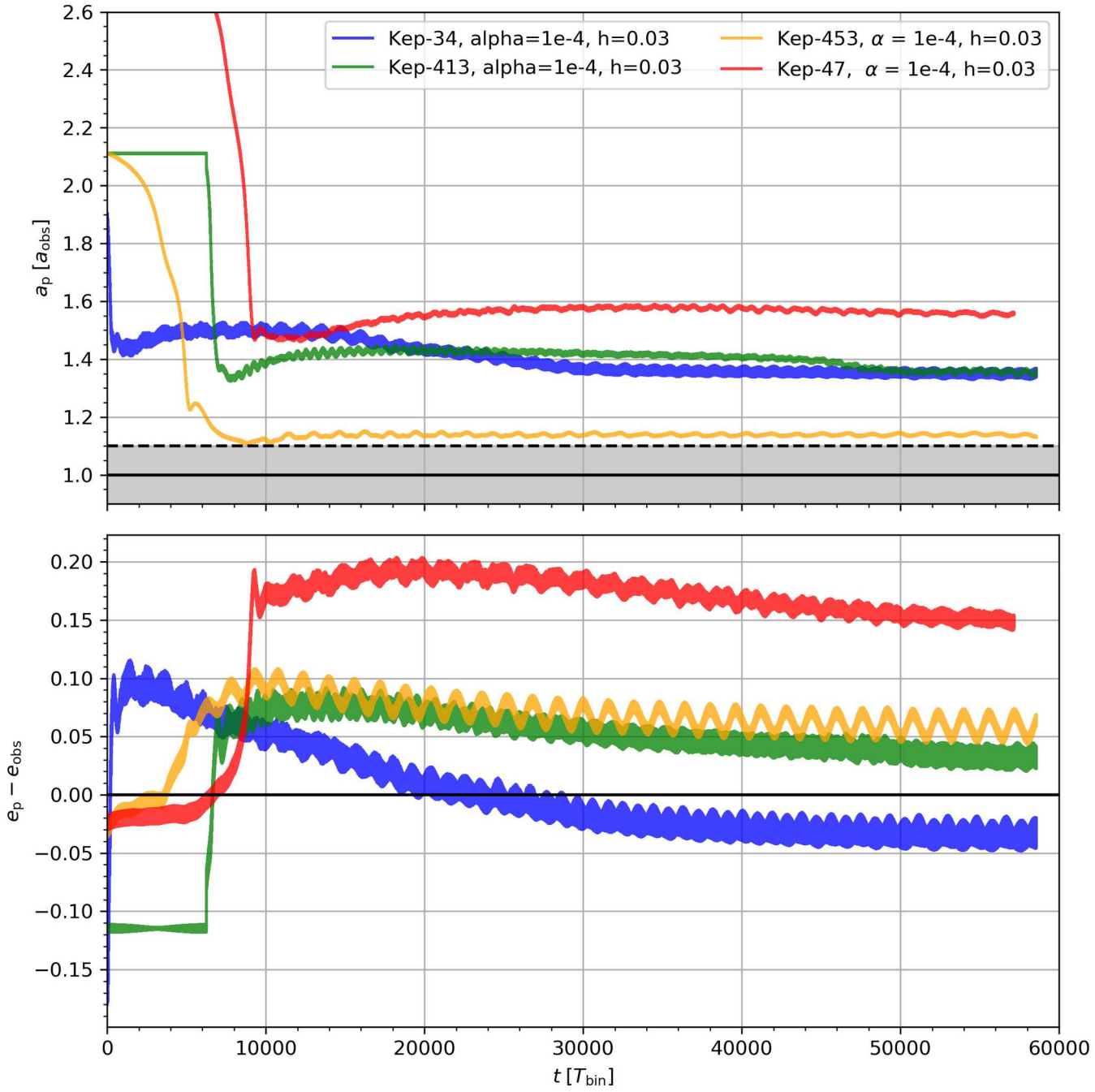
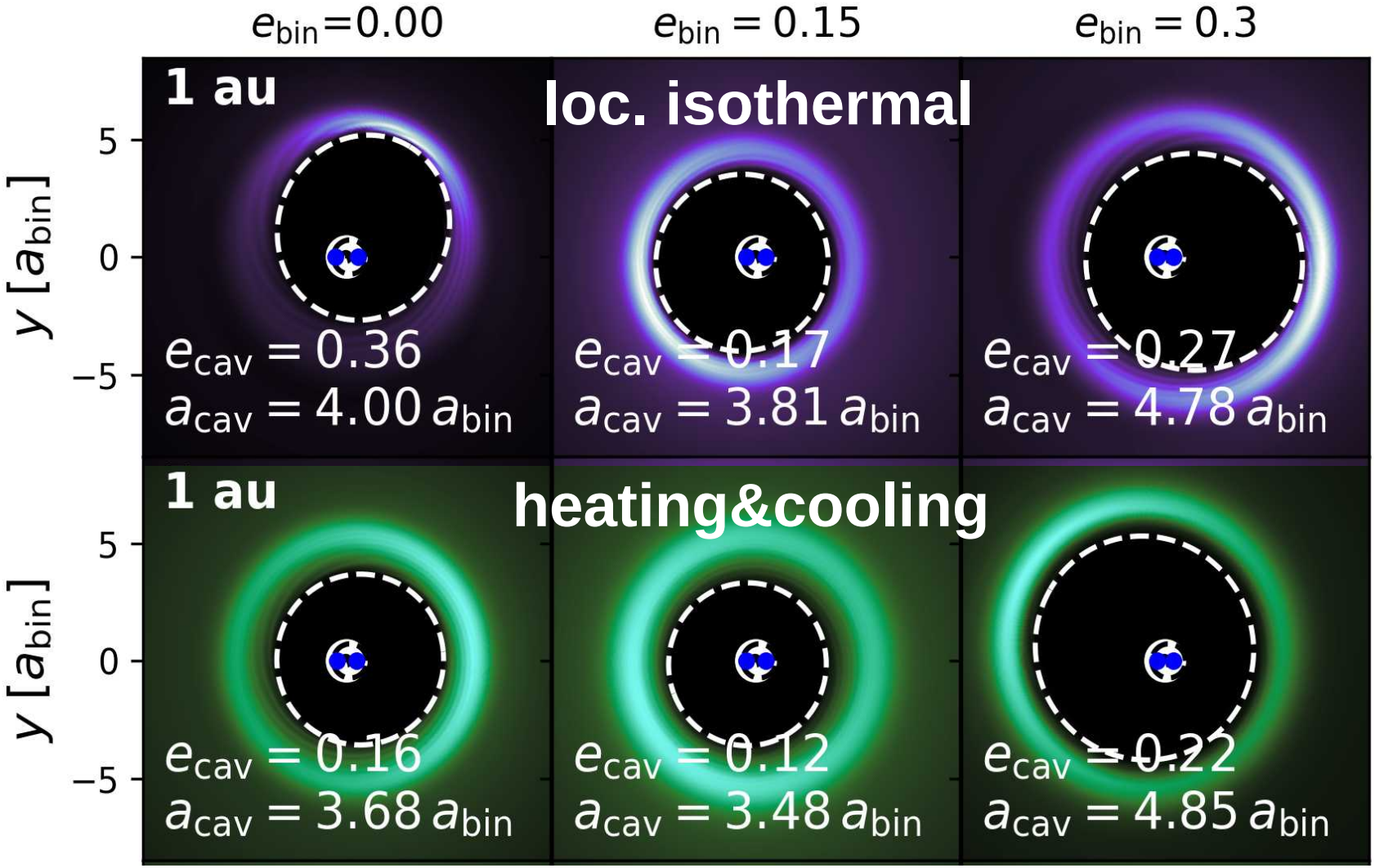
Migration of observed planets in CBD



Penzlin+ 2021

Migration of observed planets in CBD

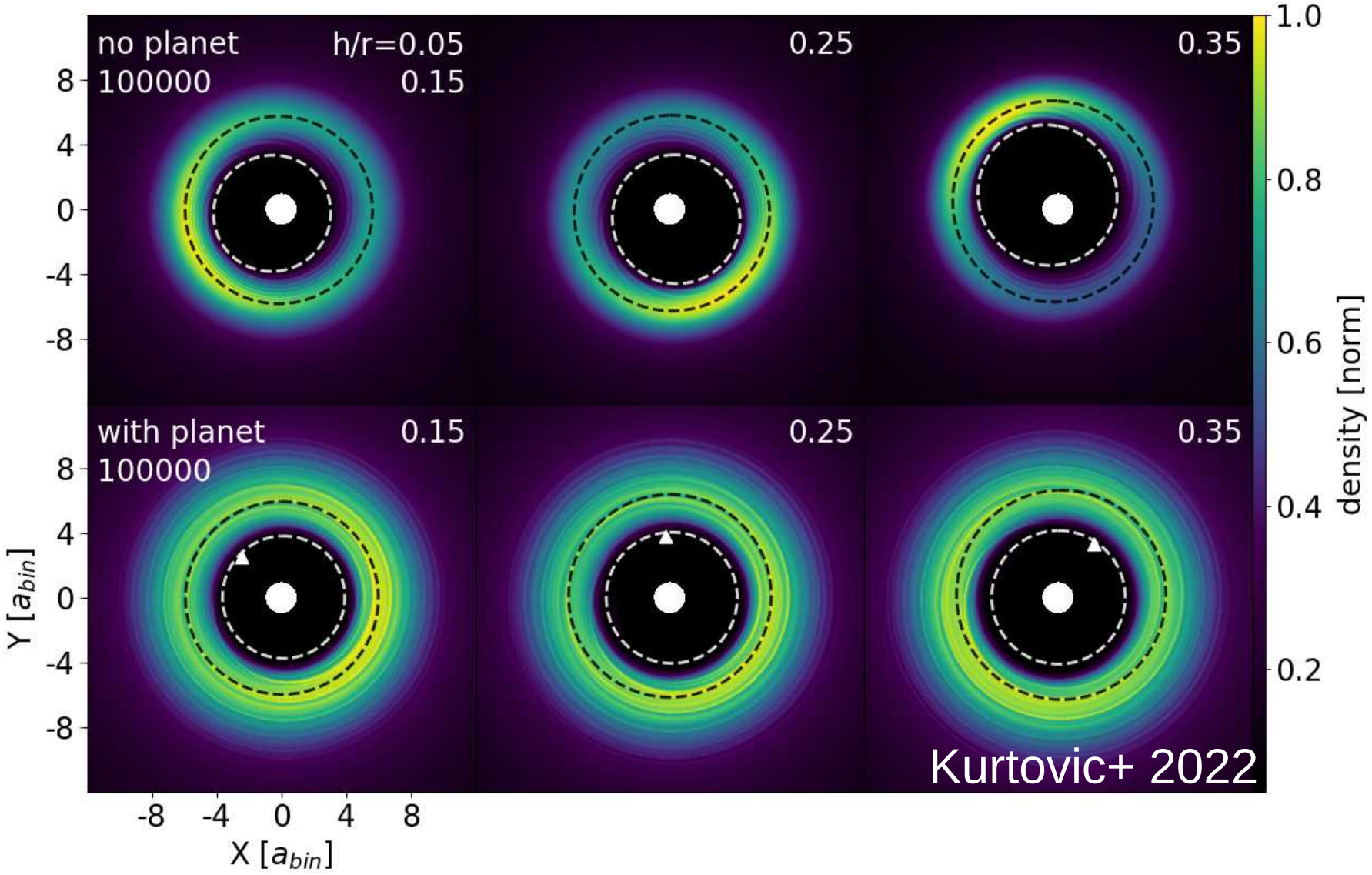
Non-isothermal conditions reduce the wave propagation and excitation of eccentricity
(Rafikov+ 2020, Sudarshan+ 2022)



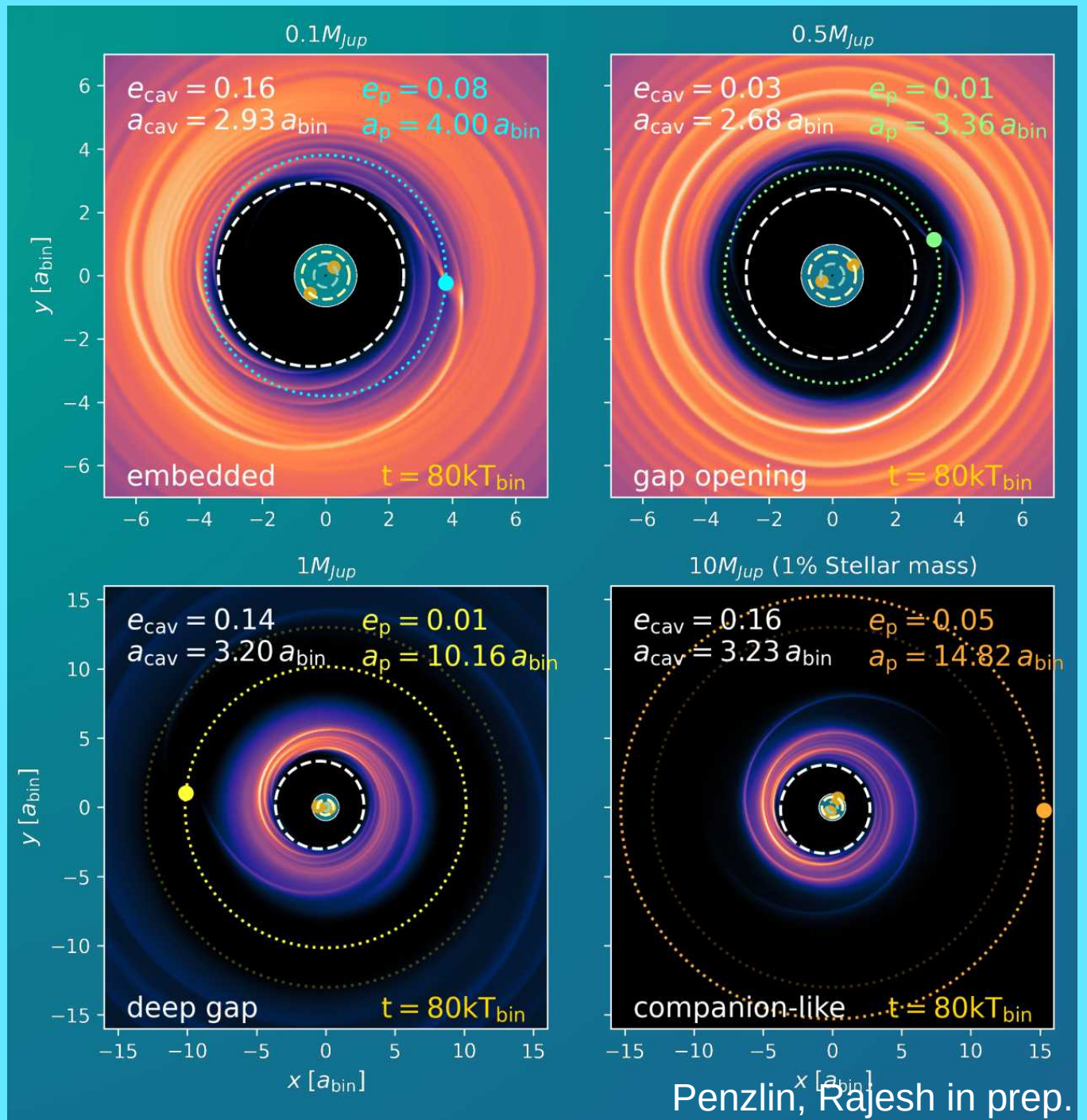
Penzlin in prep.

Effect of planets onto the disc

Planets circularise the disc beyond

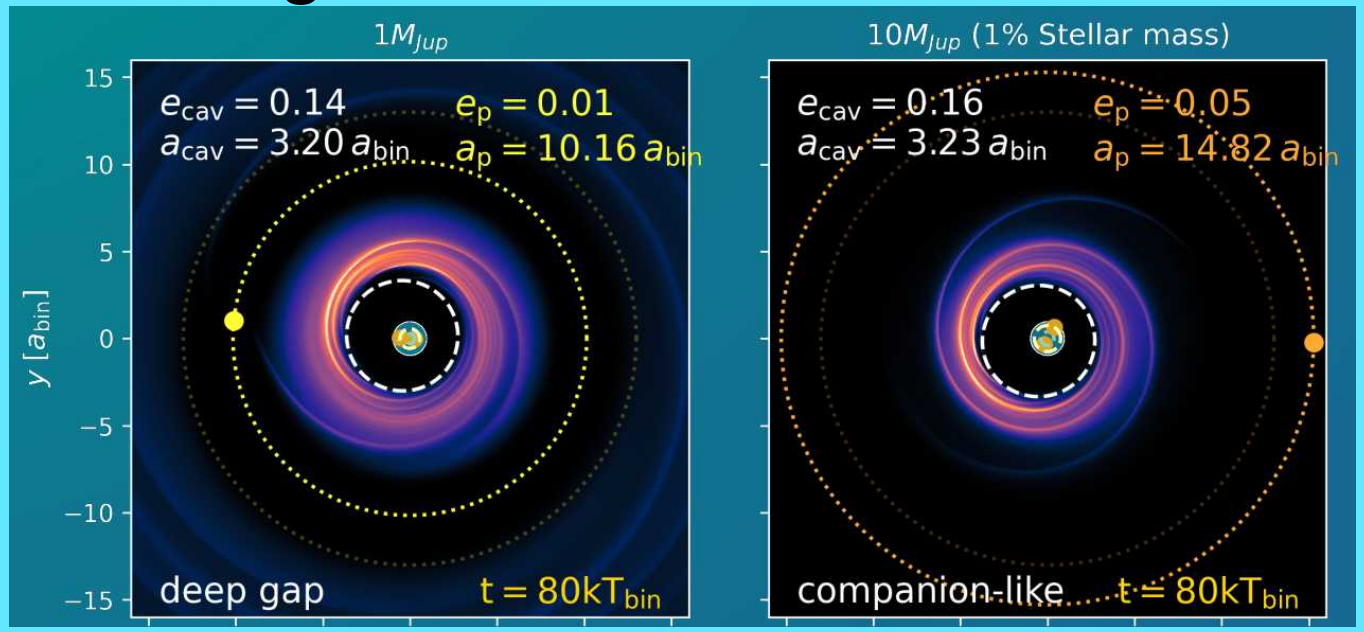


Migration of giants in CBD



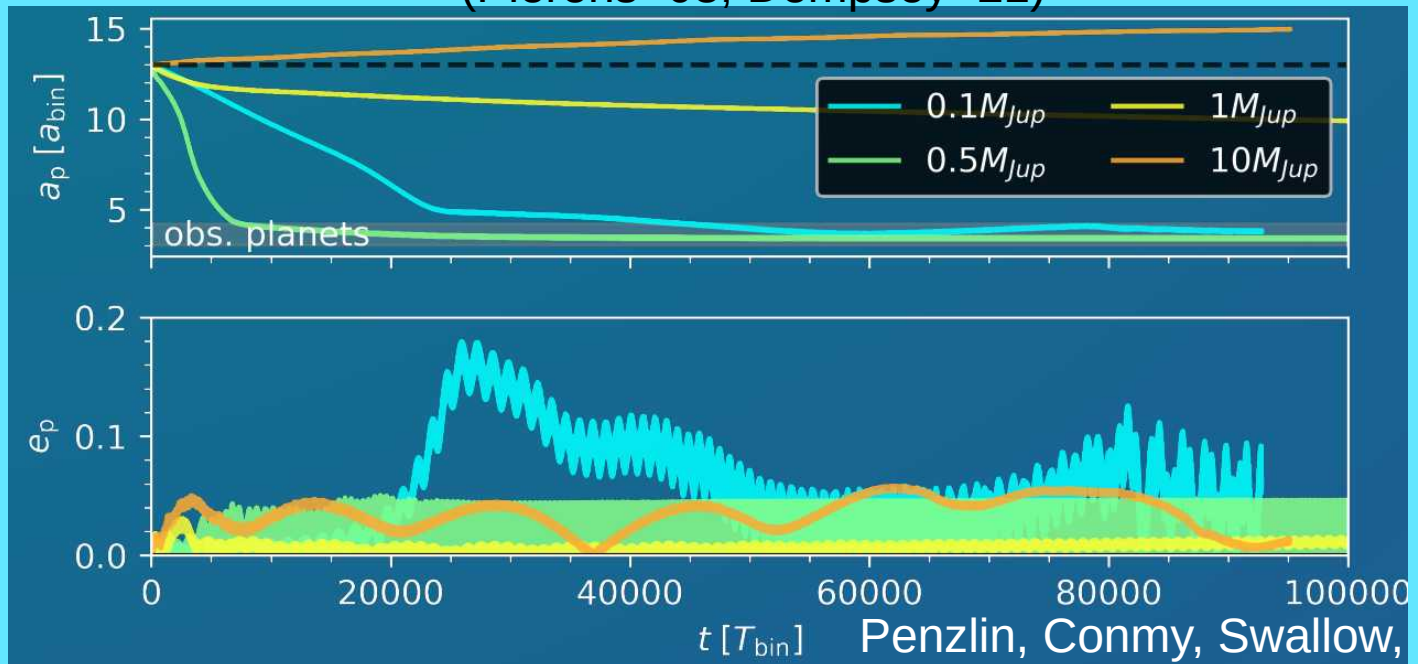
Penzlin, Rajesh in prep.

Migration of giants in CBD



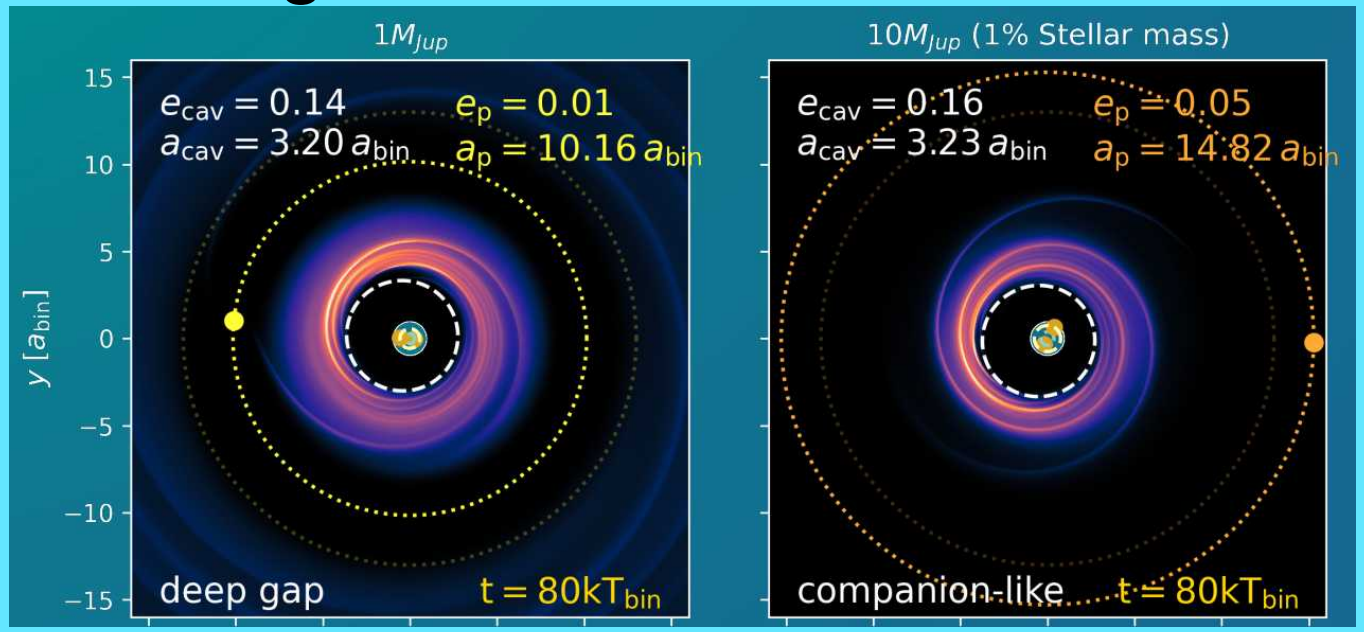
> 1 M_{Jup} planet can migrate outwards (also in non-binary discs)

(Pierens+08, Dempsey+21)

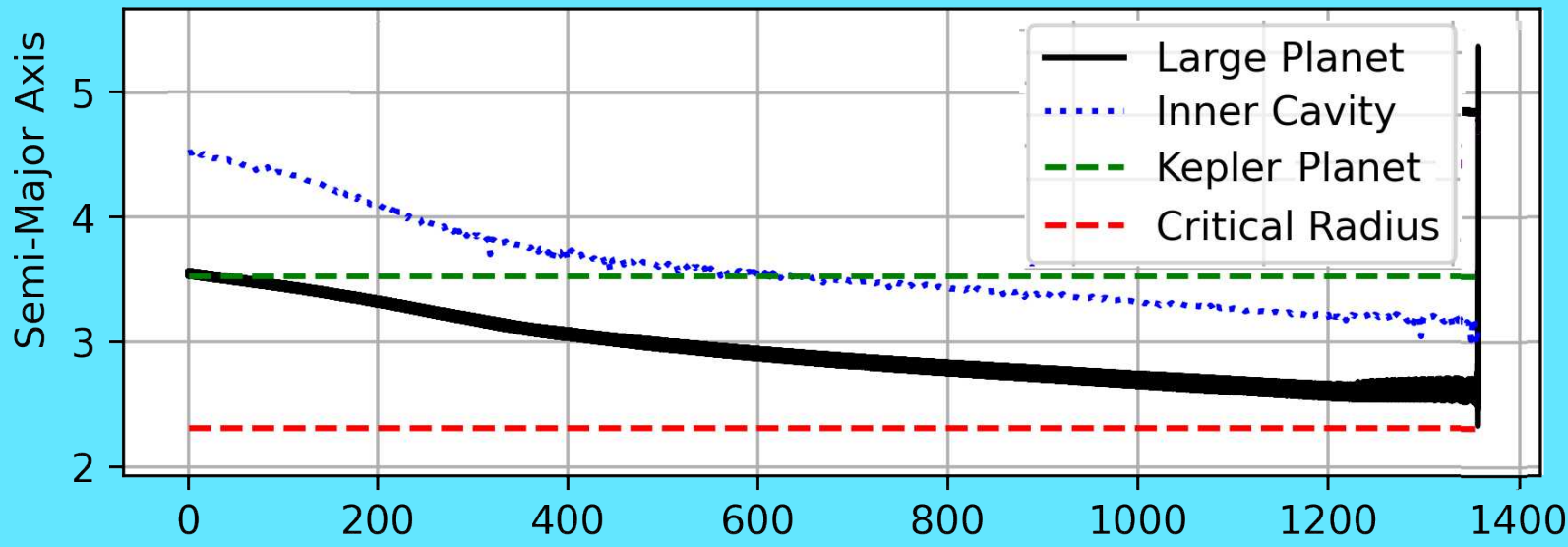


Penzlin, Conmy, Swallow, Rajesh in prep.

Migration of giants in CBD



~ 1 M_{Jup} planet migrate slowly but are not stopped by the cavity edge and can scatter (Pierens+08)



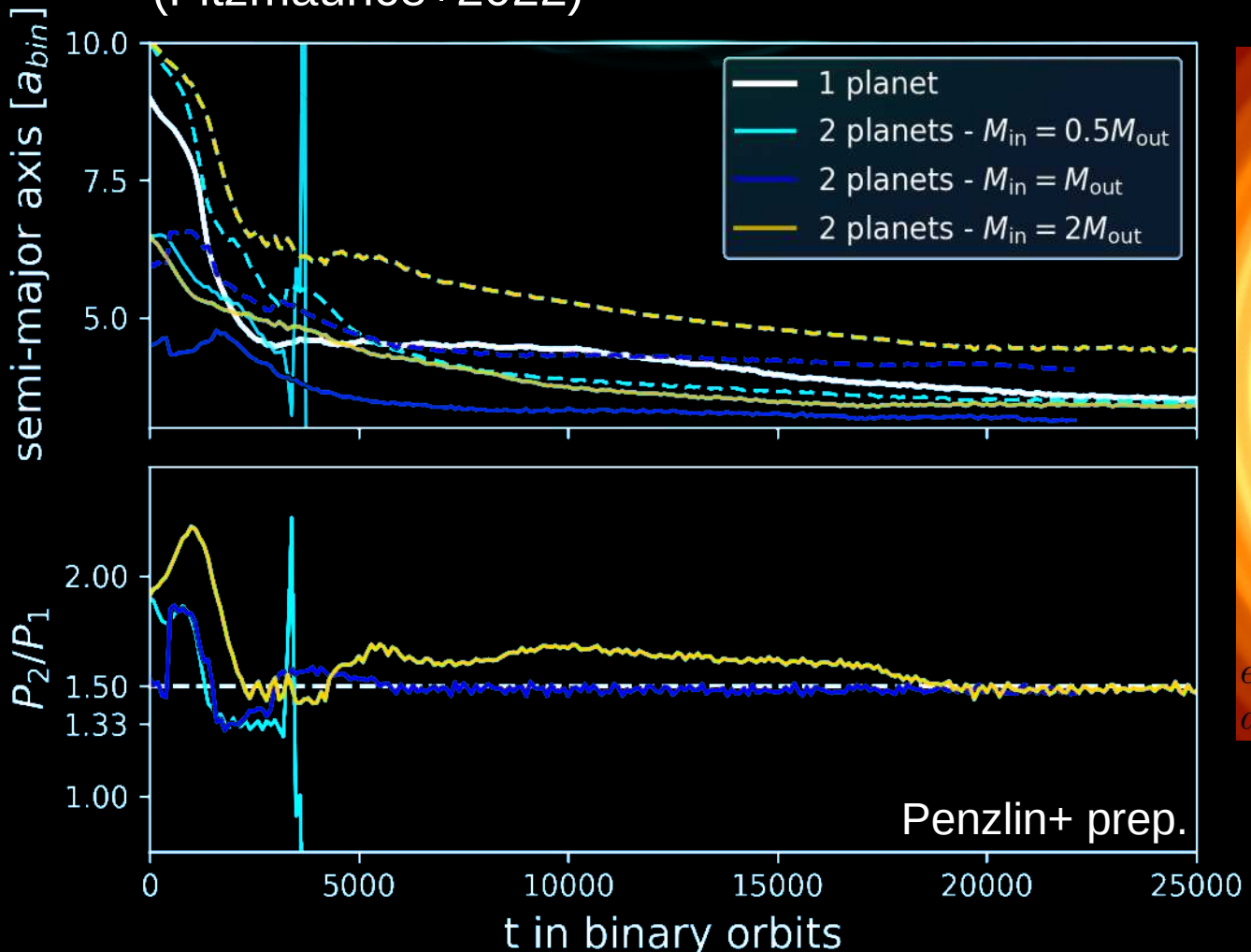
Penzlin, Conmy, Swallow, Rajesh in prep.

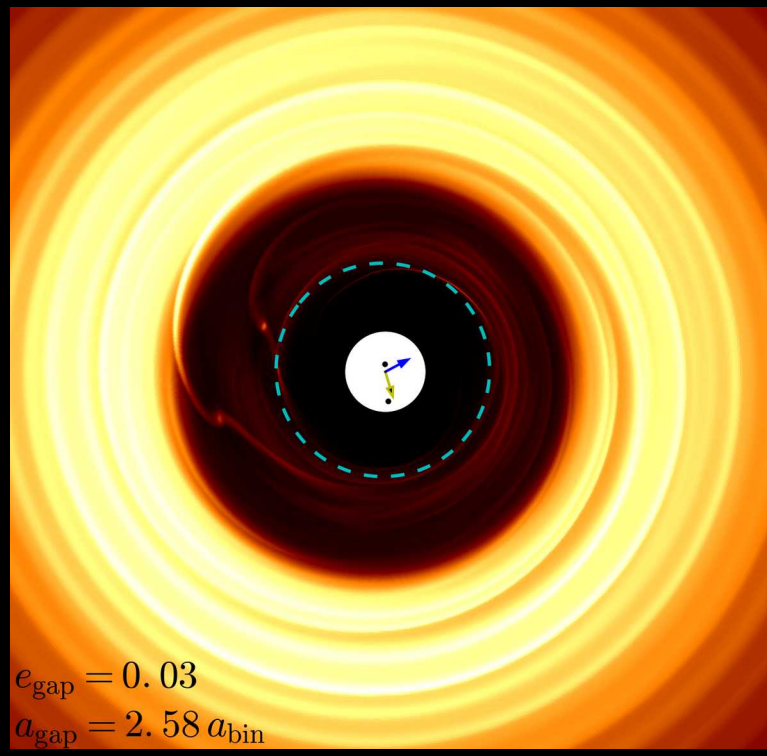
Dynamic migration of multi-planet systems

If planets migrate to close while still in the disc they can scatter

If multiplanet systems are stable, planets chain up usually in resonance (Pierens&Nelson 2008a)

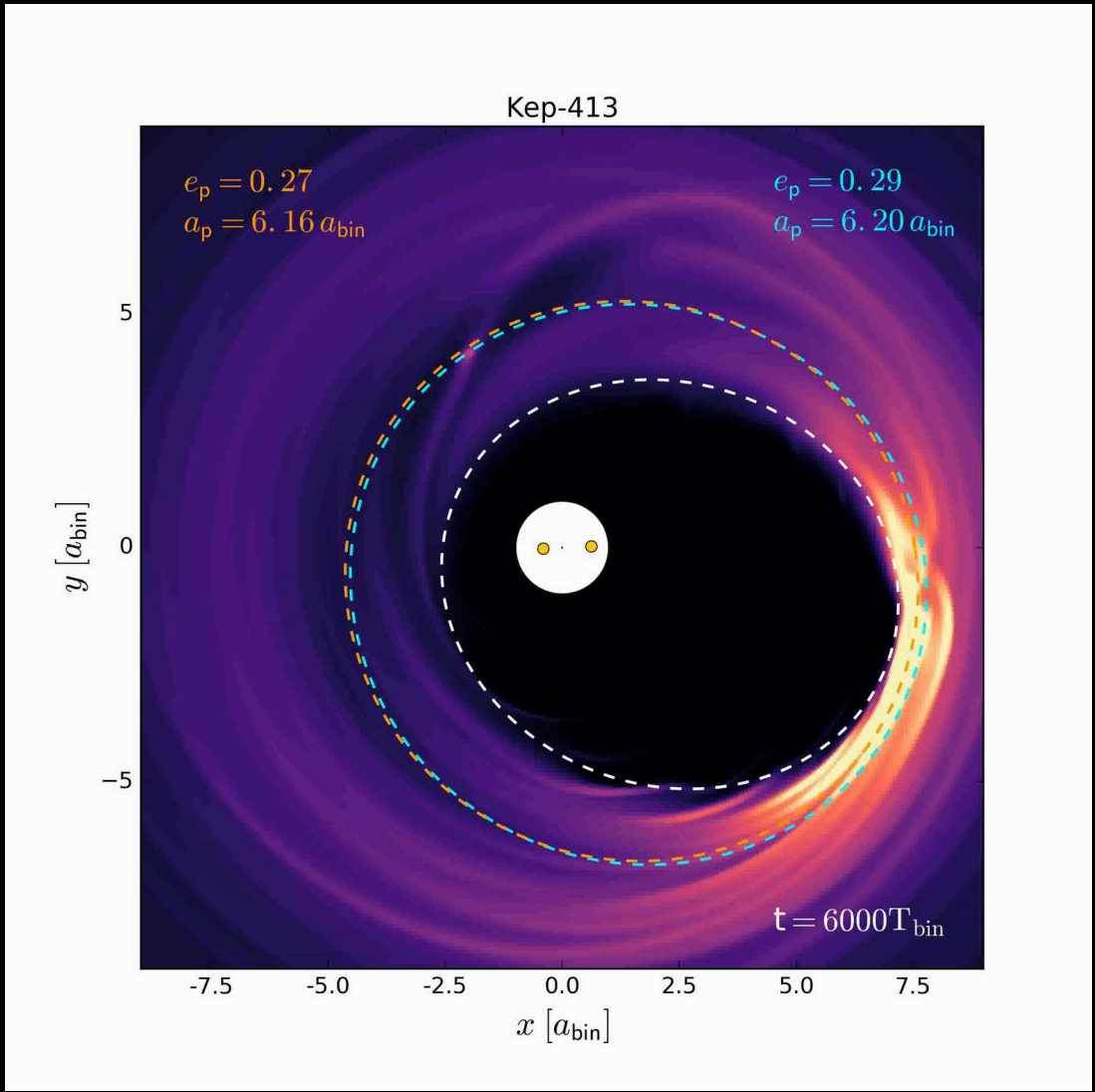
This can be reproduces with N-body+migration torques (Fitzmaurice+2022)





Dynamic migration of multi-planet systems

The damping interaction with the disc even allow the planets to reach a stable coorbital configuration.



Penzlin+ 2019

Circumbinary planets through observations

- Why are sub-Jupiter planets cluster at ~3 – 4 a_{bin}?
- Why do the sub-Jupiter planets have low eccentricities?
- Why are larger planets further out?

Circumbinary planets through observations

- Why are sub-Jupiter planets cluster at ~3 – 4 a_{bin}?

  They open a gap and reach the edge of the inner cavity and park there

- Why do the sub-Jupiter planets have low eccentricities?

  The planet detach the disc beyond their orbit and get circularized from the interaction with the outer disc

- Why are larger planets further out?

  Planets larger than Jupiter have a slow or even outward migration

Thank you!