EVERYBODY
WANTS TO SEE
GONE WITH THE WIND!

GAYLOR WAFFLARD-FERNANDEZ's PRODUCTION
OF A PLANET MIGRATION'S STORY
IN A WINDY CIRCUMSTELLAR DISK

GONE WITH THE WIND
in Technicolor

Starring

DISK GABLE
VIVIEN WIND
JUPITER de HAVILLAND

AN IPAG INTERNATIONAL PICTURE
Music by Geoffroy Lesur

IPAG

anr agence nationale de la recherche

erc European Research Council
Established by the European Commission

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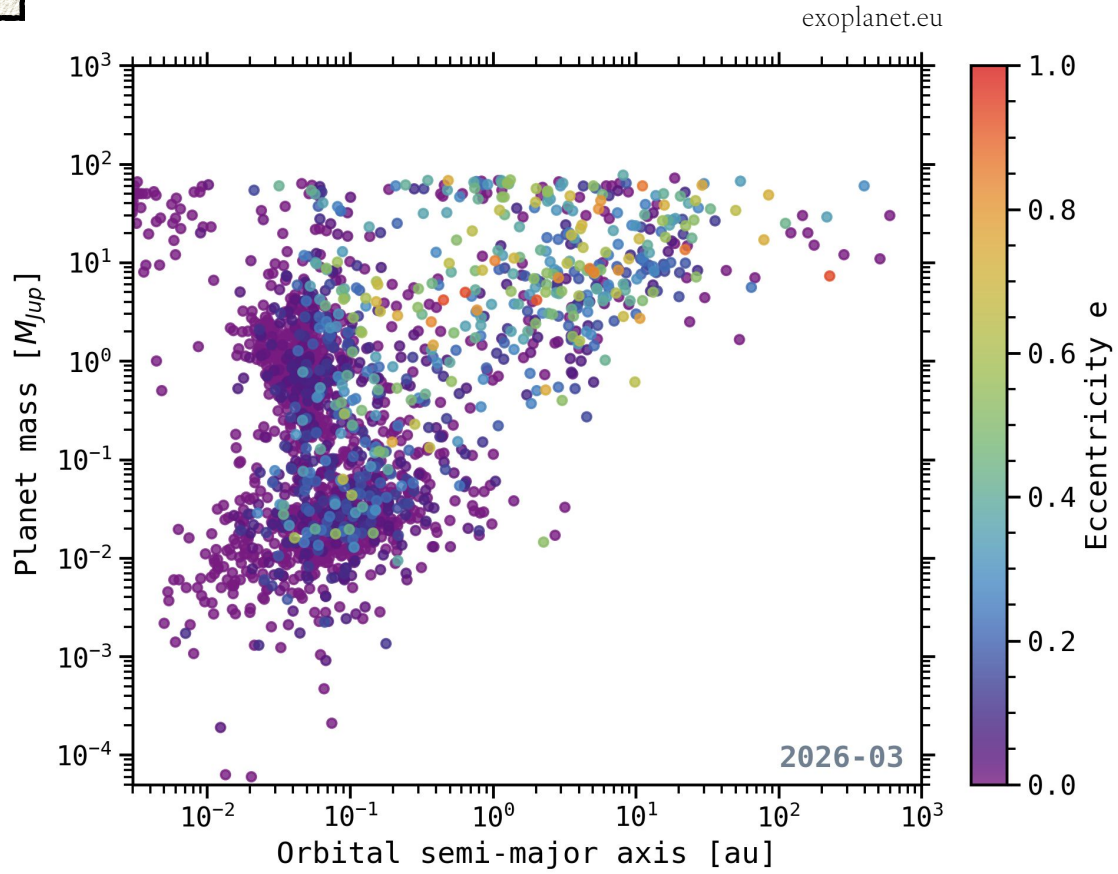
CONTEXT

Warm Jupiters



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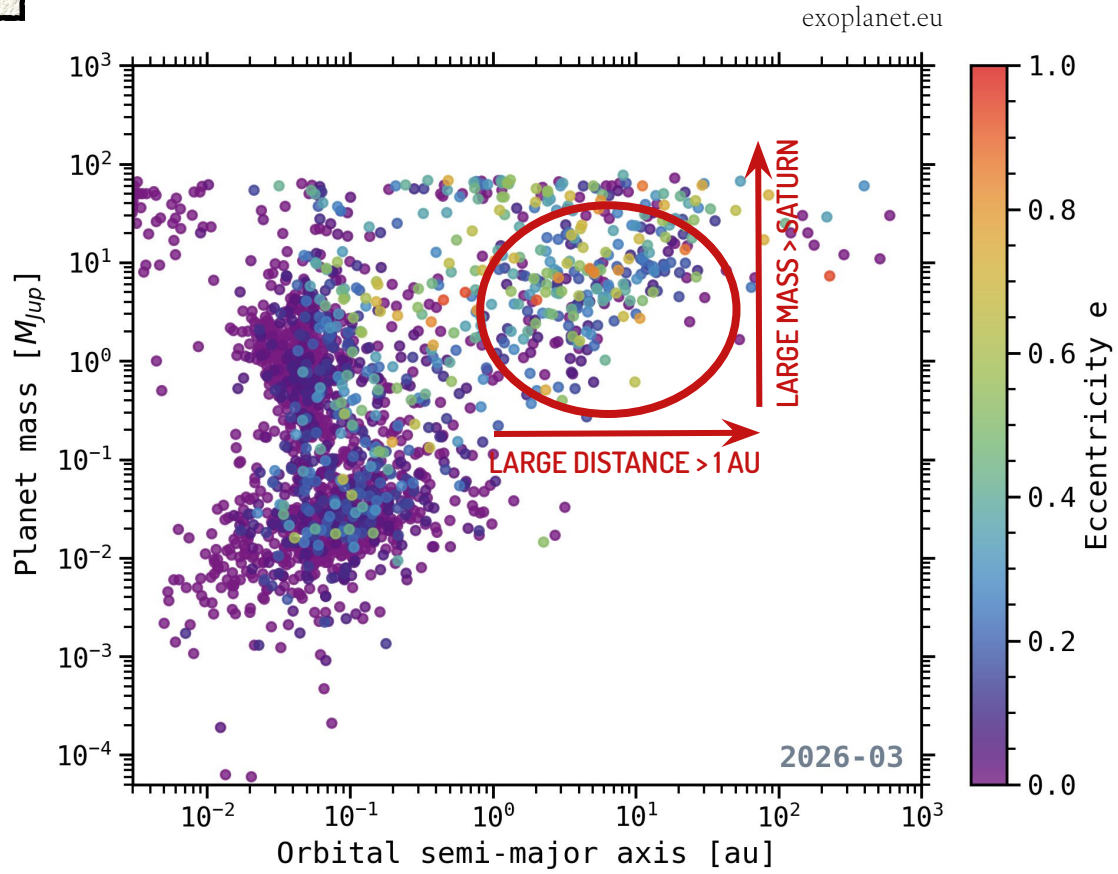
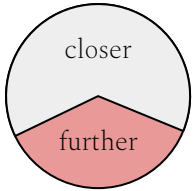


DISTANCE > 1 AU



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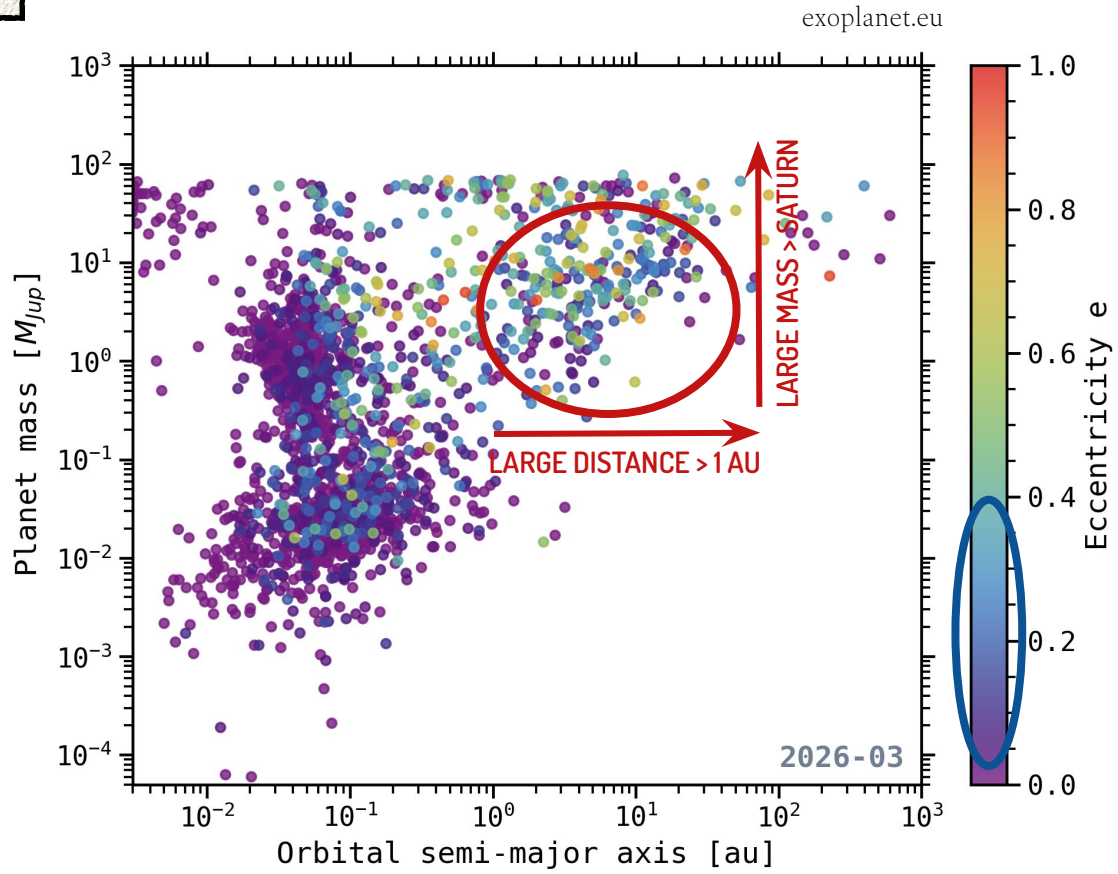

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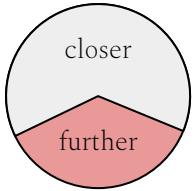
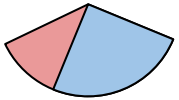


MODERATE ECCENTRICITY

$\in$ [0.05 - 0.4]



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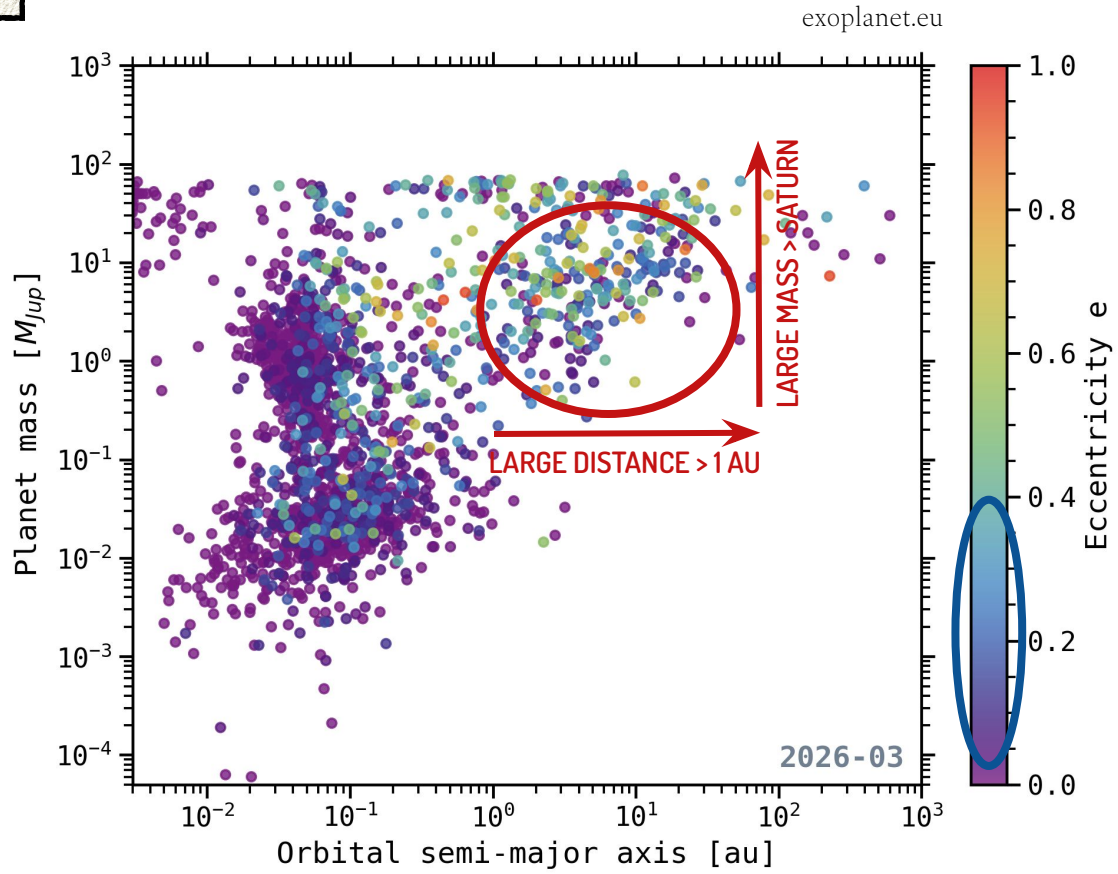

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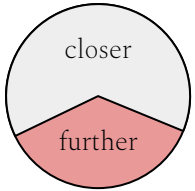

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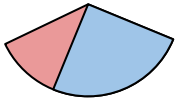

ORIGIN ?

1.2

CONTEXT

Planet / Disk interactions

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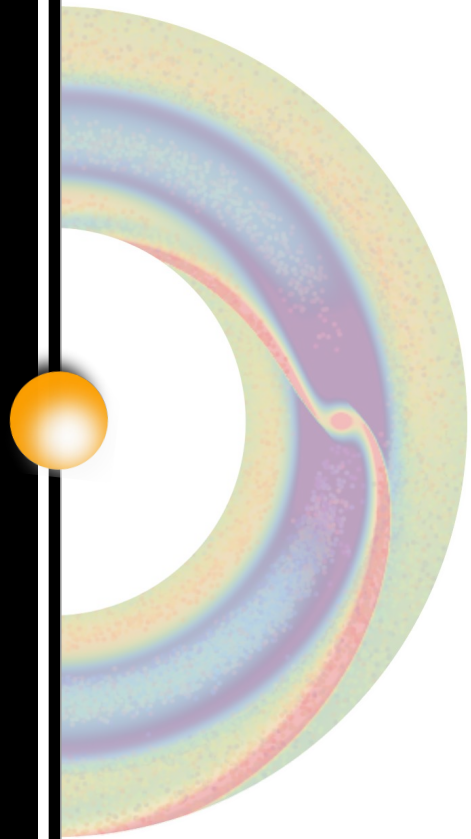

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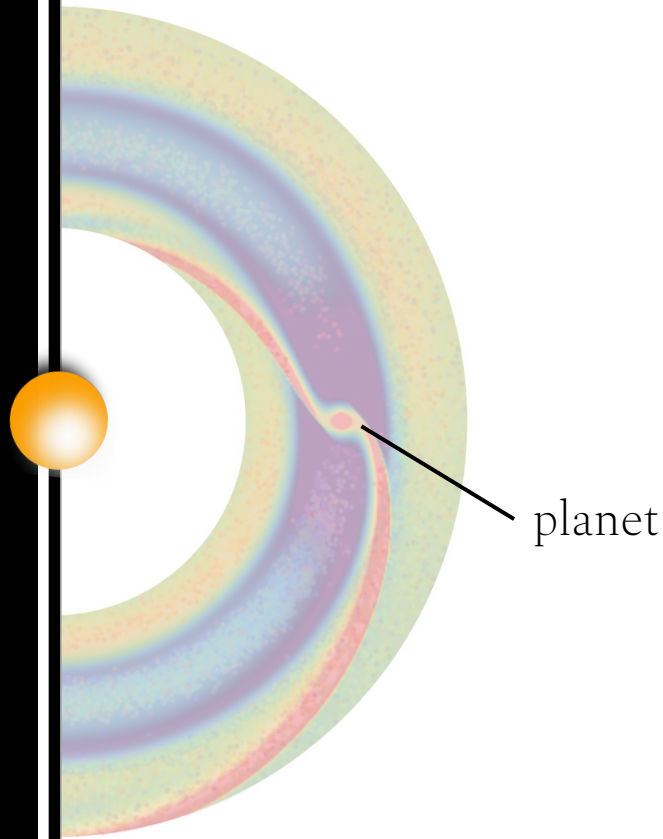

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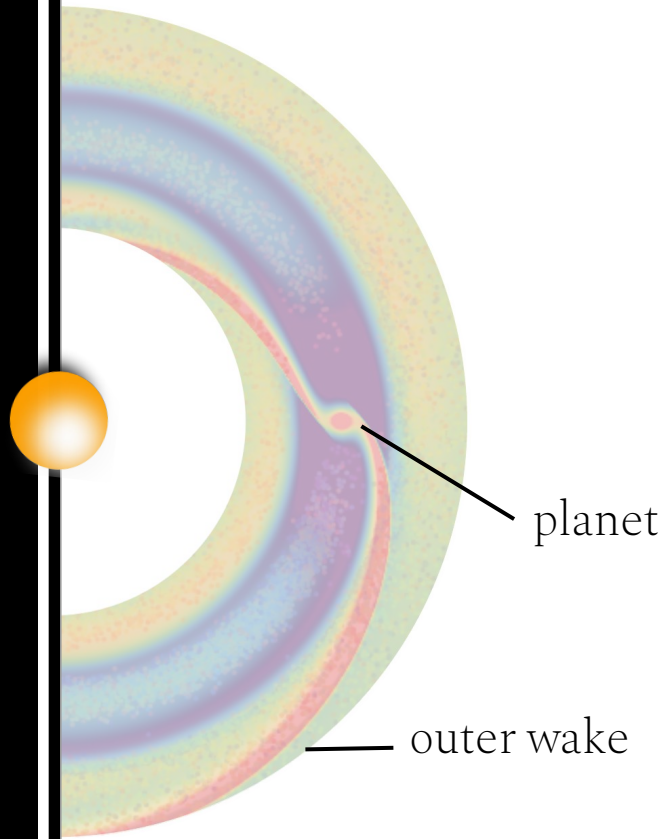

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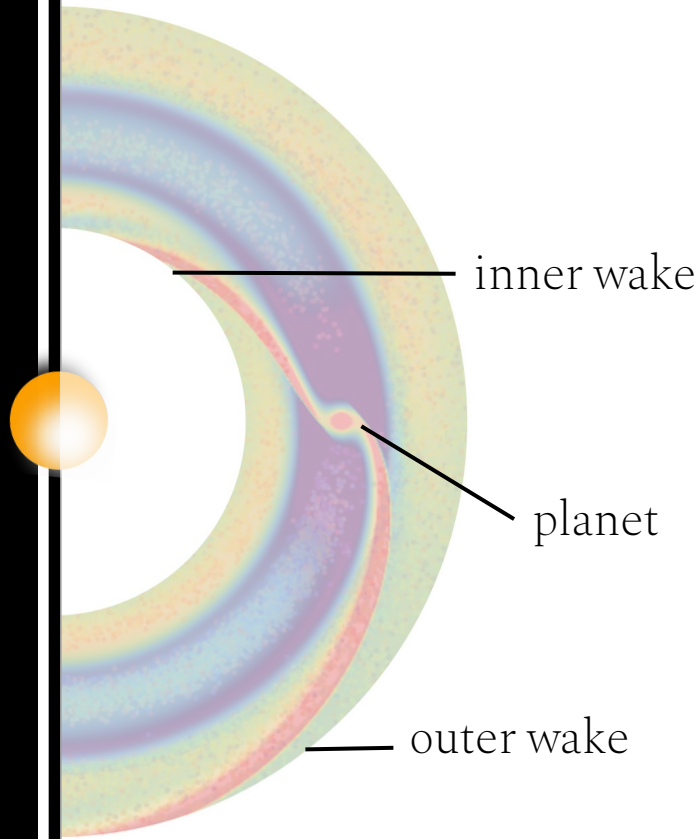

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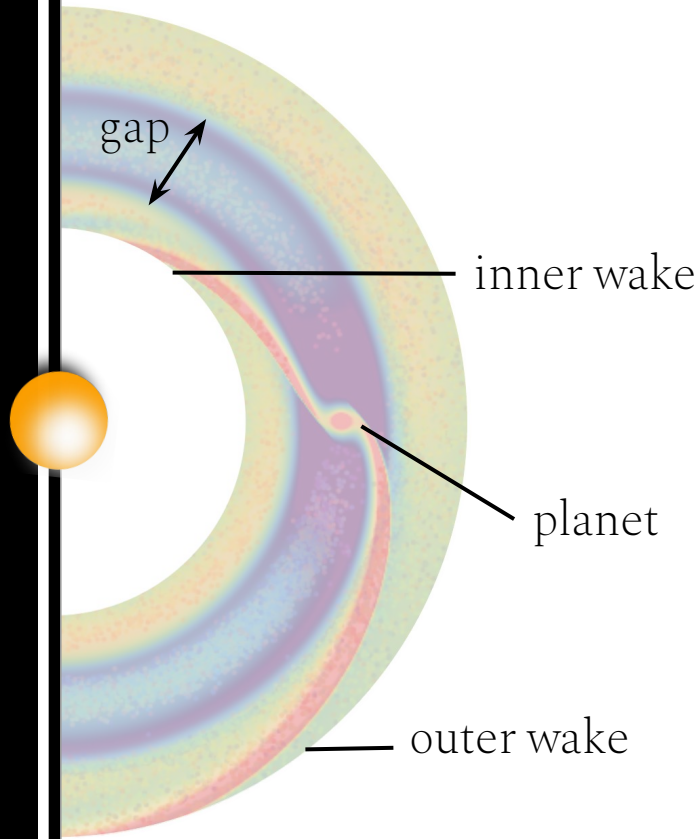

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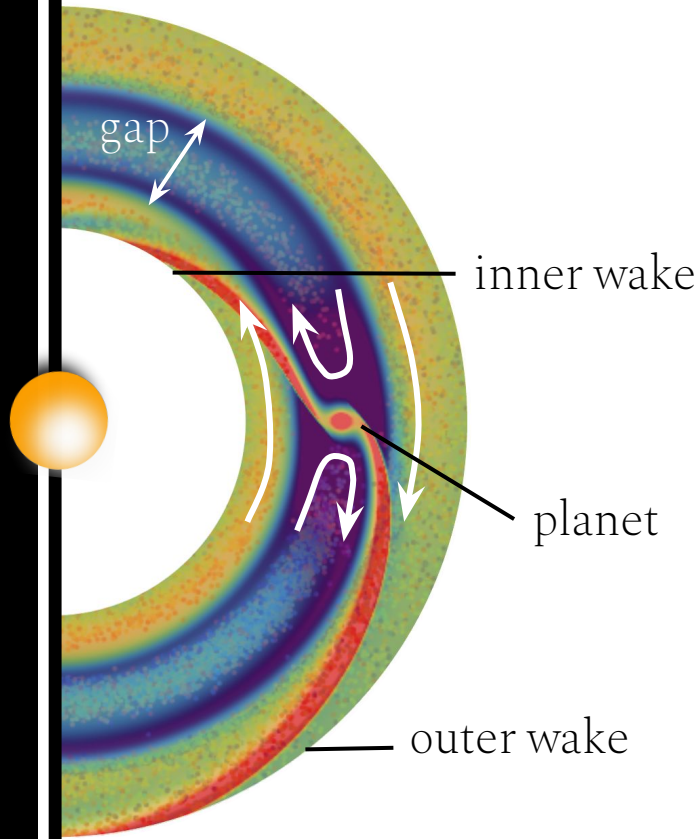

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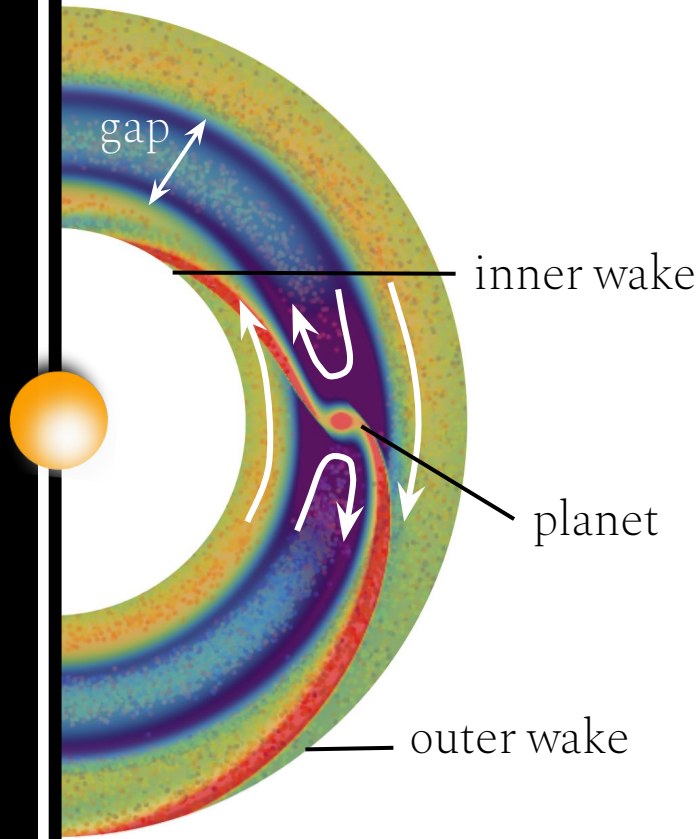

TYPE II MIGRATION

→ classically inwards Lin+Papaloizou, 1986

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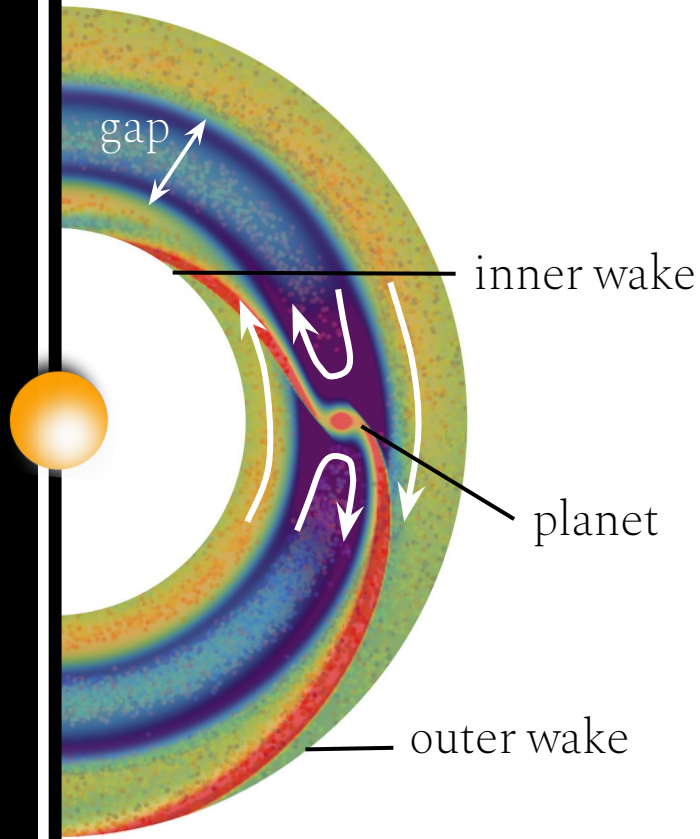

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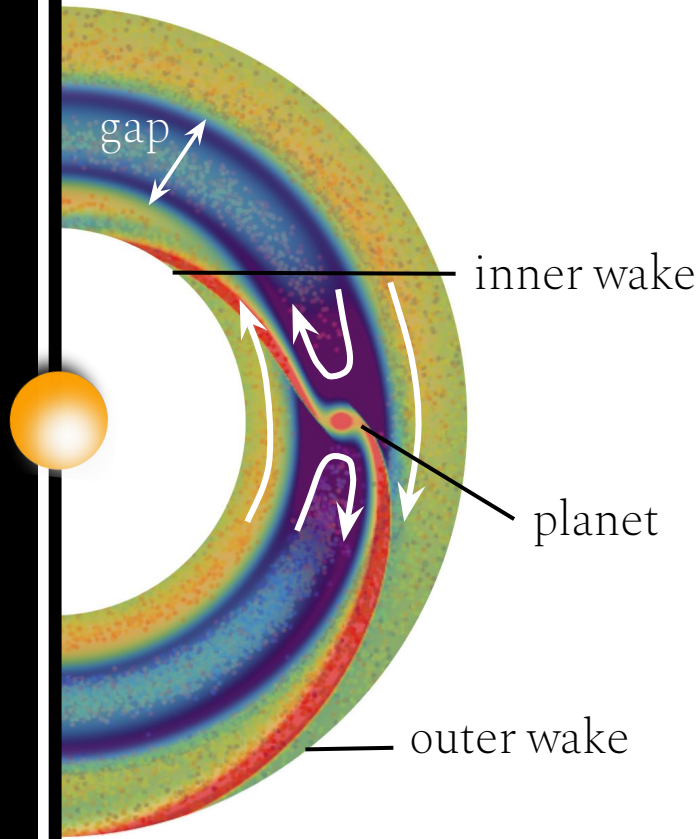
- → locked to the disk's **viscous evolution**? (no)
- → $v_r = -(3/2)(\nu/r)$: 15 au.Myr^{-1} @ 10 au
- → much shorter than the disk lifetime

CONTEXT

Planet / Disk interactions



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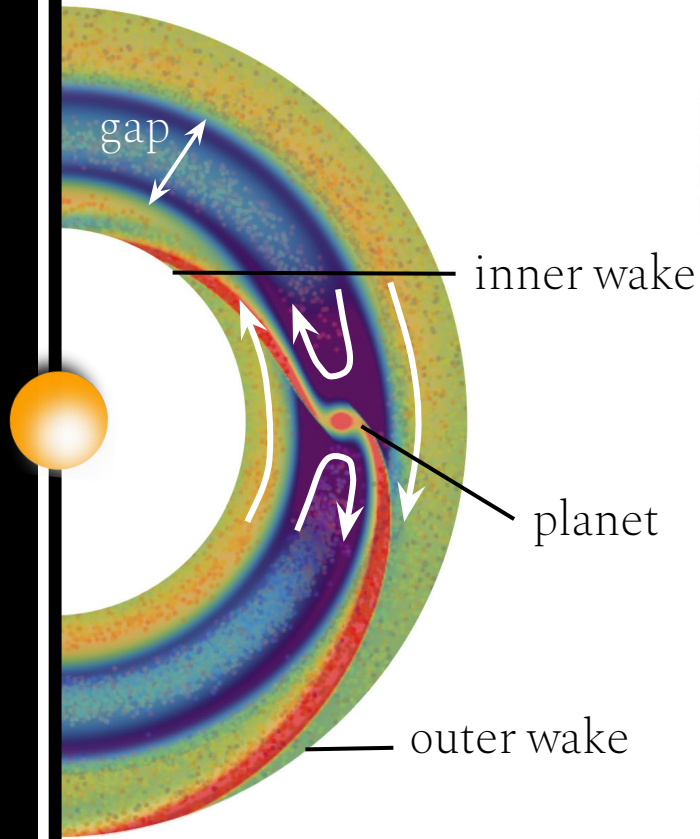
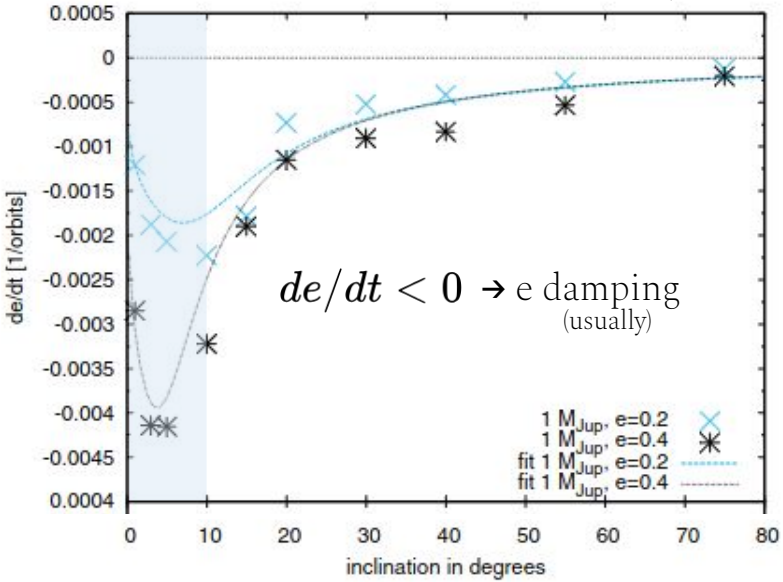


From Bitsch+, 2013



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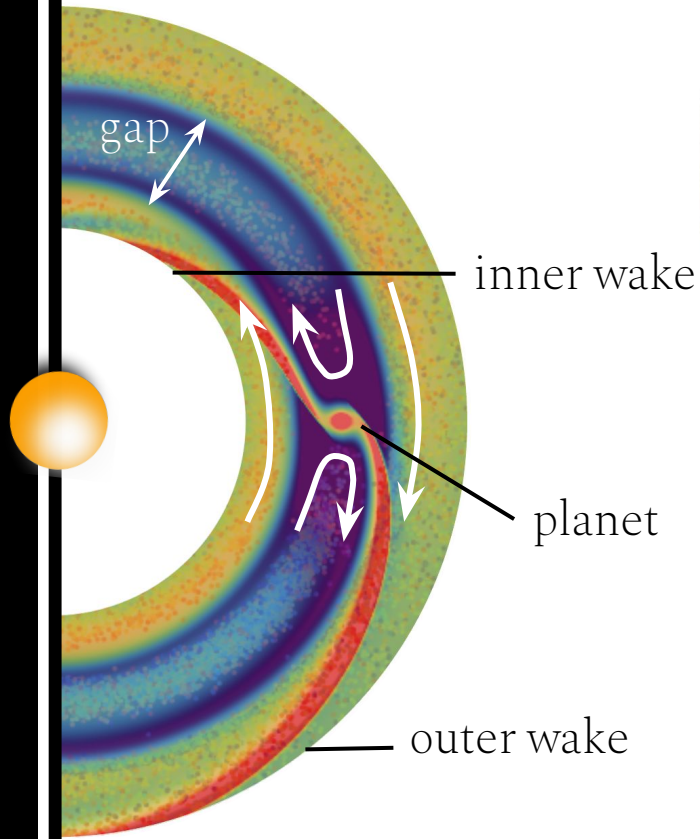

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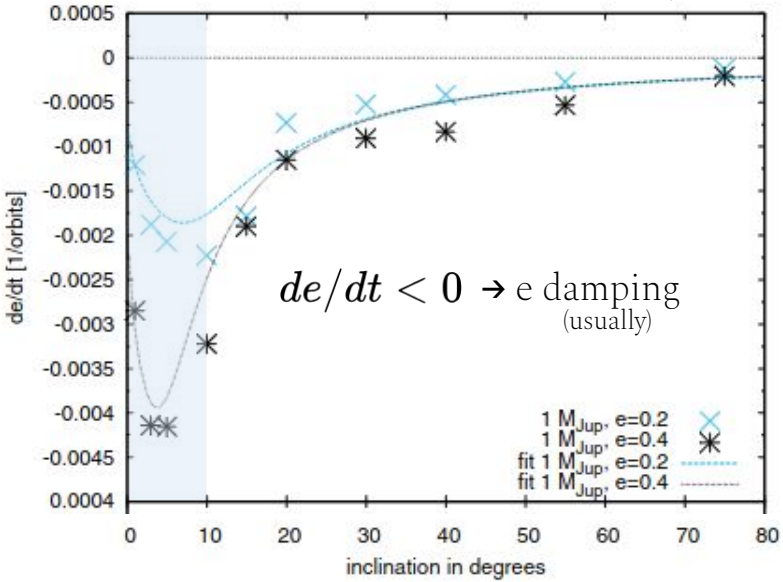

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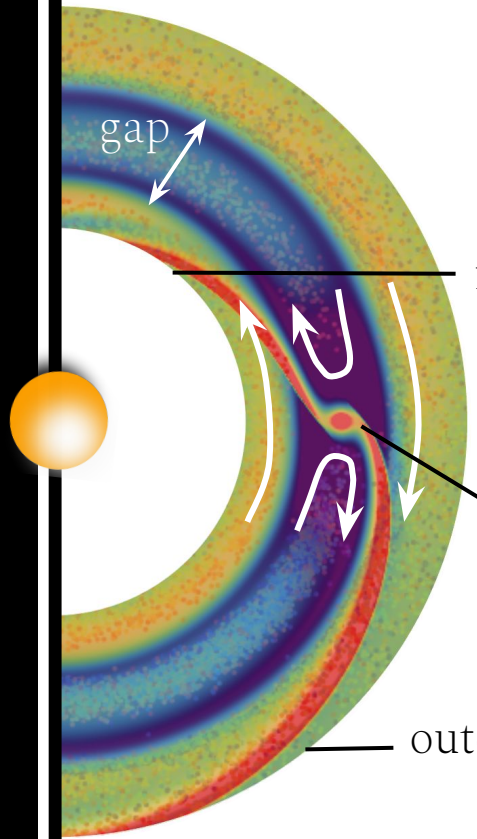

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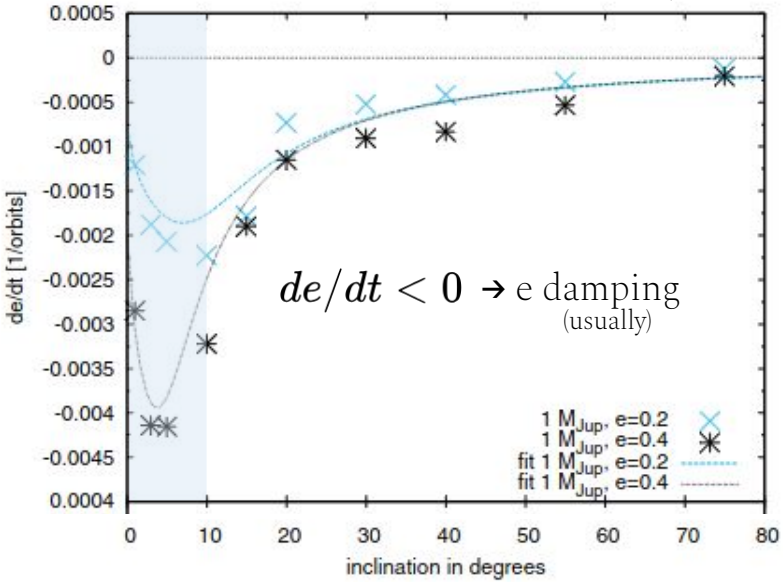

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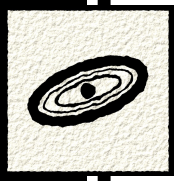
1.3



CONTEXT

Processes of accretion in disks

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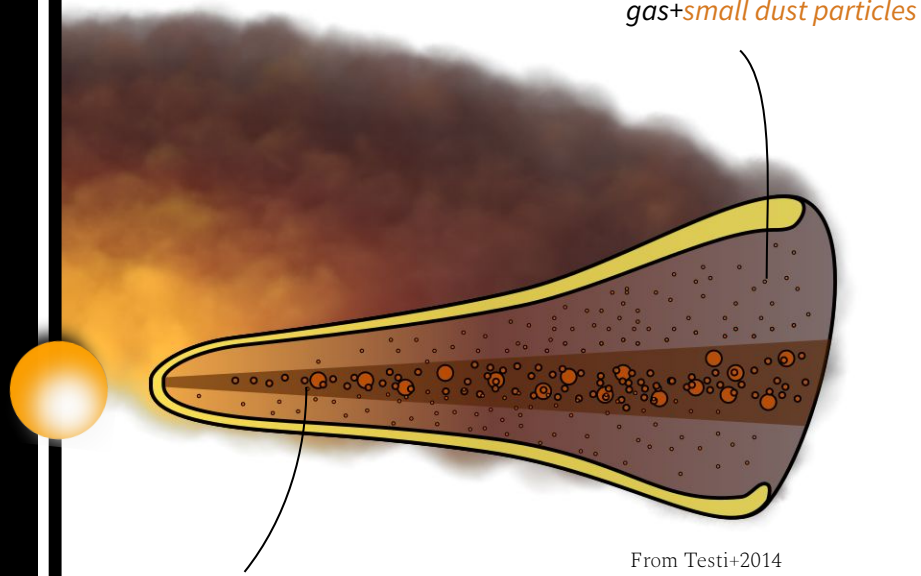


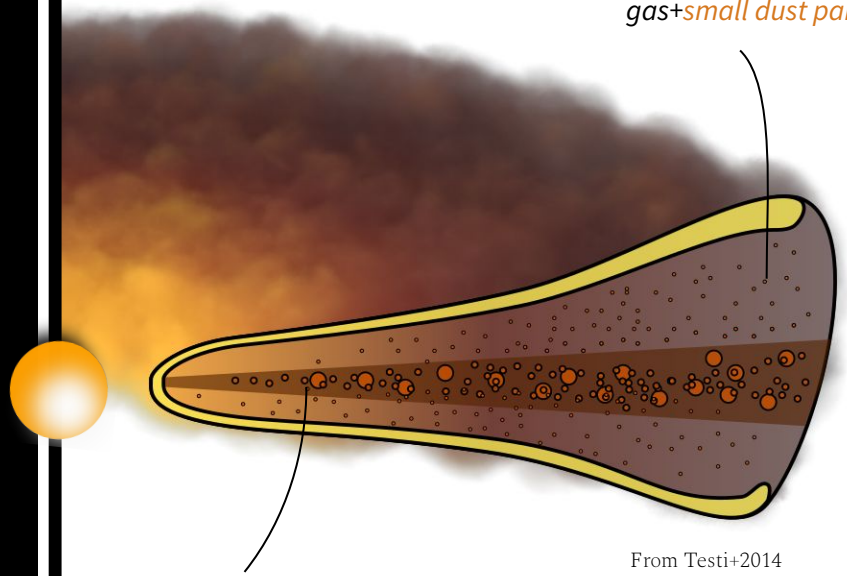
From Testi+2014

CONTEXT

Processes of accretion in disks

Upper layers

gas+small dust particles



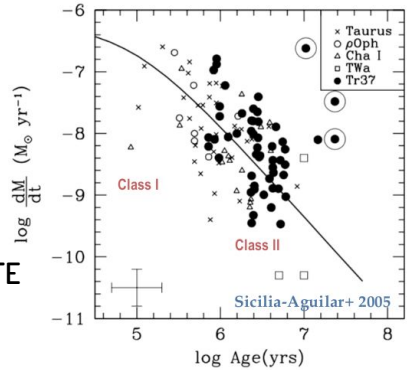
From Testi+2014

Midplane

gas+large particles

① **HIGH ACCRETION RATE**

using UV excess



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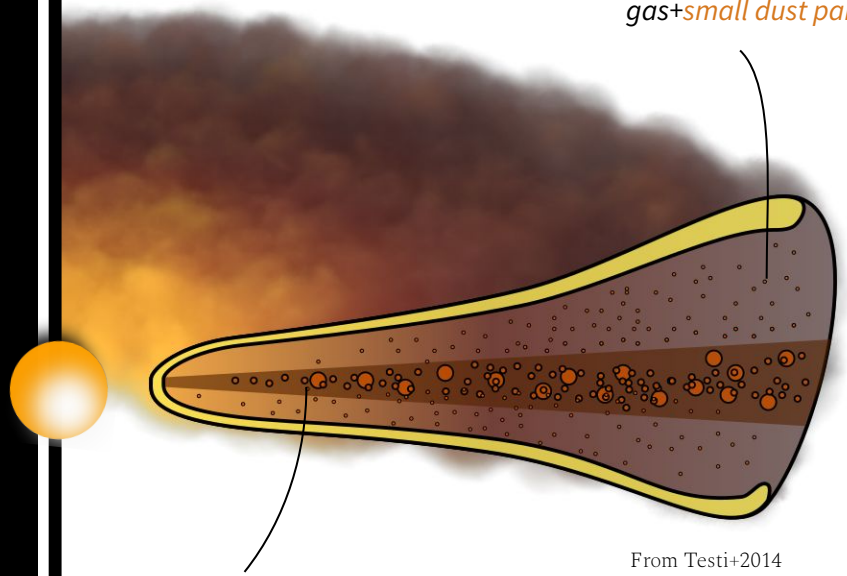

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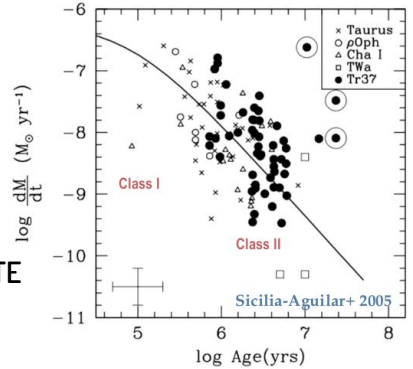
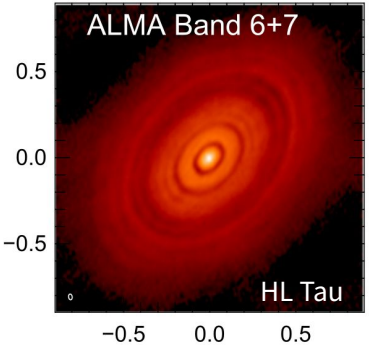


② THIN SUBSTRUCTURES

low turbulence in midplane

Pinte+2016, Villenave+2020



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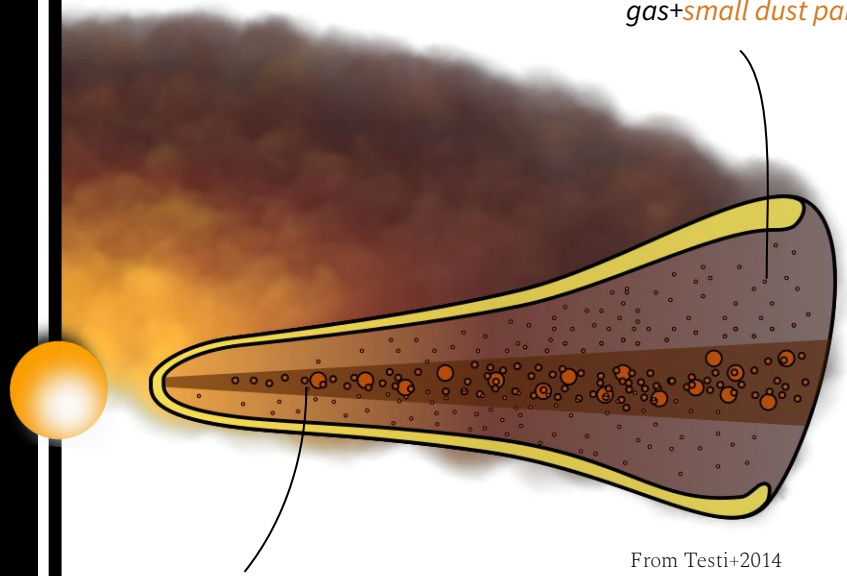

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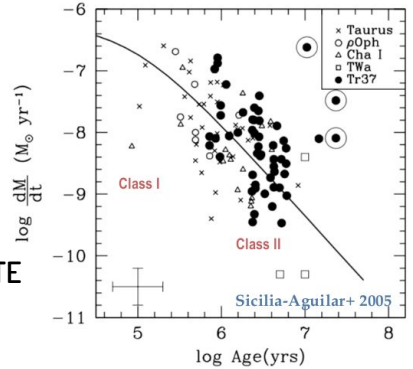

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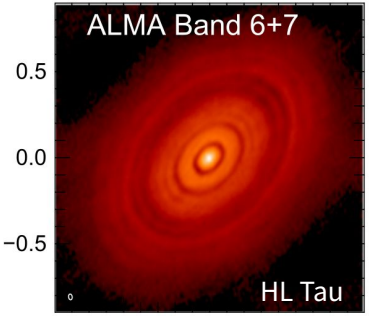
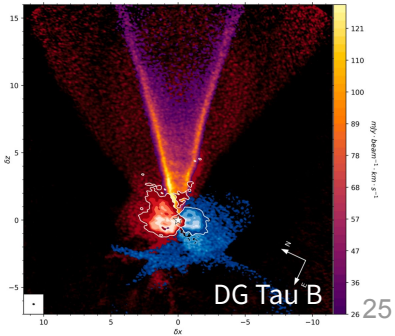


③ DETECTION OF WINDS
^{12}CO emission, de Valon+2020



CONTEXT

Processes of accretion in disks

$$-R\left[\frac{B_z B_\phi}{4\pi}\right]_{-z_S}^{z_S}$$

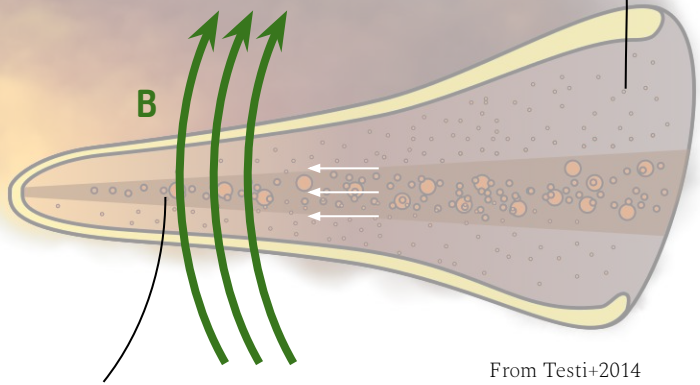
Upper layers

gas+small dust particles

VERTICAL (WIND) STRESS

LAMINAR RADIAL TRANSPORT

B



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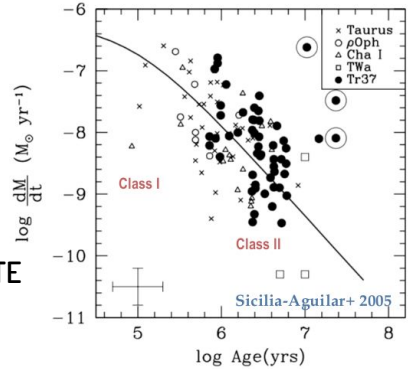

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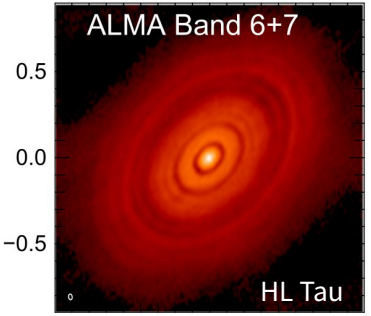

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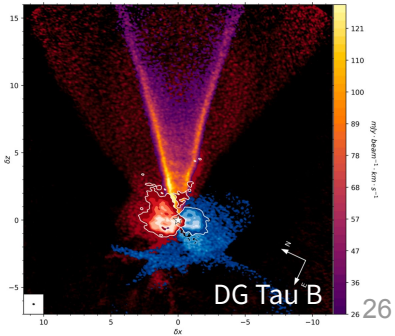

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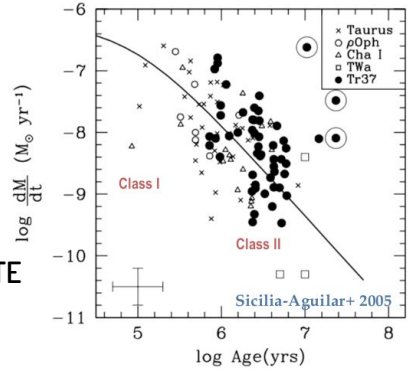

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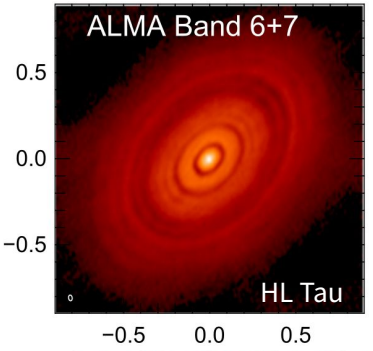

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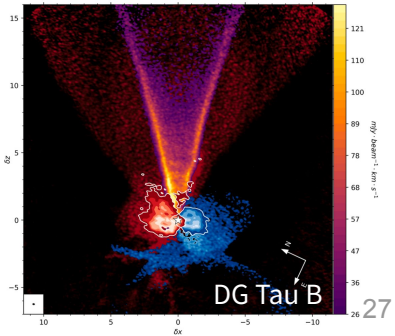


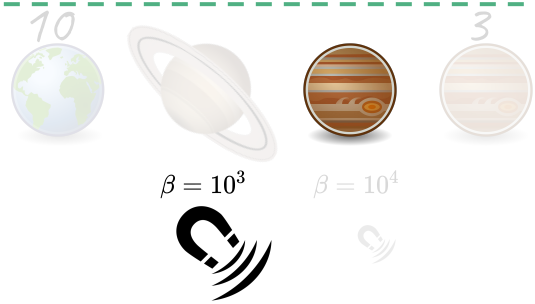
CODES & MODELS

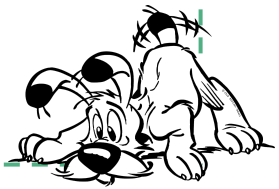
Idefix: Planet+Disk+Wind

Wafflard-Fernandez+Lesur+2025

SETUP JEAN ZAY

- ✓ GPU code Idefix Lesur+2023
- ✓ **3D** non-ideal **MHD**
- ✓ Disk thickness H/r = 0.05
- ✓ Prescribed ambipolar diffusion





A&A, 696, A8 (2025)
https://doi.org/10.1051/0004-6361/202453541

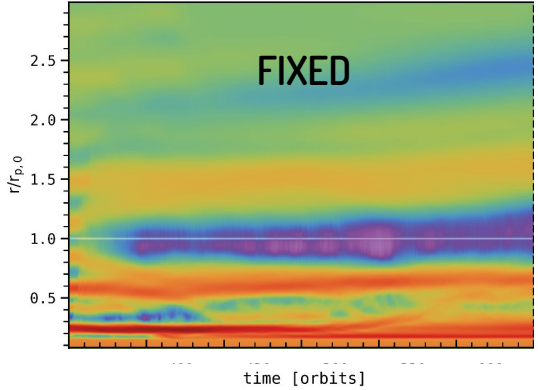
Astronomy & Astrophysics

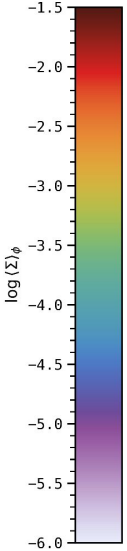
Gone with the wind: the outward migration of eccentric giant planets in windy disks

Gaylor Wafflard-Fernandez* and Geoffroy Lesur

PLANET-DISK-WIND

Gap opening





PLANET-DISK-WIND

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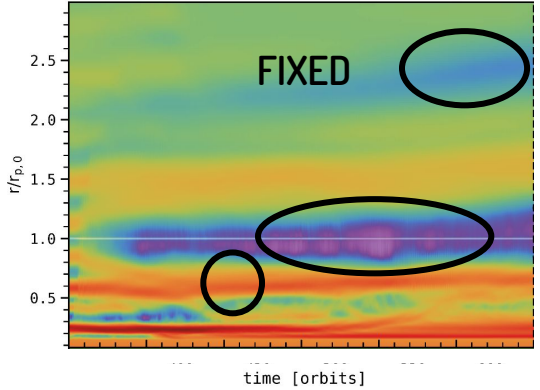
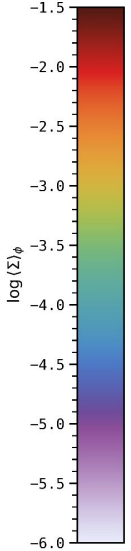


RADIAL STRUCTURES

- → planet-induced gaps
- → planet-free gaps
- → density rings

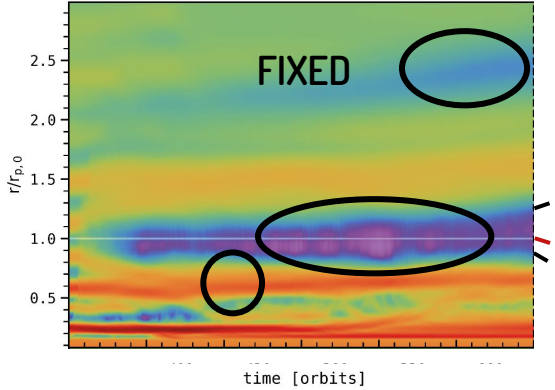


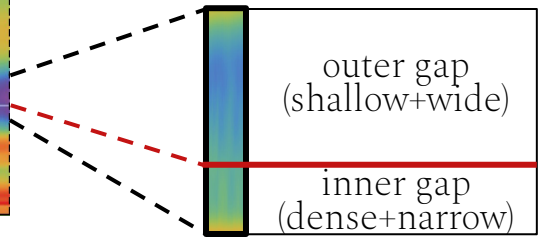
PLANET-DISK-WIND

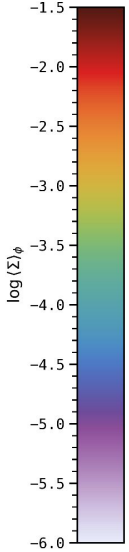
Gap opening

RADIAL STRUCTURES

- → planet-induced gaps
- → planet-free gaps
- → density rings

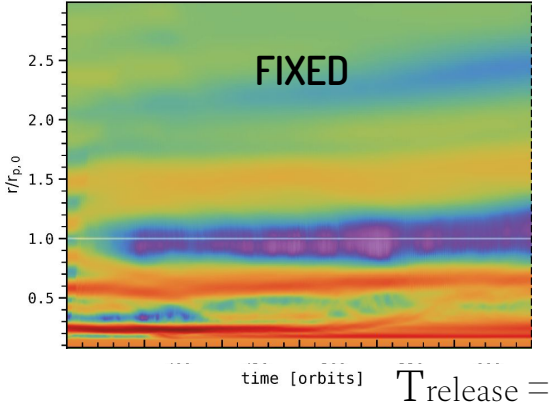






PLANET-DISK-WIND

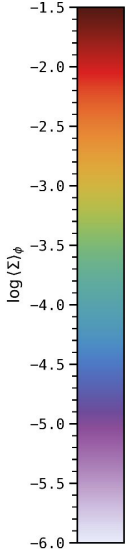
Gap opening



$T_{release} = 300$

RADIAL STRUCTURES

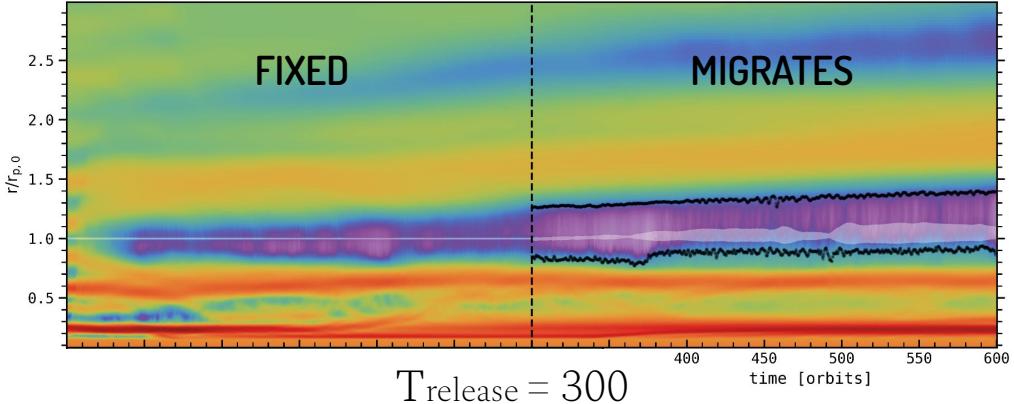
- → planet-induced gaps
- → planet-free gaps
- → density rings



PLANET-DISK-WIND

Gap opening

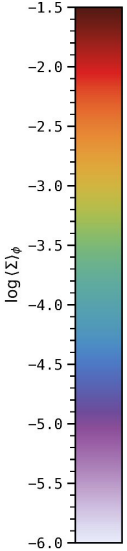
M300



Trelease = 300

RADIAL STRUCTURES

- → planet-induced gaps
- → planet-free gaps
- → density rings



PLANET-DISK-WIND

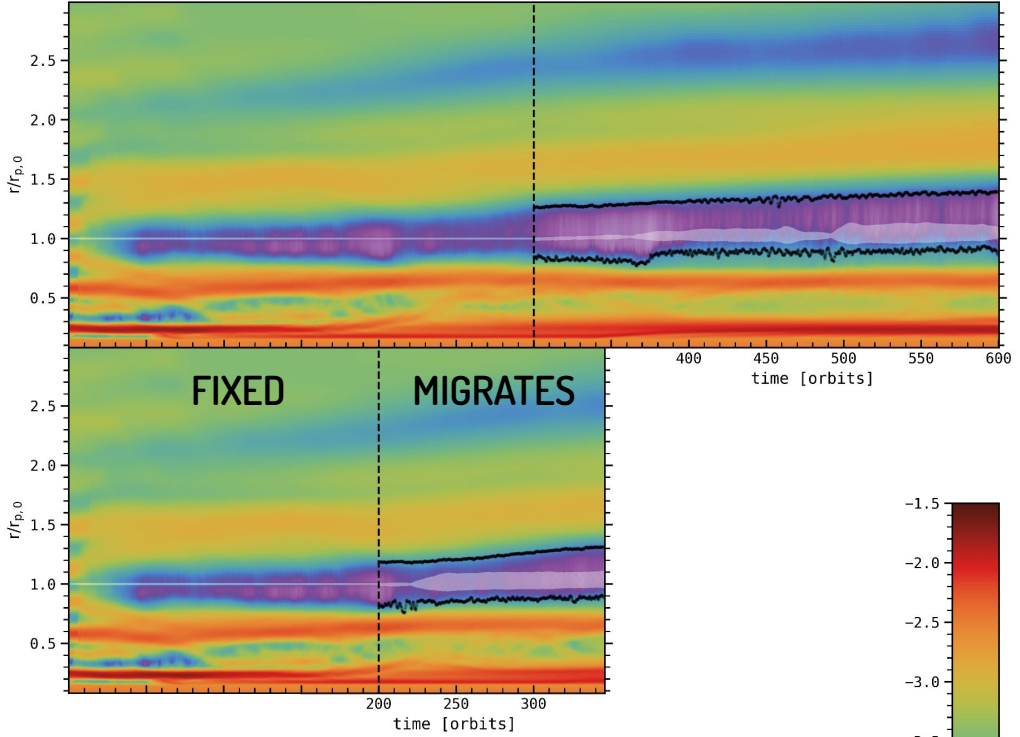
Gap opening

RADIAL STRUCTURES

- → planet-induced gaps
- → planet-free gaps
- → density rings

M300

M200

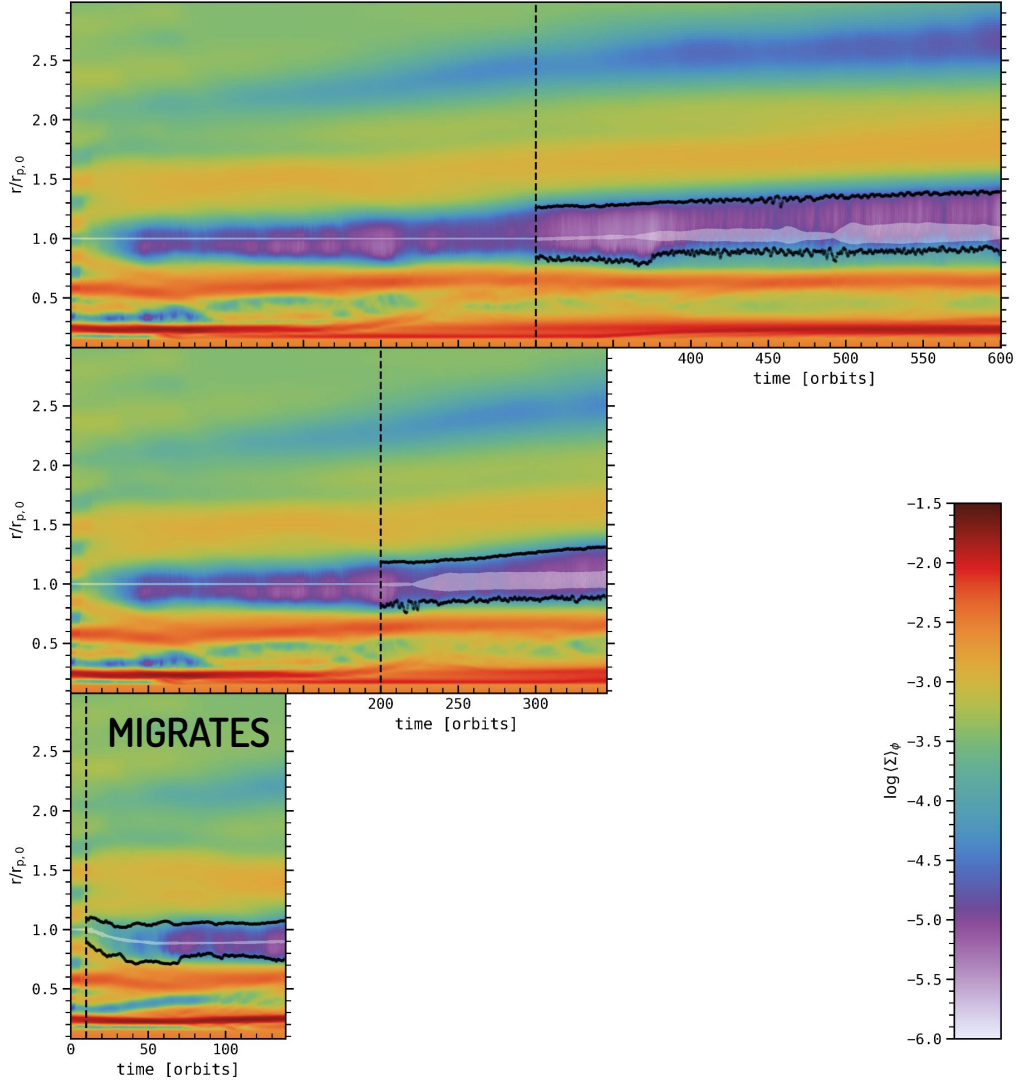


PLANET-DISK-WIND

Gap opening

RADIAL STRUCTURES

- → planet-induced gaps
- → planet-free gaps
- → density rings



PLANET-DISK-WIND

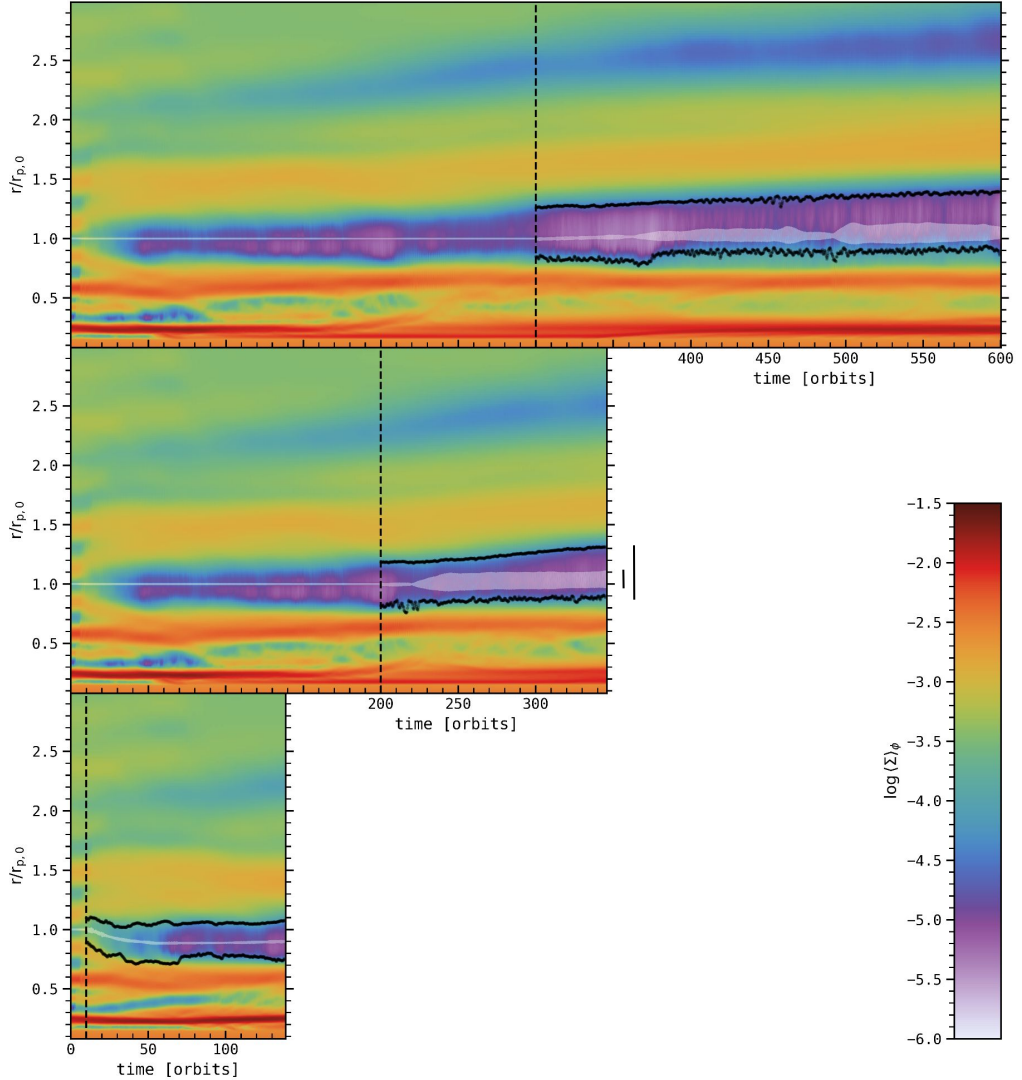
Gap opening

RADIAL STRUCTURES

- → planet-induced gaps
- → planet-free gaps
- → density rings

PLANET

- → gap variability (accretion)
- → outer gap's outward drift
- → if gap: no visible migration
- → oscillation in the gap



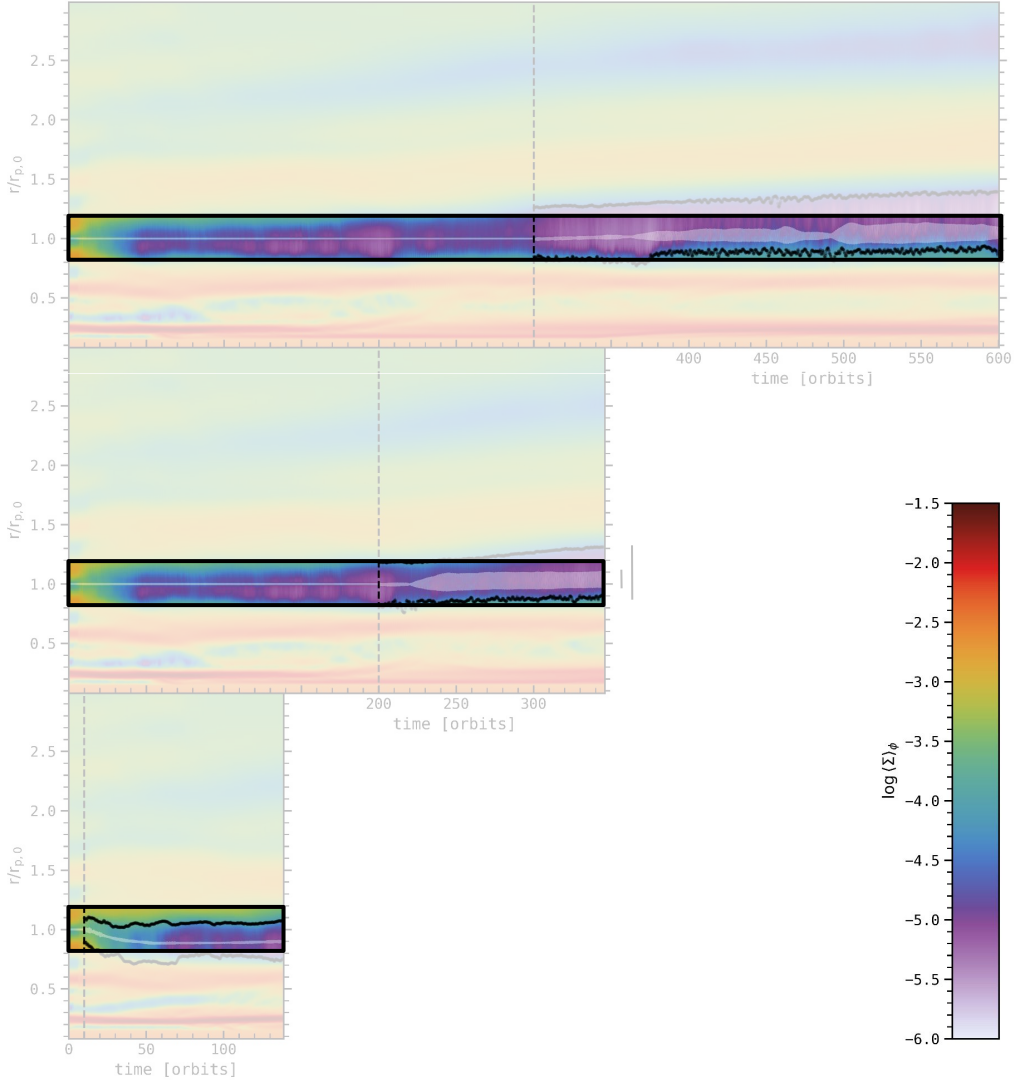
PLANET-DISK-WIND

Gap opening

M300

M200

M10



RADIAL STRUCTURES

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PLANET

- → gap variability (accretion)
- → outer gap's outward drift
- → if gap: no visible migration
- → oscillation in the gap

PLANET-DISK-WIND

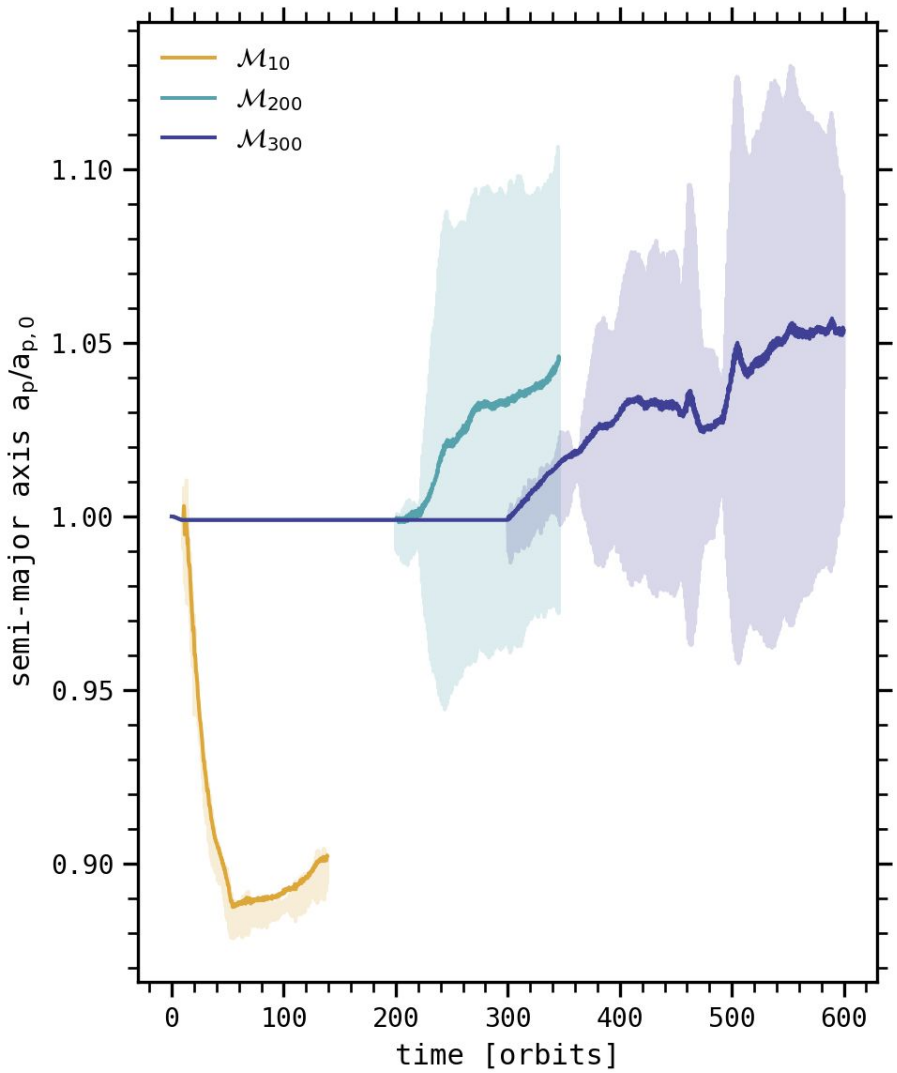
Migration: outward

GAP IS FORMED

→ slow outward migration
(few 10s of au.Myr^{-1} @ 10 au)

GAP IS NOT FORMED

→ phase 1: fast inward migration
(few 100s of au.Myr^{-1} @ 10 au)
→ migration reversal
→ phase 2: slow outward migration
(few 10s of au.Myr^{-1} @ 10 au)



PLANET-DISK-WIND

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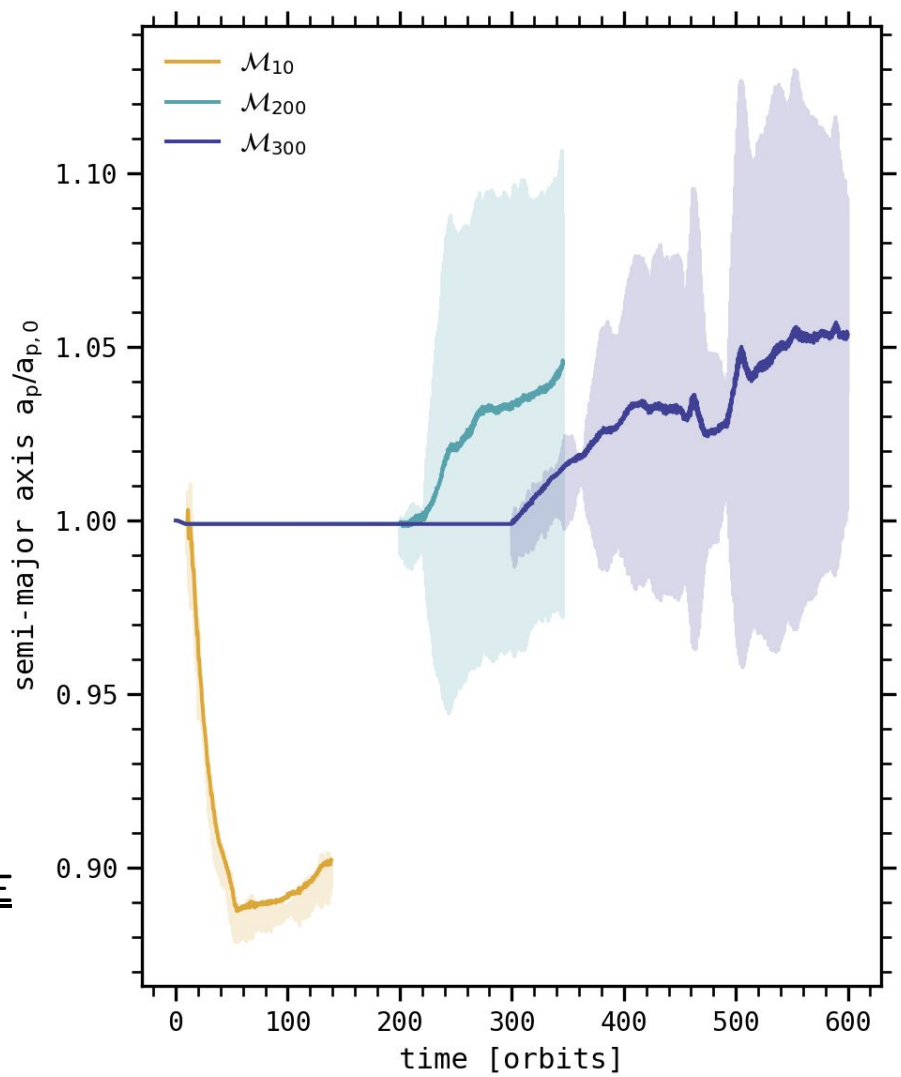
→ phase 1: fast inward migration
(few 100s of au.Myr^{-1} @ 10 au)
→ migration reversal
→ phase 2: slow outward migration
(few 10s of au.Myr^{-1} @ 10 au)

→ **GAP ASYMMETRY / INNER LINDBLAD TORQUE**



PLANET-DISK-WIND

Migration: eccentric

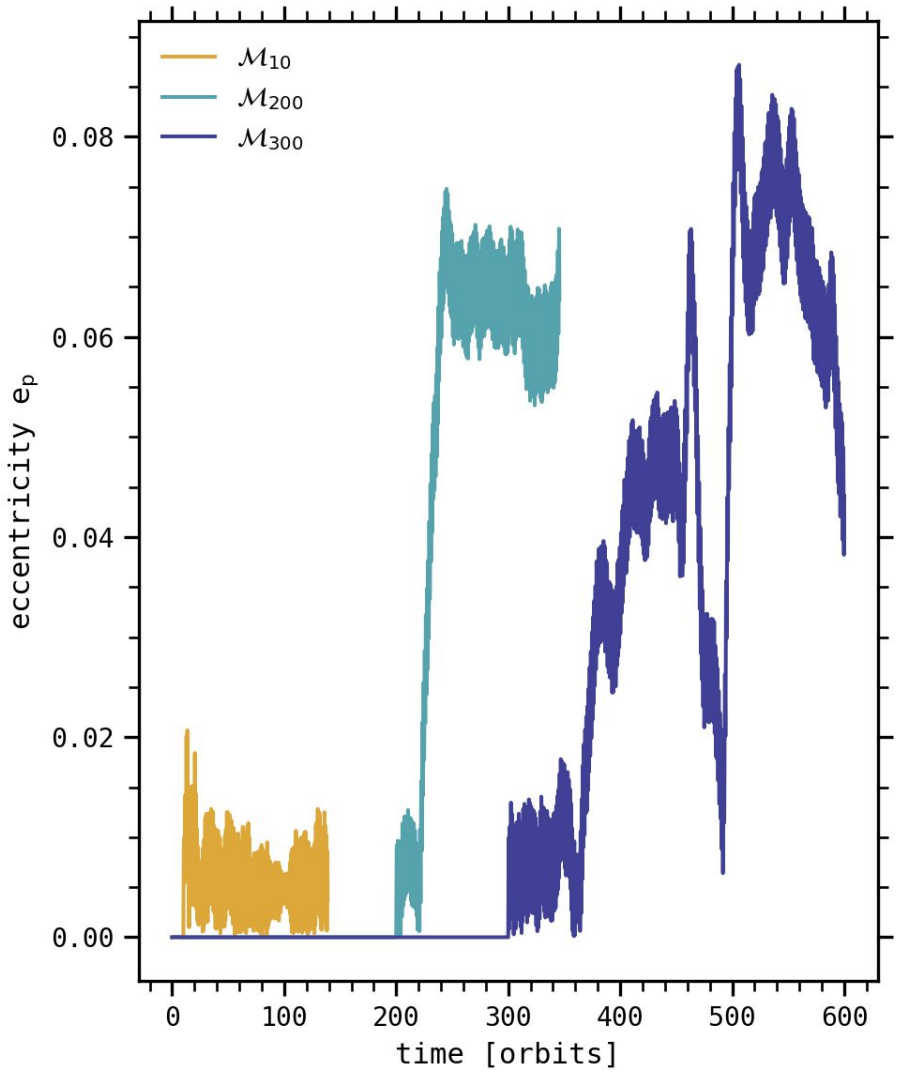
GAP IS FORMED

→ phase 1: low e_p ($\lesssim$1.5%)

→ phase 2: abrupt increase of e_p (6-8%)

GAP IS NOT FORMED

→ quasi-circular orbit



PLANET-DISK-WIND

Migration: eccentric

GAP IS FORMED

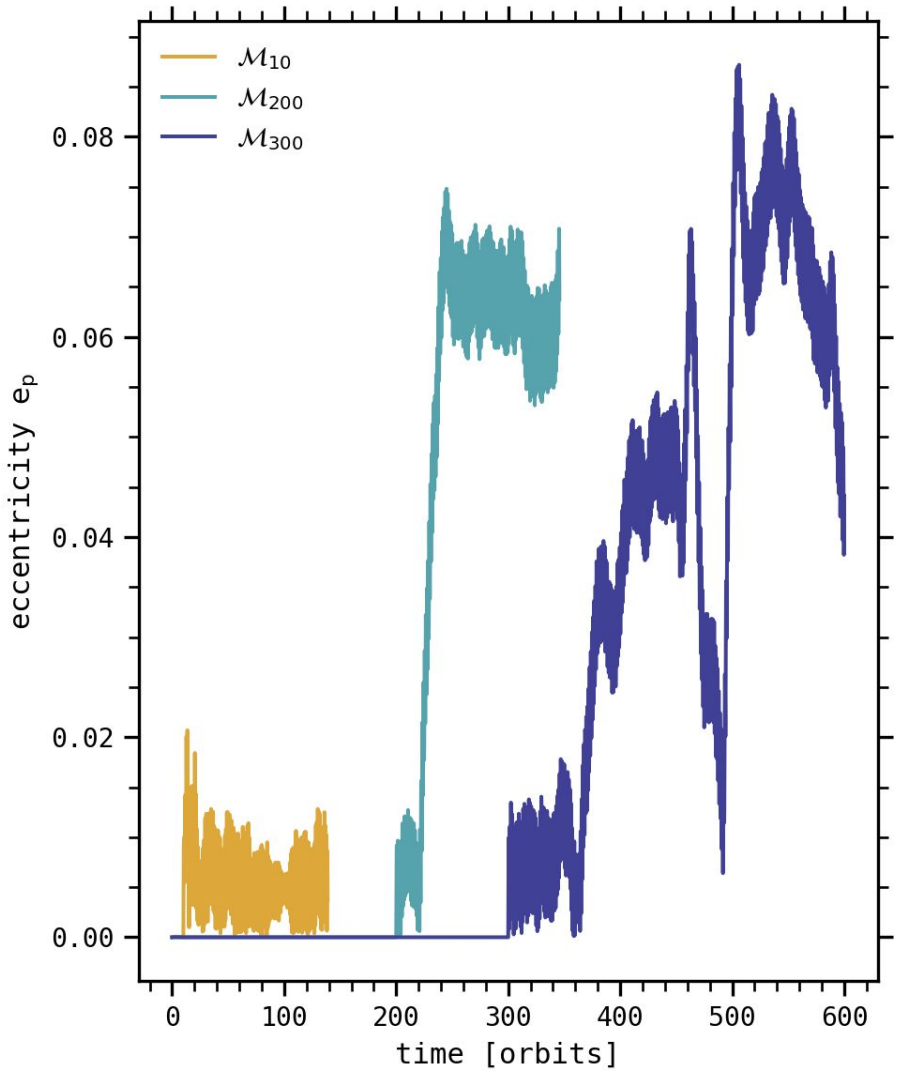
→ phase 1: low e_p ($\lesssim$1.5%)

→ phase 2: abrupt increase of e_p (6-8%)

GAP IS NOT FORMED

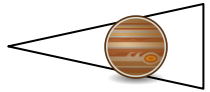
→ quasi-circular orbit

→ **FINITE-AMPLITUDE INSTABILITY**



PLANET-DISK-WIND

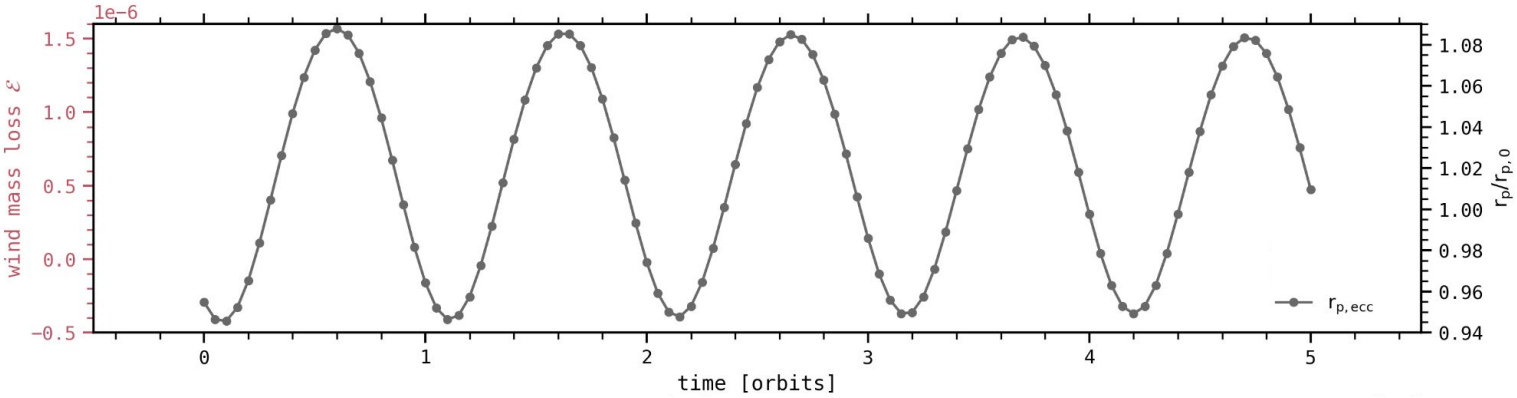
Eccentricity-driven ejection modulation



PLANET-DISK-WIND

Eccentricity-driven ejection modulation

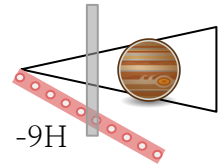
epicyclic frequency κ (= $\Omega\kappa$)

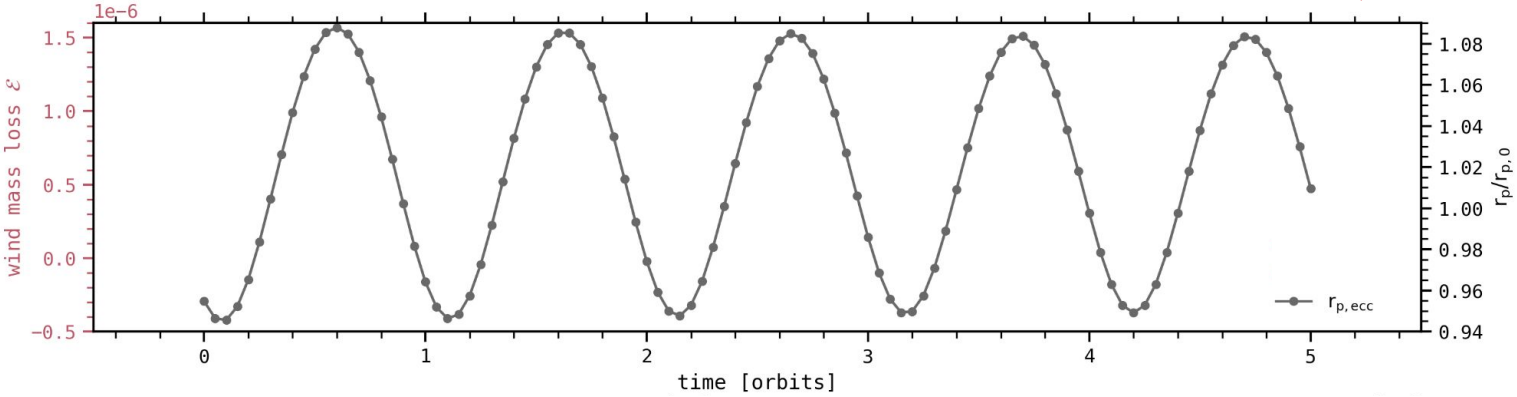


PLANET-DISK-WIND

Eccentricity-driven ejection modulation

epicyclic frequency κ (= Ω_K)

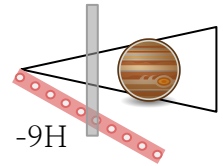


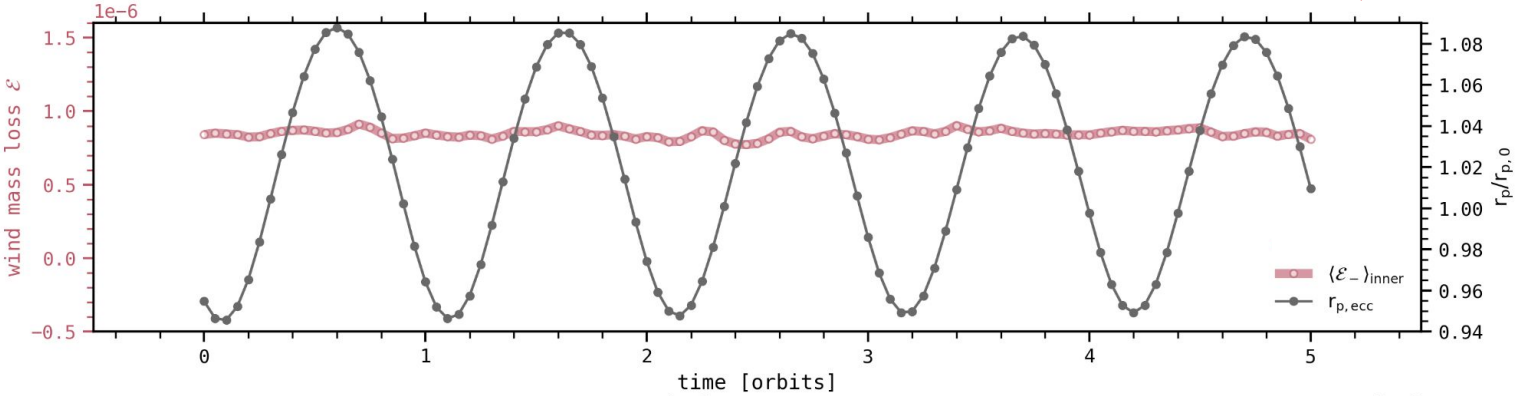


PLANET-DISK-WIND

Eccentricity-driven ejection modulation

epicyclic frequency κ (= Ω_K)

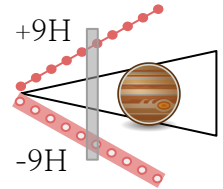


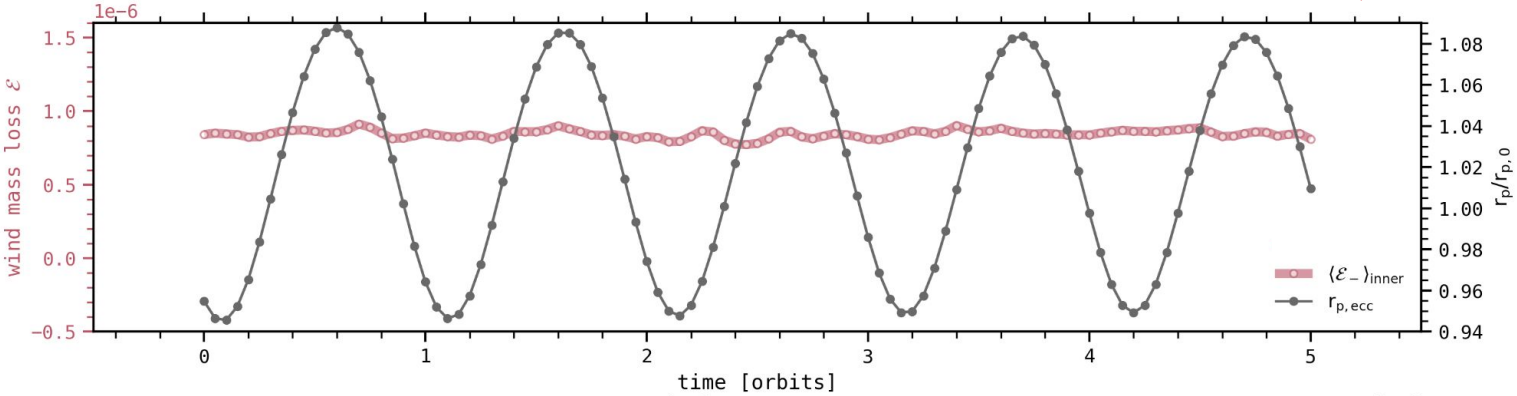


PLANET-DISK-WIND

Eccentricity-driven ejection modulation

epicyclic frequency κ (= Ω_K)

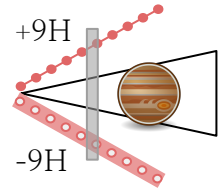


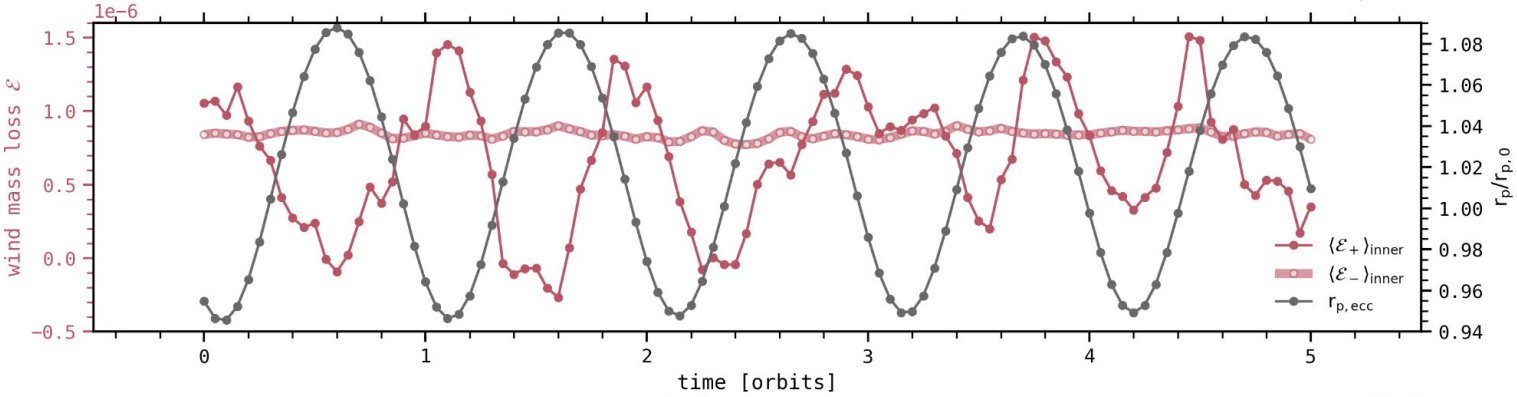


PLANET-DISK-WIND

Eccentricity-driven ejection modulation

epicyclic frequency κ (= $\Omega\kappa$)

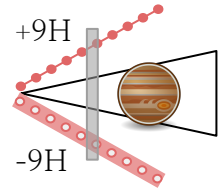


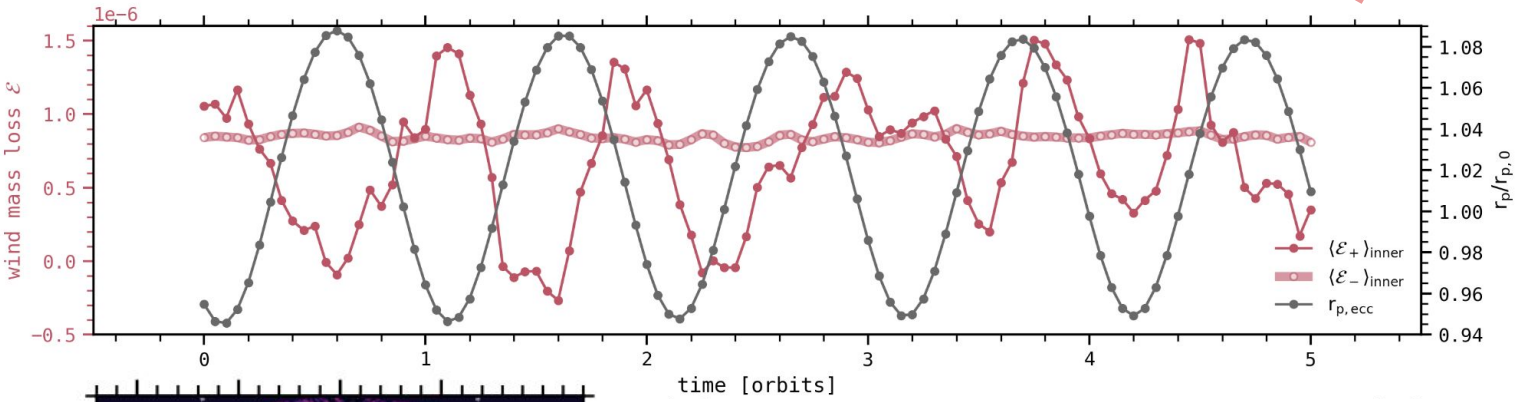


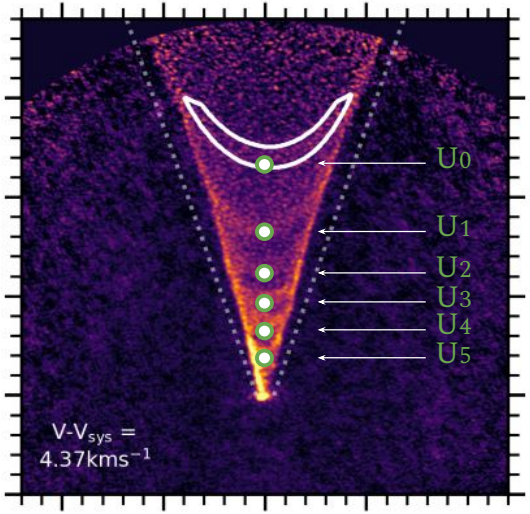
PLANET-DISK-WIND

Eccentricity-driven ejection modulation

epicyclic frequency κ (= Ω_K)







Structured wind in DG Tau B

de Valon+2020, de Valon+2022

TAKE-AWAY MESSAGES
(PLANET-DISK-WIND)

PLANET GAP

ASYMMETRIC

PLANET MIGRATION

SLOW | OUTWARD | ECCENTRIC

DISK RESPONSE

EJECTION MODULATIONS

TAKE-AWAY MESSAGES
(PLANET-DISK-WIND)

PLANET GAP

ASYMMETRIC | SONIC ACCRETION | MAGNETIC TRAP

PLANET MIGRATION

SLOW | OUTWARD | ECCENTRIC | UNSTEADY

DISK RESPONSE

ACCRETION | EJECTION MODULATIONS