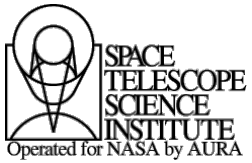
3D Global Models of Streaming Instability

Wladimir Lyra

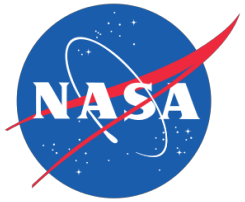
California State University

Jet Propulsion Laboratory

Funding



HST Cycle 24



Exoplanet Research Program XRP - 2016, 2018

NRAO 2017

Computational Facilities

Frejus, Mar 18th, 2019

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Funding Acknowledgement

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ROYAL ASTRONOMICAL SOCIETY

MNRAS **434,** 1460–1468 (2013) doi:10.1093/mnras/stt1104
Advance Access publication 2013 July 11

Streaming instability in the quasi-global protoplanetary discs

K. Kowalik,[1⋆] M. Hanasz,[1⋆] D. Wóltański[1] and A. Gawryszczak[2]

[1]*Centre for Astronomy, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Grudziadzka 5, PL-87-100 Toruń, Poland*
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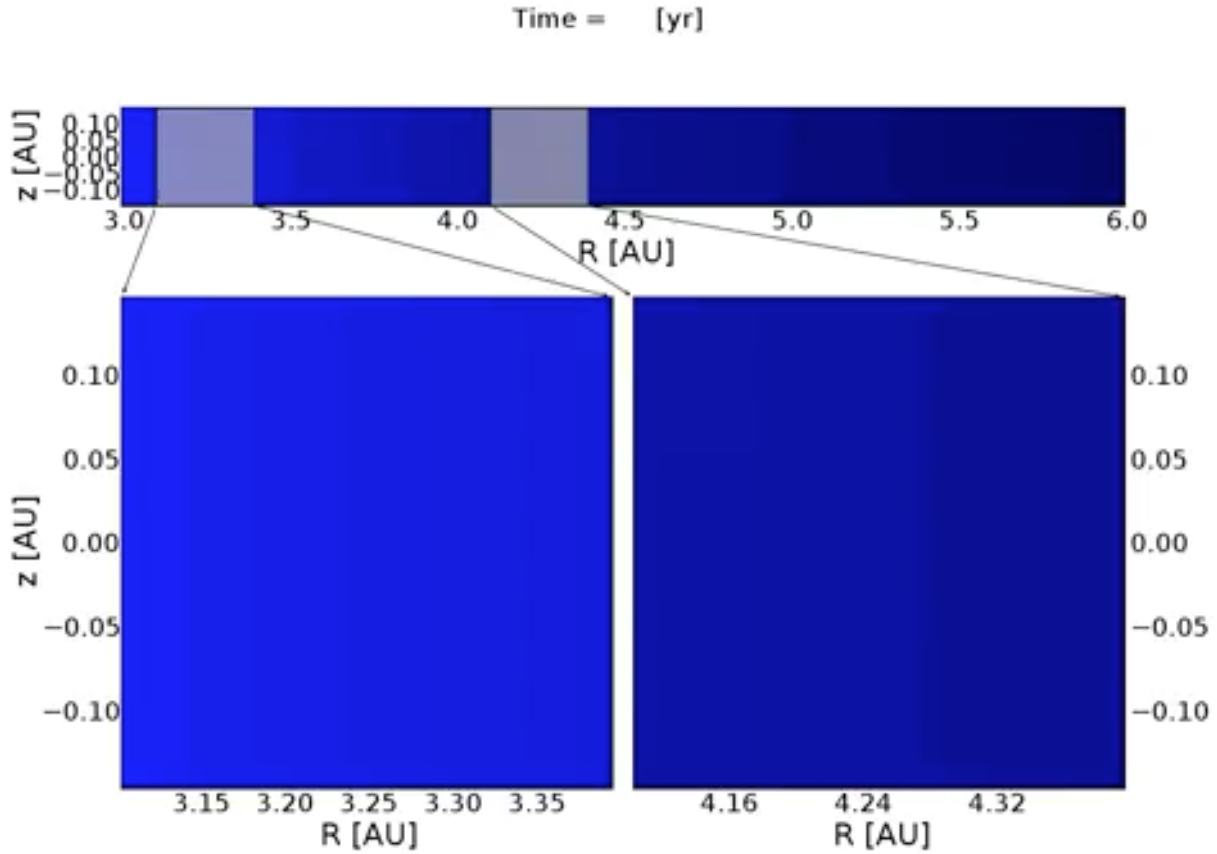
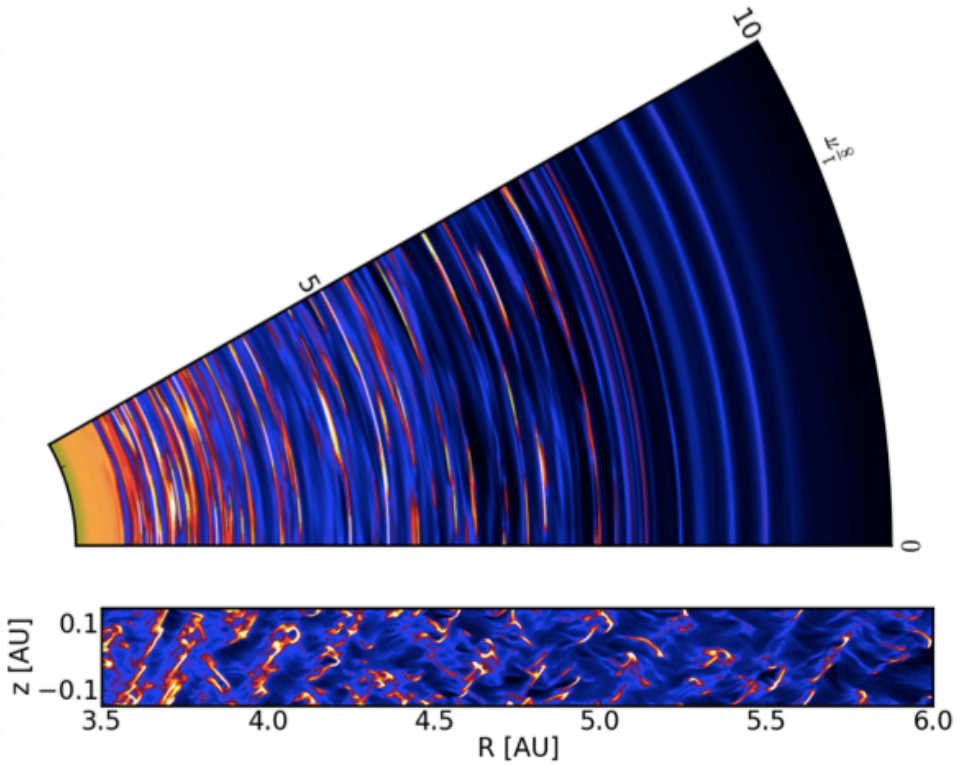
Accepted 2013 June 17. Received 2013 June 13; in original form 2013 May 15





Kowalik et al. (2013)

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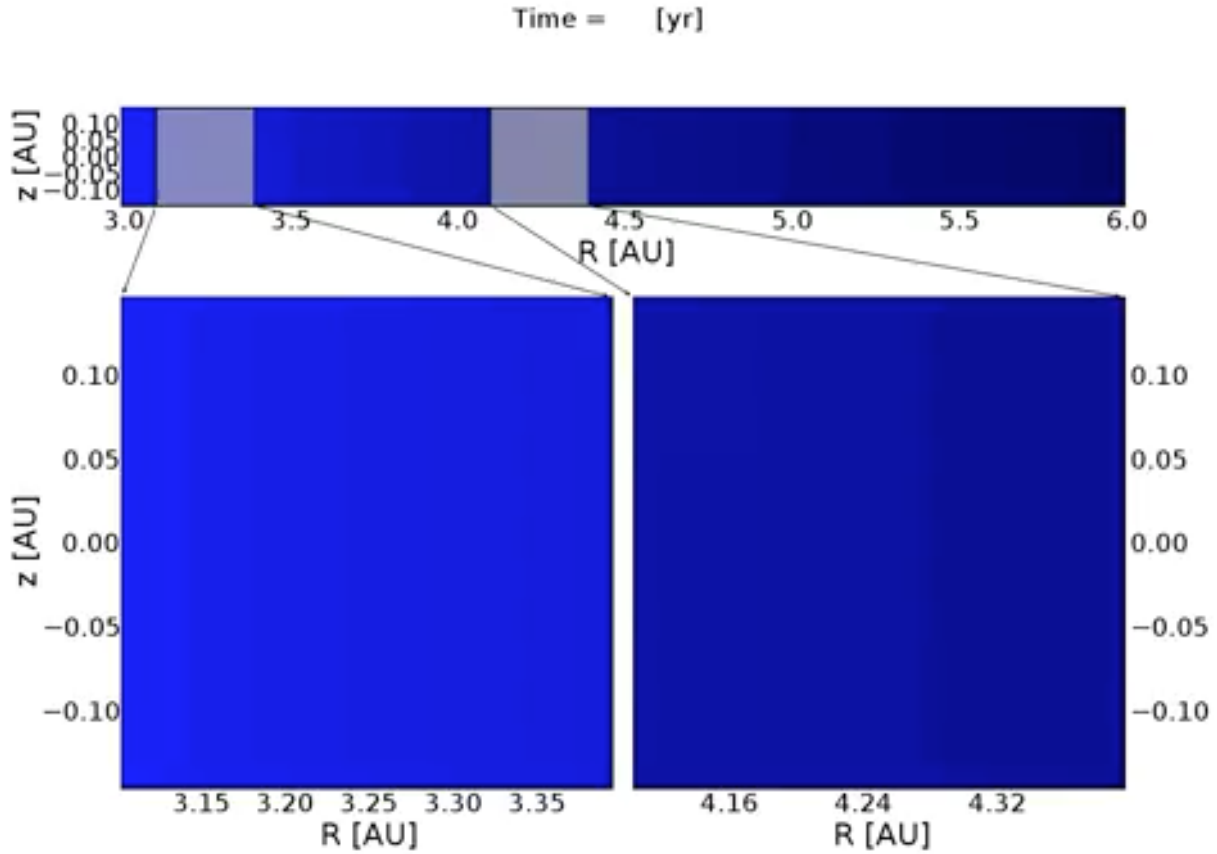
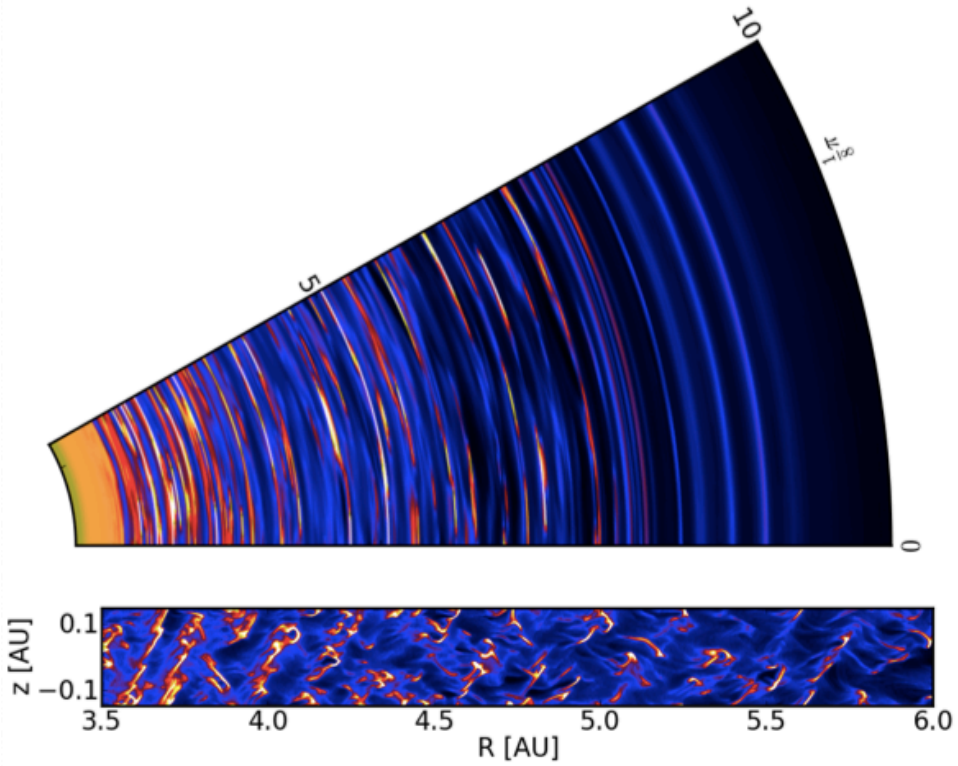
Missing

- Radial variation of clumps' IMF?
- Dominant azimuthal mode?
- Lagrangian particles
- Selfgravity





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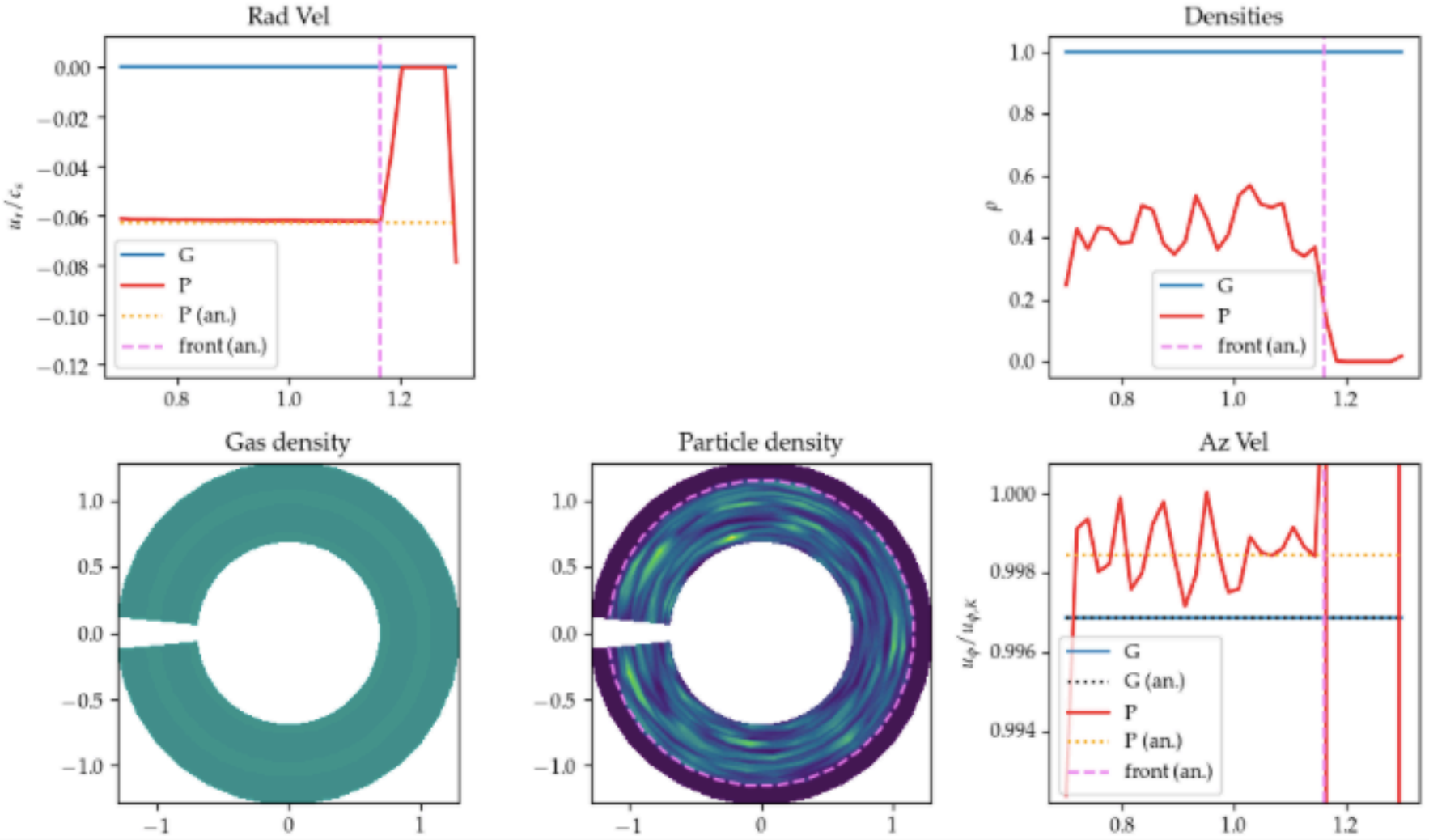
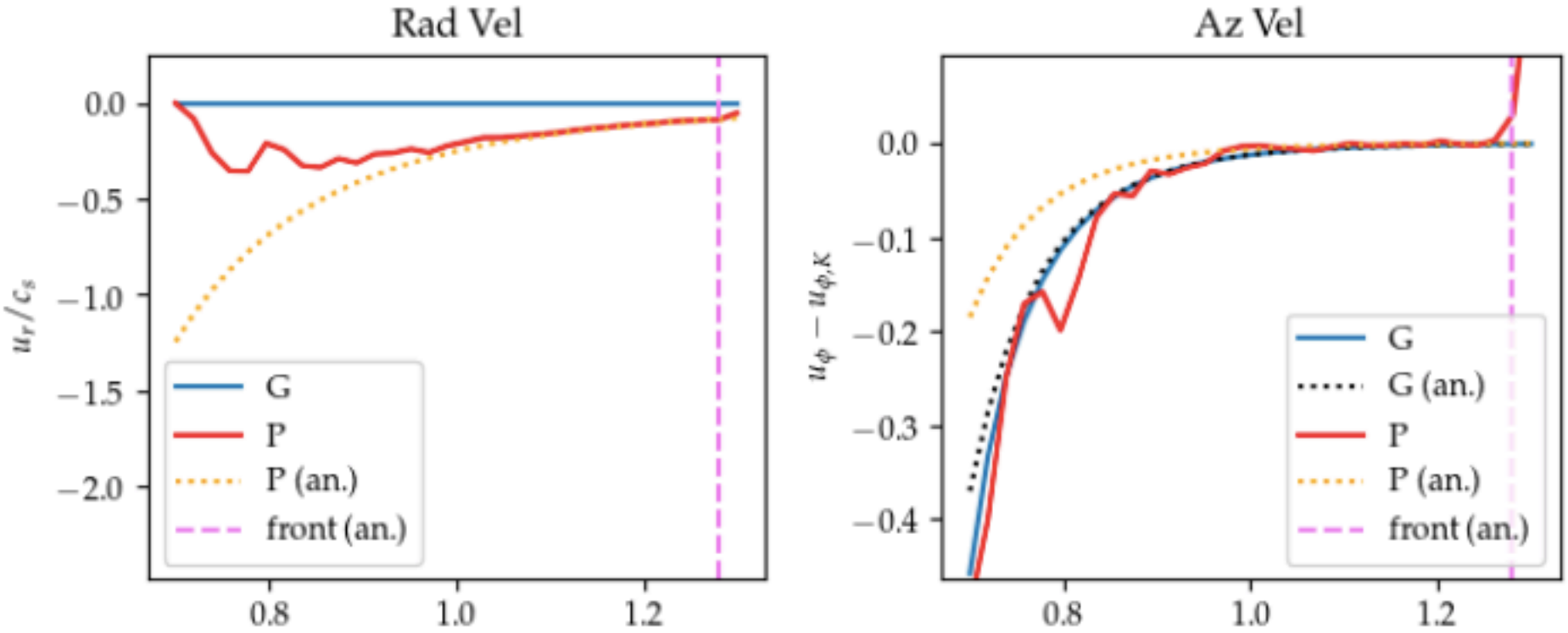


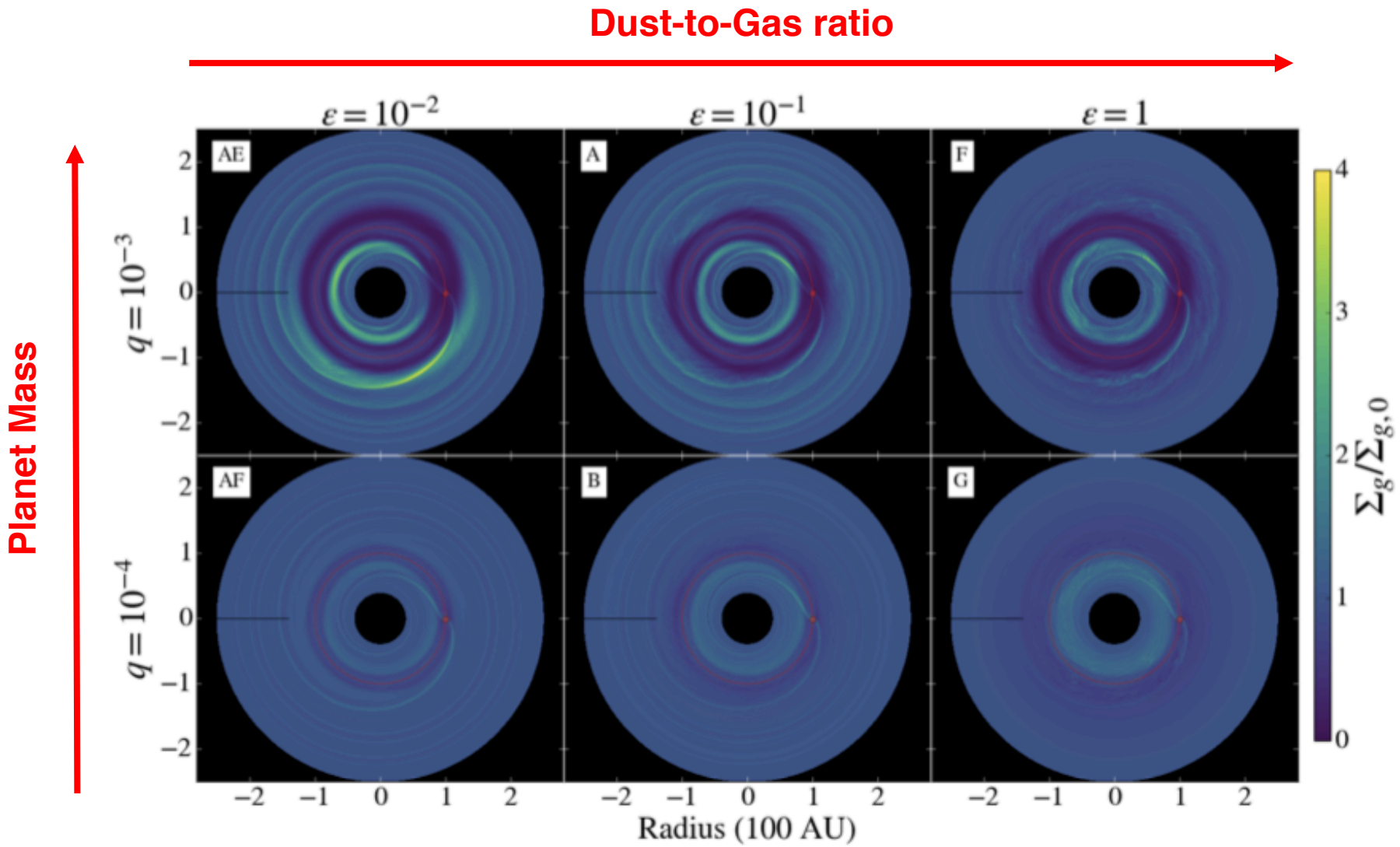
Analytical solution Youdin (2010)

Breakdown



Deviations from analytical solution for u/c ~ 0.5.

Global Models of Streaming

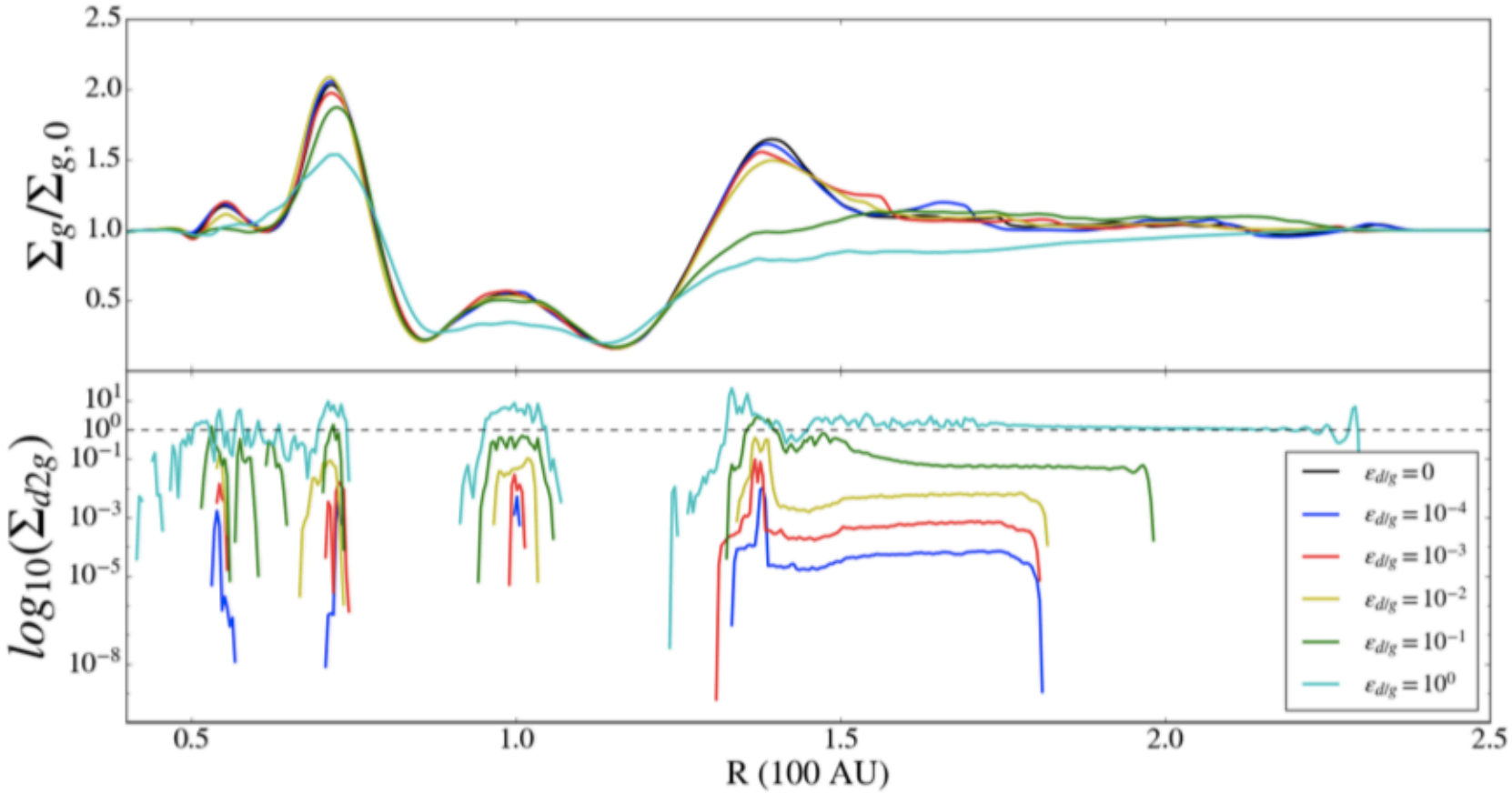


Influence on Gap Carving

Jupiter-mass planet

Gas

Pebbles



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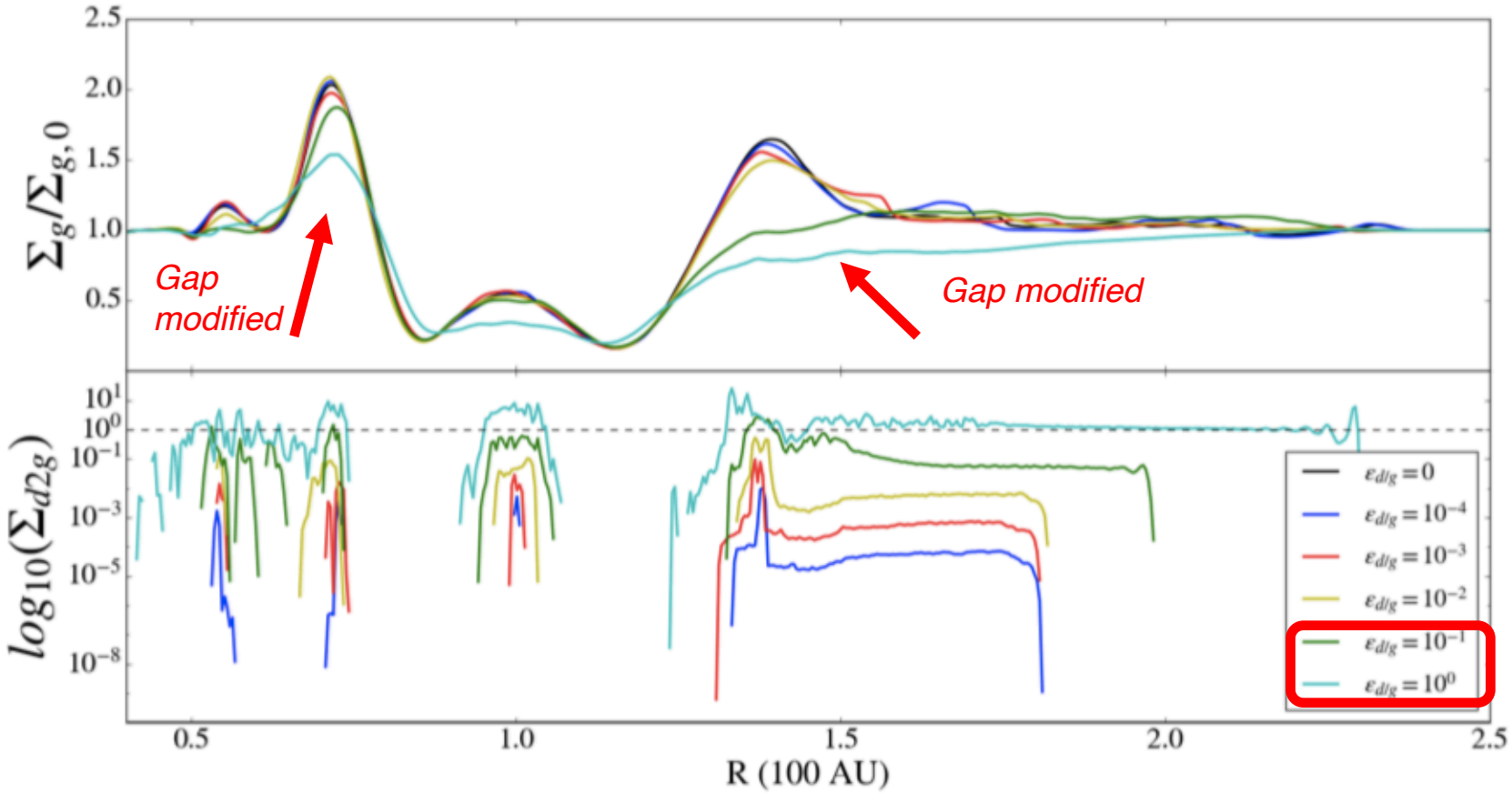

- Gap modified at high dust-to-gas ratio.

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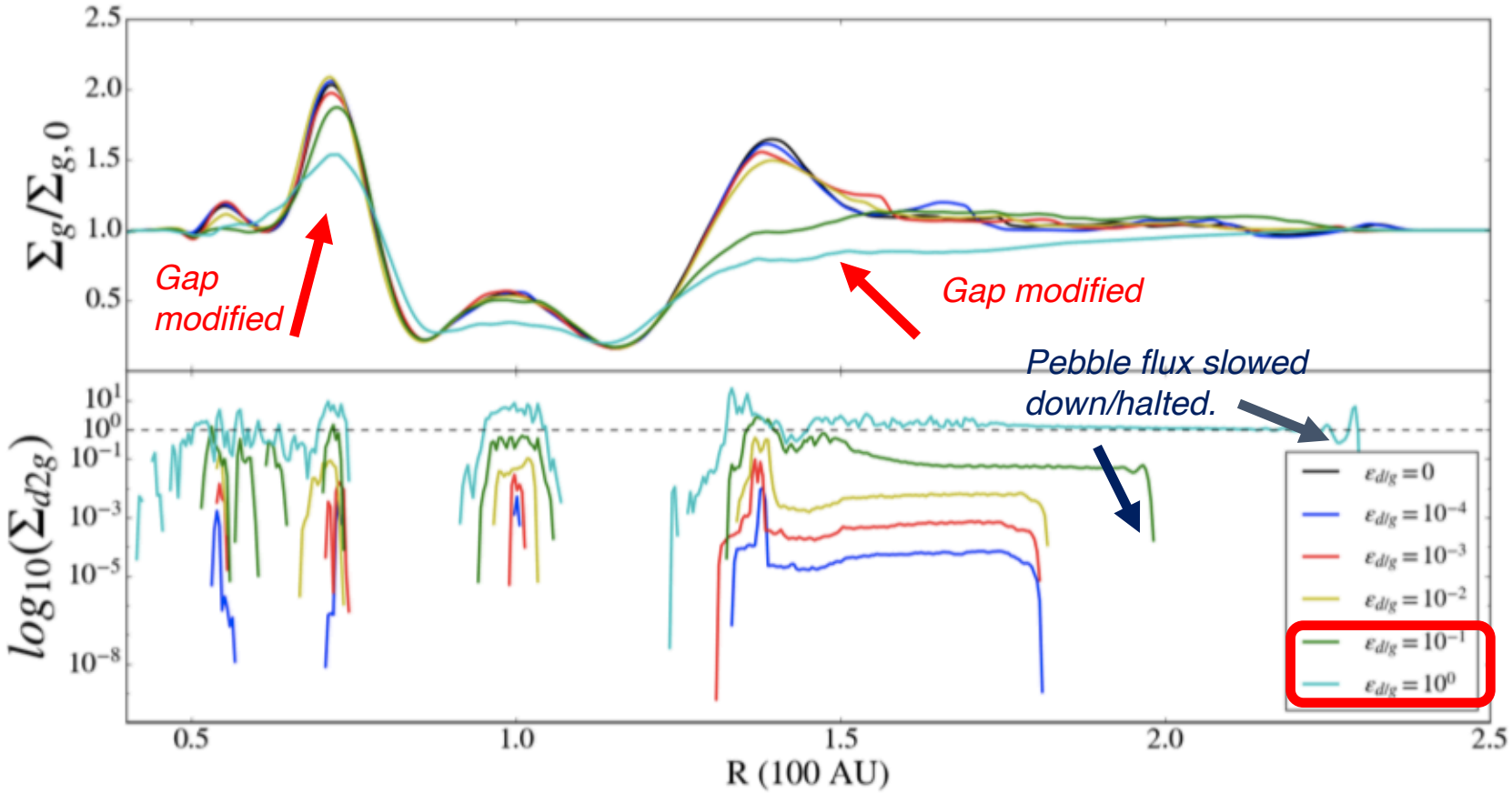
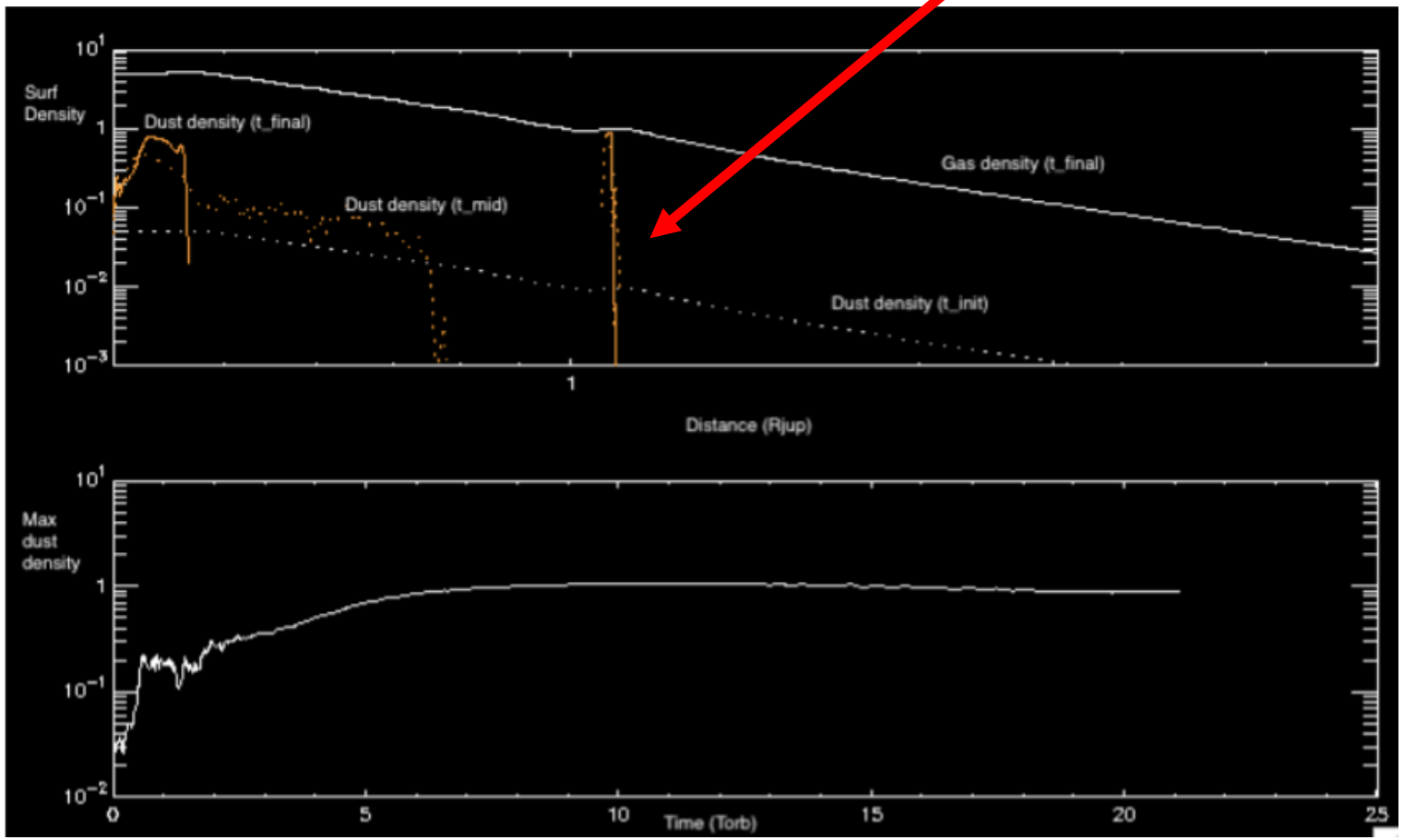


- Gap modified at high dust-to-gas ratio.
- Pebble drift slows down at high dust-to-gas ratio and halted at $\varepsilon=1$

Halting the drift

Localized ε=1 pressure-bump survives during whole simulation



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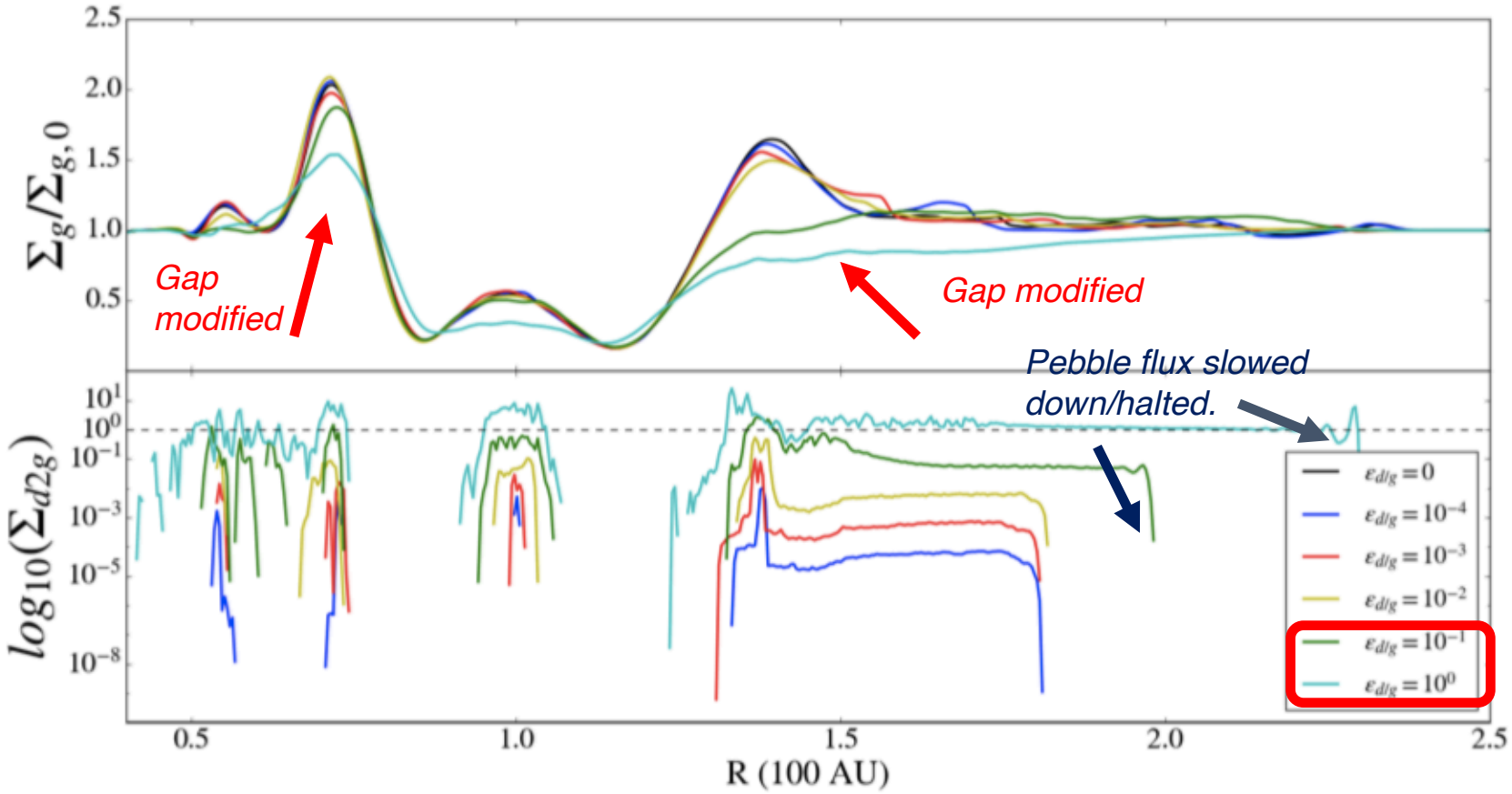

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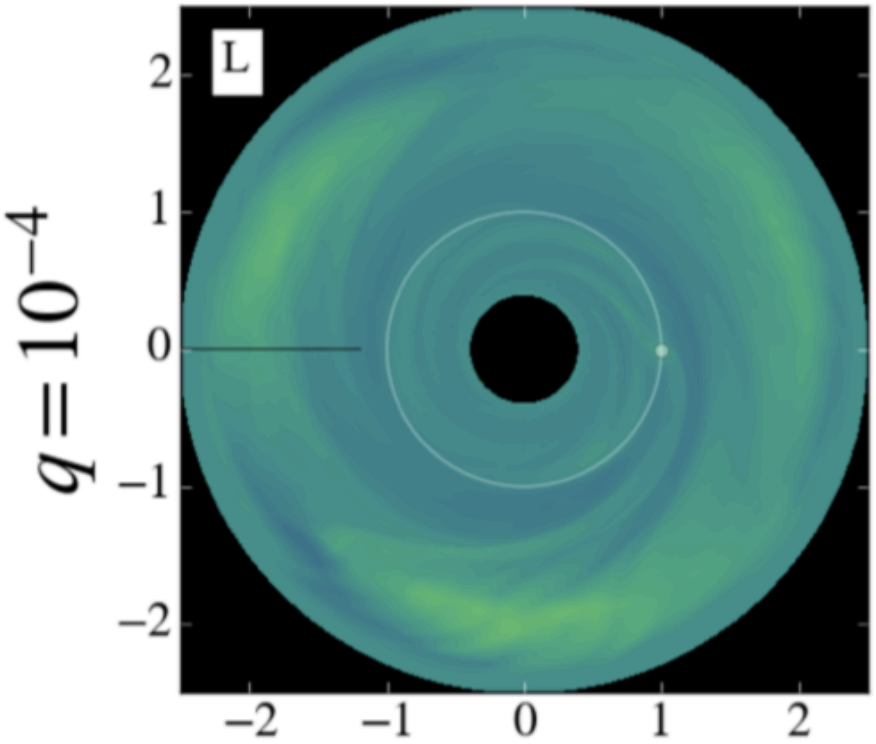
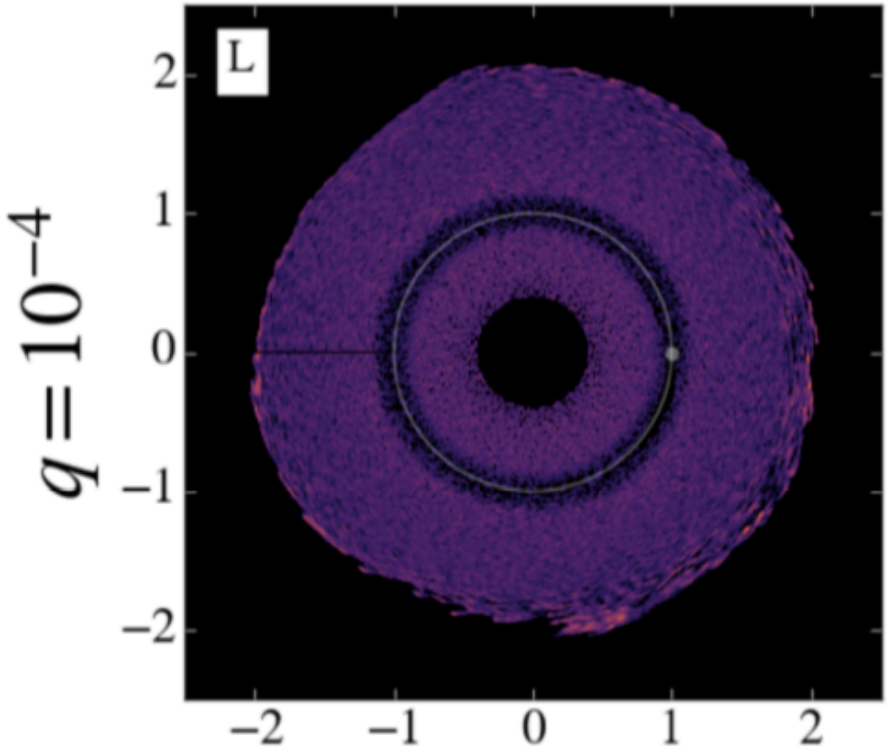
Vortices

Gas



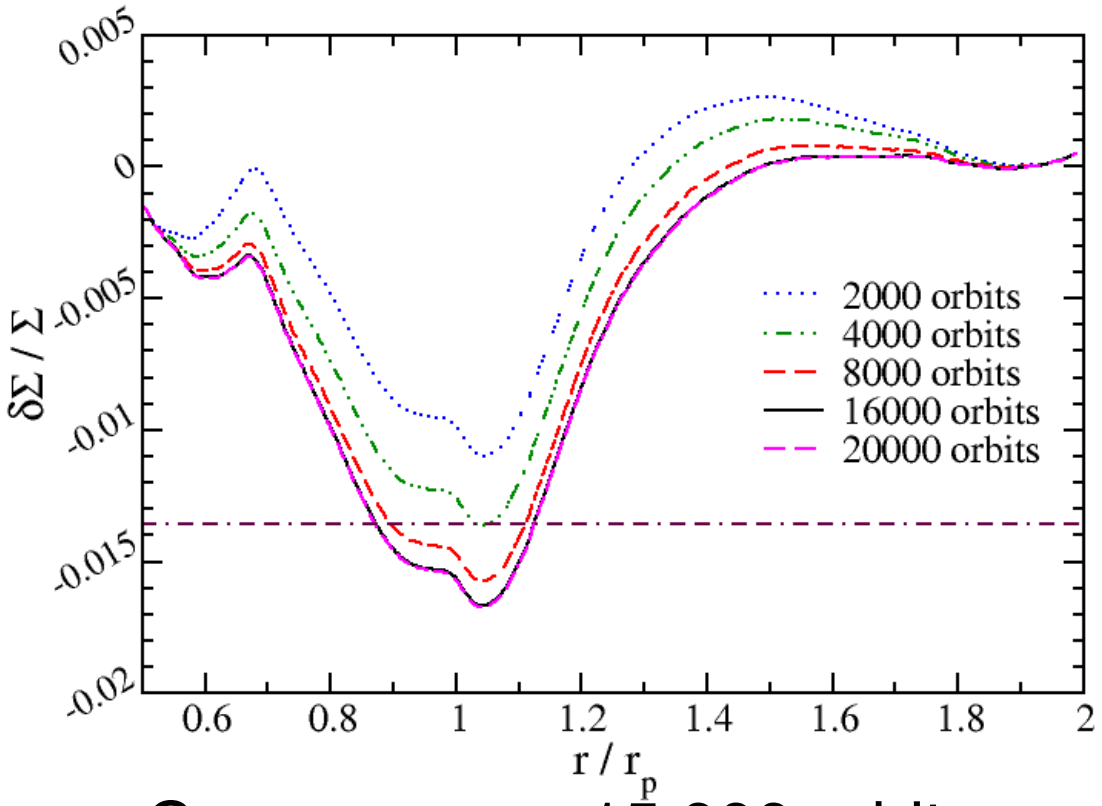
Pebbles



Rossby wave instability at the dust front !

Caveat: Convergence.

10 Earth masses; $\alpha=10^{-3}$



Convergence: 15,000 orbits

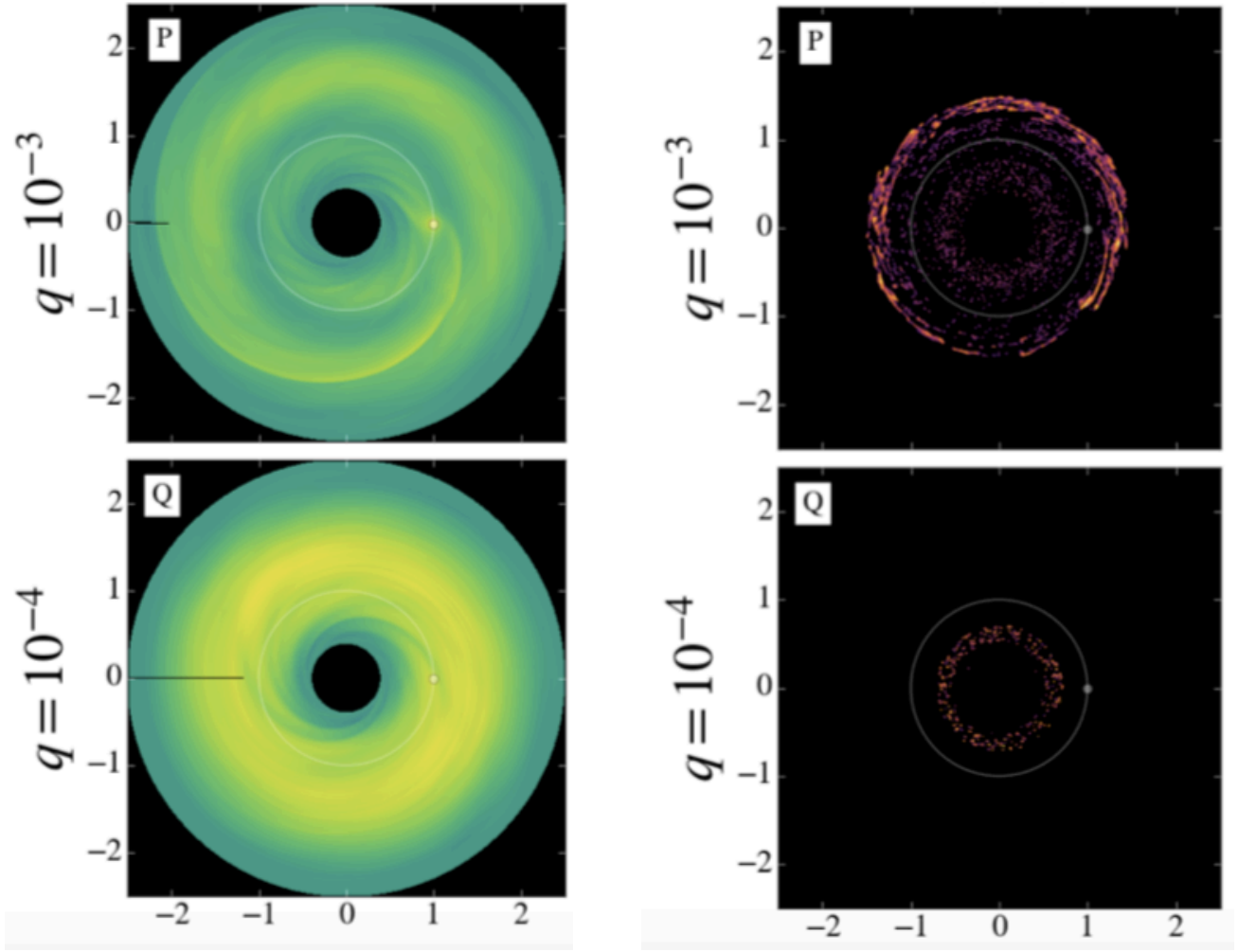
Figure by Jeff Fung

Not all planets are dust dams

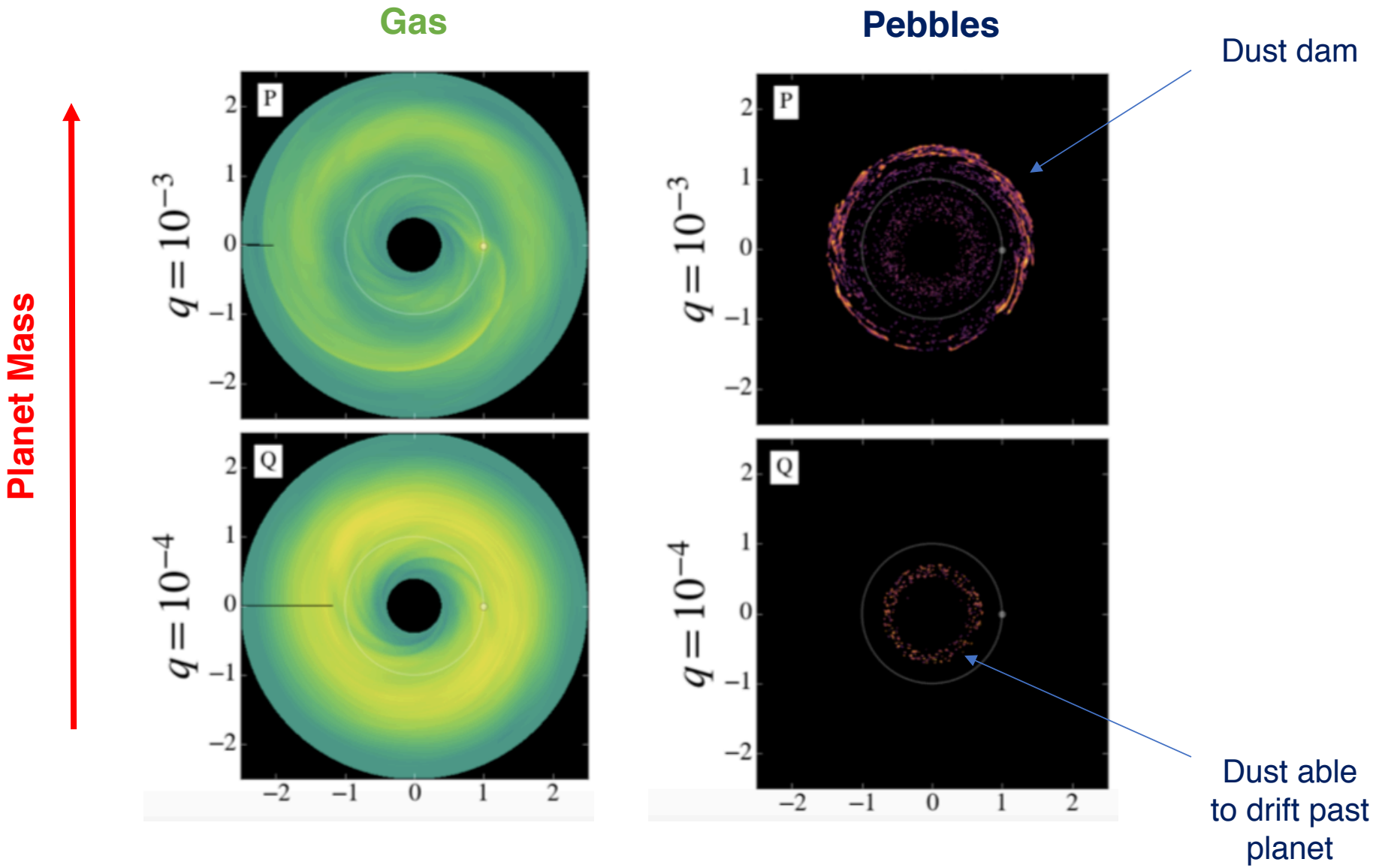
Gas

Pebbles

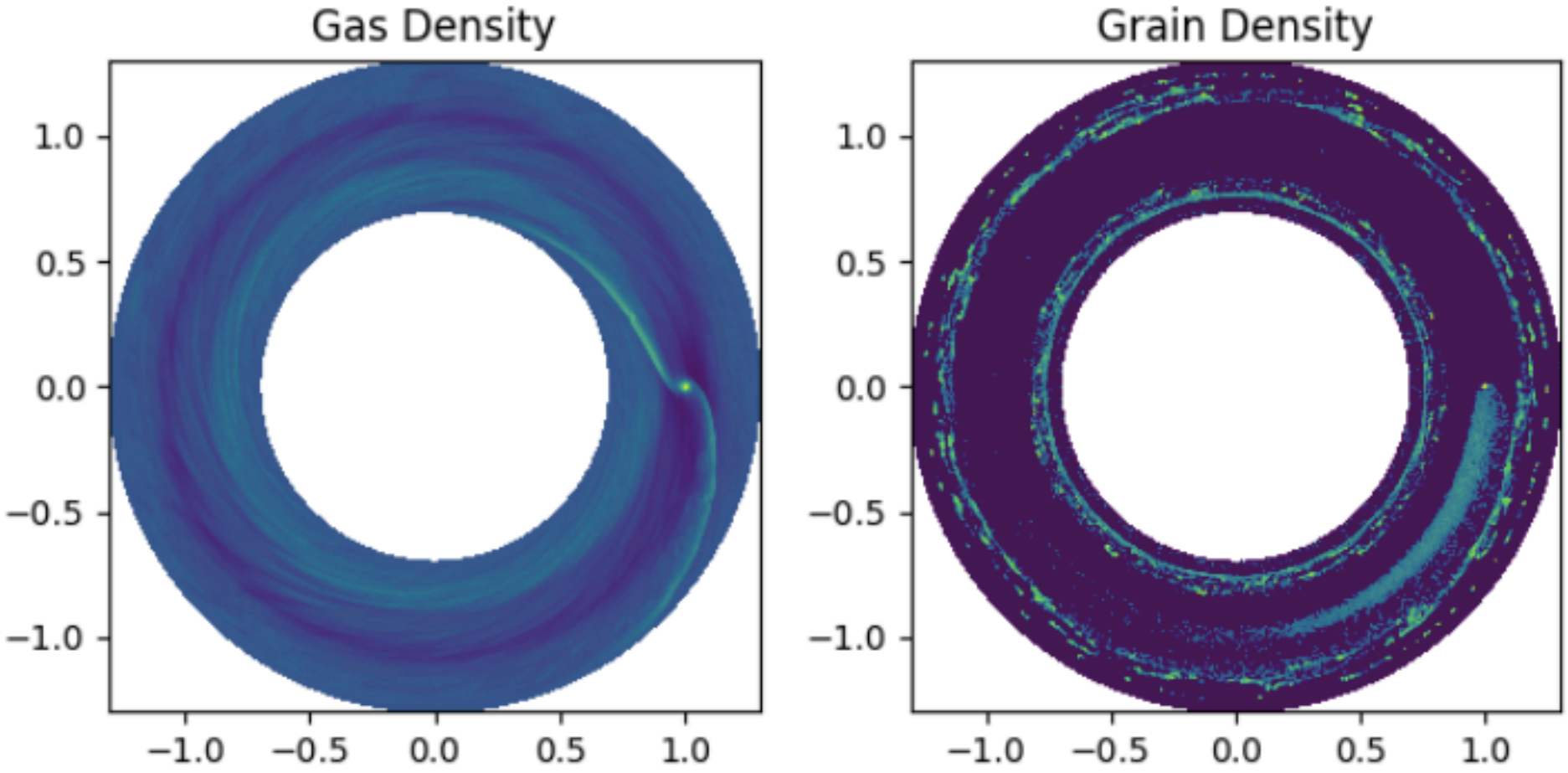
Planet Mass



Not all planets are dust dams

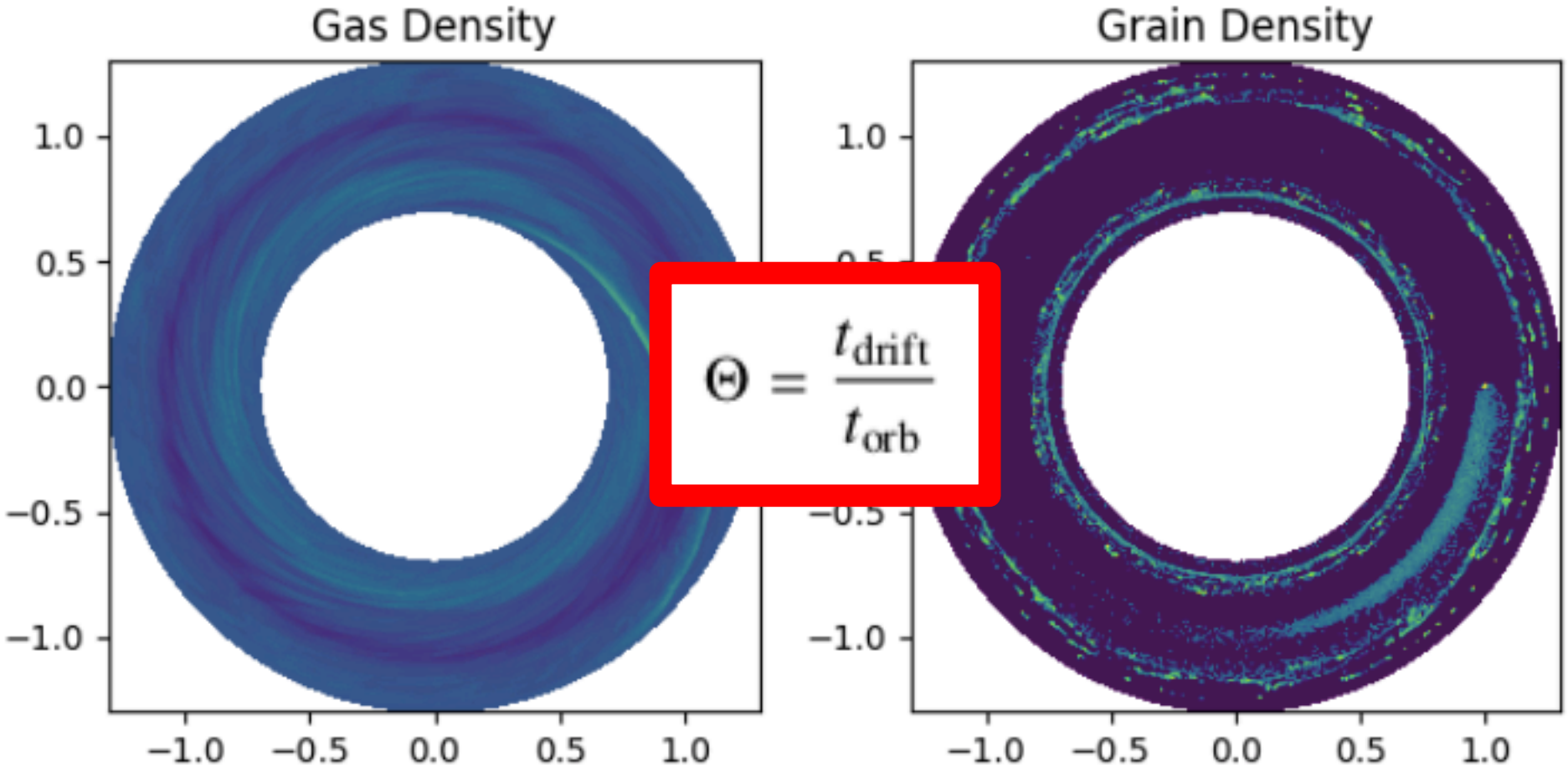


How to drift past a propeller?



A pebble has to cross the co-rotational region
faster than a planet can scatter it

How to drift past a propeller?



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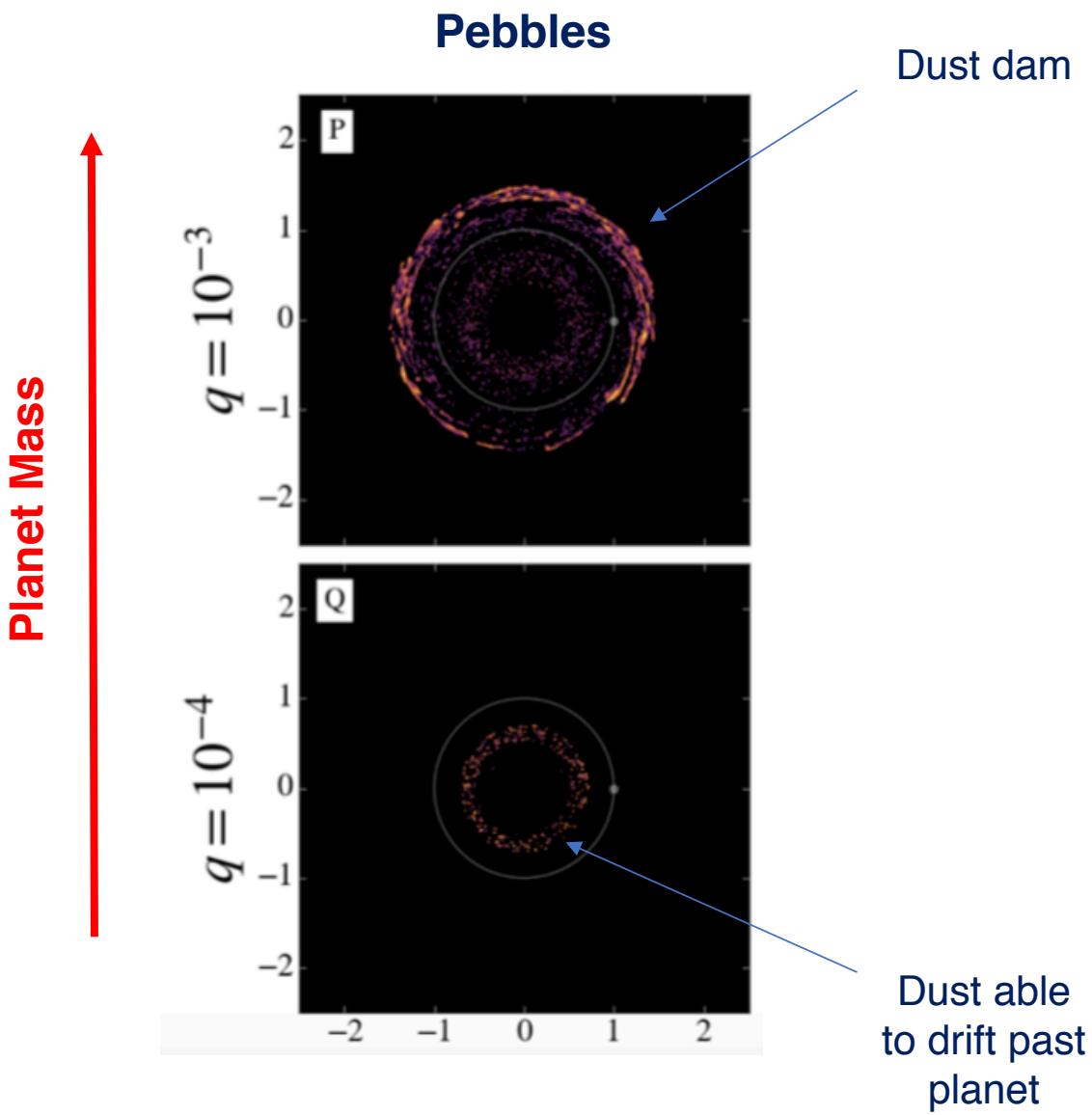
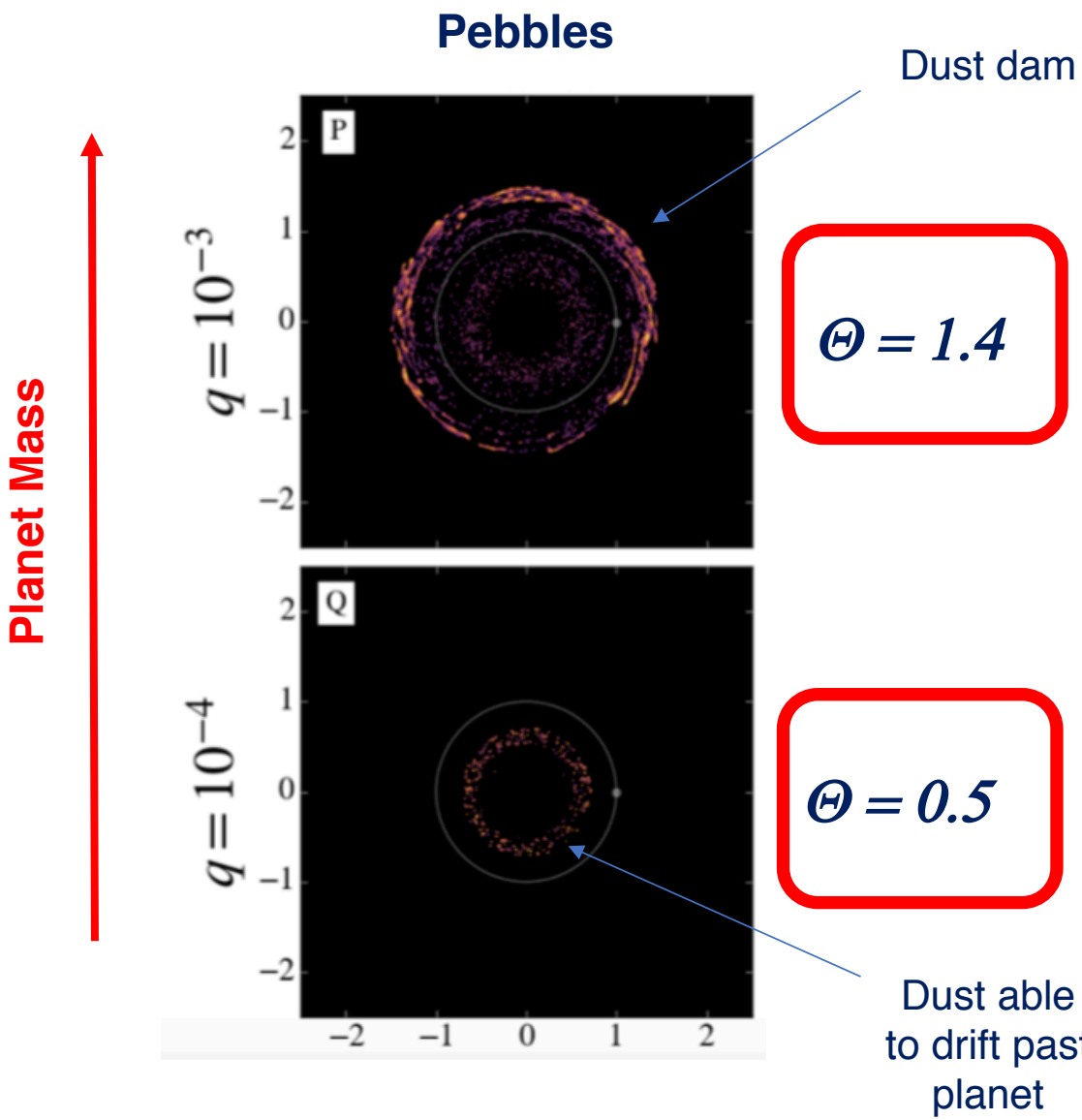


$$\Theta = \frac{t_{\rm drift}}{t_{\rm orb}} \approx 0.4\, q^{1/2} h^{-5/2} \chi^{-1} {\rm St}^{-1} \left(1 + {\rm St}^2\right)$$

q = planet mass ratio
h = disk aspect ratio
χ = power law of pressure gradient
St = Stokes number

Not all planets are dust dams



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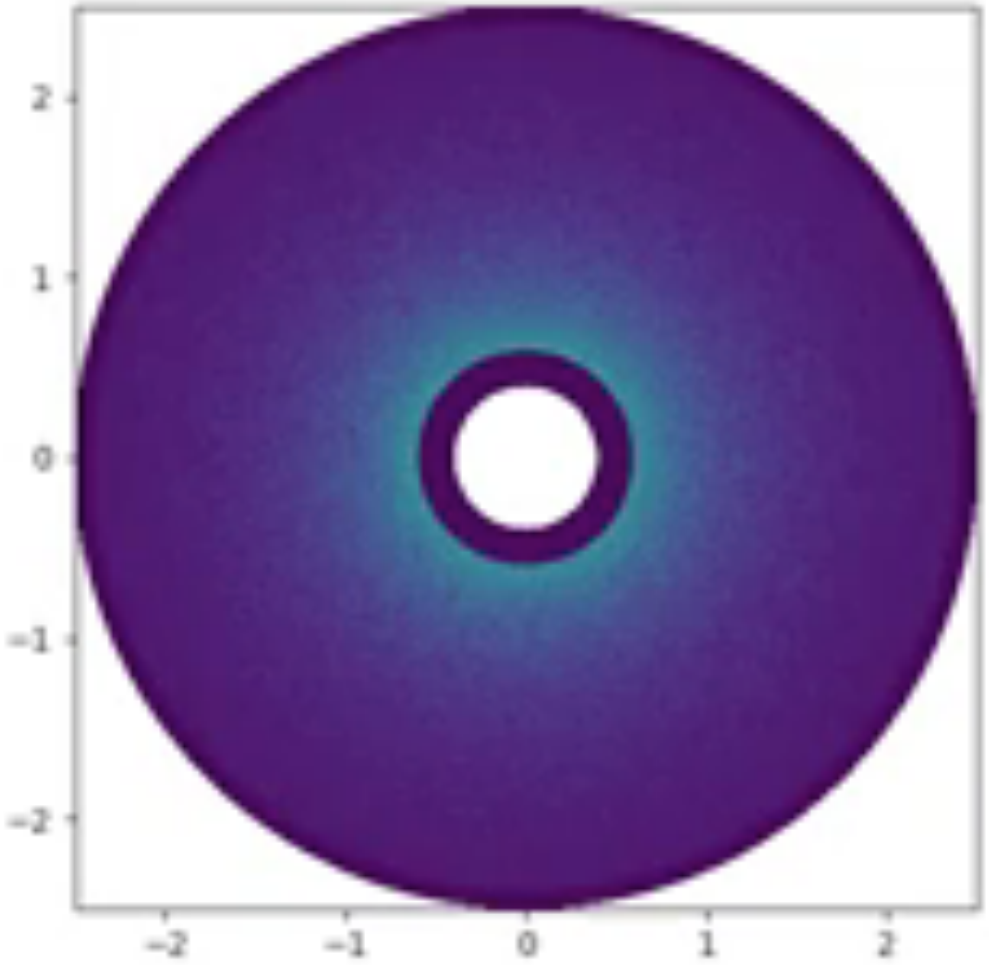
Streaming Instability

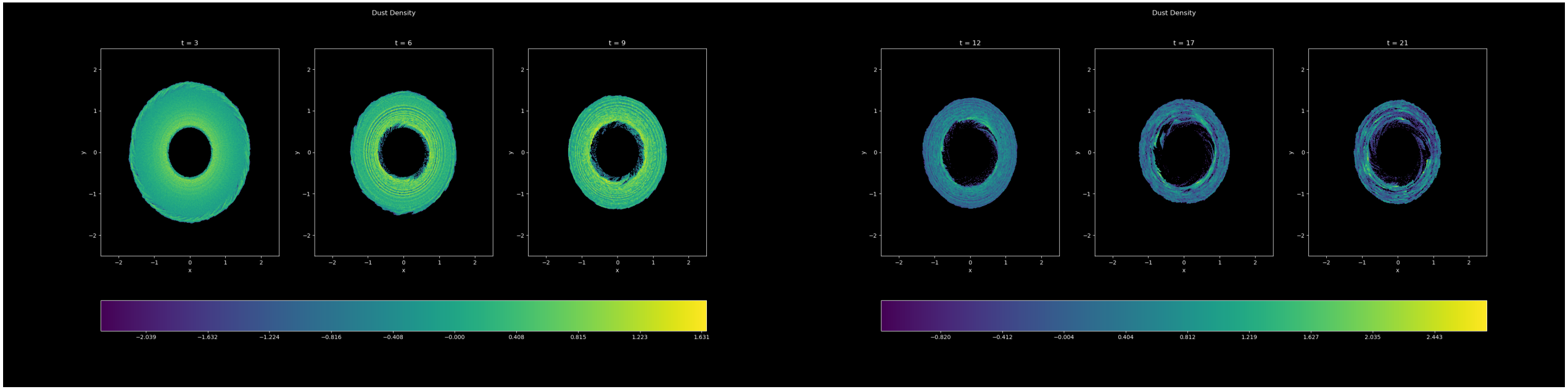


Preliminary Model

- H=0.3
- Nr,Nphi,Nz = 384,1024,32
- 12 million particles
- $\lambda_{SI}/\Delta r = 20$

Streaming Instability

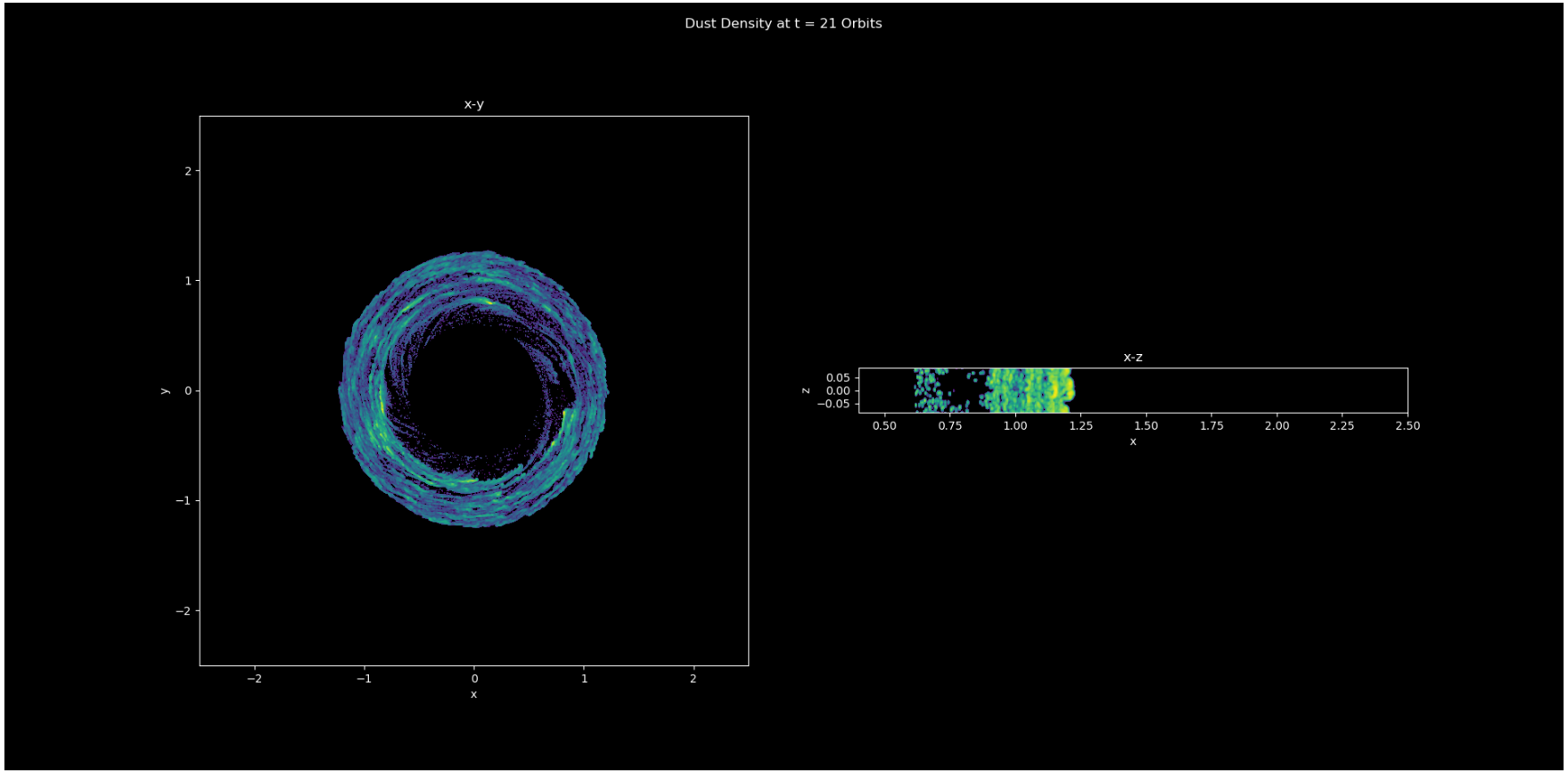
Time



Denser.

The drift is not divergenceless.

Azimuthal spectral power distribution?



Not axisymmetric!

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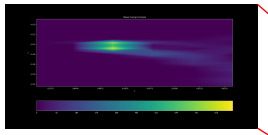
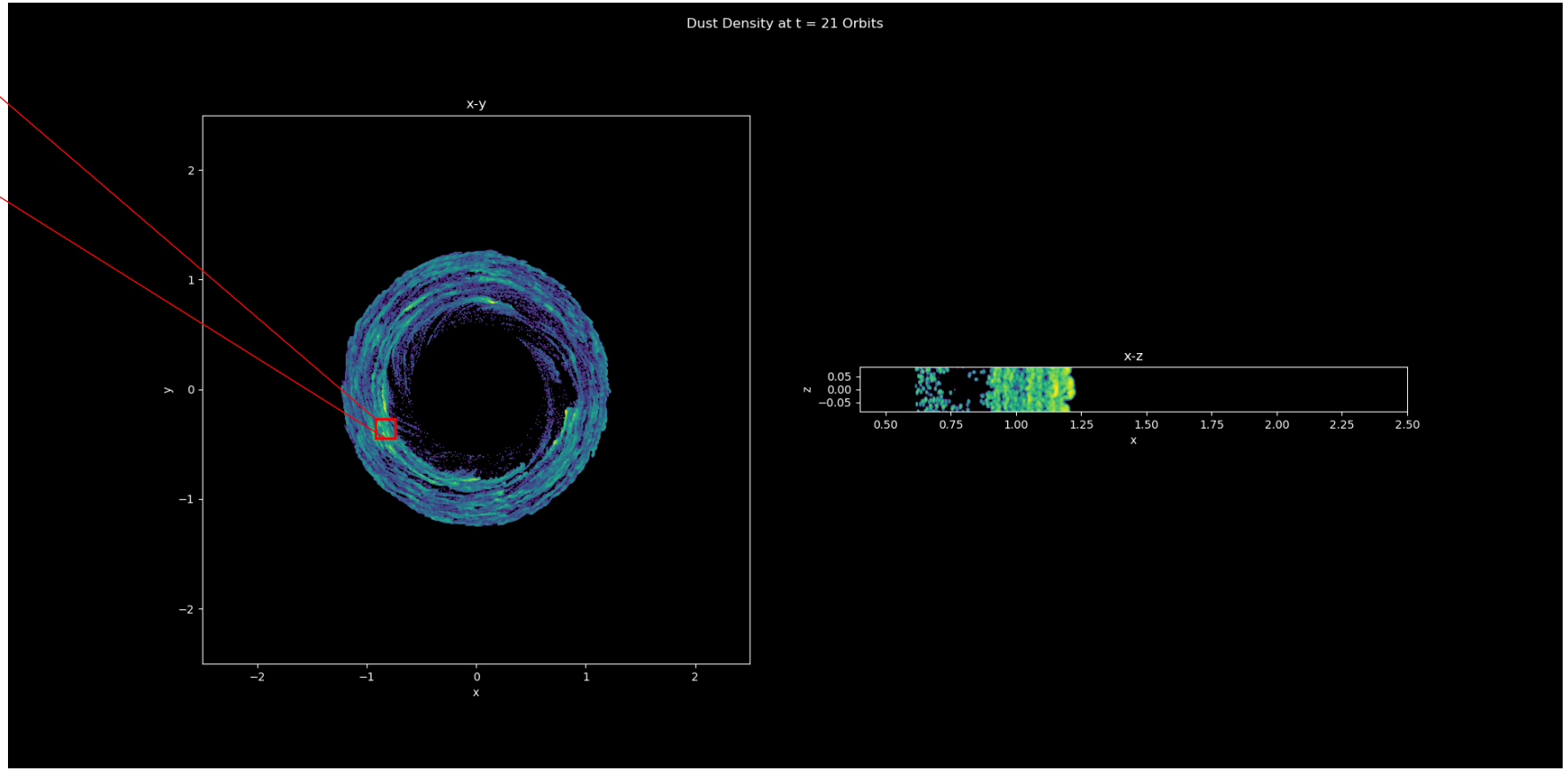


A Ceres-mass clump



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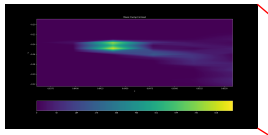

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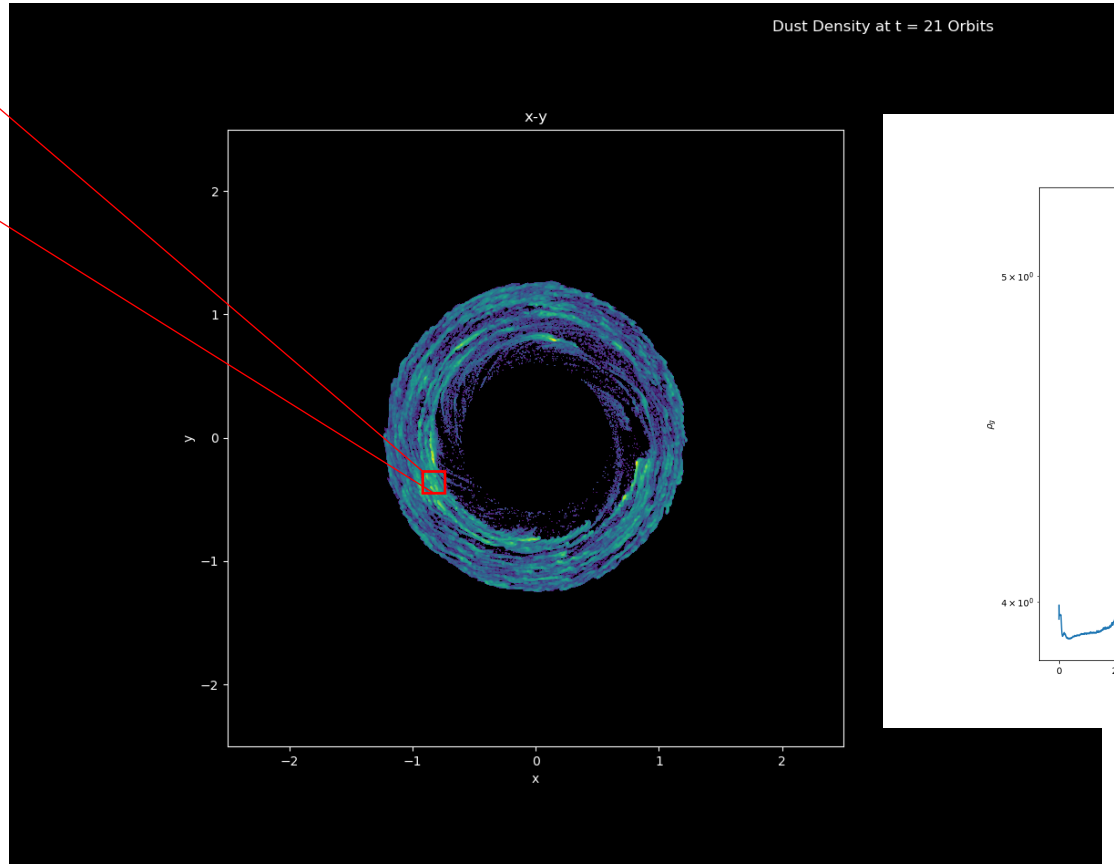
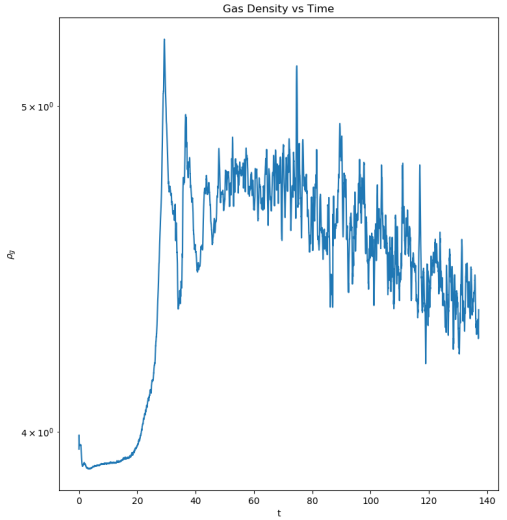
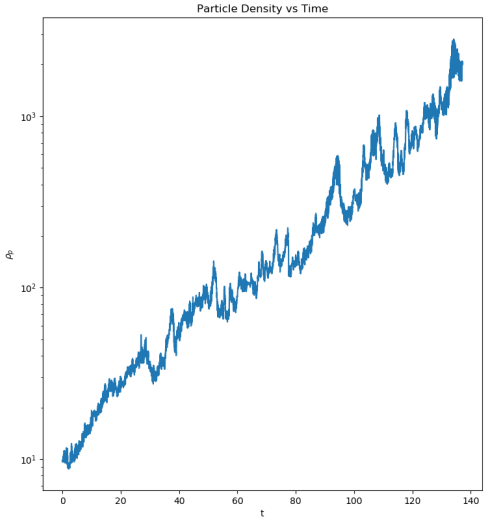
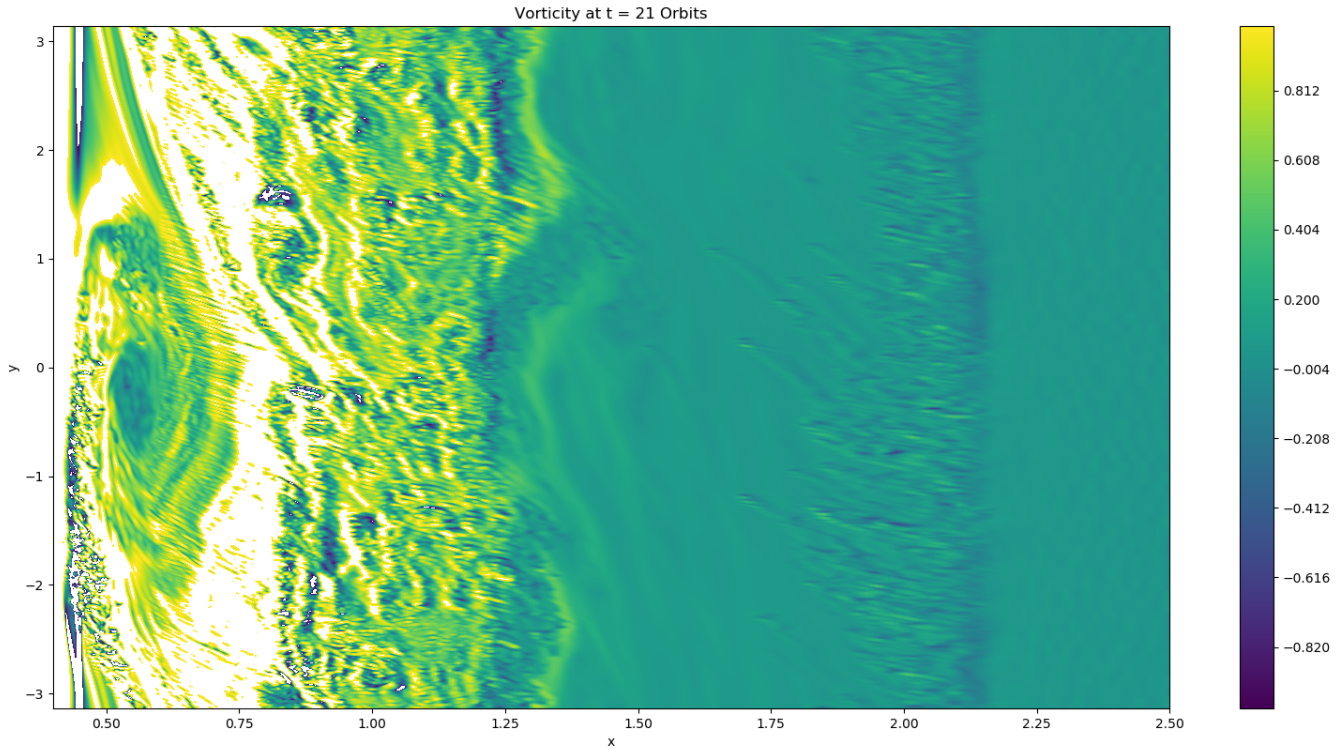






Mass not converged yet

Vortex at inner dust edge



RWI at dust sublimation radius?

Conclusions

- High dust-to-gas ratio ($\varepsilon \sim 0.1$ -1)
  - Depresses pressure bumps
  - Slows/halts pebble drift

- Vortices (RWI) at dus
  - Outer front as pe
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- Planets as dust dams
  - Criterion drift vs
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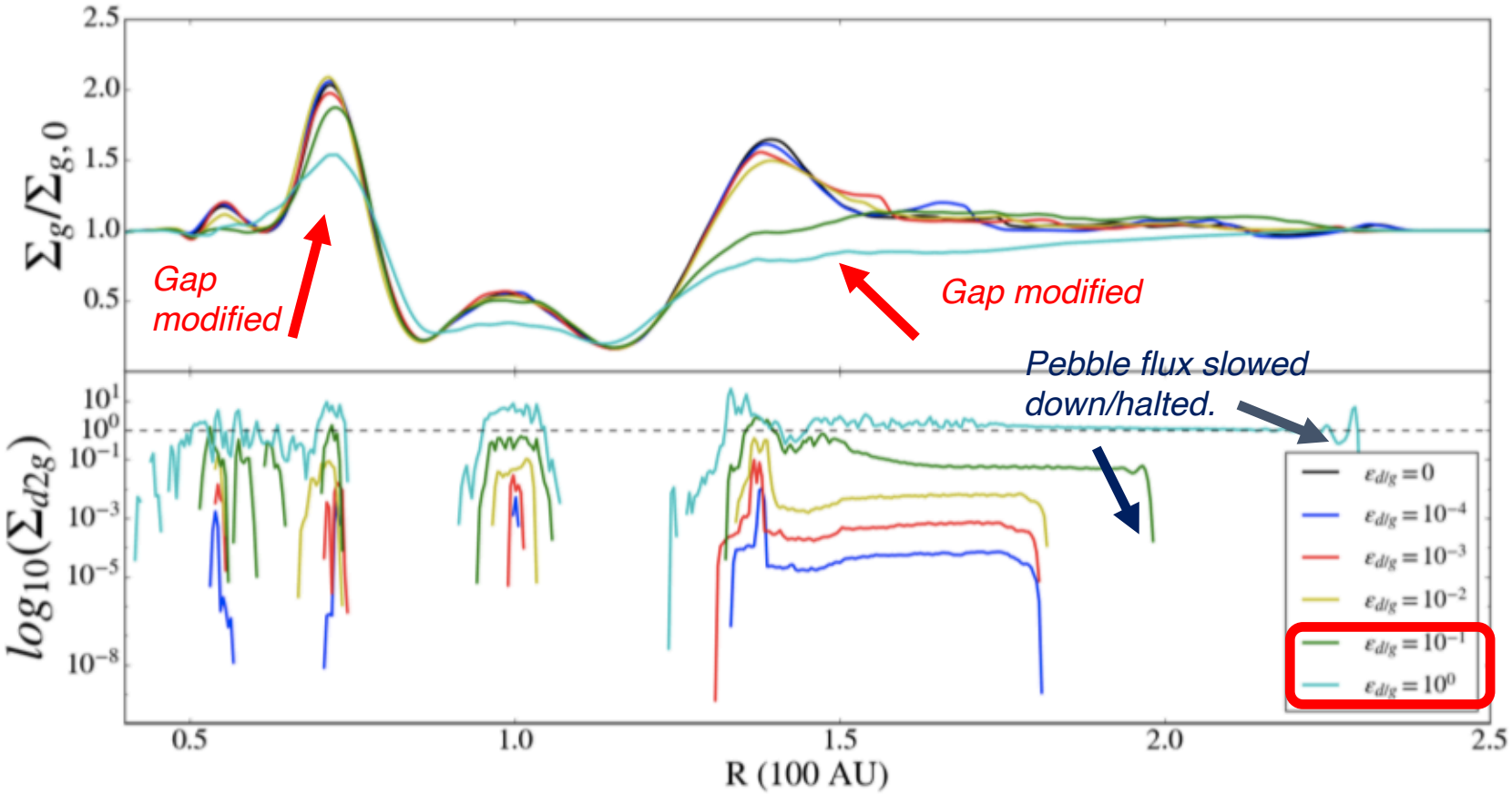
  - Non-axisymmetri
  - High-mass embry
  - *Convergence….*



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  - Outer front as pebbles drift inwards (?)
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  - Criterion drift vs dynamical time
    - Low-mass planets (small corotation radius) i

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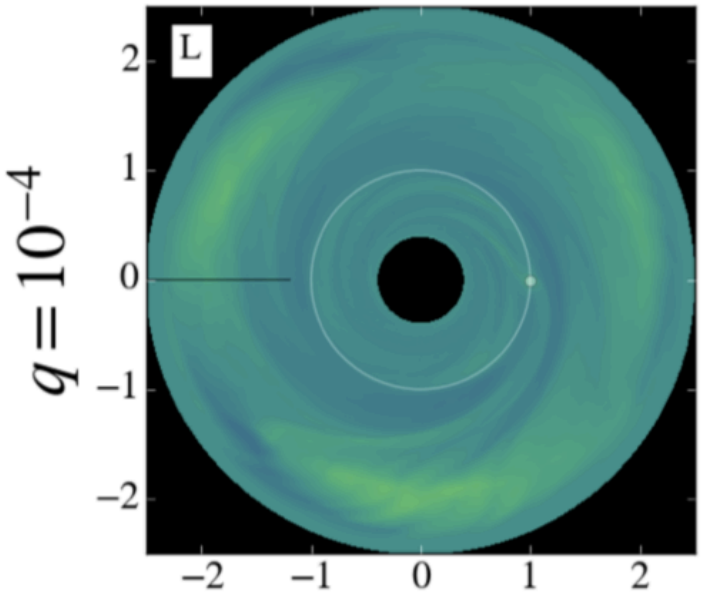

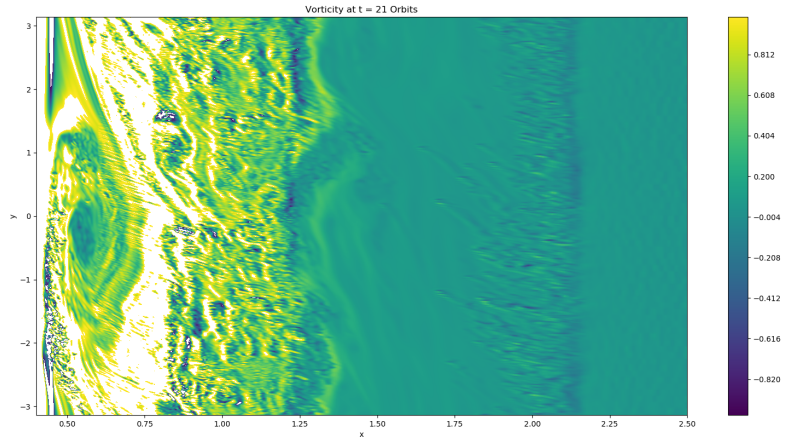

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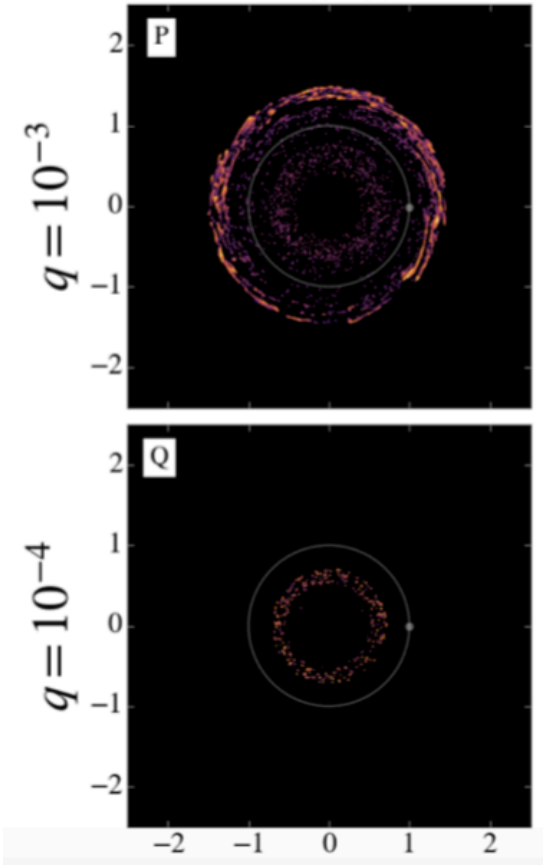

- Planets as dust dams
  - Criterion drift vs dynamical time
    - Low-mass planets (small corotation radius) in hot disks (fast drift) not good dutchmen
- Streaming Instability in 3D
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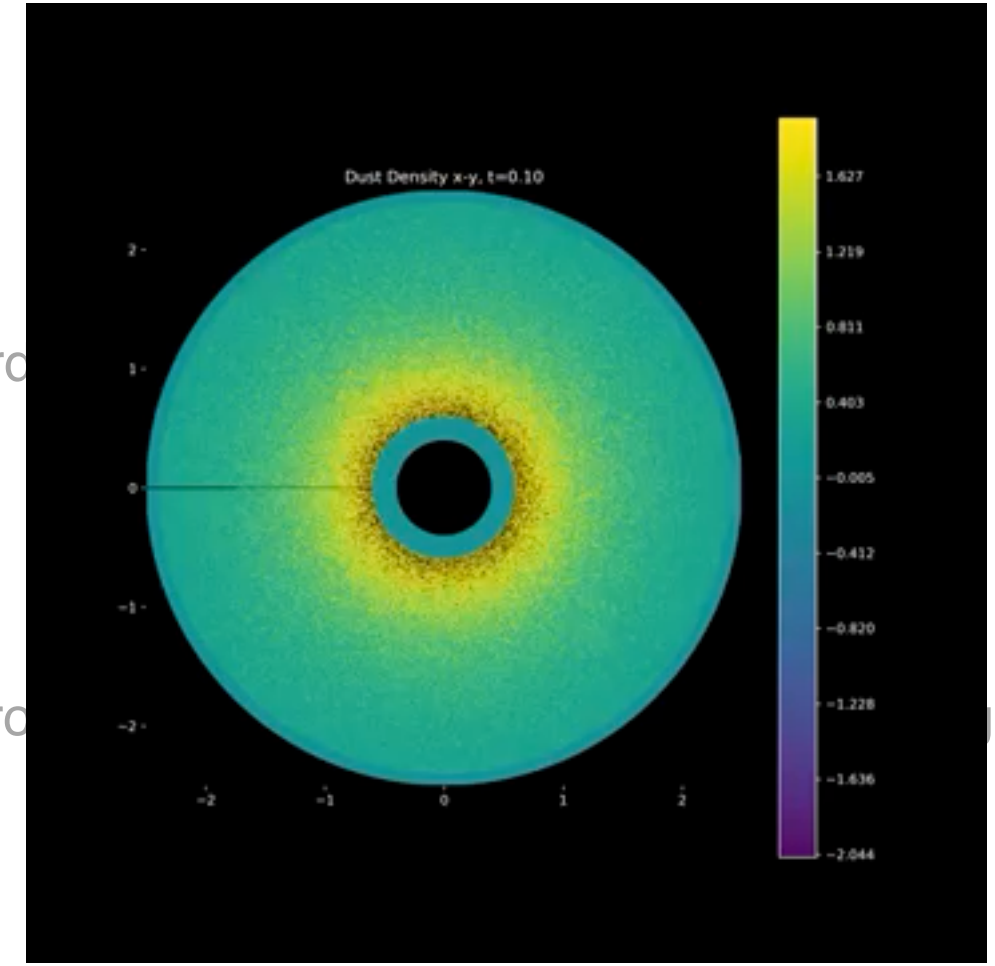

The M.Sc. students who did this work

Areli Castrejon

Chris Malek

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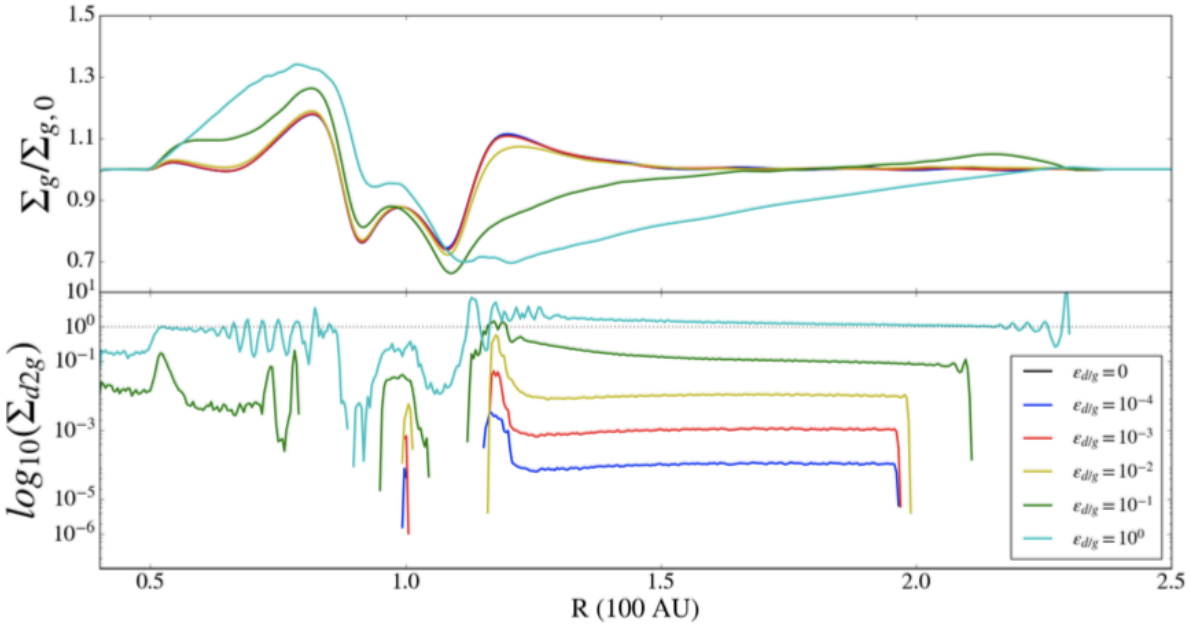
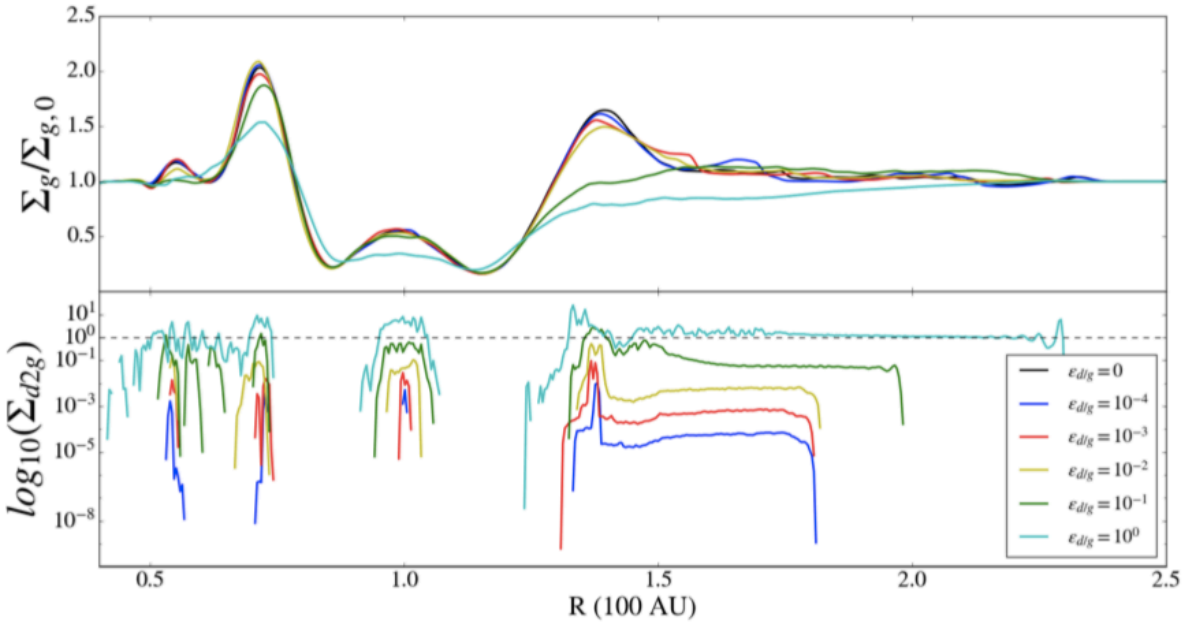
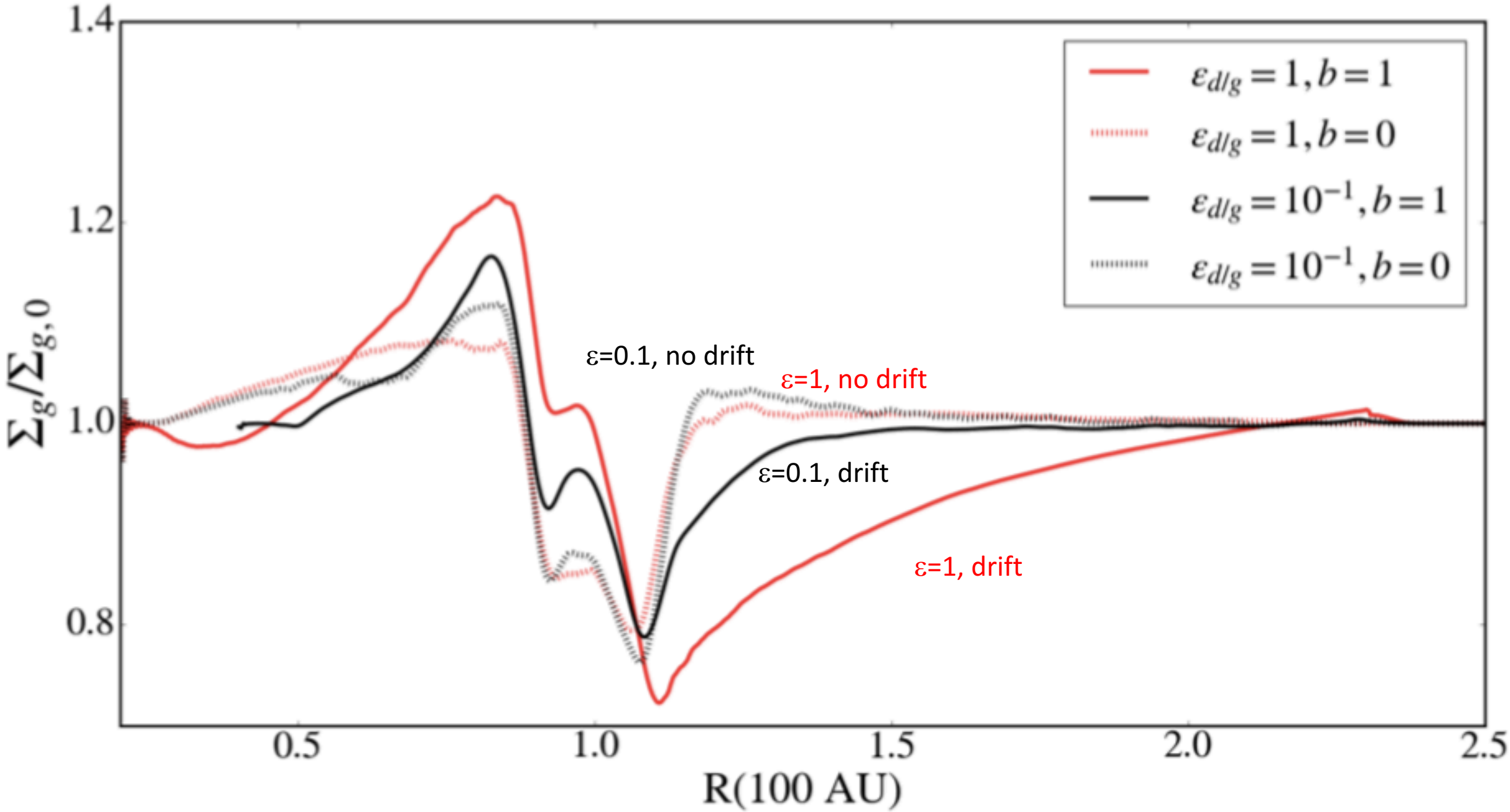
Influence on Gap Carving

Neptune-mass planet



Jupiter-mass planet




1.4
1.2
1.0
0.8
$\Sigma_g/\Sigma_{g,0}$
0.5
1.0
1.5
2.0
2.5
R(100 AU)
$\varepsilon_{d/g}=1, b=1$
$\varepsilon_{d/g}=1, b=0$
$\varepsilon_{d/g}=10^{-1}, b=1$
$\varepsilon_{d/g}=10^{-1}, b=0$
ε=0.1, no drift
ε=1, no drift
ε=0.1, drift
ε=1, drift