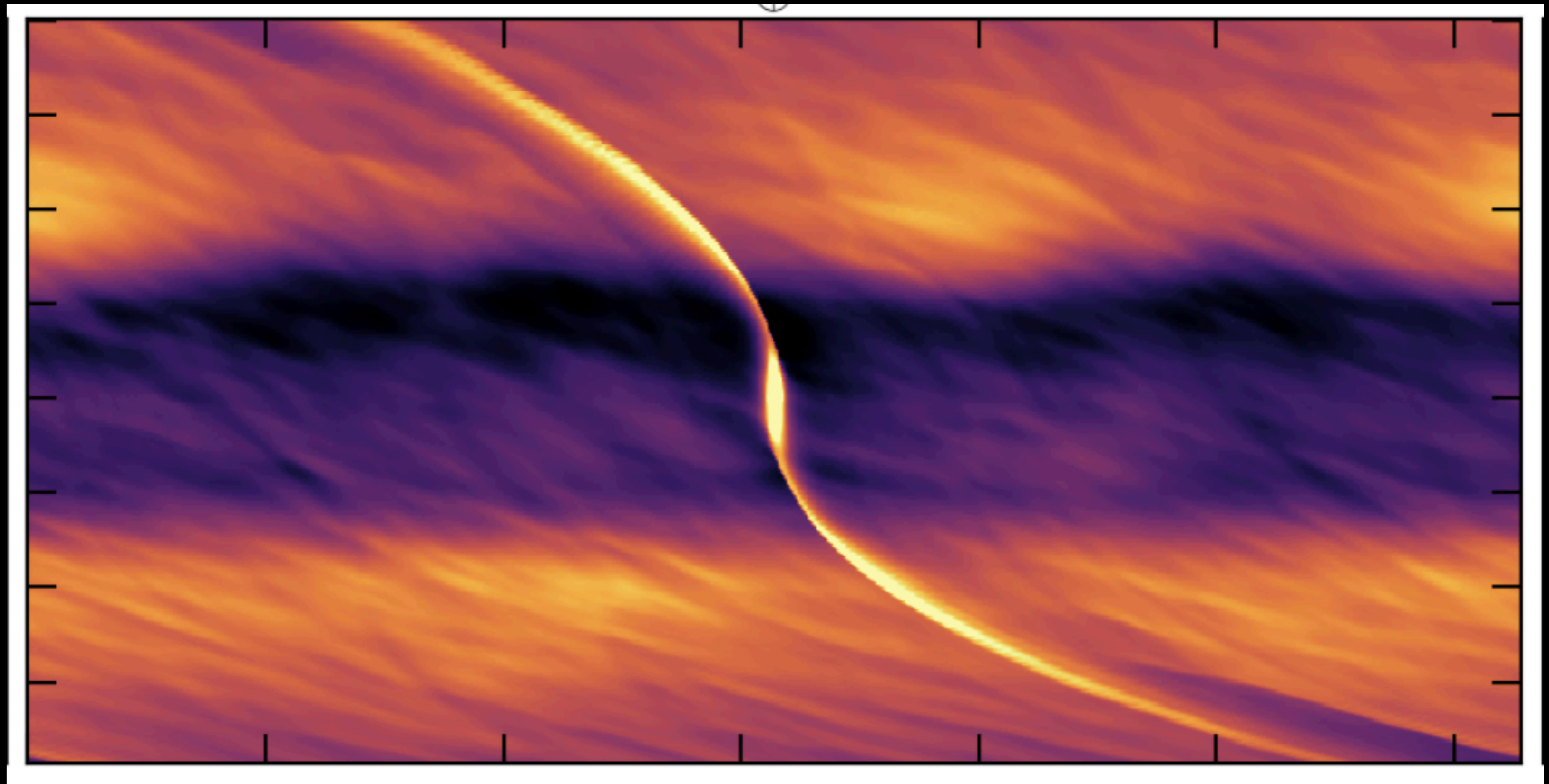
PEBBLE ACCRETION ONTO PLANETS IN TURBULENT DISCS



GIOVANNI PICOGNA - LMU MUNICH

GREAT BARRIERS IN PLANET FORMATION
PALM COVE 2019

DUST BUSTERS

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PUBLICATIONS

A&A 599, L6 (2017)
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Astronomy & Astrophysics

LETTER TO THE EDITOR

Anisotropic hydrodynamic turbulence in accretion disks

Moritz H. R. Stoll[1], Wilhelm Kley[1], and Giovanni Picogna[1,2]

A&A 604, A28 (2017)
DOI: 10.1051/0004-6361/201730668

Astronomy & Astrophysics

Planet-disc interaction in laminar and turbulent discs

Moritz H. R. Stoll[1], Giovanni Picogna[1,2], and Wilhelm Kley[1]

A&A 616, A116 (2018)
https://doi.org/10.1051/0004-6361/201732523

Astronomy & Astrophysics

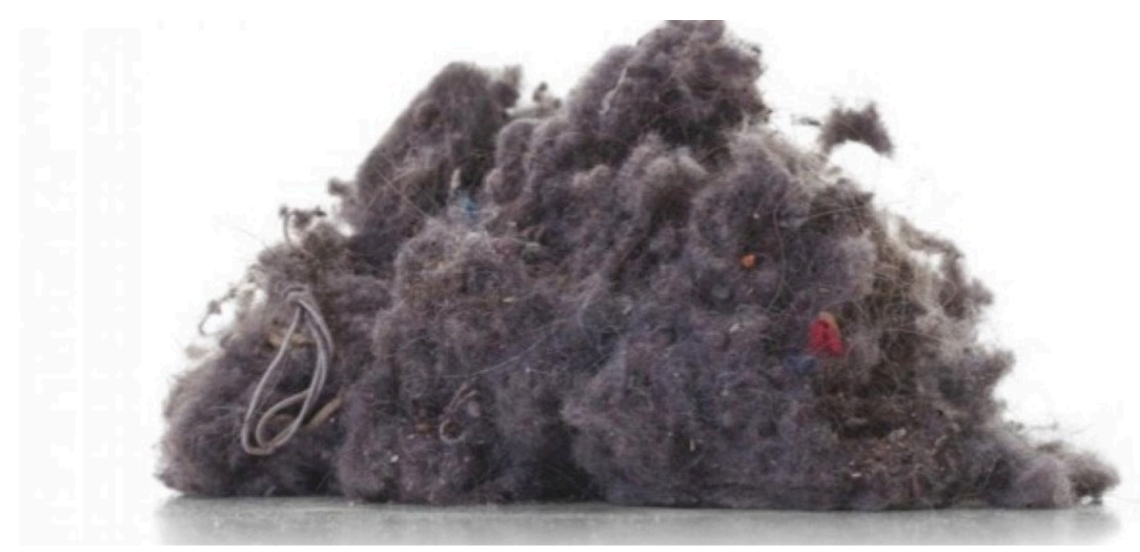
Particle accretion onto planets in discs with hydrodynamic turbulence

Giovanni Picogna[1,2], Moritz H. R. Stoll[2], and Wilhelm Kley[2]

OVERVIEW

01.

How dead is the dead zone?

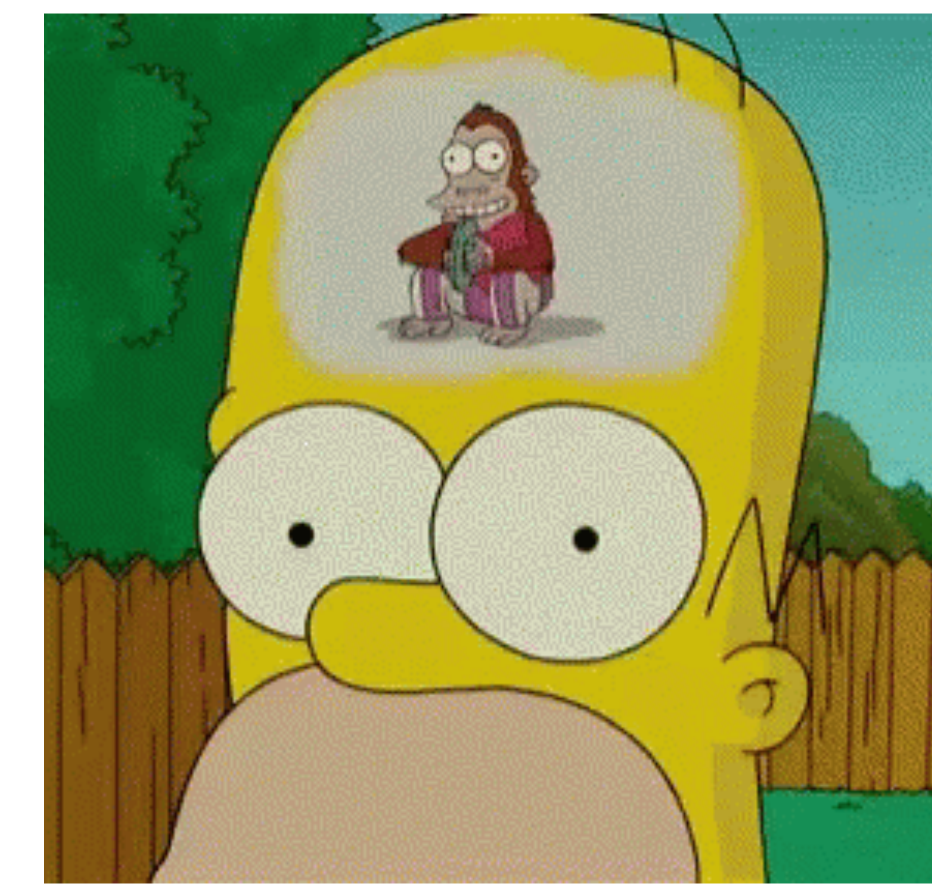


02.

Dust Evolution in Turbulent Discs

03.

Solid Accretion in Turbulent Discs



04.

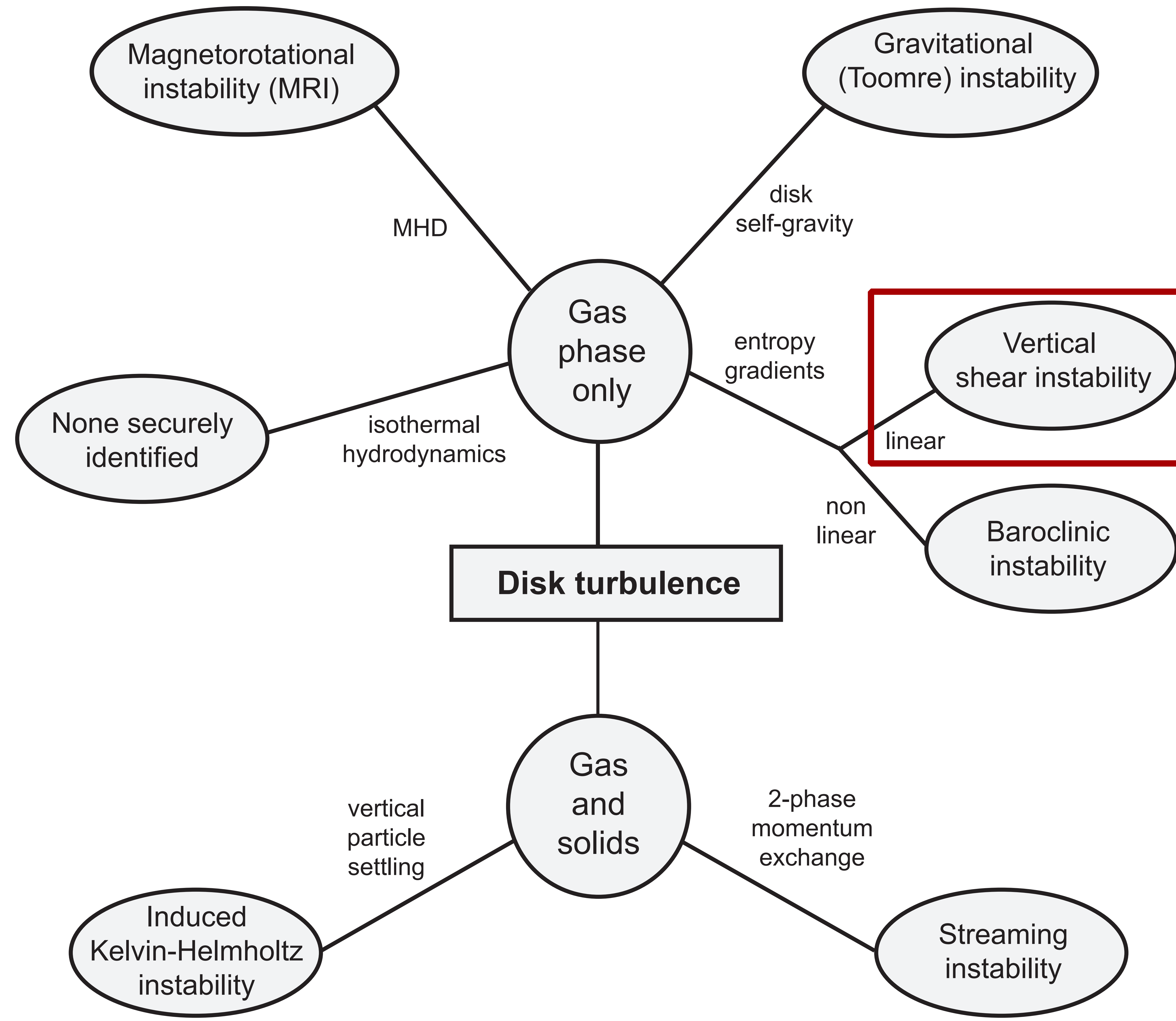
New Solutions, New Barriers

1. HOW DEAD IS THE DEAD ZONE?

HYDRODYNAMIC TURBULENCES

A Zoo of Instabilities

- many mechanisms can generate turbulence in disks (even in the dead zone)
- we modelled the vertical shear instability (VSI)
- and compared the same analysis with a laminar viscous disk



Armitage 2015

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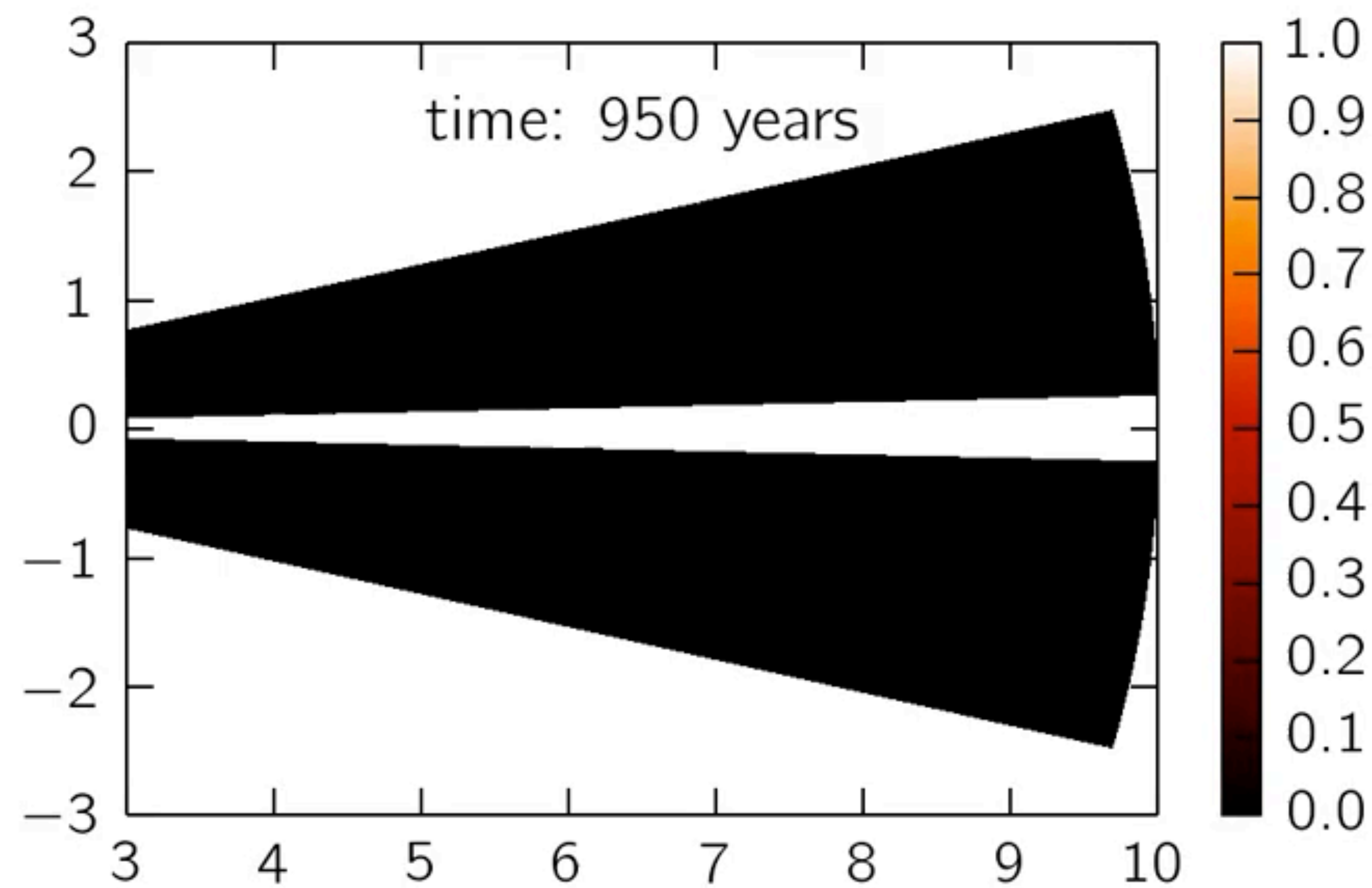
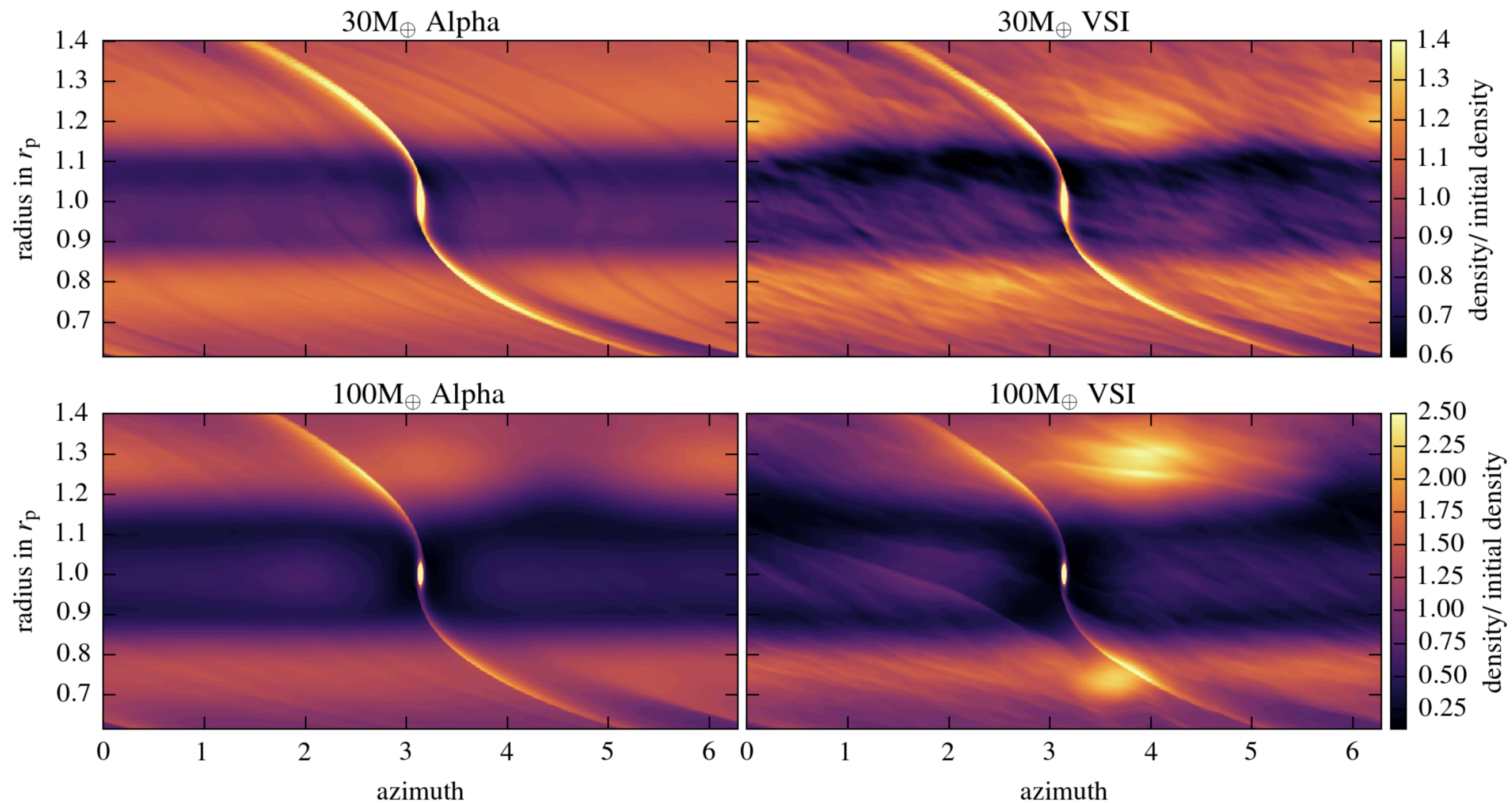


Armitage 2015

Numerical Setup

- PLUTO code (Mignone+ 2007, 2012)
- 1,000,000 Lagrangian particles representing 10 dust sizes (from sub-mm to km)
- 4 different planetary masses: 5, 10, 30, 100 $M_{\oplus}$
- a set of simulation with VSI active disks (inviscid), and a second one with laminar disks
- locally isothermal equation of state, new runs with radiative transfer, different disc aspect ratio
- no planet migration, no dust back-reaction



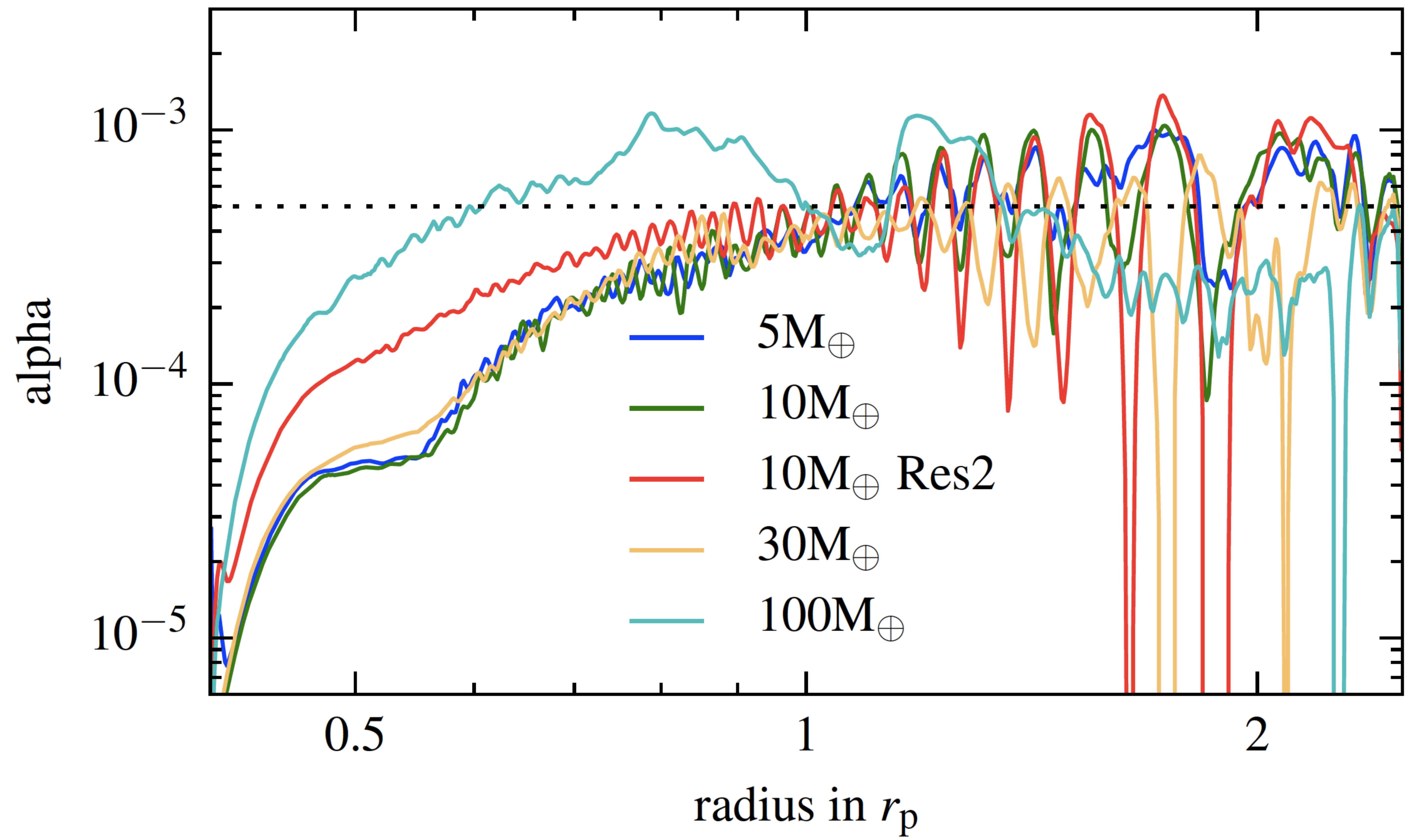
Stoll, Picogna & Kley, 2017

Effective Viscosity

- VSI generate eddies that transport angular momentum
- we can derive an α parameter from the Reynold stresses

$$\alpha(r) = \frac{< R_{R,\phi} >_{t,\theta,\phi}}{< P >_{t,\theta,\phi}}$$

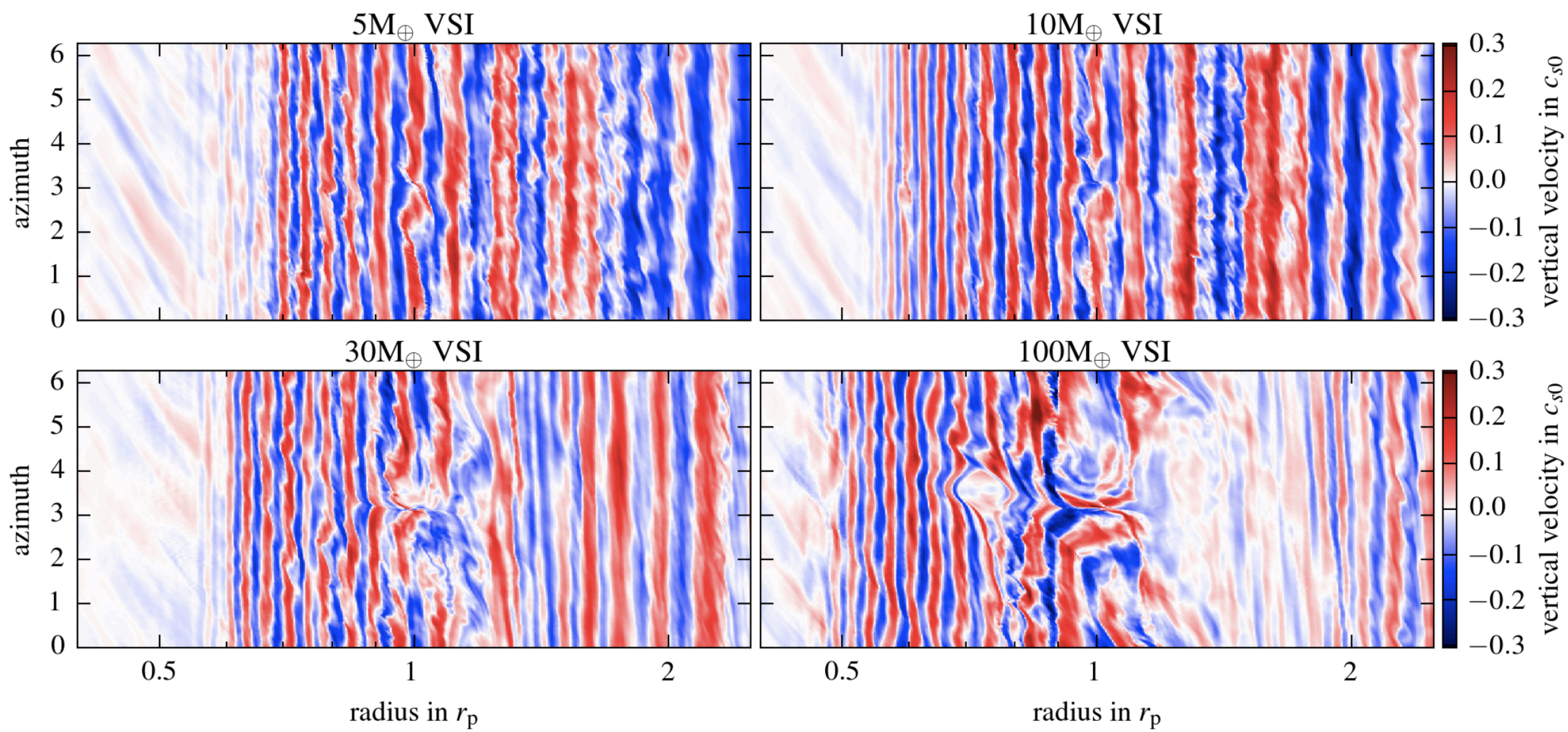
$$R_{R,\phi} = \rho u_R \delta u_\phi$$



Stoll, Picogna & Kley, 2017

VSI - RWI Vortex Interaction

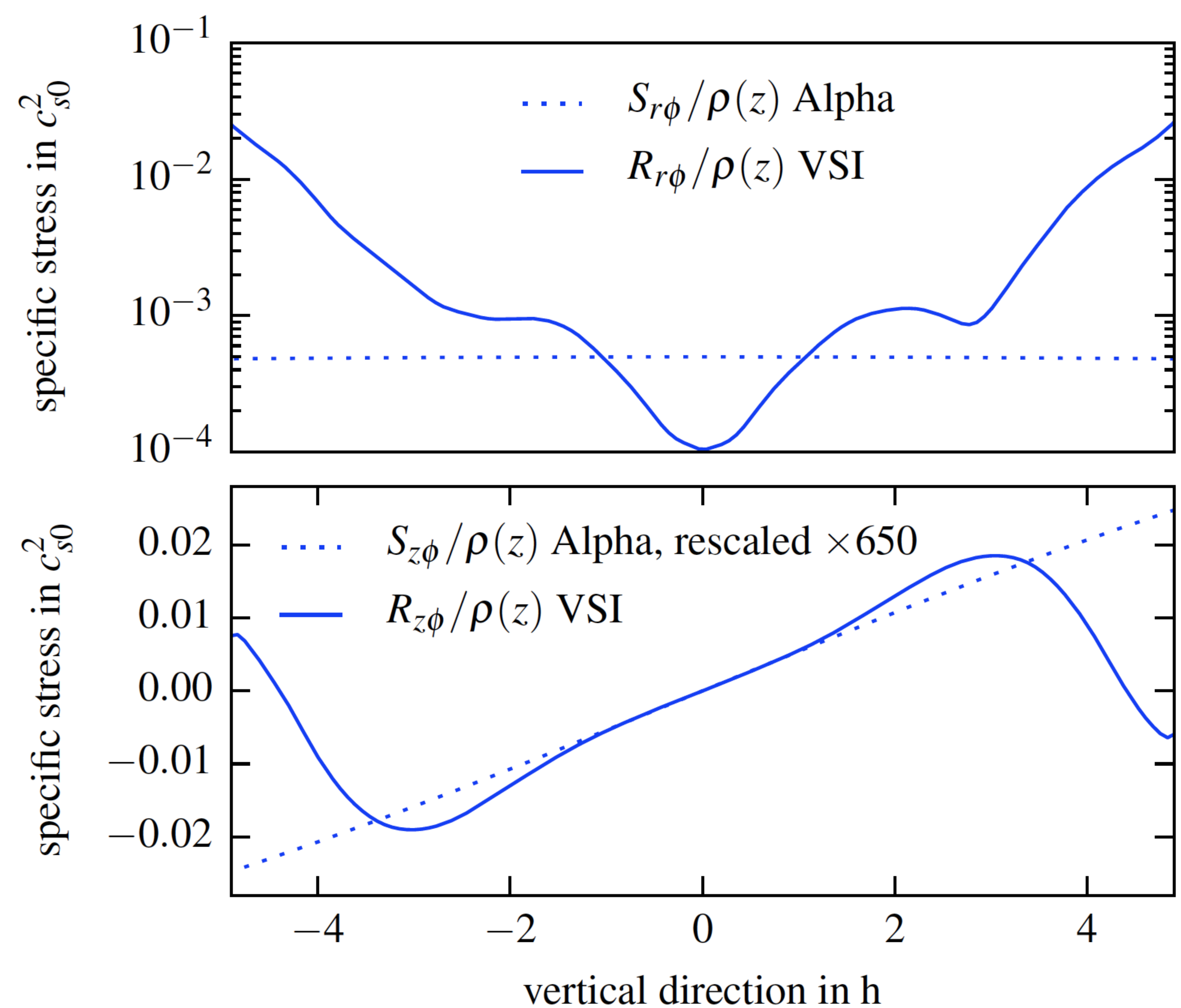
- the strong vertical motion due to the VSI is strongly quenched at the location of the RWI vortex



Stoll, Picogna & Kley, 2017

Shall we Abandon the Alpha Disc Model?

- VSI turbulence is strongly anisotropic
- the vertical stress tensor is ~650 times stronger than the radial one
- it inverts the meridian circulation flow
- can we model this with a simple laminar disc with an α-like parameter?



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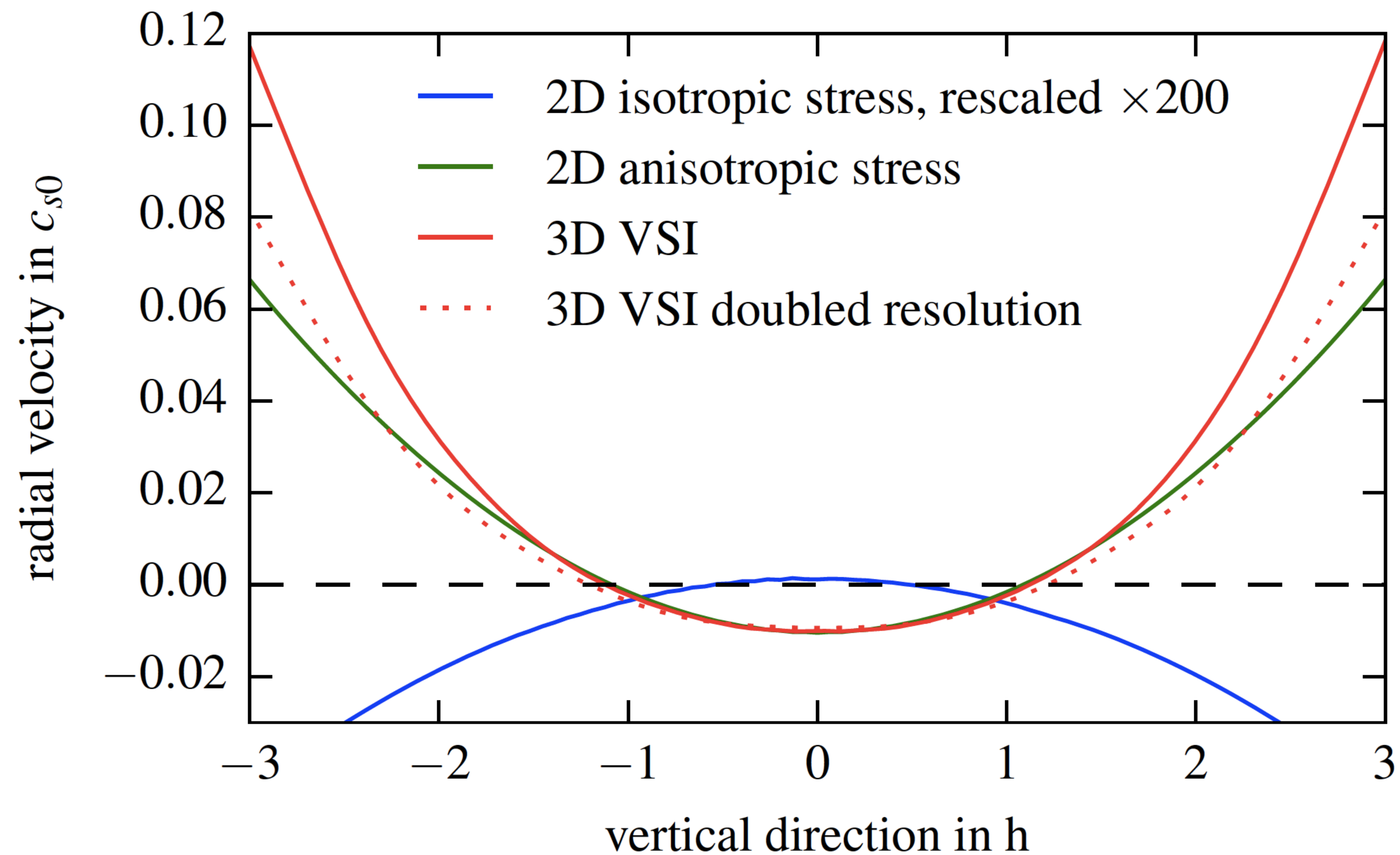
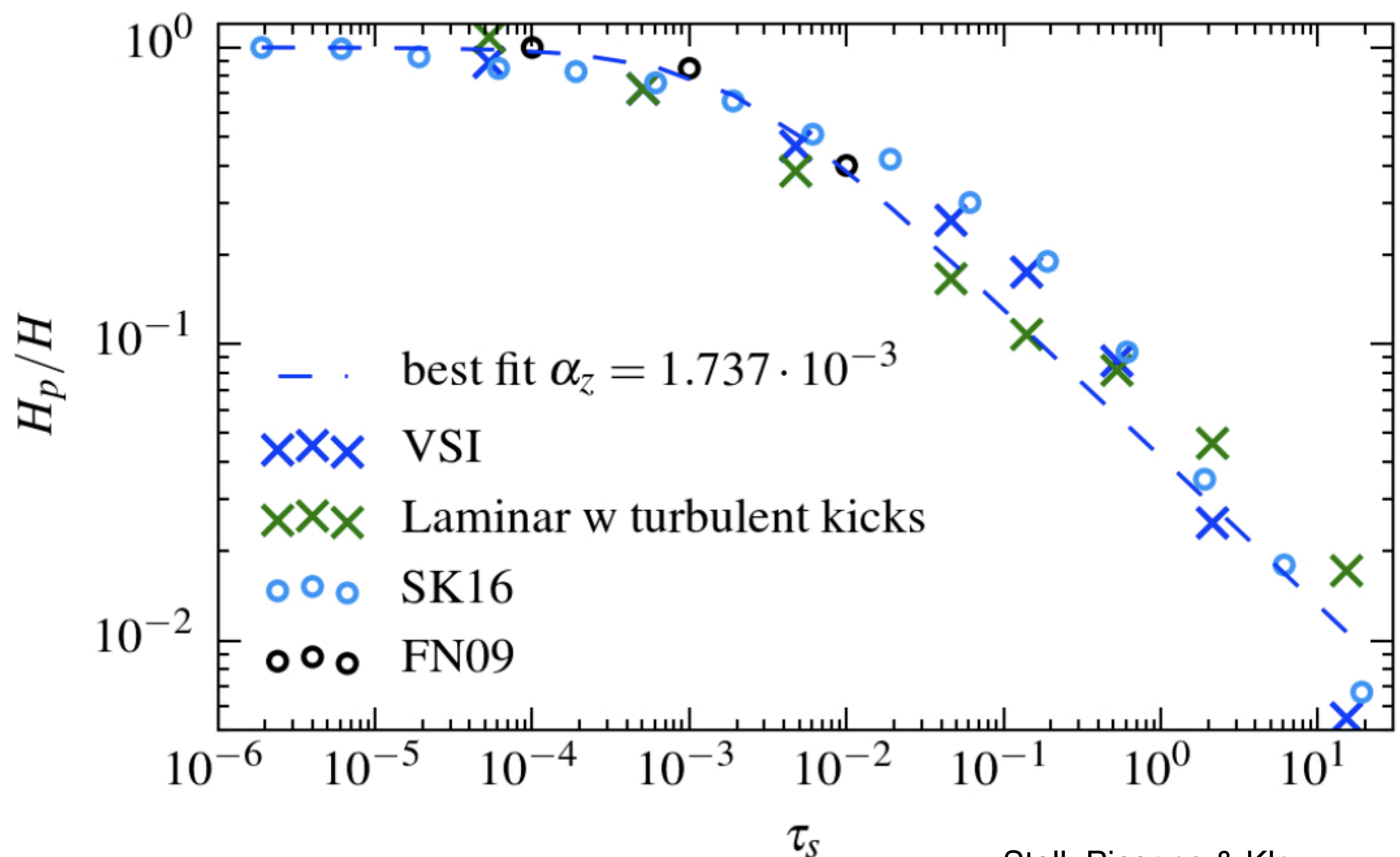


Stoll, Kley & Picogna, 2017

2. DUST EVOLUTION IN TURBULENT DISCS

PARTICLE SCALE HEIGHT

- very similar particle scale height in VSI and laminar discs with turbulent kicks!
- compatible also with MRI turbulence (Fromang & Nelson, 2009)

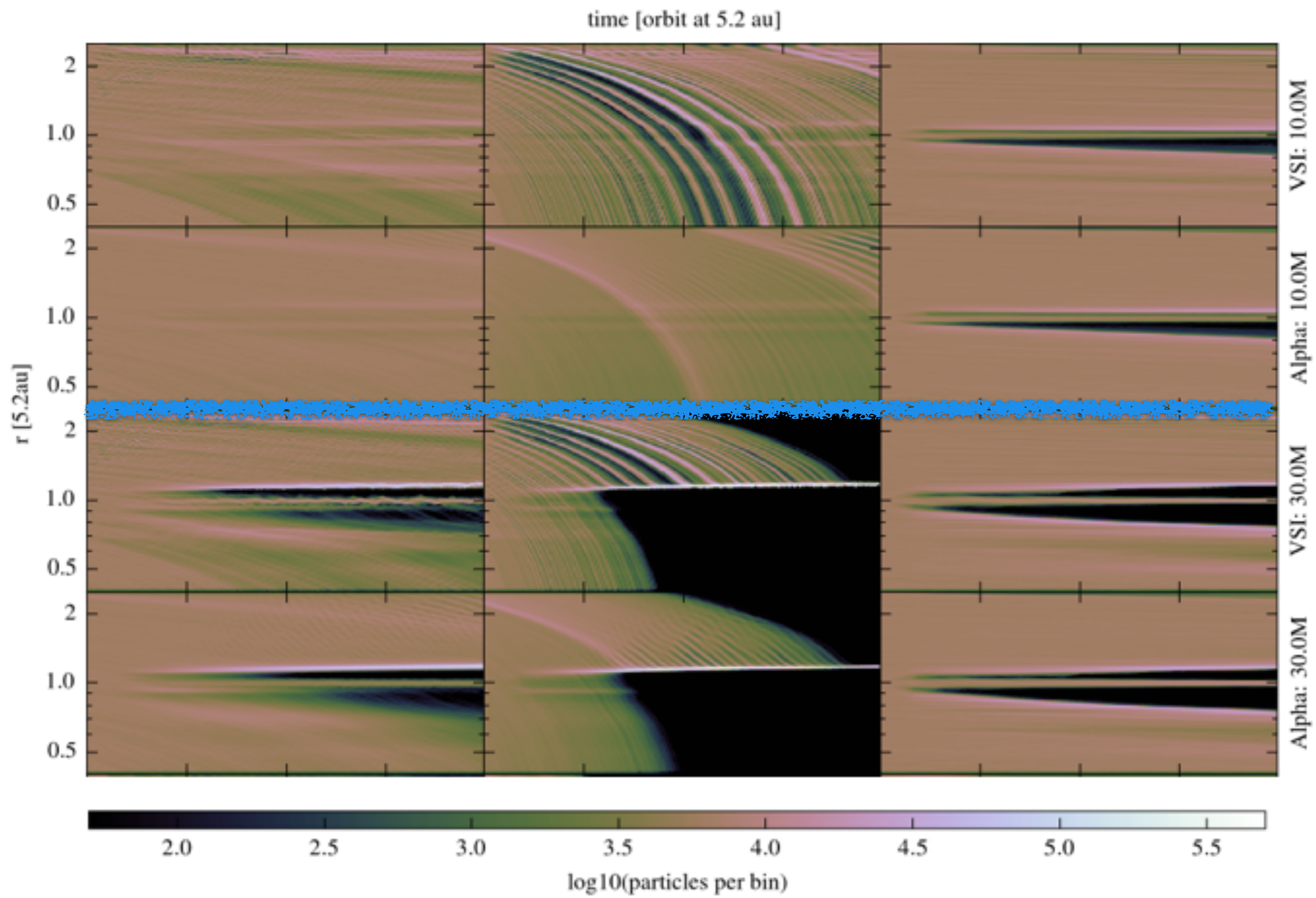


Stoll, Picogna & Kley, 2017

PARTICLE RADIAL DRIFT

- VSI create rings (and vortices - see e.g. Manger et al. 2018)

- between 10 and 30 $M_\oplus$ the pebble isolation mass is reached (compatible with non turbulent discs - e.g. Bitsch et al., 2018)



$$M_{iso} = 25\, f_{fit}\, M_\oplus$$

$$f_{fit} = \left[\frac{H/r}{0.05}\right]^3 \left[0.34\left(\frac{\log(\alpha_3)}{\log(\alpha)}\right)^4 + 0.66\right]\left[1 - \frac{\partial \ln(P)/\partial \ln(r) + 2.5}{6}\right]$$

Picogna, Stoll & Kley, 2018

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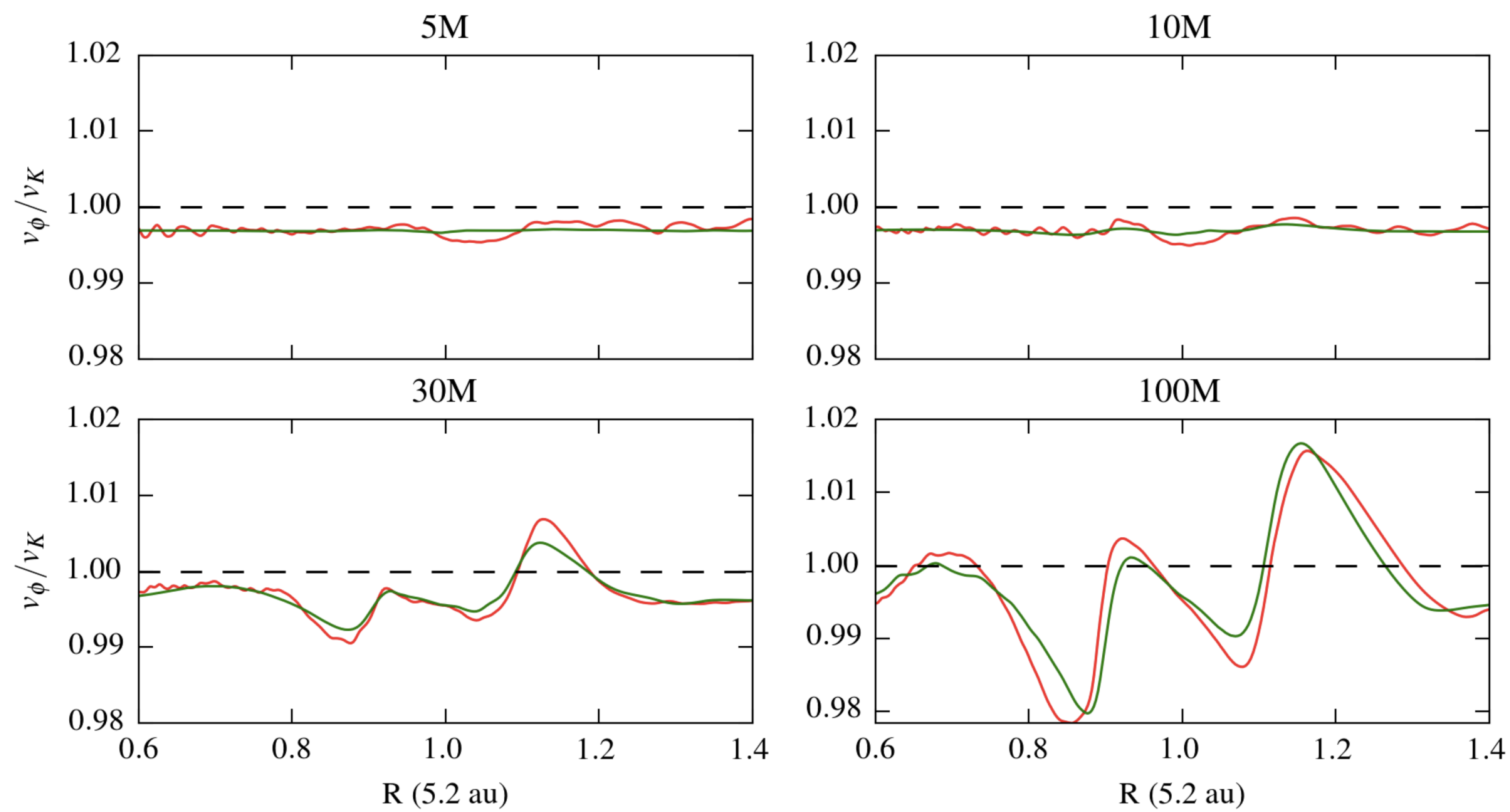

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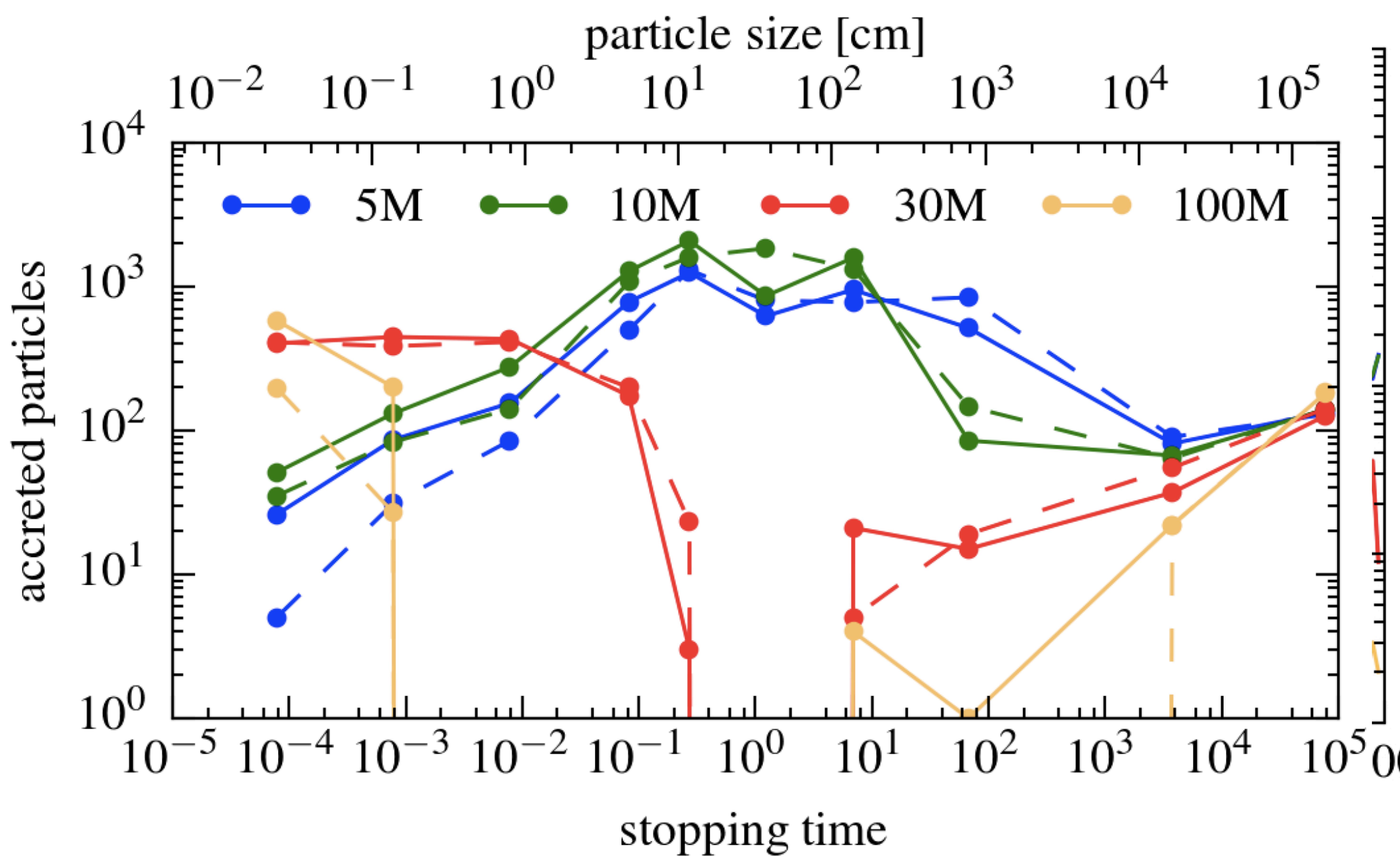
Picogna, Stoll & Kley, 2018

3. SOLID ACCRETION IN TURBULENT DISCS

Pebble Isolation Mass

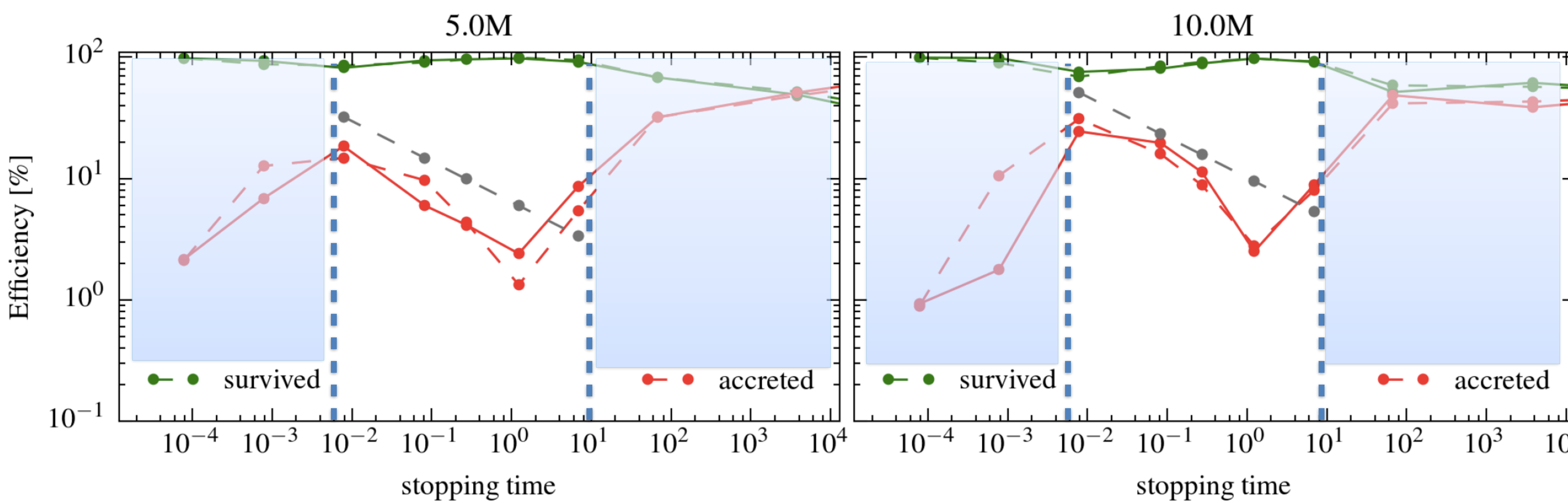
- the solid accretion rate reach a stable state within the simulation
- above 10 $M_\oplus$ pebble accretion is shut off
- there are no striking differences between the VSI and laminar case with turbulent kicks



Picogna, Stoll & Kley, 2018

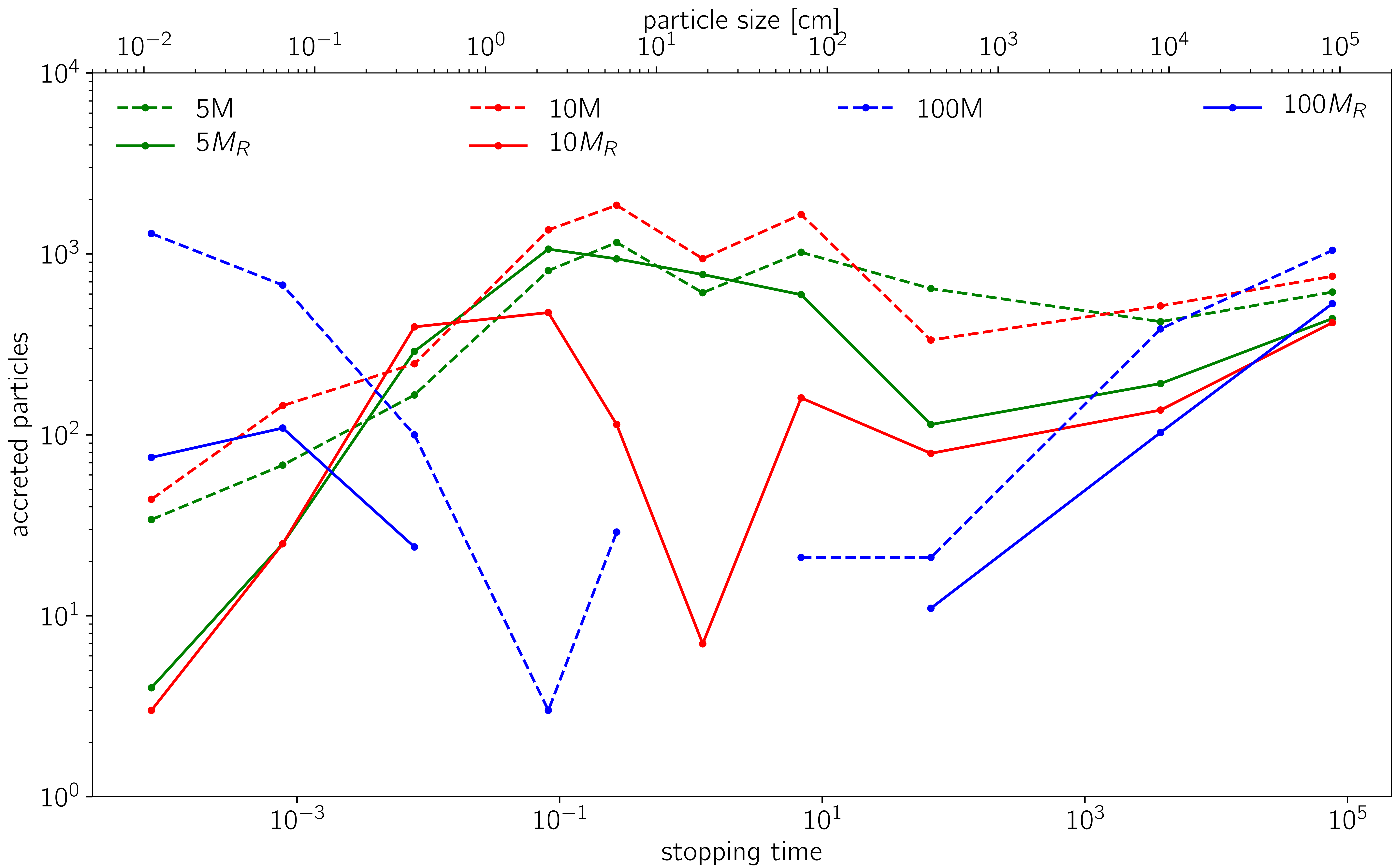
PEBBLE ACCRETION EFFICIENCY

- the efficiency of pebble accretion is the lowest between the whole sample of particles studied (2-4%)
- the slope of efficiency is compatible with theoretical prediction by Lambrechts & Johansen (2014)



Picogna, Stoll & Kley, 2018

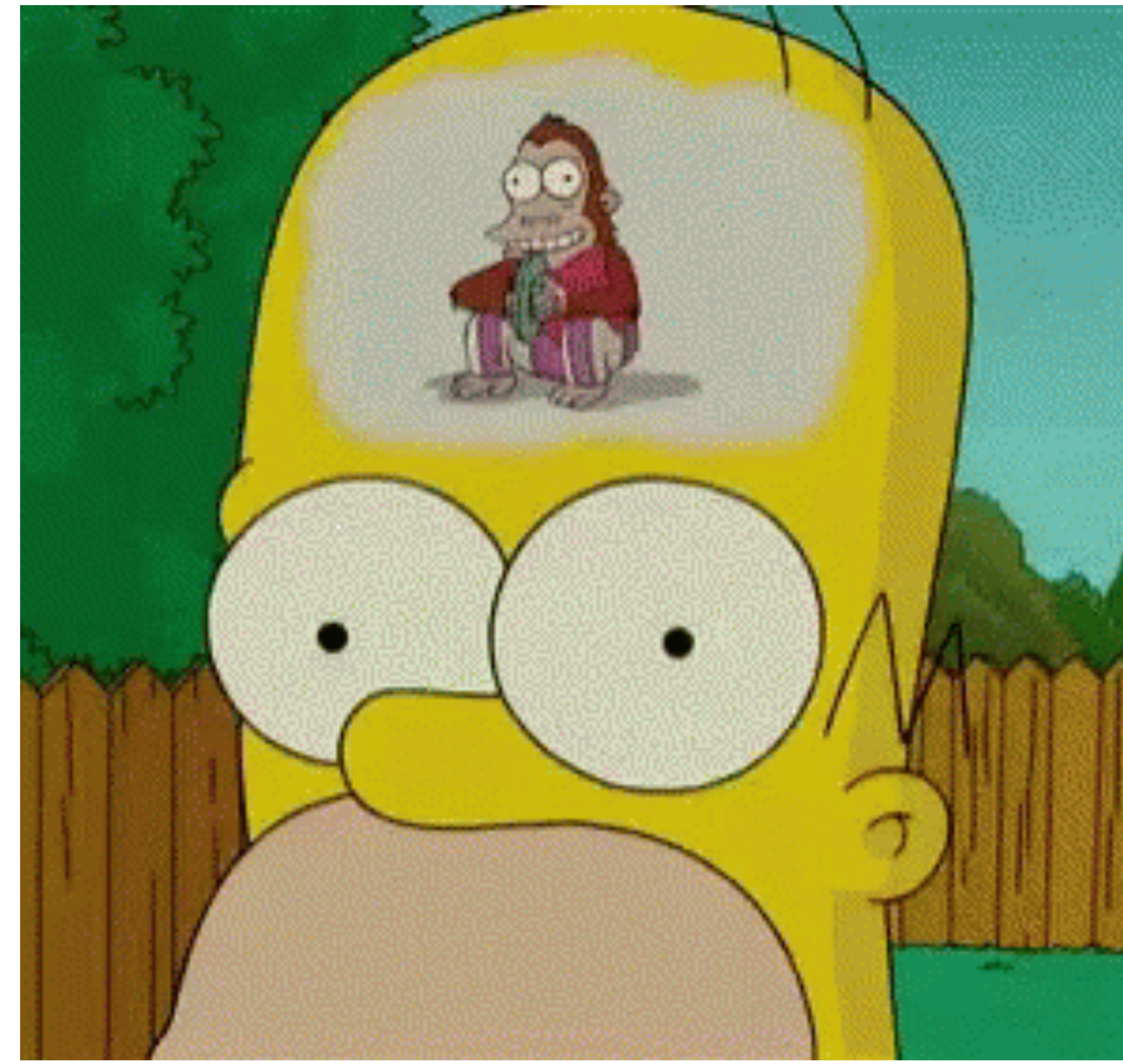
Radiative Discs



Apostolos Zorbas

- new simulations of laminar radiative discs suggest that the pebble isolation mass can be lowered including more realistic physics

4. NEW SOLUTIONS, NEW BARRIERS

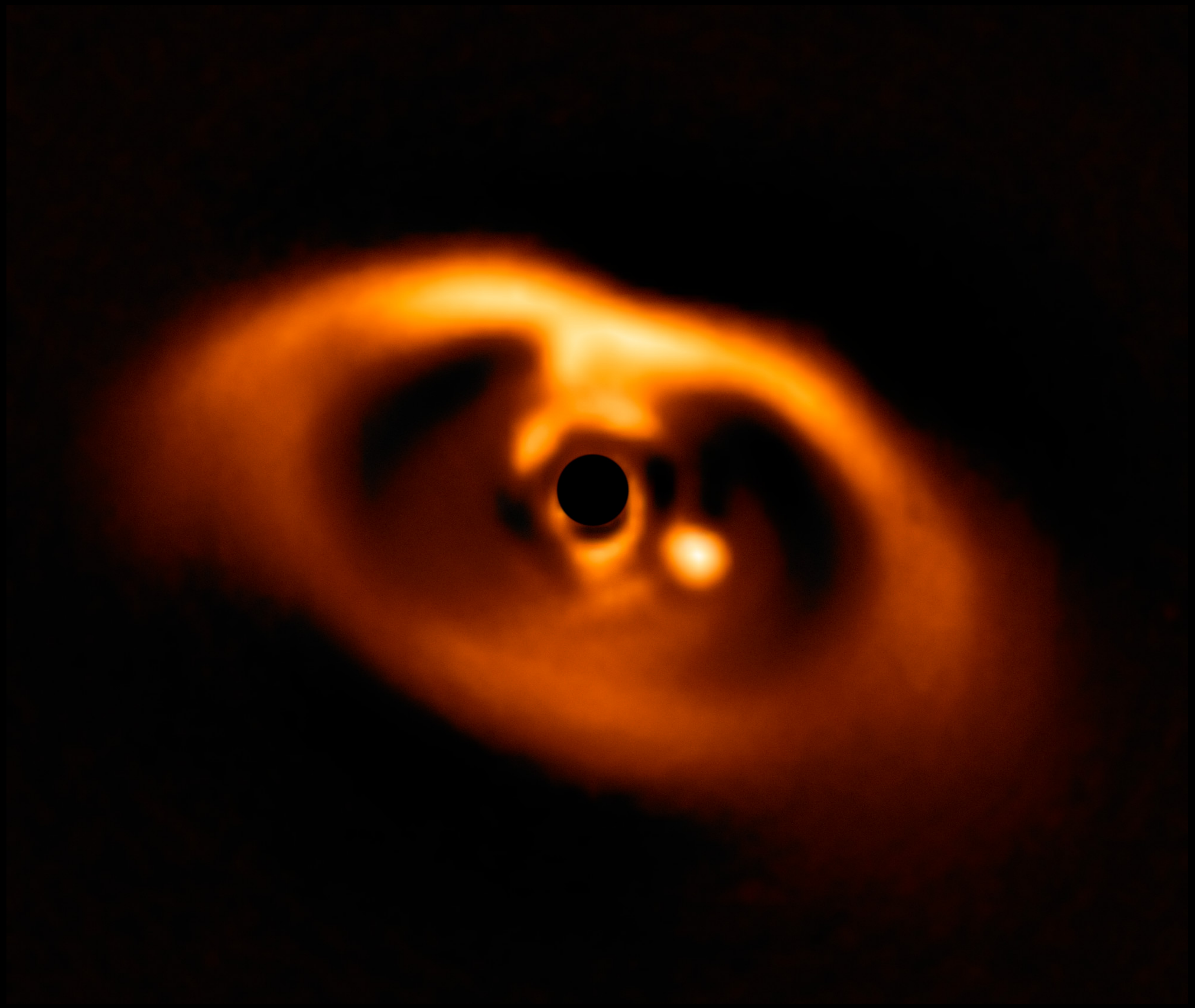


New Solutions, New Barriers

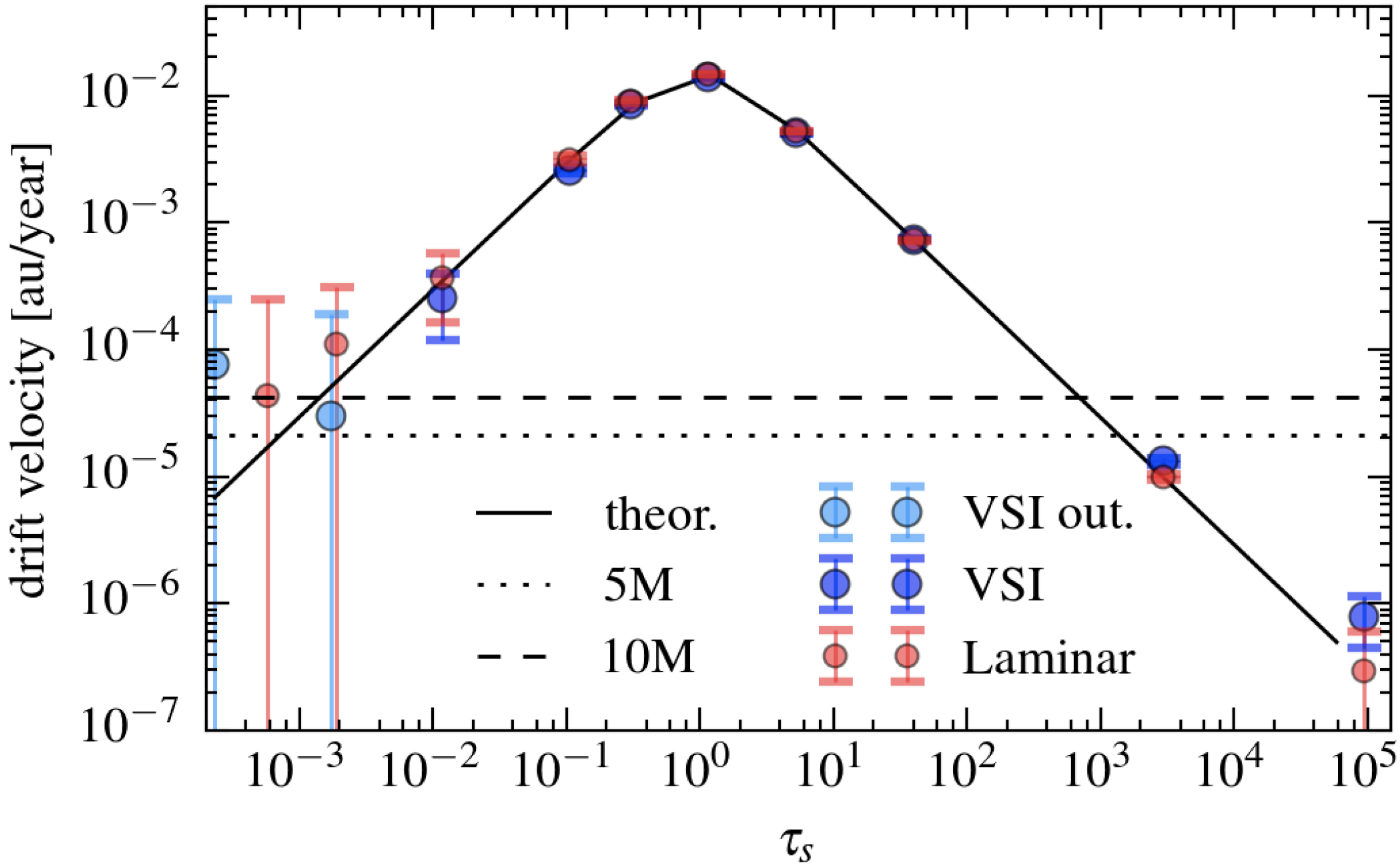
- α-disk models can be still useful to describe the evolution of dust in discs, when including turbulent kicks, and it is possible to recreate VSI turbulence assuming an anisotropic α model
- pebble accretion in turbulent 3D discs have a low (2-4%) accretion efficiency but, due to its high flux, it is the main contributor to planet solid accretion
- particle scale height in turbulent discs seem to have a similar fall-off at large Stokes number for different turbulence mechanisms
- VSI can generate rings and vortices

- pebble isolation mass can be close to 10 $M_\oplus$ in radiative discs, posing problems for giant planetary core formation
- turbulence appears everywhere in simulations yet there is no strong evidence of it in observations
- quenching of VSI due to RWI vortices
- dust feedback may quench VSI in the mid plane (wait for Min-Kai's talk)
- interaction of VSI and MRI (wait for Xuening's talk)

THANK YOU FOR YOUR ATTENTION



Planet vs Dust Migration



Picogna, Stoll & Kley, 2018