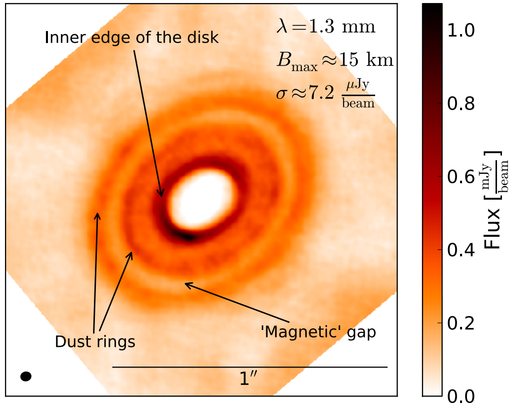
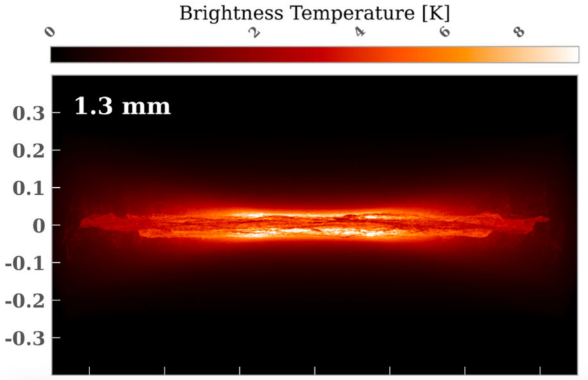
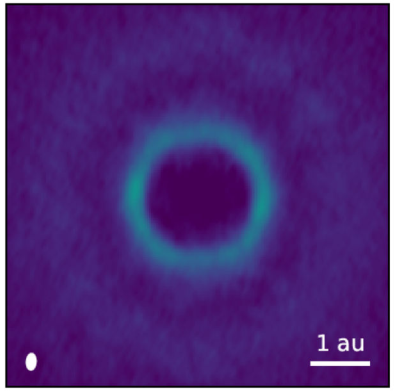
Magneto-Hydrodynamical instabilities and substructures in protoplanetary disks







Mario Flock, MIAPP, 7.11.2021

European Research Council
Established by the European Commission

Protoplanetary disks are never smooth

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CX Tau is not smooth

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Even if there are no companions, flybys, GI’s, infalls …

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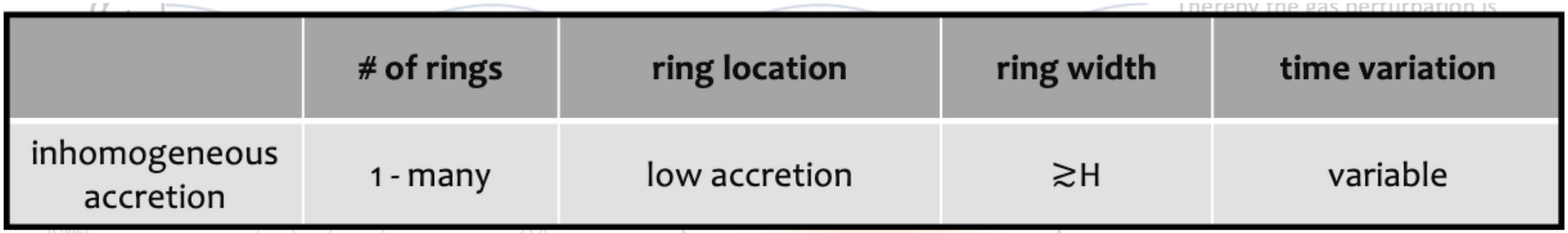


	# of rings	ring location	ring width	time variation
inhomogeneous accretion	1 - many	low accretion	≳H	variable

Talk by Jaehan Bae

Protoplanetary disks are never smooth

CX Tau is not smooth

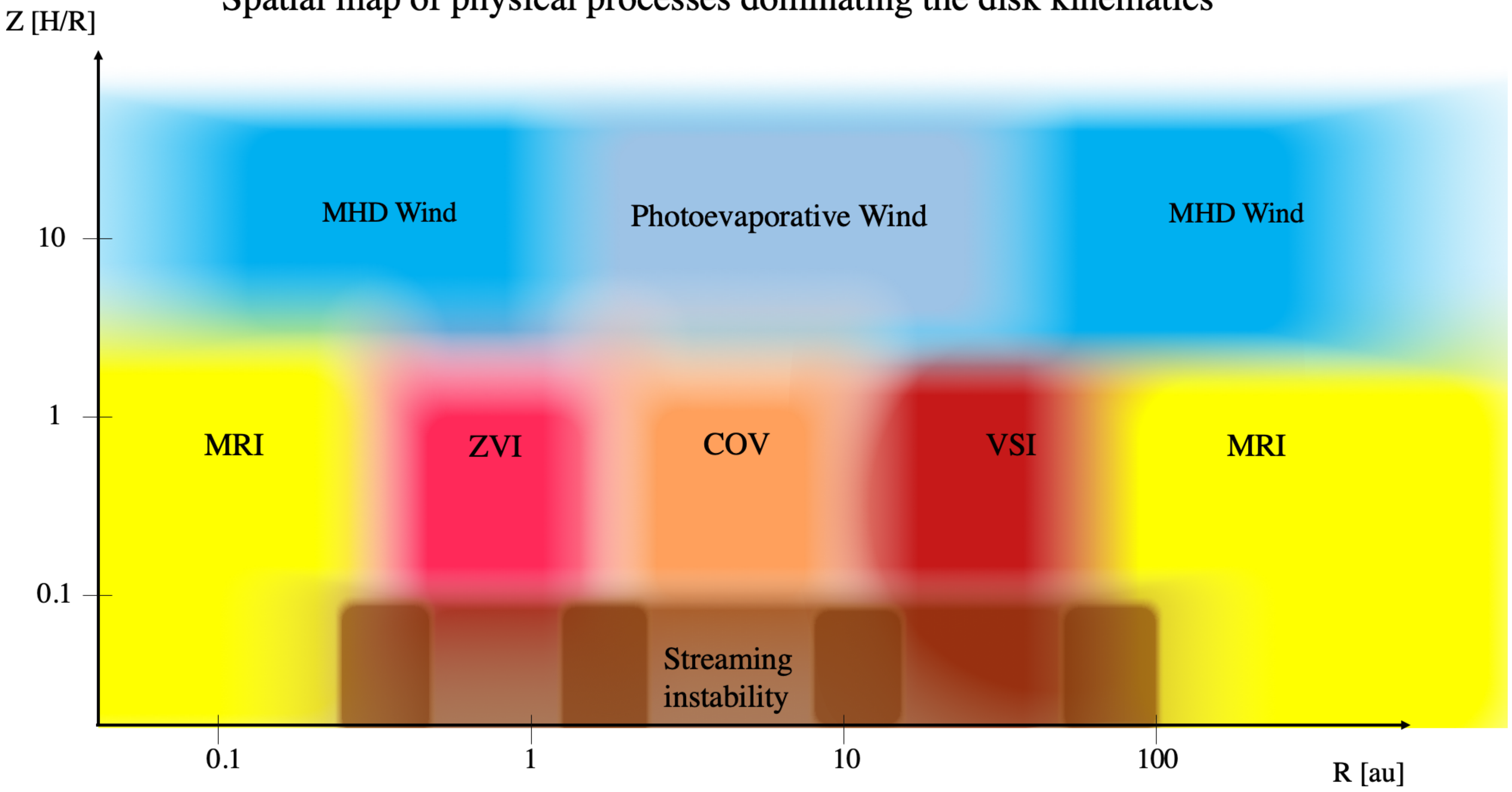
Even if there are no companions, flybys, GI’s, infalls …

	# of rings	ring location	ring width	time variation
inhomogeneous ~~accretion~~	1 - many	low accretion	$\gtrsim H$	variable

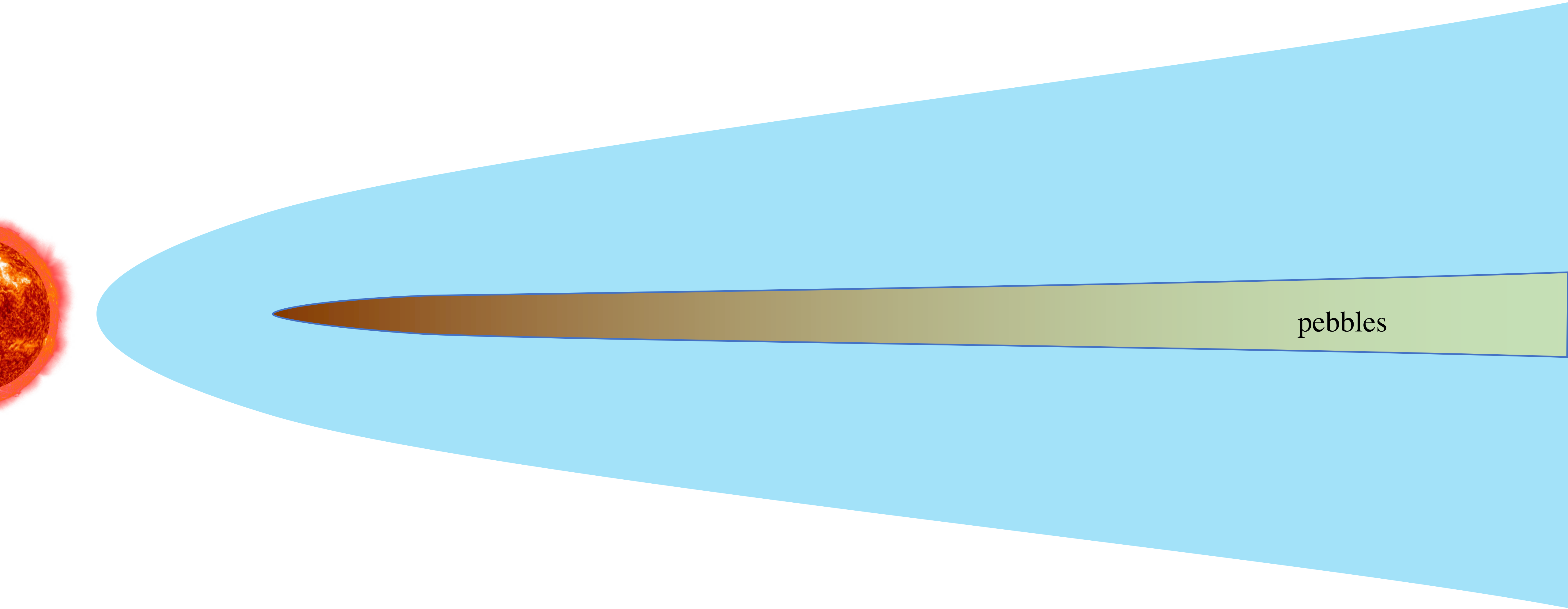
turbulence

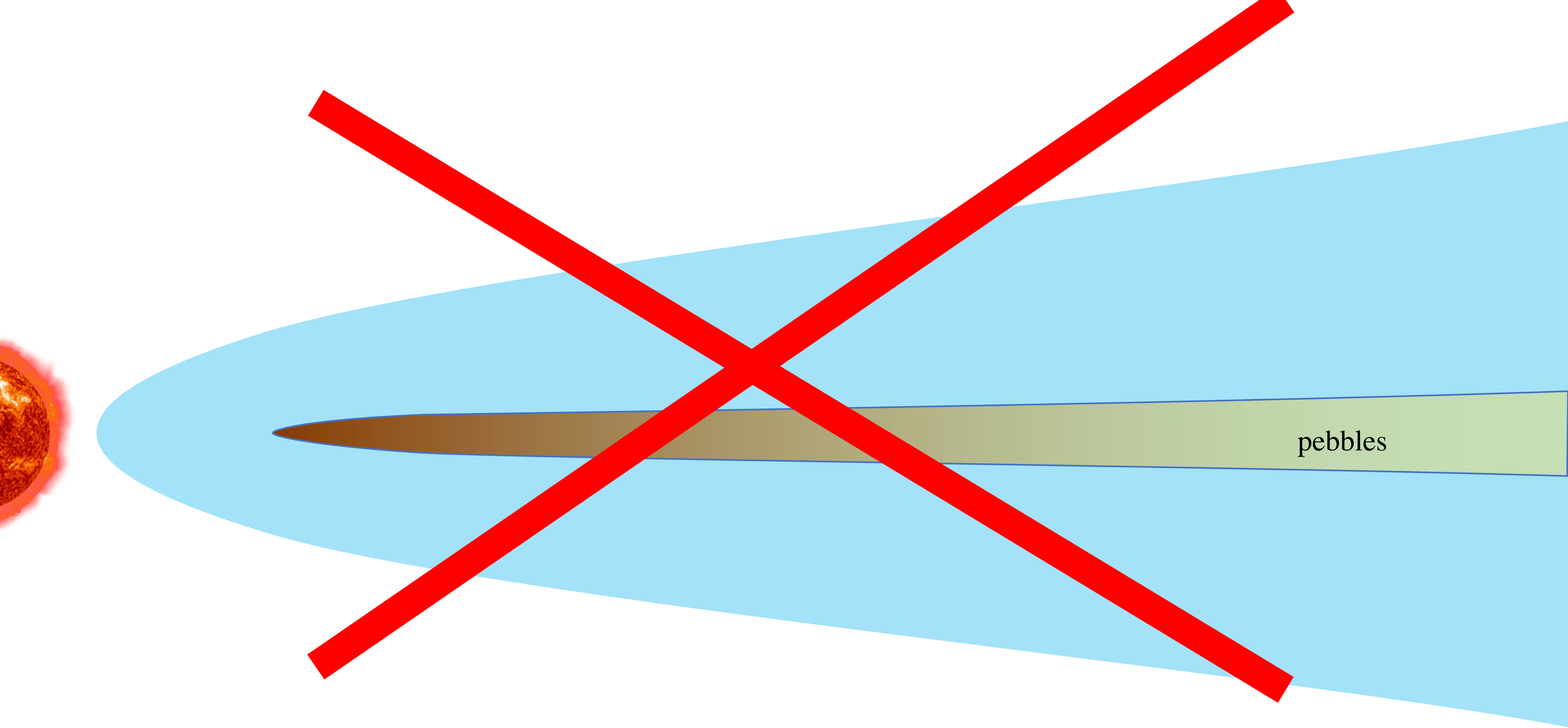
Talk by Jaehan Bae

Spatial map of physical processes dominating the disk kinematics



PPVII chapter (sneak preview)


pebbles



There is no smooth dusty disk in Stokes = 0.1 grains

Flock & Mignone A&A 2021

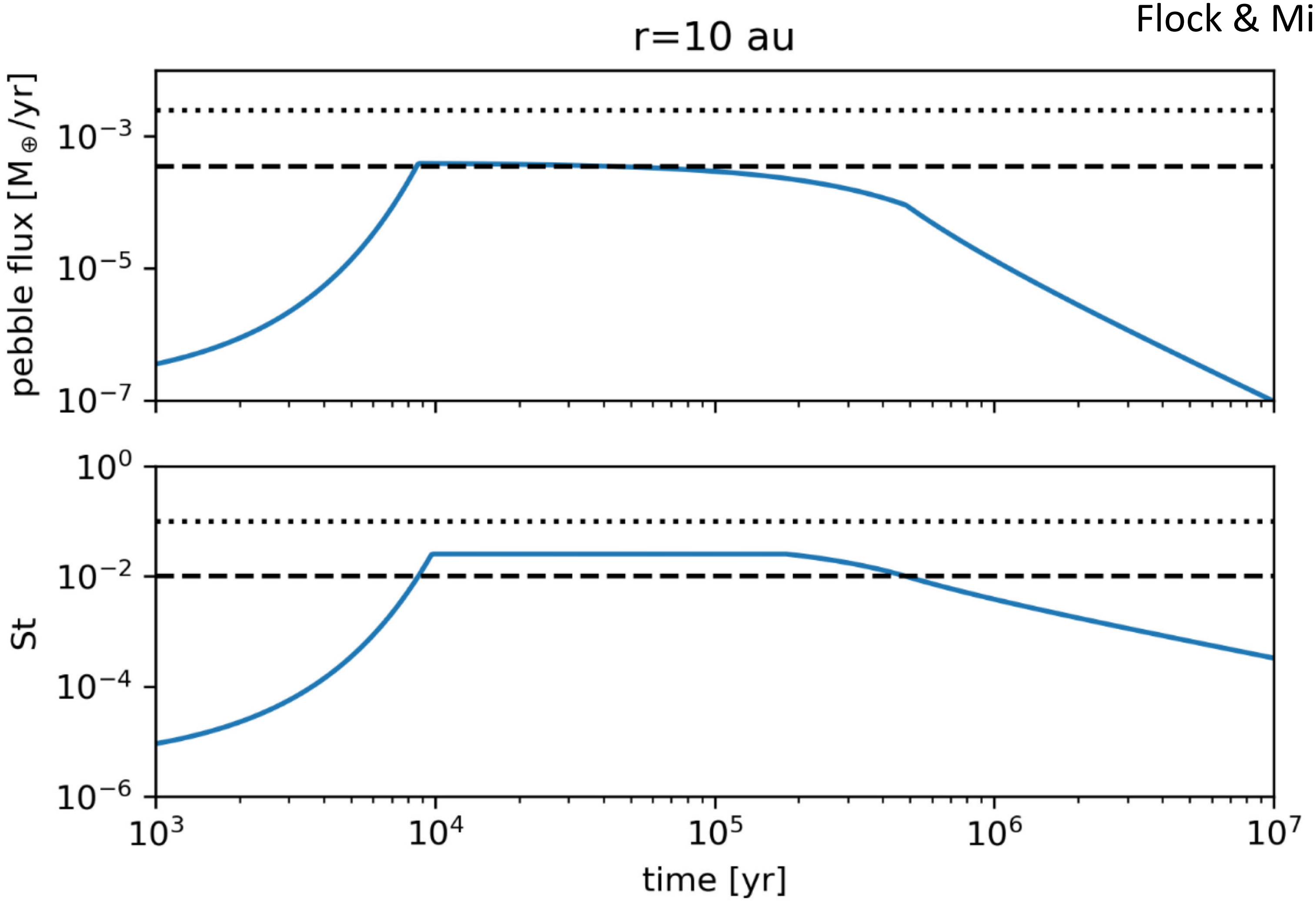


Fig. 7. Pebble flux over time, calculated with the pebble predictor tool

By Drążkowska et al. 2021

Timescale to perturb the disk

Flock & Mignone A&A 2021

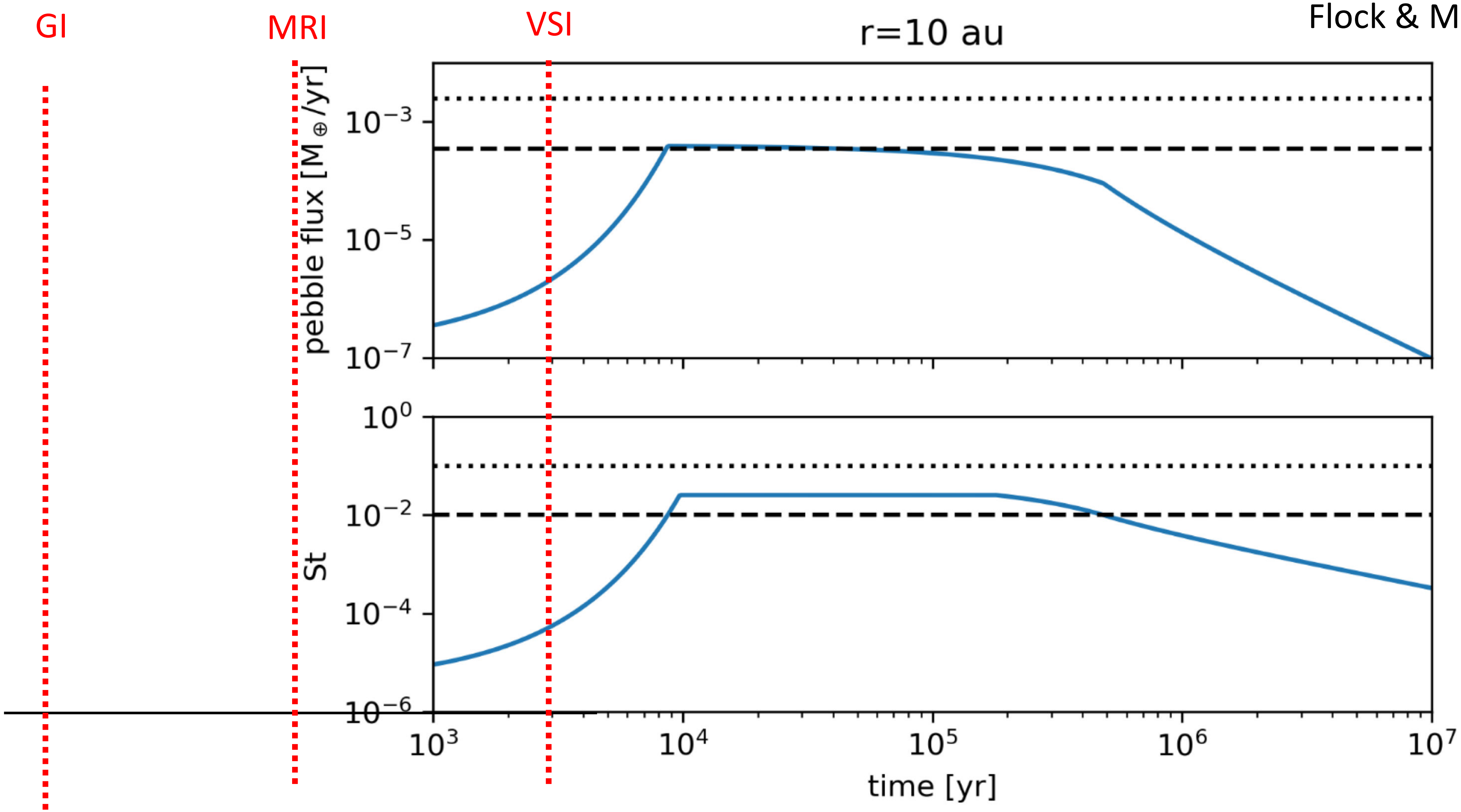


Fig. 7. Pebble flux over time, calculated with the pebble predictor tool

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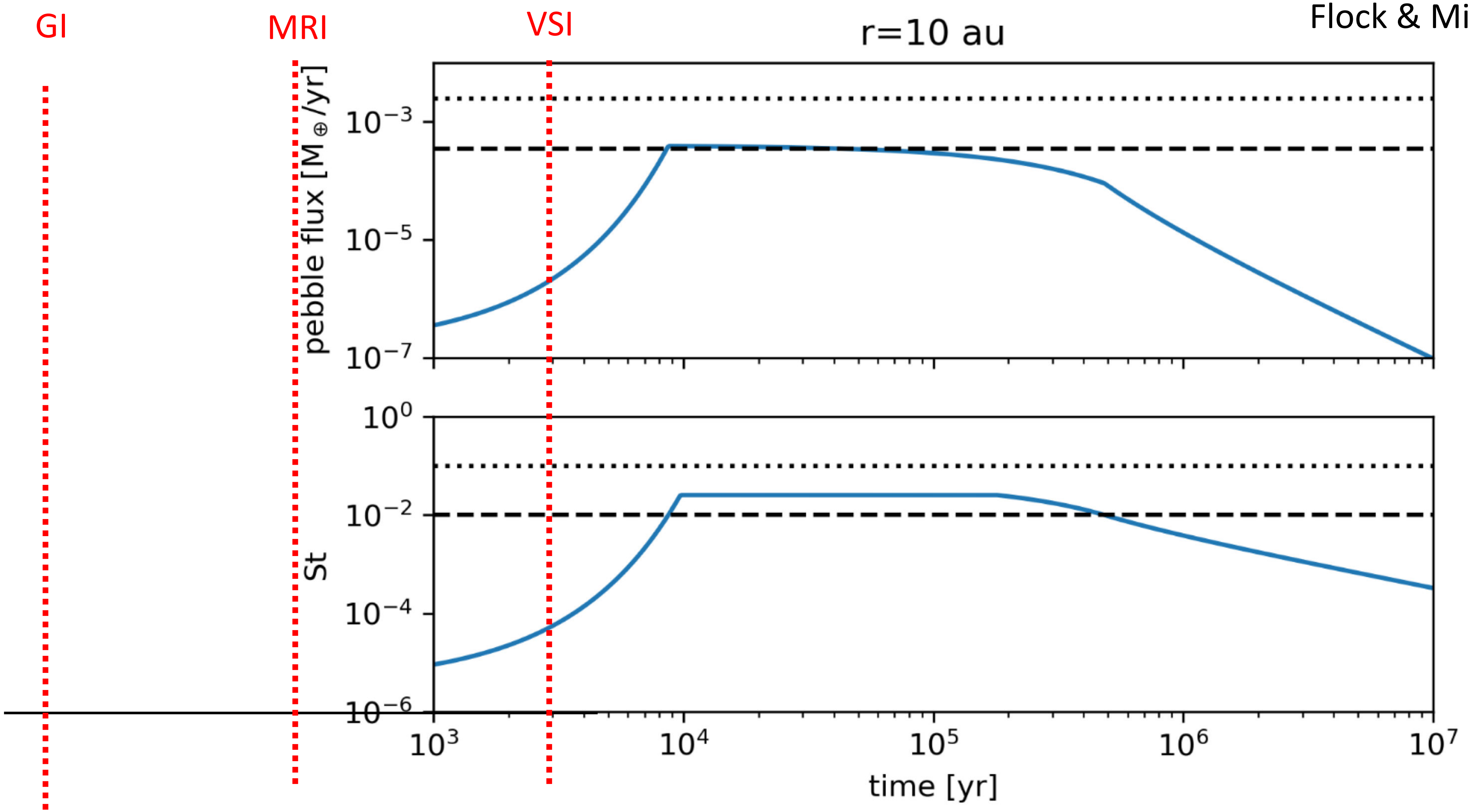
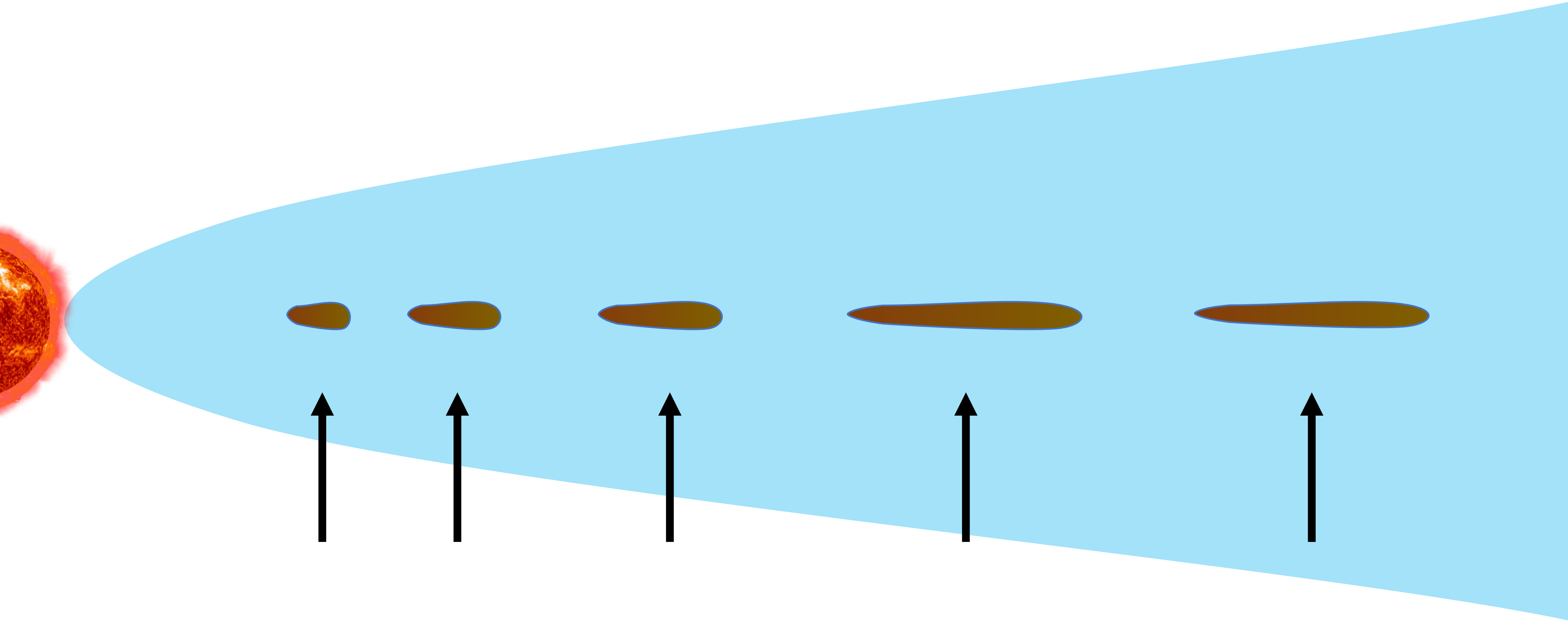
Timescale to perturb the disk



Flock & Mignone A&A 2021

The disk is perturbed before the pebbles start to drift



Grains which are either trapped at pressure maxima or slowed down

Are the features we observe created by planets?

~~Are the features we observe created by planets?~~

Advise: avoid questions which should be answered with a simple Yes or No

Planets are formed due to disk perturbations

Planets are formed due to disk perturbations

Planets can **further** perturb the disk

Planets are formed due to disk perturbations
Planets can **further** perturb the disk

Light disks

Massive disks

- Not enough dust material to form planets which could perturb the disk

- In the process of forming or already formed planets which can perturb the disk

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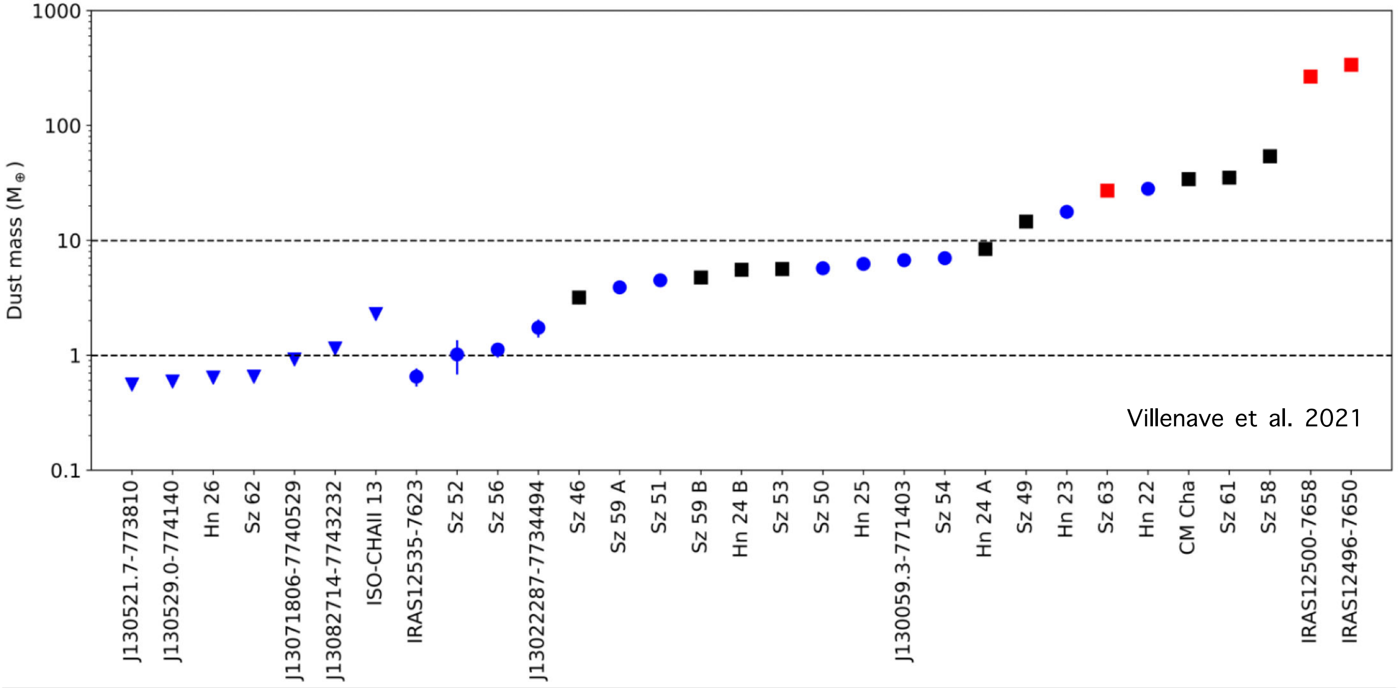

Fig. 3. Dust masses for the 31 sources in our Cha II sample expressed in Earth masses, ordered by increasing dust mass (Table 2). The black and red squares indicates the sources also detected in ^{12}CO and ^{13}CO, respectively. Round symbols show continuum only detected sources and the downward-facing triangles correspond to 3σ upper limits for non-detections.

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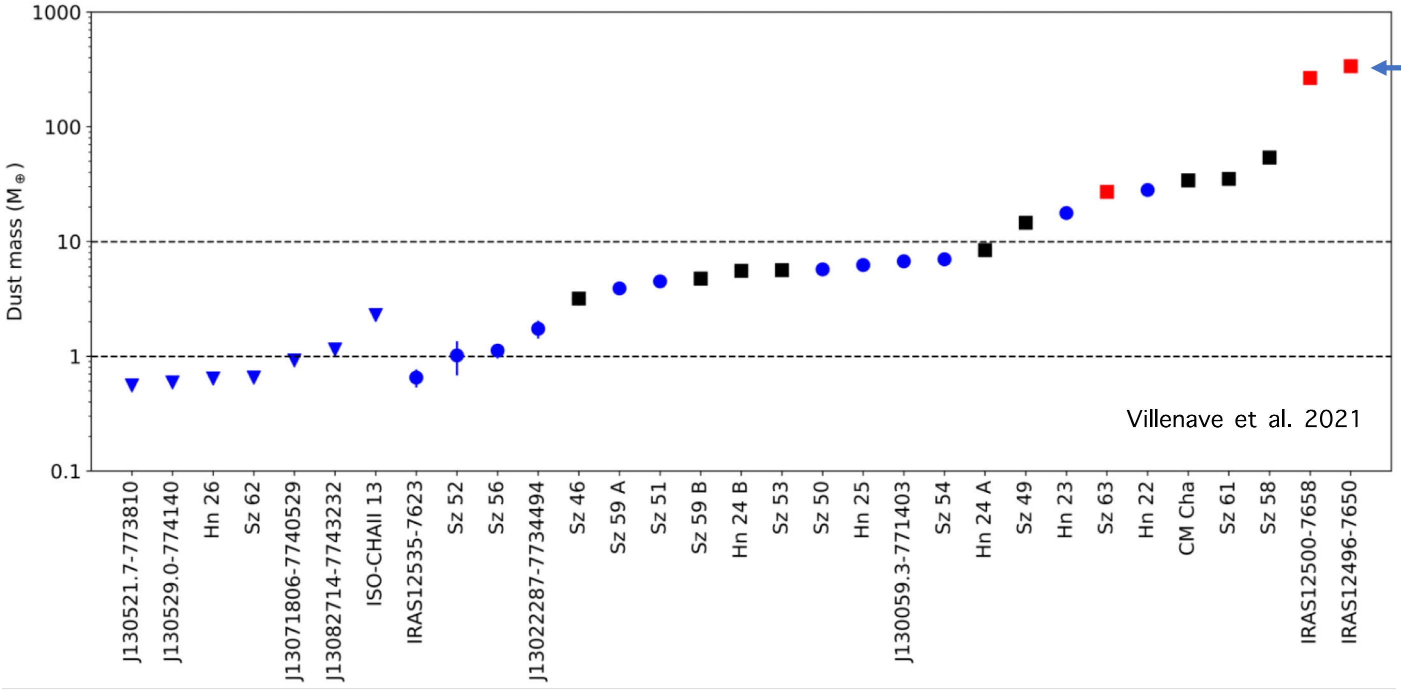

Villenave et al. 2021

HL Tau

Observational bias

(discussion on Monday)

Fig. 3. Dust masses for the 31 sources in our Cha II sample expressed in Earth masses, ordered by increasing dust mass (Table 2). The black and red squares indicates the sources also detected in ^{12}CO and ^{13}CO, respectively. Round symbols show continuum only detected sources and the downward-facing triangles correspond to 3σ upper limits for non-detections.

I. Substructures at the inner dead-zone edge

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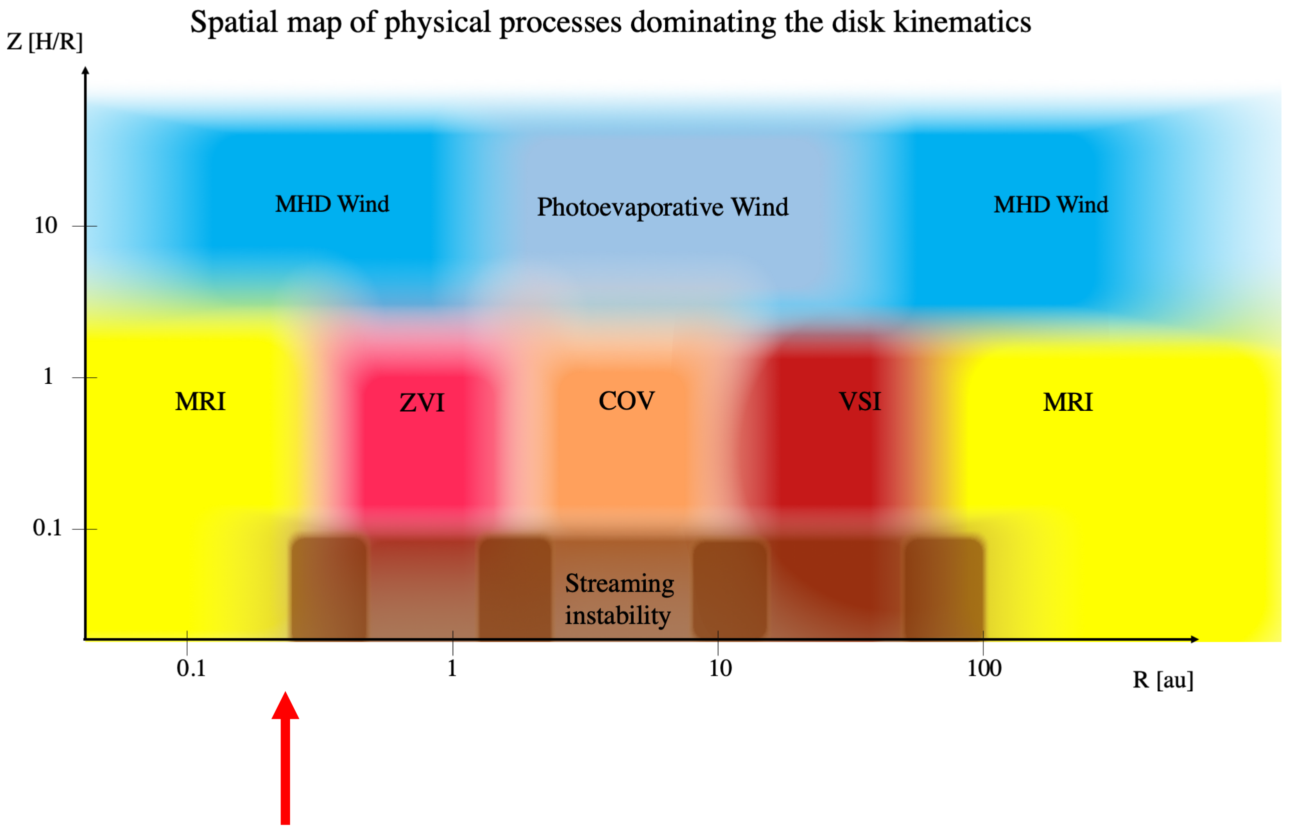
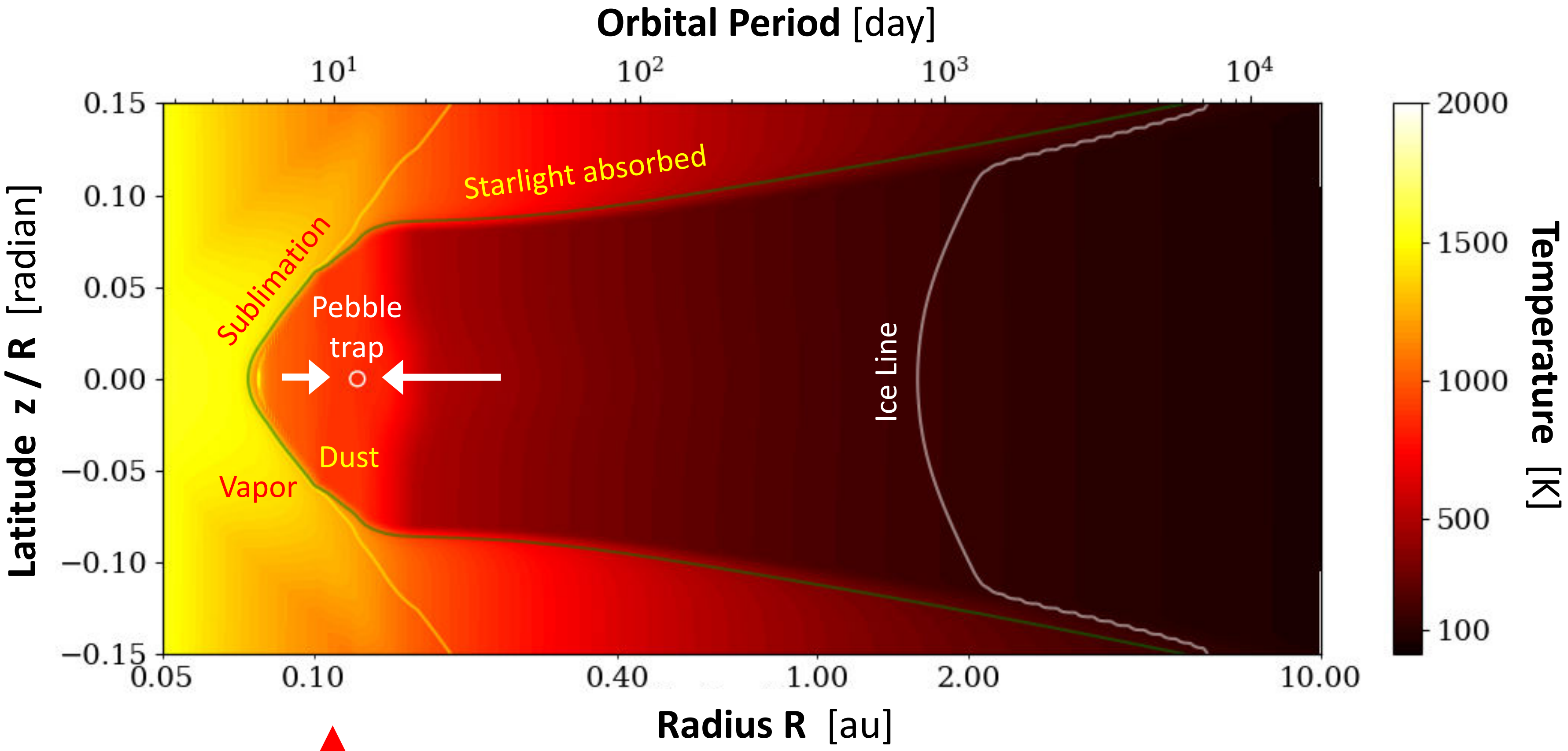


I. Substructures at the inner dead-zone edge

Flock et al. 2016, 2017

Flock et al. 2019 A&A

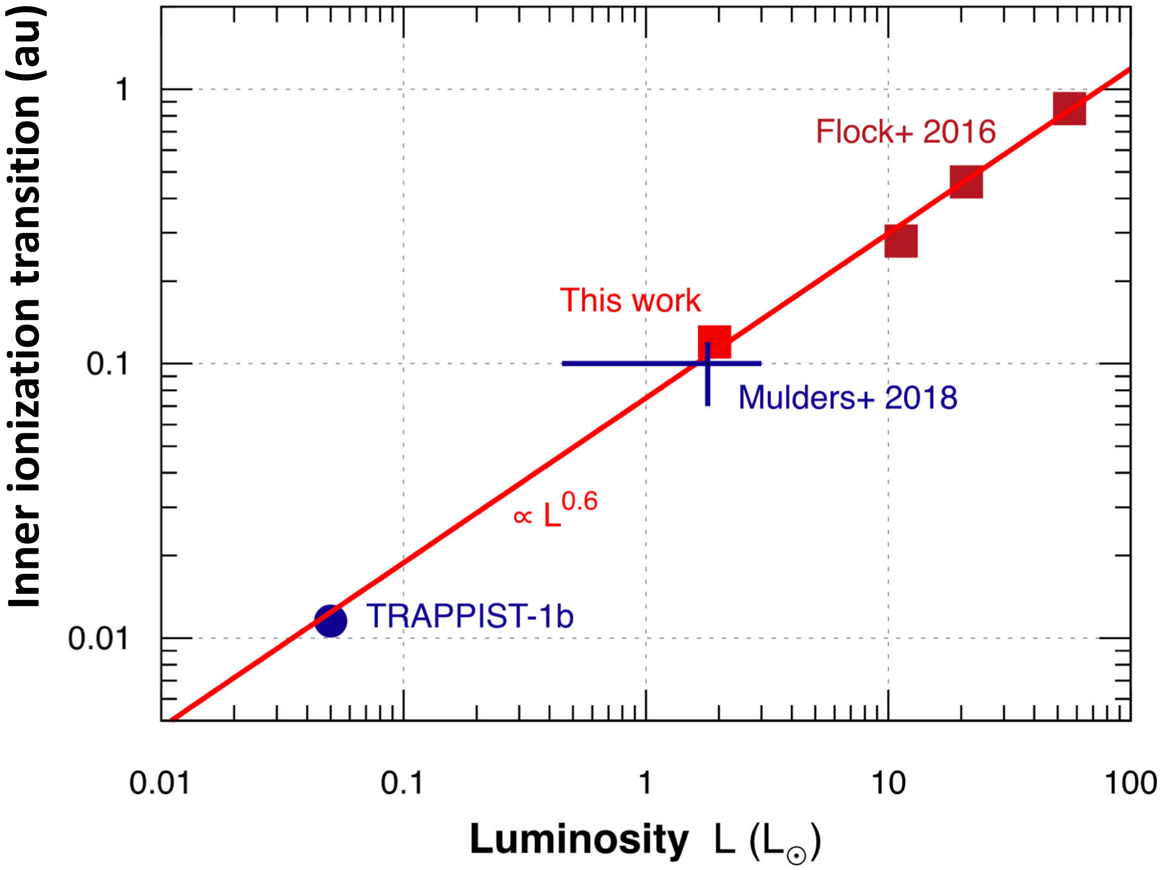


MRI/non-MRI transition

I. Substructures at the inner dead-zone edge

Flock et al. 2016, 2017

Flock et al. 2019 A&A



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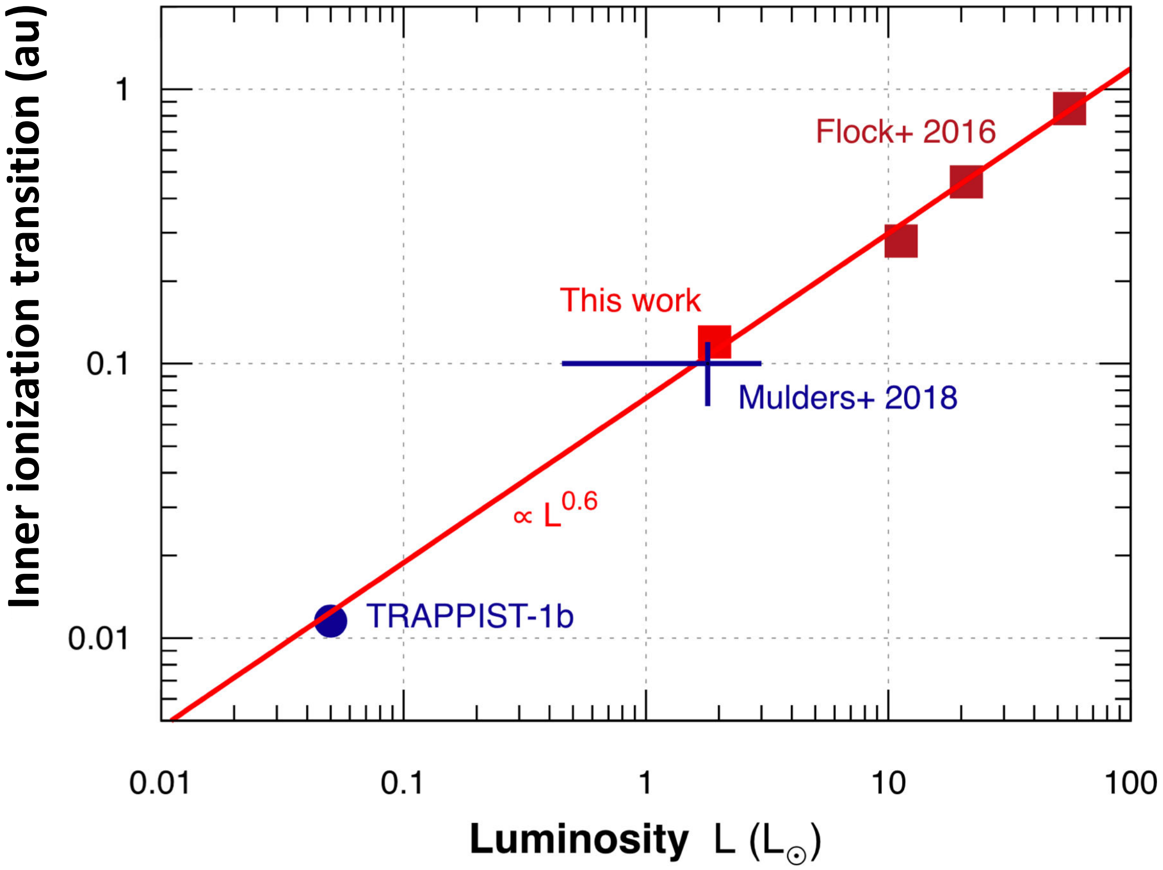
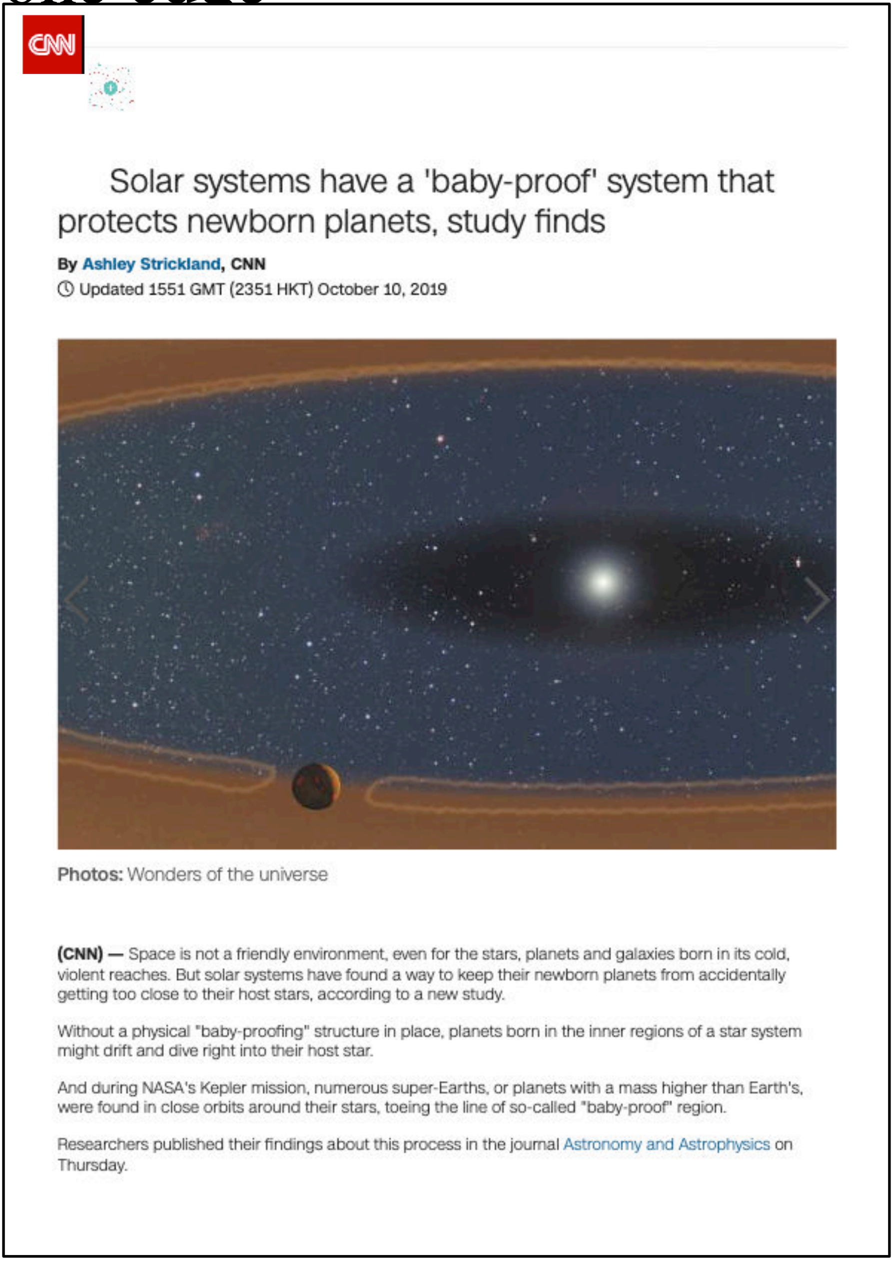
Flock et al. 2016, 2017
Flock et al. 2019 A&A





Solar systems have a 'baby-proof' system that protects newborn planets, study finds

By Ashley Strickland, CNN
Updated 1551 GMT (2351 HKT) October 10, 2019

Photos: Wonders of the universe

(CNN) — Space is not a friendly environment, even for the stars, planets and galaxies born in its cold, violent reaches. But solar systems have found a way to keep their newborn planets from accidentally getting too close to their host stars, according to a new study.

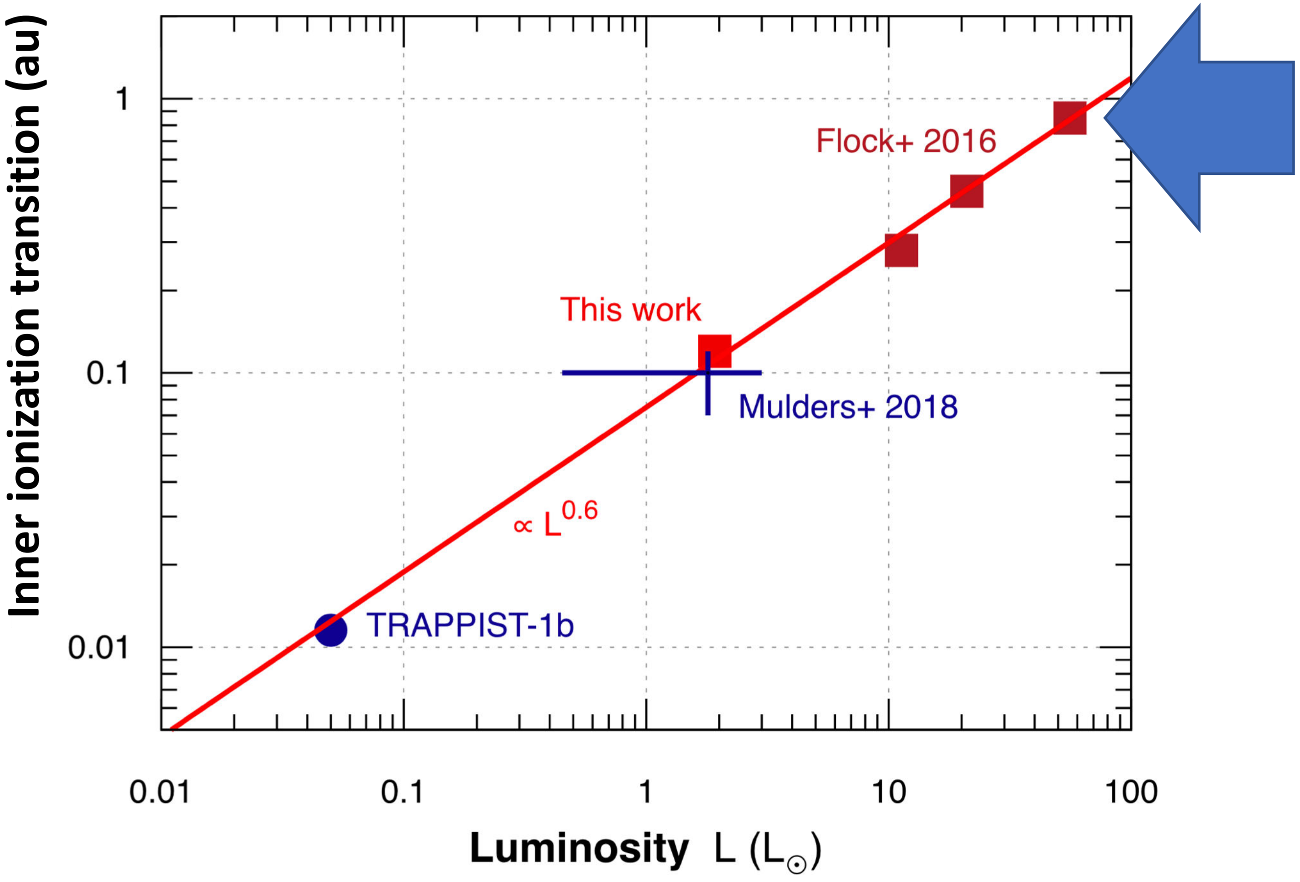
Without a physical "baby-proofing" structure in place, planets born in the inner regions of a star system might drift and dive right into their host star.

And during NASA's Kepler mission, numerous super-Earths, or planets with a mass higher than Earth's, were found in close orbits around their stars, toeing the line of so-called "baby-proof" region.

Researchers published their findings about this process in the journal Astronomy and Astrophysics on Thursday.

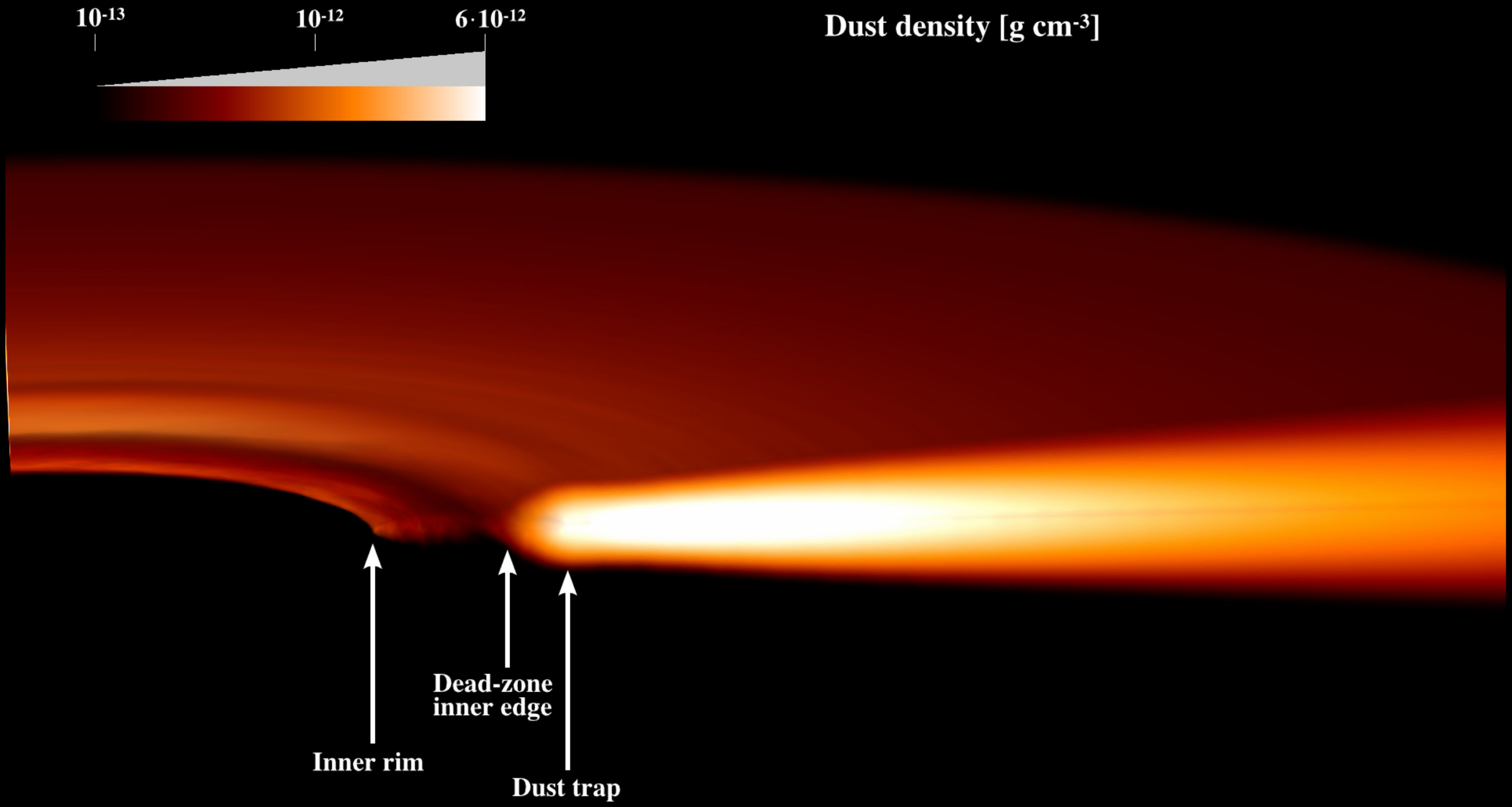
I. Substructures at the inner dead-zone edge

Flock et al. 2016, 2017
Flock et al. 2019 A&A



3D radiation non-ideal MHD models

Flock et al. 2017 - ApJ



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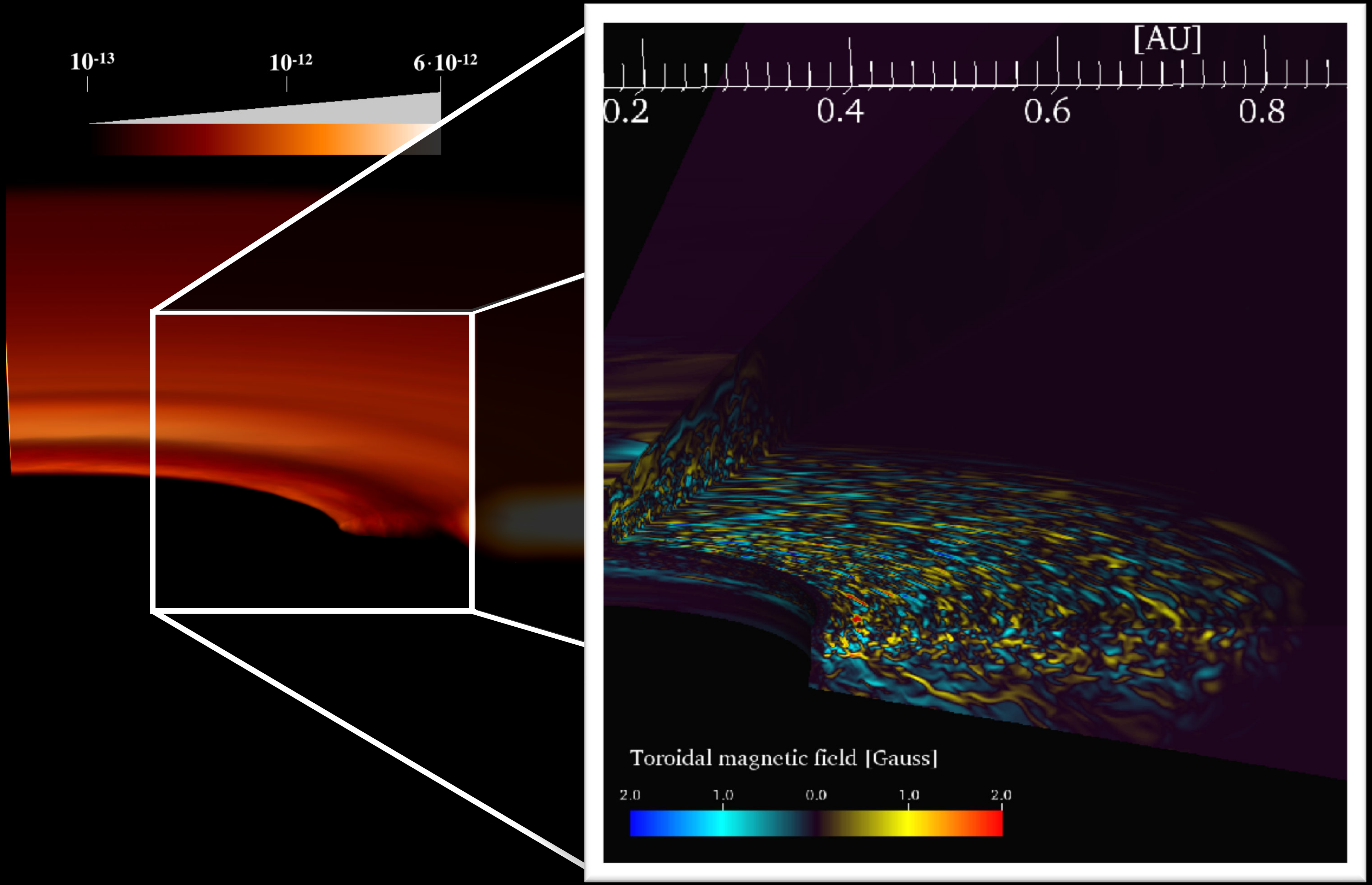
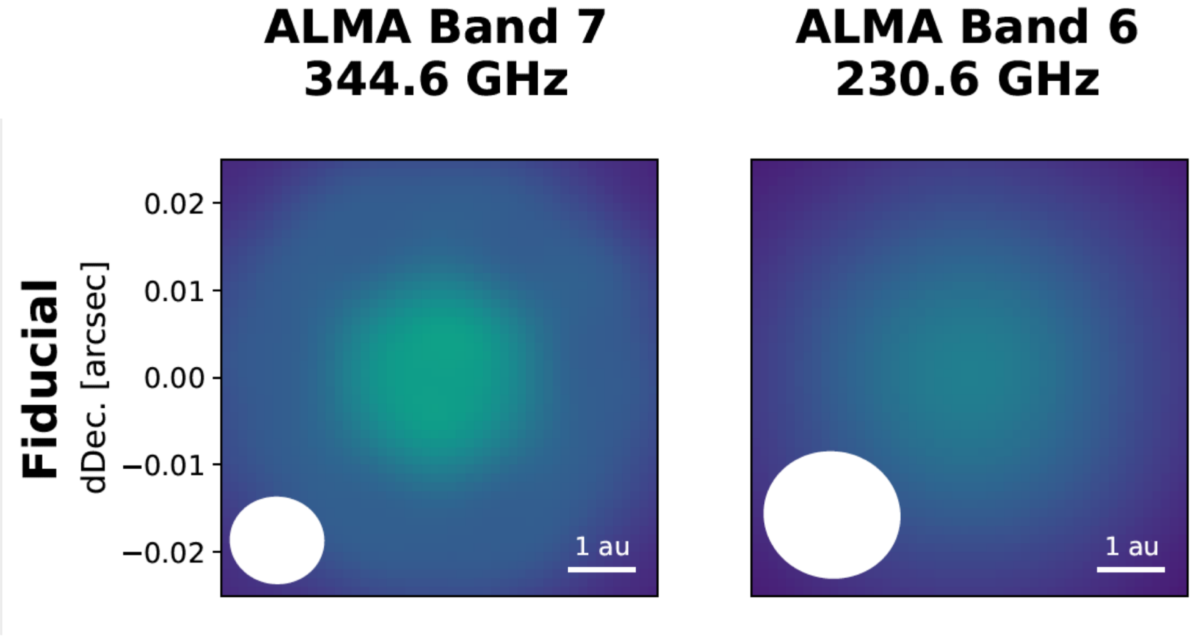


I. Substructures at the inner dead-zone edge

1D dust evolution at the inner dead-zone edge (Herbig Star)



Preliminary!!! Ueda et al. in prep.

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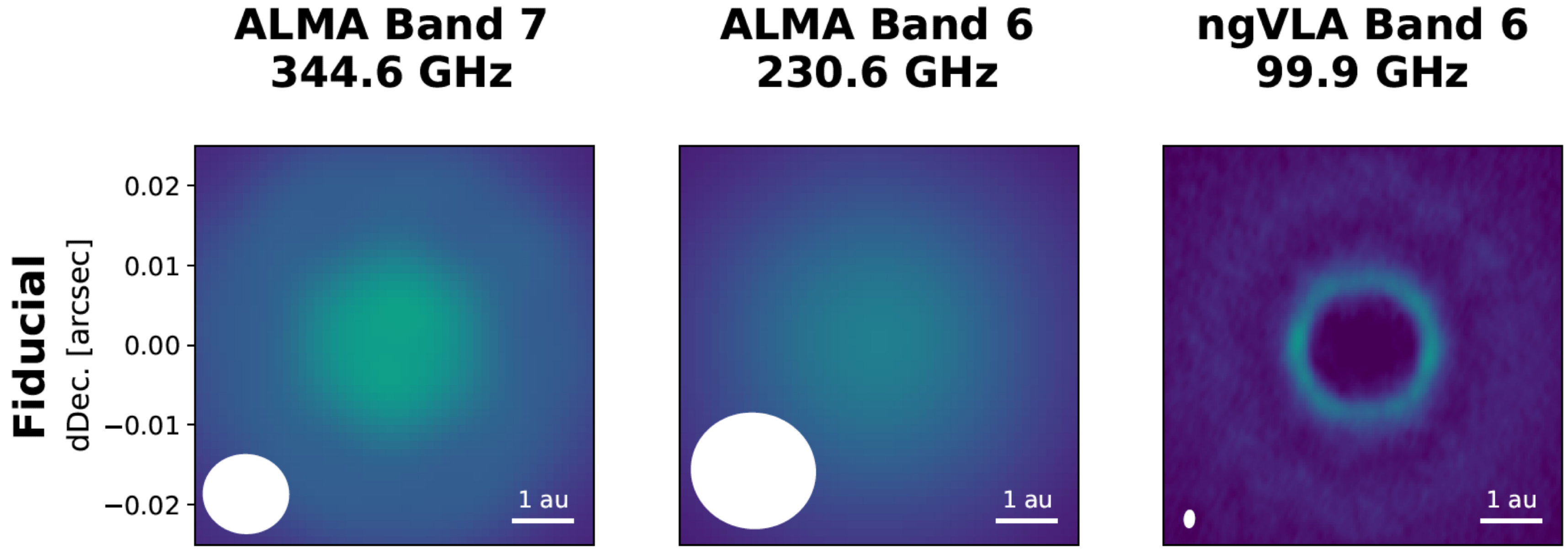
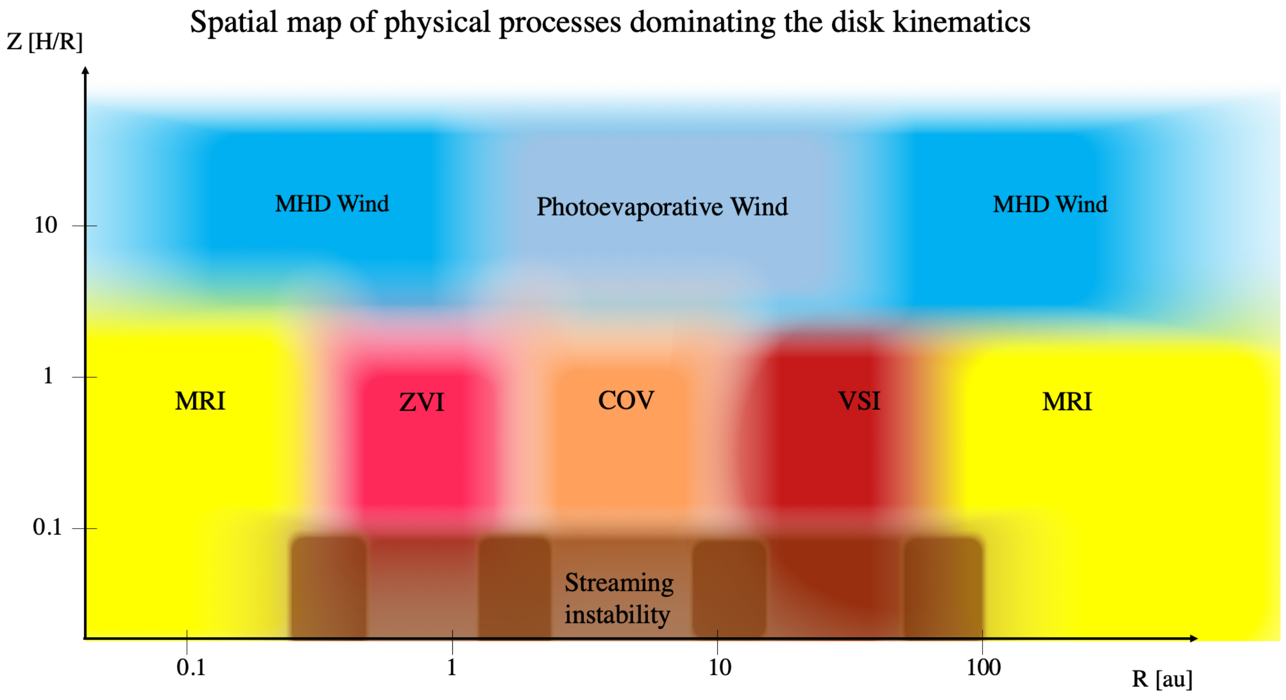


Preliminary!!! Ueda et al. in prep.

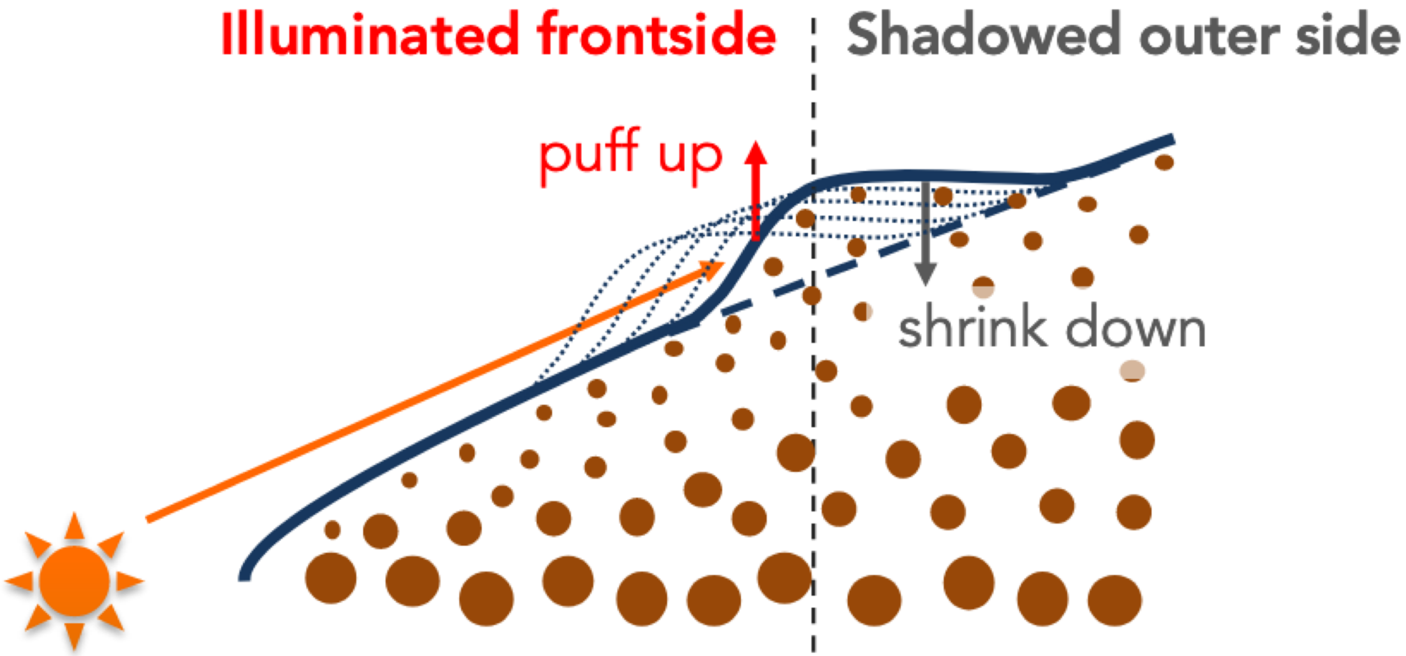
IIa. Substructures inside the dead-zone



IIa. Substructures inside the dead-zone

Thermal wave instability

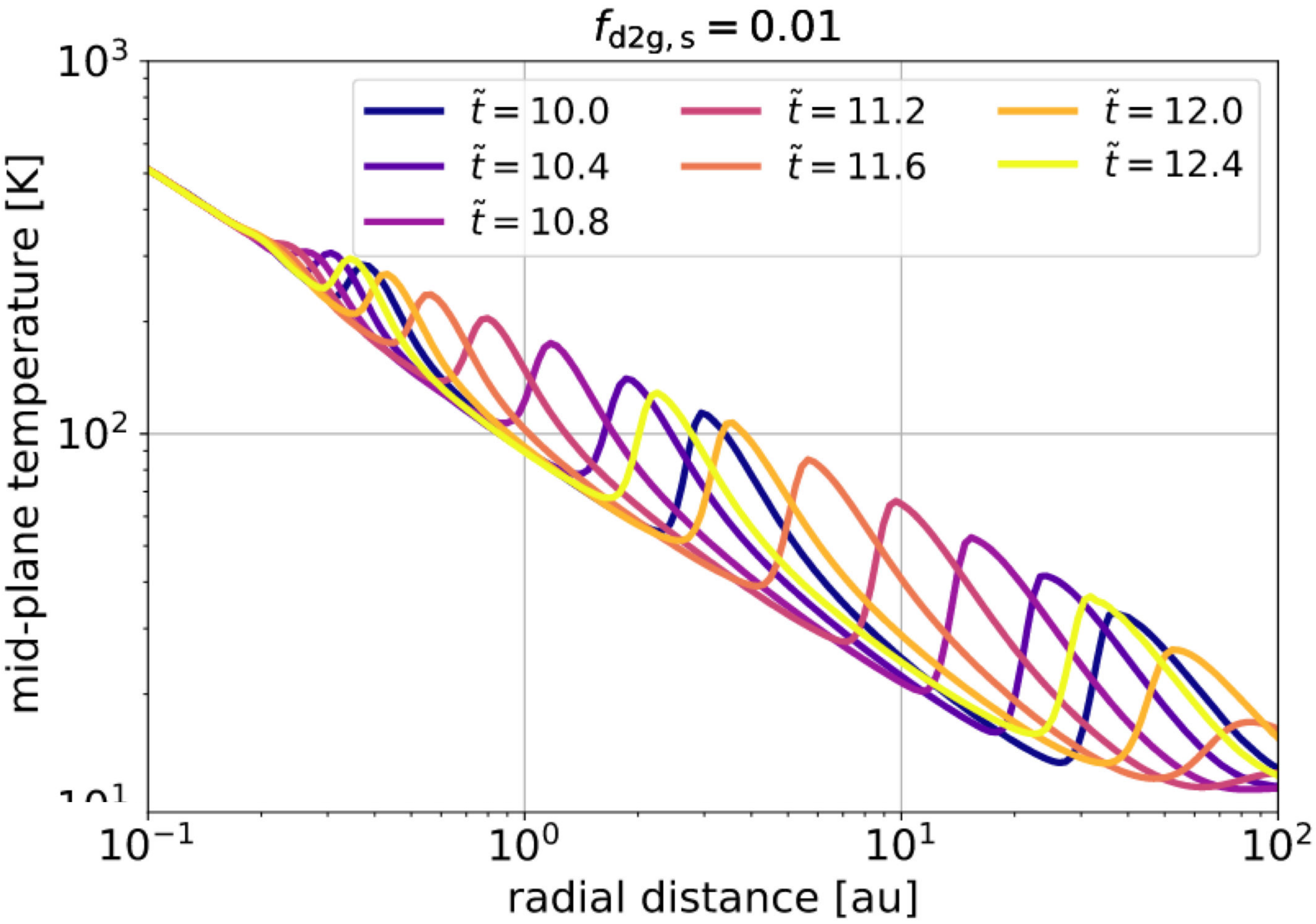
See also Watanabe & Lin 2008



Ueda, Flock, Birnstiel - ApJL 2021

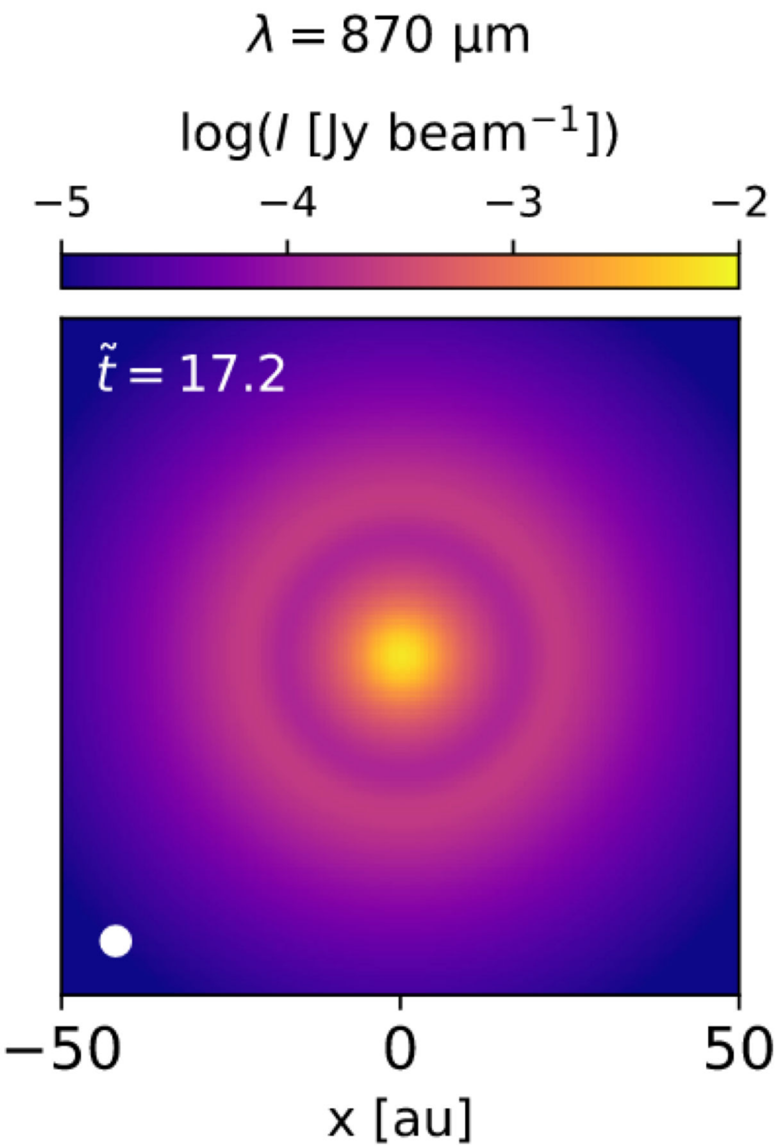
IIa. Substructures inside the dead-zone

Ueda, Flock, Birnstiel - ApJL 2021



IIa. Substructures inside the dead-zone

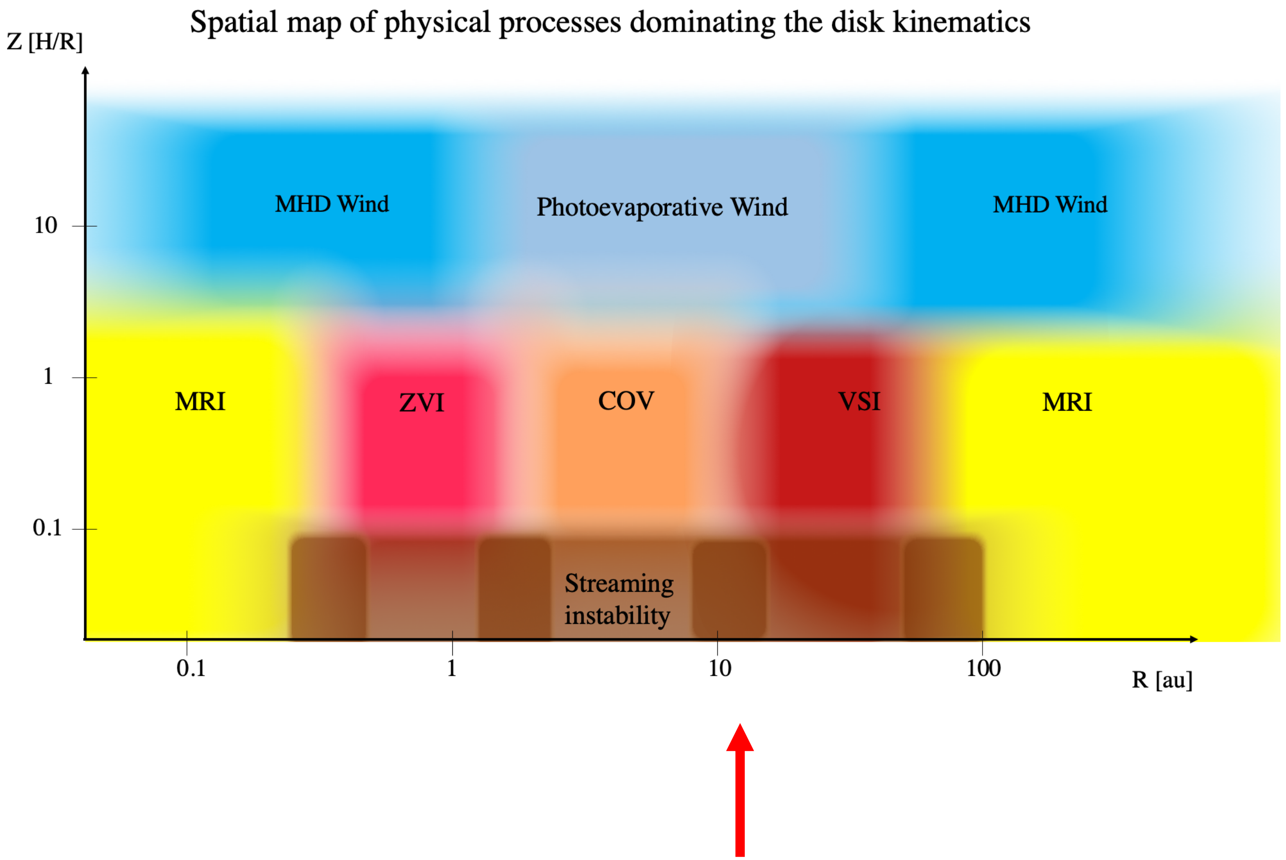
Ueda, Flock, Birnstiel - ApJL 2021



- **Substructures due to temperature variations**

  Most efficient between 1-10 au

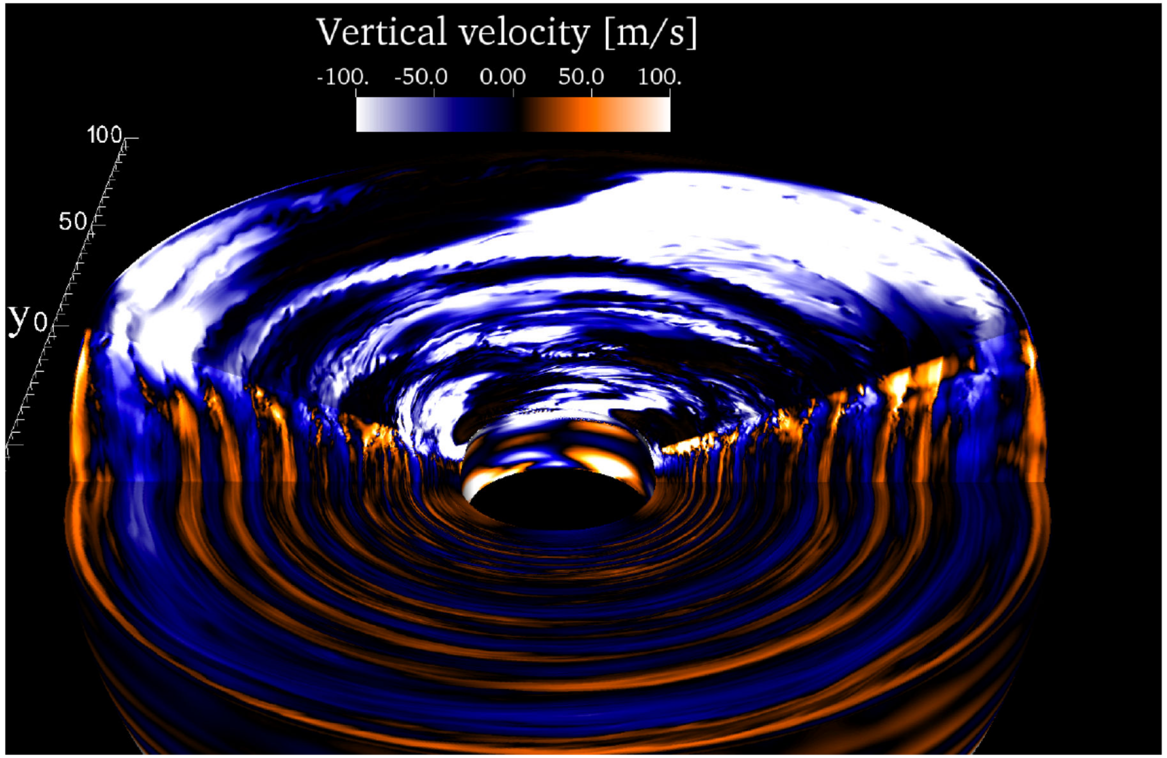
IIb. Substructures inside the dead-zone



IIb. Substructures inside the dead-zone

Flock et al. 2020
Blanco, Ricci, Flock, Turner 2021

3D radiation (M)HD simulations of protoplanetary disks



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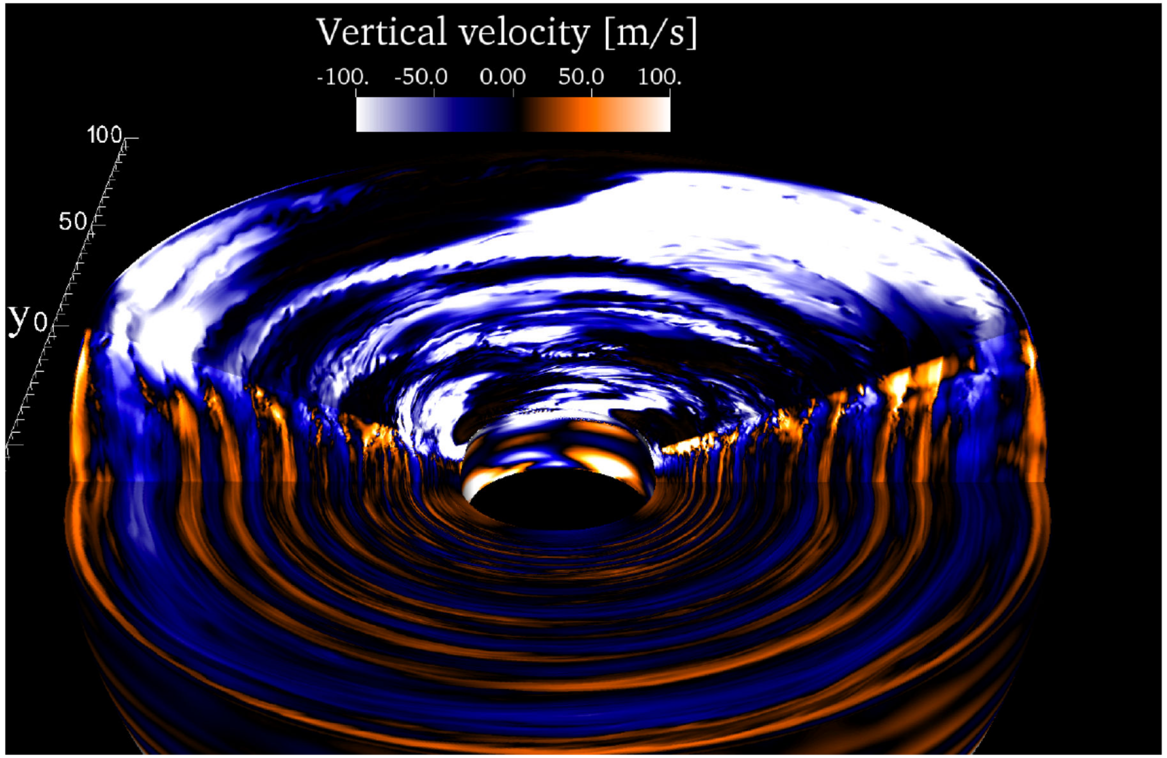

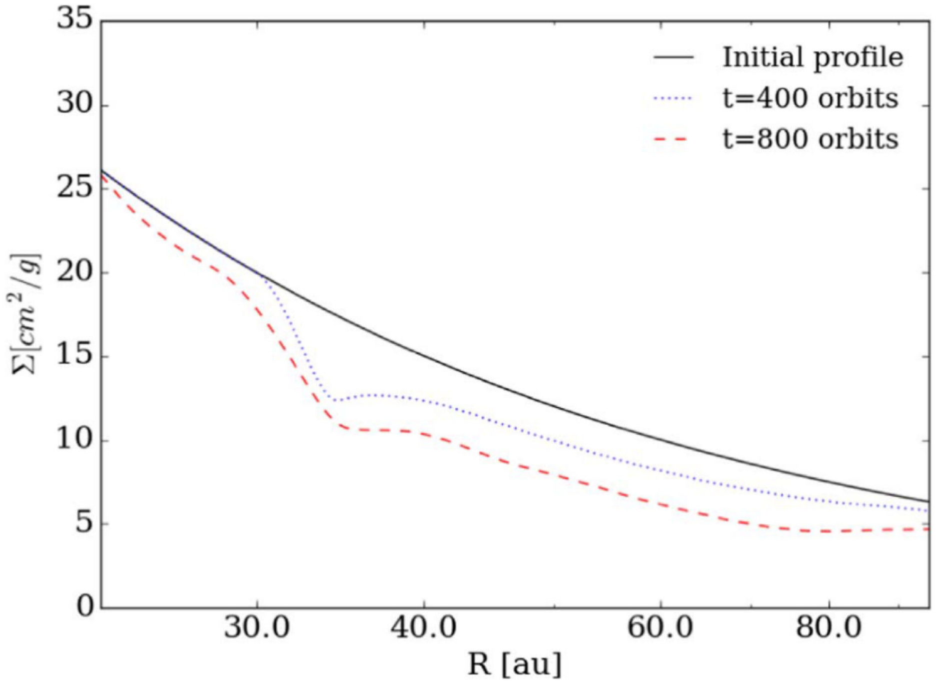

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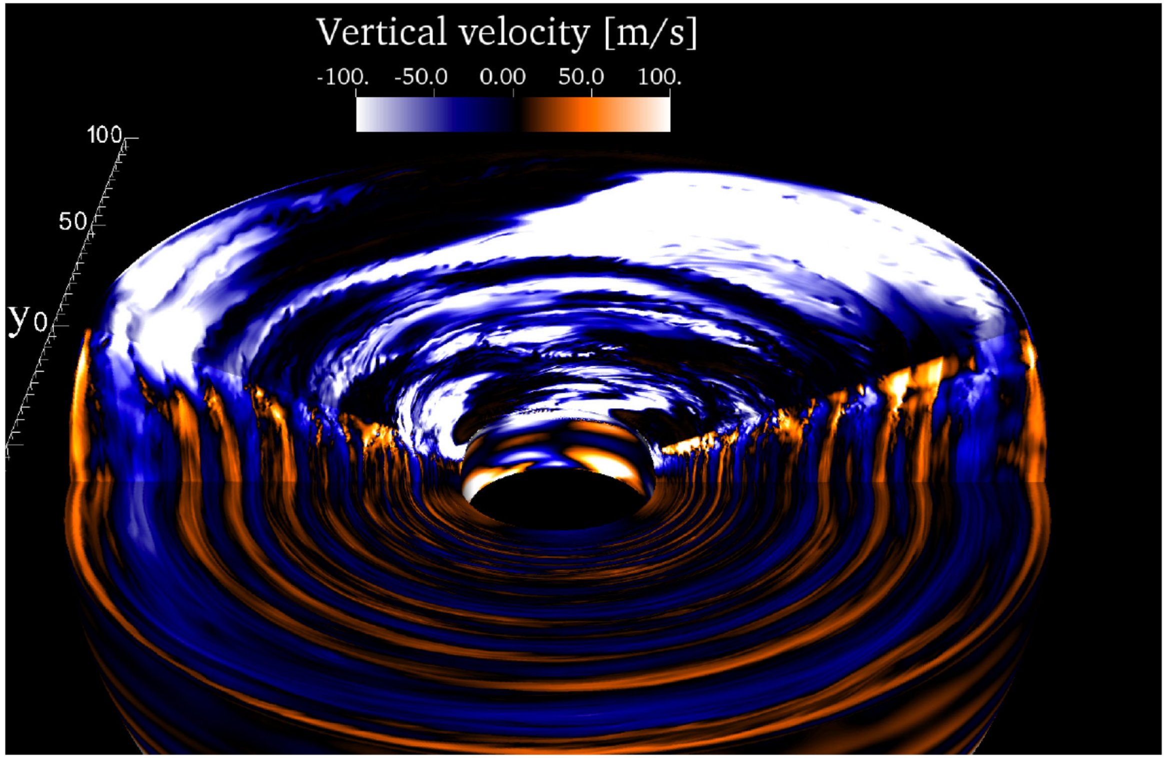
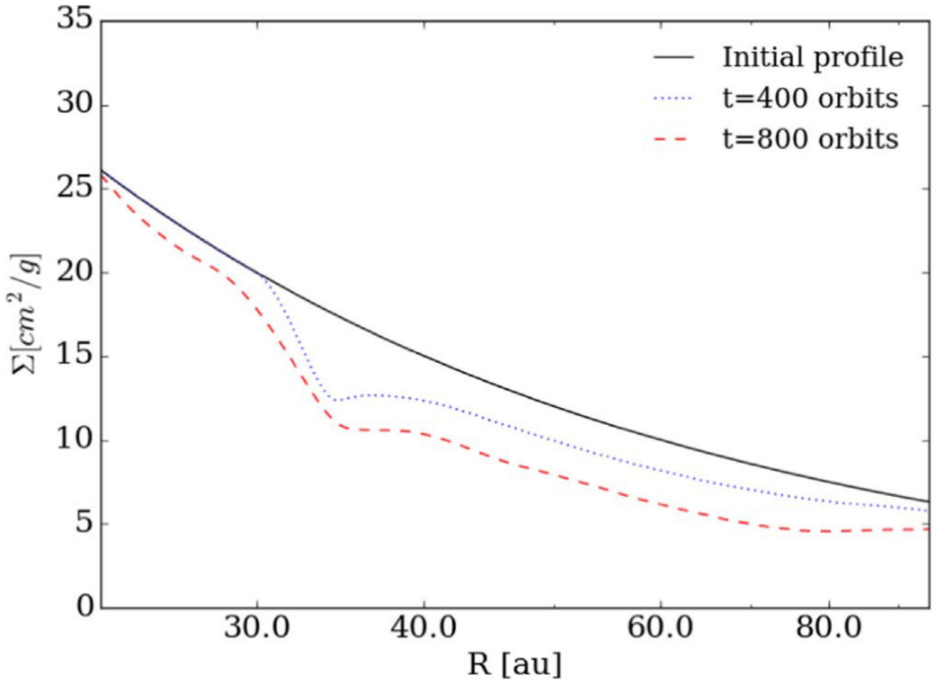
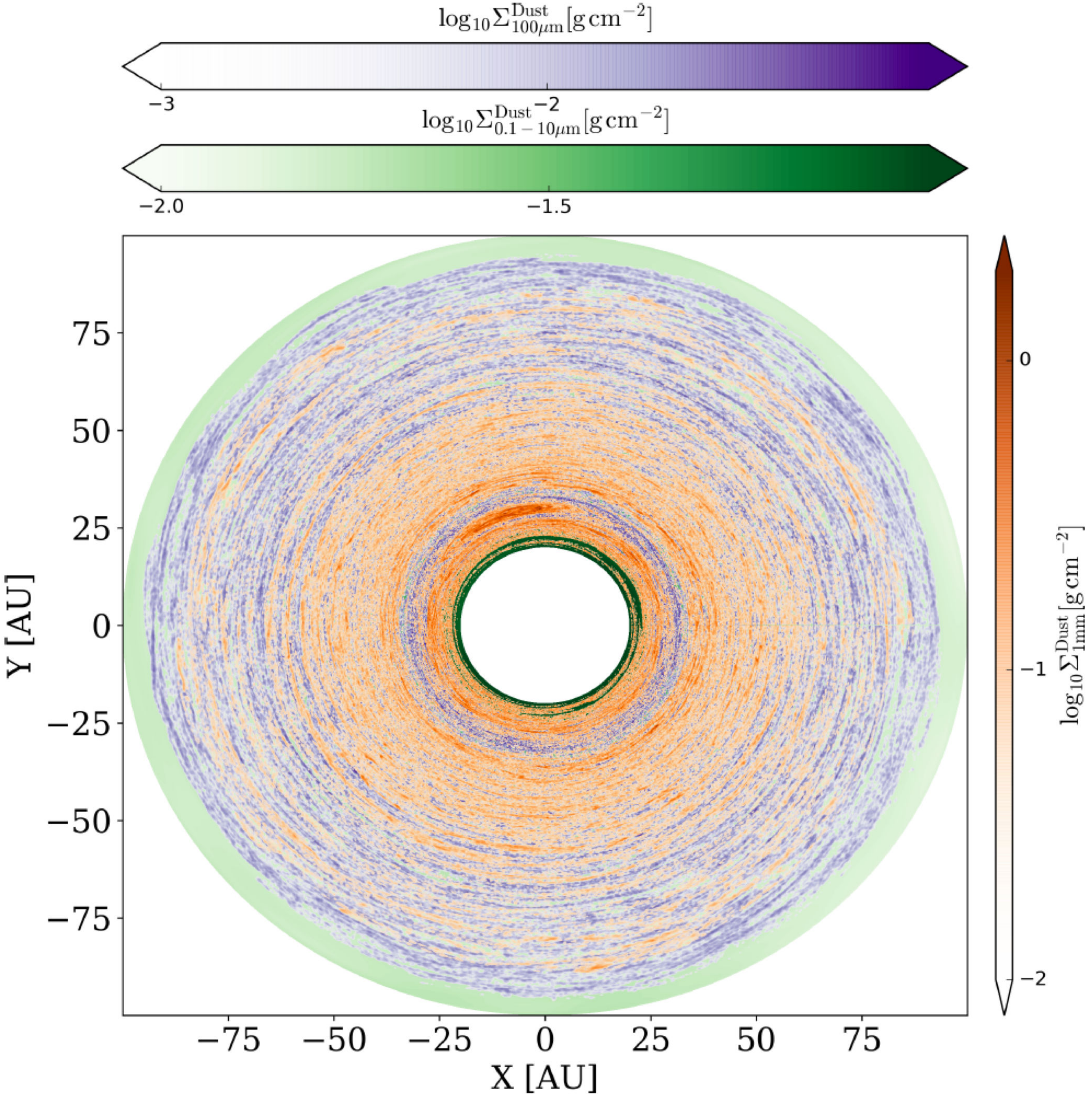




Inhomogeneous accretion at the VSI active inner edge



Flock et al. 2020
Blanco, Ricci, Flock, Turner 2021

IIb. Substructures inside the dead-zone

Flock et al. 2020
Blanco, Ricci, Flock, Turner 2021

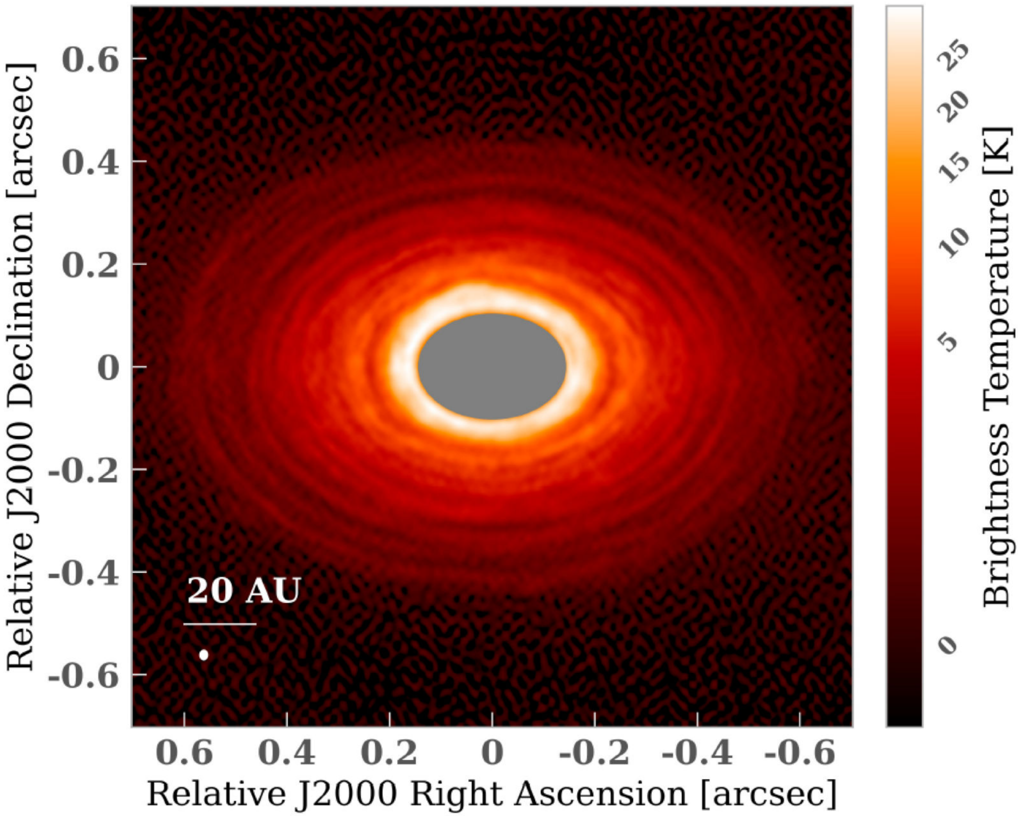


Figure 11. Simulated 40-hour long ALMA observations for the dust emission at 1.3 mm for our disk model with an inclination of 45°. The resultant RMS noise and the synthesized beam, which is shown in the lower left corner, correspond to about 1.3 μJy/beam and 18 × 15 mas, respectively.

IIb. Substructures inside the dead-zone

Flock et al. 2020
Blanco, Ricci, Flock, Turner 2021

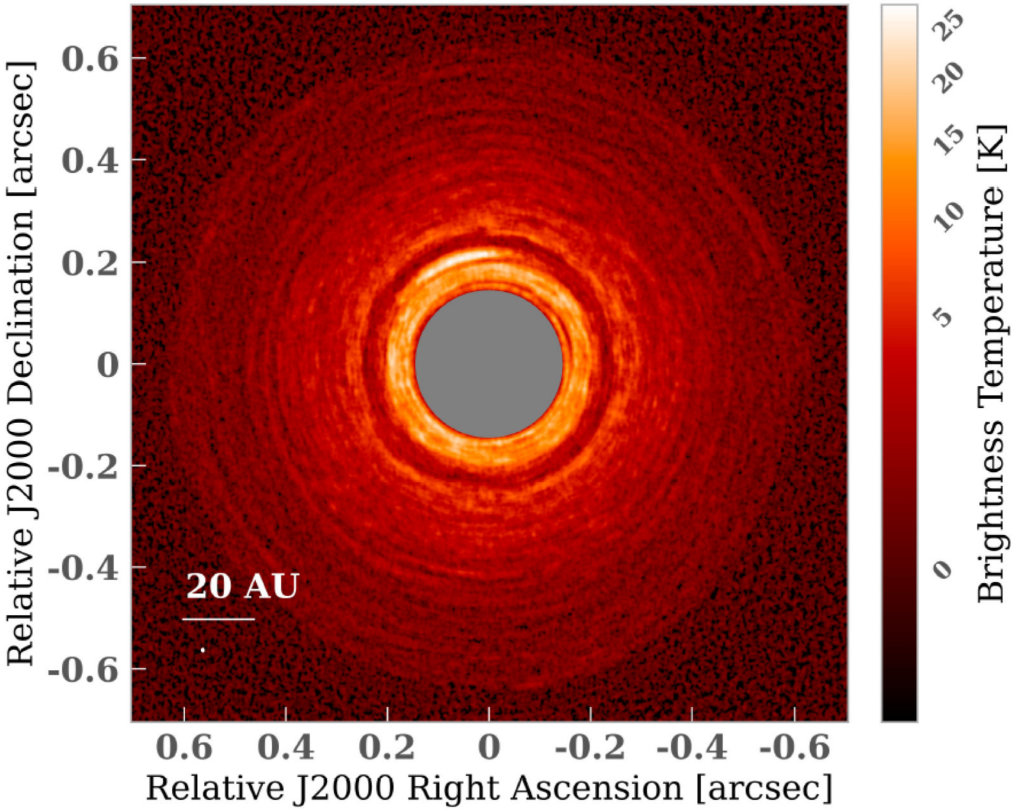
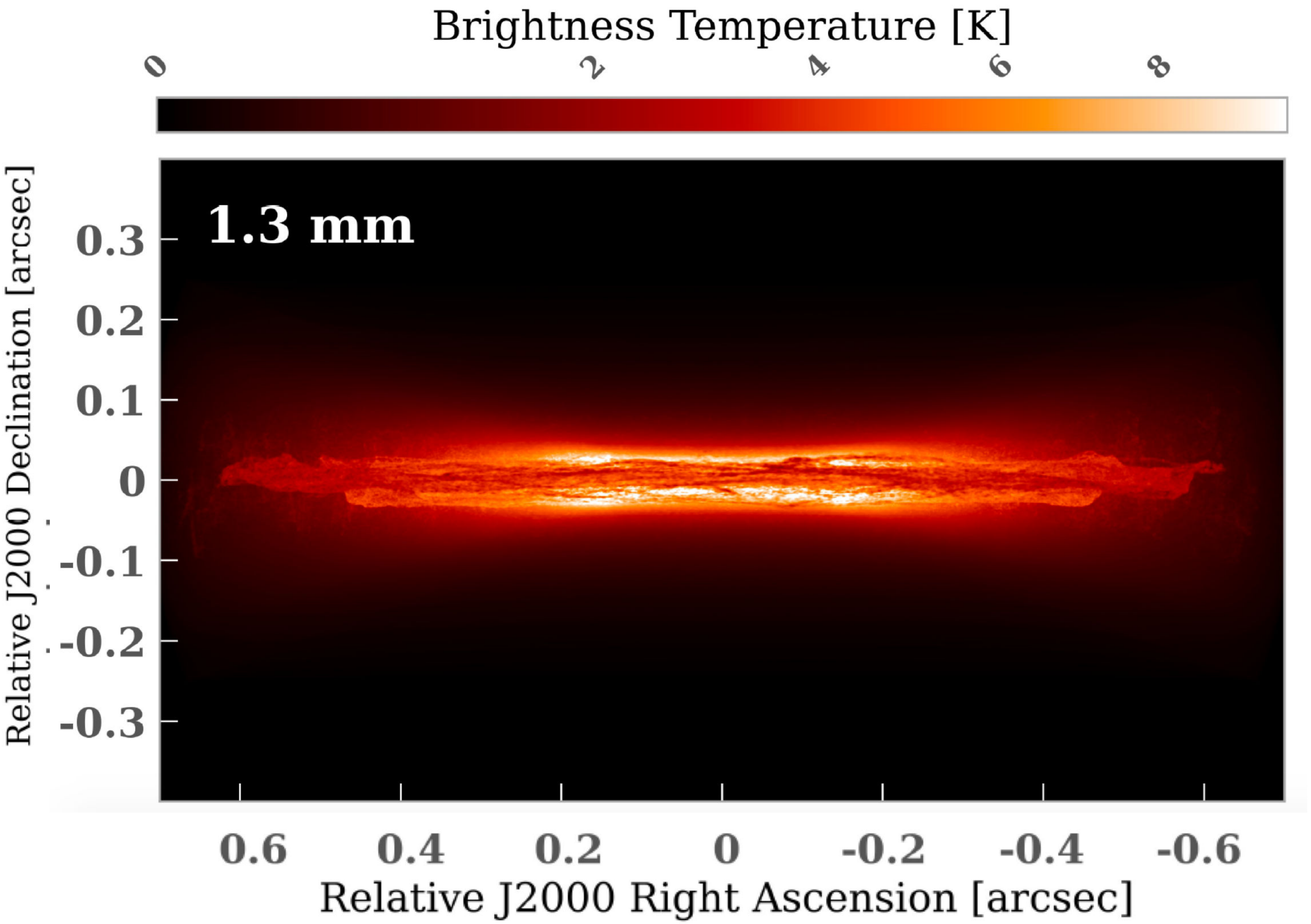


Figure 12. Simulated 80-hour long ngVLA observations for the dust emission at 3 mm for our face-on disk model. The resultant RMS noise and the synthesized beam, which is shown in the lower left corner, correspond to about 0.1 μJy/beam and 8 × 6 mas, respectively.

IIb. Substructures inside the dead-zone

Flock et al. 2020
Blanco, Ricci, Flock, Turner 2021



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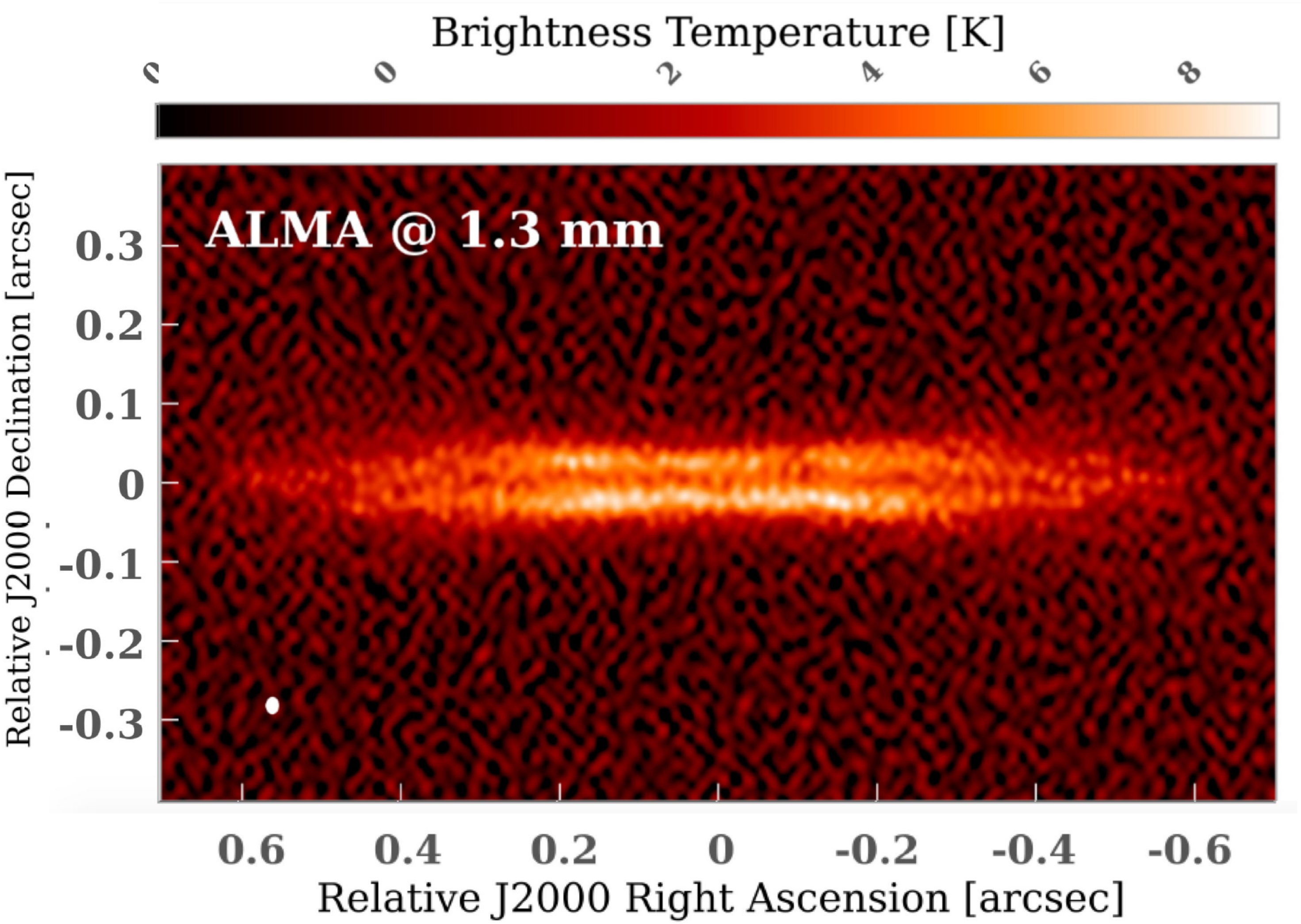
Flock et al. 2020

Blanco, Ricci, Flock, Turner 2021



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Flock et al. 2020
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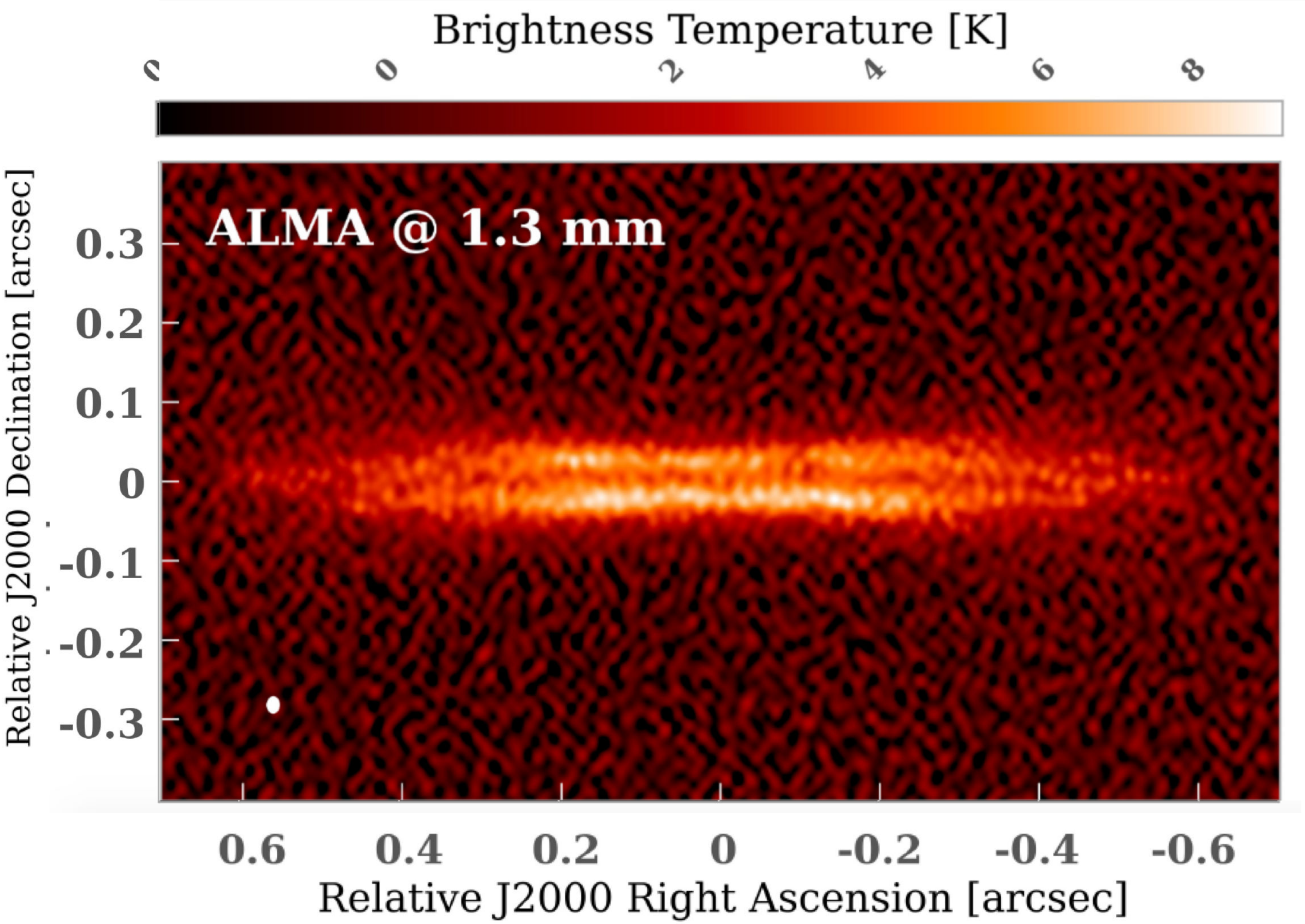
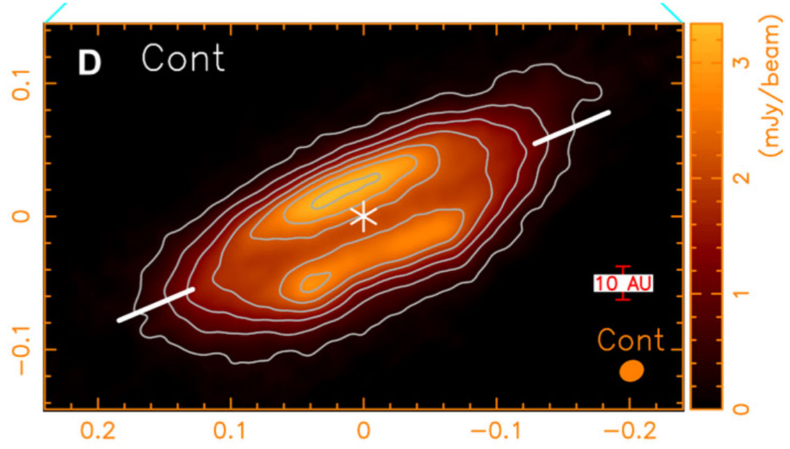
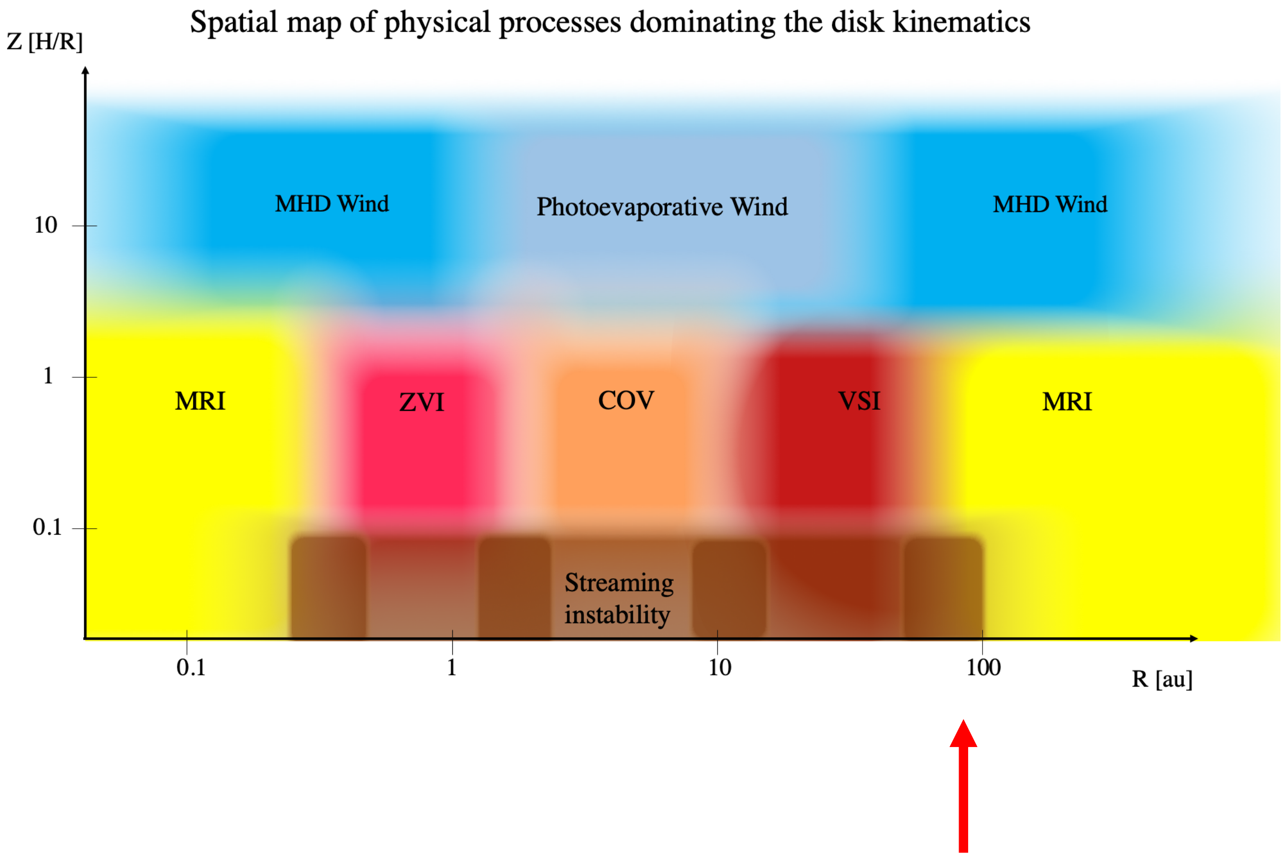




HH212 - Chin-Fei Lee et al 2017

See also Villenave et al. 2020 for more edge-on observations

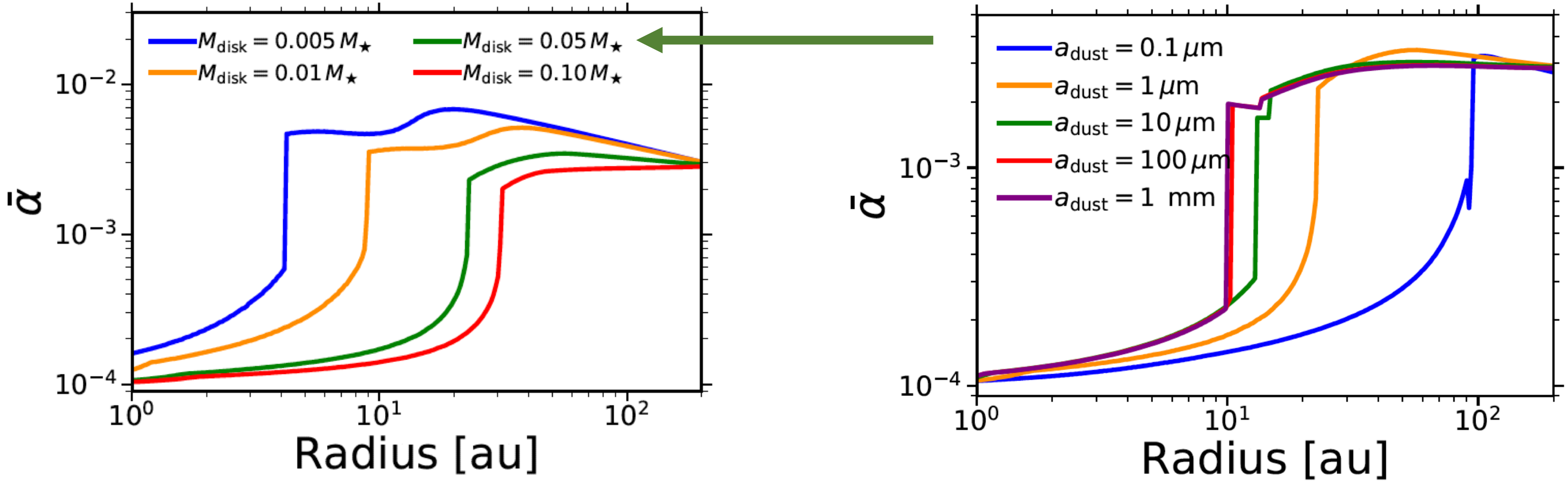
III. Substructures at the dead-zone outer edge



III. Substructures at the dead-zone outer edge

Delage et al. 2021 - A&A accepted (2 days ago)

$$M_\star = 1\,M_\odot, L_\star = 2\,L_\odot,\ a_{\rm dust} = 1\,\mu m,\ f_{\rm dg} = 10^{-2},\ \alpha_{\rm hydro} = 10^{-4}$$

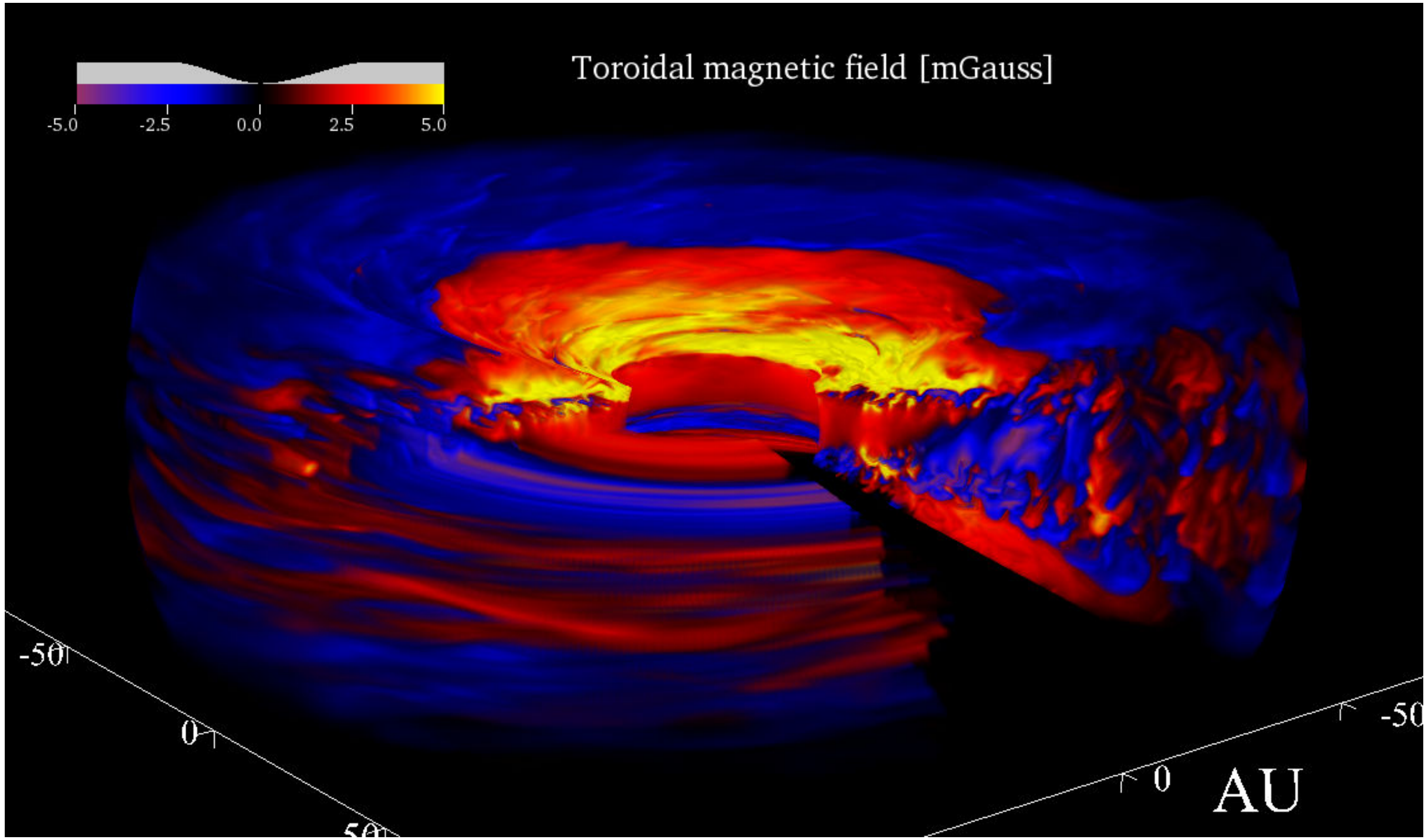


Dead-zone outer edge ranging from 4 to 100 au

III. Substructures at the dead-zone outer edge

Flock et al. 2015 A&A

Global 3D non-ideal MHD simulations



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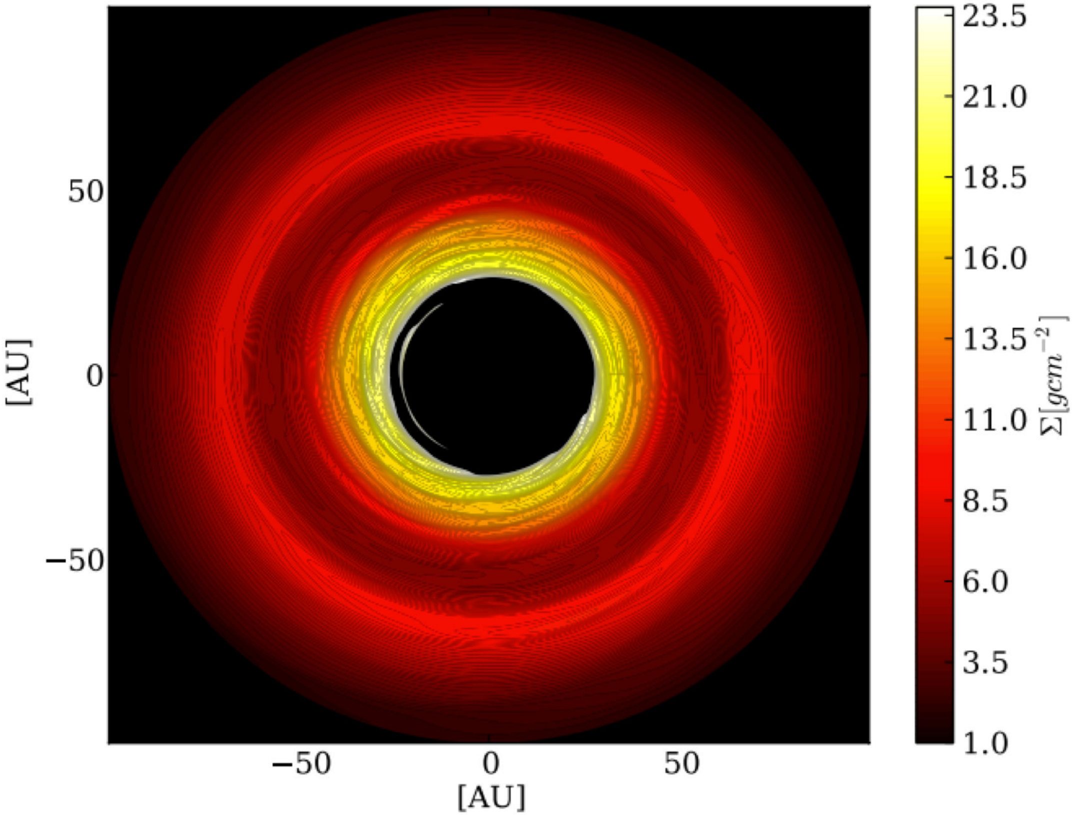
Flock et al. 2015 A&A

Global 3D non-ideal MHD simulations

Surface density

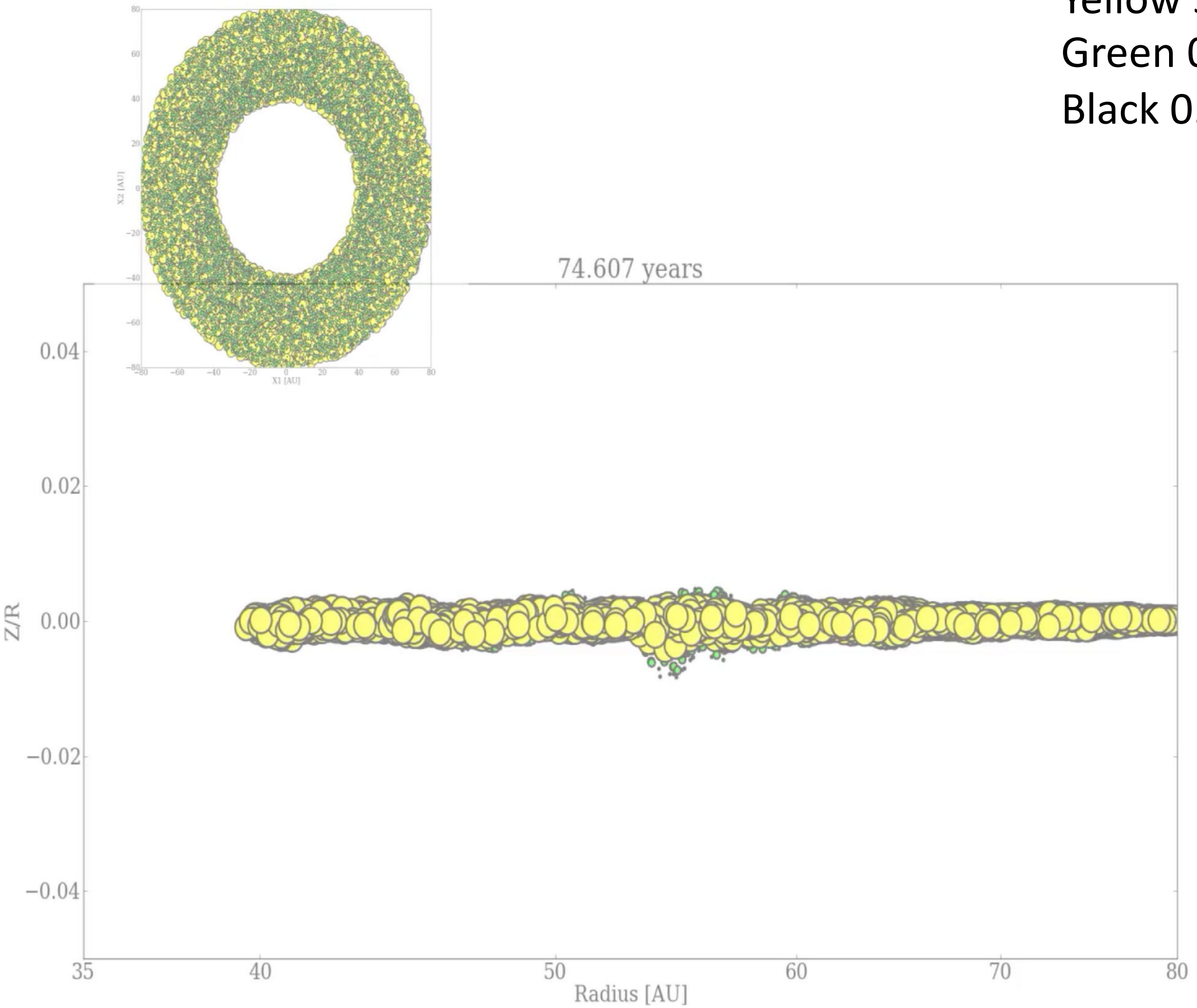


Research

Ruge, Flock et al. 2016 A&A

Gas and dust global 3D MHD simulations

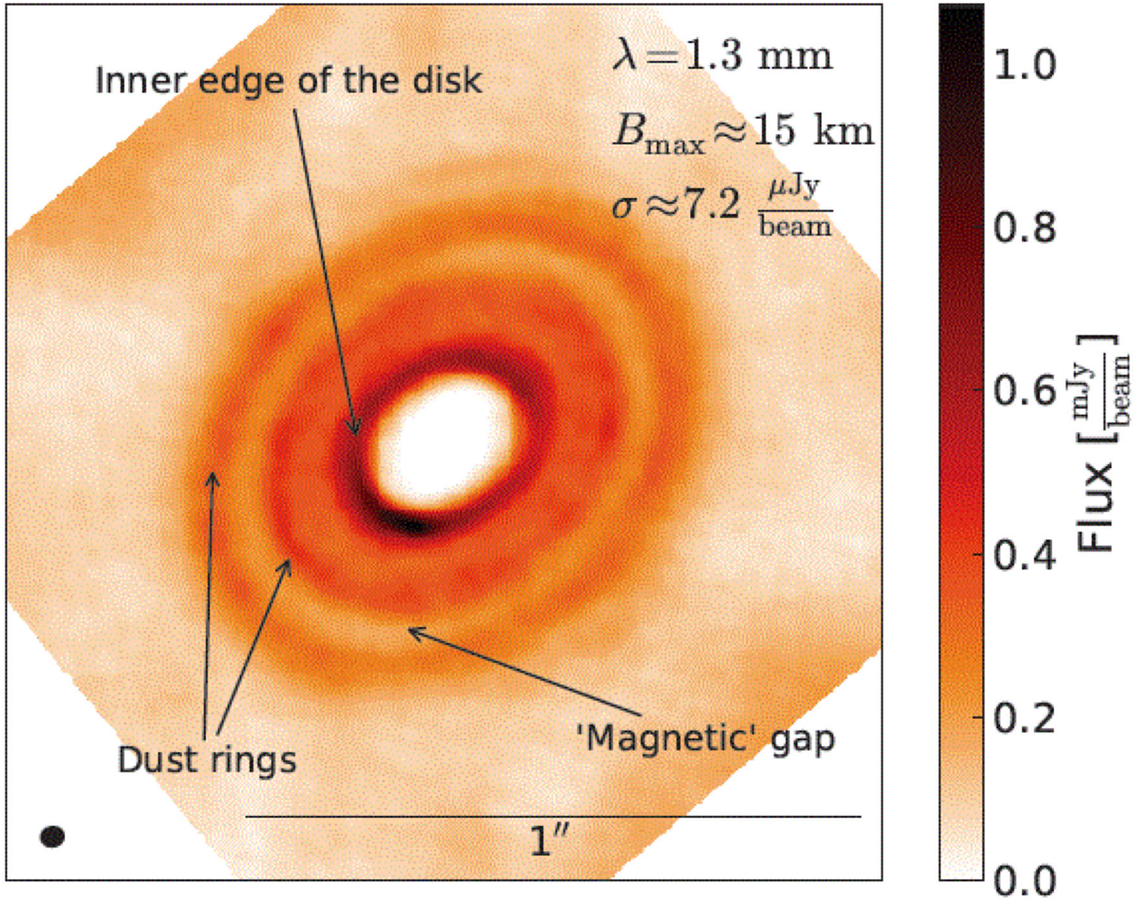
Yellow 5mm
Green 0.5mm
Black 0.05mm



Research

Ruge, Flock et al. 2016 A&A

Synthetic ALMA observation of the global model



Research

Ruge, Flock et al. 2016 A&A

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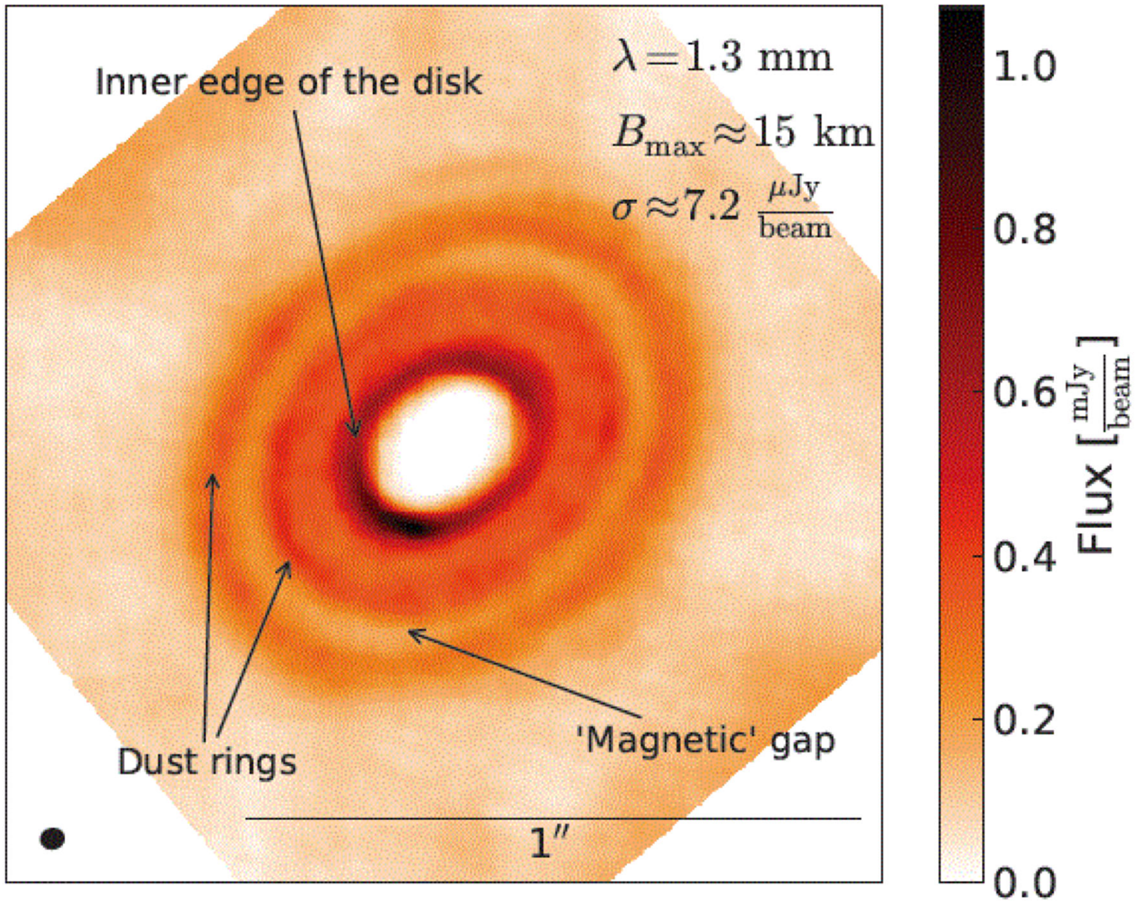

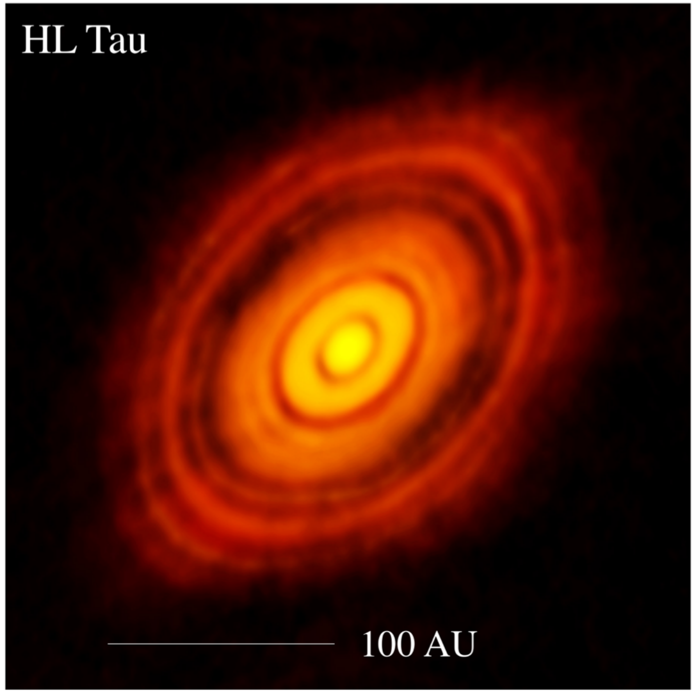

Partnership et al. 2015 ApJL

Magnetic effects can cause dust concentrations and ring formation

Summary

- Protoplanetary disks are never smooth

- Substructures created by inhomogeneous turbulence
  MRI/non-MRI VSI/non-VSI
  thermal wave instability

- Planets can **further** perturb the disk

Summary

- Protoplanetary disks are never smooth

- Substructures created by inhomogeneous turbulence

  MRI/non-MRI **VSI/non-VSI**

  thermal wave instability

- Planets can **further** perturb the disk

We need **ngVLA at 3mm (100Ghz)** 👍