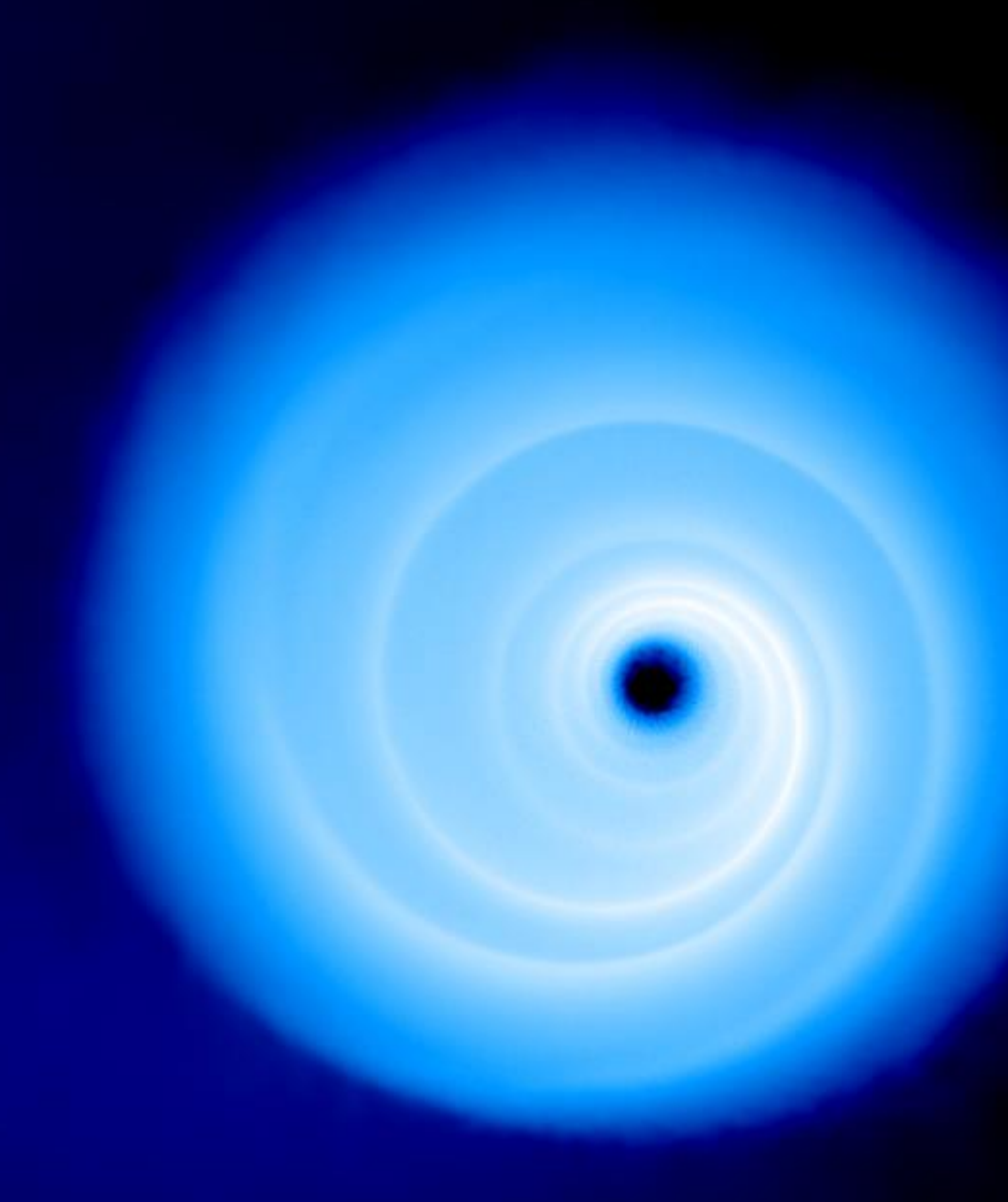

DUST DYNAMICS IN PROTOPLANETARY DISCS AFTER STELLAR FLYBYS

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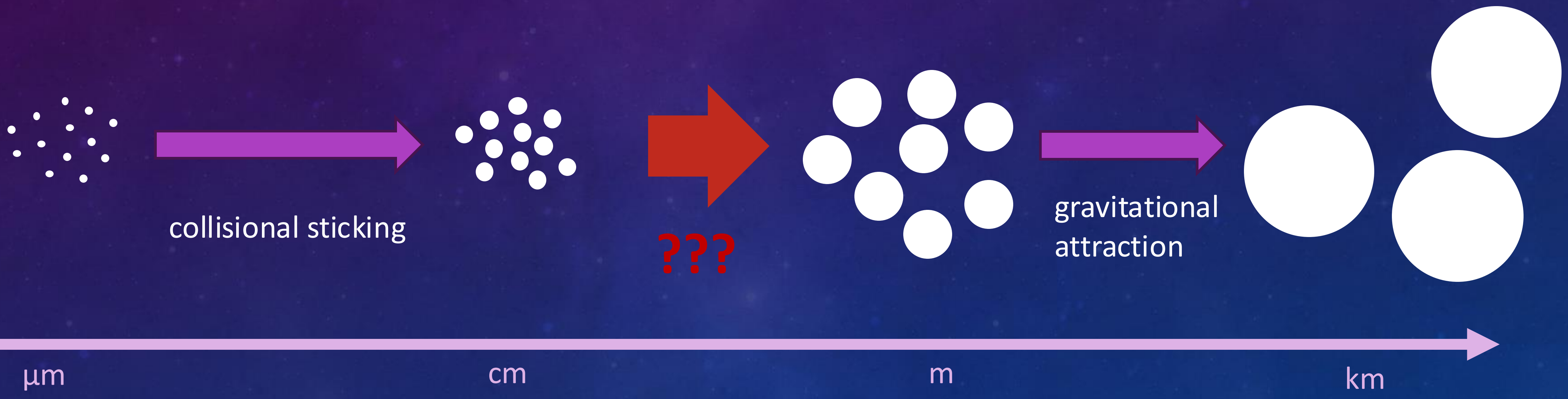
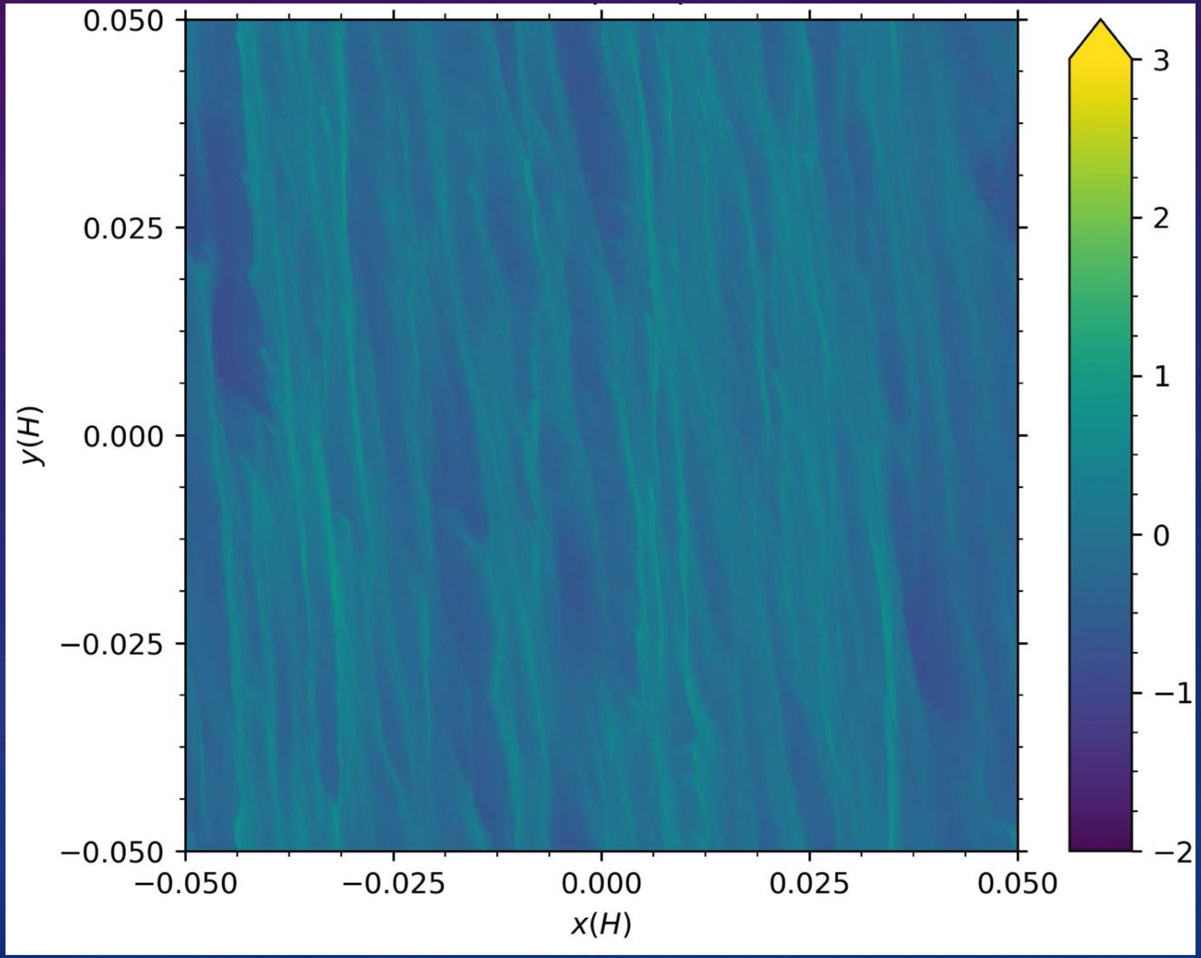
HOW DO PLANETS FORM?

- Protoplanetary discs contain small dust grains that must grow to pebble and planetesimal sizes



HOW DO PLANETS FORM?

- **How do cm-sized dust grains grow?**
- Radial drift barrier: they should fall into the star faster than they can collide together and grow
- **Streaming instability:** a drag instability that reduces dust radial drift and leads to the growth of dust overdensities



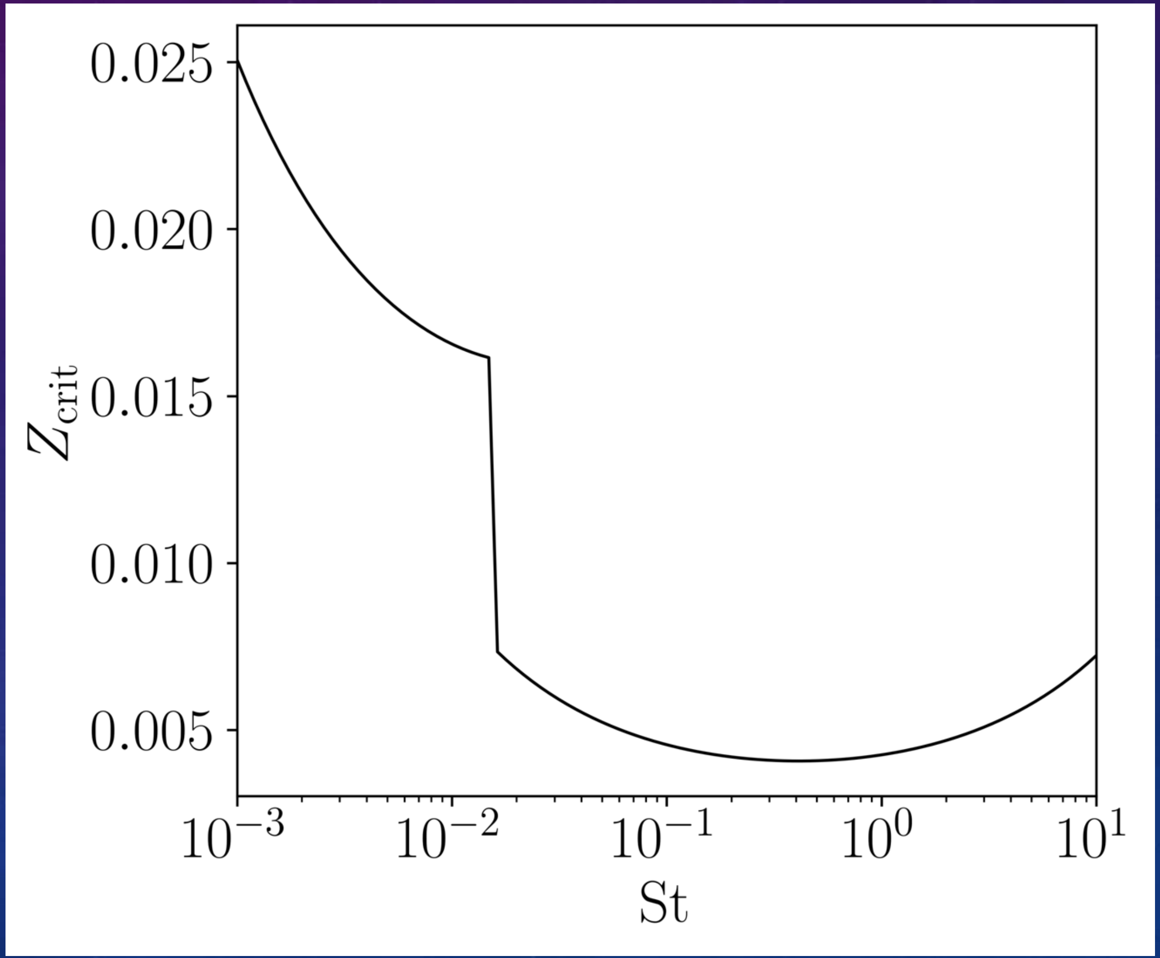
Nesvorný+ 2019

HOW DO PLANETS FORM?

- But the streaming instability is only triggered in regions with a sufficiently high **dust to gas ratio**
- Define the dimensionless Stokes number:

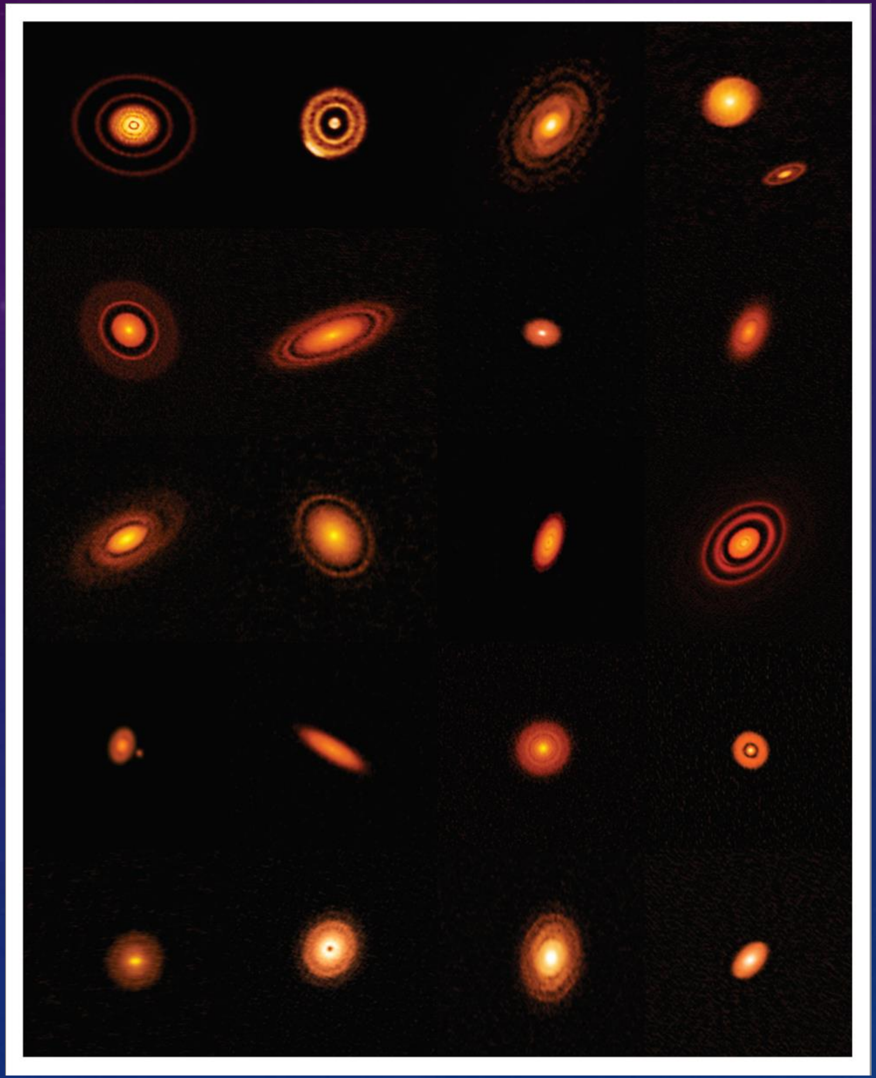
$$\mathrm{St} = \frac{\rho_{\mathrm{gr}} s}{\rho c_s} \Omega_k$$

- For cm-sized dust particles (St ≥ 1) we require surface dust to gas ratios Z ≥ 0.005
- So we need the disc to have long-lasting substructures with high dust to gas ratios



Adapted from Li & Youdin 2021

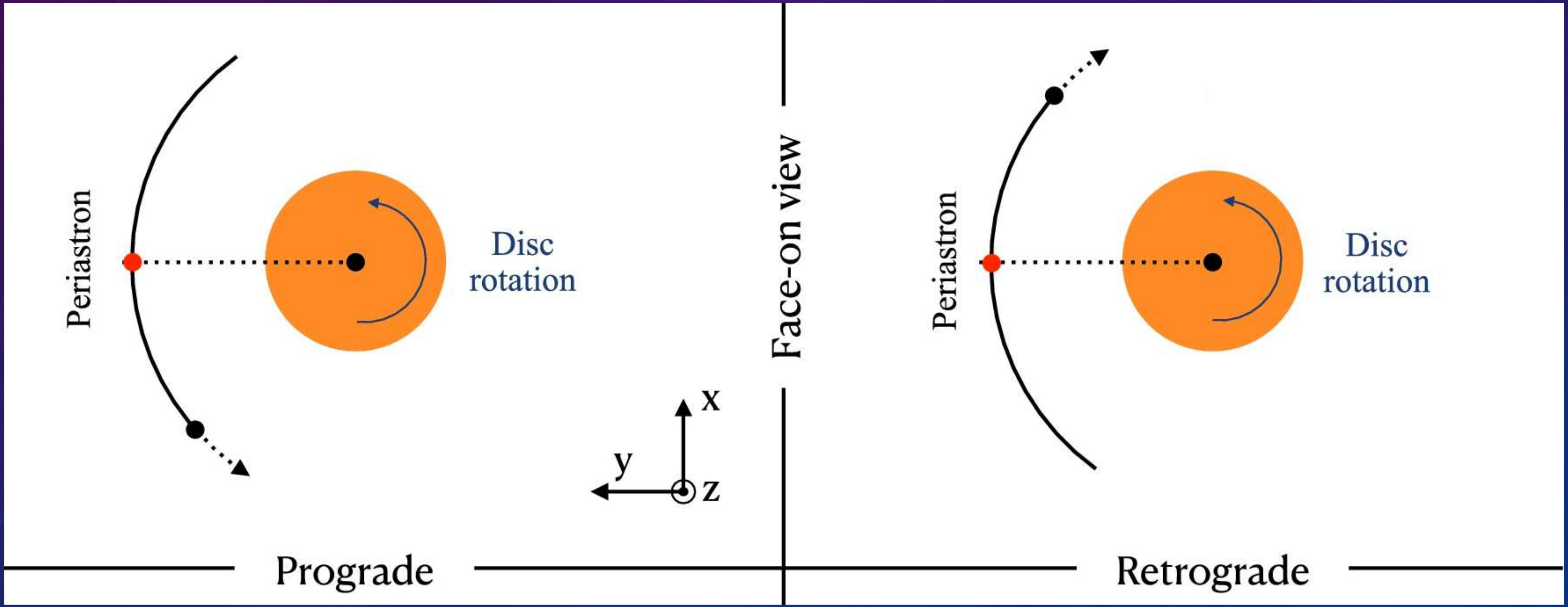
- ALMA observations show most protoplanetary discs have substructures
- Could these concentrate dust enough to trigger dust grain growth and planetesimal formation?
- And what causes these substructures anyway?
    - planets embedded in the disc
    - interactions with a bound/unbound companion…



ALMA (ESO/NAOJ/NRAO), S. Andrews et al.; NRAO/AUI/NSF, S. Dagnello

STELLAR FLYBYS

- Define a *flyby* as a single interaction with an unbound companion

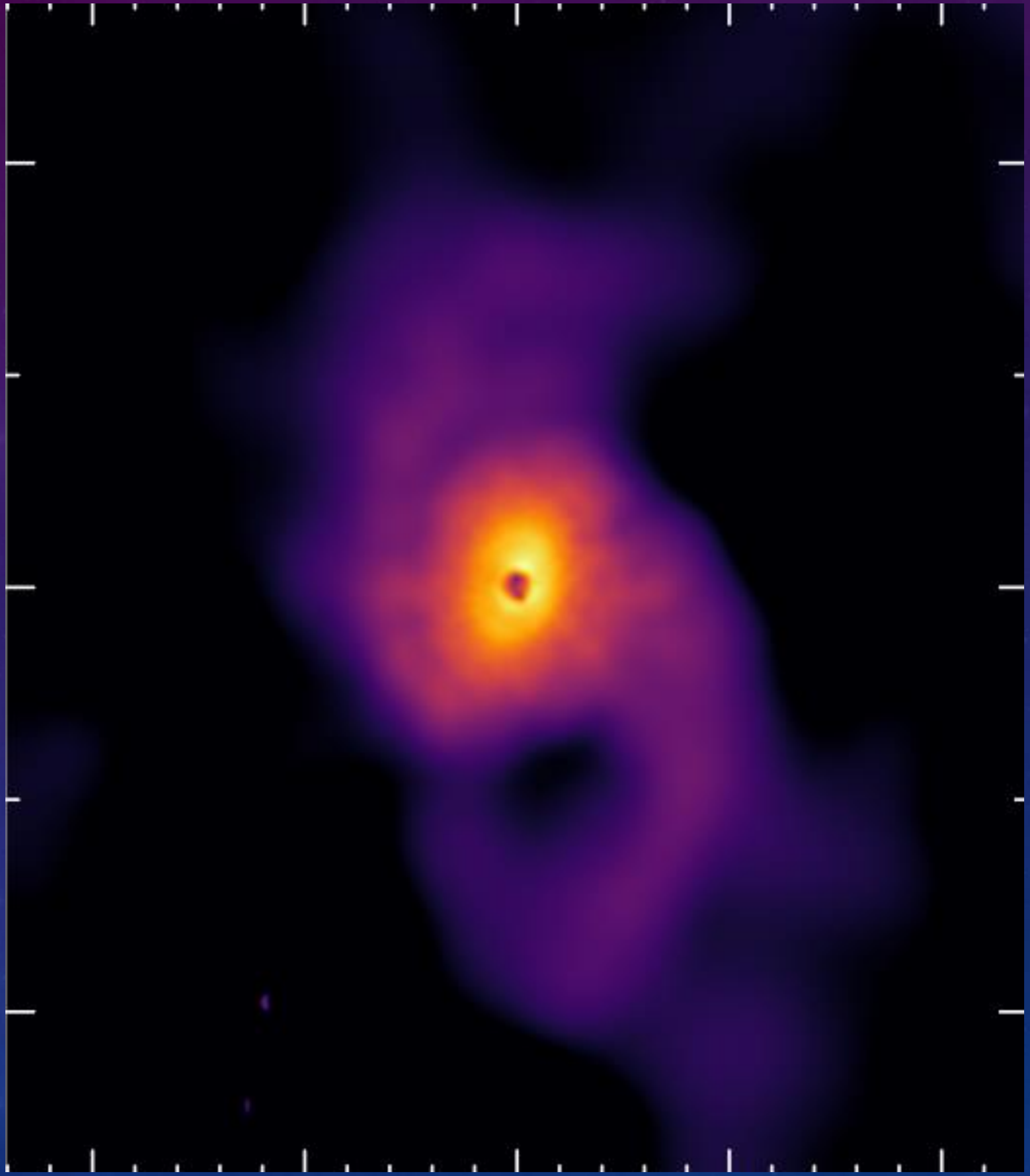


Cuello+ 2023

STELLAR FLYBYS

- Encounters with unbound perturbers are common for young stars in dense stellar environments
- If the flyby is close enough, tidally-induced spirals are seen in the perturbed disc

Can flyby-induced substructures act as dust traps?



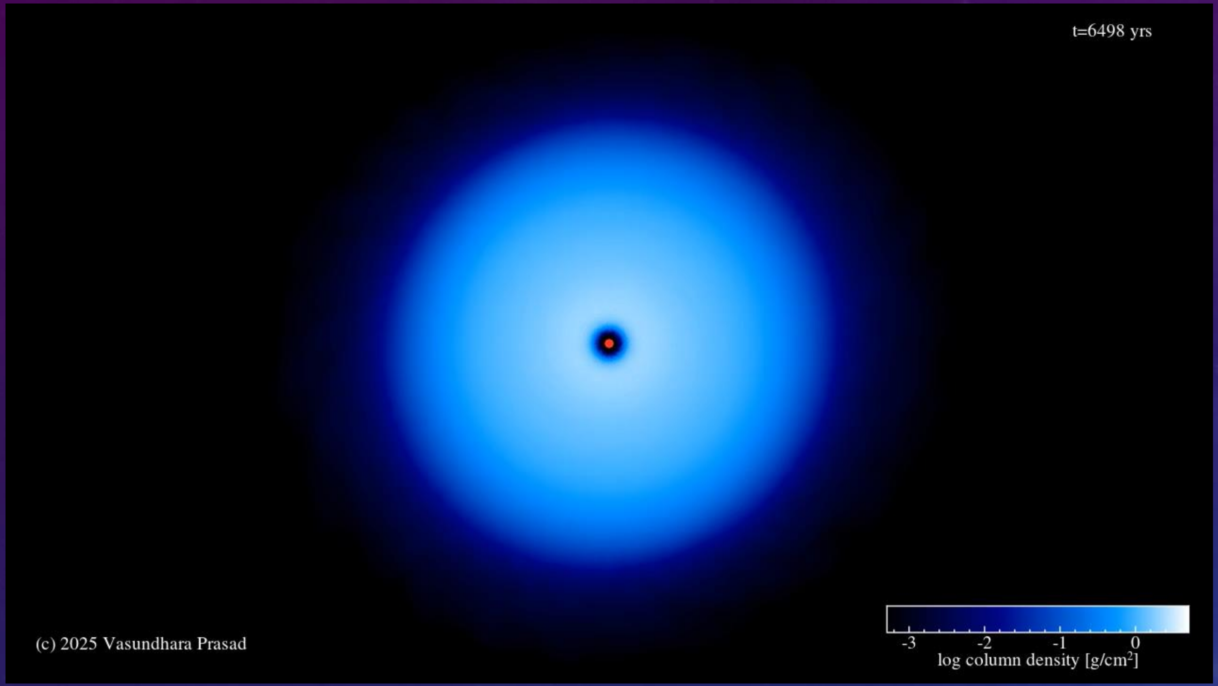
Ménard+ 2020

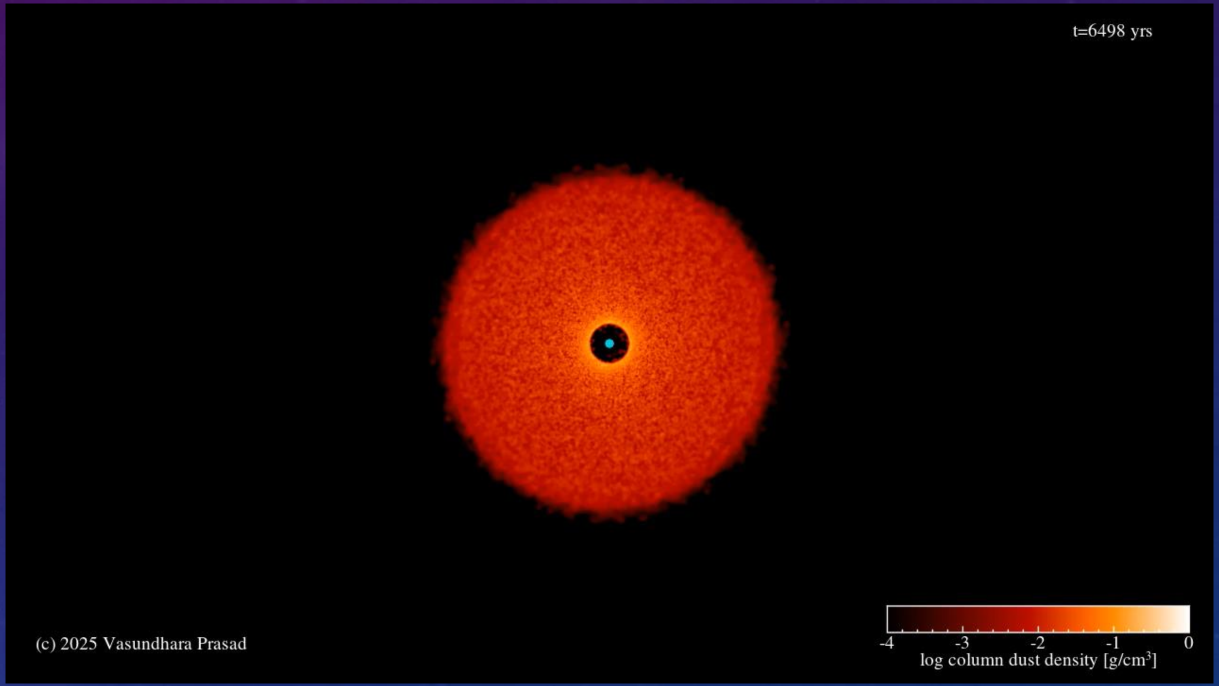
SIMULATION SETUP

- We use PHANTOM to simulate five discs perturbed by flyby encounters and one control case with no flyby
- Disc with initial extent of 150 AU around a solar-mass star
- We use 10^6 SPH gas particles and 10^5 dust particles
- Dust grains have a size of 3cm (corresponding to St > 1)
- We use the two-fluid algorithm for dust particles

Simulation ID	M_2 [$M_\odot$]	r_{peri} [AU]	inclination
standard_run	1	175	prograde
half	0.5	175	prograde
intermediate	1	263	prograde
far	1	350	prograde
retro	1	175	retrograde
no_flyby	0	∞	n/a

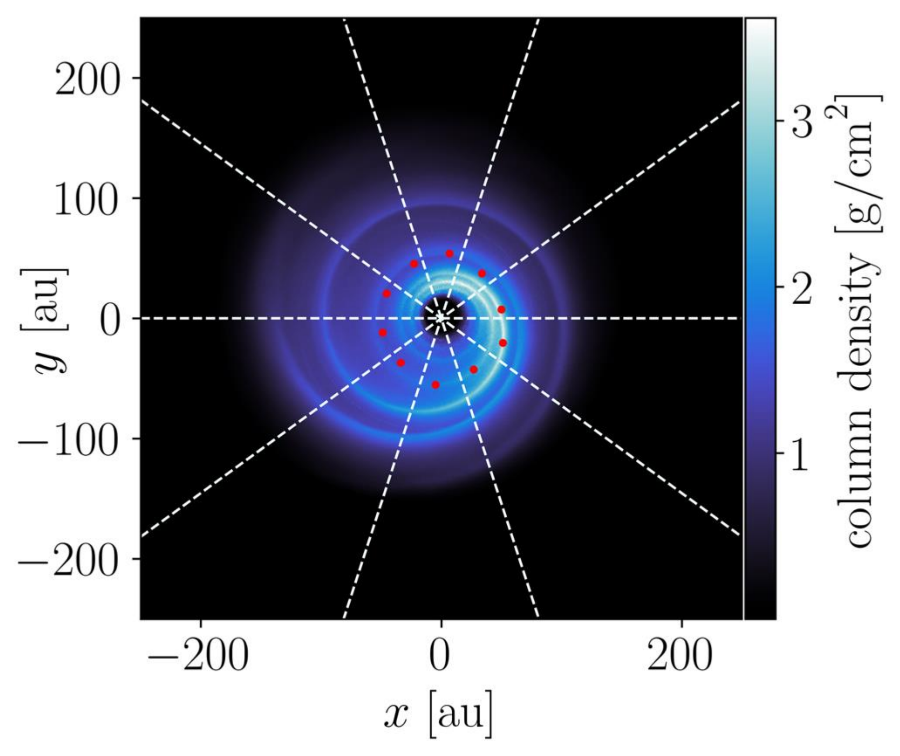
RESULTS


t=6498 yrs
(c) 2025 Vasundhara Prasad
-3 -2 -1 0
log column density [g/cm^2]


t=6498 yrs
(c) 2025 Vasundhara Prasad
-4 -3 -2 -1 0
log column dust density [g/cm^3]

TRACKING SPH PARTICLES

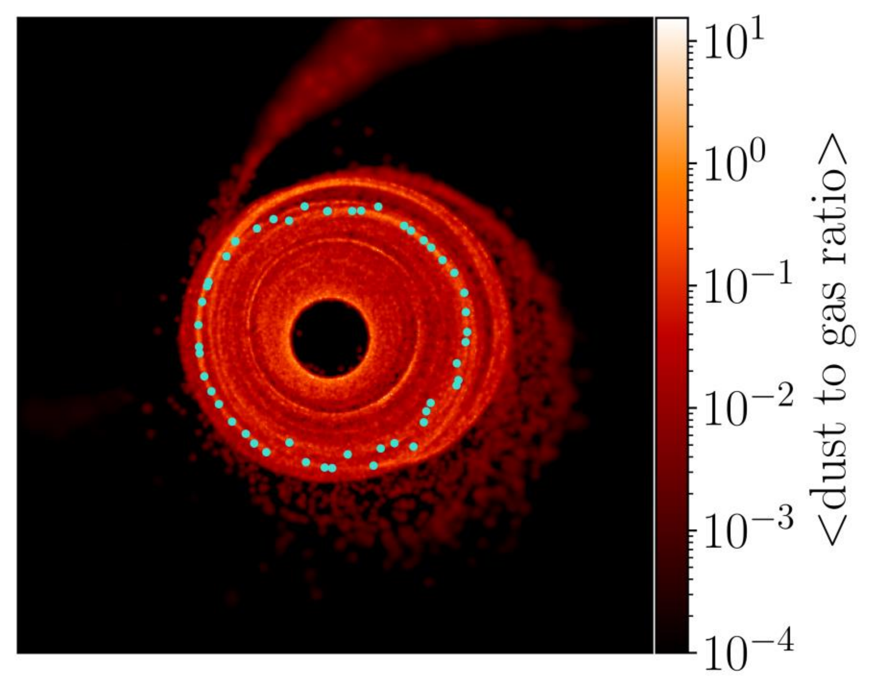
- **Aim:** follow particles in gas and dust substructures over time to see whether their dust to gas ratio increases
- We divide the disc into equal azimuths
- Then we select *dust* particles with the highest gas density/dust to gas ratio in each azimuth
- Then we track these particles' behaviour back and forth in time



Prasad+ in review

TRACKING SPH PARTICLES: DUST SUBSTRUCTURES

- We observe a significant increase in dust to gas ratio compared to the no flyby case



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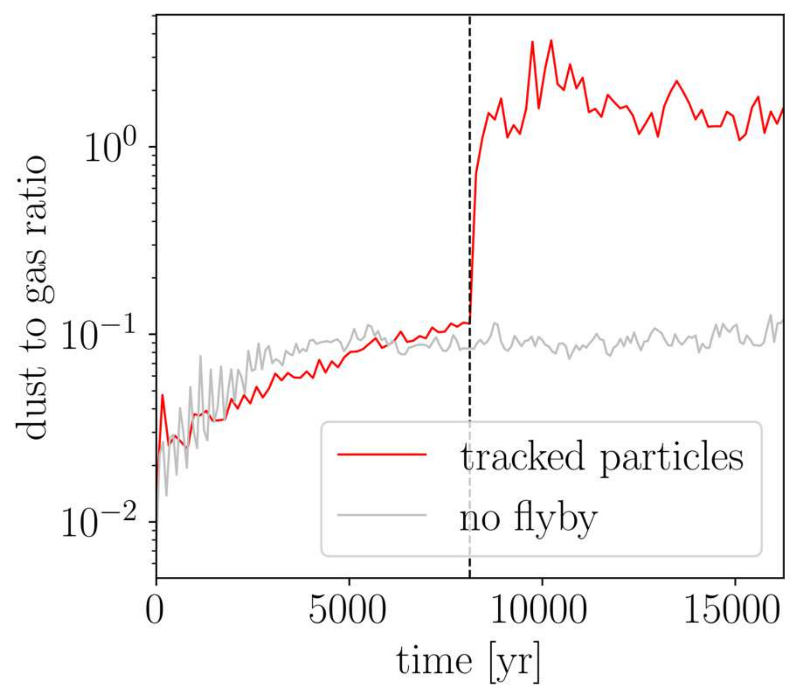
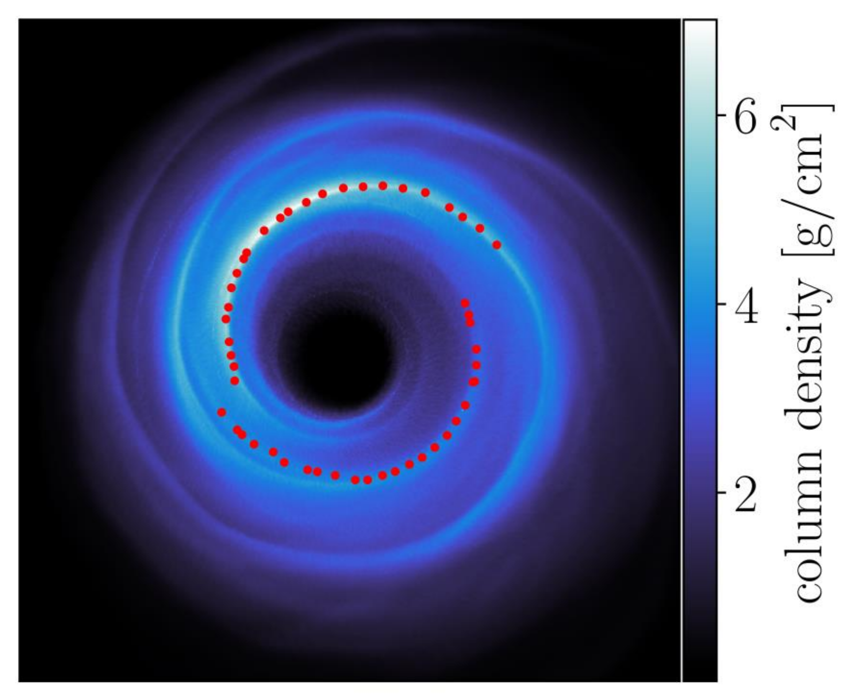


Prasad+ in review

TRACKING SPH PARTICLES: GAS SUBSTRUCTURES

- We get some dust growth in the gas spiral arms, but not in every case



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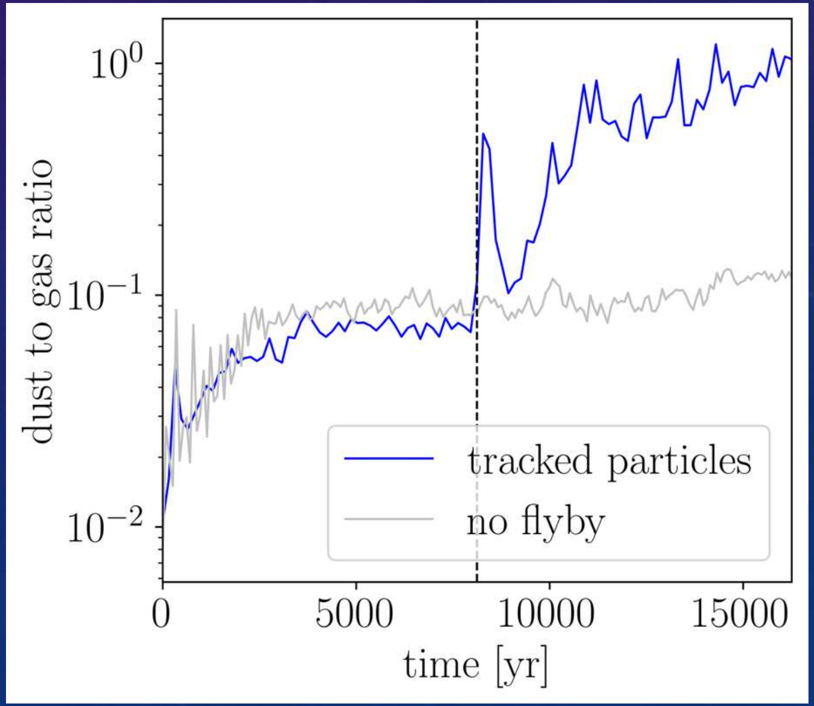

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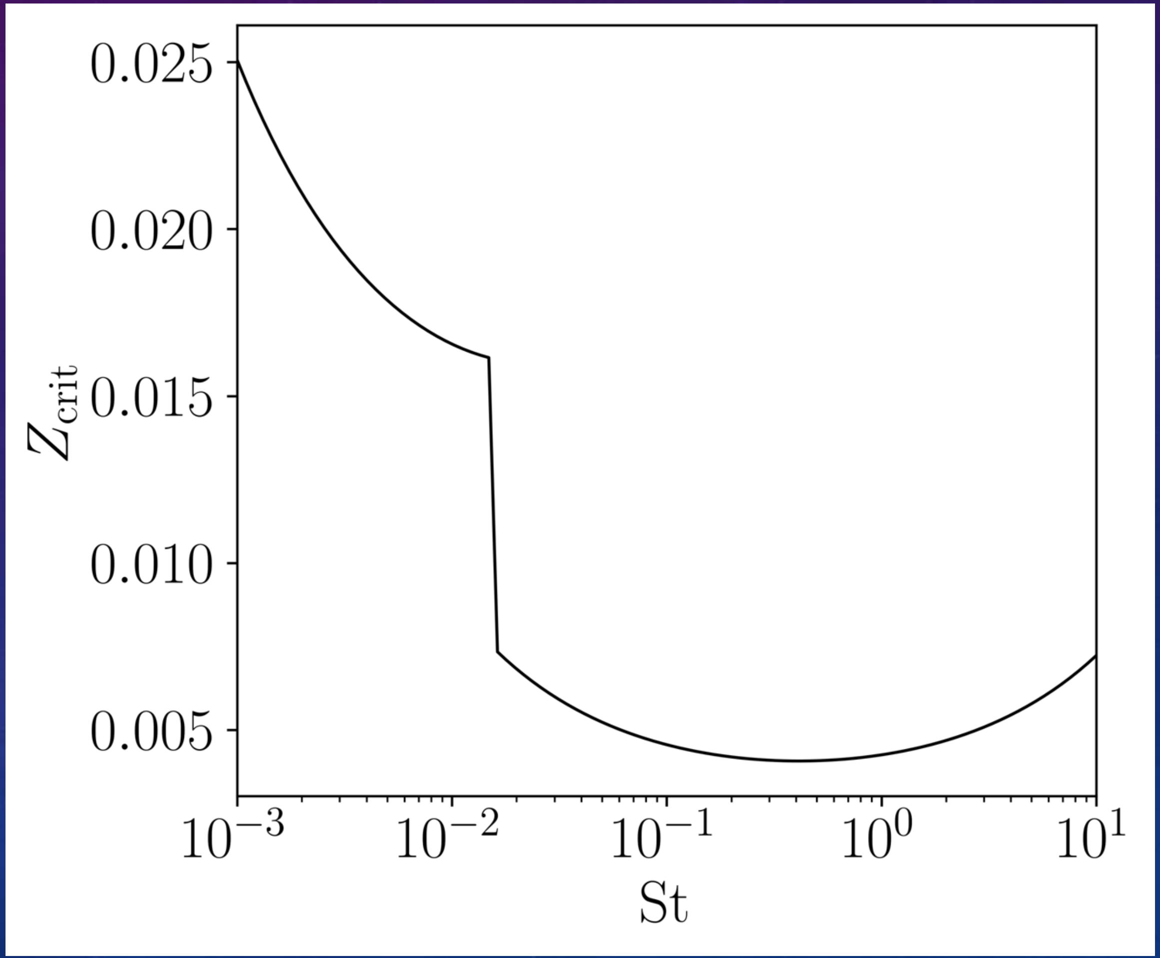
TRIGGERING THE STREAMING INSTABILITY

- Dust particles in flyby-induced substructures have high dust to gas ratios for long periods of time
- But are these dust to gas ratios sufficiently high to trigger the streaming instability?



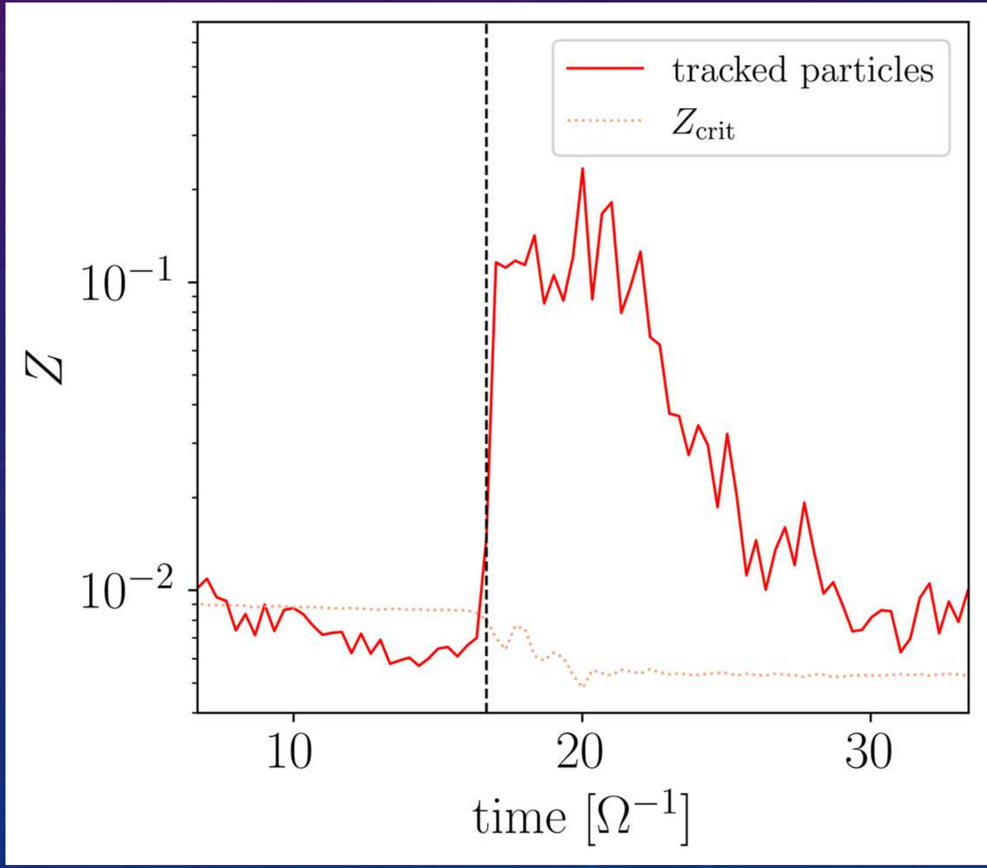
Adapted from Li & Youdin 2021

TRIGGERING THE STREAMING INSTABILITY

- We calculate the threshold Z for each particle as a function of time
- Then we compare this value to the particle's actual surface dust to gas ratio:

$$Z = \frac{\rho_d}{\rho_g}\frac{H_d}{H_g}$$

- The tracked particles' mean value of Z exceeds the threshold for many tens of dynamical times after the flyby



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SUMMARY

- The growth of dust grains from cm to m sizes is an open problem in planet formation
- Substructures that concentrate dust and promote dust grain growth can be induced by stellar flybys
- The long-lived dust substructures act as dust traps, but the shorter-lived gas spirals only exhibit dust trapping in some cases
- The dust to gas ratios induced by the flyby are large enough to trigger the streaming instability and remain so for sufficiently long timescales

THE EFFECT OF DRAG