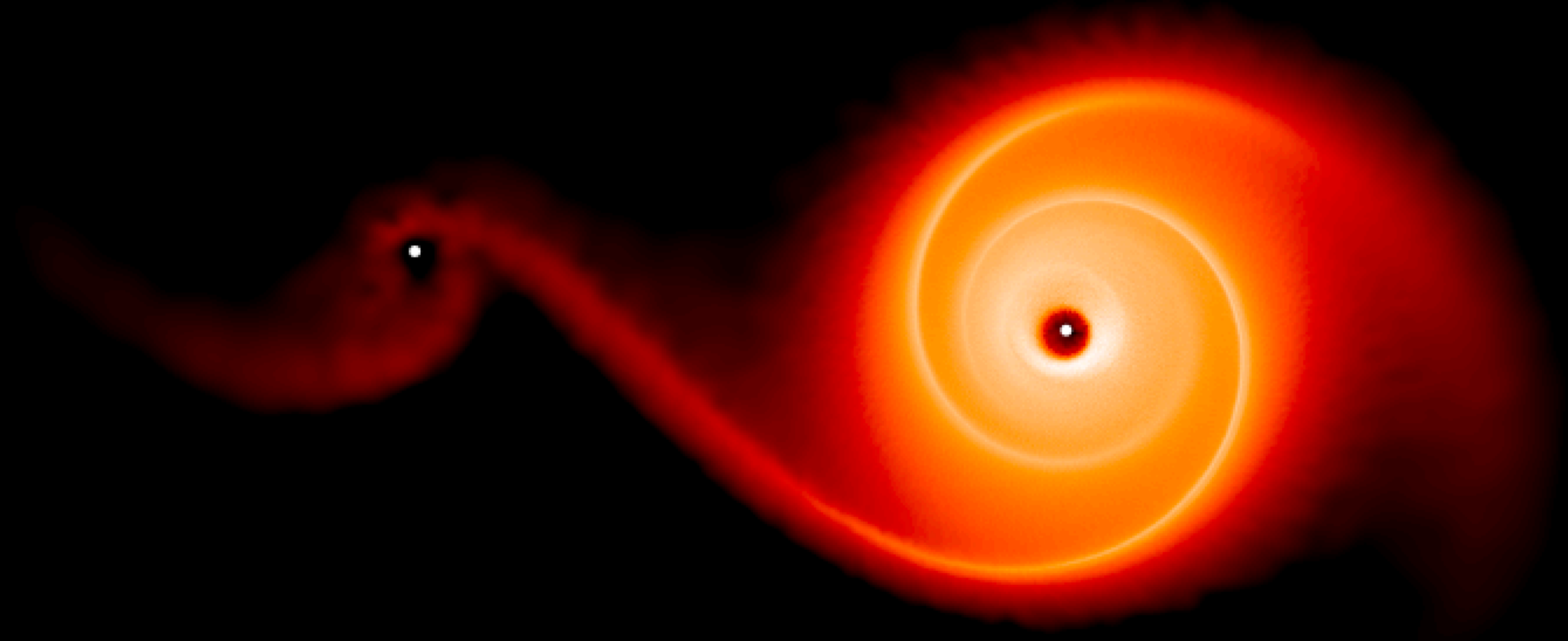
04 / 06 / 25

Dust Growth in binary stars

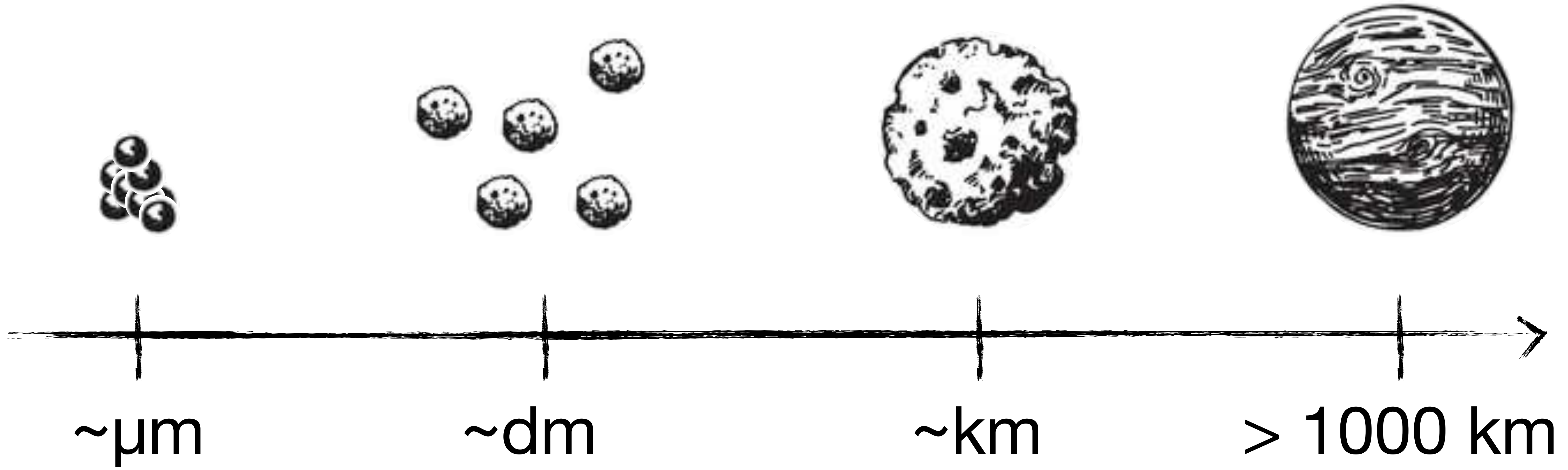
The path to planet formation in multiple systems



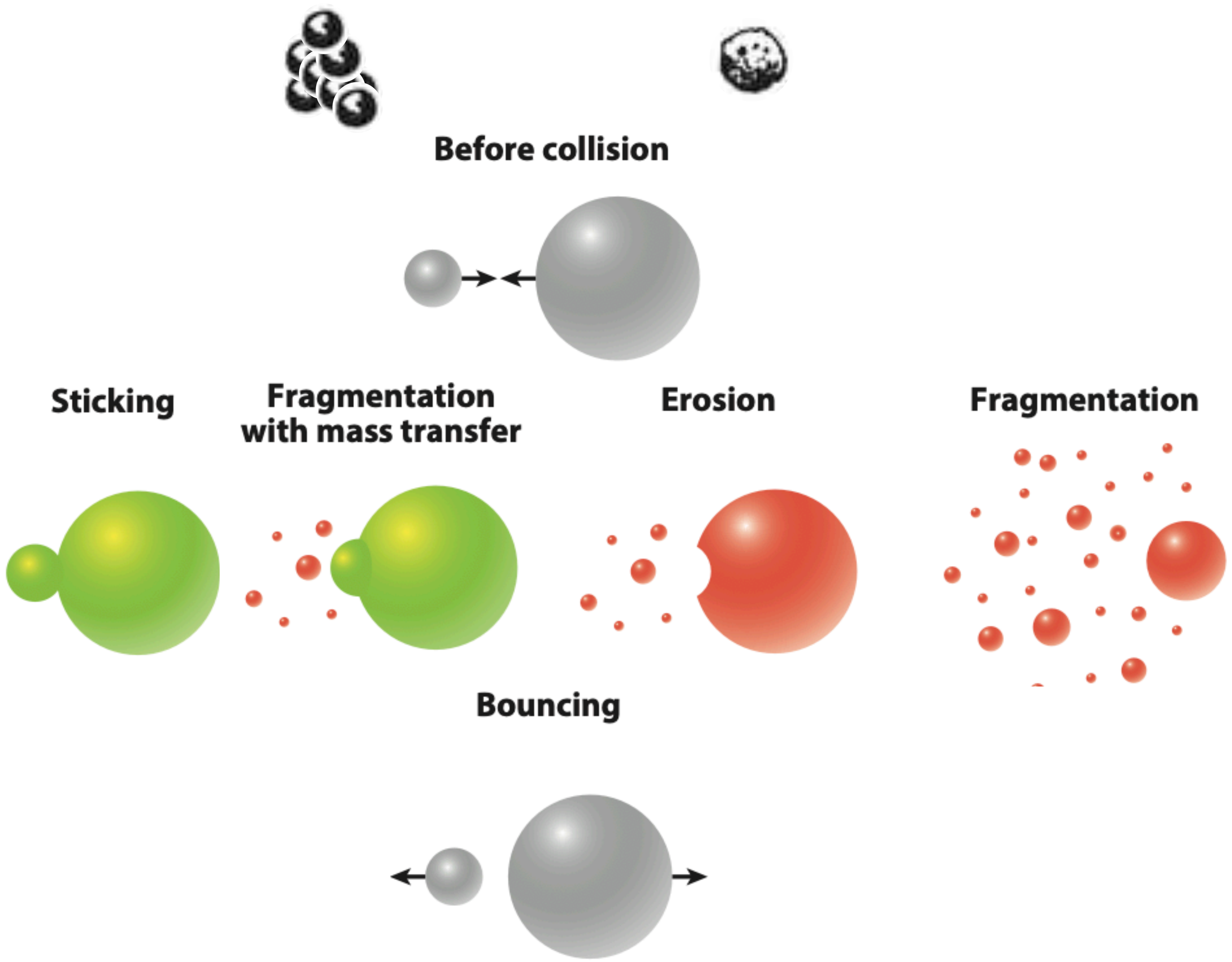
ALAGUERO Antoine

supervised by CUELLO Nicolás & MÉNARD François

Context

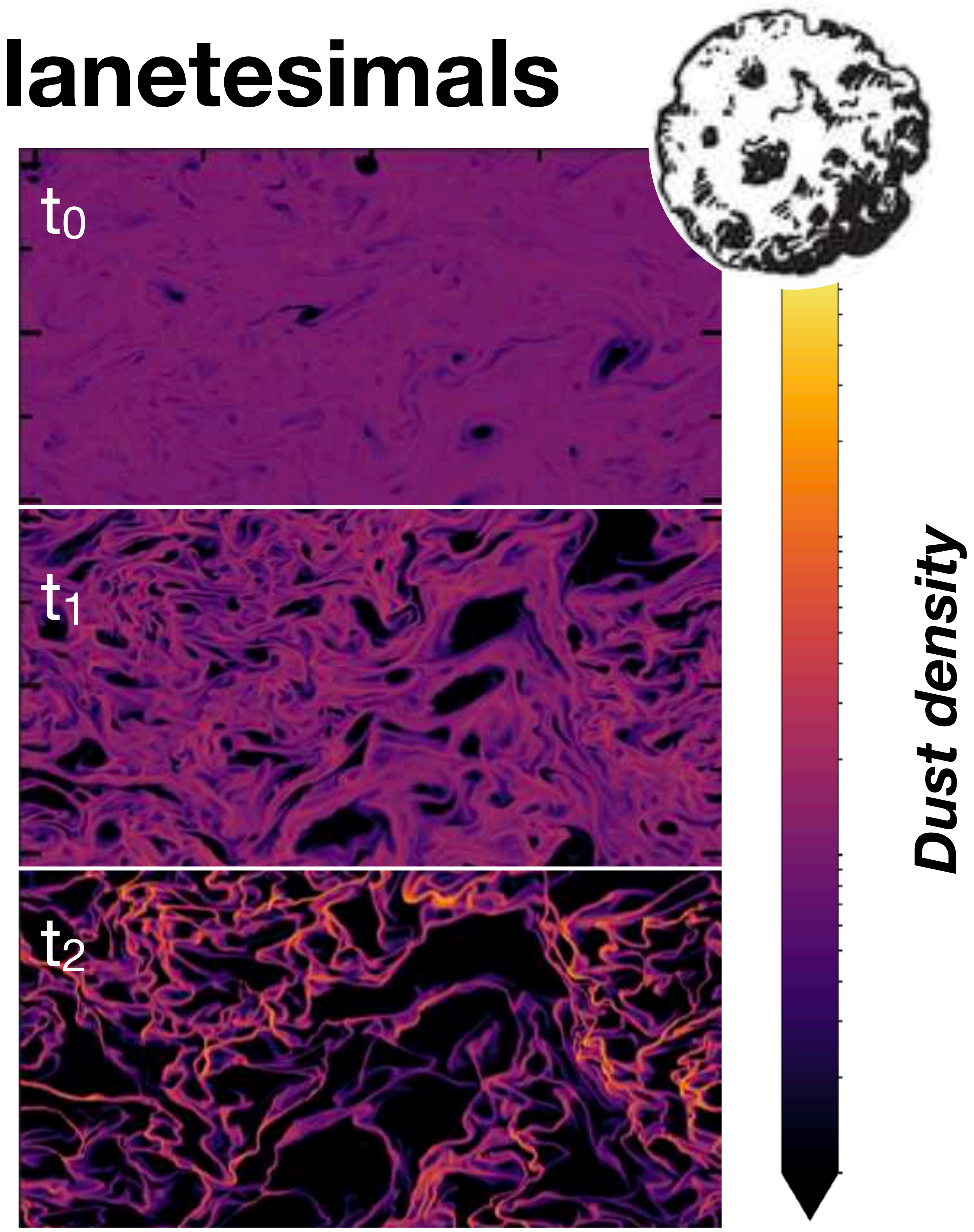


From grains to pebbles



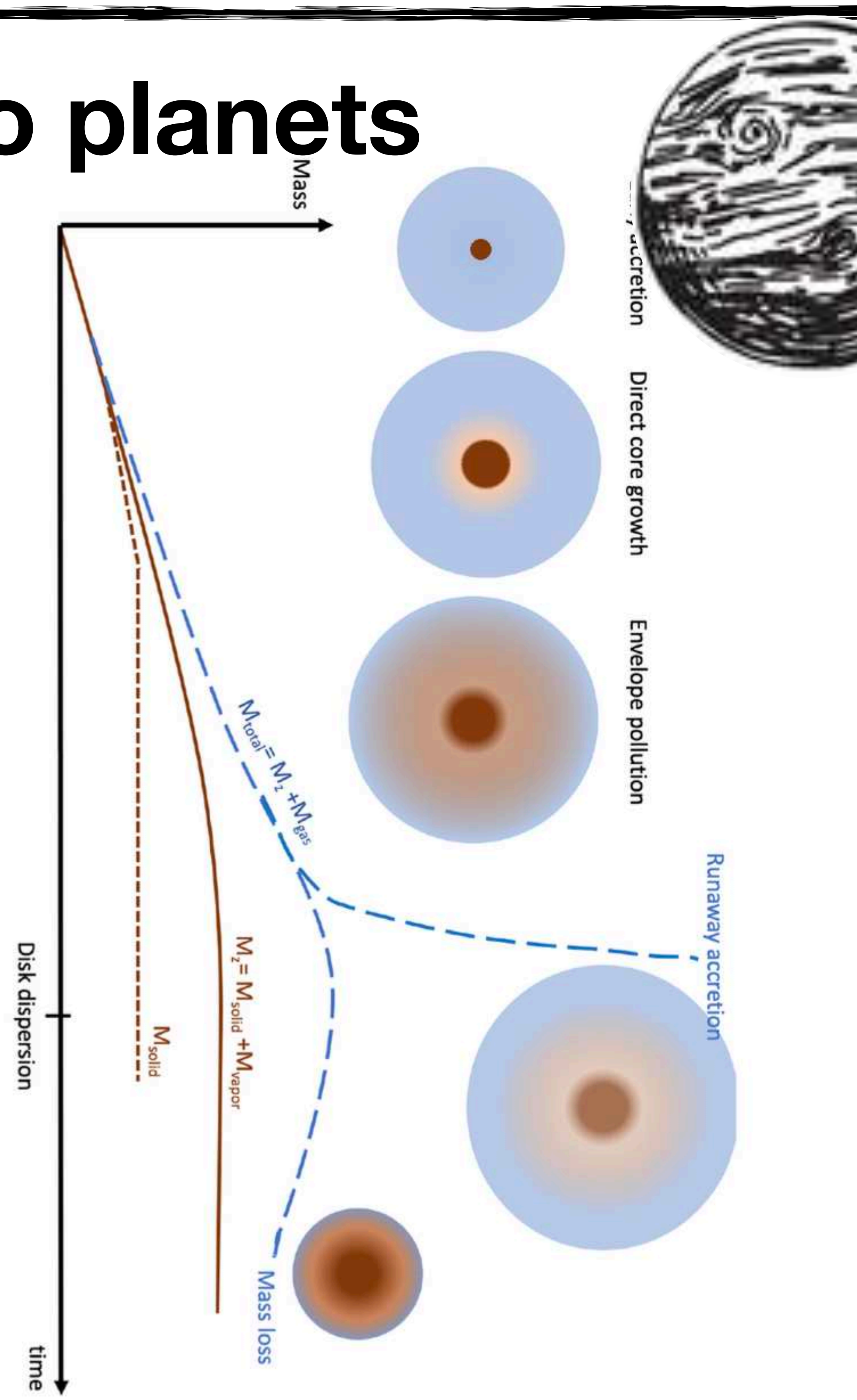
Birnstiel+2024

to planetesimals



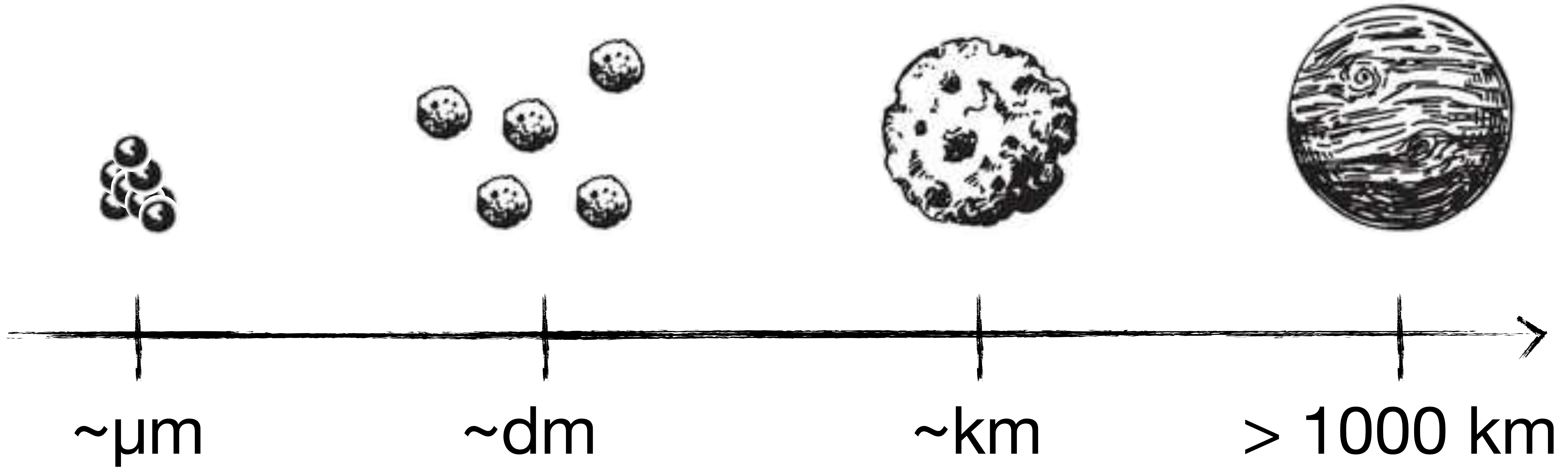
Matthijsse+2025

to planets

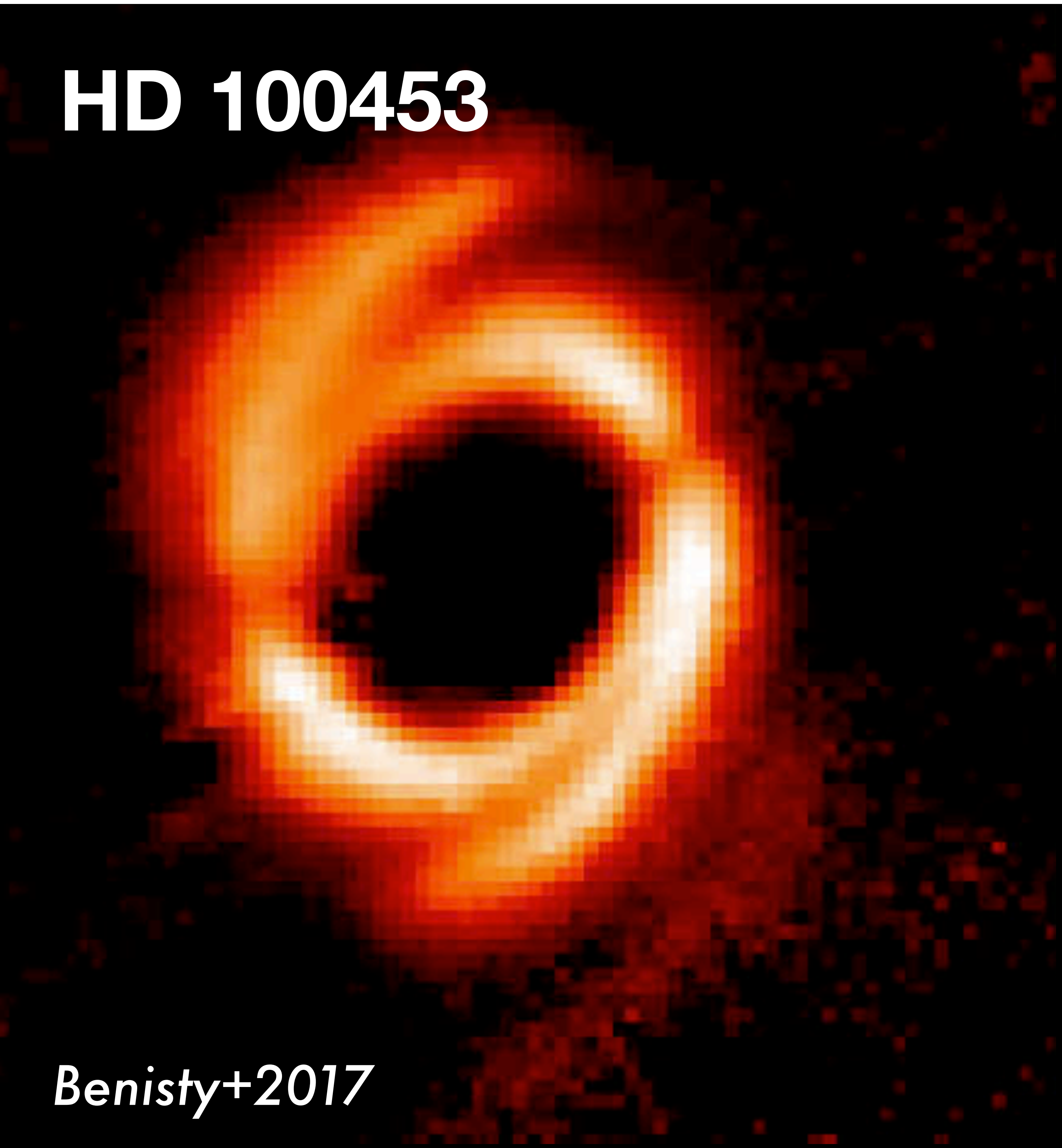


Drążkowska+2025

Context



Planet formation …

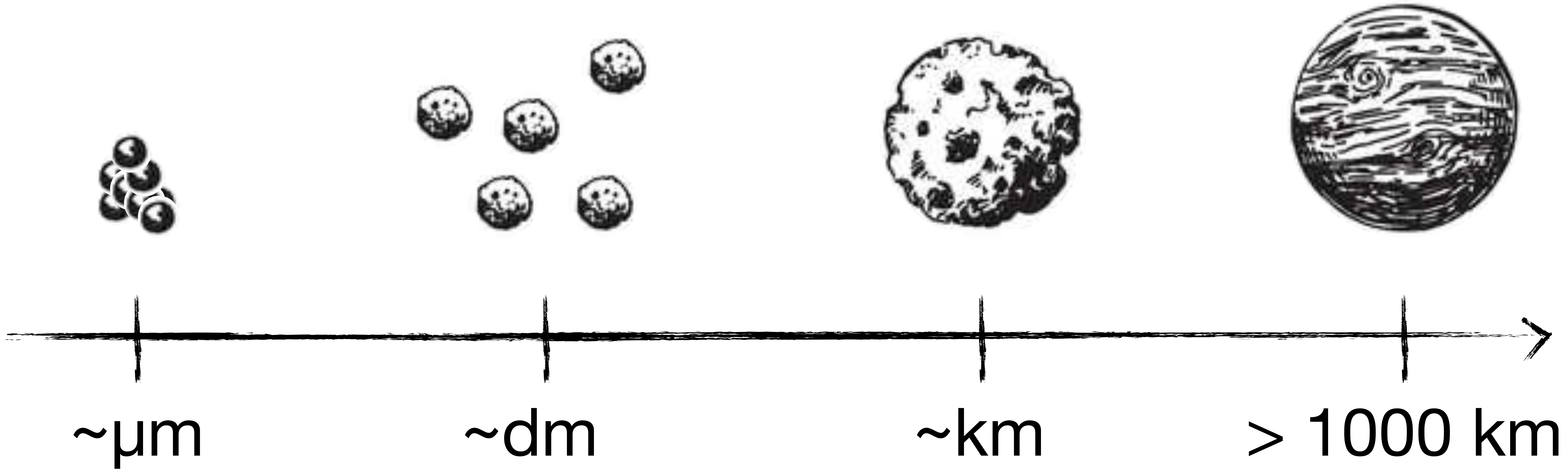


… in multiple systems

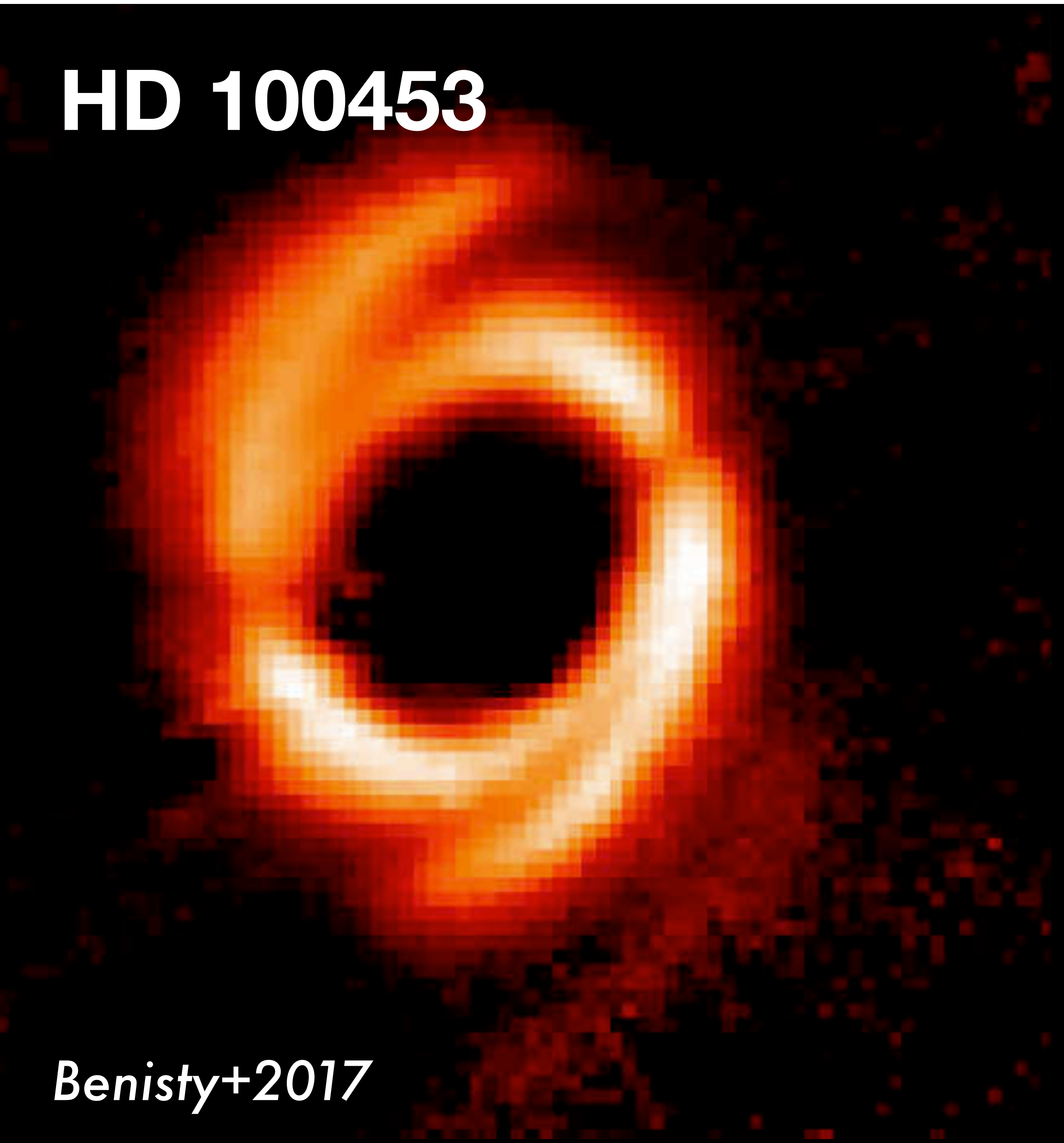
> Large velocity gradients ⇒ impede dust growth

> High density structures ⇒ enhance dust growth

Context



Planet formation …



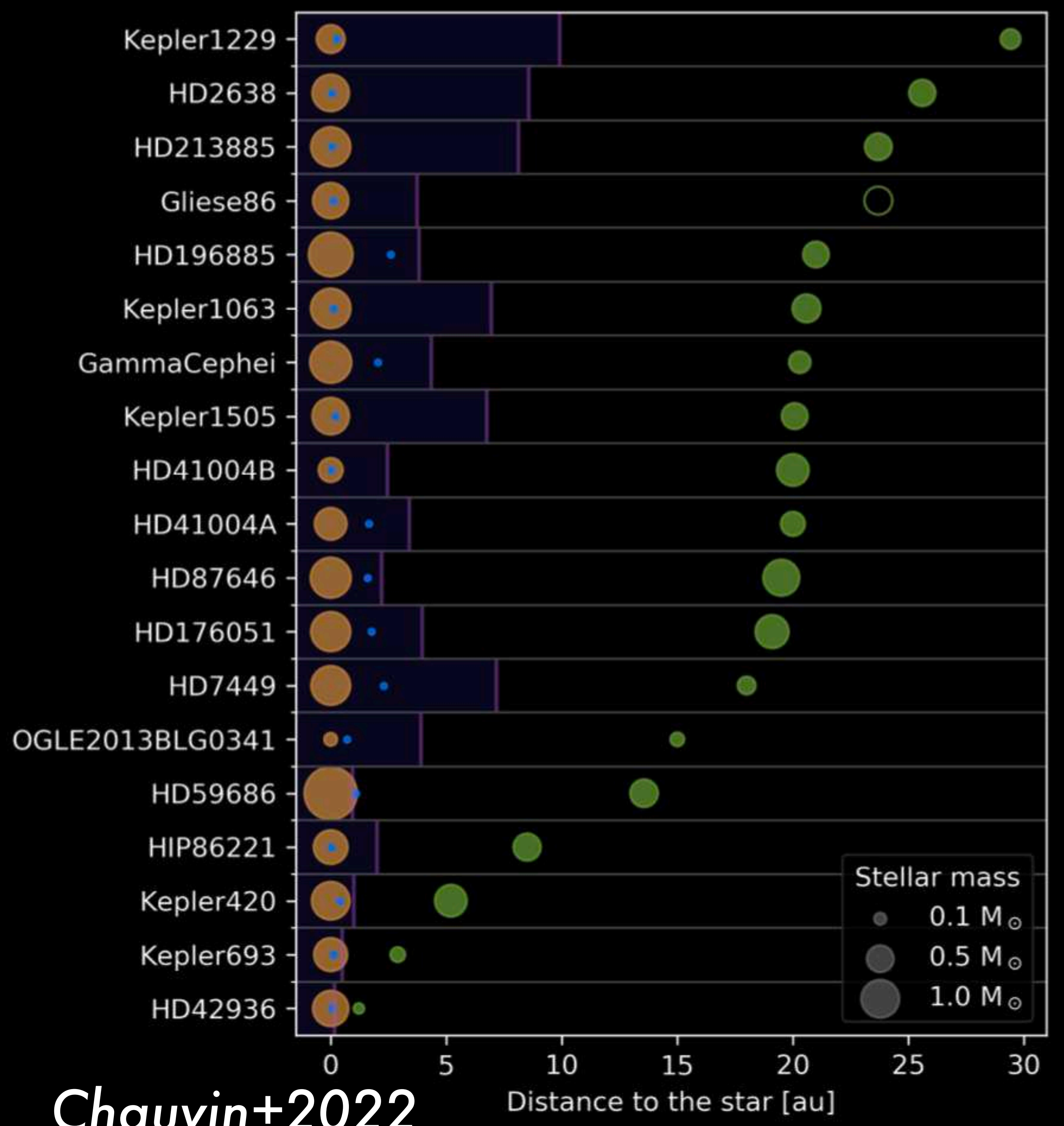
Benisty+2017

… in multiple systems

> Large velocity gradients

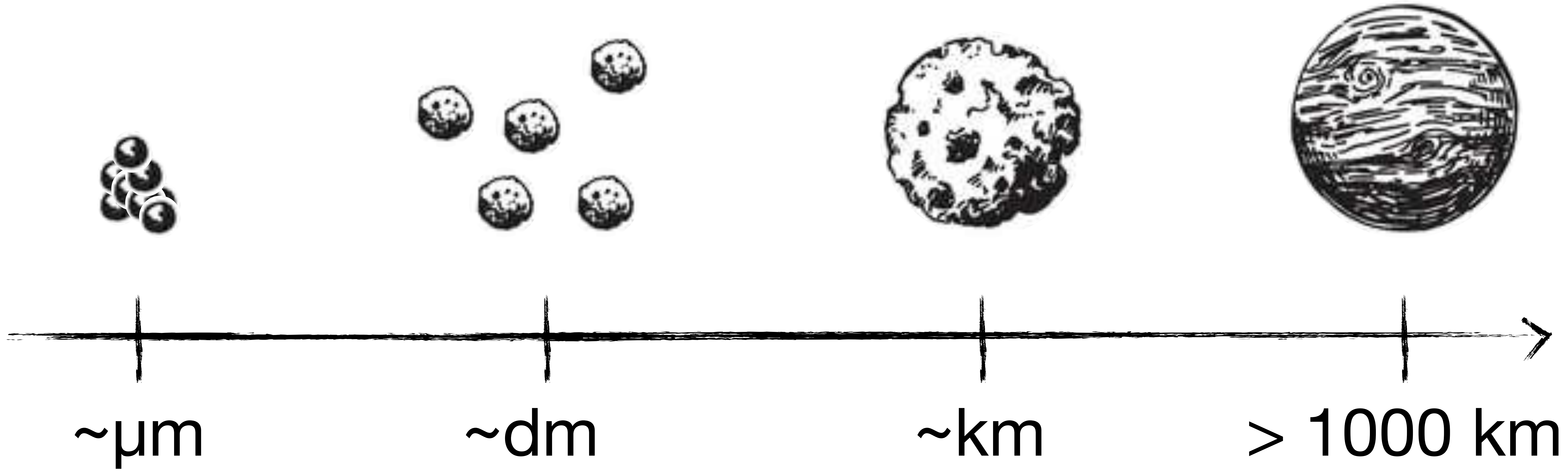
> High density structures

Planets are observed <
in multiple systems

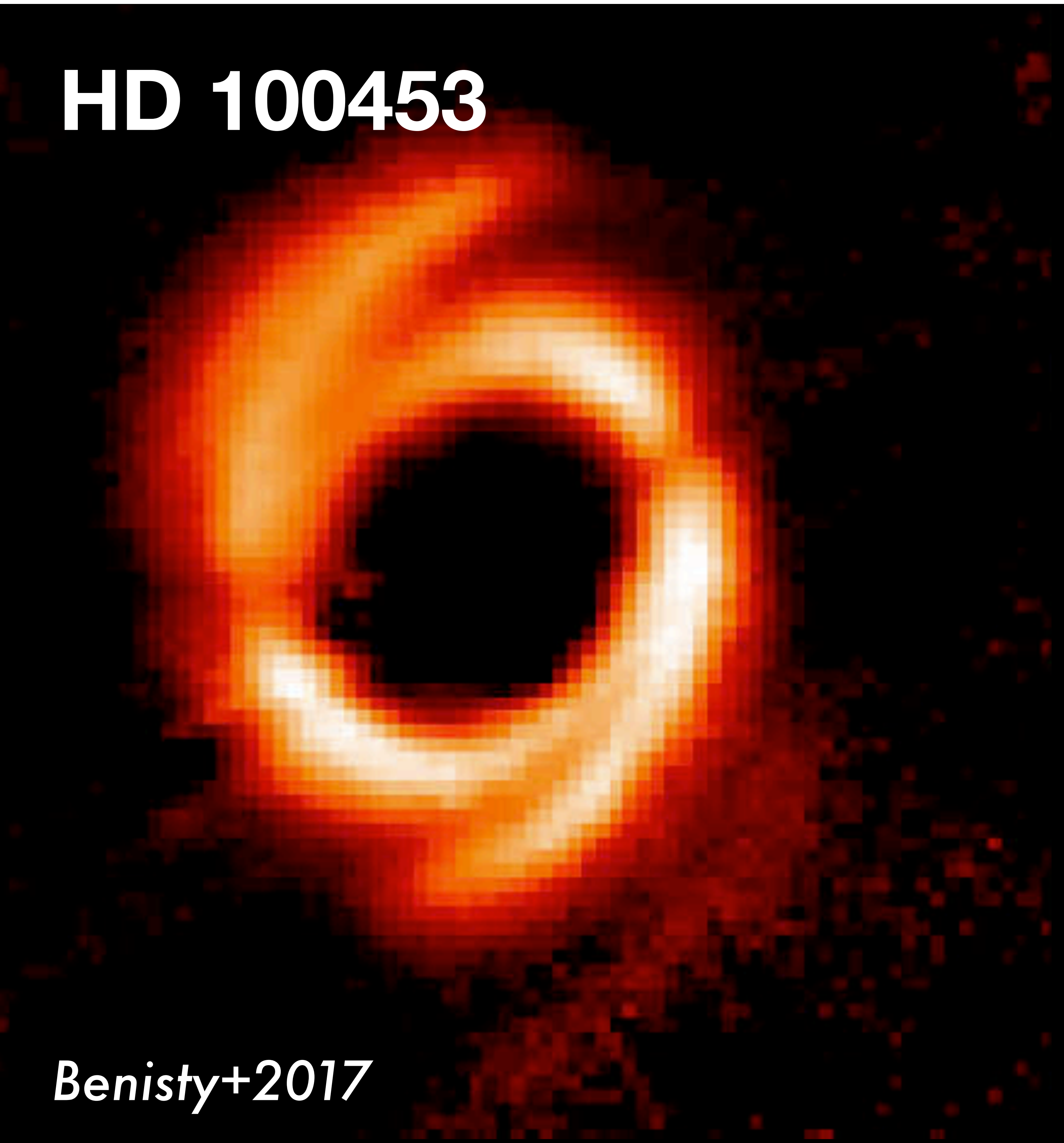


Chauvin+2022

Context



Planet formation …



Benisty+2017

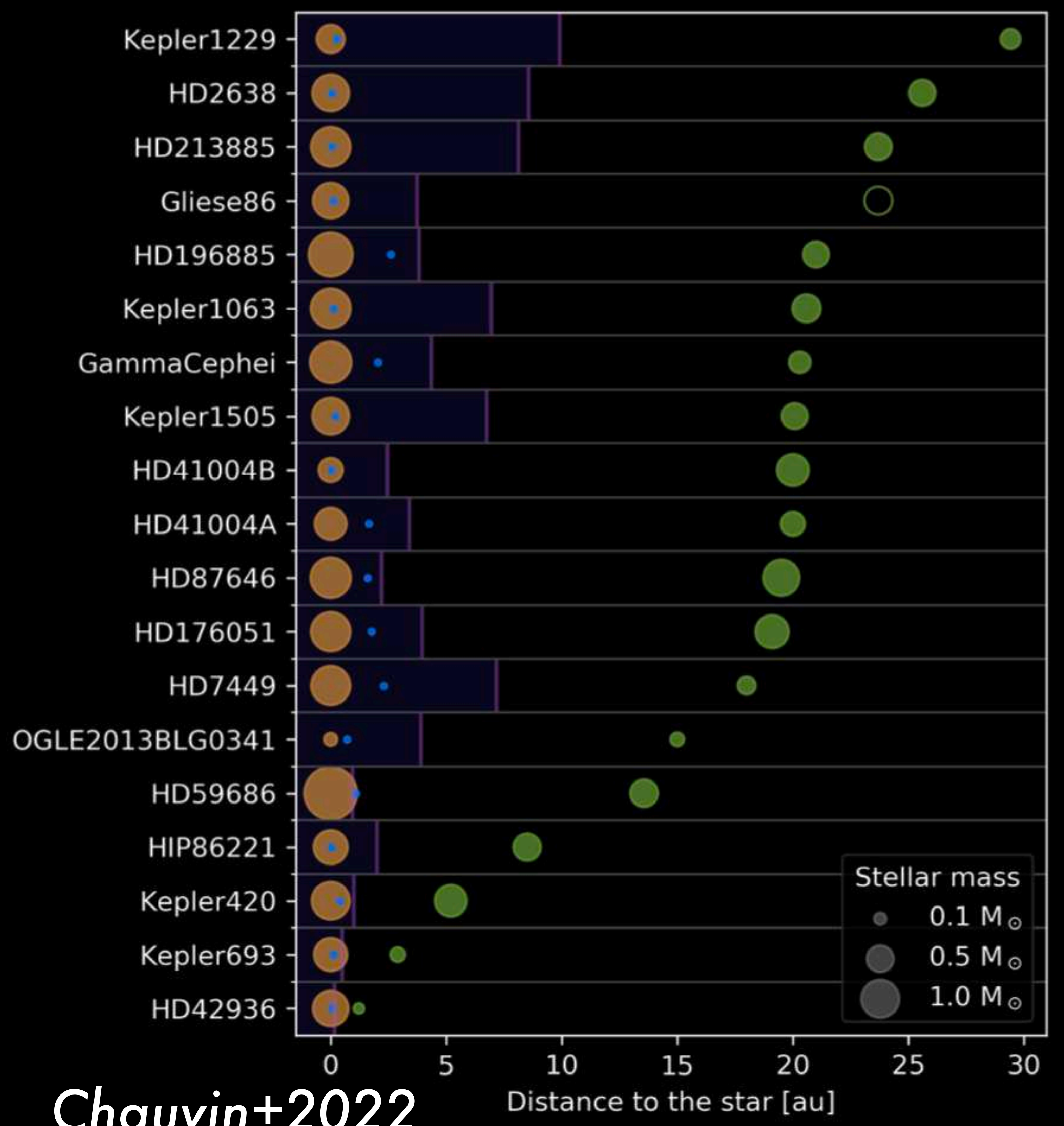
… in multiple systems

> Large velocity gradients

> High density structures

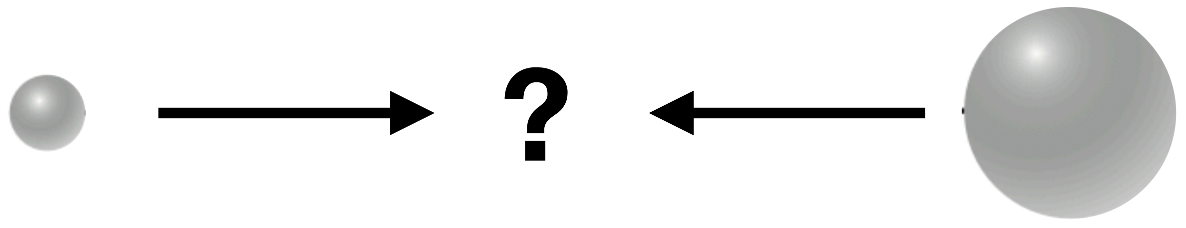
How do they form ?

Planets are observed <
in multiple systems



Chauvin+2022

Context

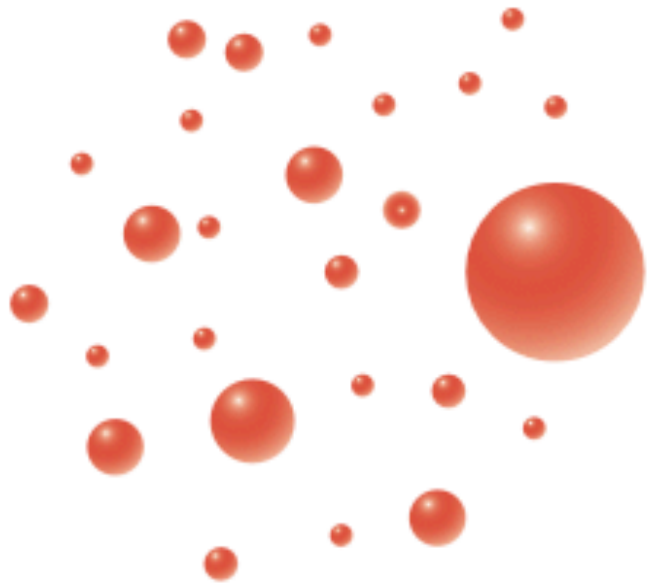


V_{rel} Relative velocity

V_{frag} Fragmentation threshold = f(grain properties)

$V_{rel} < V_{frag}$

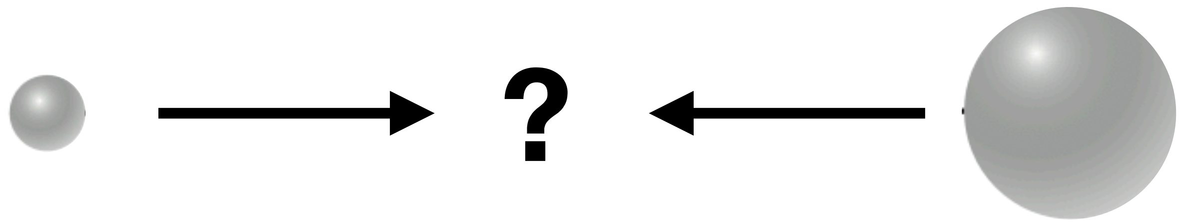
$V_{rel} > V_{frag}$



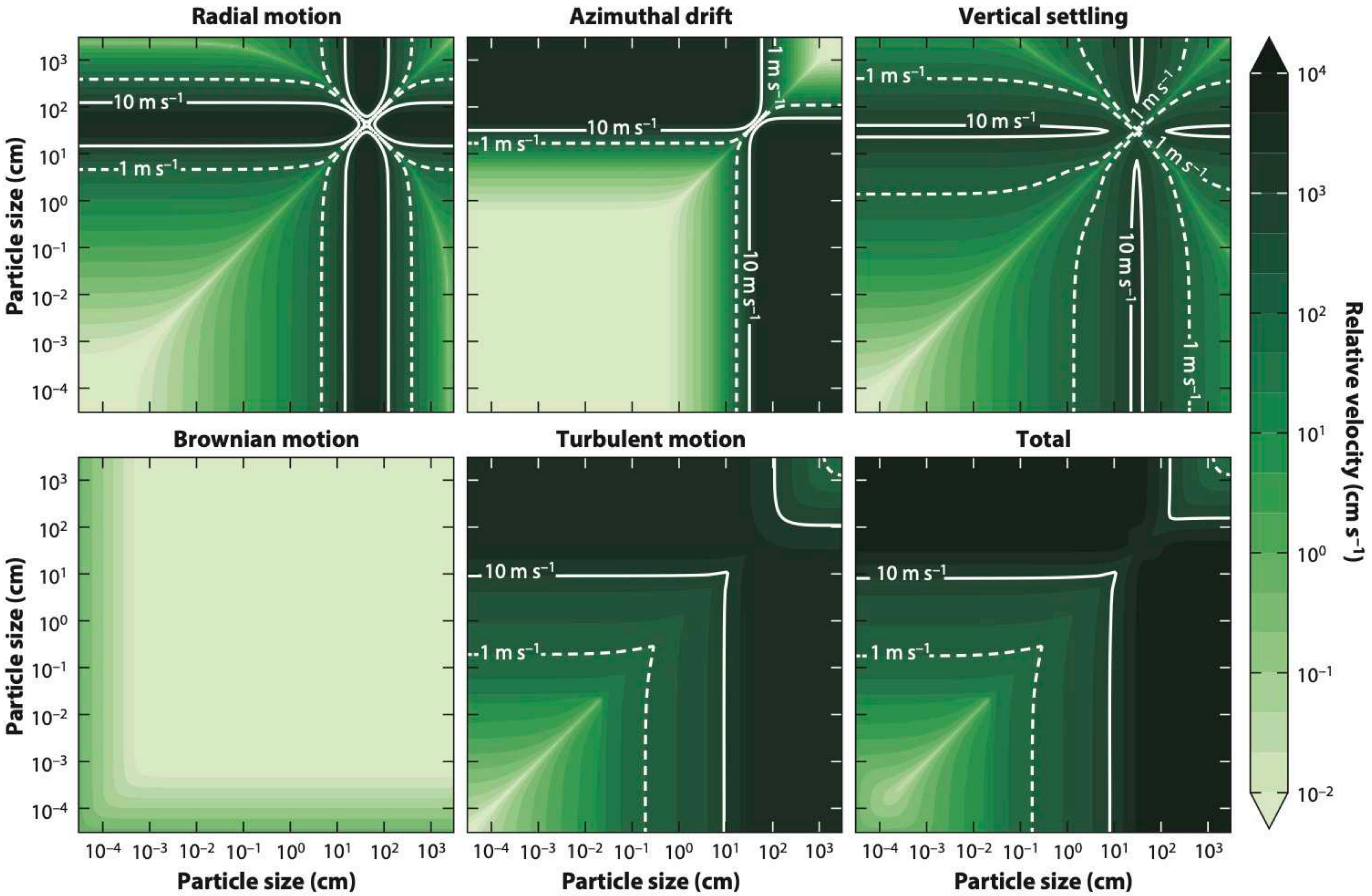
Ormel&Cuzzi2007

Birnstiel+2024

Context

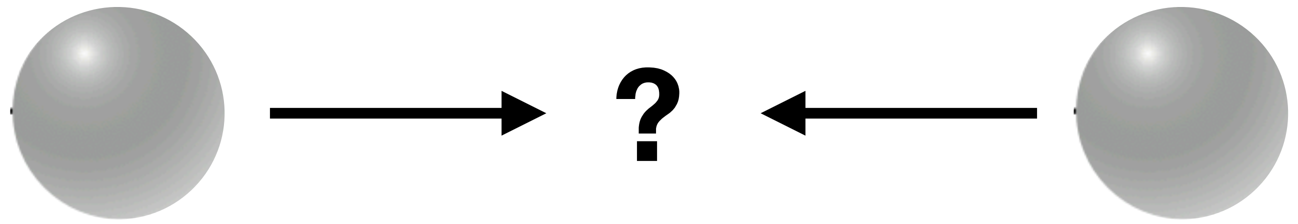


V_{rel} Relative velocity



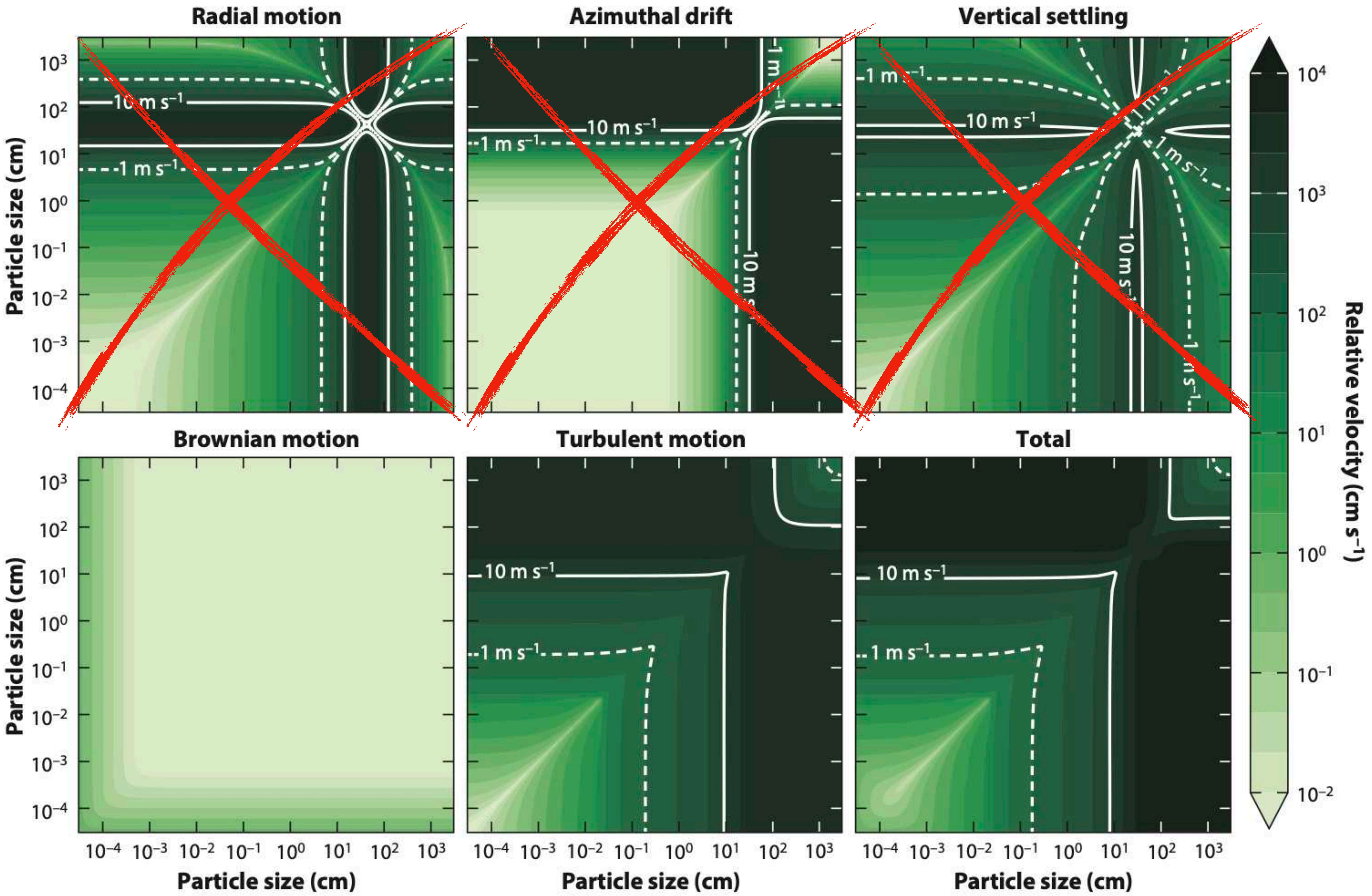
Ormel&Cuzzi2007
Birnstiel+2024

Context



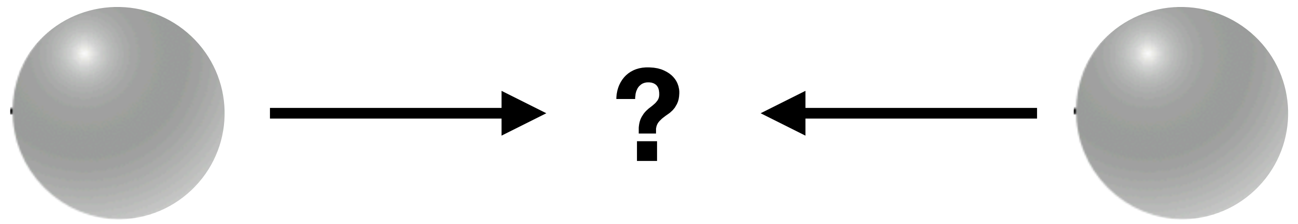
V_{rel} Relative velocity

If grains of same size =>



Ormel&Cuzzi2007
Birnstiel+2024

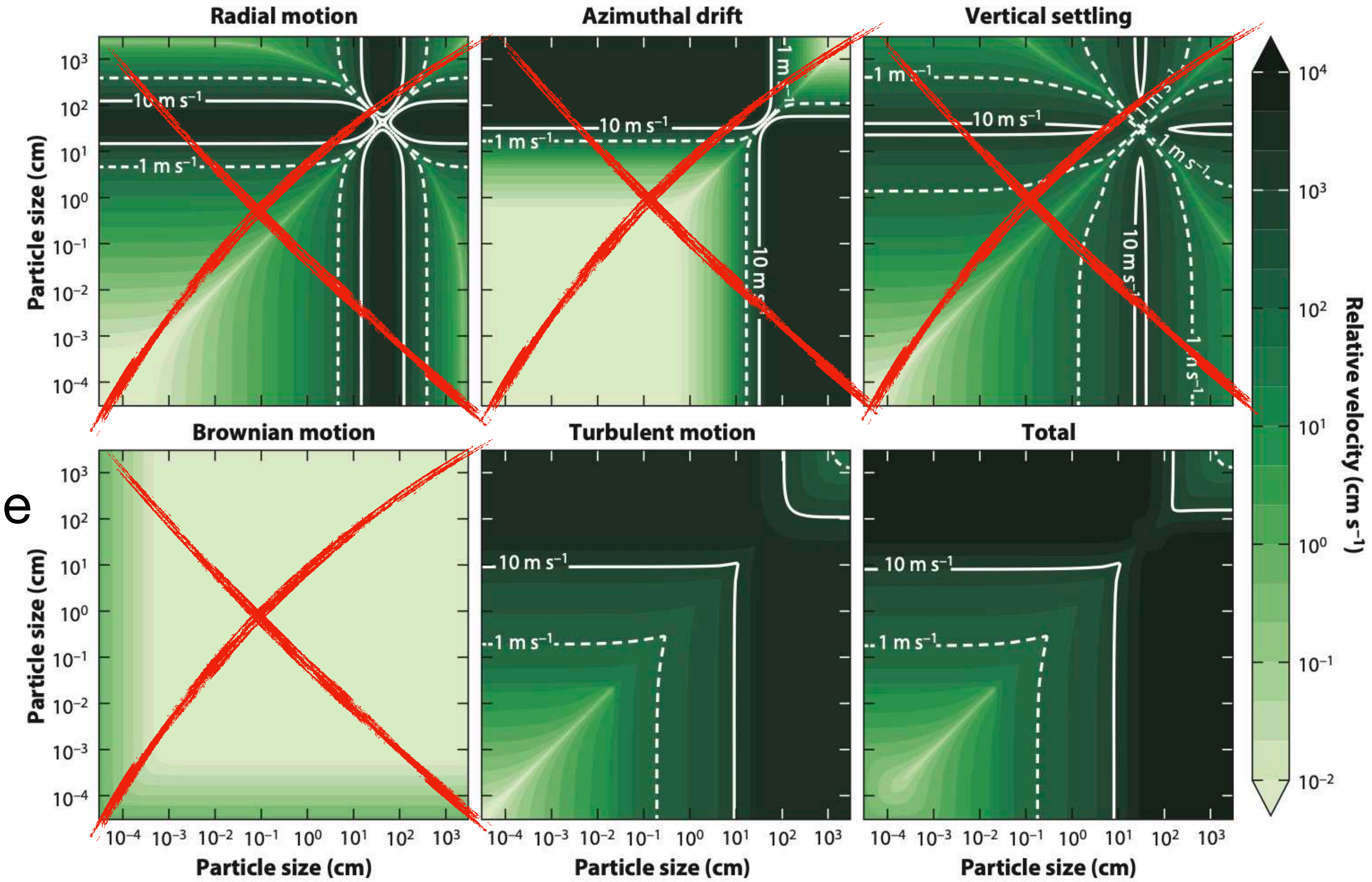
Context



V_{rel} Relative velocity

If grains of same size =>

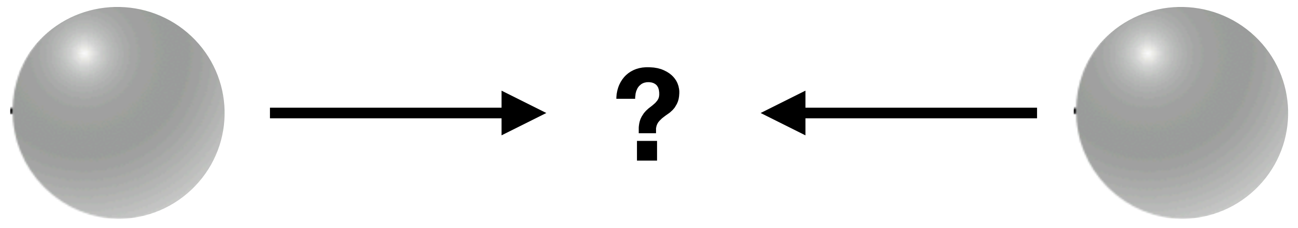
negligible



Ormel&Cuzzi2007

Birnstiel+2024

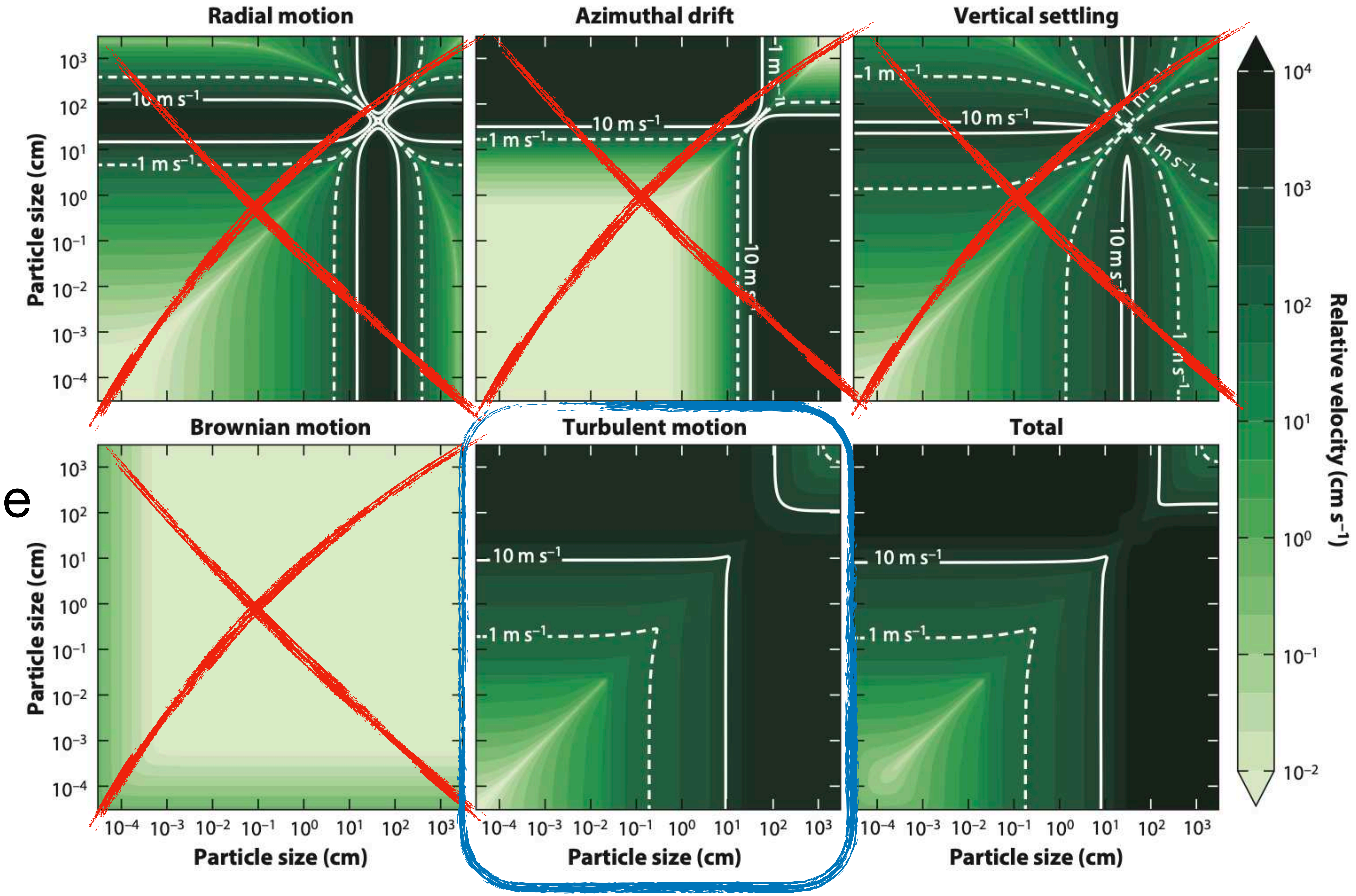
Context



V_{rel} Relative velocity

If grains of same size =>

negligible



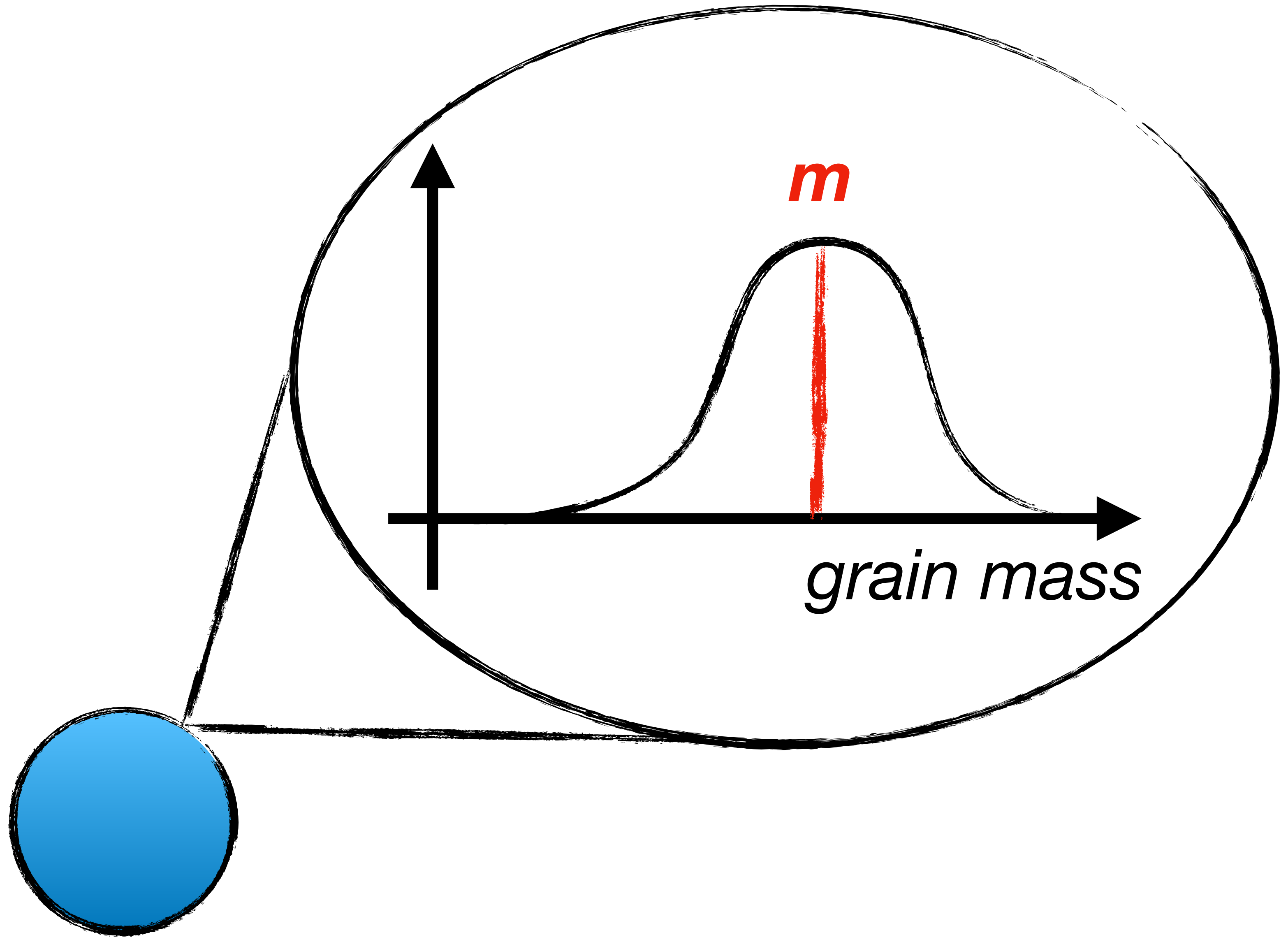
Ormel&Cuzzi2007

Birnstiel+2024

Numerical setup

Price+2018
Vericel+2021
Michoulier+2024

+ DUST GROWTH



SPH particle

Gas turbulence drives collisions

Equal-size collisions

No particle-particle collisions

Numerical setup

Price+2018
Vericel+2021
Michoulier+2024

PHANTOM + DUST GROWTH

$$St = \Omega\, t_s$$

Dust growth equations

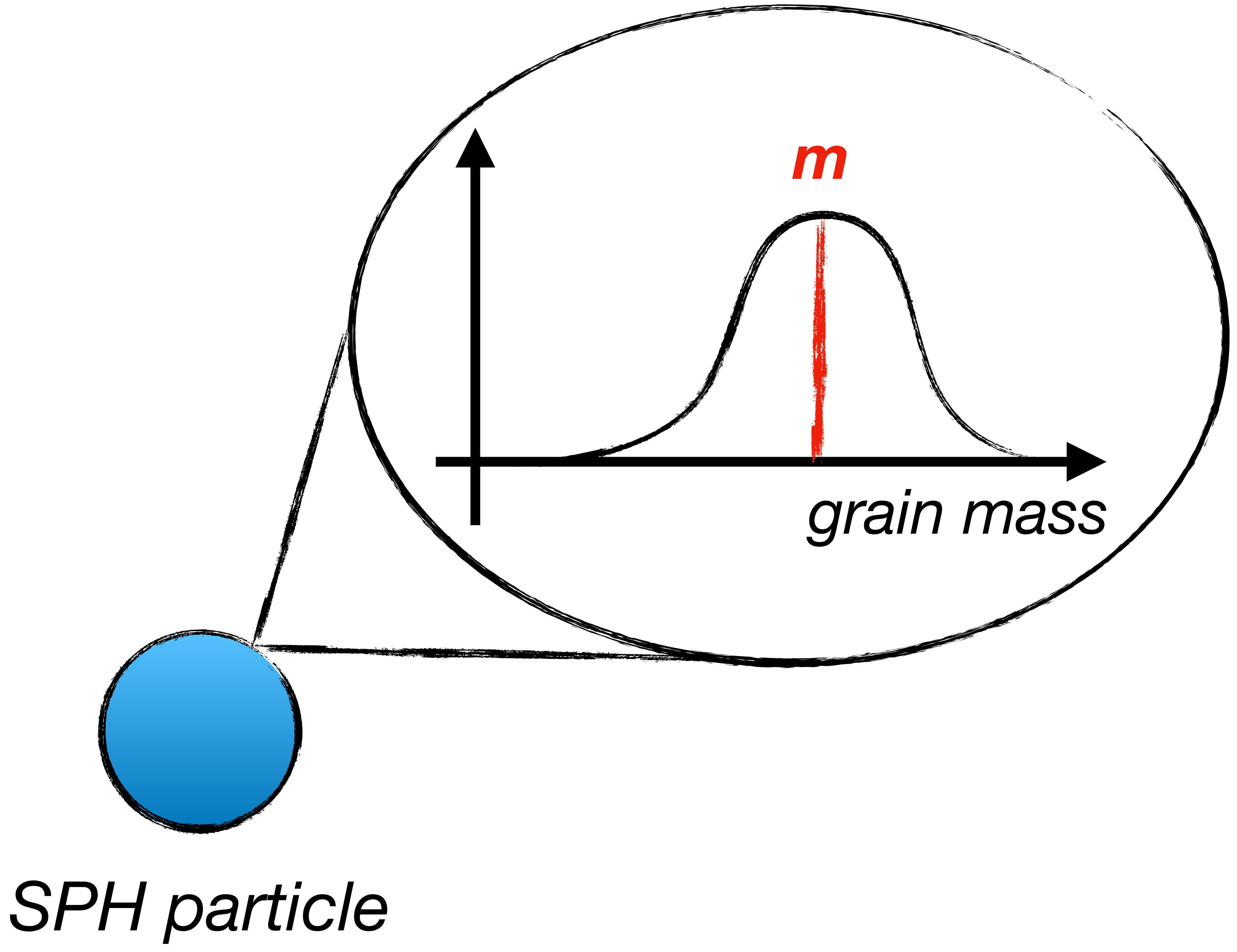
$$V_{rel} = f(v_t, St)$$

vs

$$V_{frag} = 15\ m/s$$

Stepinski&Valageas1997
Michoulier+2024

$$\dot{m} = \pm 4\pi s^2 V_{rel} \rho_d \delta$$



Gas turbulence drives collisions

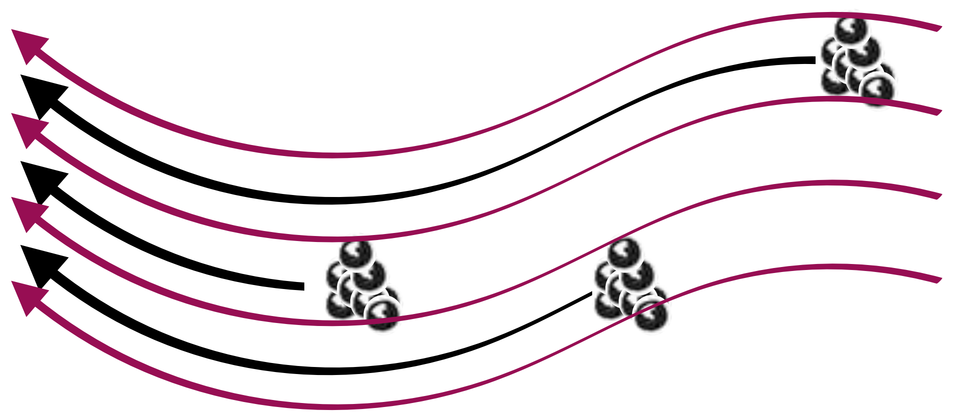
Equal-size collisions

No particle-particle collisions

Numerical setup

Price+2018
Vericel+2021
Michoulier+2024

+ **1 500 000 GAS-DUST PARTICLES**
+ **DUST GROWTH**



$$St = \Omega\, t_s$$

$$St < 1$$

Small grains

< mm-cm

1 population of particles

(coupled density, 1-fluid)

+ *Fast for small particles*
- *Wrong for the large ones*

Dust growth equations

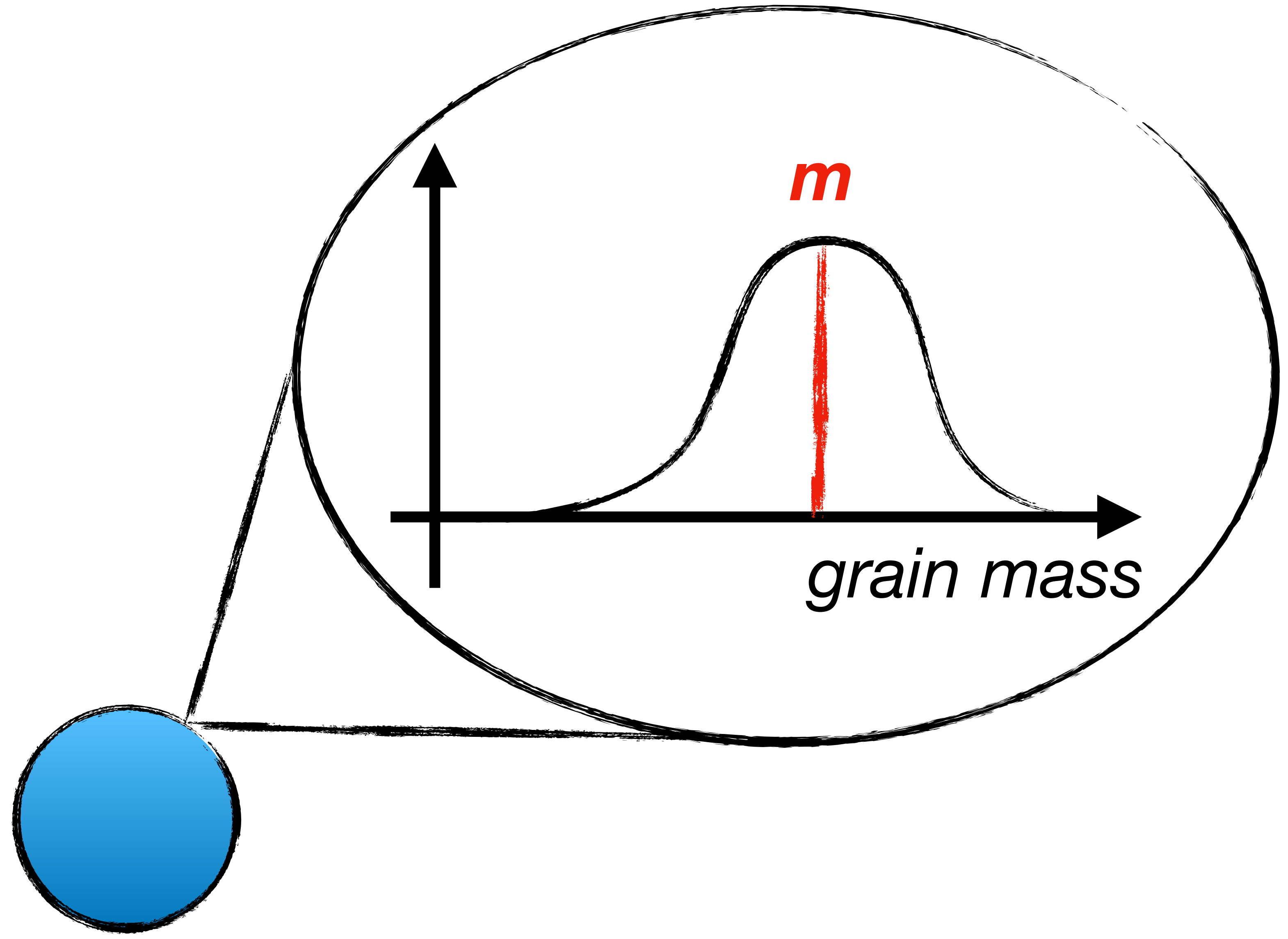
$$V_{rel} = f(v_t, St)$$

vs

$$V_{frag} = 15\ m/s$$

Stepinski&Valageas1997
Michoulier+2024

$$\dot{m} = \pm 4\pi s^2 V_{rel} \rho_d \delta$$



SPH particle

Gas turbulence drives collisions

Equal-size collisions

No particle-particle collisions

Orbital setup

Price+2018
Vericel+2021
Michoulier+2024

Disc parameters

$M_d = 0.001\ M_\odot$

$\varepsilon = \rho_d/\rho_g = 0.01$

$\Sigma \propto r^{-1}$

$\alpha = 0.005$

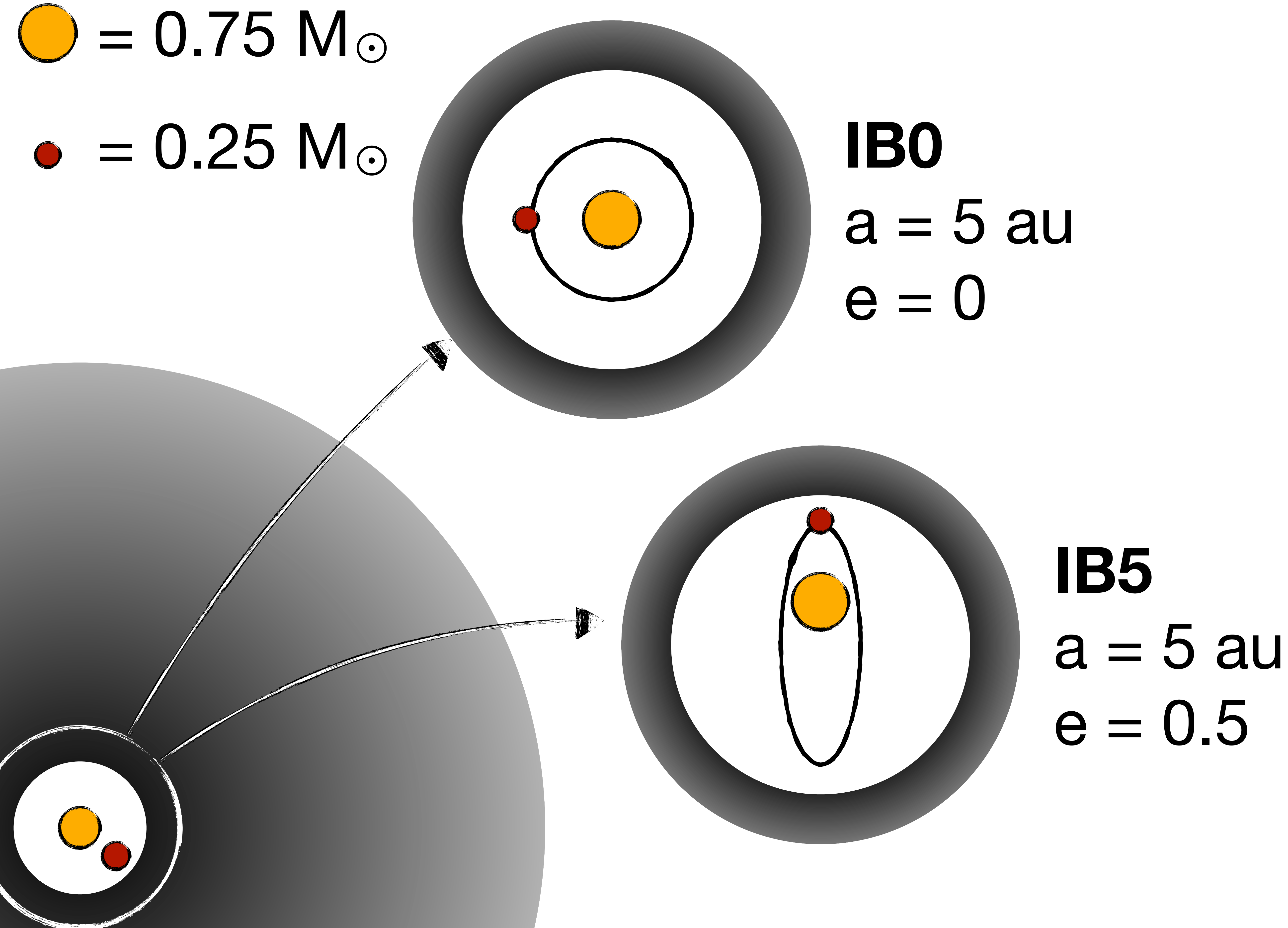
● (yellow) $= 1.0\ M_\odot$

● (red) $= 0.1\ M_\odot$

Circumbinary discs

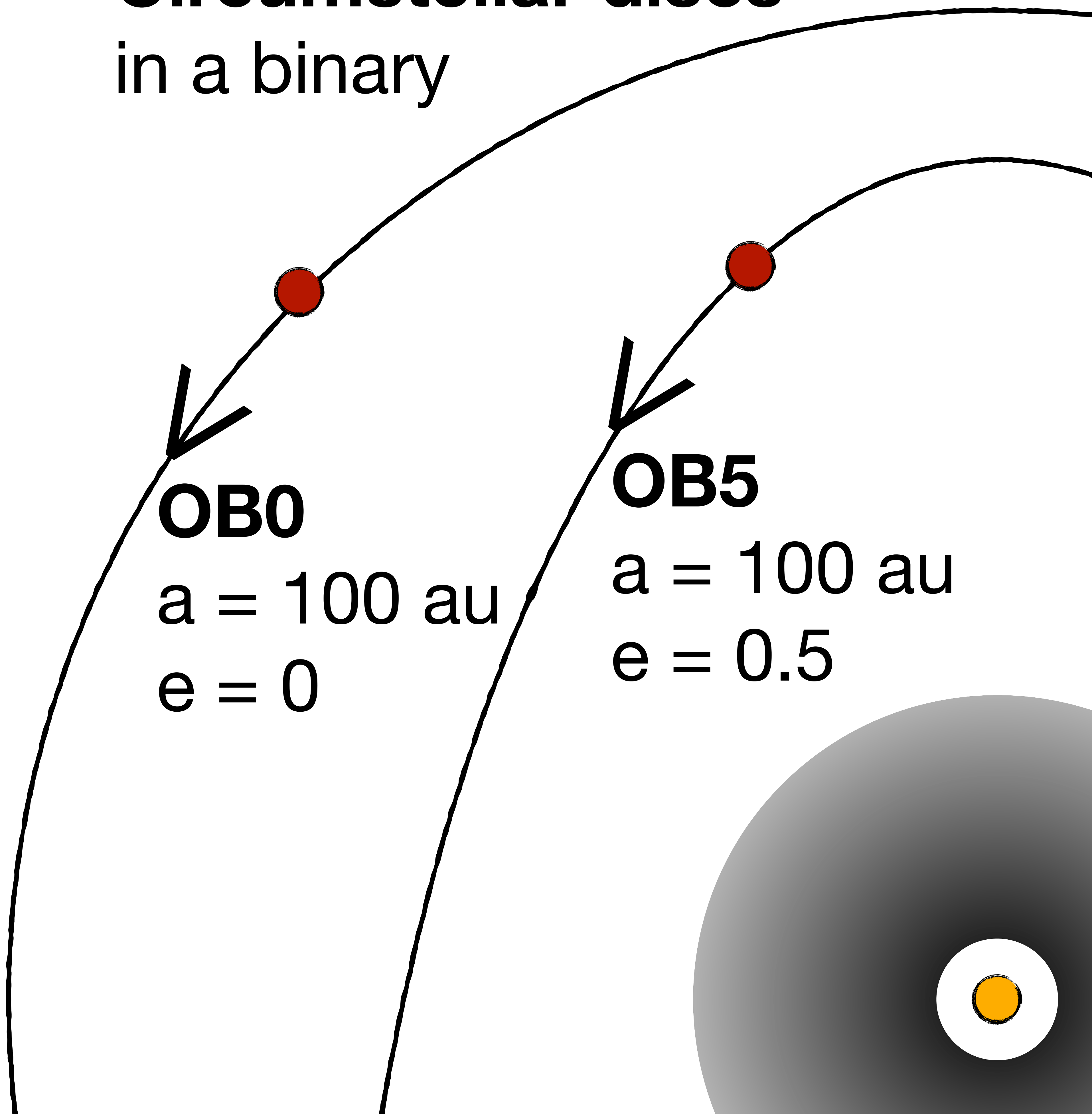
● (yellow) $= 0.75\ M_\odot$

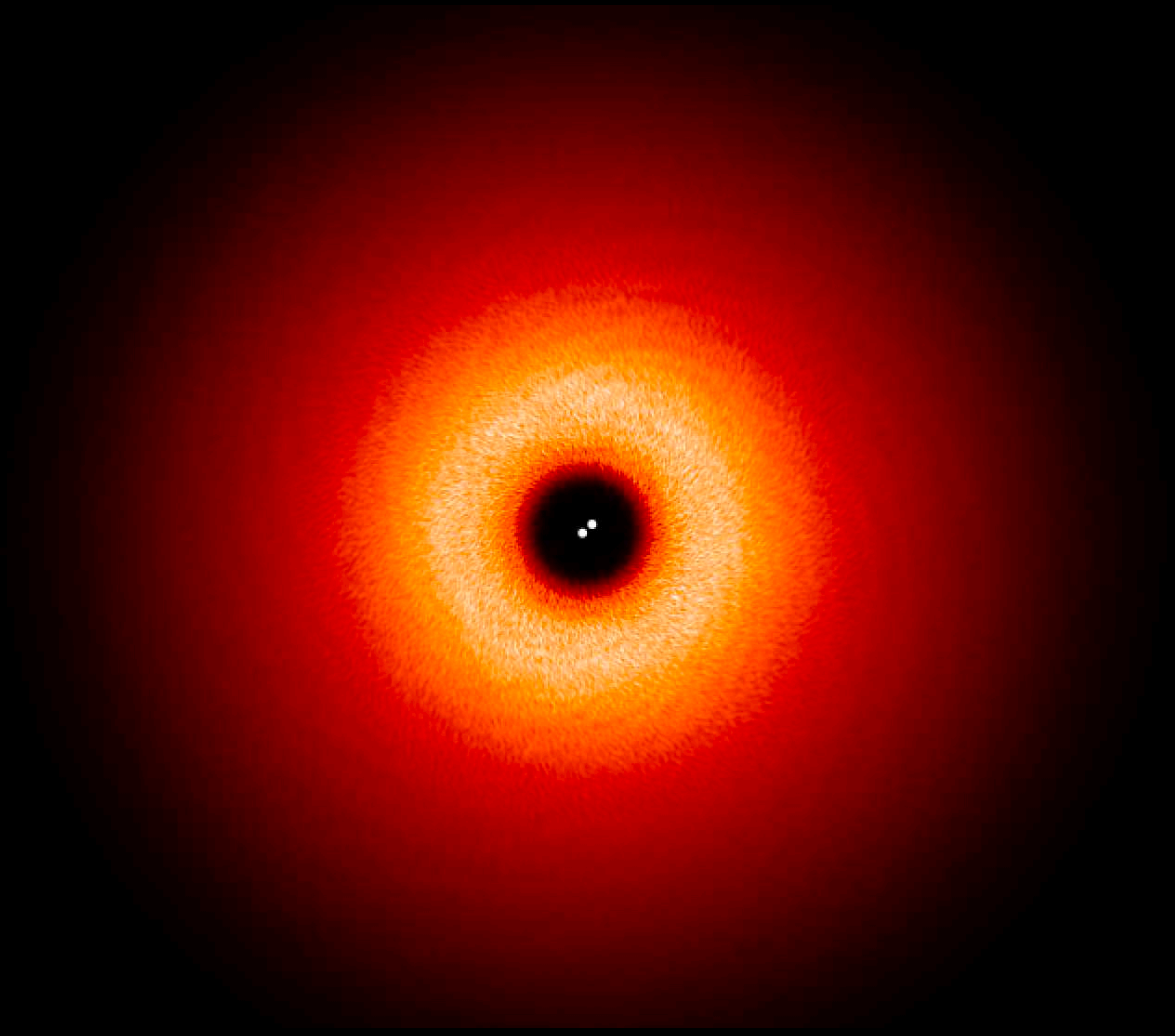
● (red) $= 0.25\ M_\odot$



Circumstellar discs

in a binary





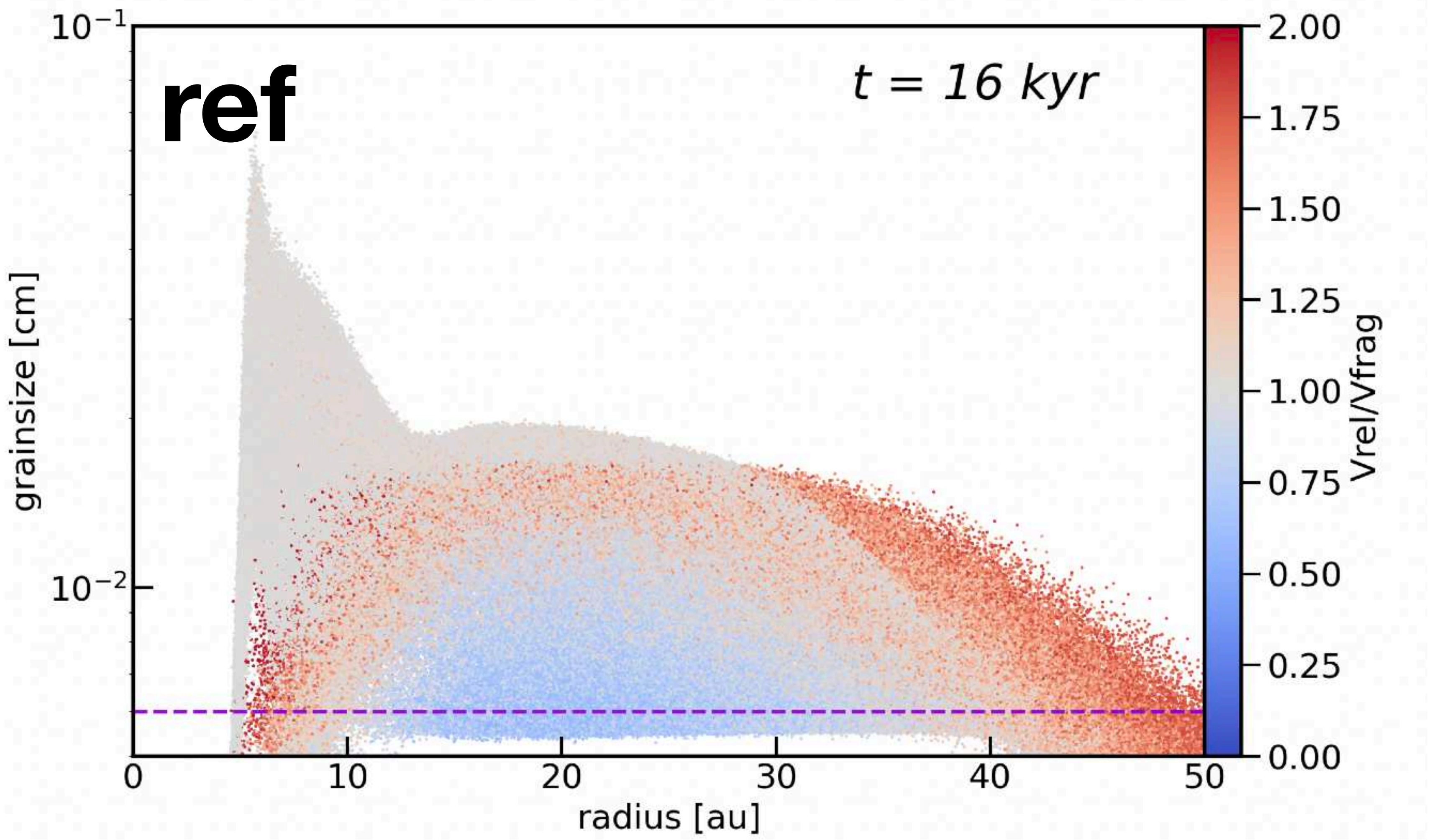
Circumbinary discs

P_{bin} = 11yr

Circumbinary discs

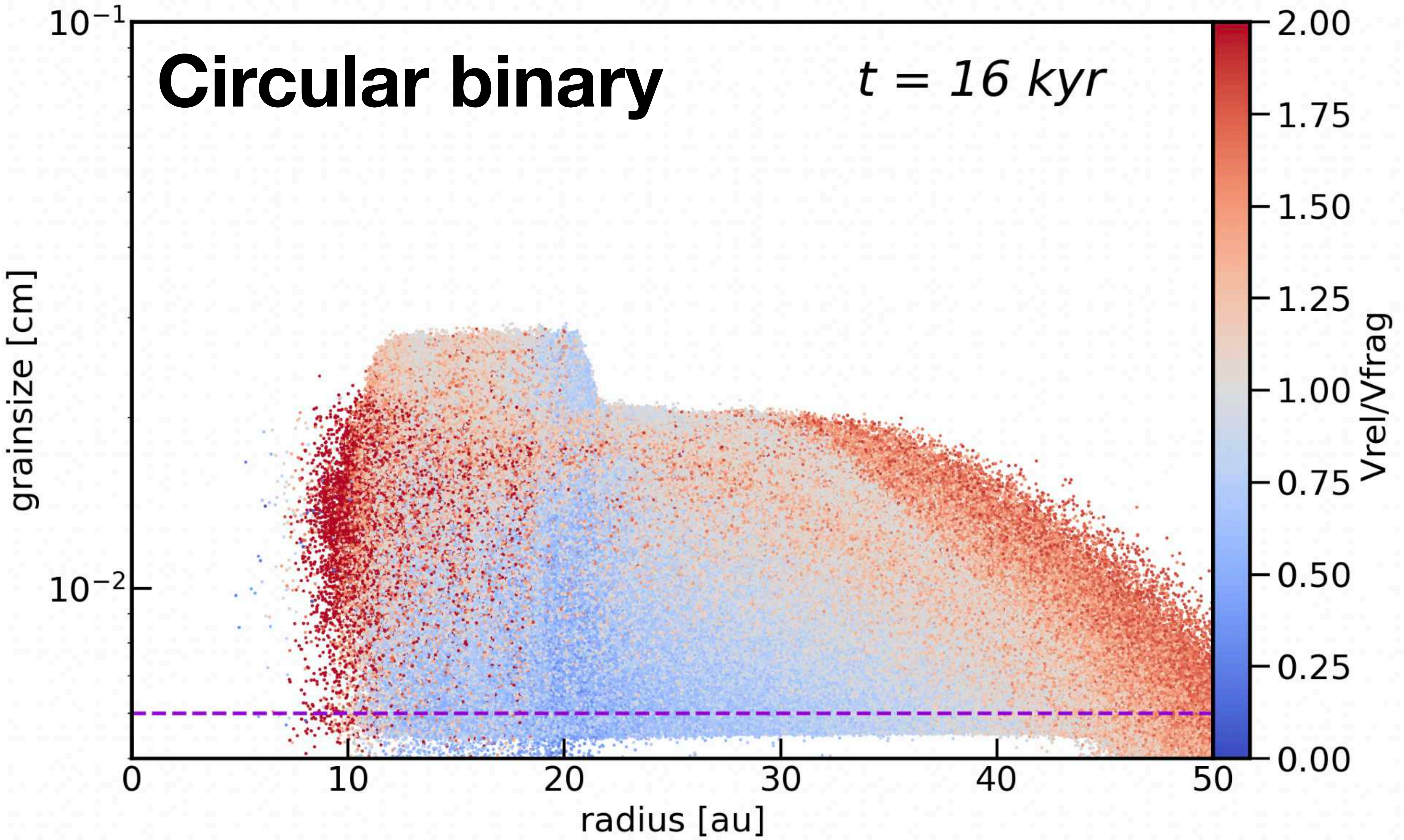
Dust grain size

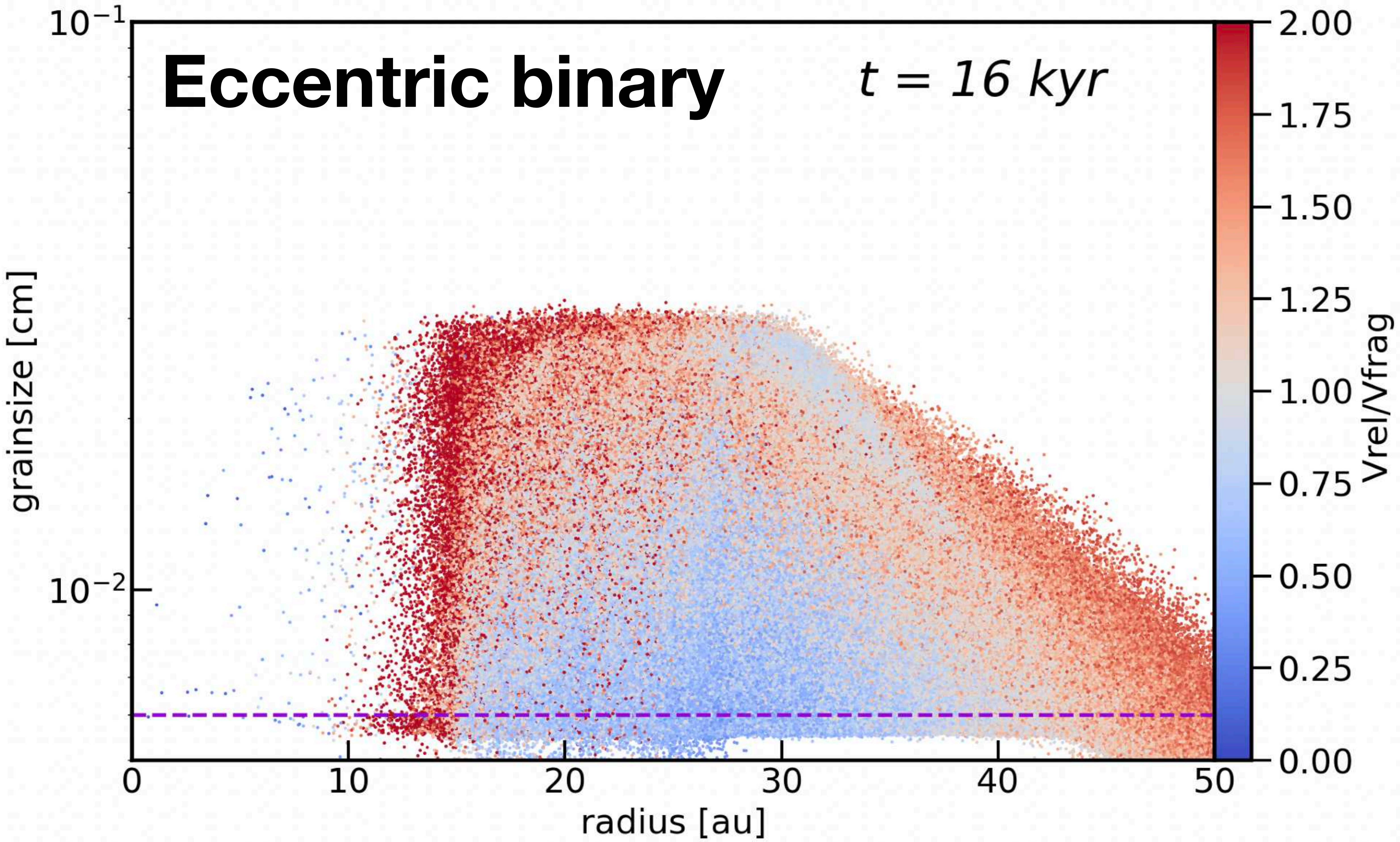
at t = 16 kyr = 500 P_{disc}

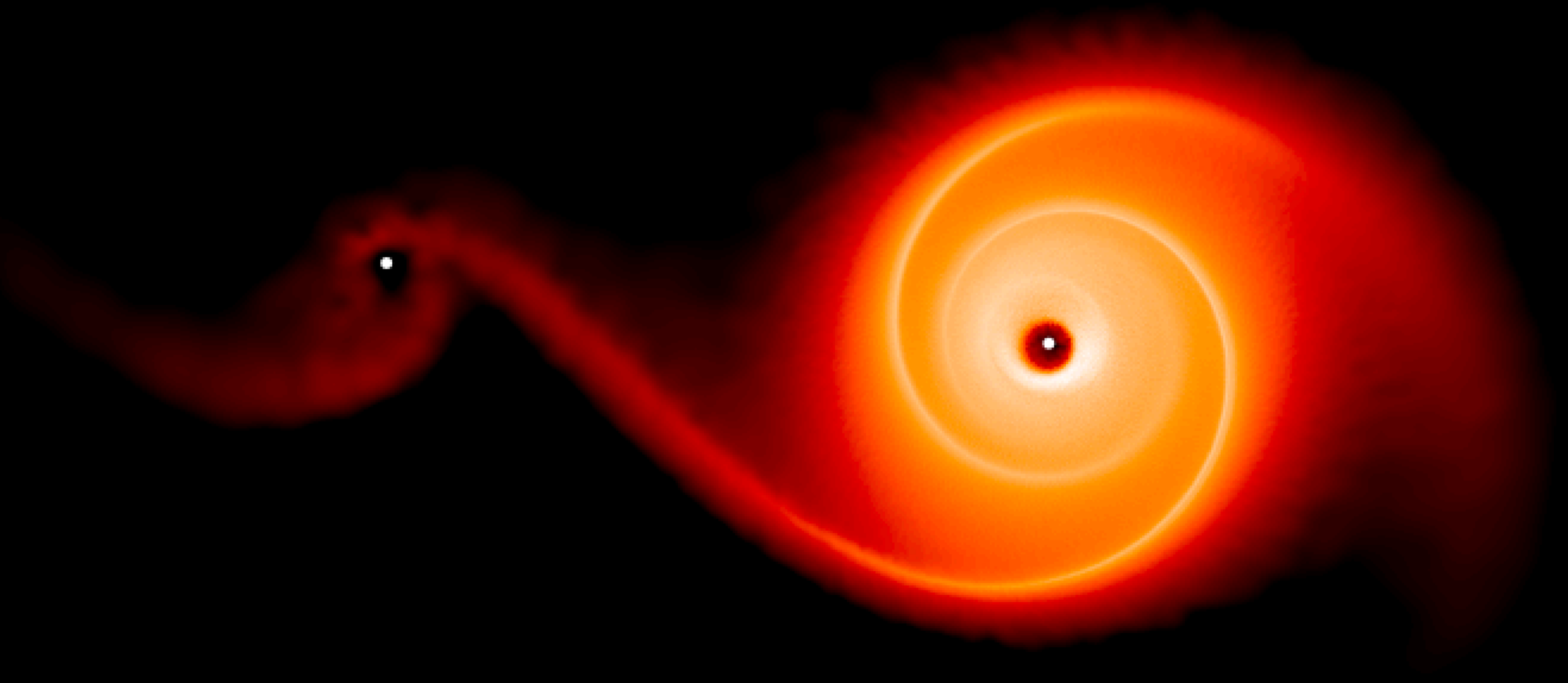


☆ **Pile-up at the cavity edge**

☆ **Fragmentation limited if e>0**







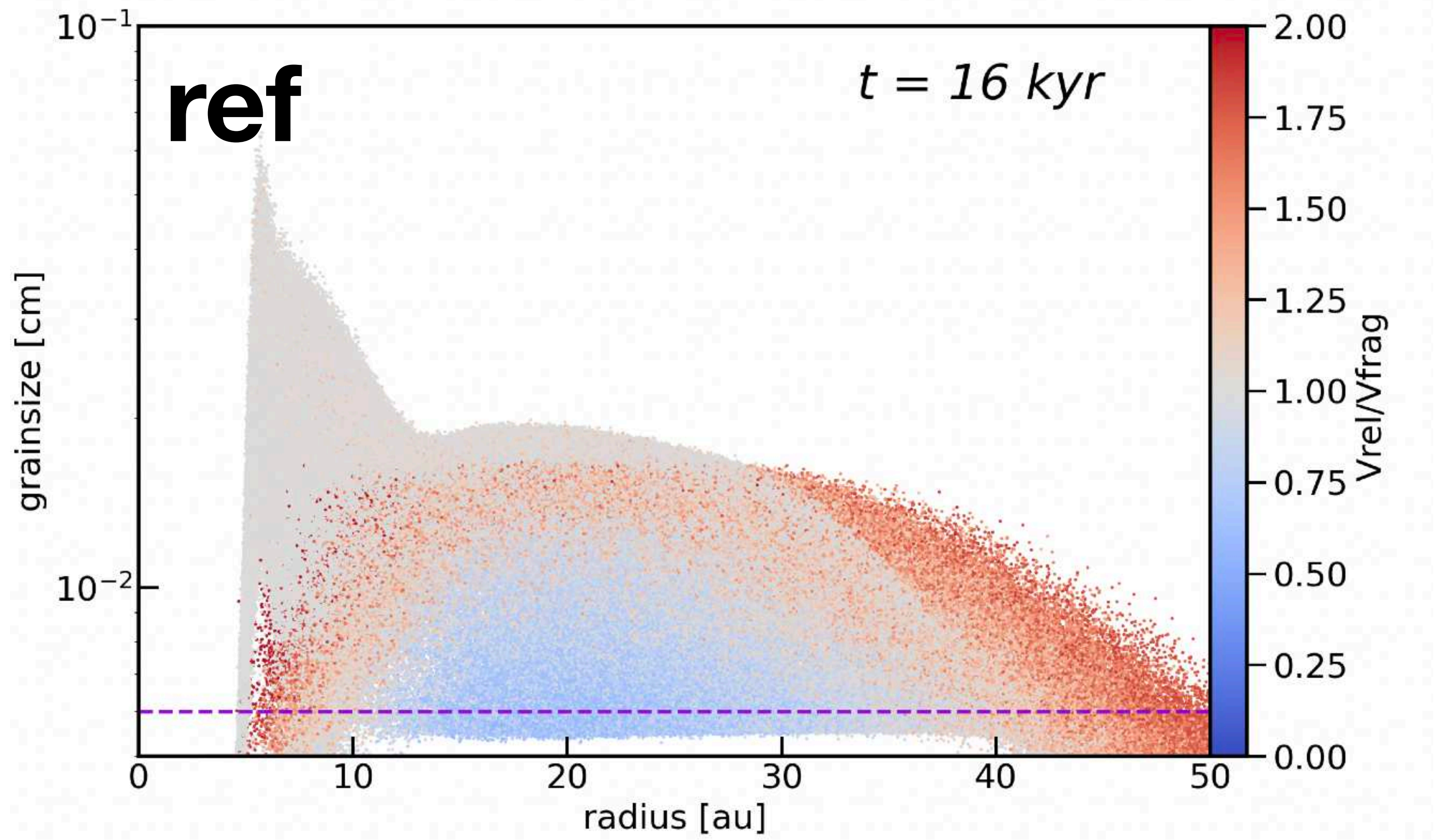
Circumstellar discs in binaries

P_{bin} = 997yr

Circumstellar discs

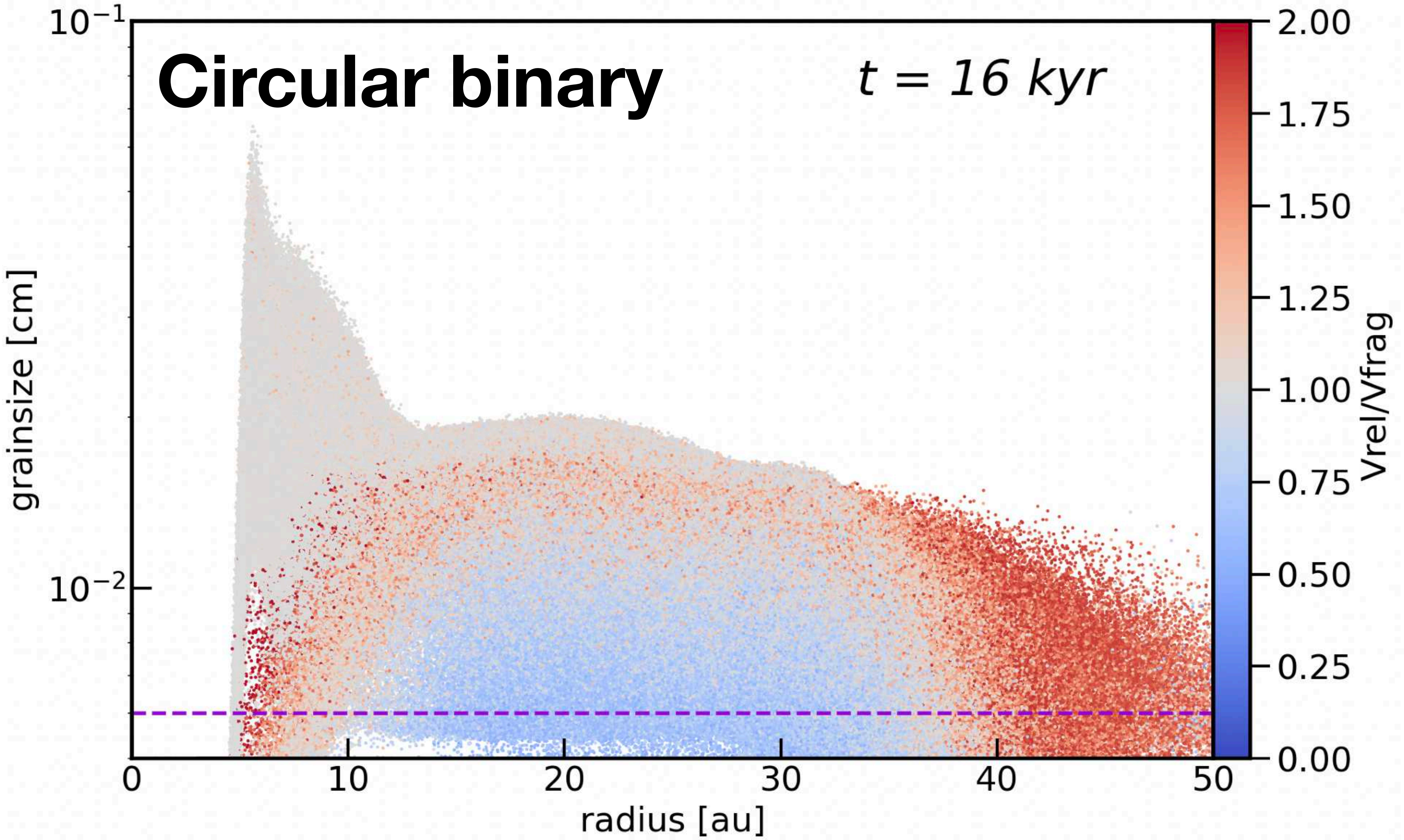
Dust grain size

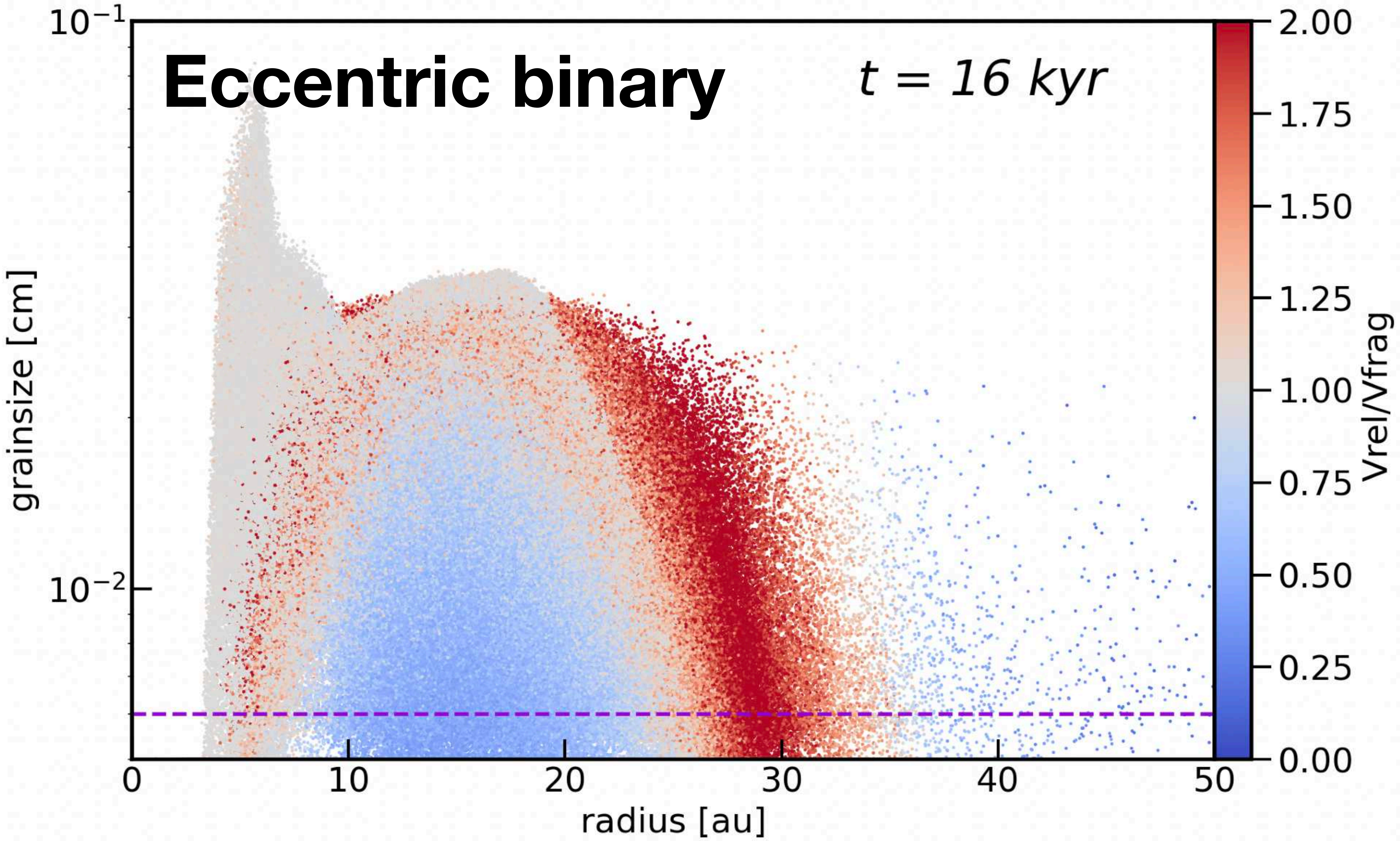
at t = 16 kyr = 500 P_{disc}



☆ **Pile-up at the cavity edge**

☆ **Fragmentation at the outer edge if e>0**





Streaming instability

Streaming instability in eccentric binaries

$\varepsilon = \rho_d/\rho_g \gtrsim 0.5$

St ~ 0.01 - 1

$\Pi = \Delta v / c_s > 0.01$

Krijt+2018

Streaming instability in eccentric binaries

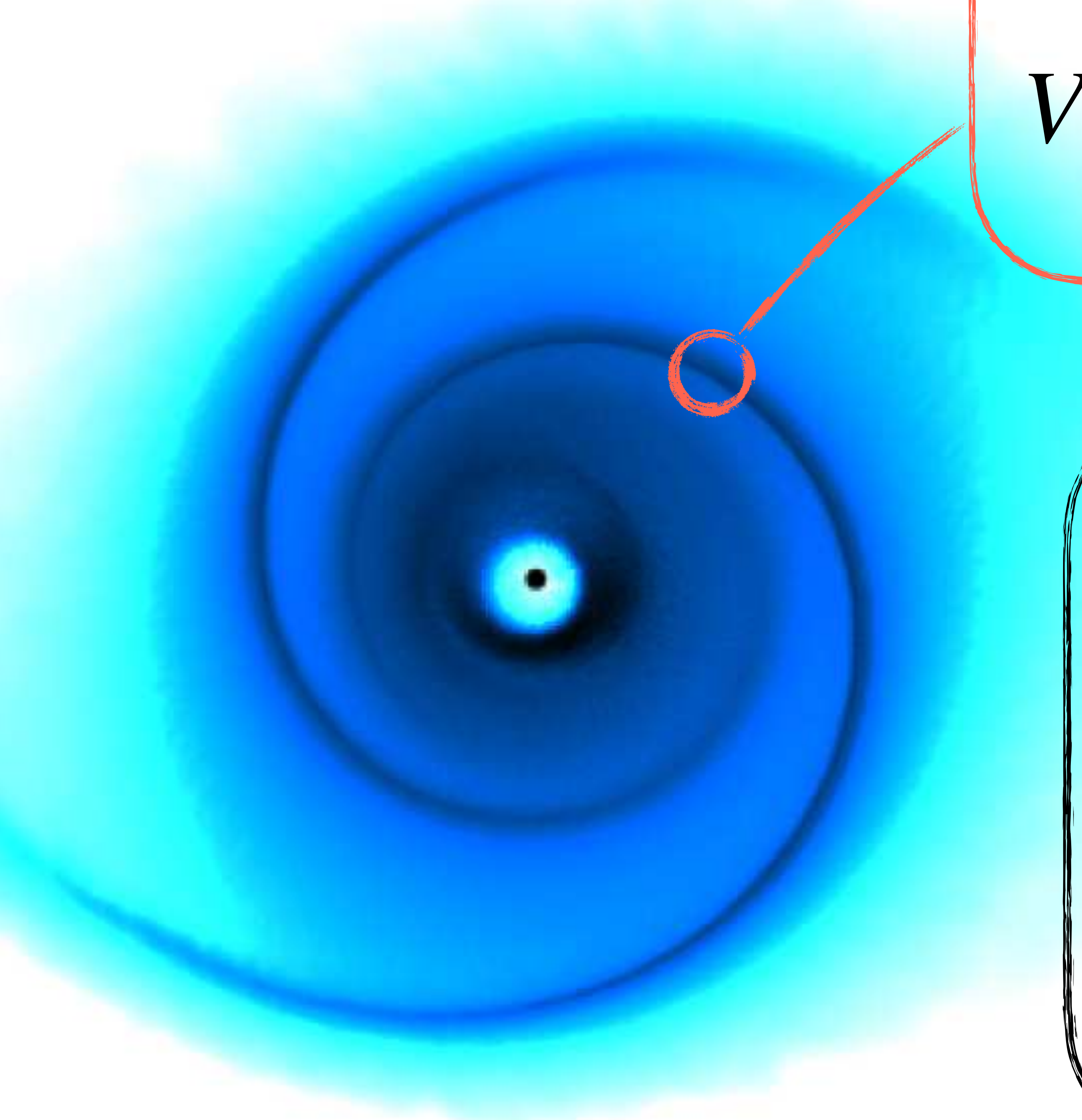
Krijt+2018

$\varepsilon = \rho_d/\rho_g \gtrsim 0.5$

St ~ 0.01 - 1

$\Pi = \Delta v / c_s > 0.01$

Limits



In the spiral arm :

ρ_g is higher

V_{rel} is higher

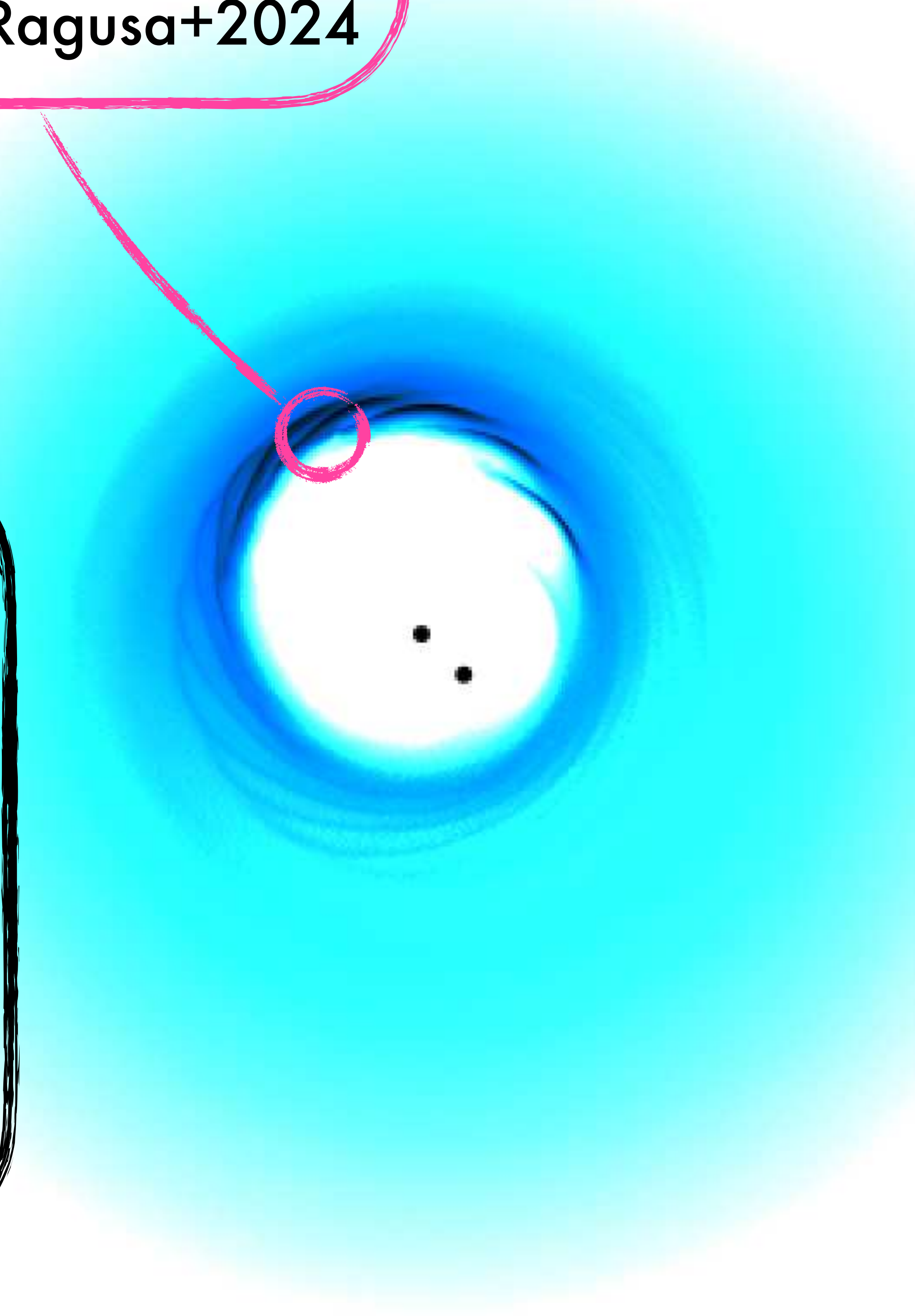
Eriksson+2024

At the cavity edge :

ρ_g is higher

V_{rel} is higher / e↗

Ragusa+2024



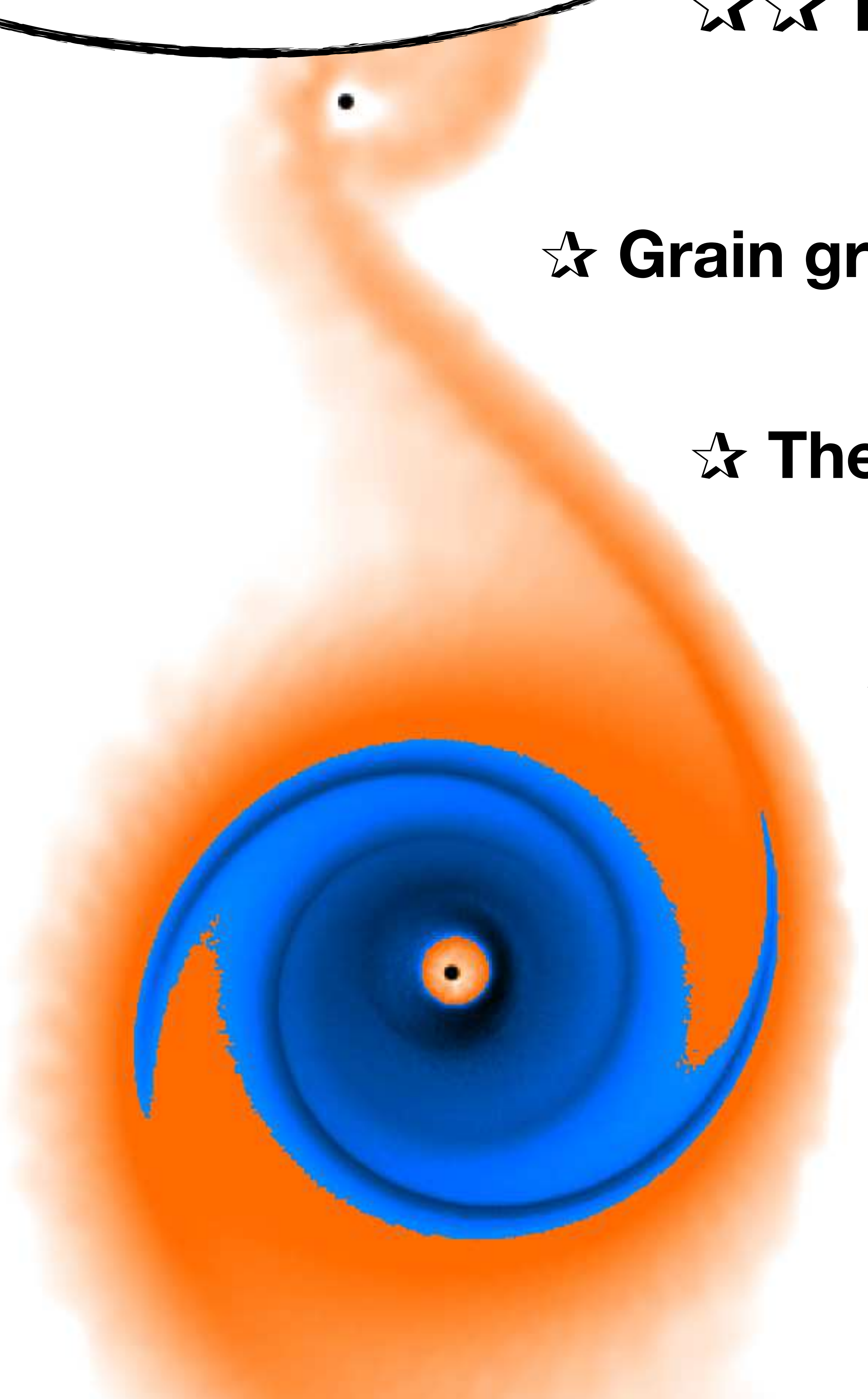
Does PHANTOM treat V_{rel} correctly in these systems ?

⇓

Is gas turbulence dominating V_{rel} ?

Conclusion

Thank you for your attention !



☆☆ Dust growth simulations in binary systems

☆ Grain growth cannot happen in the outer regions of discs

☆ The inner edge of discs is promising, even in CBDs

→ *Structures > velocity gradients*

☆ The mid plane should trigger SI in CSD

☆☆ Some perspectives :

What is the actual relative velocity of grains in multiple systems ?

How does porosity+bouncing change the game ?

What about triple systems and misaligned discs ?

☆ Appendix ☆☆

Dust growth equations

$$St = \Omega t_s$$

$$Sc = (1 + St)\sqrt{1 + \left(\frac{dv}{v_t}\right)^2}$$

$$dv = t_s \frac{\nabla P}{\rho_g}$$

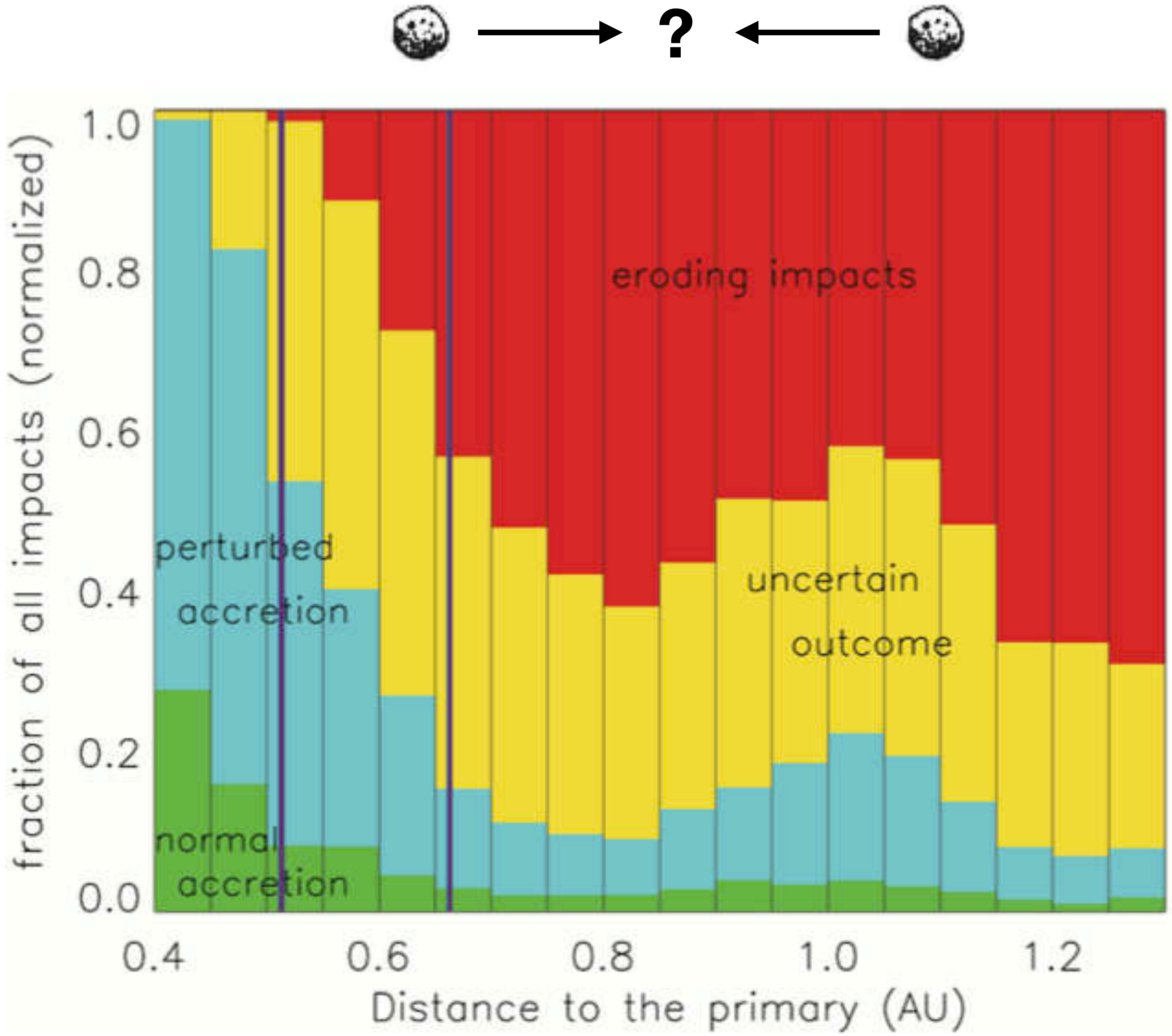
$$V_{rel} = \sqrt{2} v_t \sqrt{1 - \frac{1}{Sc}}$$

$$\dot{m} = \pm 4\pi s^2 \rho_d V_{rel} \delta$$

with $\delta = \frac{(V_{rel}/V_{frag})^2}{1 + (V_{rel}/V_{frag})^2}$

Stepinski&Valageas+1997
Vericel+2021

Fragmentation of planetesimals



Marzari&Thébault2019