# MODELLING OF THE OBSERVED STRUCTURE IN HL TAU: SIMULATING DUST IN SPH

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in collaboration with
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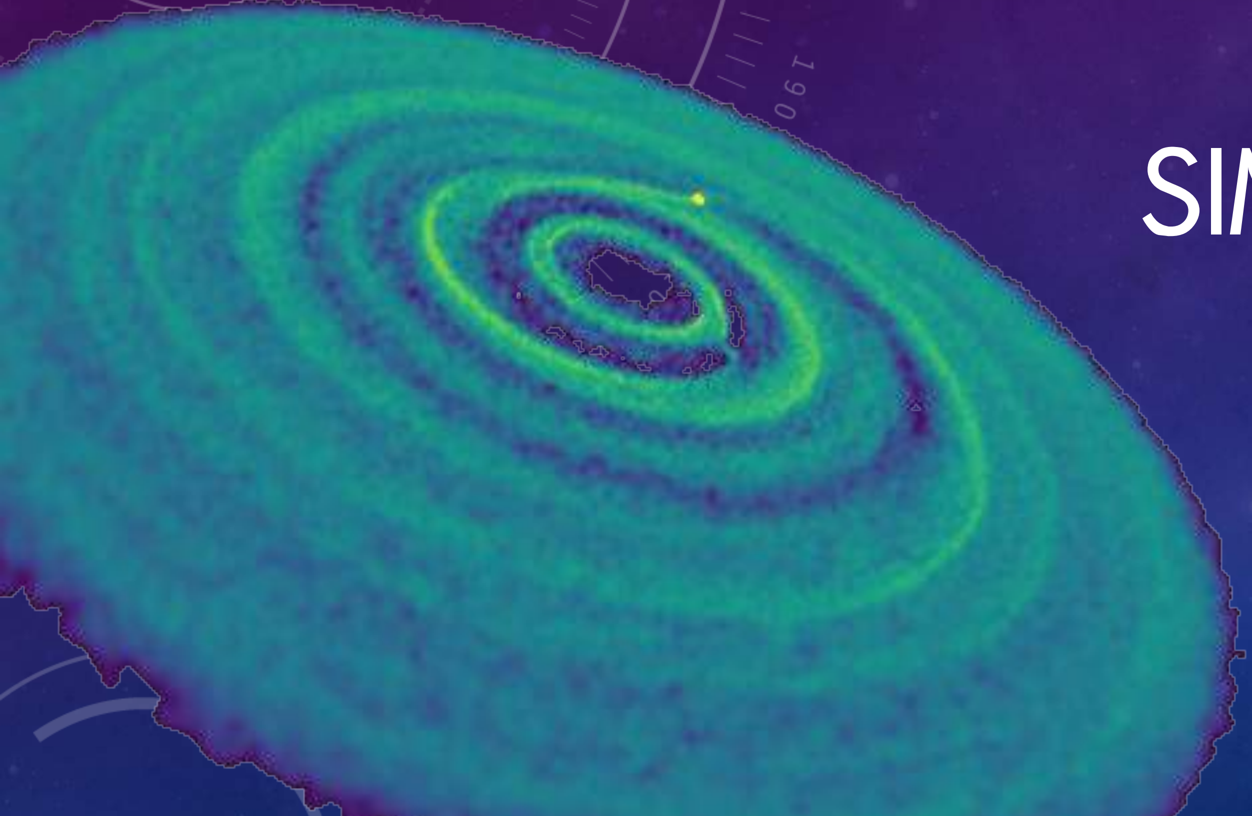
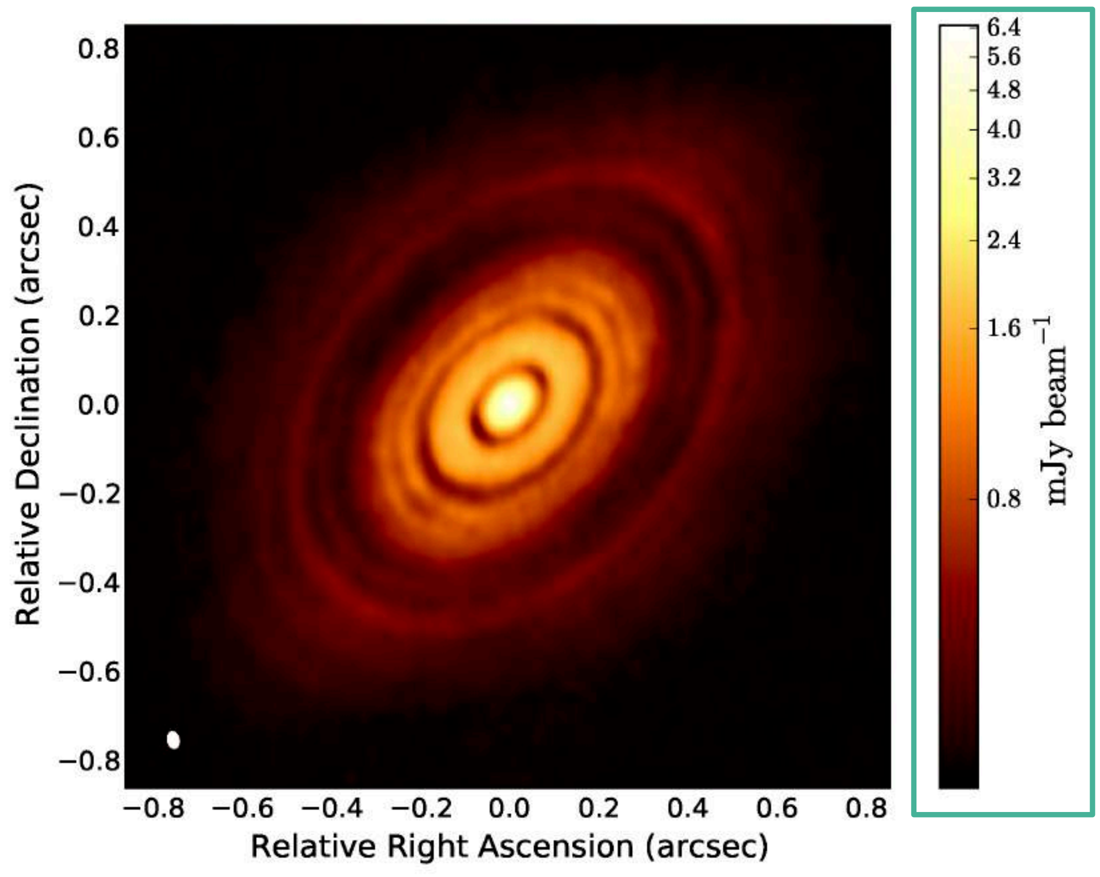


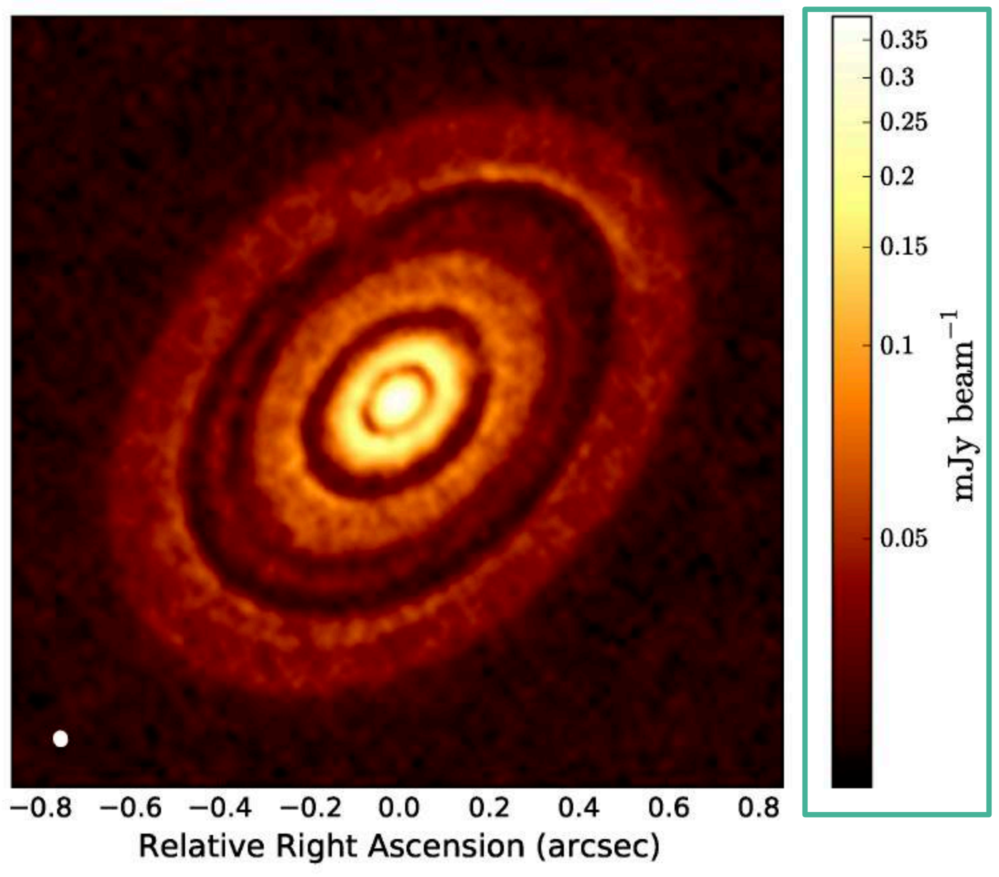
1st Phantom European Users Workshop – June 19th 2018

# – HL TAU –

Observations (ALMA Partnership, 2015)



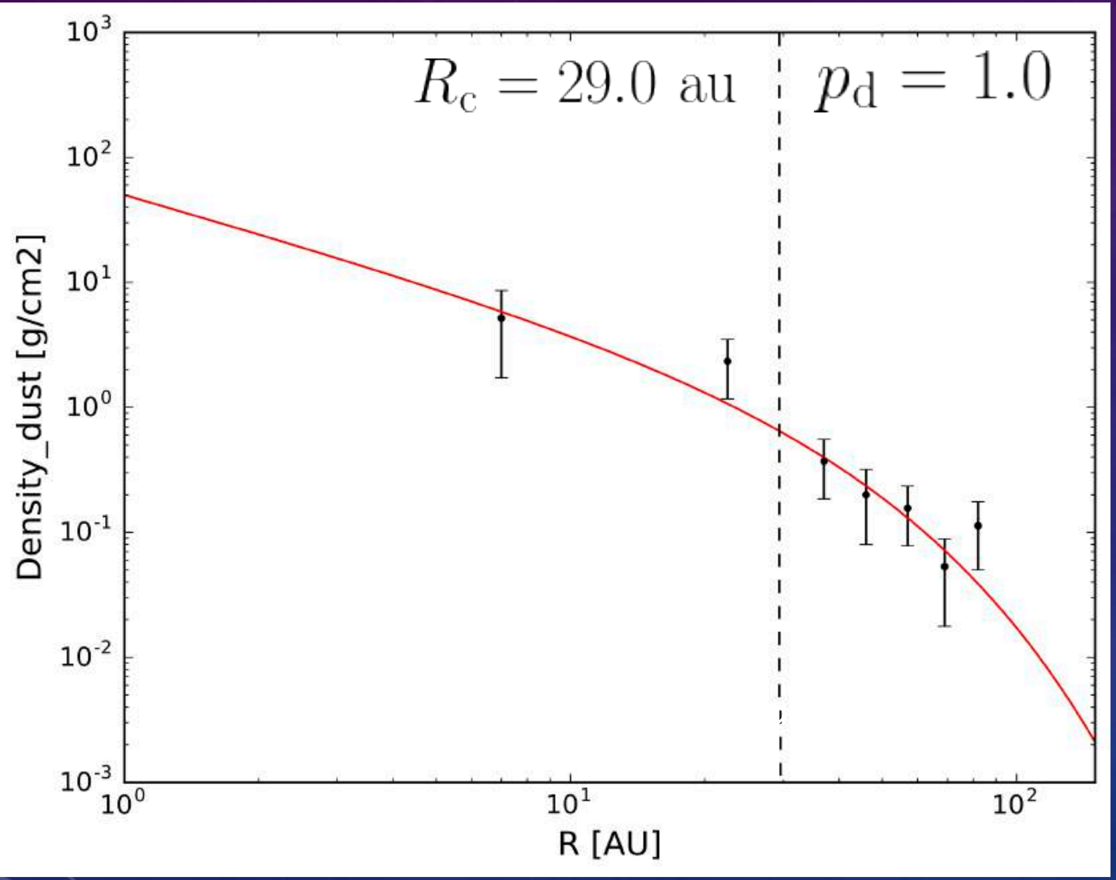

Simulations (Dipierro et al. 2015)




Aim: develop a new model describing HL Tau and identify the mass of the planets able to carve gaps in this disc, in order to reproduce the observed structures.

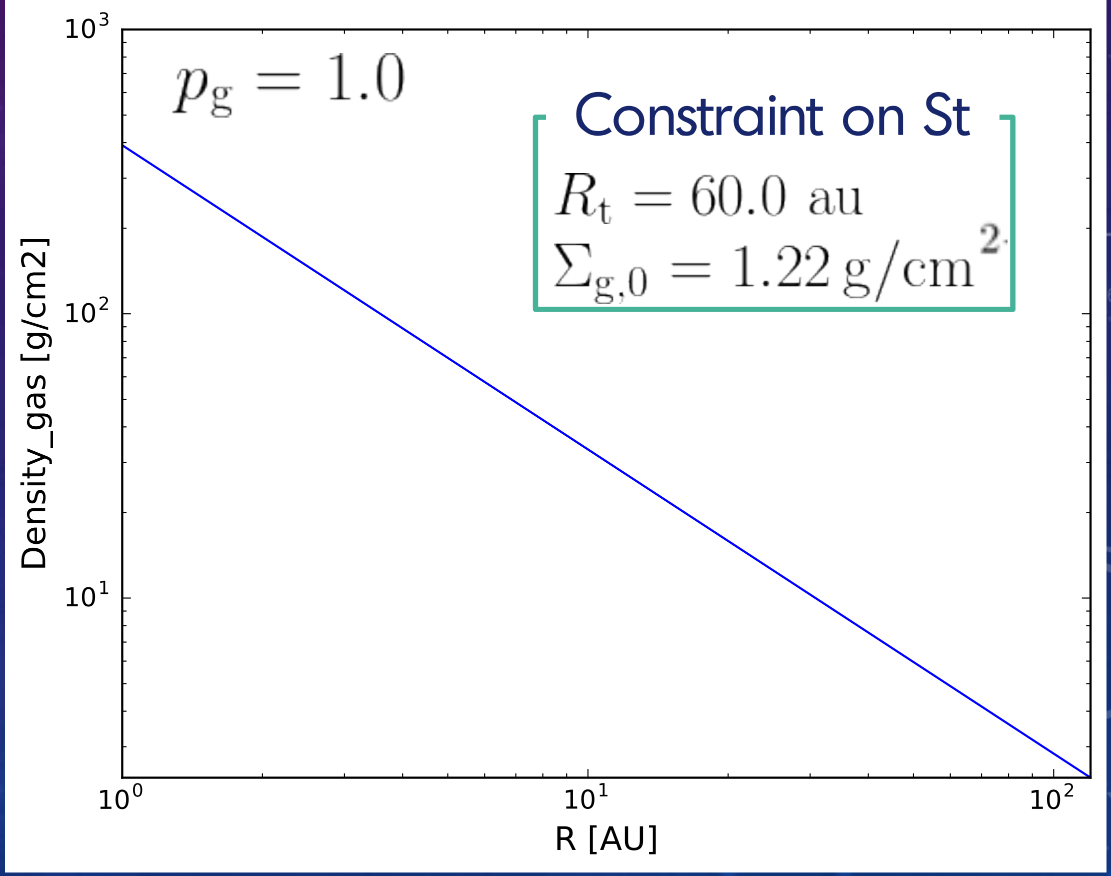
# – A NEW MODEL FOR HL TAU –

Dust density profile



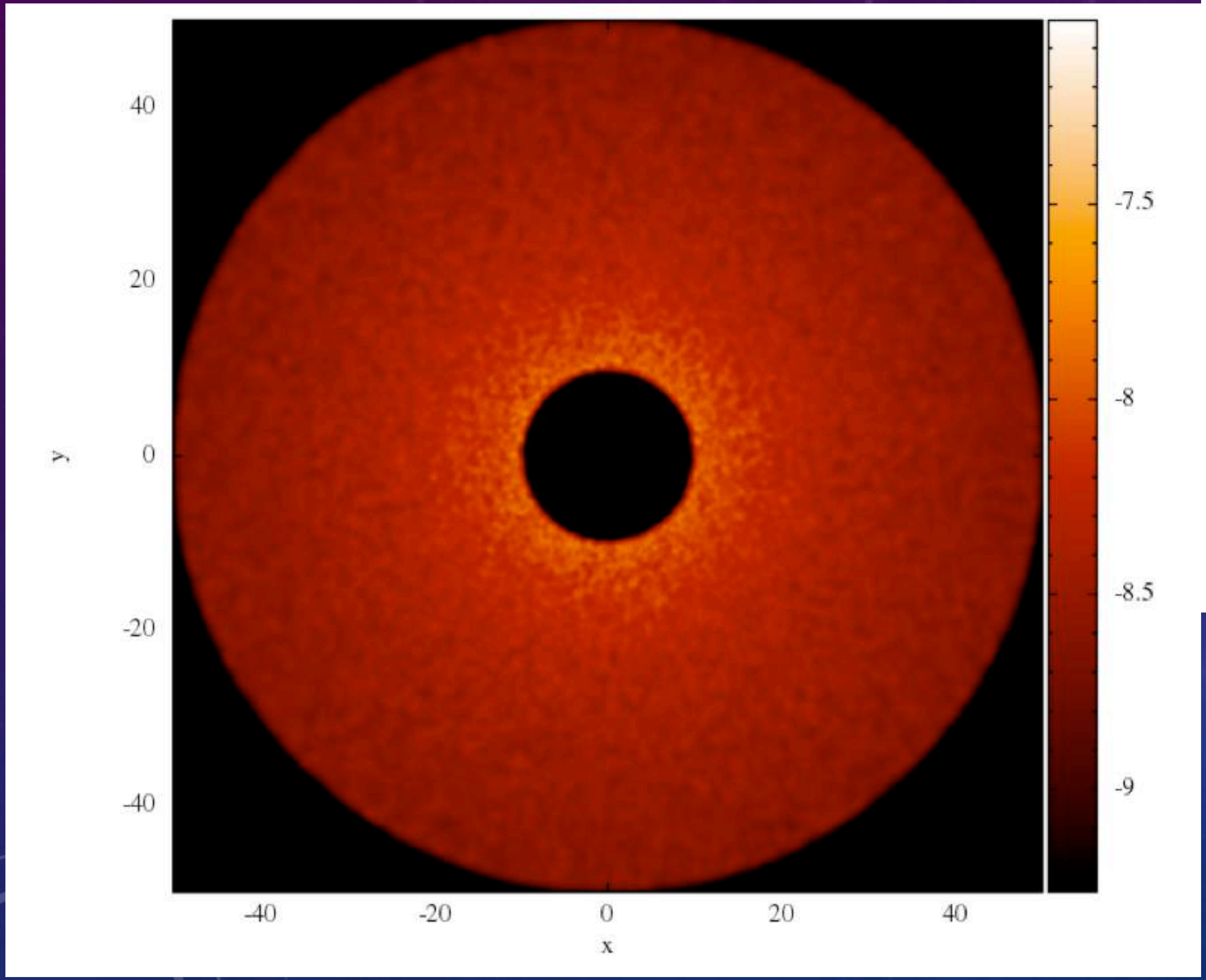

(Carrasco et al. 2016+Pinte et al. 2016)

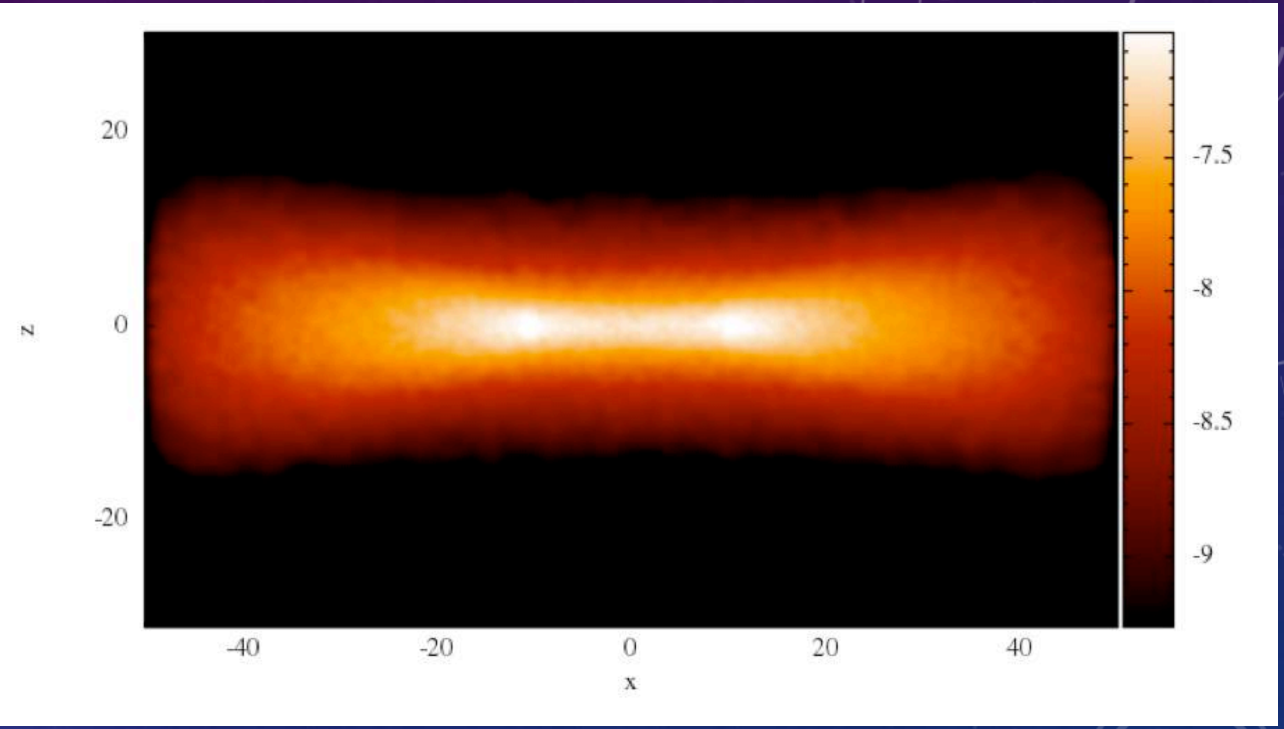
Gas density profile



# – FIRST SIMULATION WITH PHANTOM –

Rendered images of a disc with one planet




Non negligible degree of **EXTRA** dust mass, clearly visible at outer radii and in the upper layers of the disc.

# – SIMULATING DUST IN SPH –

Simulating dust in SPH

- Two fluid method: dust and gas are treated as different fluids — LARGE grains
  Used by Dipierro et al. (2015)
- One fluid method: evolution of a gas-dust mixture — SMALL grains

$$\rho = \rho_\mathrm{d} + \rho_\mathrm{g}$$

$$\mathbf{v} = \frac{\rho_\mathrm{g}\mathbf{v}_\mathrm{g} + \rho_\mathrm{d}\mathbf{v}_\mathrm{d}}{\rho_\mathrm{g} + \rho_\mathrm{d}}$$

+

$$\epsilon \equiv \frac{\rho_\mathrm{d}}{\rho}$$ DUST FRACTION

$$\Delta\mathbf{v} = \mathbf{v}_\mathrm{d} - \mathbf{v}_\mathrm{g}$$ DIFFERENTIAL VELOCITY

NAVIER-STOKES +

Dust fraction evolution

$$\frac{\mathrm{d}\epsilon}{\mathrm{d}t} = -\frac{1}{\rho}\nabla\cdot\left[\epsilon(1-\epsilon)\rho\Delta\mathbf{v}\right]$$

+

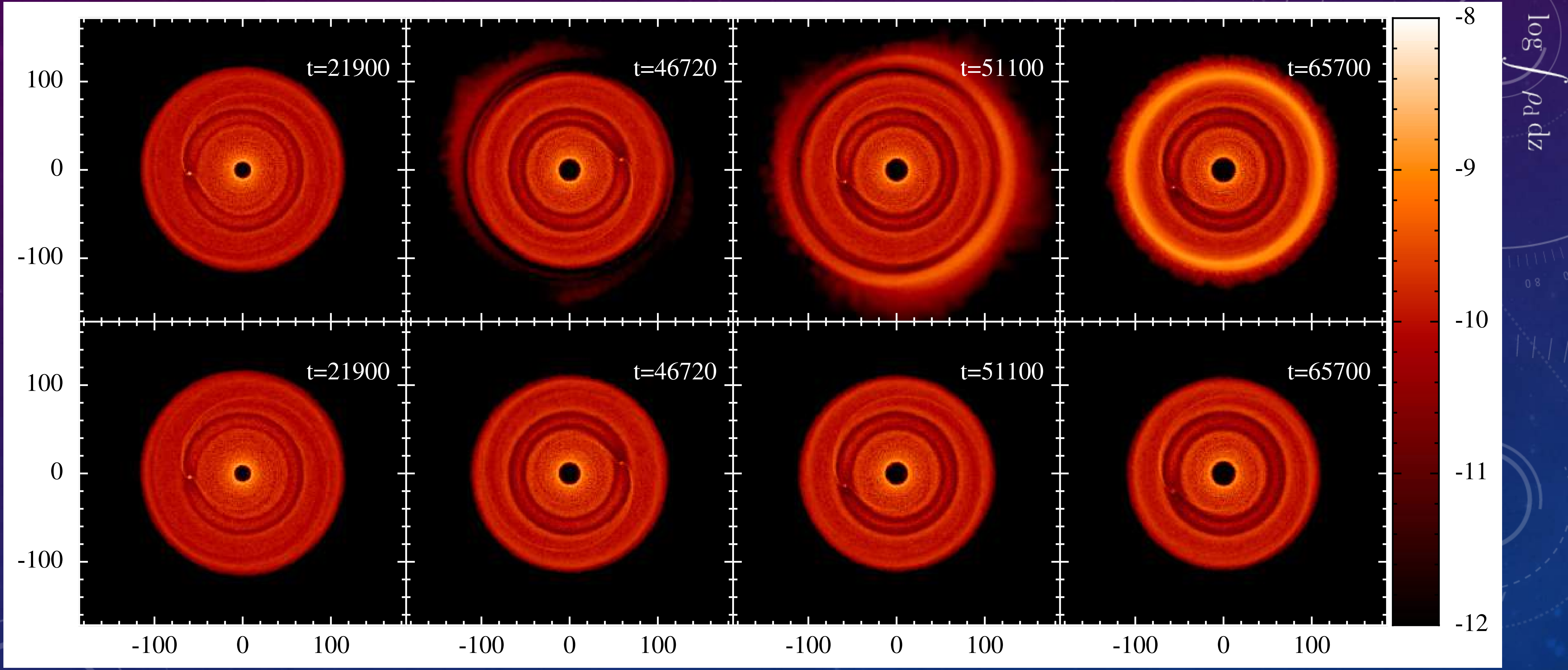
Terminal velocity approximation

$$\Delta\mathbf{v} = t_\mathrm{s}\frac{\nabla P}{\rho_\mathrm{g}} = \frac{t_\mathrm{s}}{(1-\epsilon)}\frac{\nabla P}{\rho}$$

(Laibe and Price, 2014a; 2014b)

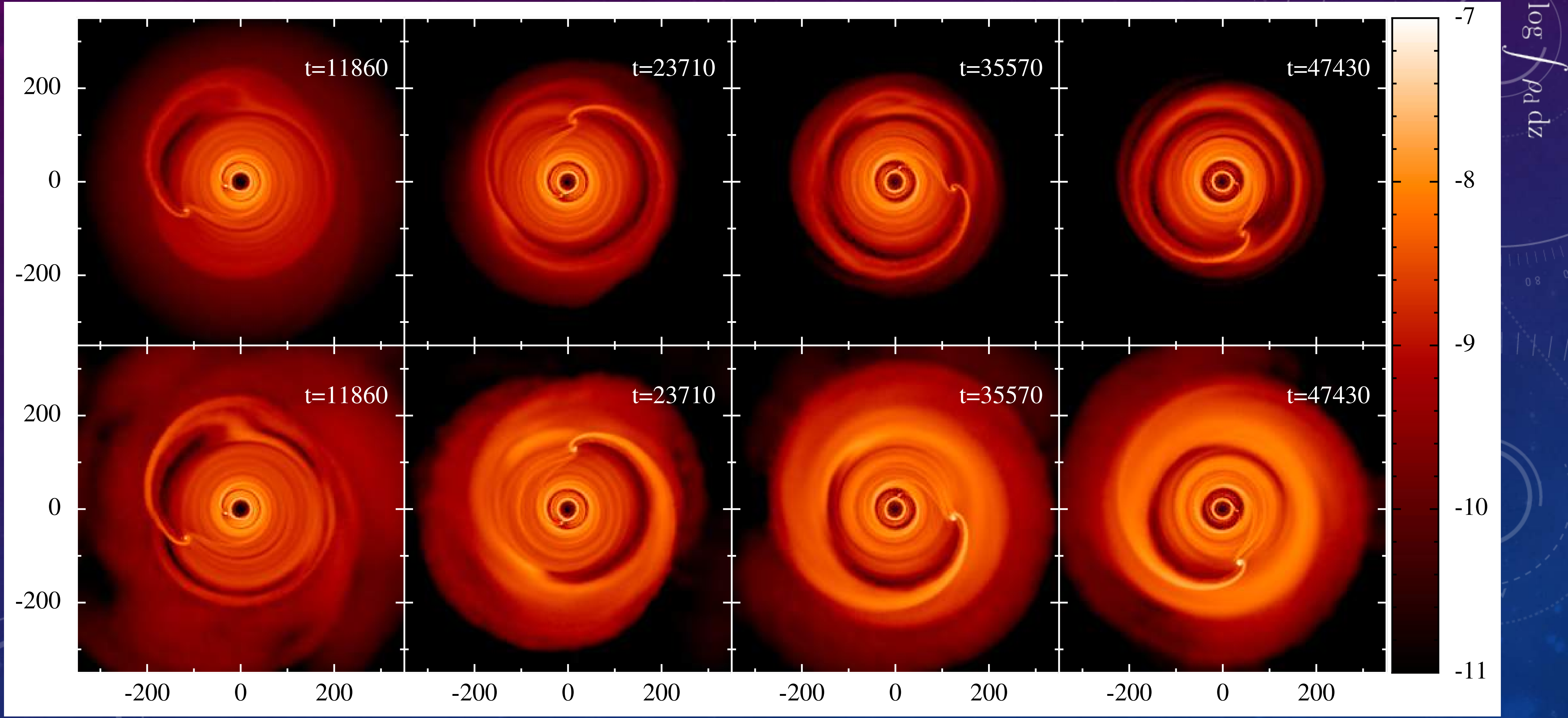
# – A NEW IMPLEMENTATION –

(Ballabio et al., 2018)

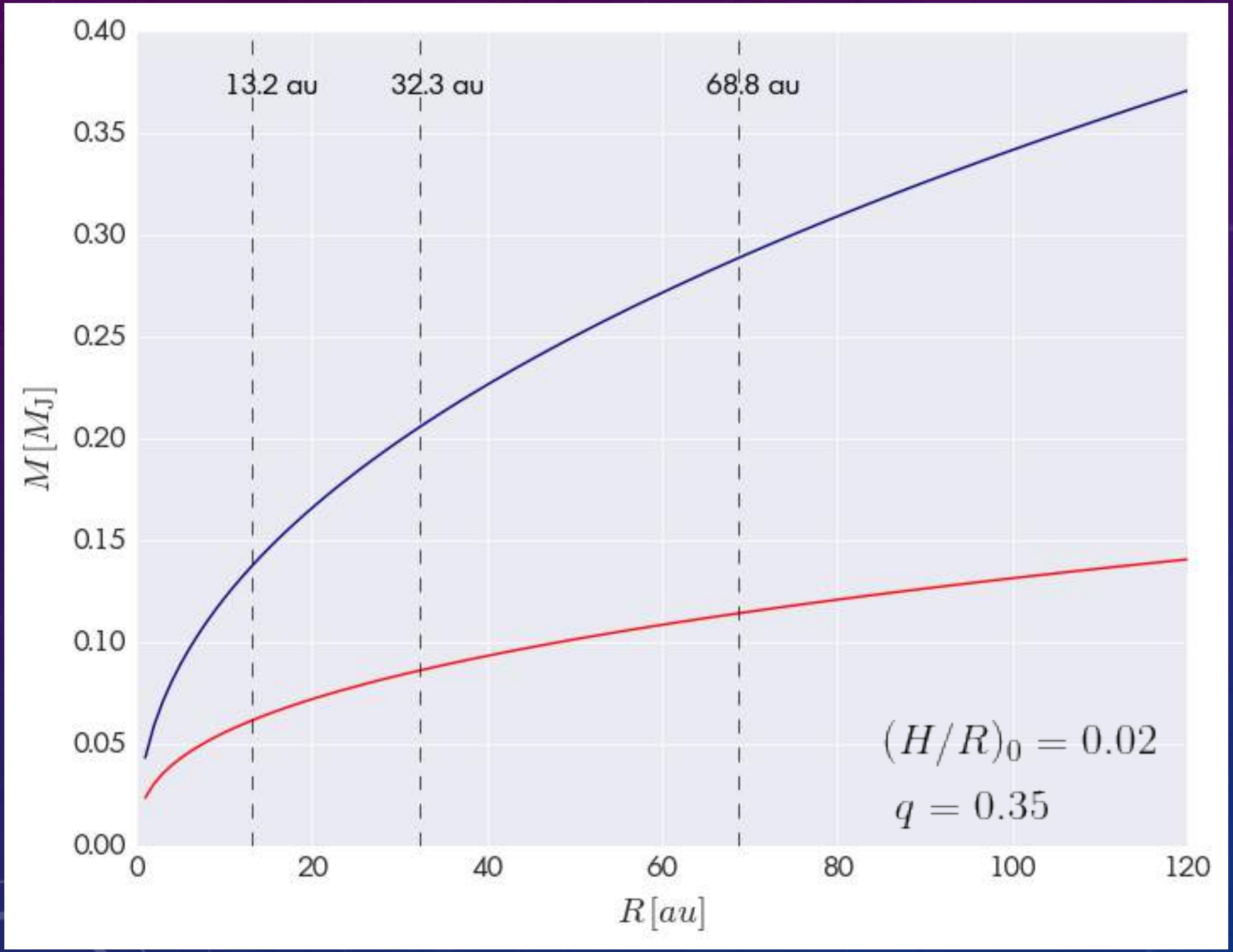


# – LIMIT THE STOPPING TIME –

(Ballabio et al., 2018)



# – GAP OPENING –




(Lin & Papaloizou, 1993)

Thermal criterion

$$M_{\mathrm{p,th}} \gtrsim 3 \left(\frac{H}{r_\mathrm{p}}\right)^3 M_*$$

+

Viscous criterion

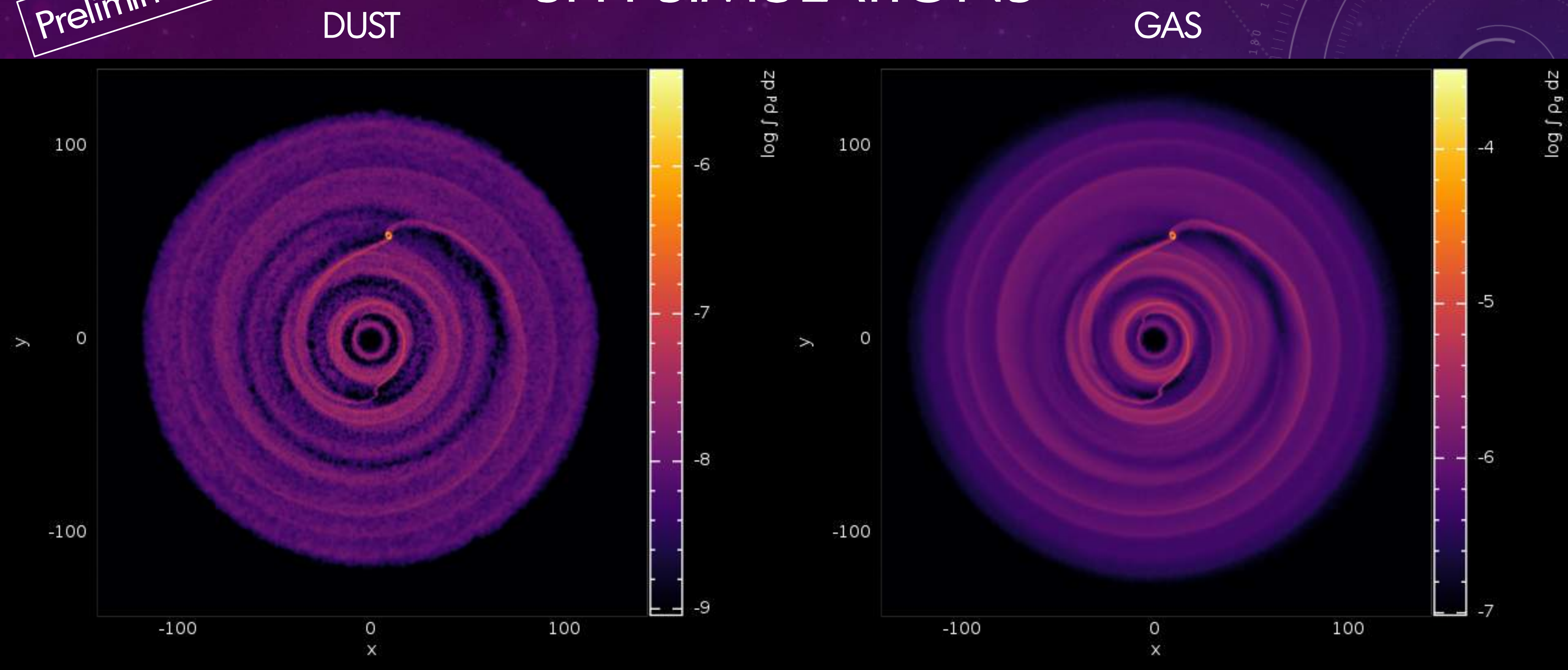
$$M_{\mathrm{p,visc}} \gtrsim C \left(\frac{H}{r_\mathrm{p}}\right)^{5/2} \alpha^{1/2}$$

$$M_\mathrm{p} = \max(0.2 M_\mathrm{th}, M_\mathrm{visc})$$

(Dipierro & Laibe, 2017)

# – SPH SIMULATIONS –

Preliminary




$M_{\mathrm{p},1} = 0,14 M_{\mathrm{J}}$ $M_{\mathrm{p},2} = 0,22 M_{\mathrm{J}}$ $M_{\mathrm{p},3} = 0,29 M_{\mathrm{J}}$

# – FURTHER DEVELOPMENTS –

1. Explore different masses for the planets:

$$M_{\rm p} \gtrsim 0.1 M_{\rm p,th}$$

→ Super-Earths can open gaps

(Rosotti et al., 2016)

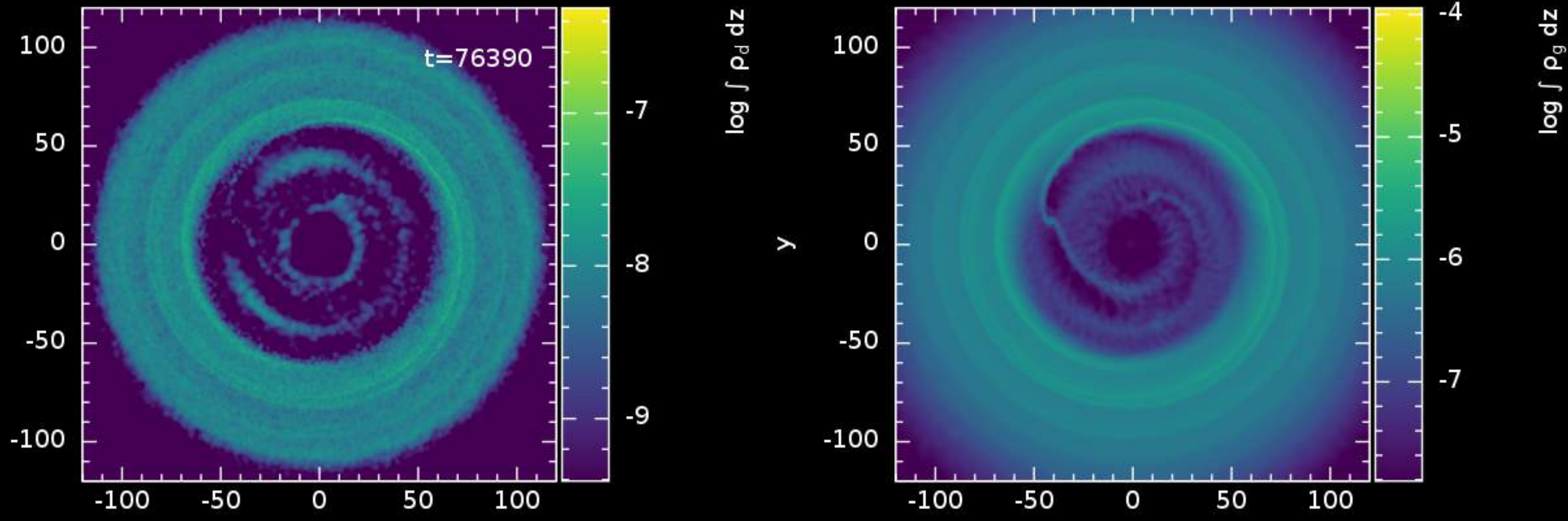
2. Multiple grain sizes:
   - 1 micron
   - 10 micron
   - 100 micron
   - 1 mm
   - 1 cm

→ MULTIGRAIN !!

(Hutchison et al., 2018)

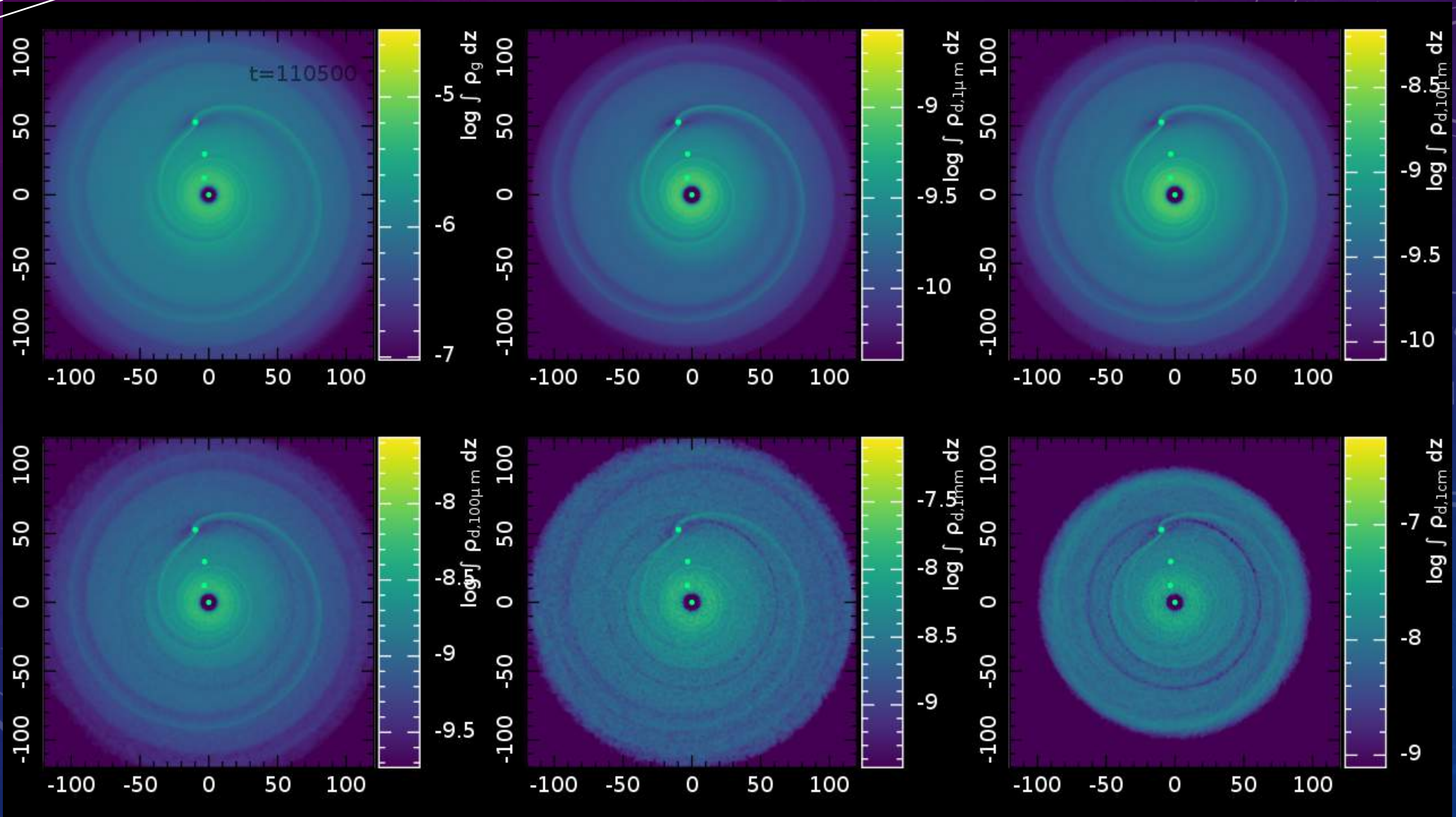
# – SINGLE GRAIN –

DUST GAS



# – MULTIGRAIN –

Preliminary

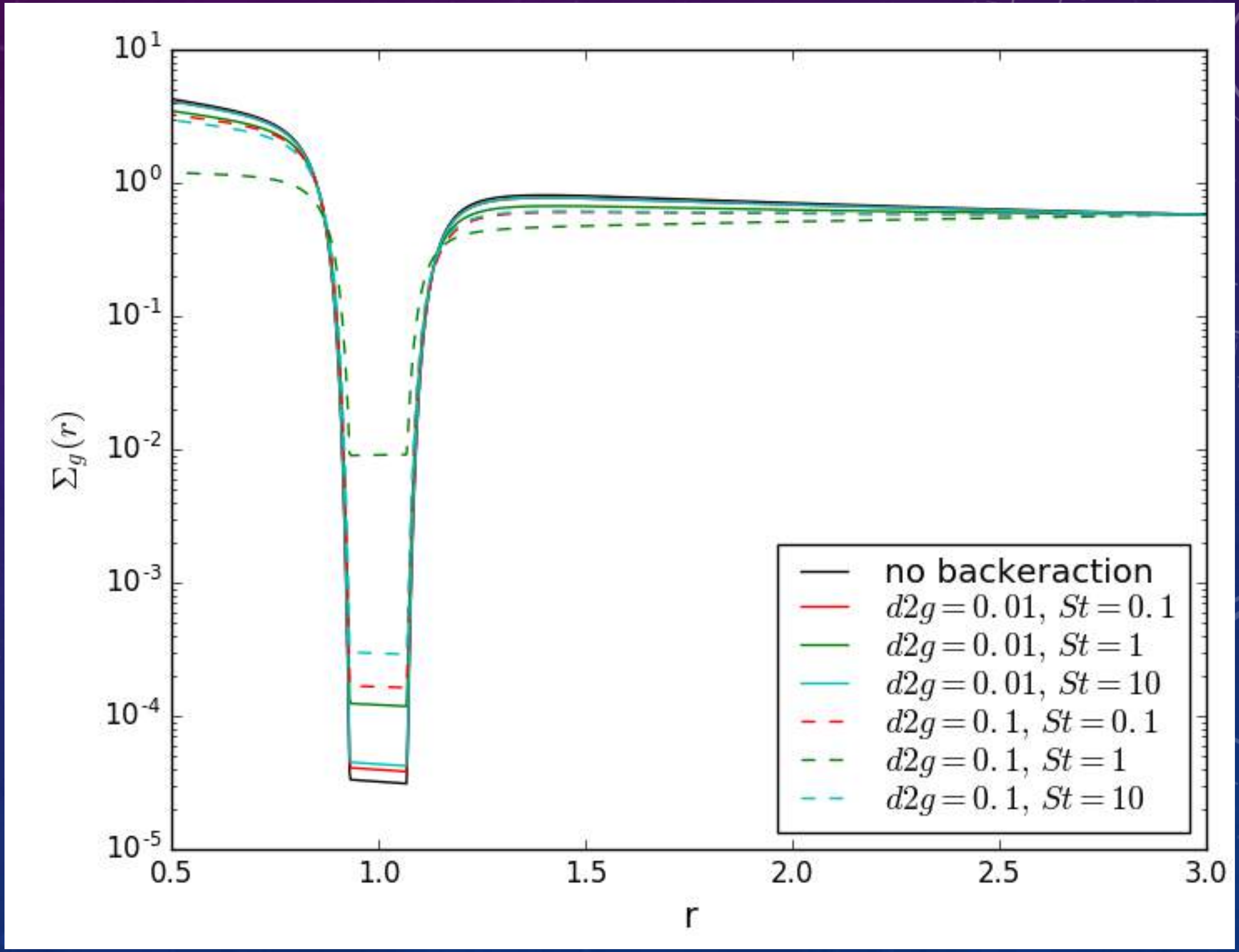


# – THE ROLE OF THE BACK REACTION –

It's a numerical issue

OR

It's physical: back reaction is important!



# – CONCLUSIONS –

- New implementation of the dust fraction + dust flux limiter.
- New promising simulations of HL Tau.
- Comparison with my implementation and Mark's implementation.

<u>TO DO</u>

- Radiative transfer simulations with MCFOST.
- More simulations with higher dust to gas ratio.
- Further investigation of the MULTIGRAIN implementation necessary to better understand the role of the back reaction!

THANKS FOR YOUR ATTENTION!