

Back-reaction of dust on gas in protoplanetary discs: crucial, yet often overlooked

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Gas and dust dynamics

- Sub-Keplerian gas drags Keplerian dust \Rightarrow dust settling and drift

$$v_{g,r} = v_{\text{visc}}$$

$$v_{d,r} = \frac{\text{St}}{1 + \text{St}^2} v_{\text{drift}} + \frac{1}{1 + \text{St}^2} v_{\text{visc}}$$

dominates for $\text{St} \gg \alpha$ dominates for $\text{St} \ll \alpha$

where $v_{\text{drift}} = \frac{1}{\rho_g \Omega_K} \frac{\partial P_g}{\partial r} = \left(\frac{H}{r} \right)^2 \frac{\partial \log P_g}{\partial \log r} v_K < 0$ Nakagawa+1986

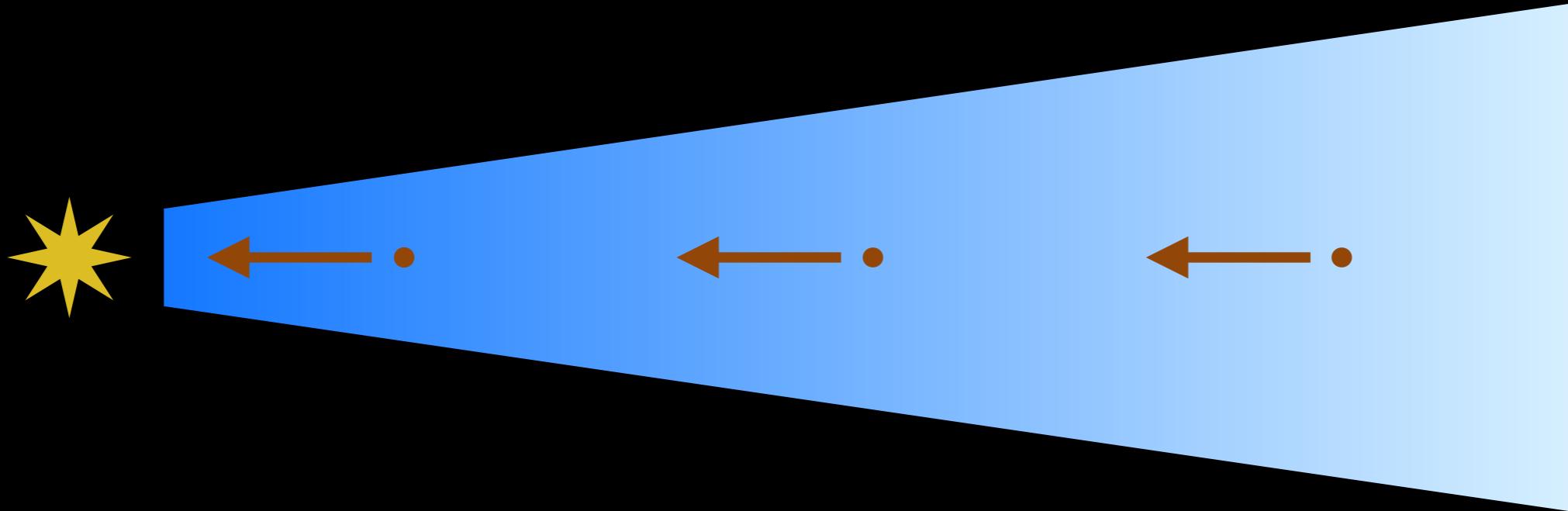
and $v_{\text{visc}} = \frac{\frac{\partial}{\partial r} \left(\rho_g \nu r^3 \frac{\partial \Omega_K}{\partial r} \right)}{r \rho_g \frac{\partial}{\partial r} (r^2 \Omega_K)} < 0$ Lynden-Bell+Pringle1974

with $\frac{v_{\text{drift}}}{v_{\text{visc}}} \sim \frac{1}{\alpha}$

- Dust dynamics controlled by the Stokes number $\text{St} = \frac{\Omega_K \rho_s s}{\rho_g c_s}$

The radial drift barrier

$$\text{St} \gg \alpha \Rightarrow v_{d,r} = \frac{\text{St}}{1 + \text{St}^2} \left(\frac{H}{r} \right)^2 \frac{\partial \log P_g}{\partial \log r} v_K$$



- $\text{St} \ll 1$, small sizes ($1-10 \mu\text{m}$): dust **coupled** to gas
- $\text{St} \sim 1$, median sizes ($100 \mu\text{m}-10 \text{ cm}$): **strong** influence of gas drag
- $\text{St} \gg 1$, large sizes ($1-10 \text{ m}$): dust **insensitive** to gas

The importance of back-reaction

- Drag of dust on gas

$$v_{g,r} = -\frac{\epsilon St}{(1 + \epsilon)^2 + St^2} v_{\text{drift}} + \frac{1 + \epsilon + St^2}{(1 + \epsilon)^2 + St^2} v_{\text{visc}}$$
$$v_{d,r} = \frac{St}{(1 + \epsilon)^2 + St^2} v_{\text{drift}} + \frac{1 + \epsilon}{(1 + \epsilon)^2 + St^2} v_{\text{visc}}$$

Kanagawa+2017, Dipierro+Laibe2017

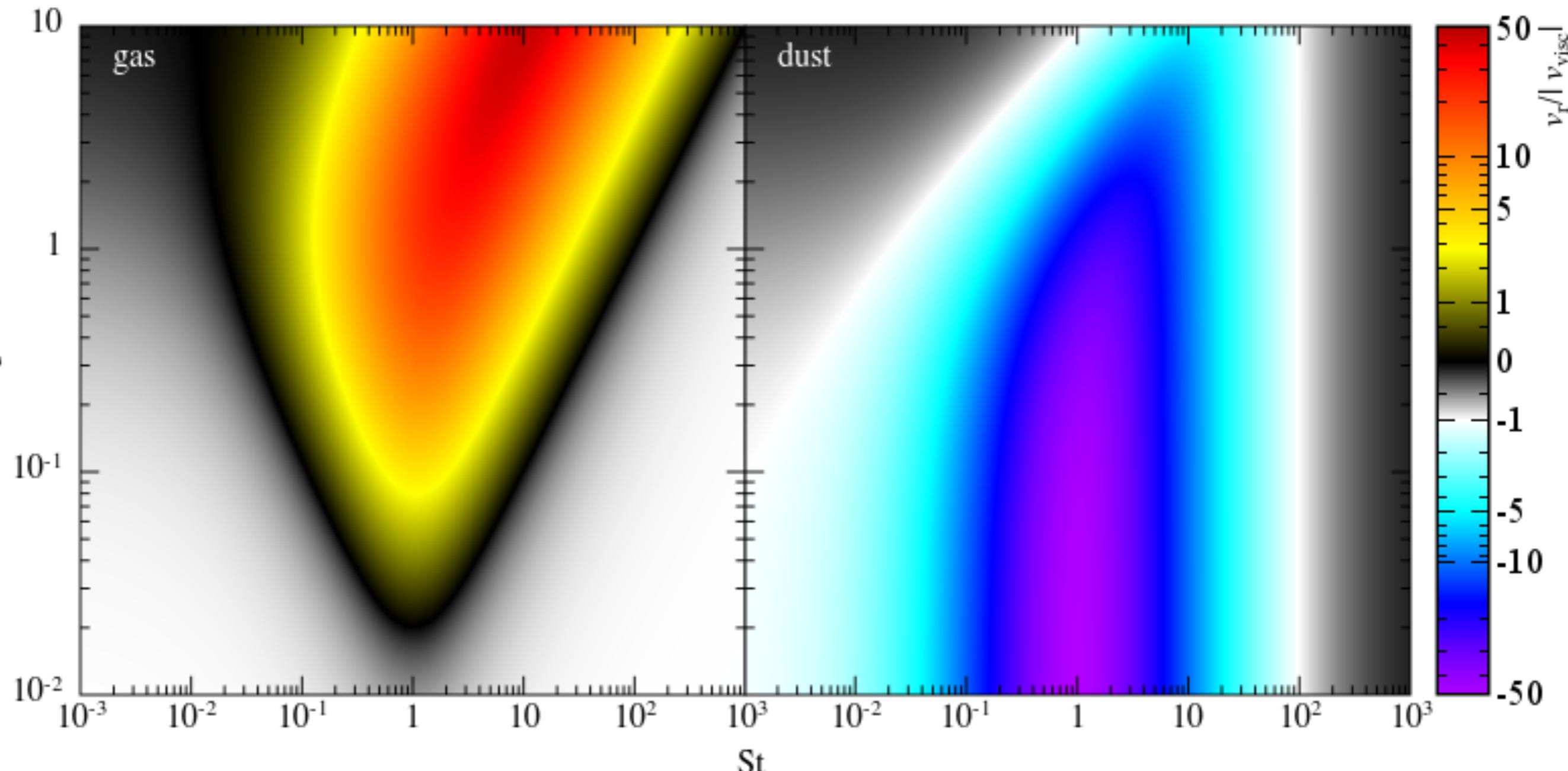
- slows down dust radial drift
- modifies the gas motion
- Consequences
 - Streaming instability
 - Self-induced dust traps
 - ...

Youdin+Goodman2005, Johansen+2007, Bai+Stone2010,
Yang+Johansen2014, Drązkowska+Dullemond2014

Gonzalez+2017a,b

Gas and dust radial velocities

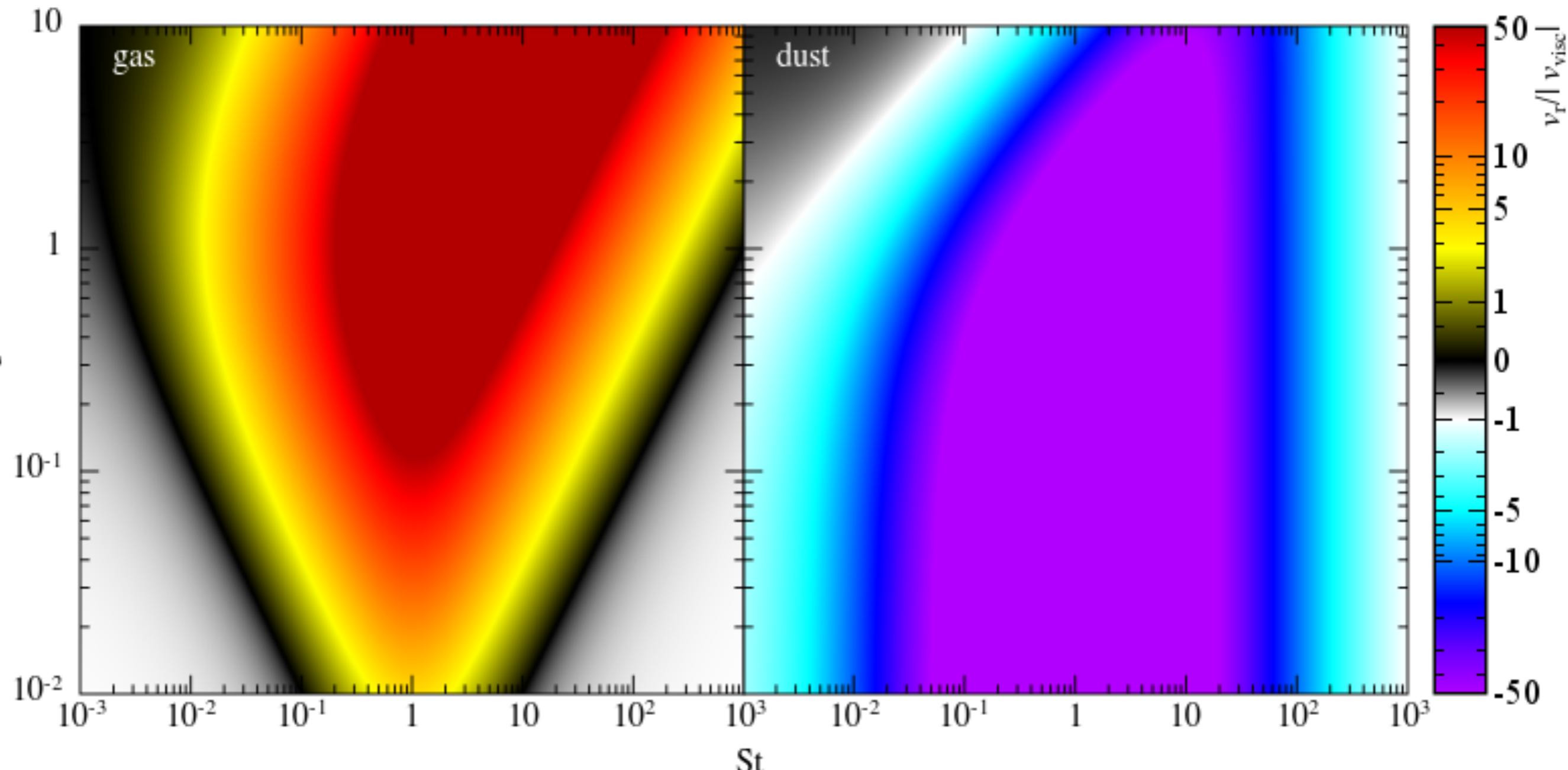
Maps of $\frac{v_r}{|v_{\text{visc}}|}$



$$\alpha = 10^{-2}$$

Gas and dust radial velocities

Maps of $\frac{v_r}{|v_{\text{visc}}|}$



$$\alpha = 10^{-3}$$

Power-law disk

$$\Sigma_{\text{g}} = \Sigma_0 \left(\frac{r}{r_0} \right)^{-p} \quad T = T_0 \left(\frac{r}{r_0} \right)^{-q}$$

$$v_{\text{drift}} = -(p+q) \frac{\nu_0}{r_0} \left(\frac{r}{r_0} \right)^{1/2-q}$$

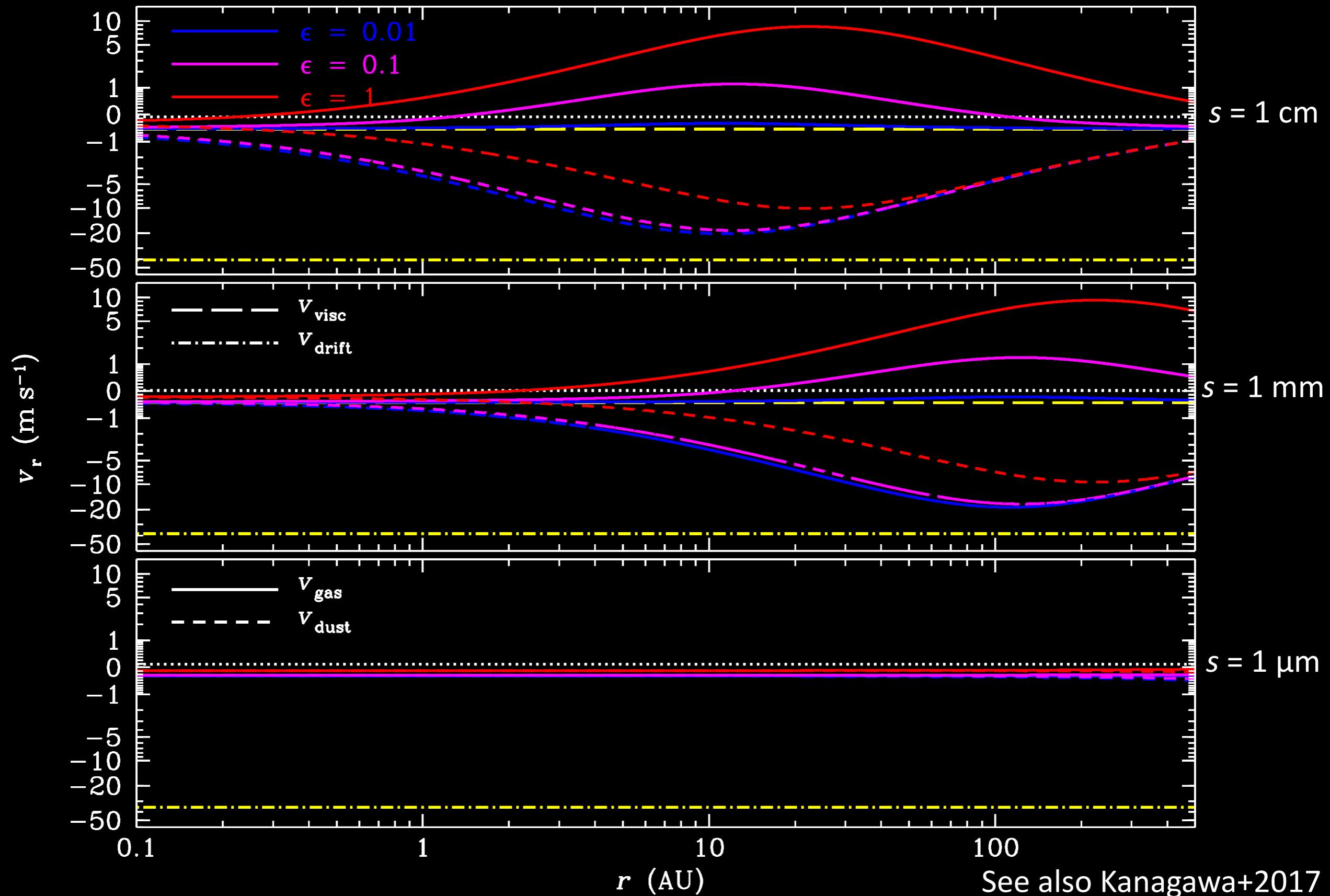
$$\frac{v_{\text{drift}}}{v_{\text{visc}}} = \frac{p+q}{3(2-p-q)} \frac{1}{\alpha}$$

$$v_{\text{visc}} = -3(2-p-q) \frac{\nu_0}{r_0} \alpha \left(\frac{r}{r_0} \right)^{1/2-q}$$

$$p = 1, \ q = 1/2 \Rightarrow v_{\text{drift}}, v_{\text{visc}} = \text{cst}; \ \frac{v_{\text{drift}}}{v_{\text{visc}}} = \frac{1}{\alpha}$$

Power-law disk

$$p = 1, q = 1/2, \alpha = 10^{-2}$$



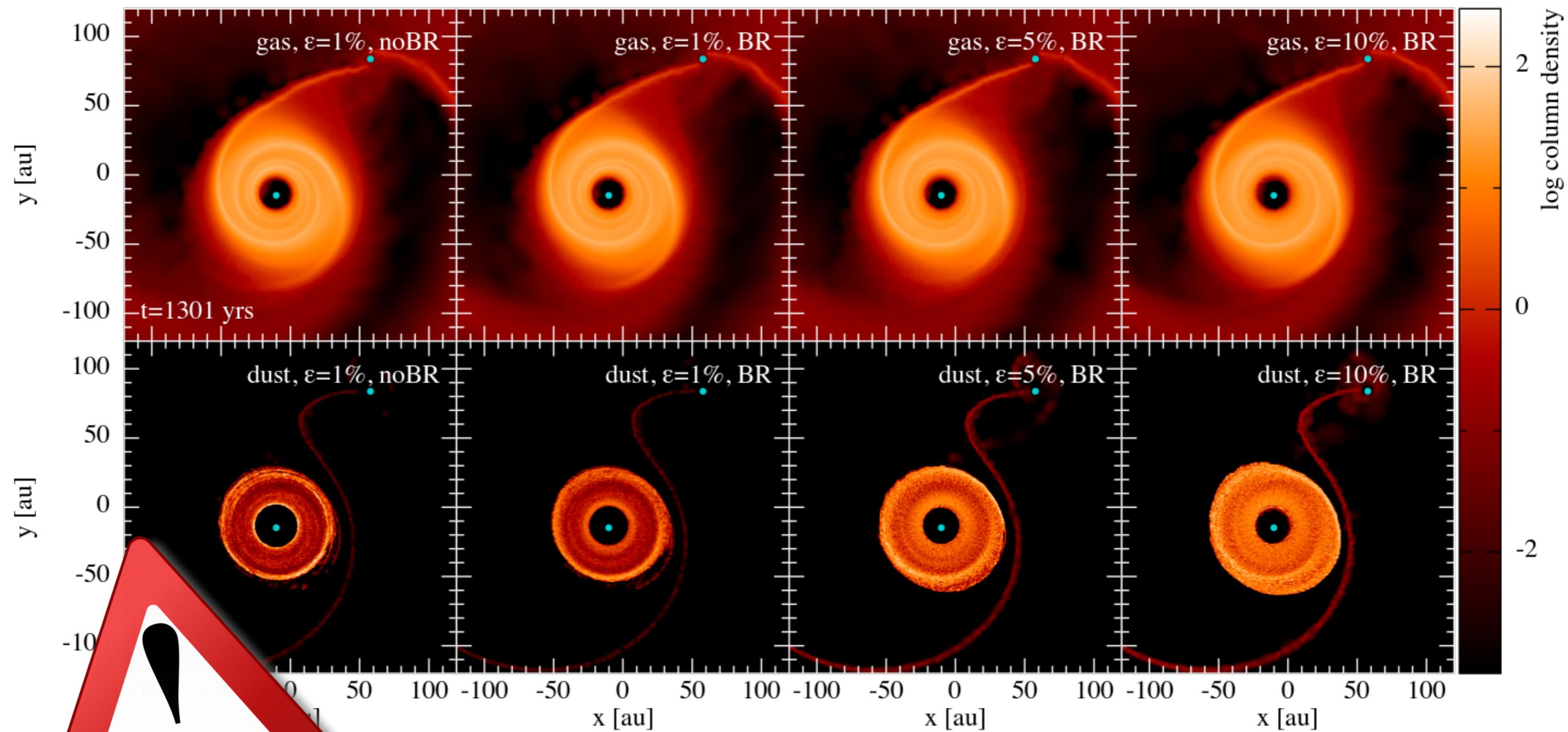
See also Kanagawa+2017

Practical case: a circumprimary disc in a binary star system



v1.1

gas + 1 mm grains, two-fluid



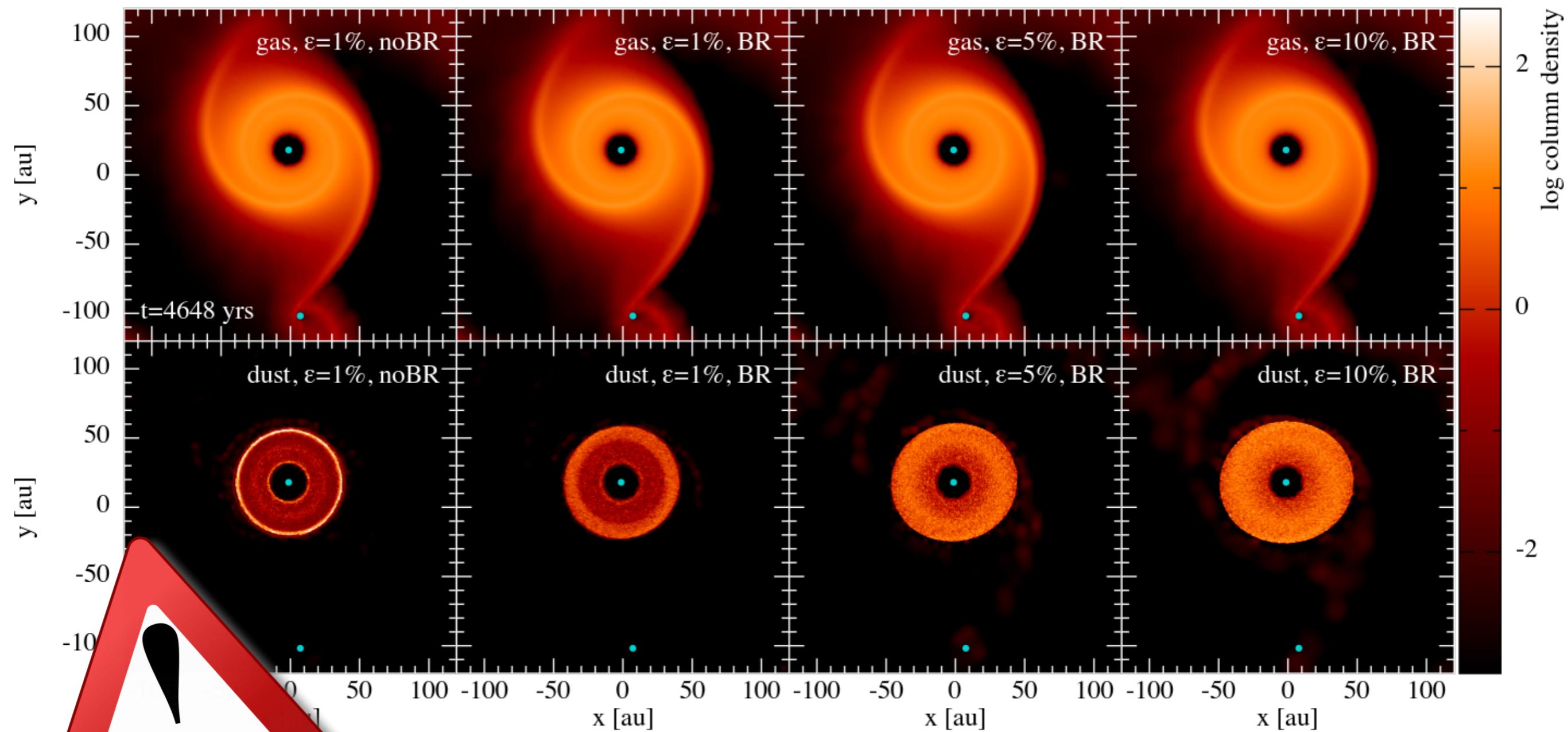
Careful when interpreting observations!

Practical case: a circumprimary disc in a binary star system



v0.9

gas + 1 mm grains, two-fluid



Careful when interpreting observations!

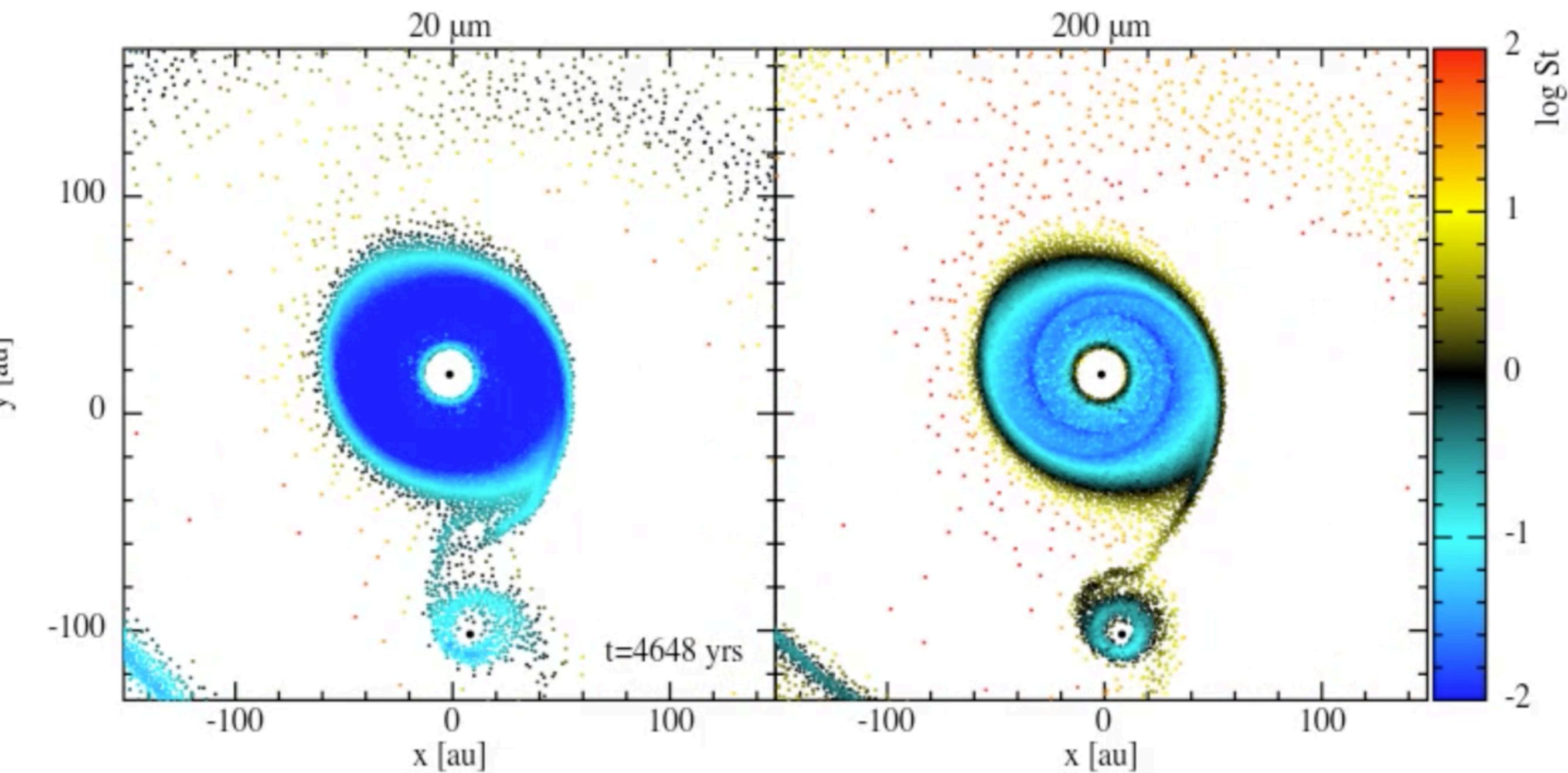
Conclusion

Back-reaction should
NOT
be neglected!

Bonus:

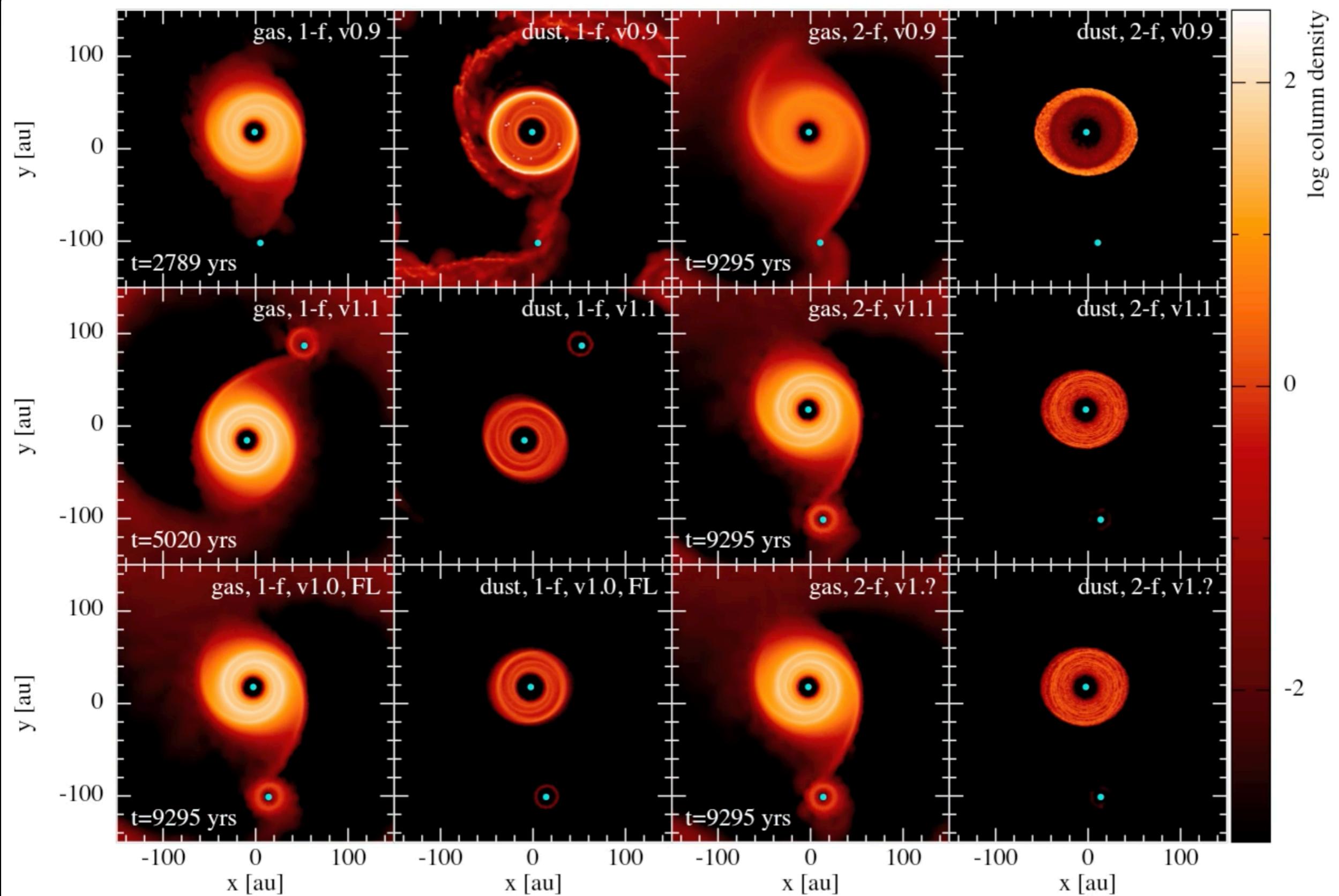
comparing
Phantom versions

one-fluid vs. two-fluid



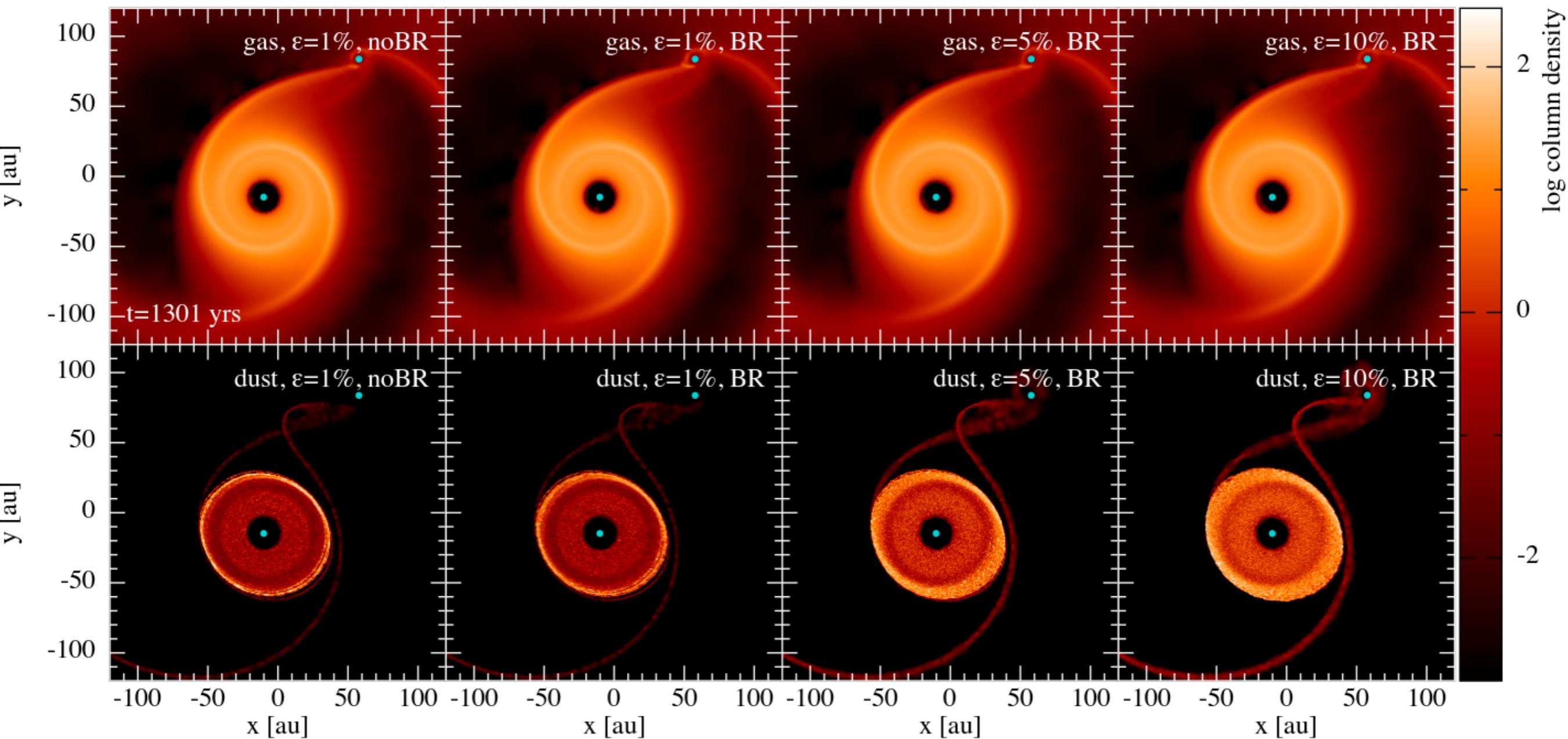
one-fluid vs. two-fluid

gas + 200 μm grains



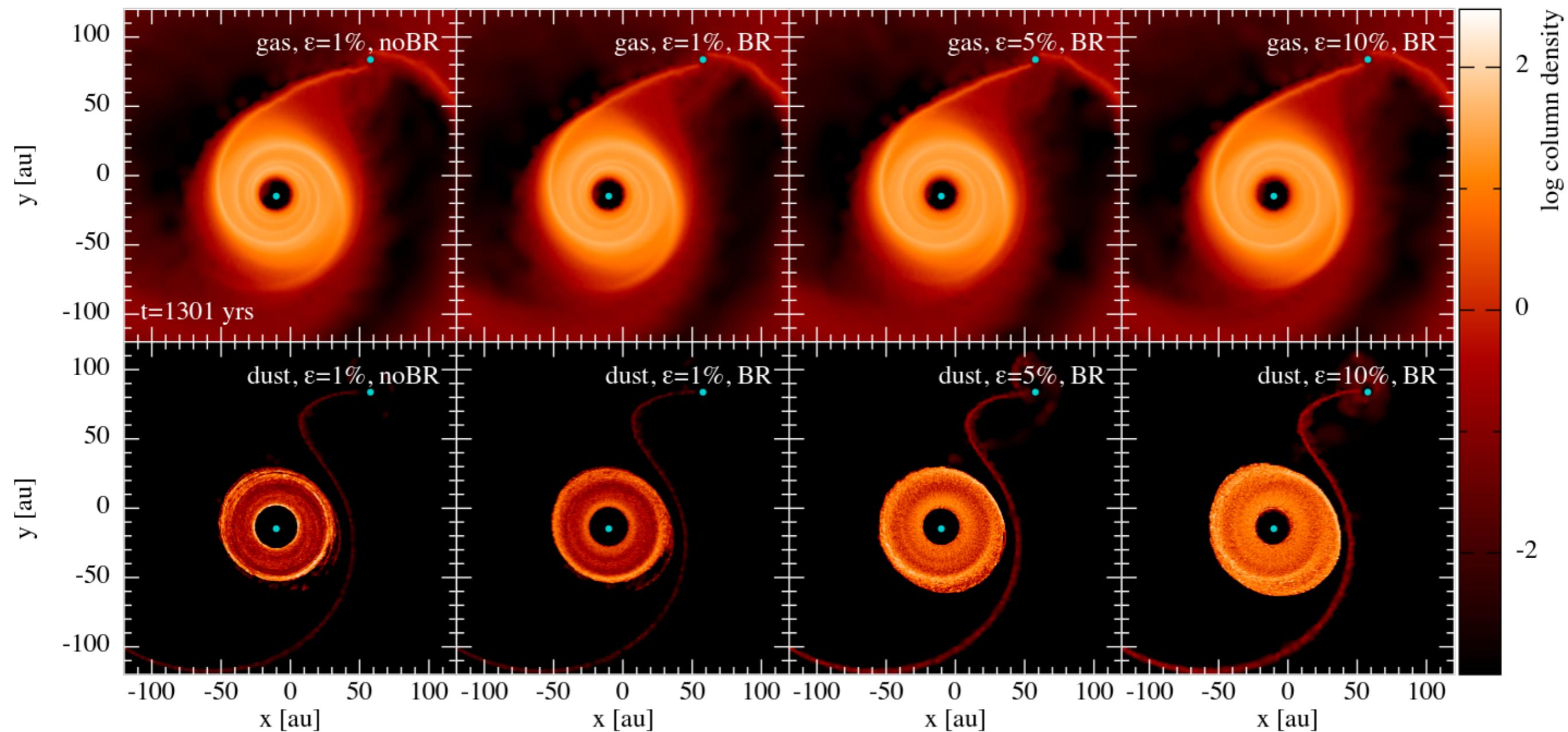
v0.9 - pre bug correction

gas + 1 mm grains, two-fluid



v1.1 - post bug correction

gas + 1 mm grains, two-fluid



get_ts: rhogas instead of rhosum

gas + 1 mm grains, two-fluid

