# On the secular behavior of dust particles in an eccentric protoplanetary disk with an embedded massive gas giant planet

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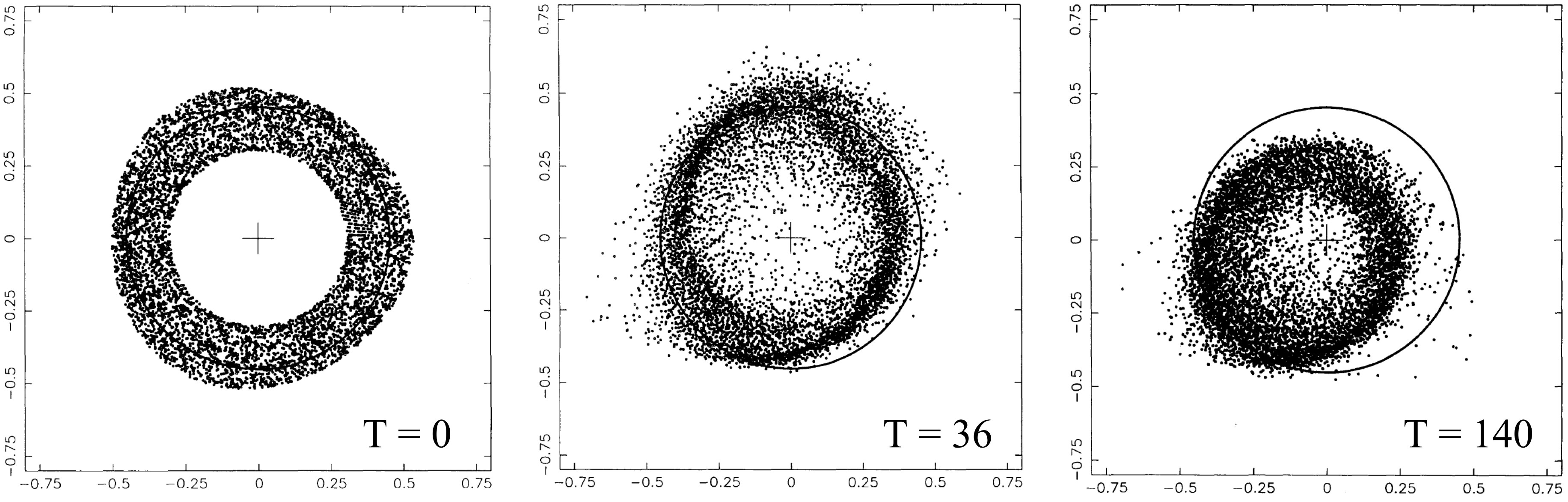
# Disk eccentricity in binary systems

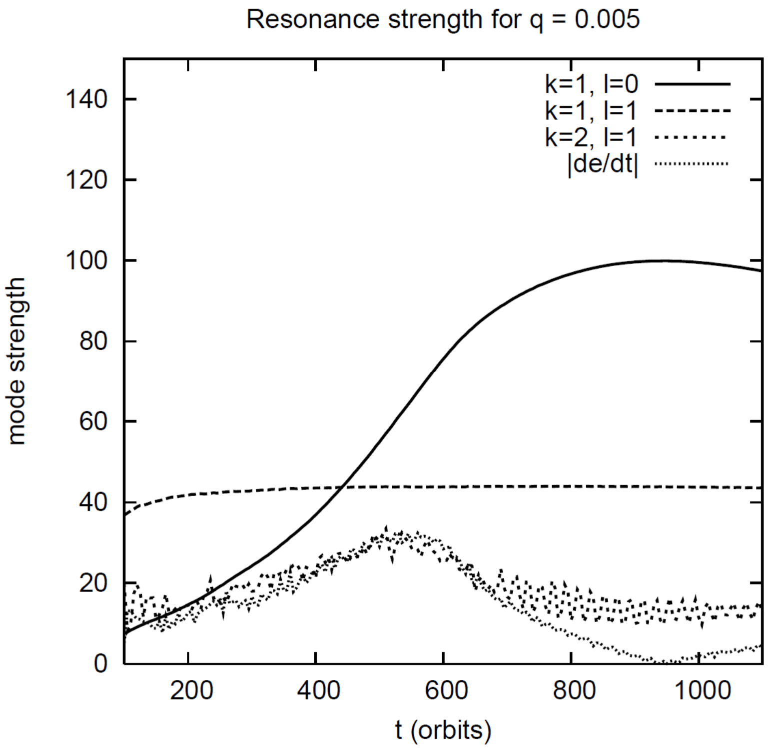
The disk eccentricity can be excited by the companion
via 3:1 inner/outer eccentric Lindblad resonance
at $r = 0.48/2.08\ a_p$.

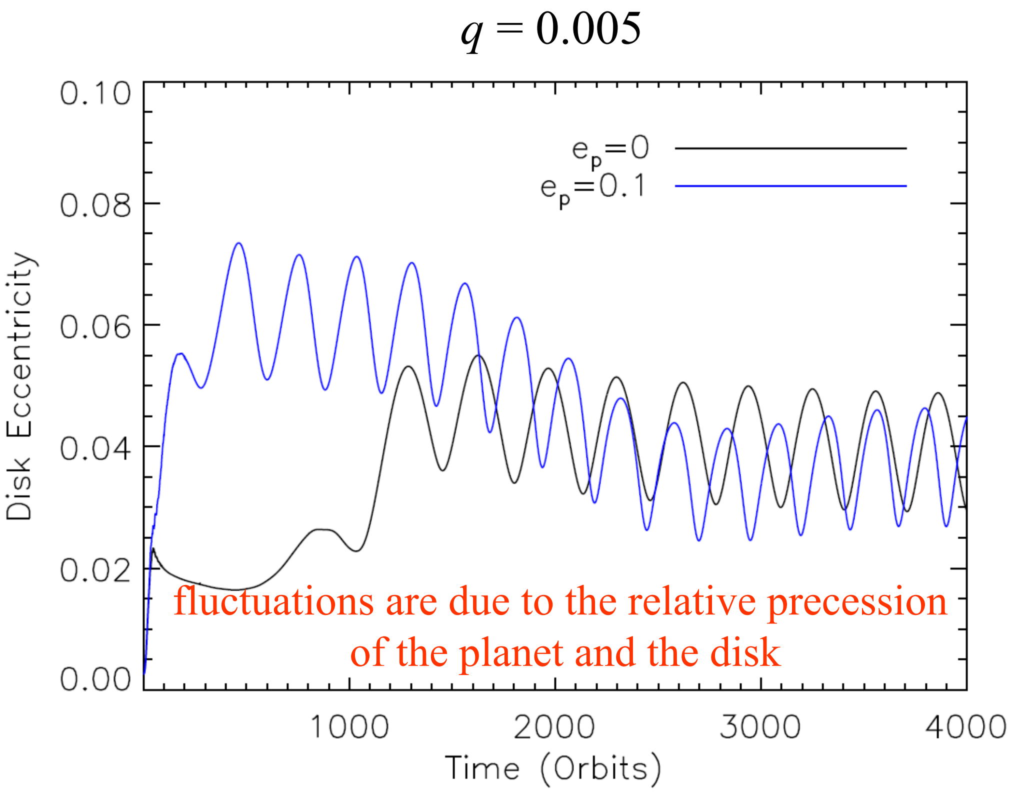


Lubow, S. H. 1991, ApJ, 381, 268

# Disk eccentricity excited by planets

For the mass ratio $q \equiv m_p / M_\bigstar > 3 \times 10^{-3}$,
the disk become substantial eccentric after few hundreds orbits.
(Kley & Dirksen 2006)



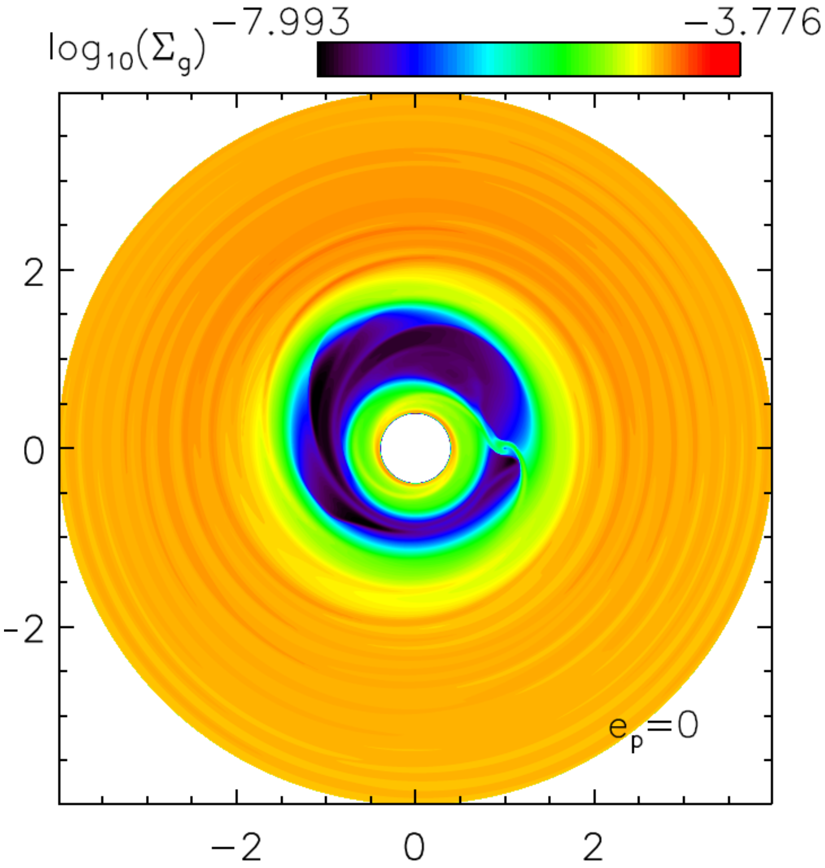


fluctuations are due to the relative precession
of the planet and the disk

Kley, W. & Dirksen, G. 2006, A&A, 447, 369

# Method

- Gas: FARGO, a 2D hydrodynamic code.
  Isothermal disk. No self-gravity and planetary migration.
- Dust: eccentricity equation (gravitational potential + gas drag) for dust in the Epstein regime ($a_d < 2.25\ \lambda_g$)



$H/r = 0.05$

$\nu = 10^{-5}$

$q \equiv m_p/M_\star = 5 \times 10^{-3}$

$e_p = 0.0$ and $0.1$

Time = 3000 orbits

dust-to-gas ratio = 0.01

$U_m = 1 M_\odot$

$U_l = 5$ AU for protoplanetary disks

100 AU for transition disks

simulation results

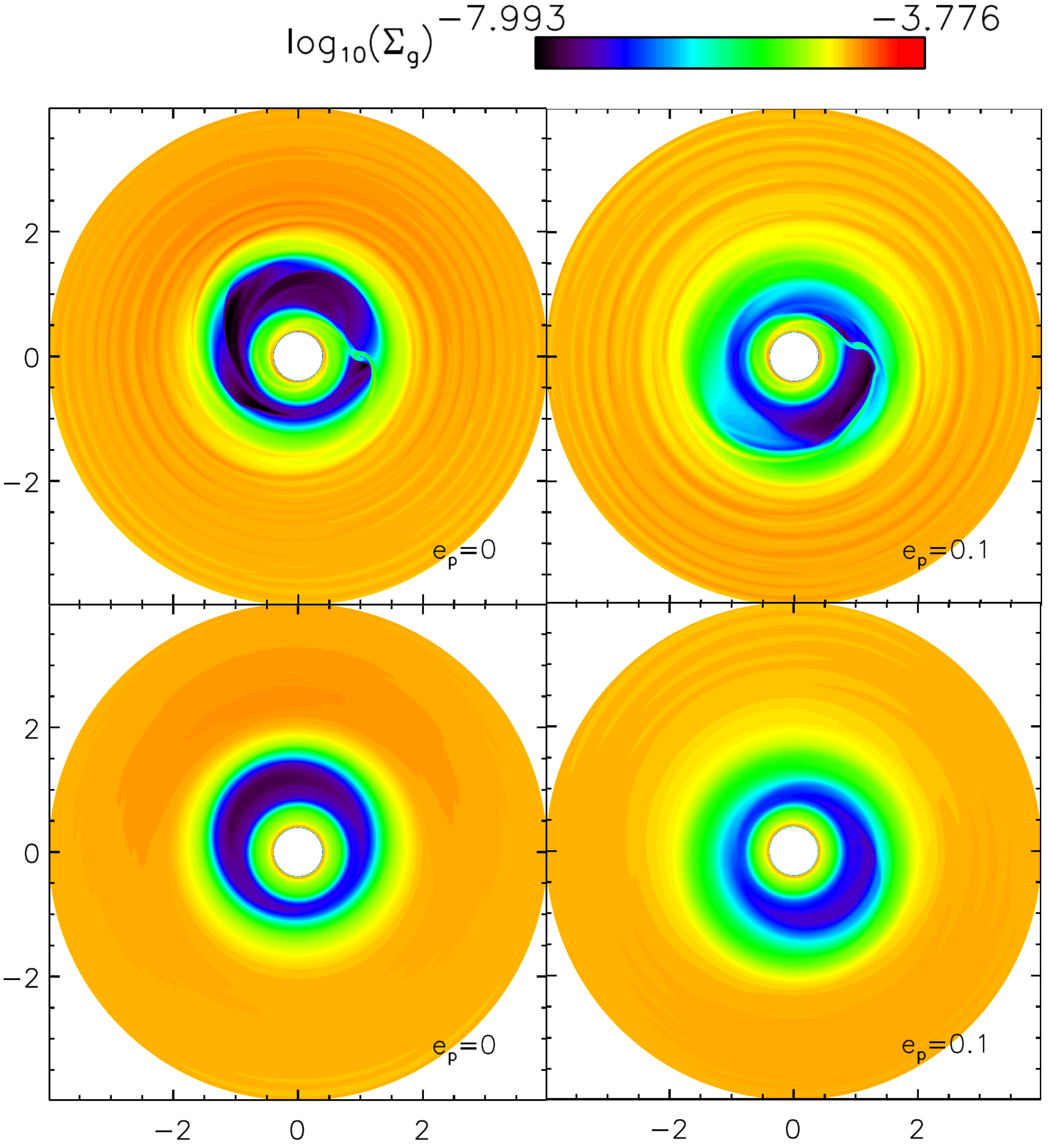
pattern speeds: $\Omega_p / m$

predominant modes:

$m$ = 1 and 2

time average

in almost one orbit



# Protoplanetary disks

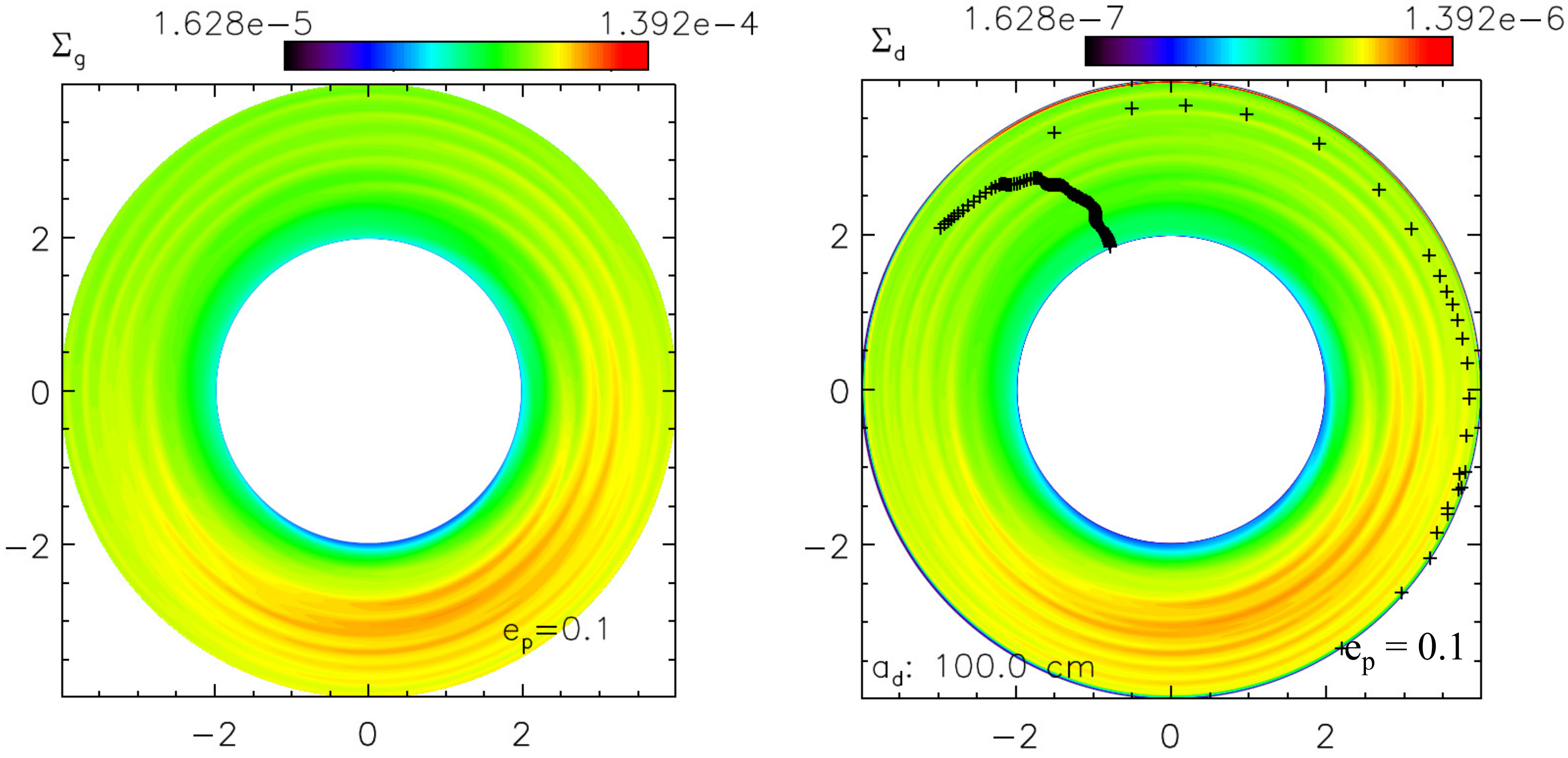
- Define the dimensionless secular stopping time

$$\tau_{s,sec} \equiv \frac{t_s}{t_{prec,d}}$$

*stopping time*

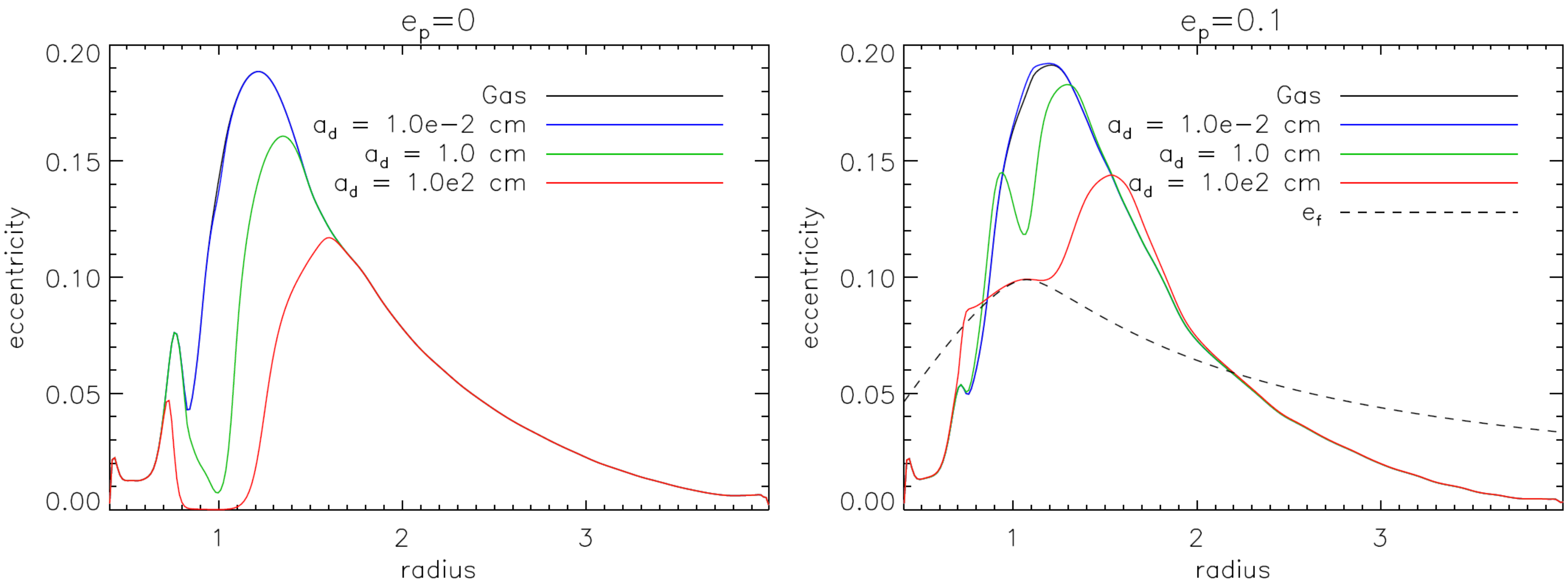
*precession timescale*

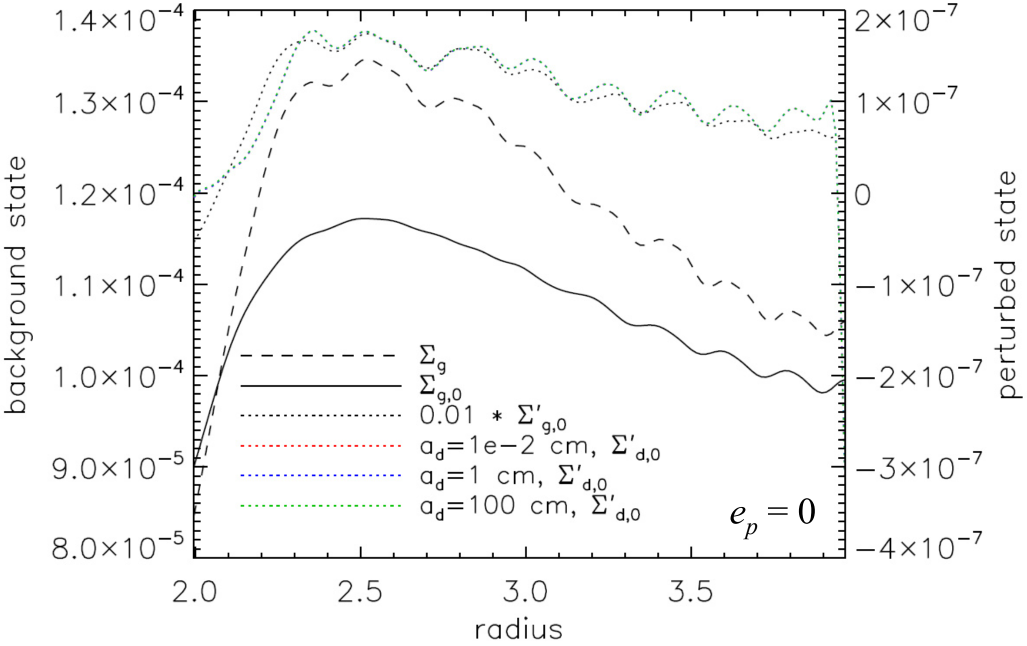
- For particles smaller than 1 m in both cases, $\tau_{s,sec} \ll 1$ (well-coupled).

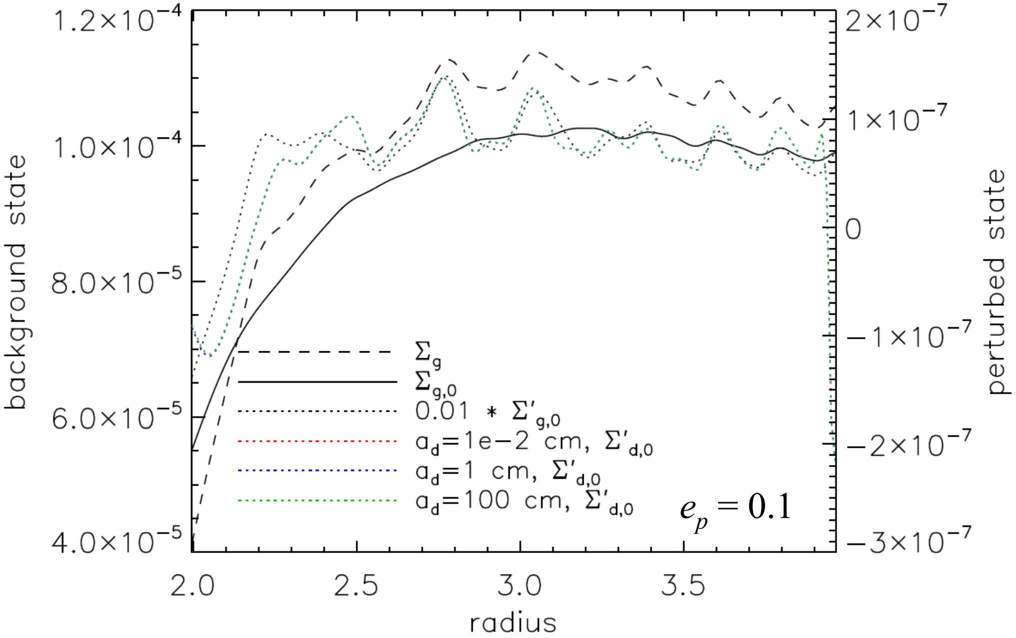


# The azimuthally averaged eccentricity

- The forced eccentricity $e_f$ is in proportional to the planetary eccentricity.





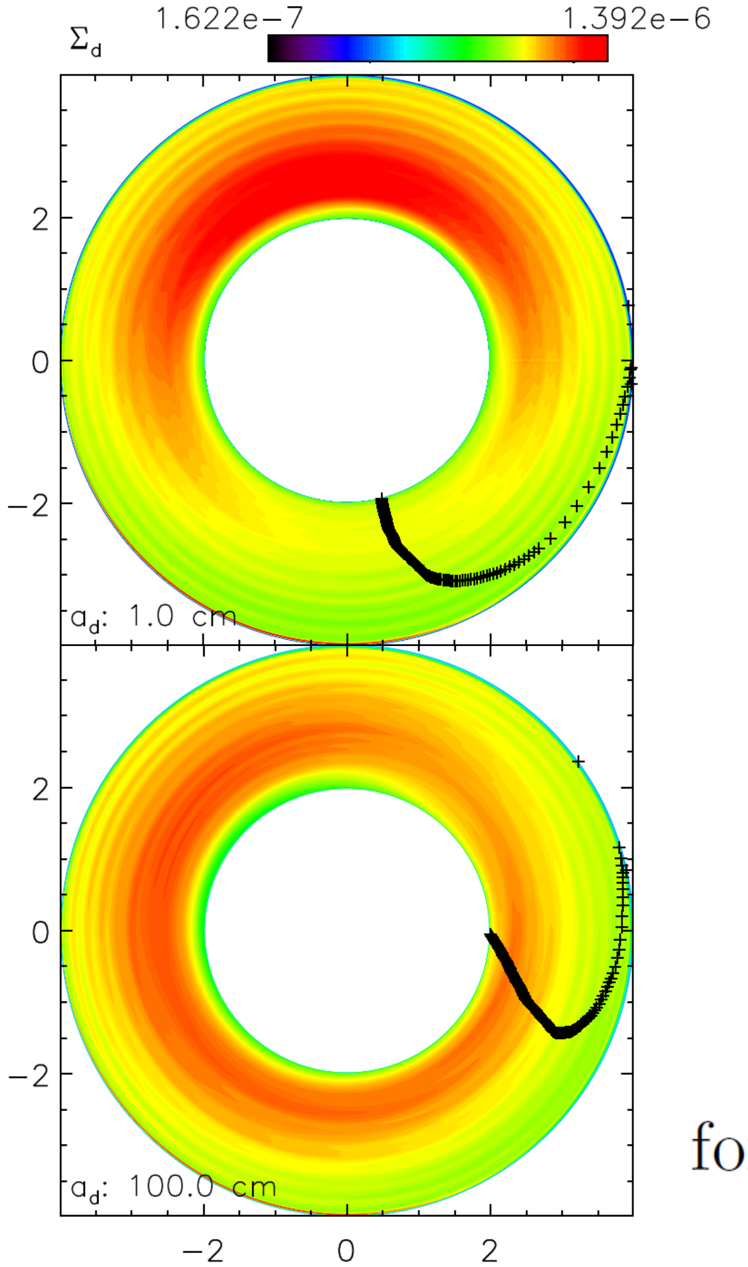


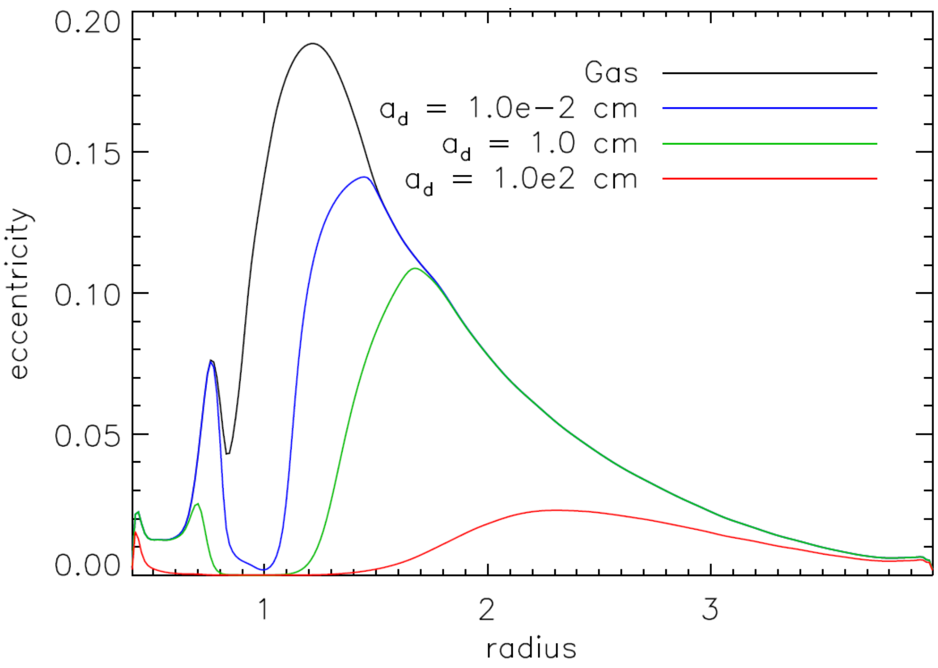
# 1D plot of density profiles

The perturbed dust density is about 10% of the background state.

$$\Sigma'_d \sim 0.1\Sigma_d$$

# Transitional disks ($e_p = 0$)





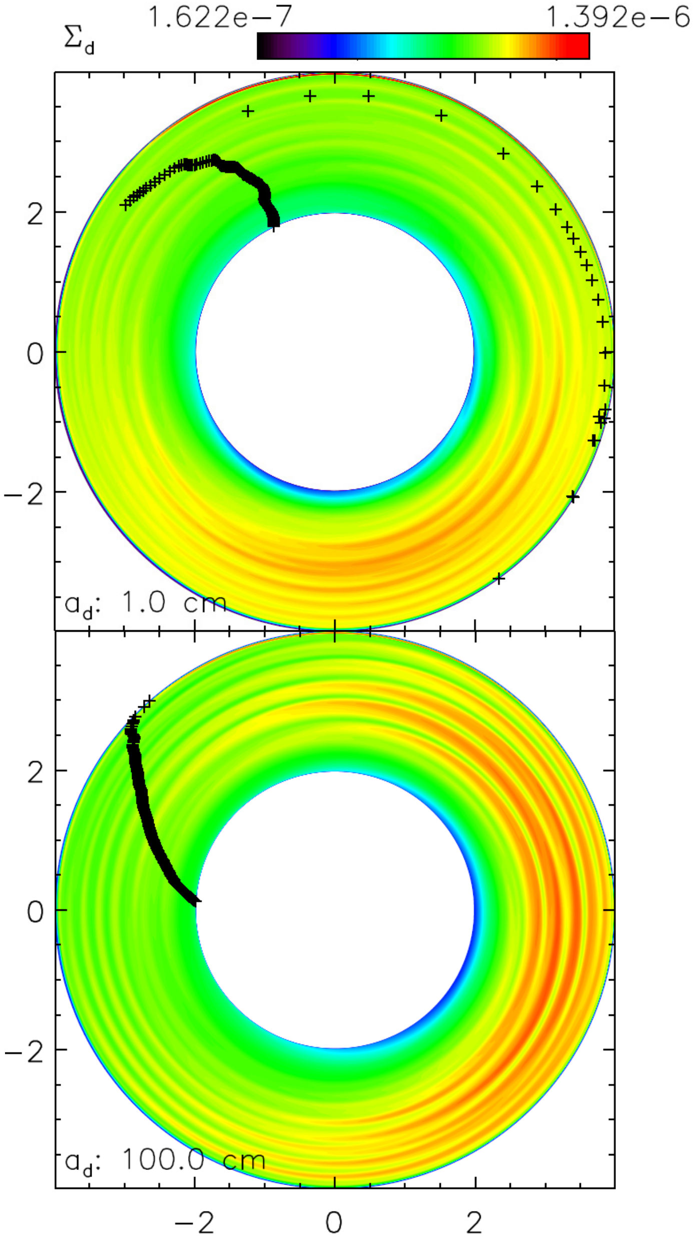
$$\Sigma'_d \sim 0.1\Sigma_d$$

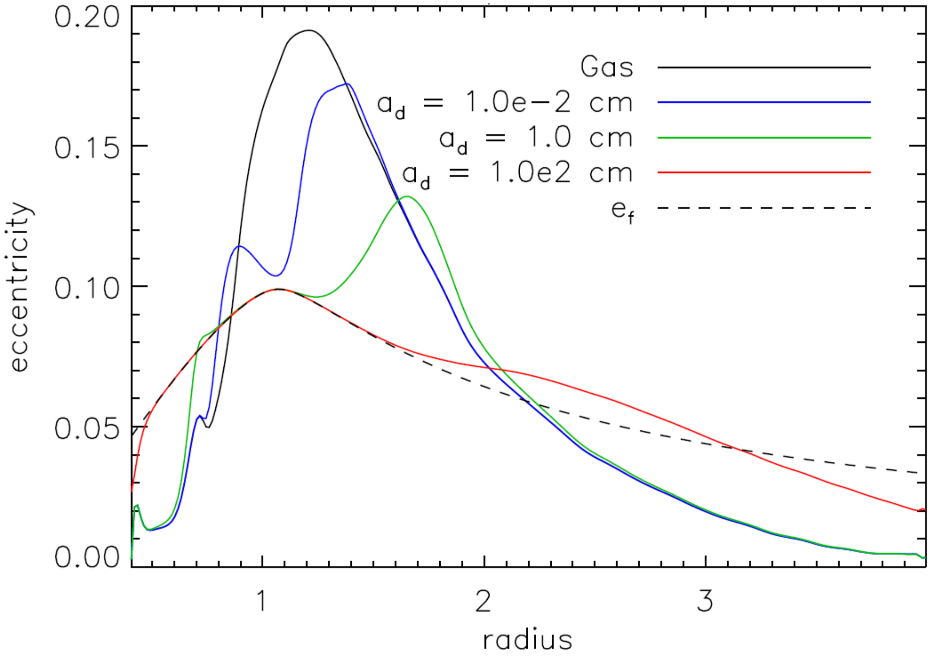
$$\tau_{s,sec} < 1, \text{ for } a_d \leq 1\text{cm}$$

$$\tau_{s,sec} \sim 10, \text{ for } a_d = 100\text{cm}$$

$$\text{for } e_p = 0, |\varpi_d - \varpi_g| = \arctan(\tau_{s,sec})$$

# Transitional disks ($e_p = 0.1$)





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