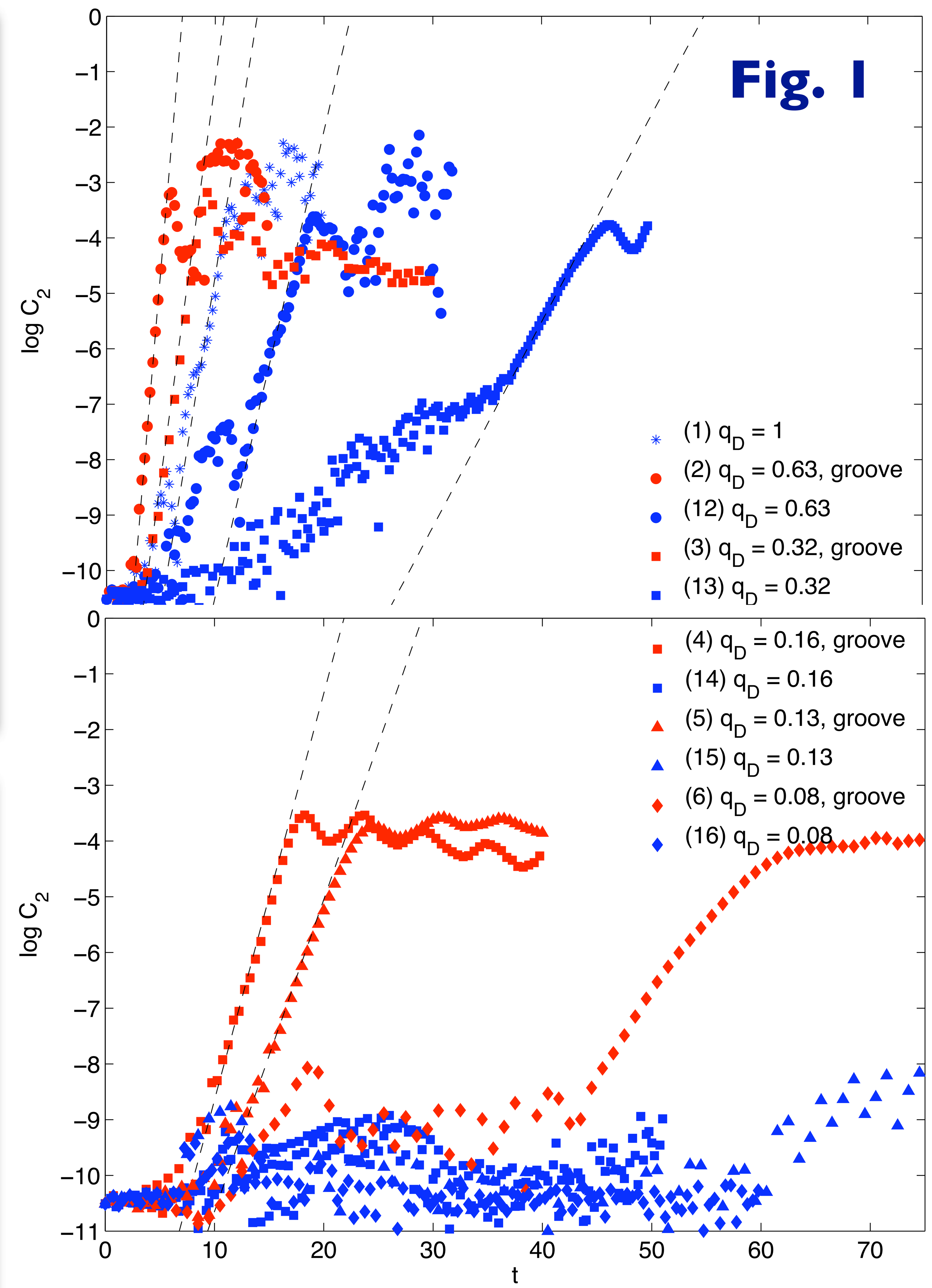
Groove modes in self-gravitating protoplanetary disks

Context: Under the appropriate balance between viscous diffusion and Type I torques, massive giant planets can carve a gap in the surrounding protoplanetary disk during formation. In analogy to the *groove modes* (Sellwood & Lin 1989) known to occur in the context of stellar dynamics when surface density depressions are present, we investigate whether the presence of a gap can excite fast-growing spiral modes in moderate to low mass self-gravitating disks.

Procedure: We model the protoplanetary disk as a thin disk with surface density parametrization

$$\sigma = \sigma_0 e^{[-(r-R_0)^2/w]} \times \left(1 - \frac{A\Delta^2}{(r-R_P)^2+\Delta^2}\right)$$

(Gaussian profile with a Lorentzian gap of depth A, radius Rp and width Δ); this density profile has the advantage of possessing a single m=2 mode. For the purposes of simple modelization, we assume a polytropic EOS. We assess the growth rate and pattern speed of emerging modes by employing a linear analysis code, which solves a generalized eigenvalue matrix equation on a radial grid. We match the predicted linear growth and pattern speed against a 2D hydrodynamical simulation, finding very good agreement between the two codes in the linear growth regime.



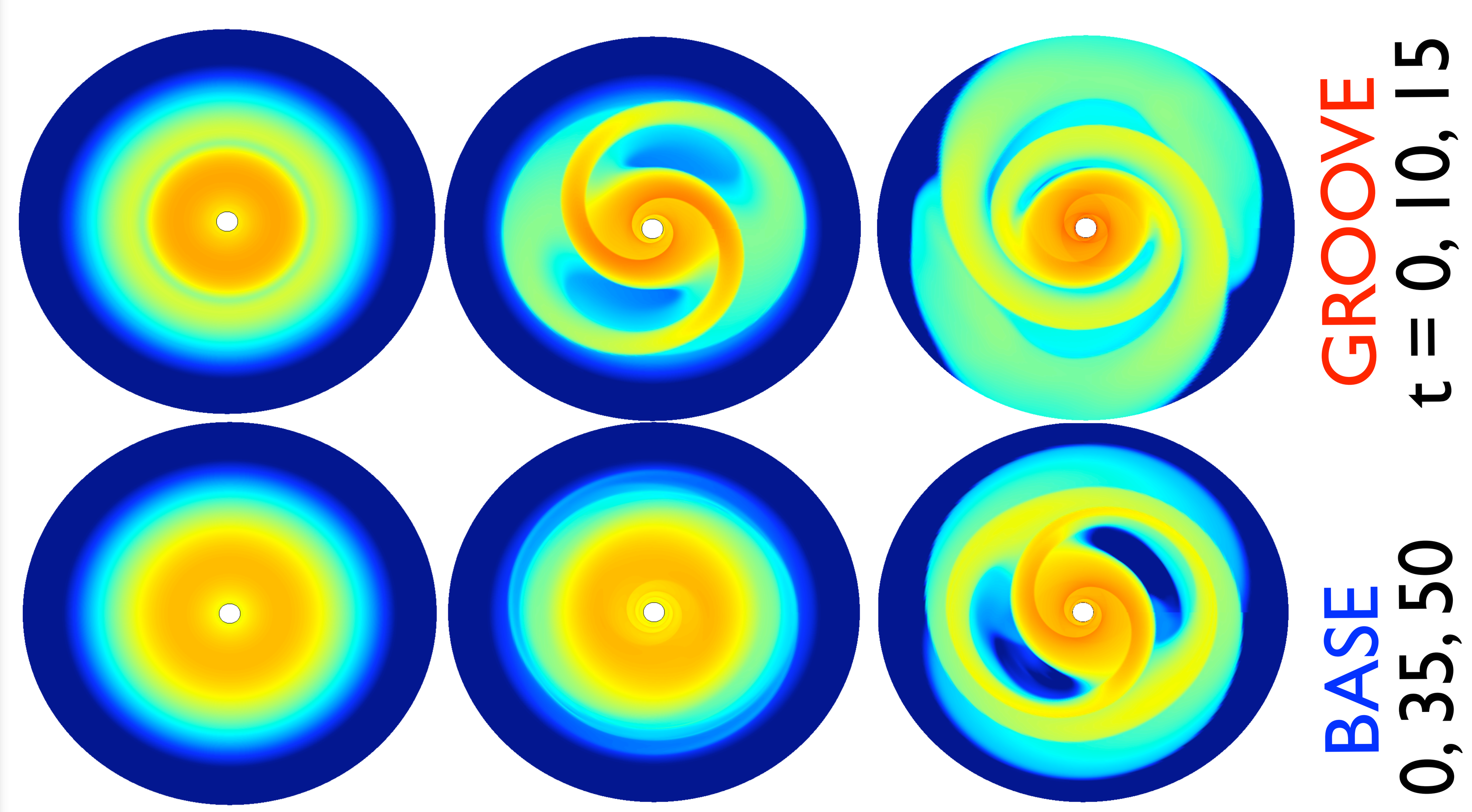


Fig. 2

Results: We consider models spanning a range of q_D, with and without a gap ('base disks') [Fig. 1]. We find that in massive disks the groove mode quickly outpaces instabilities in the same-mass base disk [Fig. 2, q_D = 0.32]. This instability is active even at masses lower than the q_D < 0.1-0.2 value at which they are assumed to occur [Tab. 1]. The mass flux causes the gap to fill in, yielding an effective α in the range ≈ 0.16-0.04. Since a forming giant planet can provide both the structure and the feedback cycle needed to excite groove modes, we speculate that the competition between the GI-induced torques and the planetary torques might lead to a modification of the gap-opening criterion. We plan to further constrain the lower mass limit using a more realistic density profile, EOS and a higher resolution code including the self-consistent disk-planet interaction.

Model	q_D	A	Q_{min}	m	γ_{lin} ($\bar{\gamma}_{nl}$)	Ω_P ($\bar{\Omega}_P$)
1	1	0	1.21	2	1.21 (0.90)	2.78 (2.69)
2	0.63	0.90	0.67	2	2.31 (2.14)	3.41 (3.37)
3	0.32	0.90	1.31	2	1.43 (1.16)	3.18 (3.05)
4	0.16	0.90	1.92	2	0.73 (0.65)	3.04 (3.00)
5	0.13	0.90	2.03	2	0.56 (0.50)	3.02 (2.89)
6	0.08	0.90	2.24	2	($0.28^{a,c}$)	(-0.14^{c}) †
7	0.06	0.90	2.76	2	‡	
12	0.63	0	1.30	2	0.84 (0.70)	2.27 (2.22)
13	0.32	0	1.52	2	0.37 (0.16, 0.31)	2.03 (2.22)
14	0.16	0	1.86	2	‡	
15	0.13	0	2.08	2	‡	
16	0.08	0	2.26	2	‡	
17	0.06	0	2.65	2	‡	

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