Stratification of gravito-turbulent protoplanetary discs and self-gravity prescription for 2D simulations

Steven Rendon Restrepo, O. Gressel, Leibniz-Institut für Astrophysik Potsdam (AIP)

April 24, 2025

In Class 0 and I as well as in the outskirts of Class II circumstellar discs, the self-gravity of gas is expected to be significant, which certainly impacts the disc vertical hydrostatic equilibrium. Notably, the contribution of dust, whose measured mass is still uncertain (Ansdell et al. 2016; Manara et al. 2016), could also be a factor in this equilibrium. In this first part of my talk, I aim to formulate and solve, approximately, the equations governing the hydrostatic equilibrium of a self-gravitating disc composed of gas and dust. Particularly, I aim to provide a fully consistent treatment of turbulence and gravity that almost symmetrically affects gas and dust. From an observational perspective, I study the possibility of indirectly measuring disc masses through gas layering and dust settling measurements (Rendon Restrepo et al. 2025).

The Gravitational Instability (GI) is a dominant theory that explains angular momentum transport in young protoplanetary disks. Additionally, it is a key theory in planet formation, describing how a disk can fragment into clumps for efficient cooling (Kratter & Lodato 2016). Most simulations characterizing GI have been conducted using a thin disc (2D) approximation, which employs a smoothing length prescription for the gravitational potential. Even if it was demonstrated that the smoothing length should scale as the pressure scale height (Müller et al. 2012), difficulties emerged in thin disc simulations. On one hand, a finite smoothing length suppresses the Newtonian character of gravity (Rendon Restrepo & Barge 2023), potentially quenching gravitational collapse, and does not respect Newton's third law (Baruteau & Masset 2008). On the other hand, a vanishing smoothing length artificially amplifies gravity, which could call into question the stochastic nature of fragmentation (Paardekooper 2012). In the second part of my talk, I will introduce the exact self-gravity prescription, derived through analytical means. This prescription is designed for use in 2D simulations and eliminates the need for the smoothing length approach (Rometsch et al. 2024; Rendon Restrepo et al. in prep.). Specifically, I will demonstrate how its usage solves the inherent issues associated to a Plummer potential, notably addressing the short-range suppression of the Newtonian nature of gravity. I will conclude my talk demonstrating its implications to the GI paradigm of planet formation, supported by 2D global simulations.

References

Ansdell, M., Williams, J. P., van der Marel, N., et al. 2016, , 828, 46

Baruteau, C. & Masset, F. 2008, , 678, 483

Kratter, K. & Lodato, G. 2016, , 54, 271

Manara, C. F., Rosotti, G., Testi, L., et al. 2016, A&A, 591, L3

Müller, T. W. A., Kley, W., & Meru, F. 2012, A&A, 541, A123

Paardekooper, S.-J. 2012, , 421, 3286

Rendon Restrepo, S., Rometsch, T., Ziegler, U., & Gressel, O. in prep.

Rendon Restrepo, S. & Barge, P. 2023, A&A, 675, A96

Rendon Restrepo, S., Ziegler, U., Villenave, M., & Gressel, O. 2025, A&A, arXiv:2503.13136

Rometsch, T., Jordan, L. M., Moldenhauer, T. W., et al. 2024, A&A, 684, A192