Refractory abundances of the inner regions of protoplanetary disks.

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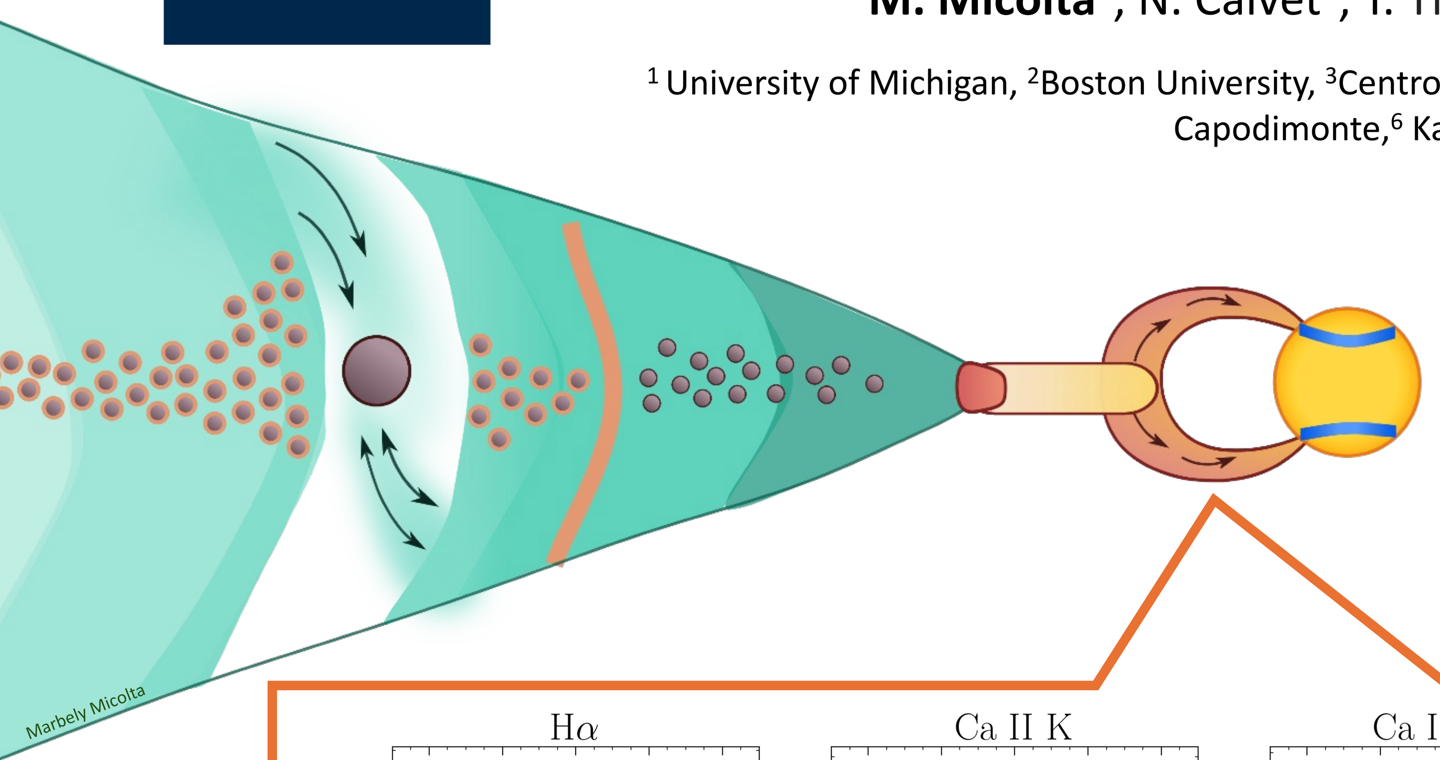

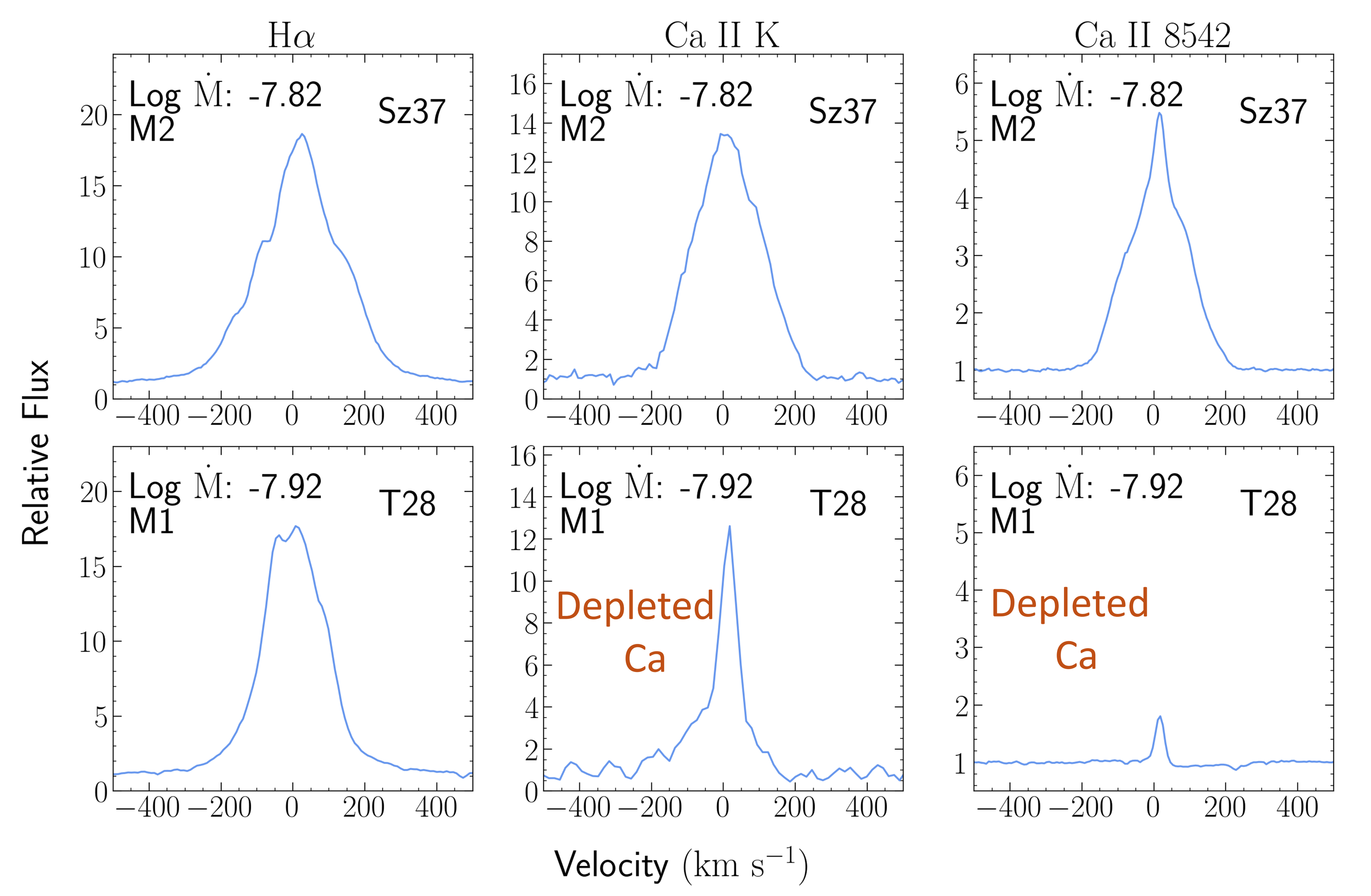

Fig. 1: Line profiles for two stars of the ChaI region. Both stars have similar physical properties but T28 shows weaker Ca lines, interpreted as depletion of Ca in its inner disk.

Background

The emission lines in young low-mass stars are formed in the magnetospheric **accretion flows, which feed from the inner gas disk (see Fig.1, [1]).** Studying the elemental abundance of refractory elements in the accretion flows allows us to **characterize the abundance of the material that *survived* to the inner gas disk, tracing the dust evolution in the system, disk substructures, and planet formation** [2, 3, 4].

Data

X-shooter data and stellar parameters from Chamaeleon I (ChaI) [5], Lupus (Lup) [6,7], OB1b [8,9,10], and WTTS [11,12]

Ca abundances

To estimate Ca abundances, we used the ratio of the Ca II K and Hα line luminosities vs the accretion rate ($\dot{M}$). L(Hα) traces the amount of gas falling into the star while L(Ca II K) traces the content of Ca because the L(Ca II K) will be smaller than expected for its $\dot{M}$ for a depleted star [13]. The accretion rates for epoch 1 are obtained from UV excess independently [5, 6, 7].

We calculated a large grid of magnetospheric accretion models [14, 15], including 4896 different physical configurations, around stars of 6 different spectral types(SpT), and considered 4 possible calcium abundances respective to solar (1, 0.5, 0.1, 0.01). To determine abundances, we compared the observed line ratios with those predicted by the magnetospheric accretion model [14, 15]. Fig.2 shows the M3 observations and model results color-coded by abundance values (where purple is solar).

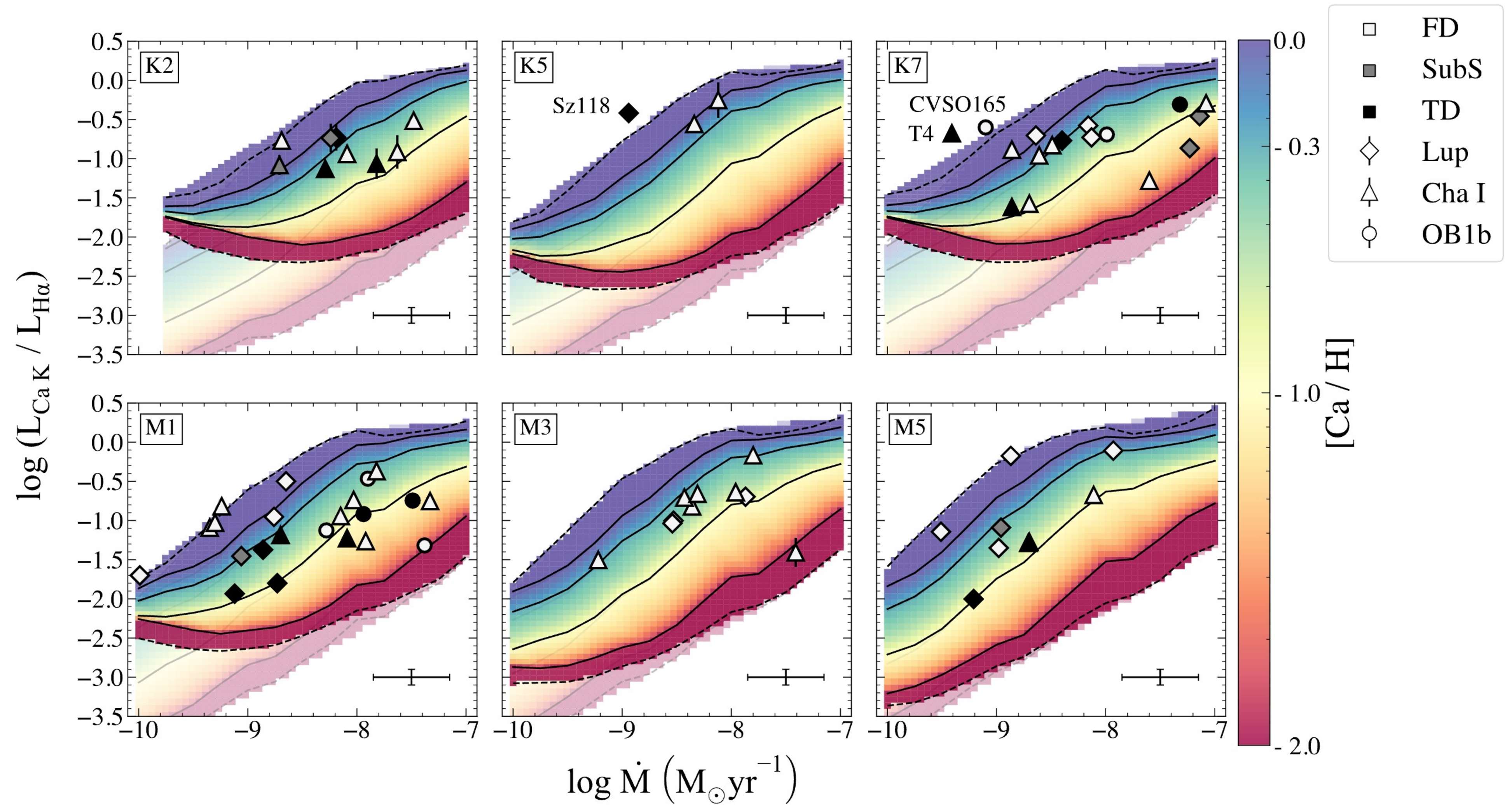

Fig. 2: Comparison of L(Ca II K)/L(Hα) and $\dot{M}$ between models and observations. Models are colored by [Ca/H], with purple representing solar abundance and depletion increasing toward red. The grey-out region represents the magnetospheric models without the contribution of WTTS.

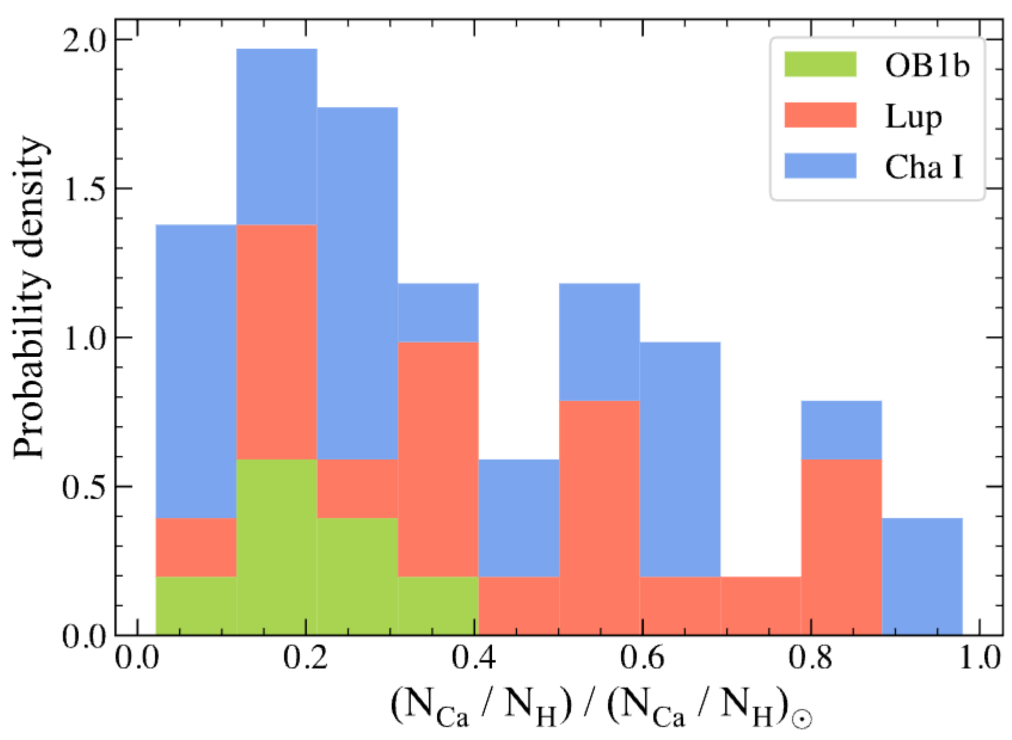

Fig. 3: Distribution of the abundance by number, colored by star-forming region.

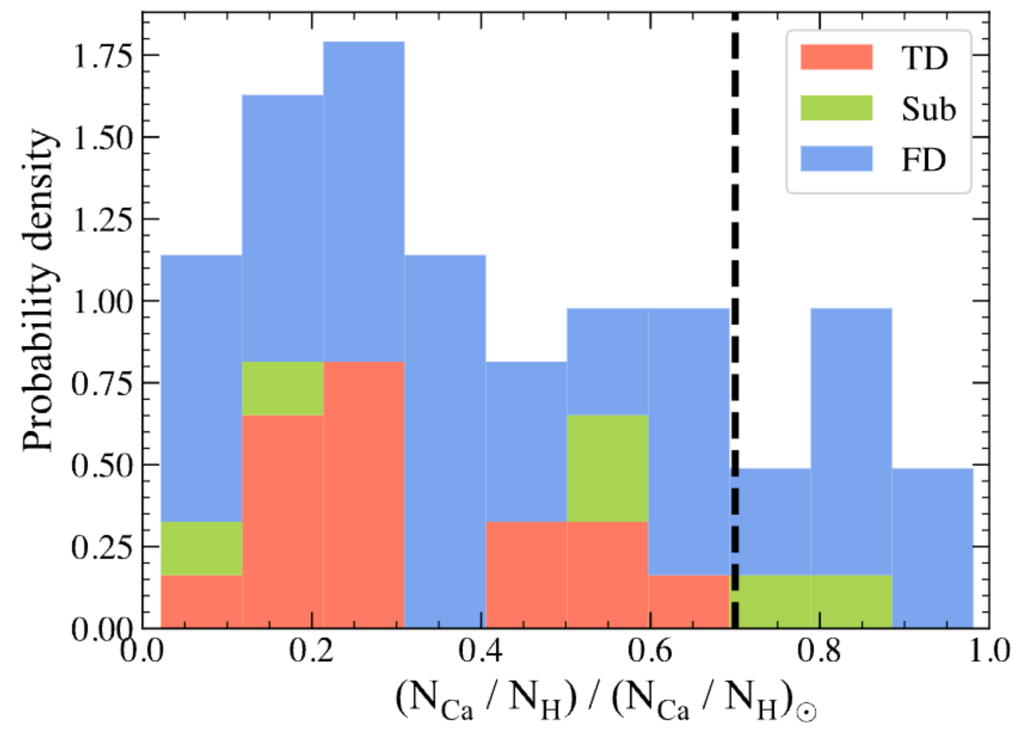

Fig 4. Distribution of abundance by number, colored according to the presence of gaps (red, TD), substructures (green, Subs), or absence of both (blue, FD).

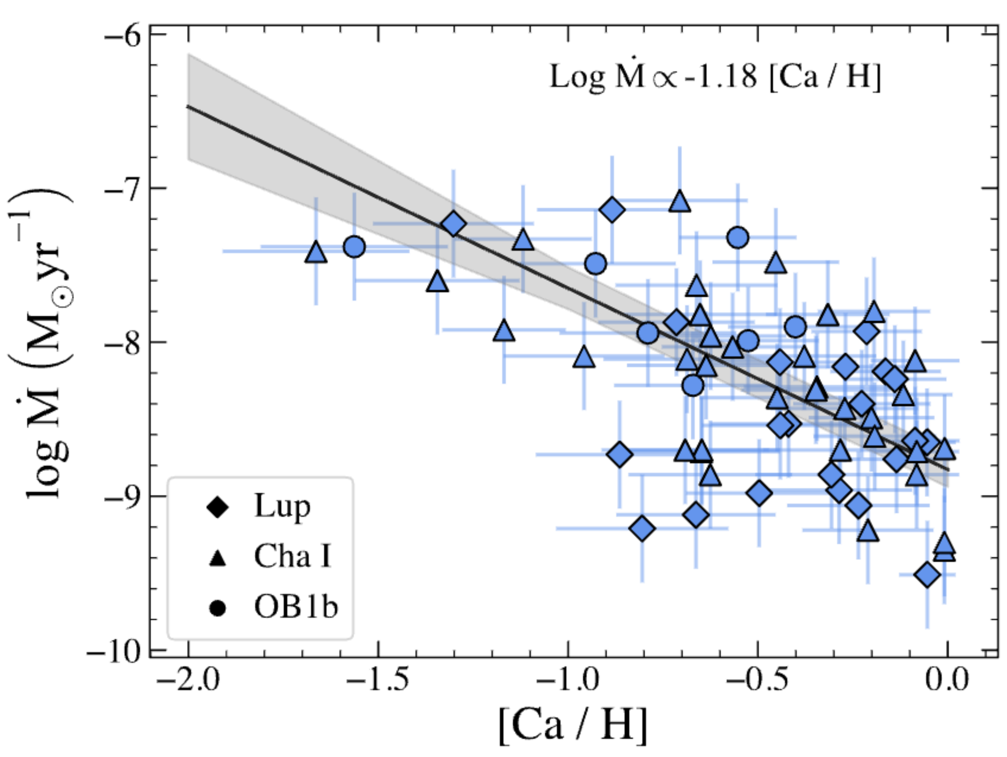

Fig 5. [Ca/H] vs Log $\dot{M}$. The black line represents the best fit from the MCMC linear regression; 1σ confidence intervals are shown grey.

Takeaways

- We estimate Ca abundance values from the emission lines formed in the accretion flows. These abundances are representative of the refractory abundance of the innermost disk.
- **We find a wide range of Ca abundances, with Ca depletion present in all three star-forming regions. The overall distribution of Ca abundances is skewed toward low [Ca/H] values (high values of depletion), with 57% of the sample having [Ca/H] < -0.30 relative to the solar** (see Fig. 3). This indicates that refractory depletion is a common result in CTTS, most likely caused by dust/disk evolution.
- **All transitional disks are depleted in calcium with abundance-by-number values < 0.7, relative to solar,** while disks with substructures in a wide range of abundance values. We find ~60% of the full disks show significant Ca depletion, with [Ca/H] < -0.30 (see Fig. 4). However, we cannot rule out the possibility of hidden substructures or cavities in these targets.
- **We find a negative correlation between [Ca/H] and the mass accretion rate** (see Fig. 5) A possible scenario is that the inner and outer disks are decoupled and that the mass accretion rate is related to a mass reservoir in the inner disk while refractory depletion reflects phenomena in the outer disk, maybe associated with the presence of structure and forming planets.
- Our results of refractory depletion and timescales for depletion are qualitatively consistent with expectations of dust growth and radial drift including partitioning of elements [16] and constitute direct proof that radial drift of solids locked in pebbles takes place in disks.

References: [1] Hartmann et al. 2016, ARA&A, 54, 135; [2] Kama et al. 2015, A&A, 582, L10; [3] McClure et al 2019, A&A, 632, A32. [4] Schneider & Bitsch 2021a, A&A, 654, A71; [5] Manara et al. 2017 A&A, 604, A127; [6] Alcalá et al. 2014 A&A, 561, A2; [7] Alcalá et al. 2017, A&A 600, A20; [8] Manara et al. 2021, A&A, 650, 196. [9] Manara et al. 2023, zenodo.10024073; [10] Pittman et al. 2022, AJ, 164, 201; [11] Manara et al. 2013 A&A, 551, A107; [12] Manara et al.2017 &A, 605, A86; [13] Micolta et al. 2023, ApJ, 953, 177; [14] Hartmann et al. 1994, ApJ, 426, 669; [15] Muzerolle et al. 2001, ApJ, 550, 944. [16] Hühn. & Bitsch. 2023, A&A, 676, A87.