Transport of dust grain particles in the accretion disk

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Abstract

Entrainment of dust particles in the flow inside and outside of the proto-planetary disk has implications for the disk evolution and composition of planets. Using quasi-stationary solutions in our star-disk simulations as a background, we add dust particles of different radii in post-processing of the results, using our Python tool DUSTER. The distribution and motion of particles in the disk is followed in the cases with and without the backflow in the disk. We also compare the results with and without the radiation pressure included in the computation.

Introduction

Entrainment of the dust particles in the flow inside and outside of the proto-planetary disk influences the disk evolution and composition of planets. With our newly developed Python tool DUSTER, we performed post-processing of the results from the PLUTO (Mignone et al., 2007, 2012) code simulations obtained in Čemeljić (2019), by adding dust particles of different radii. Similar results were obtained using the expressions for the disk solutions from Čemeljić et al. (2019), instead of results from the simulations. Any other disk and corona model can easily be supplied as the DUSTER input.

We perform computations with DUSTER in the cases with and without backflow in the disk. Trajectories of four kinds of particles are followed, with the radii a of 0.1, 0.5, 1 and 2 µm. We compute the paths of 25 particles of each kind. Since the particles melt on approach to the star closer than some critical distance (Vinković, 2006, 2009, 2012), we add the lost particles at the disk outer rim, so that there are always 25 particles inside the computational box. The paths of the melted particles are erased. Only the particles that remain in the disk or are pushed away from the star out of the computational domain are followed. The trajectories of the particles are computed with the equation for the acceleration of particles, with gravity, gas drag and radiation pressure:

$$\ddot{\vec{r}} = -G\frac{M_\star}{r^3}\vec{r} - \frac{\rho_{gas}}{\rho_{gr}}\frac{c_s}{a}(\dot{\vec{r}} - \vec{v}_{gas}) + \vec{\beta}G\frac{M_\star}{r^2}$$

The coefficients are (Vinković 2006):

$$\beta = 0.4\frac{L_\star}{L_\odot}\frac{M_\odot}{M_\star}\frac{3000\frac{\mathrm{kg}}{\mathrm{m}^3}}{\rho_{gr}}\frac{\mu m}{a},\ R_{in} = 0.0344\Psi\left(\frac{1500K}{T_{gr}}\right)^2\sqrt{\frac{L_{tot}}{L_\odot}}[\mathrm{AU}],$$

with the correction factor for the diffuse heating from the dust itself, $\Psi \sim 2$. To test the influence of radiation pressure on the distribution of particles, we perform computations with and without the radiation pressure–see Fig. 3

Results

We show examples with trajectories of particles, computed in cases with and without backflow in the disk. We also show an example with computation performed without the radiation pressure.

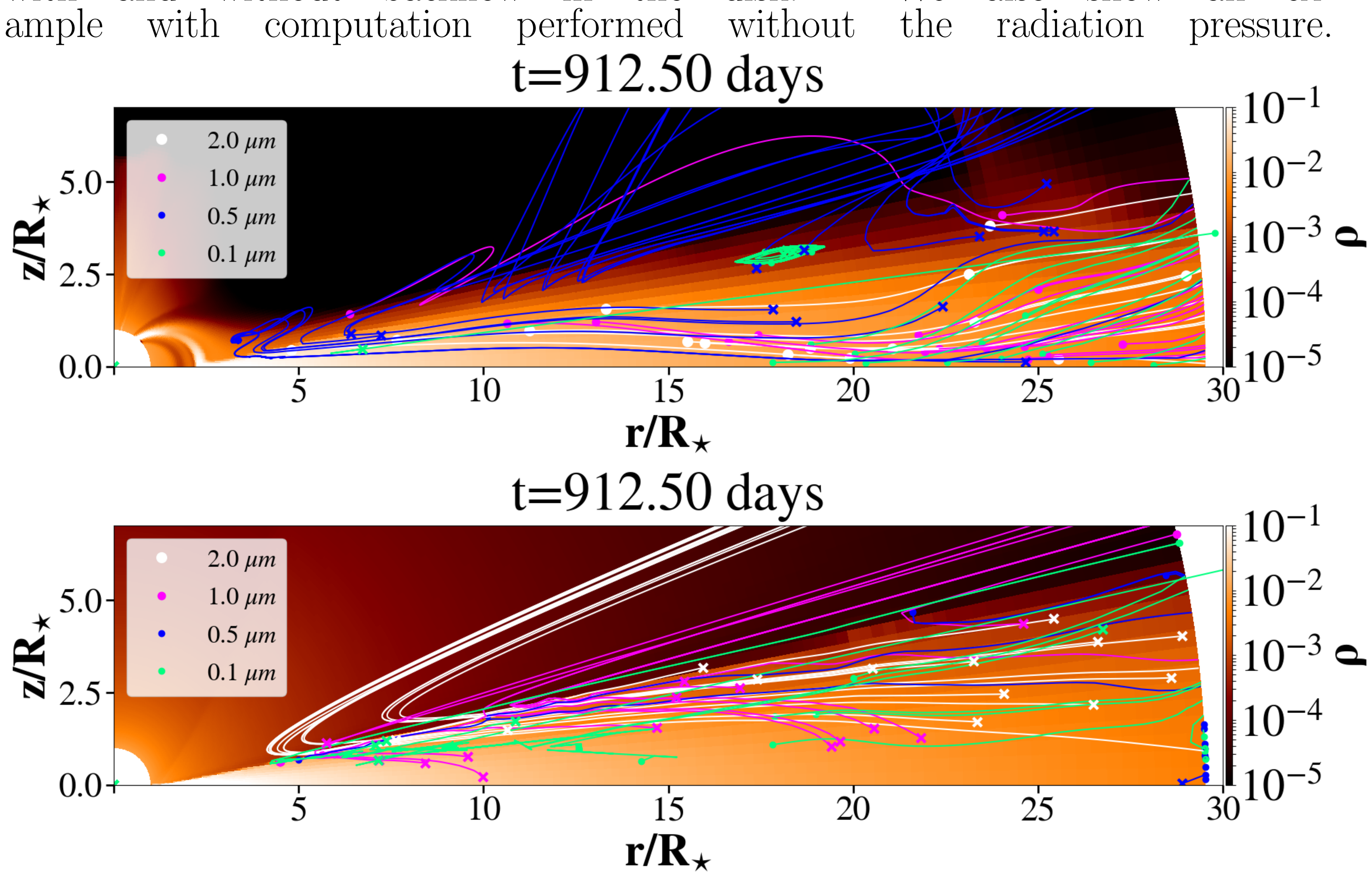

Fig. 1. Particles and their trajectories in a case without backflow in the disk (top panel) and with backflow in the disk (bottom panel). Radiation pressure is included in both cases, with a fully transparent disk. Paths of particles that melted after approaching the star to the critical distance of 4.5 stellar radii were erased, shown are only particles pushed away from the star, or those which remained inside the disk.

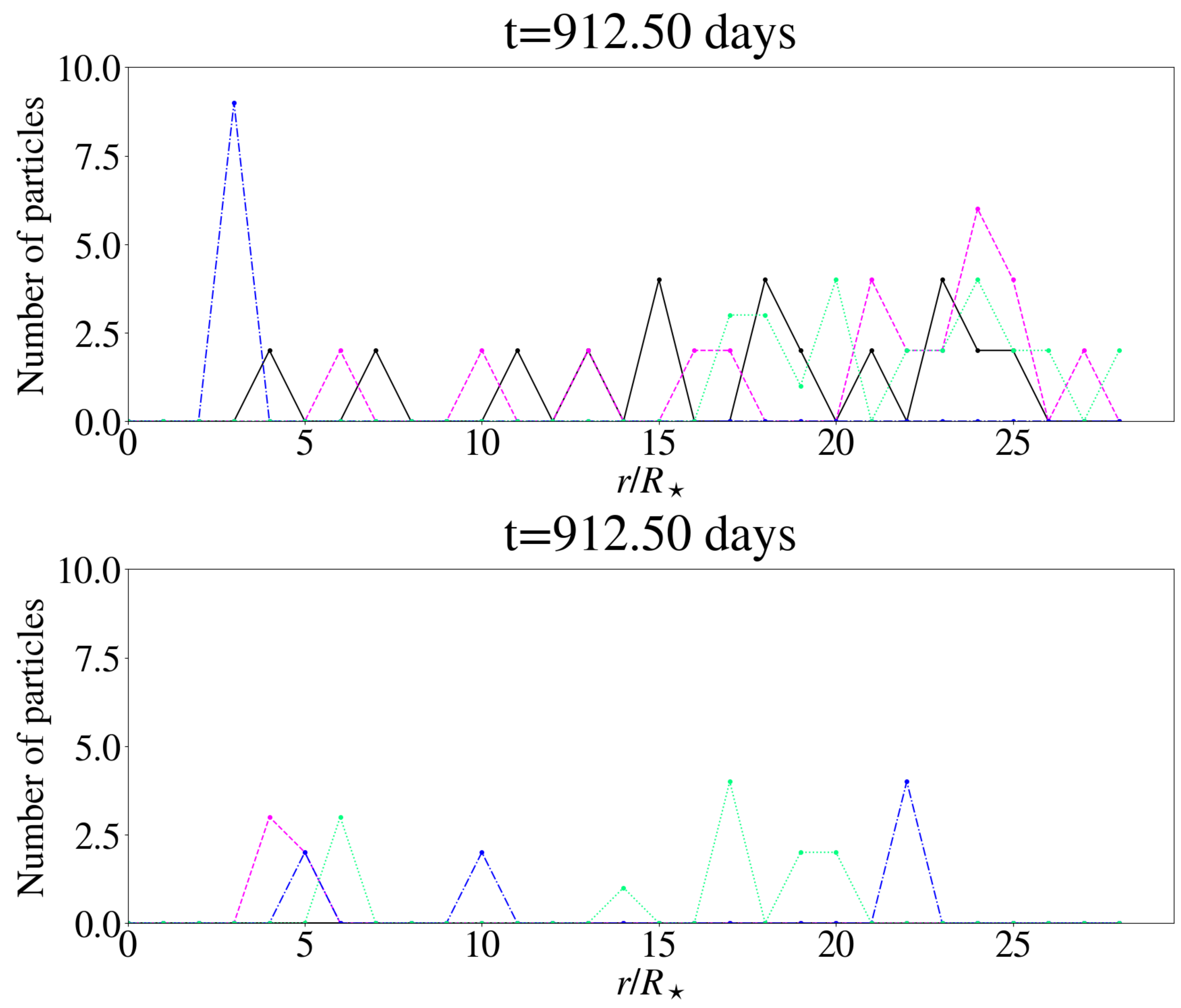

Fig. 2. The number of particles at different distances from the star. In the top panel is shown a case without backflow and in the bottom panel a case with backflow. Colors correspond to the particles in Fig 1, with white particles shown in black color line.

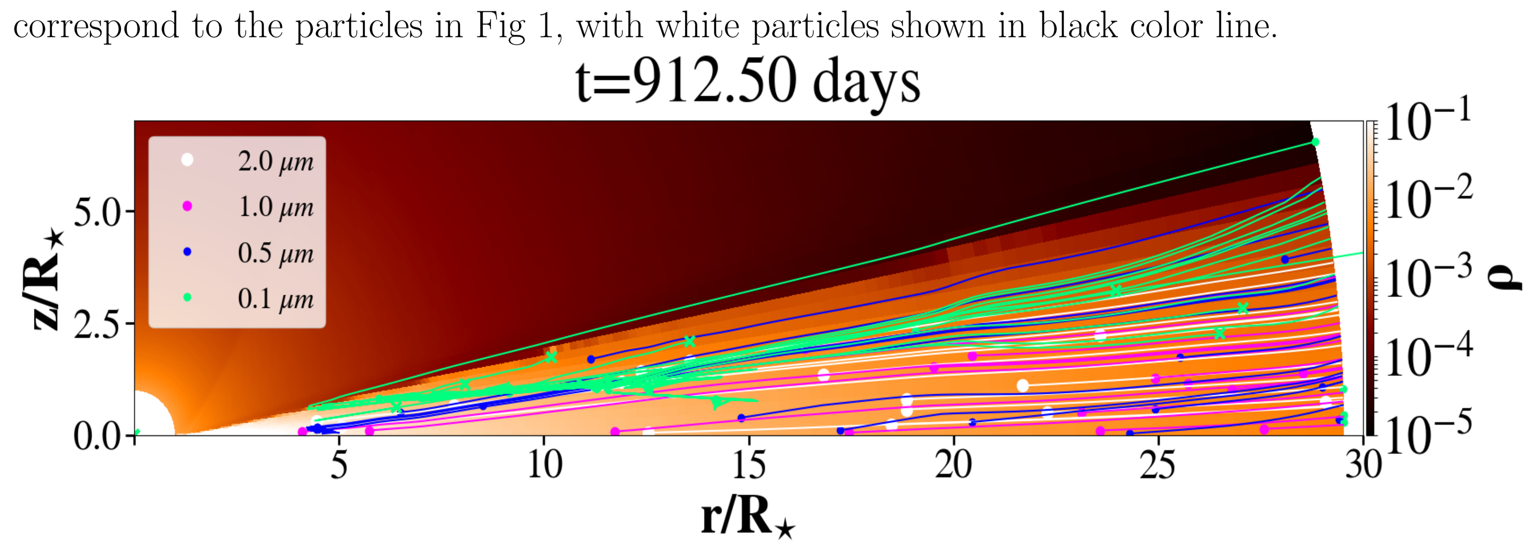

Fig.3. A case with backflow in the disk, but without radiation pressure.

Conclusions

Backflow influences paths of dust particles inside the disk. The drag force in the disk backflow and the radiation pressure push particles to the outer edge of the disk. In the case without backflow in the disk, particles move towards the disk equatorial plane and towards the star. The radiation pressure in an optically thin disk is preventing the transport of particles towards the star.

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References

Čemeljić, M., 2019, A&A, 624, A31
Čemeljić, M., Kluźniak, W., Parthasarathy, V., 2019, arXiv:1907.12592
Kluźniak, W., Kita, D., 2000, arXiv:astro-ph/0006266
Mignone, A., et al., 2007, ApJS, 170, 228
Vinković, D., 2006, ApJ, 651, 906
Vinković, D., 2009, Nature, 459, 227
Vinković, D., 2012, MNRAS, 420, 1541