The tool DUSTER for computation of dust trajectories in a protoplanetary disk

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Abstract: We present our newly developed Python code DUSTER, for computation of the dust particles trajectories in a star-disk system. The flow of matter in and above a thin protoplanetary accretion disk is introduced in the code as an initial condition, from a numerical simulation or analytical model. Such a flow is then used as a stationary background for the computation of grain particles trajectories with DUSTER, with the inclusion of radiation pressure. As the DUSTER output, the final distribution of particles with respect to the star is presented in histograms.

Introduction

Dust in a protoplanetary disk contains grains of various physical and chemical properties. Closer to the star, particles are subject to sublimation in the different ways, depending on their properties. Precise description of radiative transfer in such dust is complicated (Vinković, 2012). We study motion of the dust grains of different radii in post-processing of the results from our numerical simulations with the PLUTO code, using the Python code DUSTER.

Numerical setup

As a background in the computations, we use our results from numerical simulations of star-disk magnetospheric interaction in Čemeljić (2019). The solutions are obtained starting from Kluźniak & Kita (2000) hydrodynamical disk, with the addition of stellar dipole magnetic field. Resistive and viscous magneto-hydrodynamical equations are solved using the PLUTO code (Mignone et al. 2007, 2012), and the results are used as input density and velocity for DUSTER code computation.

Equation of motion solved by DUSTER is (Vinković, 2009, 2012):

$$\ddot{\vec{r}} = -G\frac{M_{star}}{r^3}\vec{r} - \frac{\rho_g}{\rho_s}\frac{c_s}{a}(\dot{\vec{r}} - \vec{v}_g) + \vec{\beta}\, G\frac{M_{star}}{r^2}$$

where

$$\beta = 0.4\frac{L_{star}}{L_{sun}}\frac{M_{sun}}{M_{star}}\frac{3000\,{}^{kg}/_{m^3}}{\rho_s}\frac{\mu m}{a}$$

is the coefficient describing the radiation pressure. The first two terms compute the gravity and gas drag pressure on the particles of radius *a*.

Examples of DUSTER computation

DUSTER can easily be used with any simulations or analytical model, by importing the corresponding data or equations to the code. We show an example in Fig.1, with computation from the result of numerical simulation from Čemeljić (2019) as a background, for the case of Classical T Tauri Stars. The disk accretion rate is of the order of 10^{-9} M☉/yr, with the stellar mass 0.5M☉, radius 2R☉, the stellar dipole field of 500G, rotating with the 20% of the breakup rotation rate.

At the start of DUSTER, the terminal query prompts the user to provide the number of particles and the way of adding the particles. The choices for adding particles are: random addition throughout the computational box, randomly in the disk, circle-shaped "cloud" of dust, uniform across the whole domain, uniform angular distribution, uniform radial distribution, and Gaussian distribution in the polar angle. By a simple modification of the script, user can easily add another way of adding the dust or modifying the forces acting on the grains.

In the shown examples, disk is transparent for the radiation. With appropriate modifications one can include the disk opacity. The stellar wind and other properties of corona can also be separately defined.

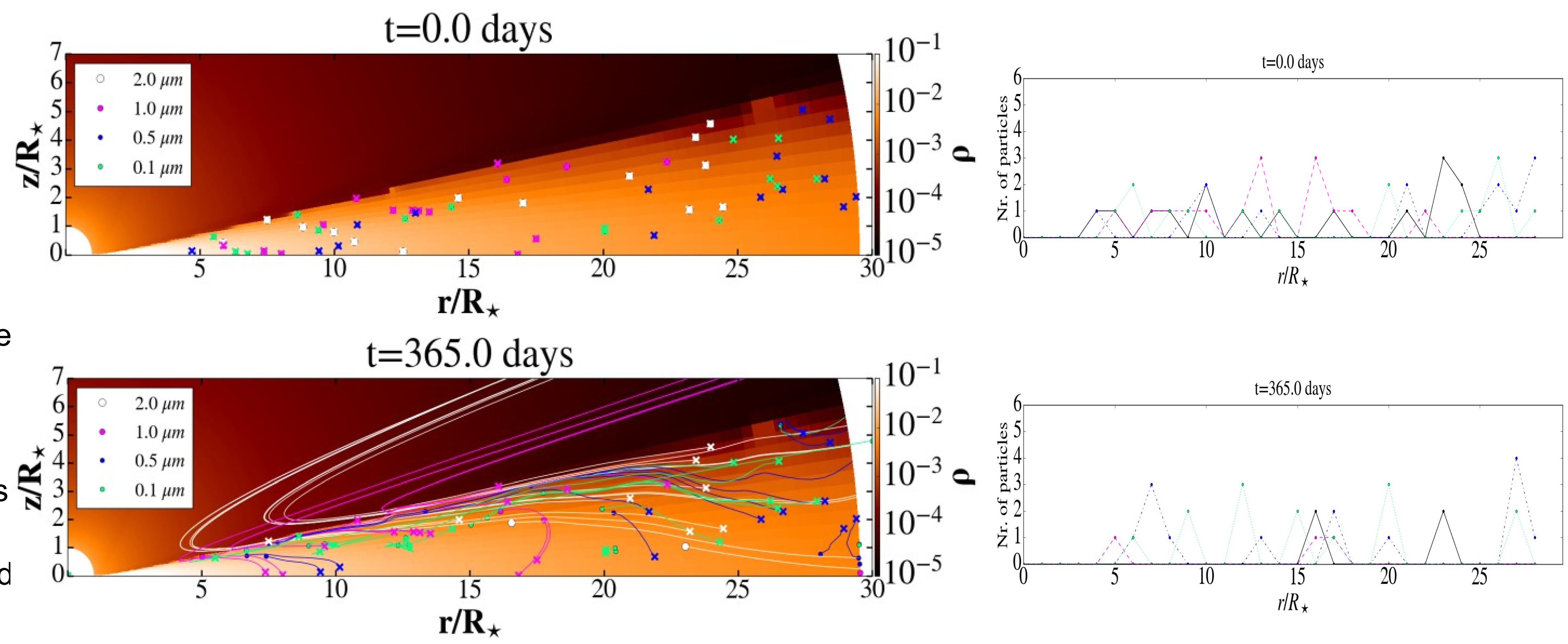

Figure 1: *Background matter density distribution with the use of solutions from numerical simulations performed with the PLUTO code, together with the trajectories of four kinds of particles initially randomly distributed in the disk, computed with DUSTER. Right side panels show the distribution of particles.*

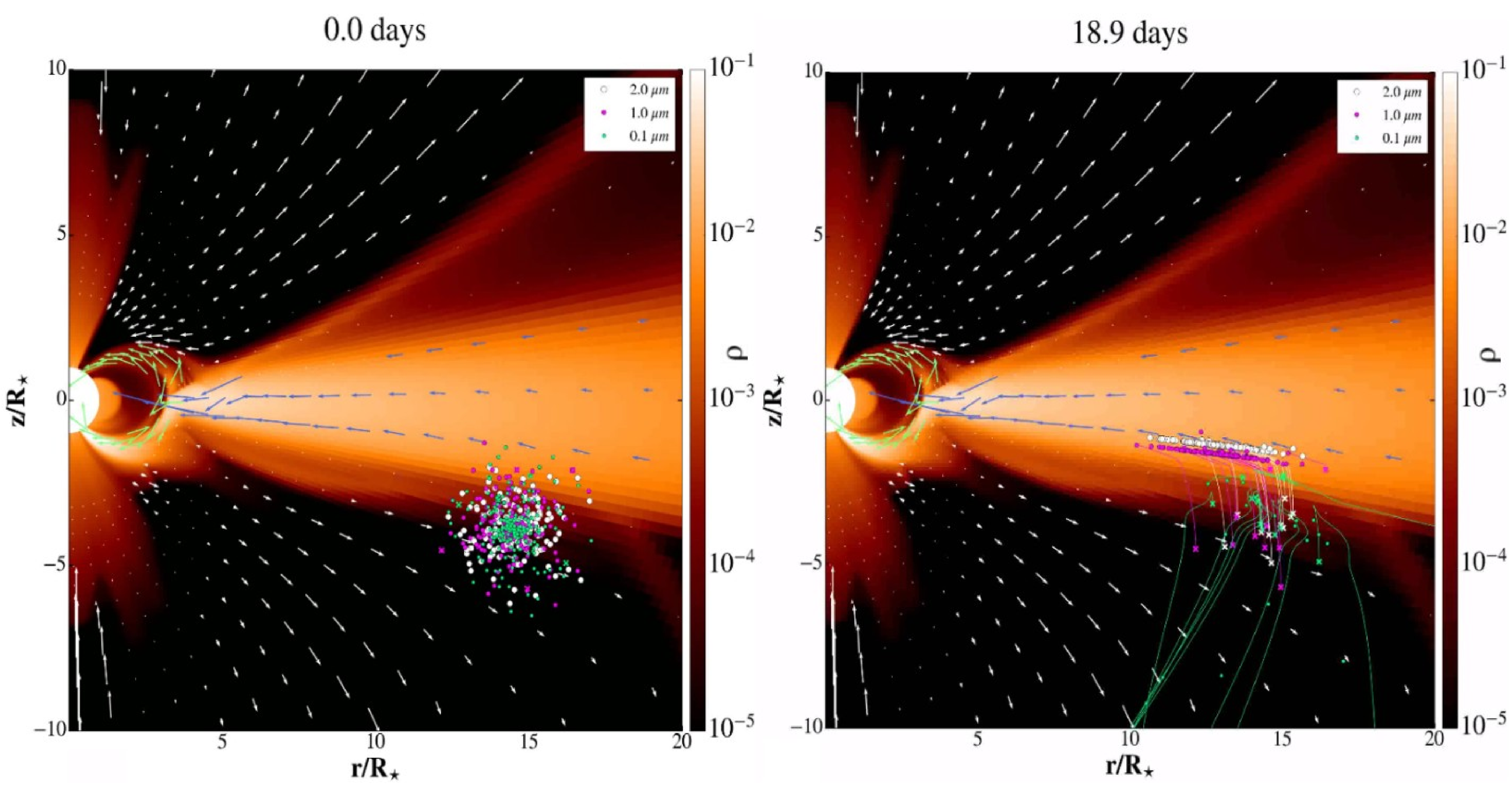

Figure 2: *Trajectories of three kinds of particles initially distributed in the circular shape, computed with DUSTER.*

Results

With DUSTER, we compute trajectories of the particles of different radii in the background flow from the numerical simulations.

In Fig. 1 we show an example of computation with the initially random distribution of four kinds of particles with different radii in the disk. Shown is the initial distribution and after one year.

In another example, in Fig.2 we show the result with three kinds of particles initially positioned in a circular "cloud" above the disk, which later redistribute in the disk and corona. Similar setup can be repeated with e.g. a layer of dust falling onto the disk.

Conclusions

With our newly developed Python tool DUSTER, we compute the trajectories of the dust particles in a post-processing of the results from numerical simulations or analytical solutions of star-disk interaction. The number and initial distribution of the particles is entered as an input in the terminal upon starting DUSTER computation. As an output, the tool provides histograms or curves of the distribution of particles during the computation, which can be used in further analysis of the results.

DUSTER is largerly customizable: by adding the wished force of interaction, kind and and distribution of particles in the source code, one can modify the script to be used with any background flow and physical conditions.

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References

Čemeljić, 2019, A&A, 624, A31
Kluźniak, W., Kita, D., 2000, arXiv:astro-ph/0006266
Mignone, A., Bodo, G., Massaglia, S., et al., 2007, ApJS, 170, 228
Mignone, A., Zanni, C., Tzeferacos, et al., 2012, ApJS, 198, 7
Vinković, D., 2006, ApJ, 651, 906
Vinković, D., 2009, Nature, 459, 227
Vinković, D., 2012, MNRAS, 420, 1541