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

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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, taken 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.

1 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 the 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 our Python code DUSTER.

2 Numerical setup

As a background in the computations, we use 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), and the results are used as input density and velocity for DUSTER code computation. Equation of motion solved by DUSTER is (Vinković, 2009, 2012):

$$\ddot{\vec{r}} = -G\frac{M_\star}{r^3}\vec{r} - \frac{\rho_{\rm gas}}{\rho_{\rm gr}}\frac{c_{\rm s}}{a}(\dot{\vec{r}} - \vec{v}_{\rm gas}) + \vec{\beta}G\frac{M_\star}{r^2}. \tag{1}$$

3 Examples of computation with DUSTER

DUSTER can easily be used with any simulations or analytical model, by importing the corresponding data or equations to the code. At the start of DUSTER, user

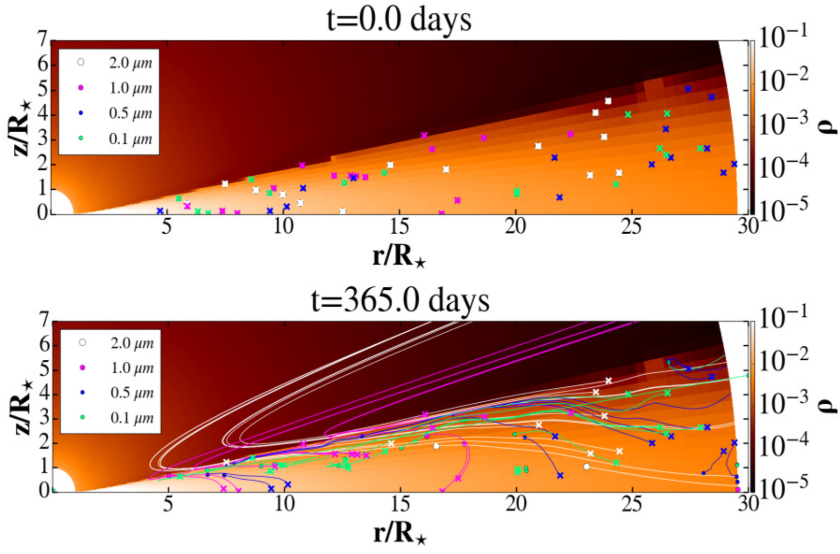

Fig. 1: Background matter density distribution with the use of solutions from numerical simulations performed with the PLUTO code (top panel), and trajectories of four kinds of particles initially randomly distributed in the disk, computed with DUSTER (bottom panel).

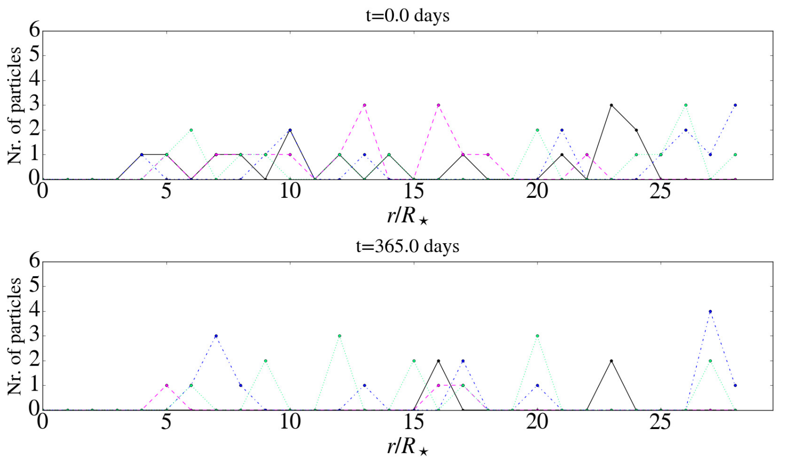

Fig. 2: Distribution of particles in the cases from Fig. 1.

provides 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, another way of adding the dust or modifying the forces acting on the grains can be defined. In the shown examples,

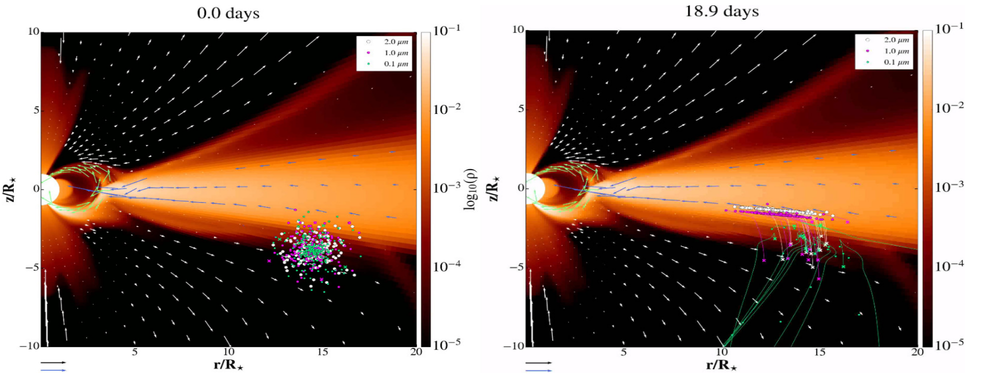

Fig. 3: Trajectories of three kinds of particles initially distributed on the circular trajectories, computed with DUSTER.

disk is transparent for the radiation. With appropriate modifications one can include the disk opacity. Properties of a corona can also be separately defined.

An example of computation with DUSTER is shown on Fig. 1. Background solution is the case of Classical T Tauri Stars from Čemeljić (2019), with the disk accretion rate of the order of $10^{-9}\,\mathrm{M_\odot\,yr^{-1}}$, stellar mass $0.5\,\mathrm{M_\odot}$, radius $2\,\mathrm{R_\odot}$ and the stellar dipole magnetic field of 500 G. Star is rotating with the 20% of the breakup rotation rate. Particles with four different radii are initially randomly distributed in the disk. Their distribution after one year is plotted in a histogram. Another case, with particles of three different radii, initially positioned in a spherical "cloud" above the disk is shown in Fig. 3.

4 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. DUSTER is largely customizable: by adding the desired force of interaction, kind 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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