Dust accretion on planet formation

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Abstract

Context. Recent works have shown that accretion of dust and small bodies could play an important role on planet formation. Especially, embryos can accrete high amount of dust (Ormel & Klahr 2010).

Methods. We computed the planetary formation consistently with the evolution of dust. We coupled our planet formation model, with the coagulation/fragmentation and radial drift of dust. In addition we included the recent results on accretion rates of small bodies.

Model for the evolution of dust

Gas disk model (1+1D)

- For each distance to the central star, we derive **the vertical structure**, by solving the hydrostatic equation, the energy conservation and the diffusion for the radiative flux. The **radial profile** of the gas surface density is computed by solving the diffusion equation.

Dust disk model (1D) (Birnstiel et al. 2012)

- We compute **the evolution of dust** surface density solving an advection-diffusion equation 1D :

$$\frac{\partial \Sigma_d}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left[r \left(D_{gas}\Sigma_d \frac{\partial}{\partial r}\left(\frac{\Sigma_d}{\Sigma_g}\right) - \Sigma_d u_d \right)\right]$$

where, Σ_{dust} and Σ_{gas} are the dust and gas surface density, D_{gas} the gas diffusivity, and u_d the radial velocity.

- This model evolves also the maximum size of dust, which is computed taking into account the radial drift and the coagulation/fragmentation of dust.
- Thus this 1D model provides, the **total dust mass**, and the **maximum size of dust particles**.

Dust accretion rates

- The growth of the core is assumed to be caused by the accretion of small dust. Its growth rate can be calculated with :

$$\frac{dM_{core}}{dt} = \left(\frac{2\pi\Sigma_d R_H^2}{P_{orbital}}\right) P_{col} \ ,$$

where, Σ_{dust} is the dust surface density, R_H the Hill radius, $P_{orbital}$ the planet's orbital period, and P_{col} is the collision probability.

- The collision probability, P_{col} , is the probability for particles to be accreted by the planet:

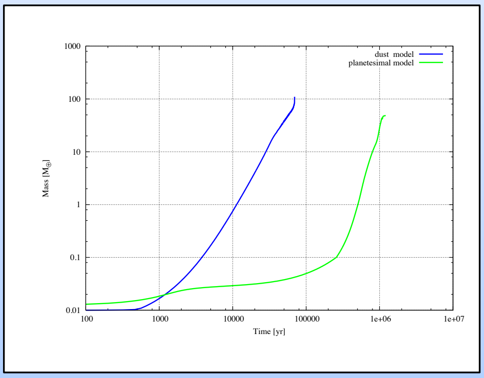
$$P_{col} = b_{col}.V_{app} \ ,$$

where, b_{col} is the impact radius and V_{app} the approach velocity of the particle.

- Ormel & Klahr 2010, derived **analytical solutions to compute the impact radius taking into account the effect of gas-drag**. Thus we can compute in a fast way the dust accretion rates by the planet.

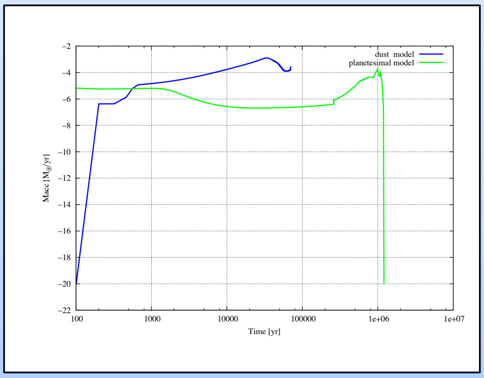
Results on planet formation

- We compute a planet using our formation model based on the classical **core accretion paradigm** but including **planet migration and disk evolution** (Alibert et al. 2005, Mordasini et al. 2012). Here the solid component of the disk is assumed to be in the form of small dust contrary to previous works.
- We present in Fig 1, the mass of the planet as a function of time. We compare this work with the planetesimal model (Fortier et al. 2013). First, to reach 10 earth masses the dust accretion model take 10^5 yr, while the planetesimal model (green line) reach 10^6. In Fig 2 we also show the accretion rates for both models which are different two order of magnitude. We stress that the collisions probabilities are computed assuming all the dust in the midplane. If the dust scale-height exceed the impact radius, the collision probability should be lower.



← Fig 1 : Mass of the planet versus time. The dust and the planetesimal accretion models are shown, respectively, with blue and green line.

Fig 2 : Solid accretion mass vs time. The color-label is the same as Fig 1. →



Discussion

We showed that the accretion of small dust can modify substantially the planet formation (Fig1). The small dust accretion rates (Fig2) are considerably higher than the usual accretion rates computed in planetesimals models and therefore decrease the growth timescales by at least on order of magnitude. The cross-over mass (~10 M_{earth}) is reached in less than 10^5 yr for the dust model, before the disk gas dissipates. Thus it should be easier to form giant planets by dust accretion. Work is under progress to obtain planet population synthesis using this dust accretion model.

Conclusions

- **We confirm that accretion dust can form efficiently gas-giant cores.**
- **Dust accretion rates accelerate considerably the planet growth timescales by at least one order of magnitude.**

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