Origins: From the Protosun to the First Steps of Life
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Interaction of solid bodies with atmospheres of protoplanets

Ernst A. Dorfi[1] **and Florian Ragossnig**[2]

[1]Institut für Astrophysik, Universität of Wien,
Türkenschanzstr. 17, A-1180 Wien, Austria
email: ernst.dorfi@univie.ac.at

[2]email: florian.ragossnig@univie.ac.at

Abstract. During the early stages of planet formation accretion of small bodies add mass to the planet and deposit their energy kinetic energy. Caused by frictional heating and/or large stagnation pressures within the dense and extended atmospheres most of the in-falling bodies get destroyed by melting or break-up before they impact on the planet's surface. The energy is added to the atmospheric layers rather than heating the planet directly. These processes can significantly alter the physical properties of protoplanets before they are exposed with their primordial atmospheres to the early stellar source when the protoplanetary disk becomes evaporated.

Keywords. solar system: formation, celestial mechanics, hydrodynamics

1. Introduction

Planets are embedded in a protostellar disk when they form. The outermost layers of their atmospheres are in direct contact with variable boundary conditions during the early phases of disk evolution. IR-observations indicate that the typical disk life-times are less than 10^7 years before the gas is evaporated. To study the time-dependent evolution of atmospheres of earth-like planets (e.g. Stökl *et al.* 2015) we perform computations in spherical symmetry, based on solutions of the equations of radiation hydrodynamics (RHD) including convective energy transport, a realistic equation of state and recent dust opacities. Such protoatmospheres are influenced by several time-dependent processes like the evaporation of the protoplanetary disk and changes of the stellar irradiation. Typical atmospheric masses are around $10^{-2}\,M_{\rm p}$ and therefore not comparable with current atmospheres of earth-like planets. Here we concentrate on the bombardment by a population of solid bodies ranging over a wide scale in mass and diameter. During the passage through the atmosphere they are heated by friction, can melt and are partially or fully eroded. Hence, depending on the initial conditions the larger bodies will reach the planetary surface and deposit their remaining kinetic energy. Smaller bodies are eroded and provide a height-dependent source of energy as well as an additional source of dust particles modifying the atmospheric properties by changing the opacity. Since the thick envelopes can insulate the hot planetary surface the cooling rate and the further evolution of the young planets are modified.

2. Results

Depending on the mass of the planet the atmospheres react on the accretion rate and the size distribution of the planetesimals. In Fig. 1 the velocities are plotted for bodies (radii between $a = 1\,\rm cm$ and $a = 100\,\rm km$) falling on a protoplanet with $M_{\rm p} = 1\,M_\oplus$. Only

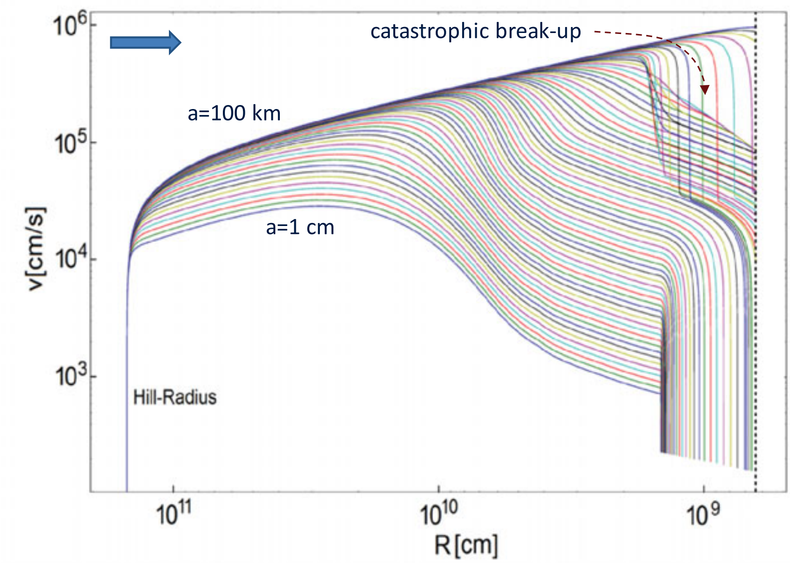

Figure 1. The inward velocity of planetesimals for initial radii between $a = 1$ cm and $a = 100$ km as a function distance R. In the case of an earth-sized planet only the most massive bodies can reach the surface (vertical dashed line) because of melting and/or break-up.

km-sized bodies are able to impact on the surface of the planet (plotted as vertical dashed line) thereby heating the surface by deposition of their remaining kinetic energy. Since all accreted bodies are orbiting the protosun, we can use the escape velocity as initial inward velocity at the Hill-radius. The motion is controlled by friction, heating and ongoing evaporation. If the stagnation pressure becomes comparable to the material strength, a simple break-up model is included which cuts in half the mass of a planetesimal (as seen in upper right corner of Fig. 1). At these stages only rather solid planetesimals above 1 km size can reach the surface, all other will deposit their kinetic energy well above the planet. Solid bodies of sizes up 10 km are stopped or melt by frictional dissipation and explode into smaller fragments during their flight. The larger the mass of the planetary body the better the accreted bodies get stopped in the dense and extended atmospheres of these newly born protoplanets.

3. Conclusions

As shown by the computations a significant amount of gravitational energy is indeed dissipated into the atmosphere (especially for larger planetary cores) which consequently can not contribute to the atmospheric planetary luminosity. Furthermore, we examine that planetesimal infall-events for cores with $M_{\rm p} \geqslant 2\,M_{\oplus}$ actually result in a local cooling of the atmosphere which is totally in contradiction with the classical model. More details (and references therein) of these computations are published in Ragossnig *et al.* (2018).

References

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