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Time-Dependent Simulations of the Formation and Evolution of Disk-Accreted Atmospheres Around Terrestrial Planets

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In the early, embedded phase of evolution of terrestrial planets, the planetary core accumulates gas from the circumstellar disk into a planetary envelope. This atmosphere is very significant for the further thermal evolution of the planet by forming an insulation around the rocky core. The disk-captured envelope is also the staring point for the atmospheric evolution where the atmosphere is modified by outgassing from the planetary core and atmospheric mass loss once the planet is exposed to the radiation field of the host star. The final amount of persistent atmosphere around the evolved planet very much characterizes the planet and is a key criterion for habitability.

The established way to study disk accumulated atmospheres are hydrostatic models, even though in many cases the assumption of stationarity is unlikely to be fulfilled. We present, for the first time, time-dependent radiation hydrodynamics simulations of the accumulation process and the interaction between the disk-nebula gas and the planetary core. The calculations were performed with the TAPIR-Code (short for The adaptive, implicit RHD-Code) in spherical symmetry solving the equations of hydrodynamics, gray radiative transport, and convective energy transport. The models range from the surface of the solid core up to the Hill radius where the planetary envelope merges into the surrounding protoplanetary disk.

Our results show that the time-scale of gas capturing and atmospheric growth strongly depends on the mass of the solid core. The amount of atmosphere accumulated during the lifetime of the protoplanetary disk (typically a few Myr) varies accordingly with the mass of the planet. Thus, a core with Mars-mass will end up with about 10 bar of atmosphere while for an Earth-mass core, the surface pressure reaches several 1000 bar. Even larger planets with several Earth masses quickly capture massive envelopes which in turn become gravitationally unstable leading to runaway accretion and the eventual formation of a gas planet.