Molecular imprint of dust evolution in protoplanetary disks

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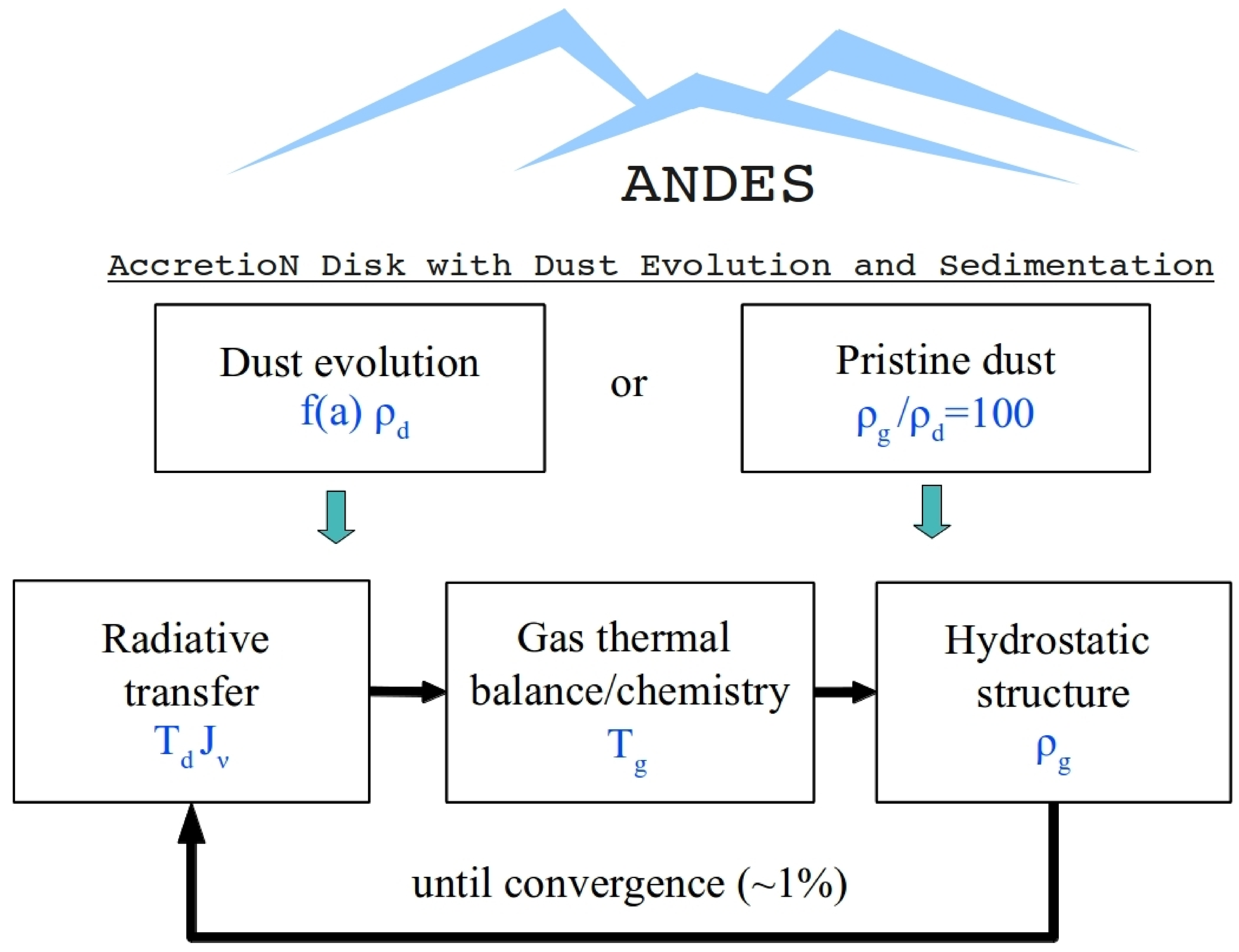
Introduction

Evolution of sub-micron grains is an essential process during early stages of planet formation. The impact of dust growth and sedimentation toward the midplane manifests directly in a spectral energy distribution. At the same time dust evolution may strongly affect gas, a factor of 100 more massive disk component, and may be traced with molecular line observations. To study dust evolution impact on the disk structure we perform protoplanetary disk modeling by means of the ANDES code ("AccretioN disk with Dust Evolution and Sedimentation").

Model components

ANDES includes [1]:
– a 1+1D frequency-dependent continuum radiative transfer module;
– a module to calculate the chemical evolution using an extended gas–grain network with UV/X-ray-driven processes and surface reactions;
– a module to calculate the gas thermal energy balance;
– a 1+1D module that simulates dust evolution and computes size distribution of grains affected by the coagulation, fragmentation and sedimentation processes.

Such a set of the considered physical processes allow deriving the impact of dust to gas component. We consider two cases: **Model E** with dust grains after 2 Myr of evolution and a fiducial **Model A**, where pristine monodisperse dust grains (0.1μm) are mixed with gas with proportion 1:100.



Dust evolution impact on the disk structure

Grain growth and sedimentation affect both dust and gas thermal structures (Fig. 1). Higher dust temperatures at the disk surface in the evolved dust model are explained by the not-settled population of small dust grains. Gas temperature differences arise from the reduced abundance of grains in disk atmosphere in Model E due to the dust sedimentation and correspondingly reduced photoelectric heating.
The absolute chemical abundances of the majority of species show a noticeable increase in column densities (up to 1-3 orders) in evolved dust model (Fig. 2). Such a general trend is explained by the sedimentation-driven shift of the warm molecular layer toward the midplane with higher densities.

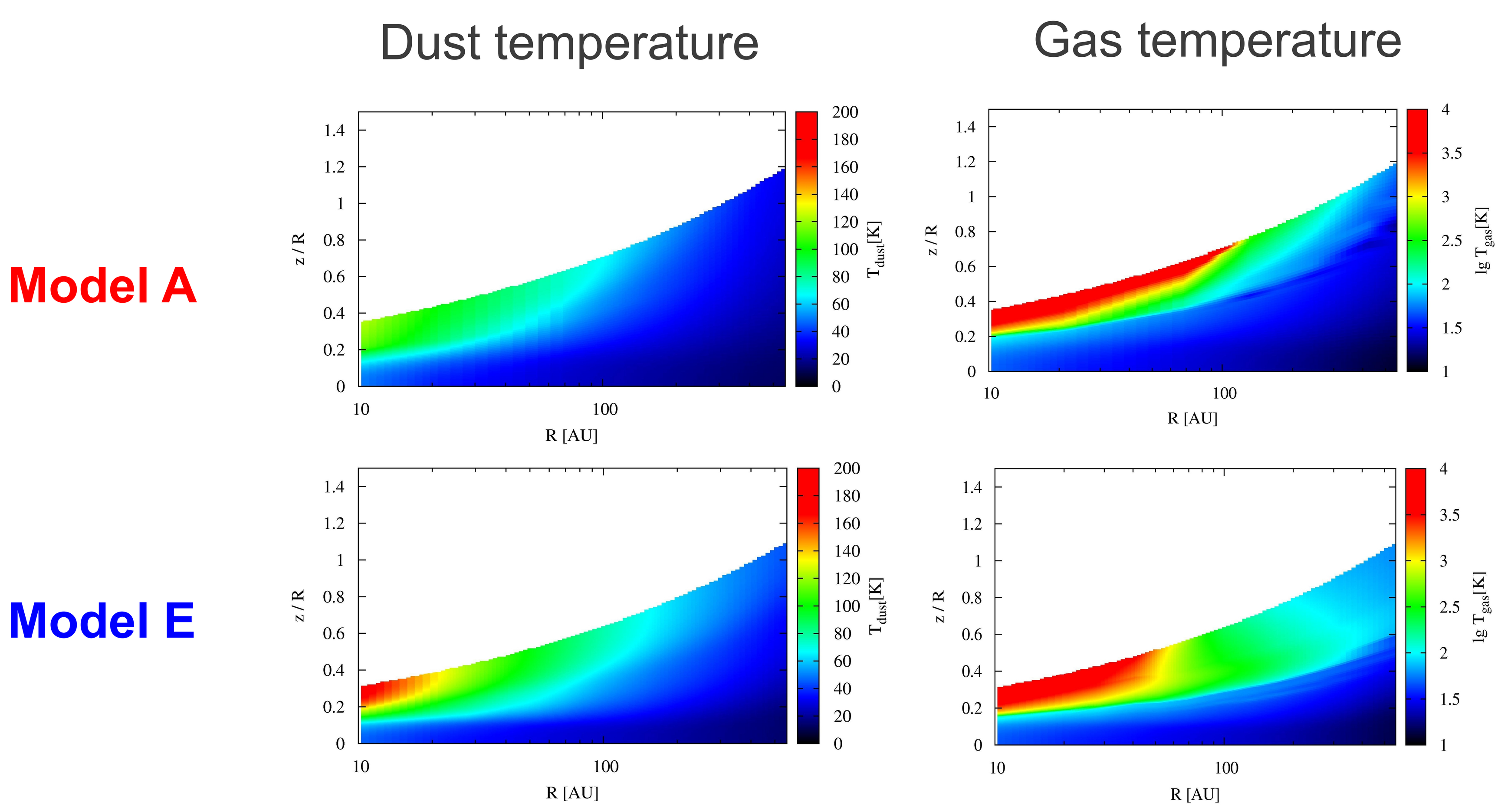


Fig. 1. Dust and gas temperature distributions for evolved (E) and pristine (A) dust.

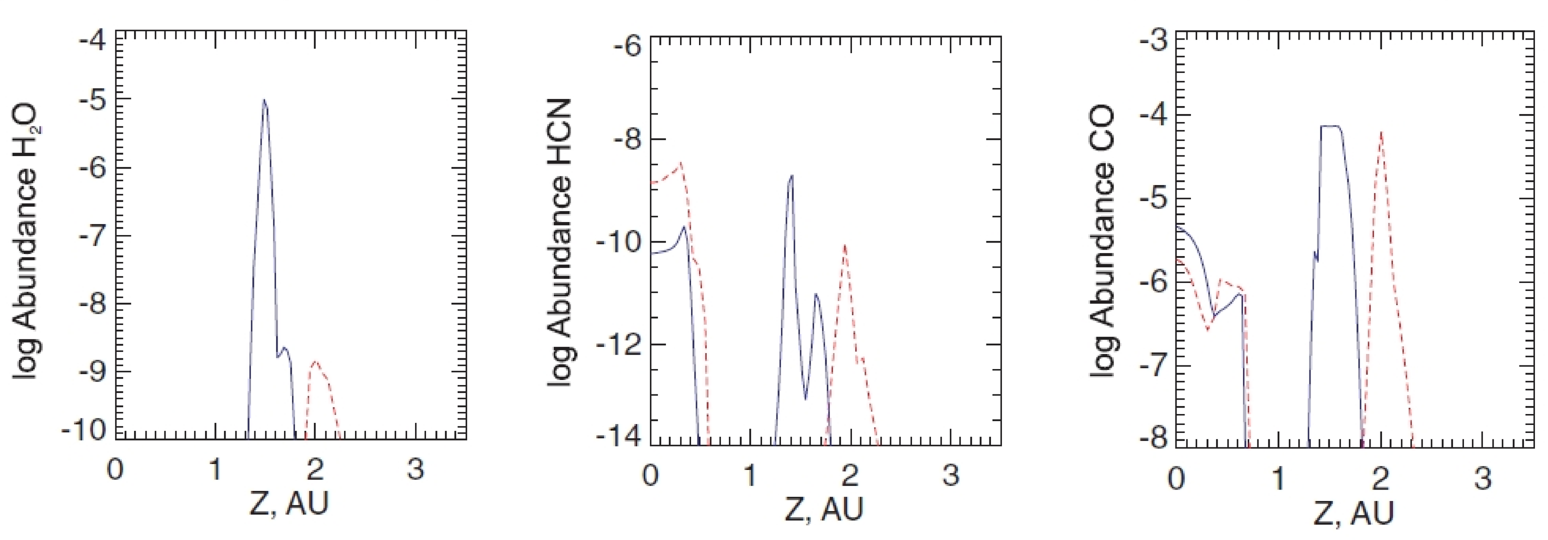


Fig. 2.Vertical abundance distributions of H_2O, HCN and CO at 10 AU for evolved (blue) and pristine (red) dust.

DM Tau disk modeling

As a next step to observational data interpretation we perform simulations of DM Tau disk along with the line radiation transfer for HCO+(3-2) molecule. Disk physical and chemical structure is computed with the ANDES code for the evolved dust case (2 Myr, Fig. 3), while the line radiation transfer is based on the URANIA code ([2], Fig. 4). HCO+ emission shows ring and cone-like patterns similar to the CO emission recently observed by ALMA [3, 4].

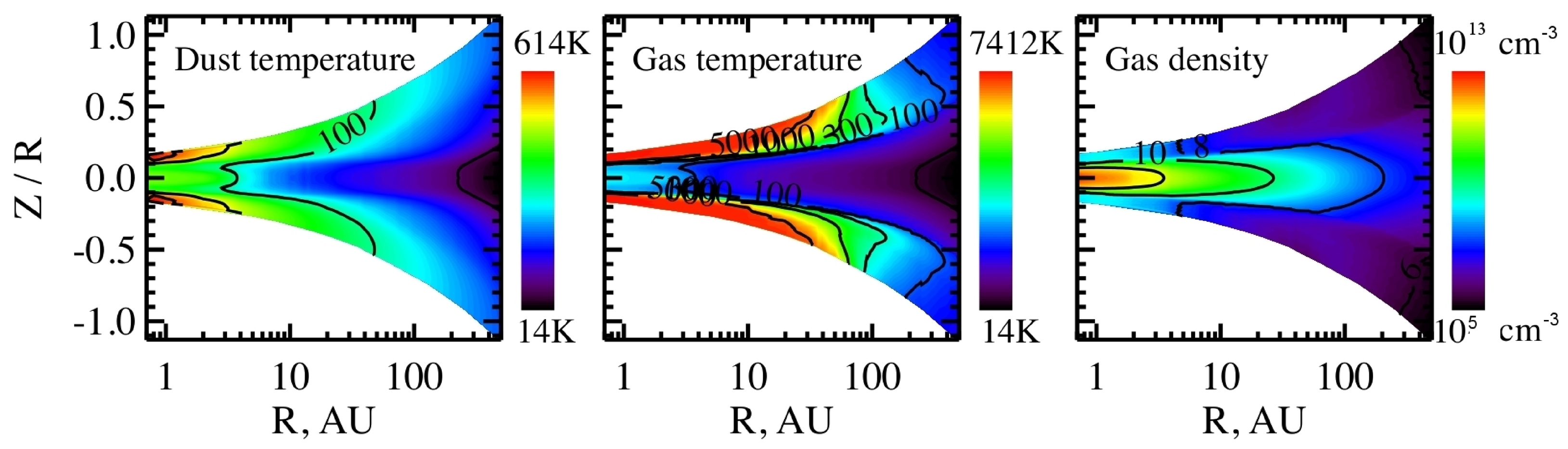


Fig. 3. Physical structure of DM Tau disk as calculated with the ANDES thermochemical model.

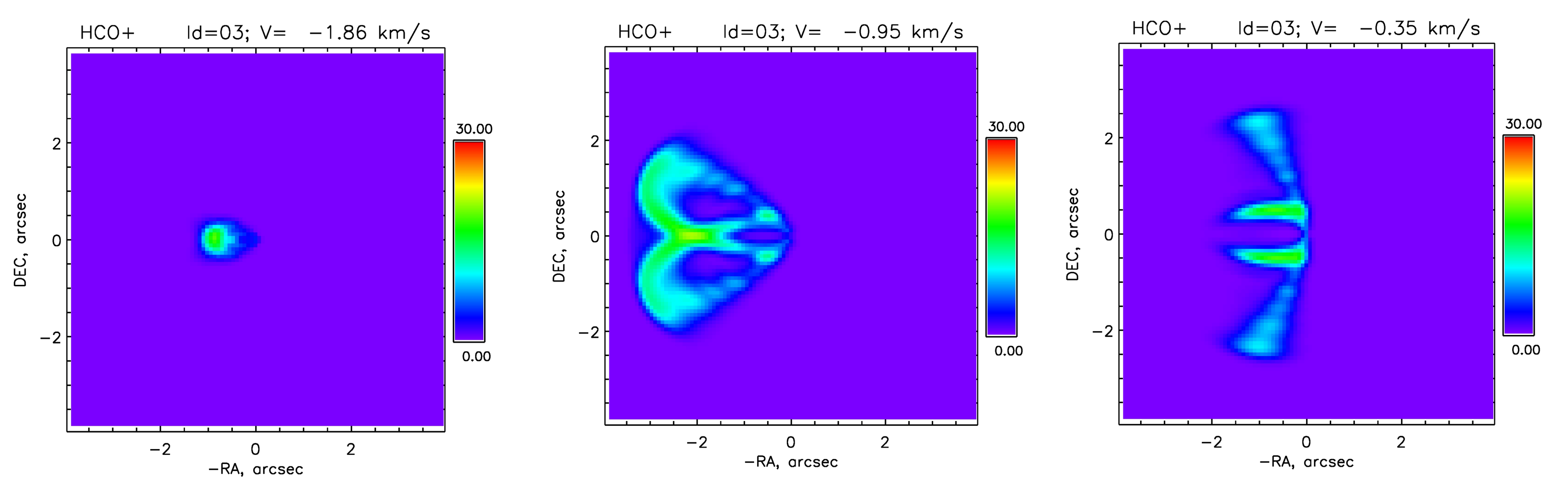


Fig. 4. Channel velocity maps for HCO+ (3-2) molecule at V= -1.86, -0.95 and -0.35 km/s. Disk inclination is 30°.

References

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