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Radiation hydrodynamics of protoplanetary disks with frequency-dependent dust opacities

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In protoplanetary disks of gas and dust, sub-micron interstellar grains must grow at least 13 orders of magnitude in size to become terrestrial planets. The frequency-dependent opacities of these silicate grains to pre-main-sequence stellar radiation affect the thermodynamic structure of the disk, which itself influences the various stages of planet formation and migration. With a reduced overall opacity skewed toward shorter wavelengths, the tenuous disk atmosphere heats up as dust preferentially absorbs ultraviolet rays from the young star, while settled grains make the disk midplane optically thick and cooler. Conventional disk and planet formation models, however, use simplified assumptions about the thermodynamic structure, including vertically isothermal temperature profiles, Planck- or Rosseland-mean dust opacities, and flux-limited-diffusion approximations to radiation transport valid only in optically thick regions. Thus, further development of more detailed and self-consistent disk profiles using multifrequency radiation hydrodynamics is warranted. We use the Athena++ finite-volume hydrodynamics code, extended with multigroup radiation transport, to develop and analyze new stellar-irradiated disk models that include the frequency-dependent opacities of silicate dust grains. As the radiation module neither assumes a diffusion-dominated limit nor treats the radiation field as another fluid, our models can better capture the full dynamic range in disk optical depths.