# The astrophysical indication by resolving anomalously low spectral indices

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The Kepler space mission has demonstrated that rocky planets of 1-10 earth masses are commonly found around solar-like stars. “What is the dust mass budget in protoplanetary disks?”, and “How do the micron-sized interstellar dust grains coagulate to eventually form 1-1000 km sized planetesimals and planetary embryos?” are two outstanding astrophysical questions toward the understanding of our own origin.

Dust temperatures in protoplanetary disks are typically 10-20 Kelvin, at which the black-body radiation peaks at submillimeter wavelengths. Thus, observations with the Atacama Large Millimeter/submillimeter Array (ALMA) have been widely used to constrain dust masses and sizes in protoplanetary disks.

In this presentation, I will outline an important radiative transfer effect: when dust grains grow to 100-300 micron in size, and if dust grains are compact (i.e., morphologically similar to icy droplets rather than snowflakes), the scattering opacity of dust becomes considerably higher than the absorption opacity. In addition, the ratio of scattering to absorption opacities rapidly decreases with increasing wavelengths at millimeter and submillimeter bands. Under such circumstances, the (sub)millimeter emission from disks is largely attenuated, and the spectral energy distribution is skewed toward long wavelengths. This is analogous to observing the Sun during sunset. As a consequence of overlooking these physics, previous works likely systematically underestimated dust masses by 1-2 orders of magnitude, and systematically overestimated dust sizes by 2-3 orders of magnitude. These effects have been unambiguously demonstrated by analyzing multi-wavelength, high-resolution ALMA observations of the nearest protoplanetary disk, TW Hya, and by performing 3D Monte-Carlo radiative transfer simulations. We concluded that the maximum grain sizes in protoplanetary disks may be on the order of 100 microns. We infer that grain growth may not be as efficient as how people used to consider, which is coherent with the updating laboratory measurements of the stickiness of water-ice-coated dust and bare silicates.

Keywords: protoplanetary disk, dust growth