Simulating Early Dust Evolution in Protostellar Systems: A Radiation-MHD Framework

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Dust grains are essential to the star- and planet-forming processes, influencing their evolution by regulating gas cooling, enabling molecular chemistry, and seeding planet formation. They are well known to grow to millimeter or even centimeter sizes in Class II protoplanetary disks. Moreover, protoplanets have been directly detected in this phase, providing compelling evidence that planet formation may begin earlier than previously thought. While previous (sub)millimeter interferometric observations have revealed tentative signs of grain growth even in Class 0/I protostellar envelopes, the timing, location, and physical environments in which growth occurs during the earliest evolutionary phase remain uncertain.

To better understand the conditions under which grain growth proceeds during protostellar collapse and how this growth manifests in observations, we combine magnetohydrodynamic (MHD) simulations and radiative transfer modeling. We perform MHD core collapse simulations using the RAMSES code, forming an embedded protostar and a surrounding envelope in a magnetized core. Since the physical conditions evolve during the collapse, we also track grain growth using a new dust evolution model COALA, which includes both coagulation and fragmentation and computes time-dependent grain size distributions across the simulation domain. We then post-process these simulation outputs using the radiative transfer codes RADMC-3D and POLARIS to generate synthetic continuum maps and polarization signatures at (sub)millimeter wavelengths. In addition, we implement various dust populations, such as compact silicate grains, aggregates, and icy mantles, to explore how different grain properties affect the resulting observables.

This comprehensive modeling framework helps reveal how grain properties, shaped during the initial evolutionary phases, translate into observable features, enabling better constraints on grain growth in protostellar environments. In this presentation, we will introduce our modeling framework and present preliminary results, highlighting their implications for early dust evolution.

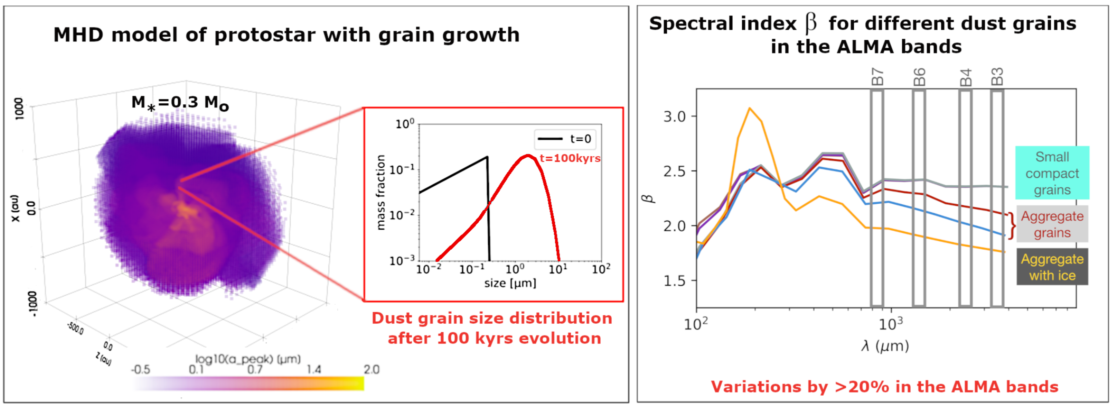

Figure 1: *(Left)* MHD simulation of a protostellar system. Color shows the peak grain size, with warmer colors indicating larger grains. *(Right)* Dust emissivity index β as a function of wavelength for various dust grain models. Shaded regions indicate ALMA Bands, where differences between the models exceed 20%.