## Models of dust evolution in the disk-building stage





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maxime.lombart@cea.fr Need realistic dust growth and fragmentation MHD simulations in 3D hydrodynamics simulations Radiative Synthetic Realistic dust observations transfer model fragmentation growth distribution 3 orders of magnitude in size  $(1 \mu m - 1 m m)$ Dullemond et al., 2012 ⇔ 9 orders in mass **RAMSES** +COALA **CASA**  Size discretization +THEMIS 2.0 **POLARIS** ~ 20 size bins Reissl et al., 2016 (low numerical cost) size ~ 1mm ~ 1µm **Numerical requirements Dust size evolution** Full process for characterizing Synthetic observations model the dust evolution during the disk-building stage Code COALA Optical properties How early do pebbles form Solve conservative form of the Computation of optical properties by discrete dipole approximation growth and fragmentation equations around YSOs? with the code ADDA (Yurkin &  $\frac{\partial g(m,t)}{\partial t} + \frac{\partial F[g](m,t)}{\partial t} = 0$ Hoekstra 2011) additive kernel:  $K(m_1, m_2) = m_1 + m_2$ --- 1.1 μm Agg. ISM CLOUD **PROTOSTAR**  1.1 μm Compact sph 0.1 μm aSil sphere emissivity < 100 kyrs 2.50 What are the dust 0.1 μm aCH sphere index for Benchmarking properties in for growth monomers protostellar environments? aggregates Size? constant kernel: K = 1Shape? <u>6</u> 10° Composition?  $\bullet$   $\beta$  varies with grain  $\frac{15}{5}$   $10^{-2}$ Benchmarking for <u>is</u> 10−3 fragmentation porosity **PLANETS** DISK redits: Bill Saxton, NSF/AUI/NRAO Up to 20% of difference Coala, order 3, N = 20,  $t_{final}$ in range of wavelengths **PEBBLES** project: 0.1 - 1 mm Characterizing dust properties in protostars with **Dust growth and** new observations and new dust models Up to 10% of difference fragmentation in 3D in range of wavelengths hydrodynamics 1 - 3 mm simulations 3D MHD model of B335-like Ysard et al., 2024 protostar (Maury+2018) **THEMIS** with grain growth Dust growth in The Heterogeneous dust Evolution Model for Interstellar Solids **Dust model** RAMSES + COALA protostellar collapse Need realistic dust optical properties for micrometer aggregates Density (g / cc) -14.9 -13.9 -12.8 -11.7 amorphous carbon amorphous silicate core + carbon mantle hydrogenated a-CH Mass of grains in the envelope Monomers ~0.1µm (in % of total dust mass) Initially (MRN distribution):  $\bullet$  ~ 0.25 µm  $\to$  20% After 100 kyrs: Aggregates ~1µm  $\bullet$  ~ 0,25 µm  $\to$  13%

**PEBBLES** project aims to characterize dust properties to determine how large grain can be in protostellar envelope. New models are developed based on 3D MHD models of protostellar collapse with dust evolution associated with realistic optical properties.

Lombart, M. et al., 2025 (submitted A&A) Carpine, M.-A. et al., A&A, 698, A200, 2025 Lombart, M. et al., MNRAS, 533, 2024 Lombart, M. et al., MNRAS, 517, 2022

Lombart, M., Laibe, G., MNRAS, 501, 2021

aggregate



size [µm]

compact sphere