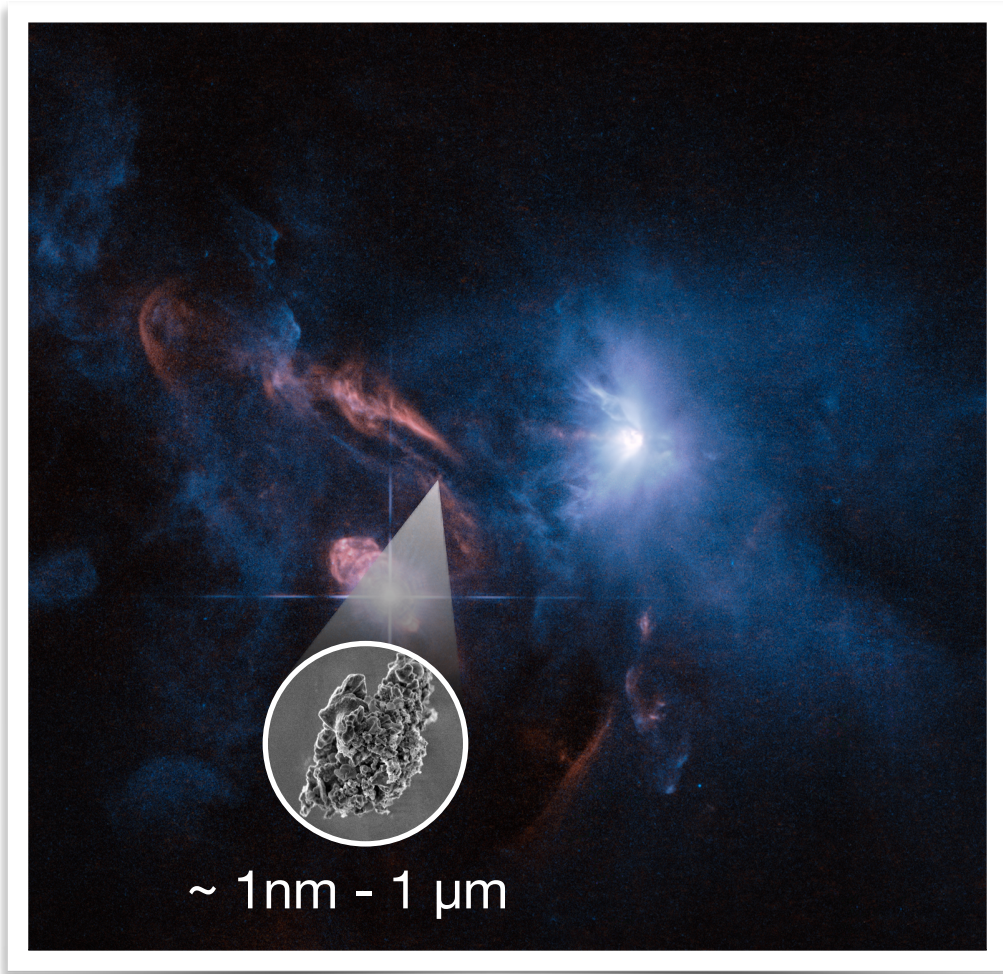


Dust evolution in 3D simulations of protostellar collapse

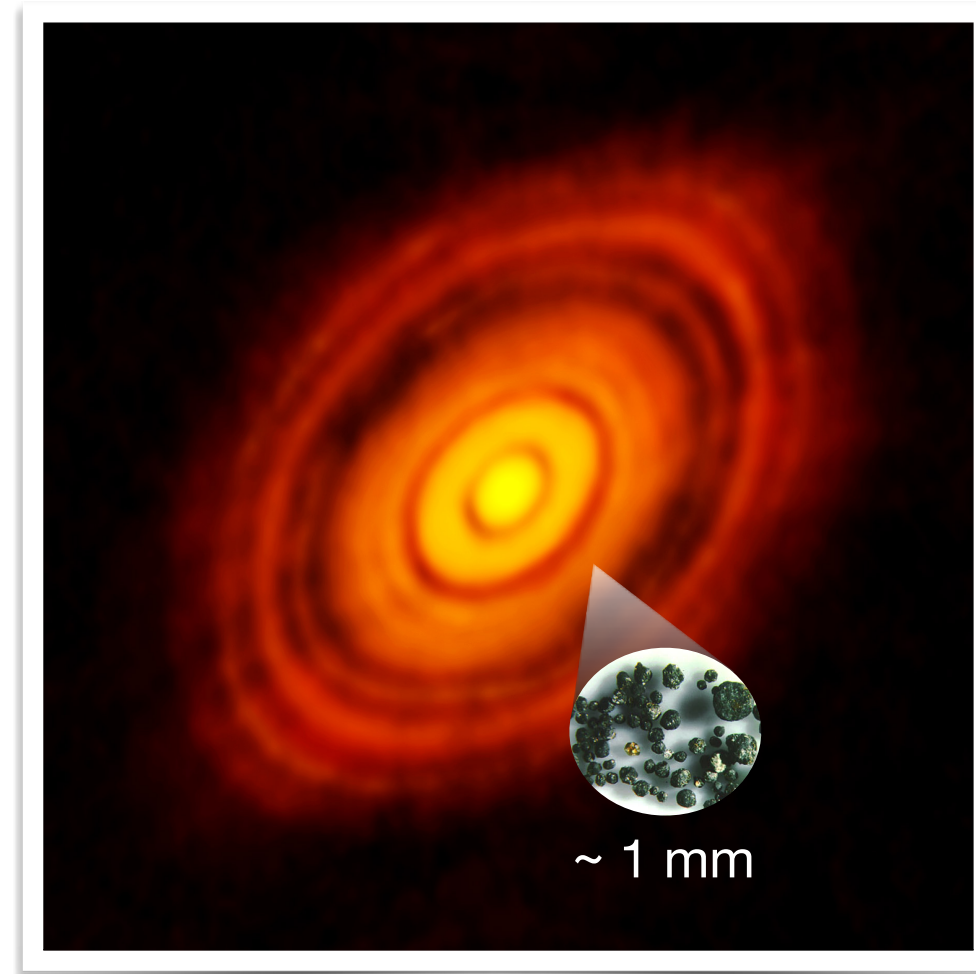


Maxime Lombart¹, Ugo Lebreuilly¹, Anaëlle Maury^{2,3,1}
maxime.lombart@cea.fr

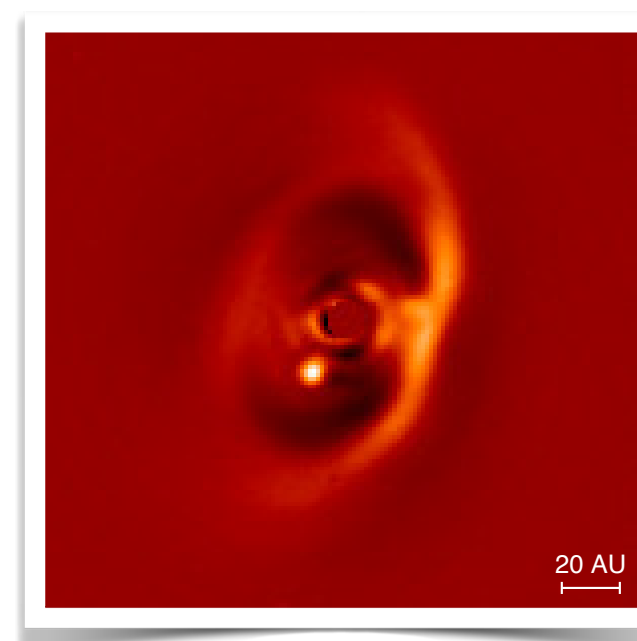
How can microscopic dust grains grow to form planet in less than 1 Myr ?



Taurus molecular cloud



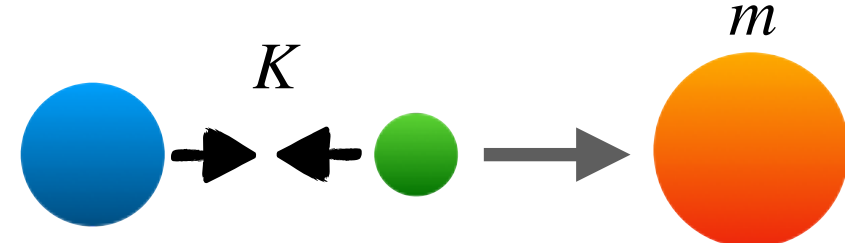
HL Tau



PDS 70

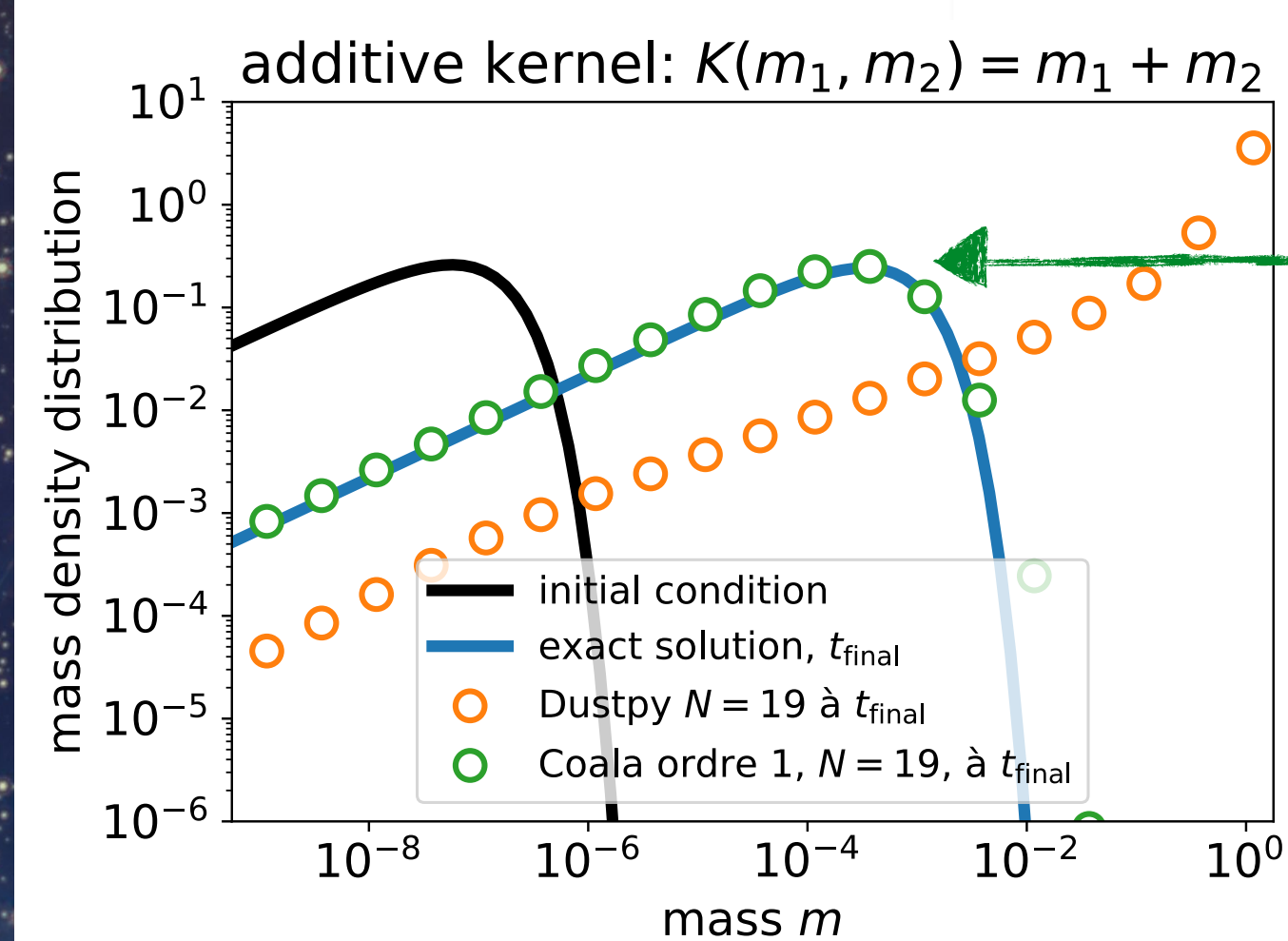
Goal

Coagulation



$$F[g](m, t) \equiv \int_0^m \int_{m-m_1}^{\infty} \frac{K(m_1, m_2)}{m_2} g(m_1, t) g(m_2, t) dm_2 dm_1$$

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



COALA vs DustPy

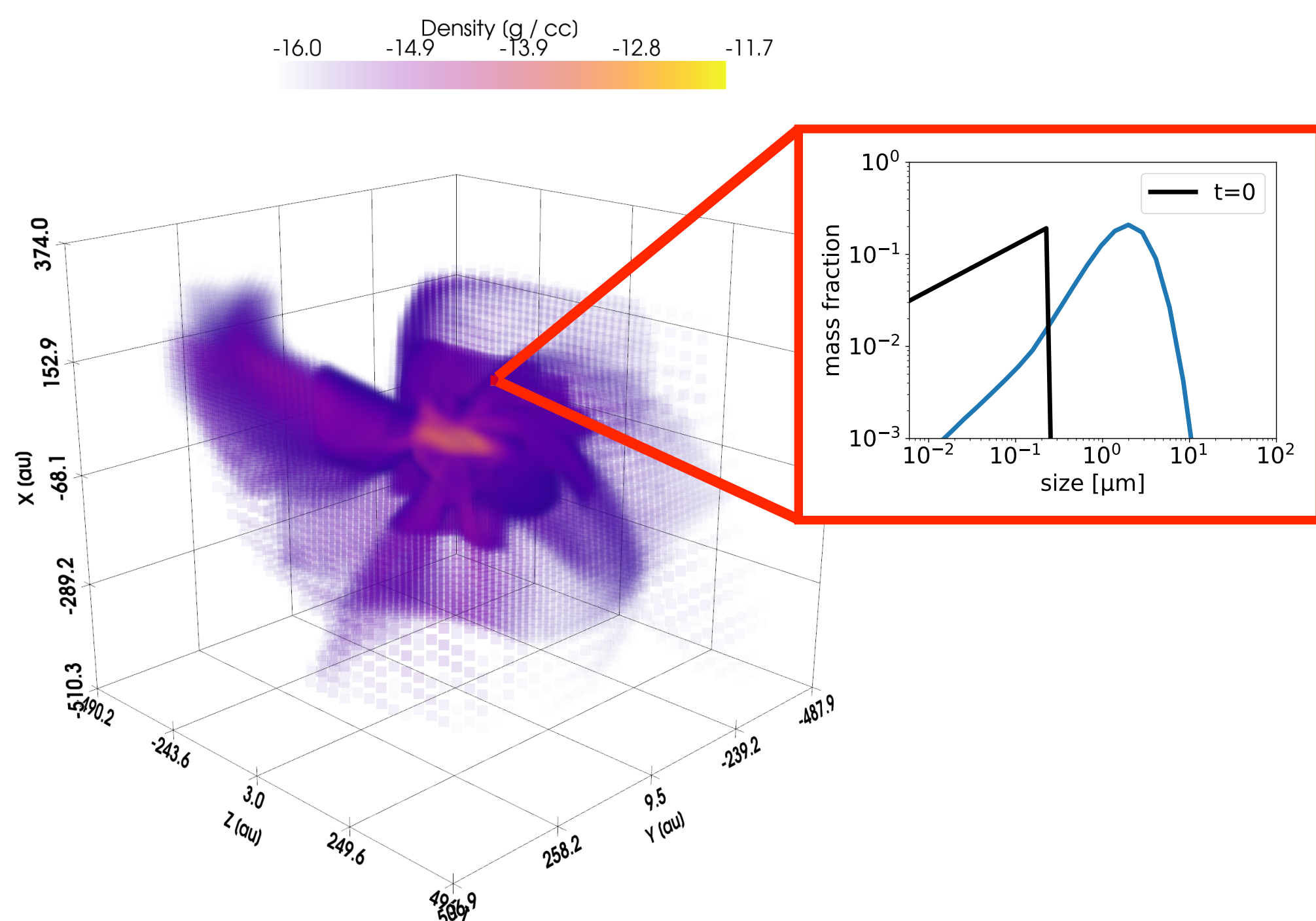
Numerical requirements

Dust coagulation in 3D hydrodynamics simulations

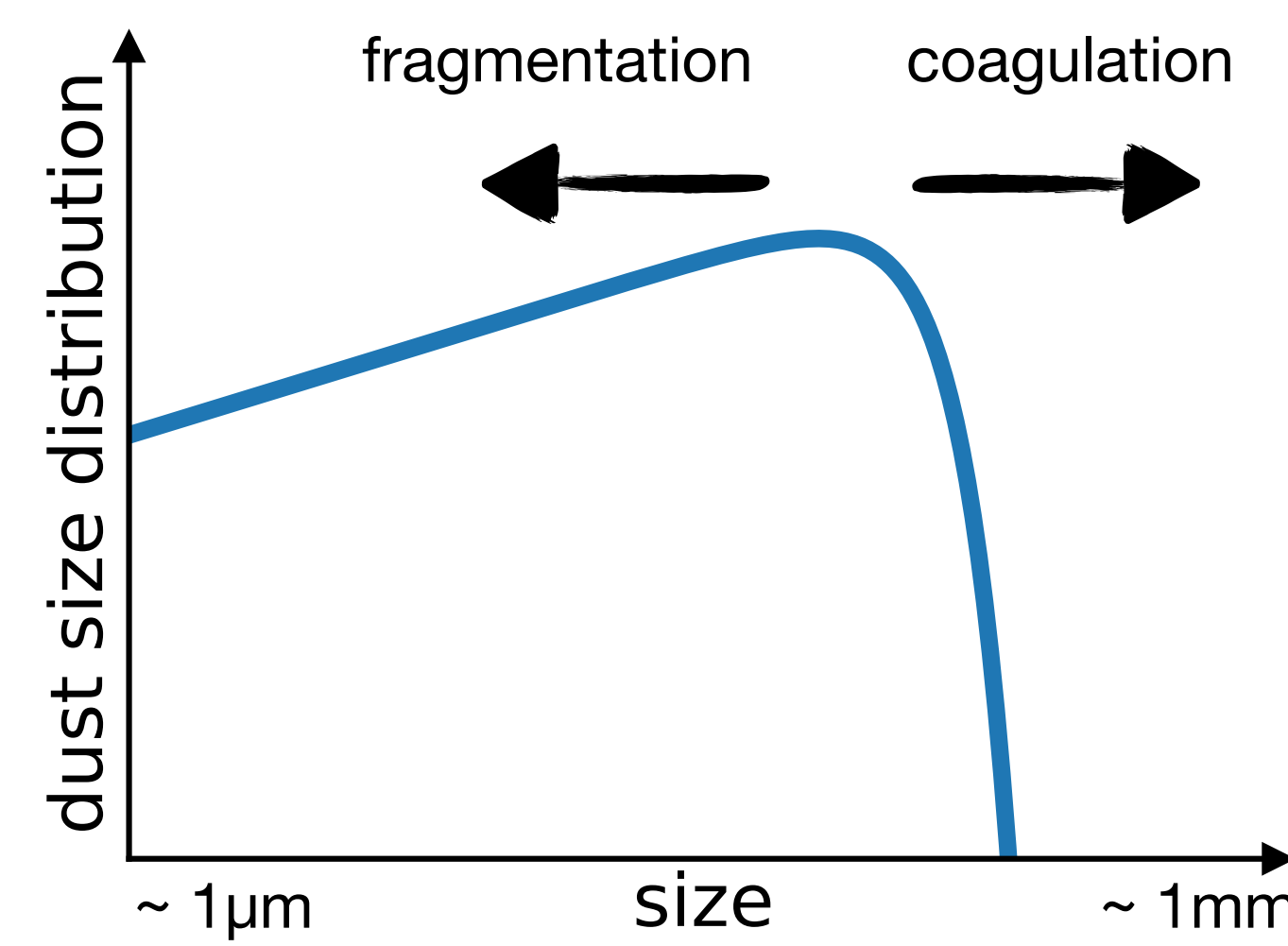
RAMSES + COALA

Dust growth in protostellar collapse

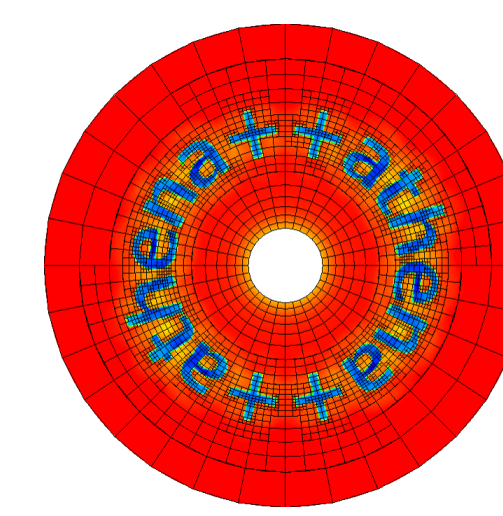
3D MHD model of B335-like protostar (Maury+2018) with grain growth
 Gas + dust dynamics (40 sizes)



Requirements for dust coagulation and fragmentation in 3D hydrodynamics codes:



- 3 orders of magnitude in size (1 μm - 1 mm)
 $\Leftrightarrow$ 9 orders in mass
- Size discretization $\rightarrow$ ~ 20 size bins (low numerical cost)

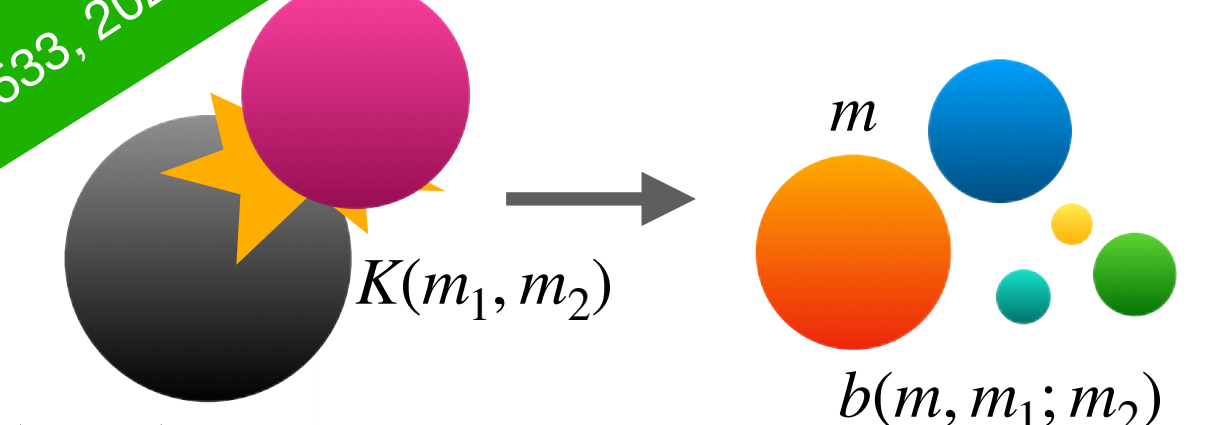


RAMSES
FARGO3D

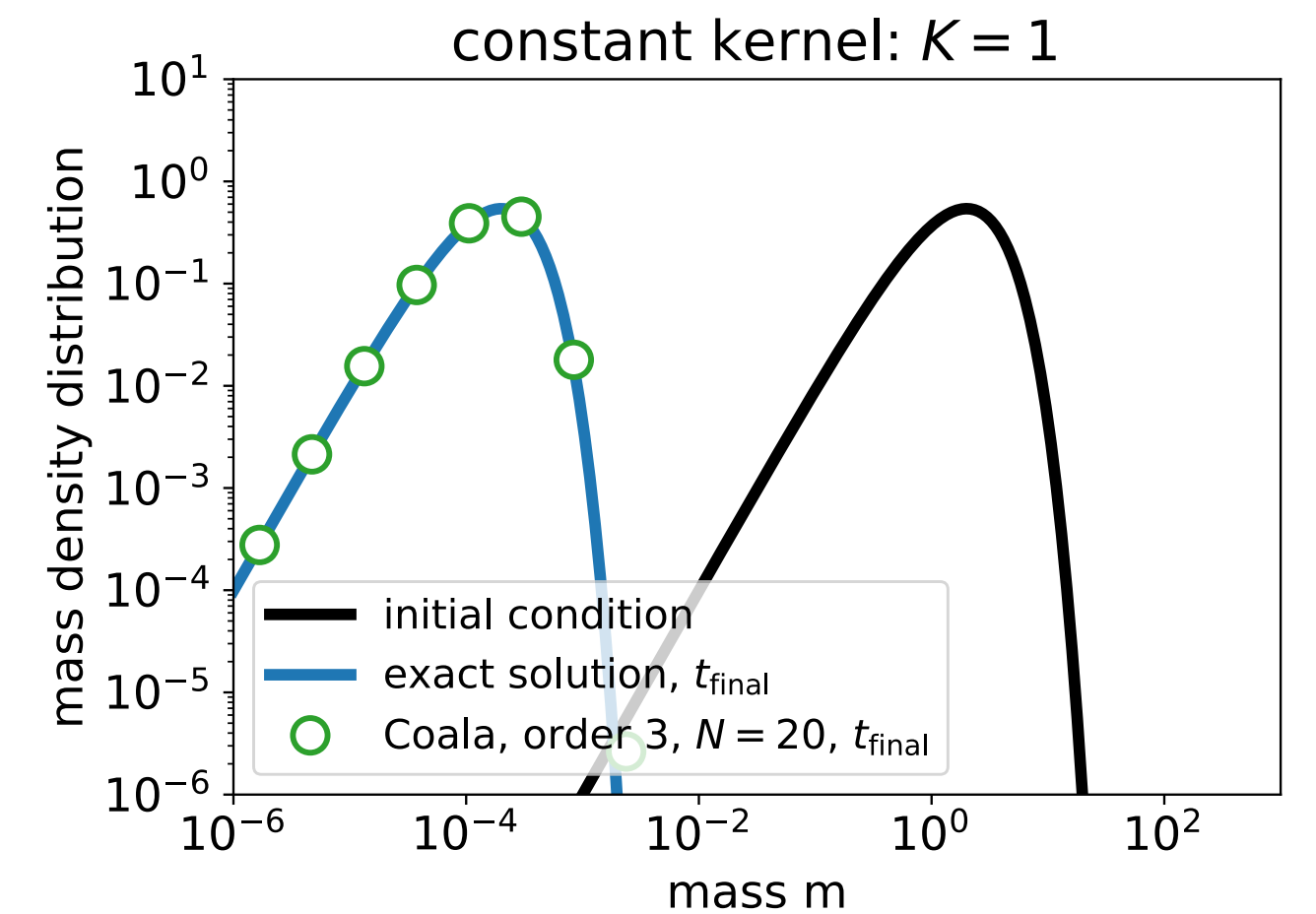
Numerical challenge

Collisional fragmentation

Lombart, M. et al., MNRAS, 533, 2024

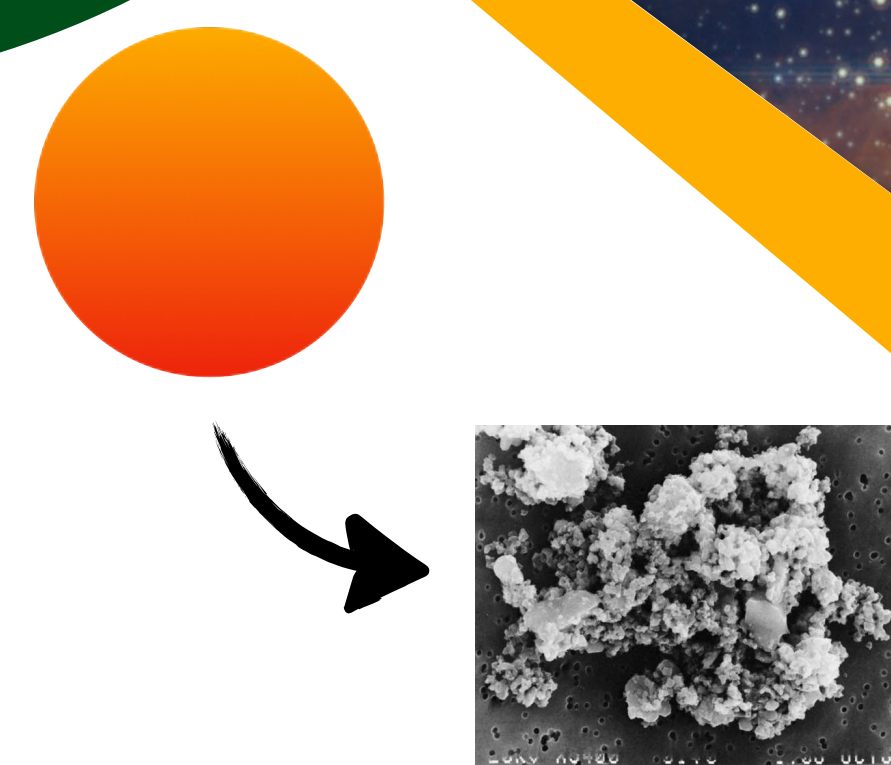


$$F[g](m, t) \equiv \int_0^m \int_{m-m_1}^{\infty} \frac{K(m_1, m_2)}{m_2} g(m_1, t) g(m_2, t) dm_2 dm_1 - \frac{1}{2} \int_0^m \int_0^{m_1} \int_0^{m_1-m_2} \frac{m_{frag}}{m_1 m_2} b(m_{frag}, m_1, m_2) K(m_1, m_2) g(m_1, t) g(m_2, t) dm_2 dm_1 dm_{frag}$$



Numerical requirements

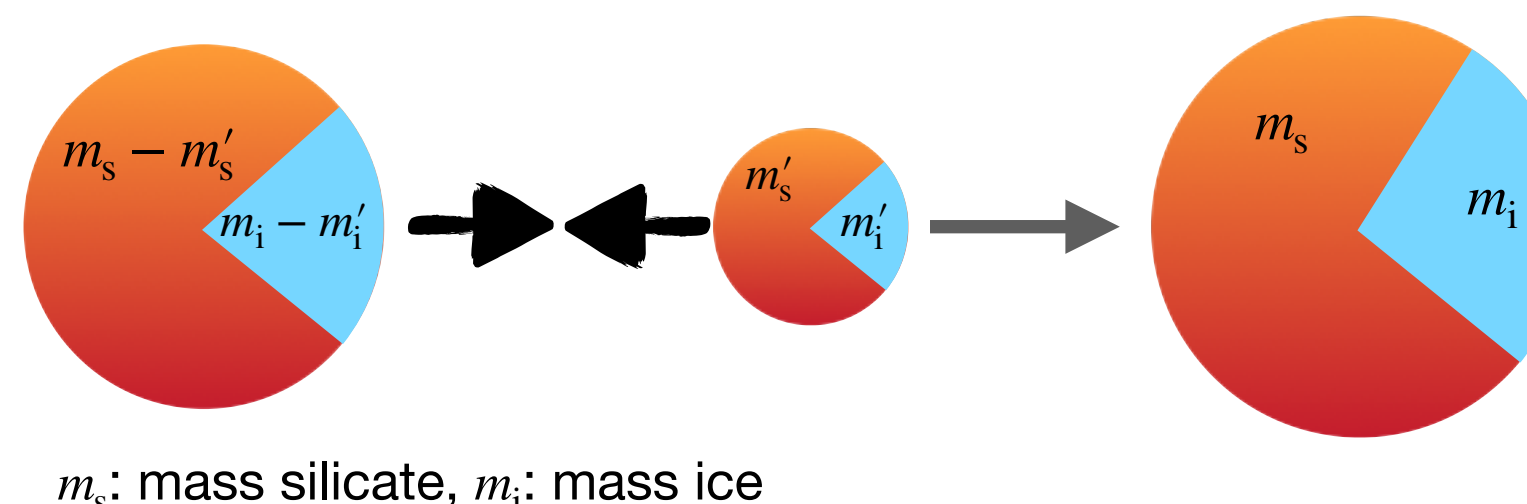
Dust fragmentation in 3D hydrodynamics simulations



Growth and fragmentation of multi-component dust aggregates

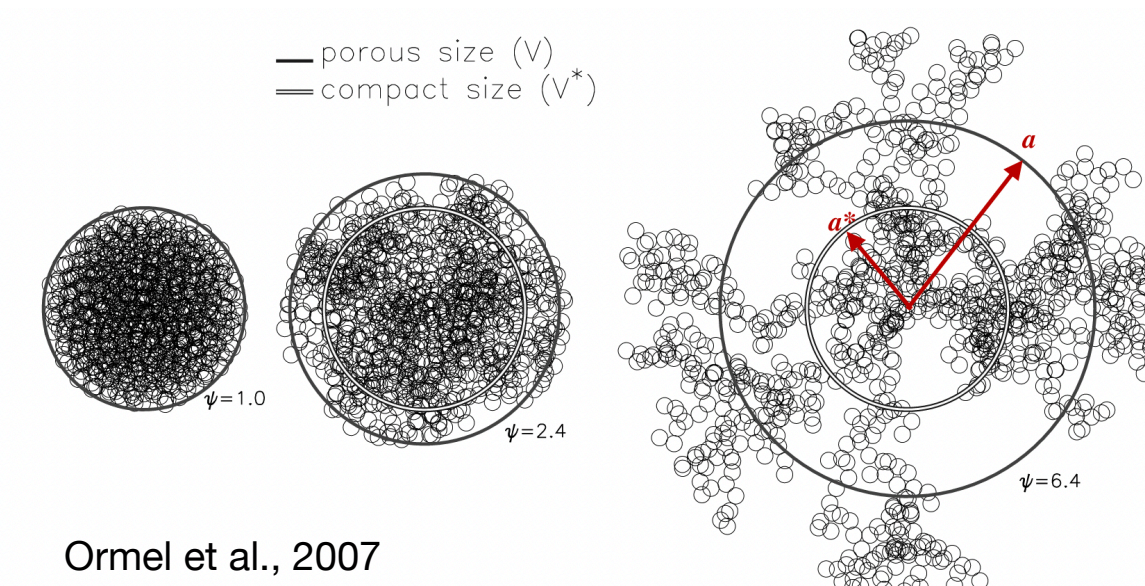
Improved dust model

Multi-component dust



m_s : mass silicate, m_i : mass ice

Dust aggregates defined by mass and porosity



Ormel et al., 2007

Need 2D coagulation and fragmentation equations

COALA + data from lab experiments

COALA treats efficiently polydisperse dust coagulation/fragmentation.
 RAMSES MHD models now include dust evolution with COALA. This new code is well designed to include more realistic dust model.

Lombart, M. et al., MNRAS, 533, 2024
 Lebreuilly, U. et al. (incl. Lombart, M.), MNRAS, 518, 2023
 Lombart, M. et al., MNRAS, 517, 2022
 Laibe, G., Lombart, M., MNRAS, 510, 2022
 Lombart, M., Laibe, G., MNRAS, 501, 2021

