Image credit: NASA/JPL-Caltech

CHANGING PARADIGMS IN PLANET FORMATION THEORY

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MPS
MAX PLANCK INSTITUTE
FOR SOLAR SYSTEM RESEARCH

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THE SOLAR SYSTEM

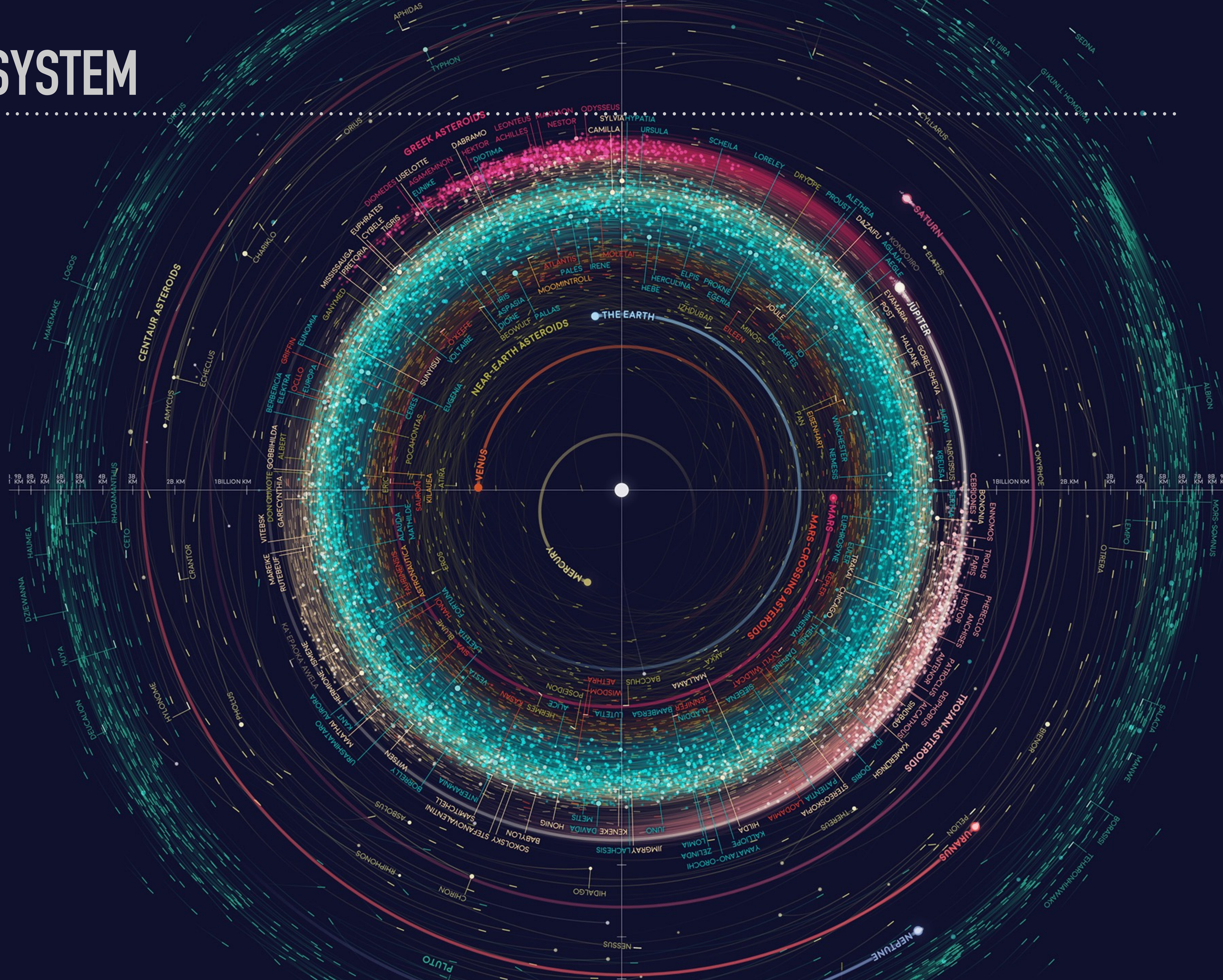
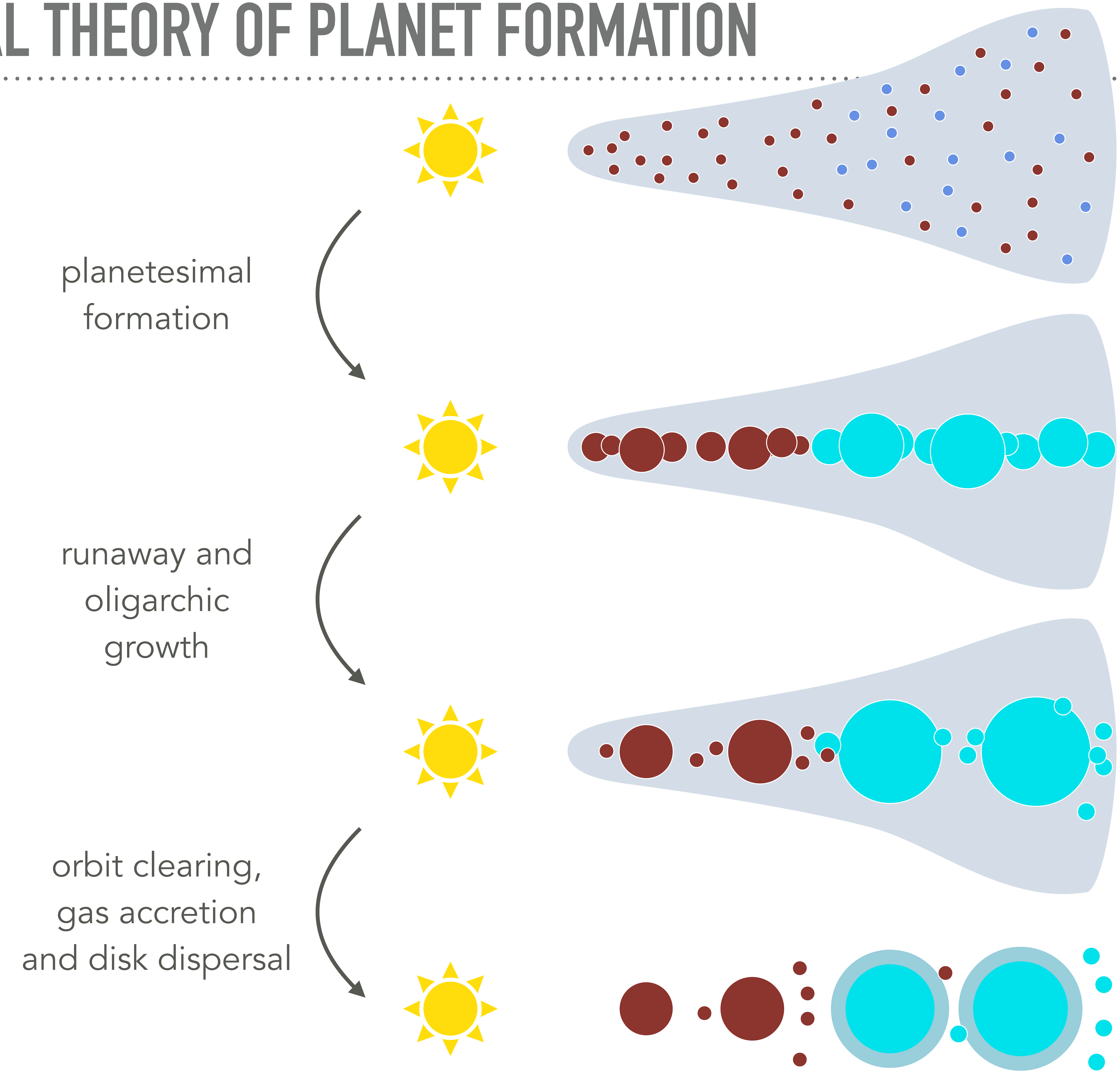


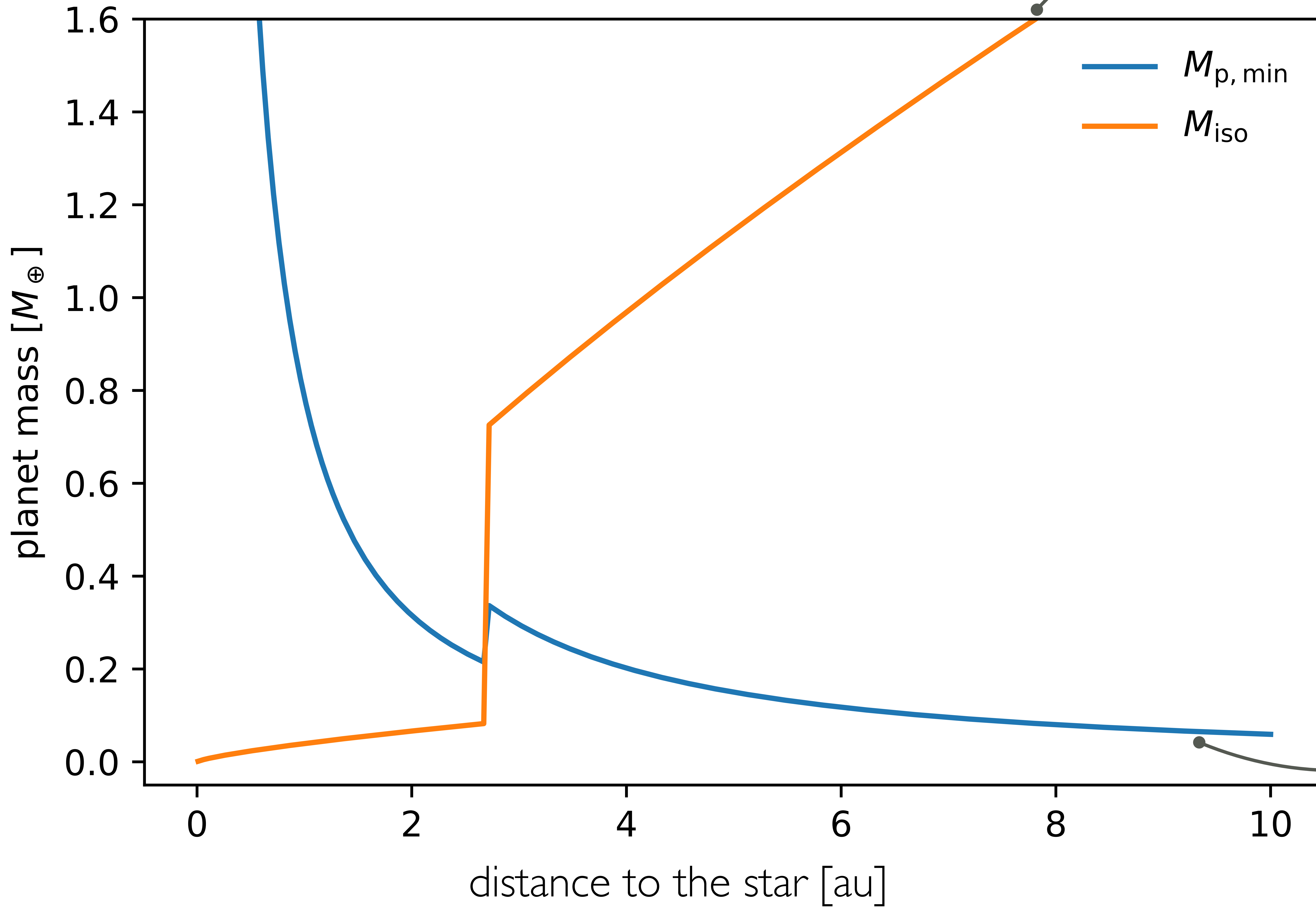
Image credit:
Eleanor Lutz

THE CLASSICAL THEORY OF PLANET FORMATION



THE GAS-RICH PLANETS FORM OUTSIDE OF THE SNOW LINE

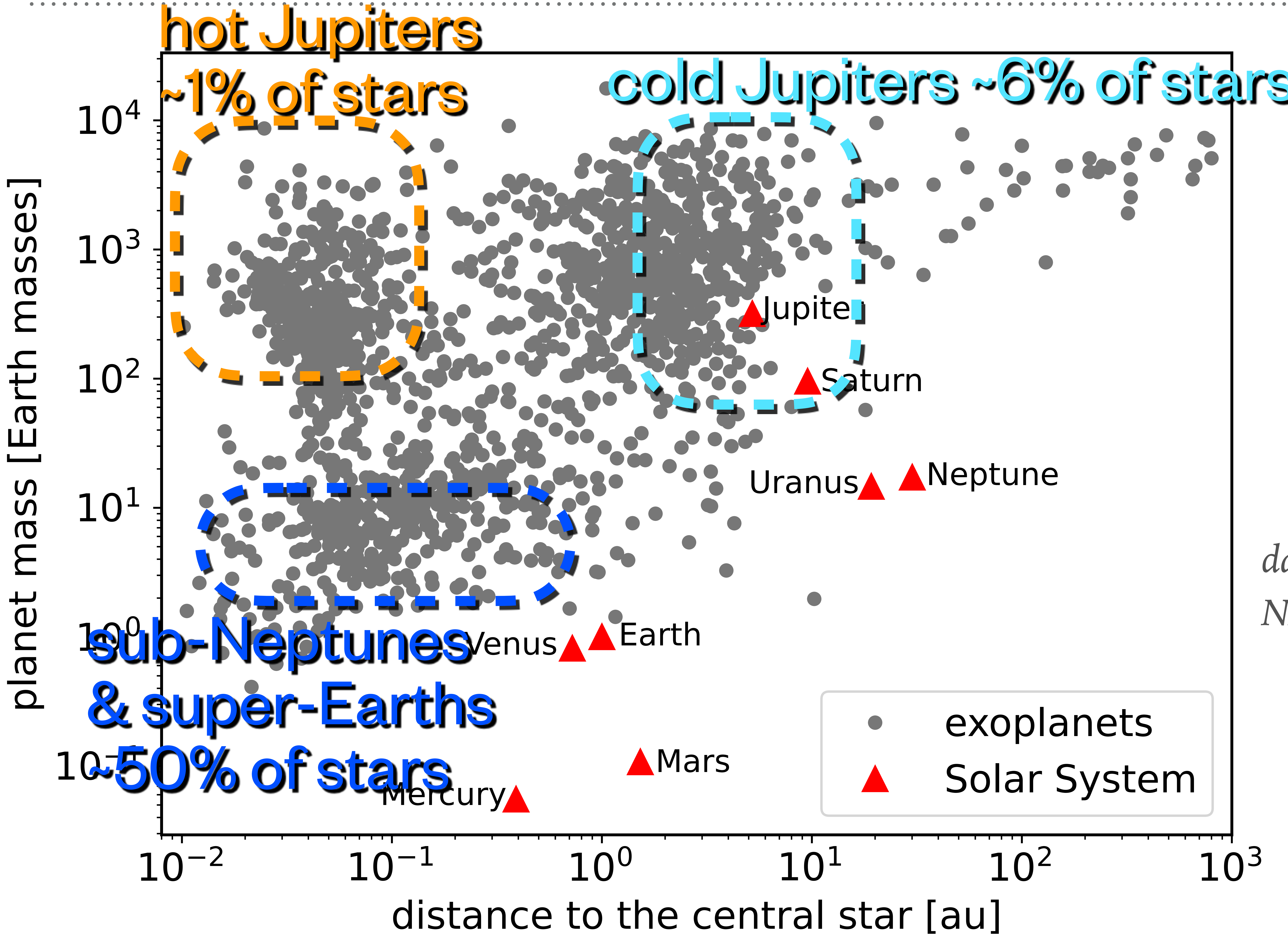
see, e.g., the book "Astrophysics of planet formation" by Armitage



Maximum mass a rocky core can grow to (the isolation mass)

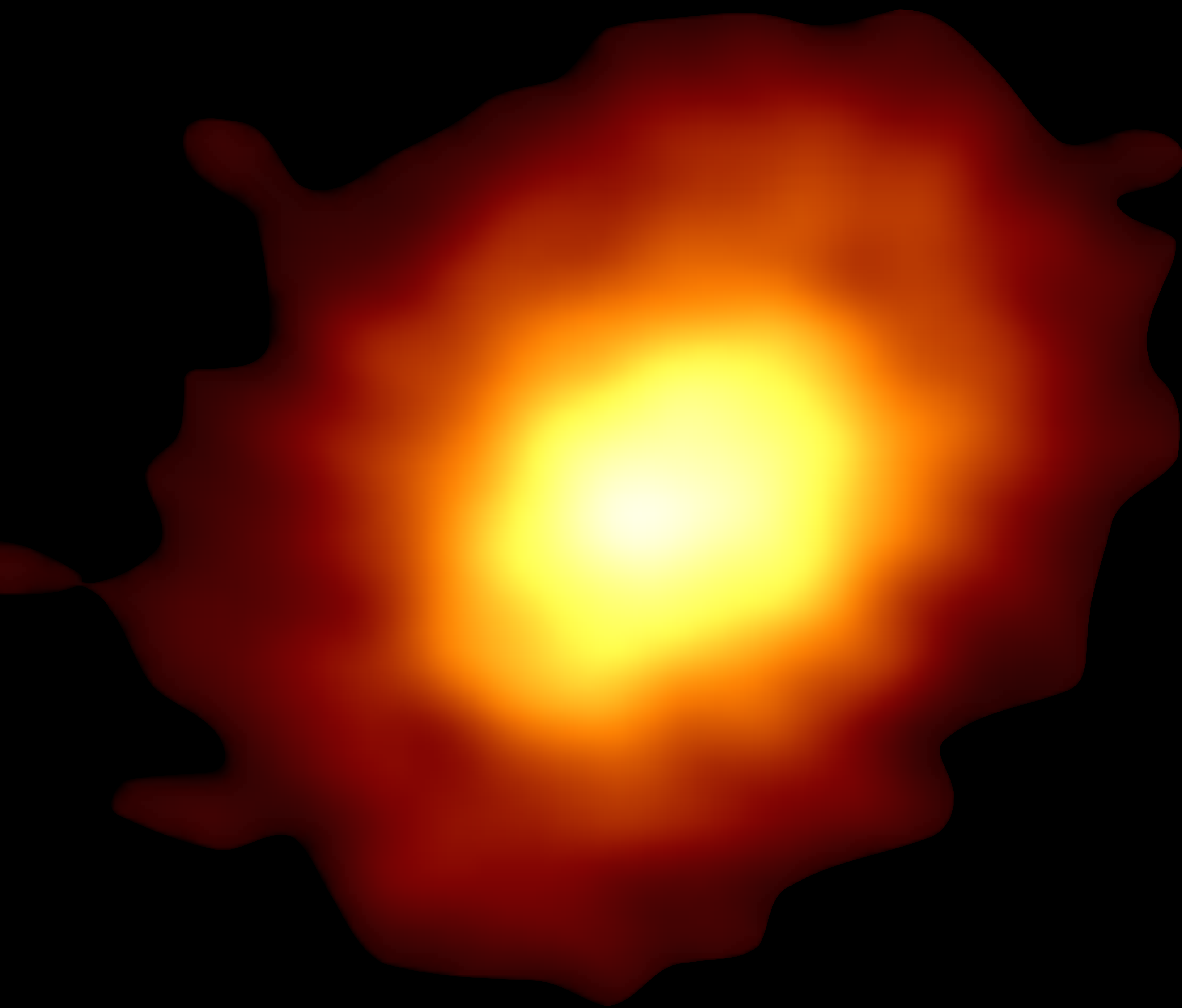
Minimum rocky core mass needed for gas accretion

EXOPLANETS DIVERSITY: CLOSE-IN GAS-RICH PLANETS

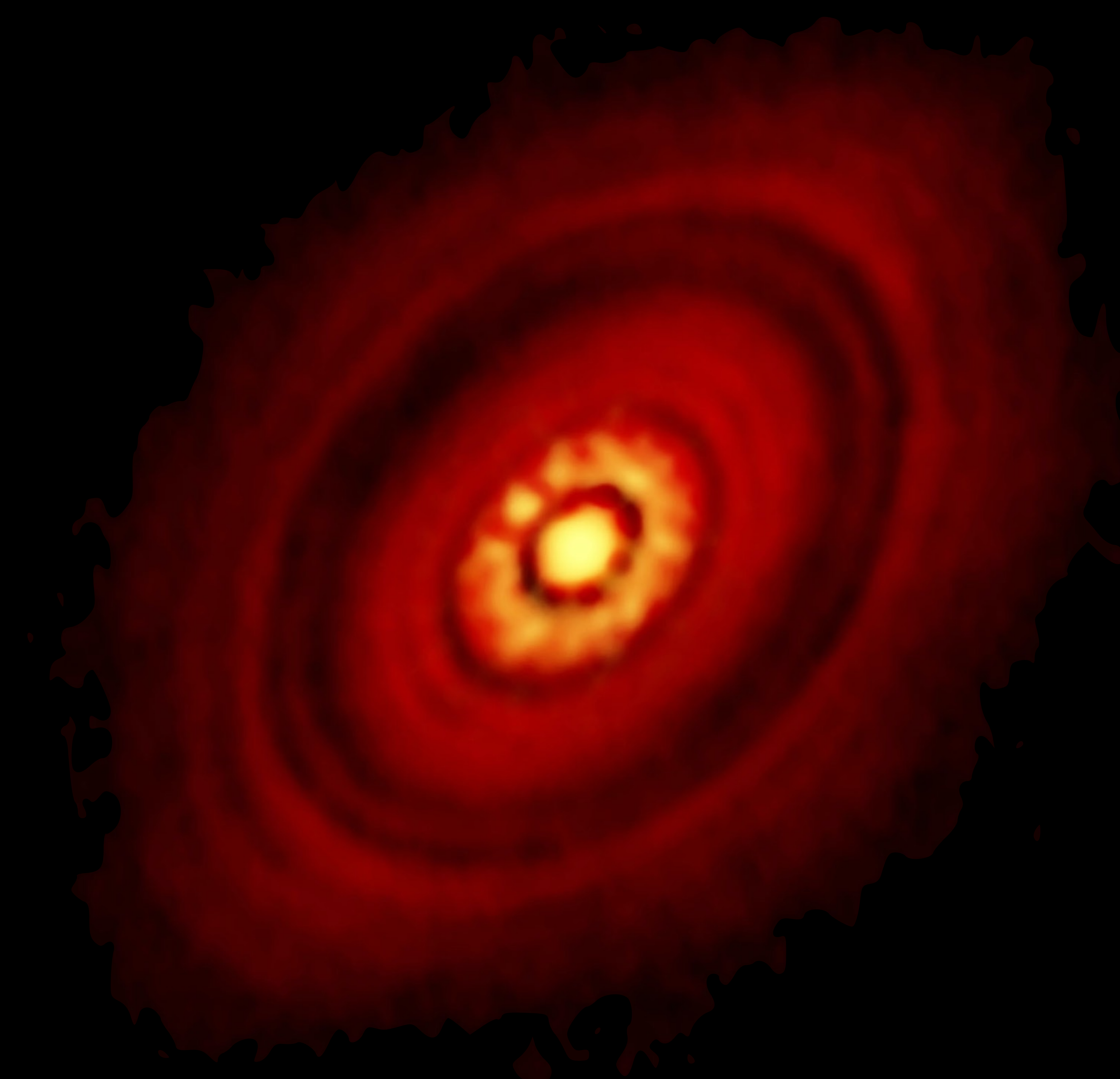


data source:
NASA Exoplanet Archive

THE ALMA REVOLUTION



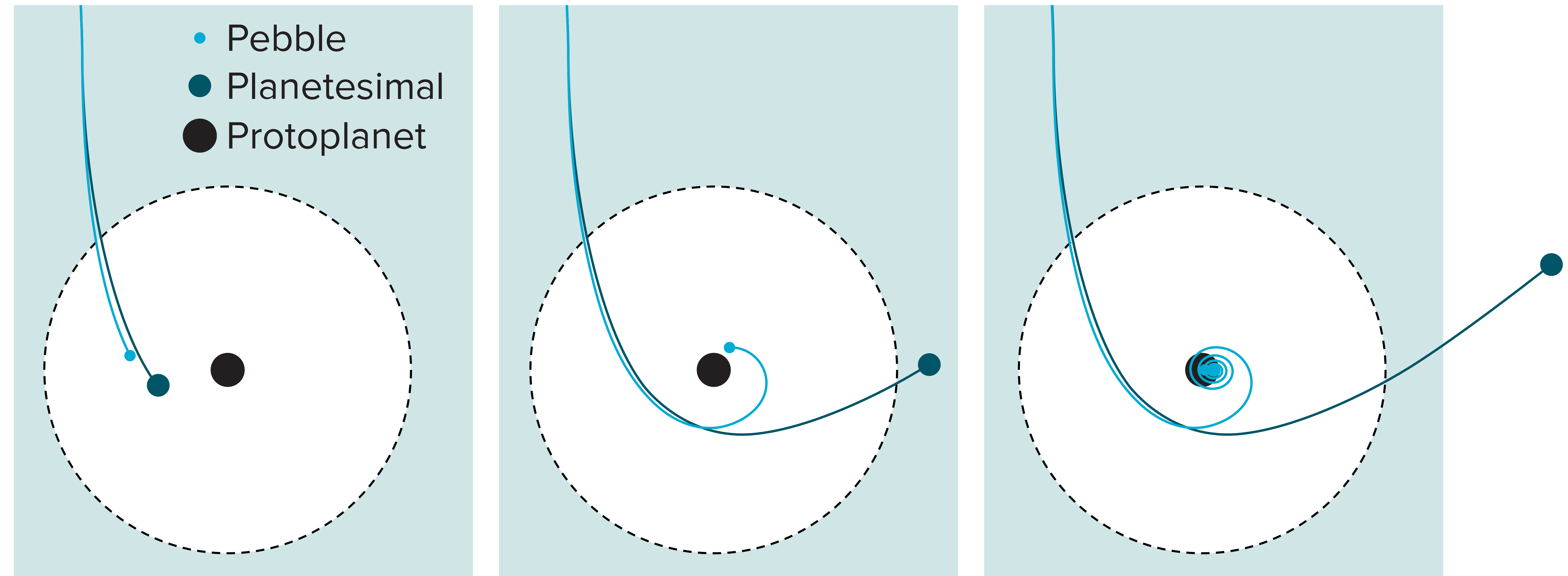
Kwon et al. 2011



ALMA Partnership 2014

THE EMERGING PARADIGM OF PEBBLE ACCRETION

→ gas drag helps the embryo to accrete pebbles

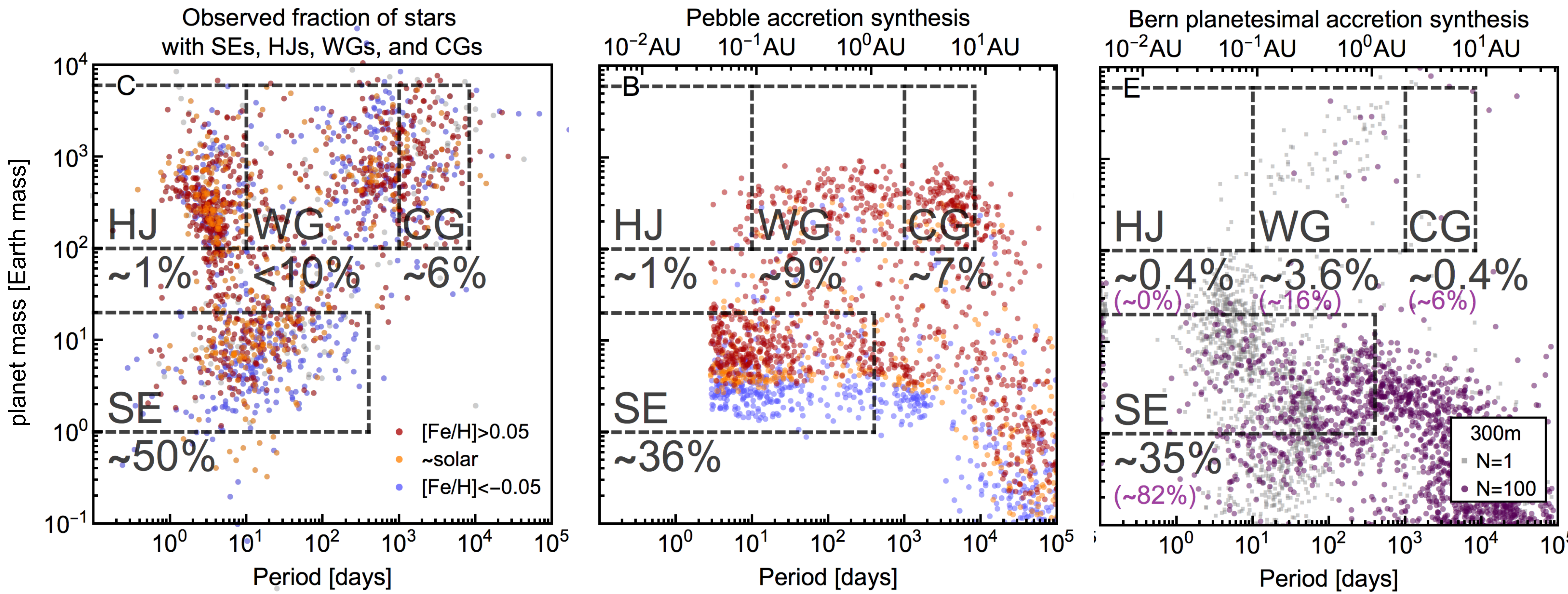


SOURCE: M. LAMBRECHTS & A. JOHANSEN

L. MODICA / KNOWABLE

→ the size of the feeding zone increases

PEBBLE ACCRETION GIVES BETTER FIT TO EXOPLANETS

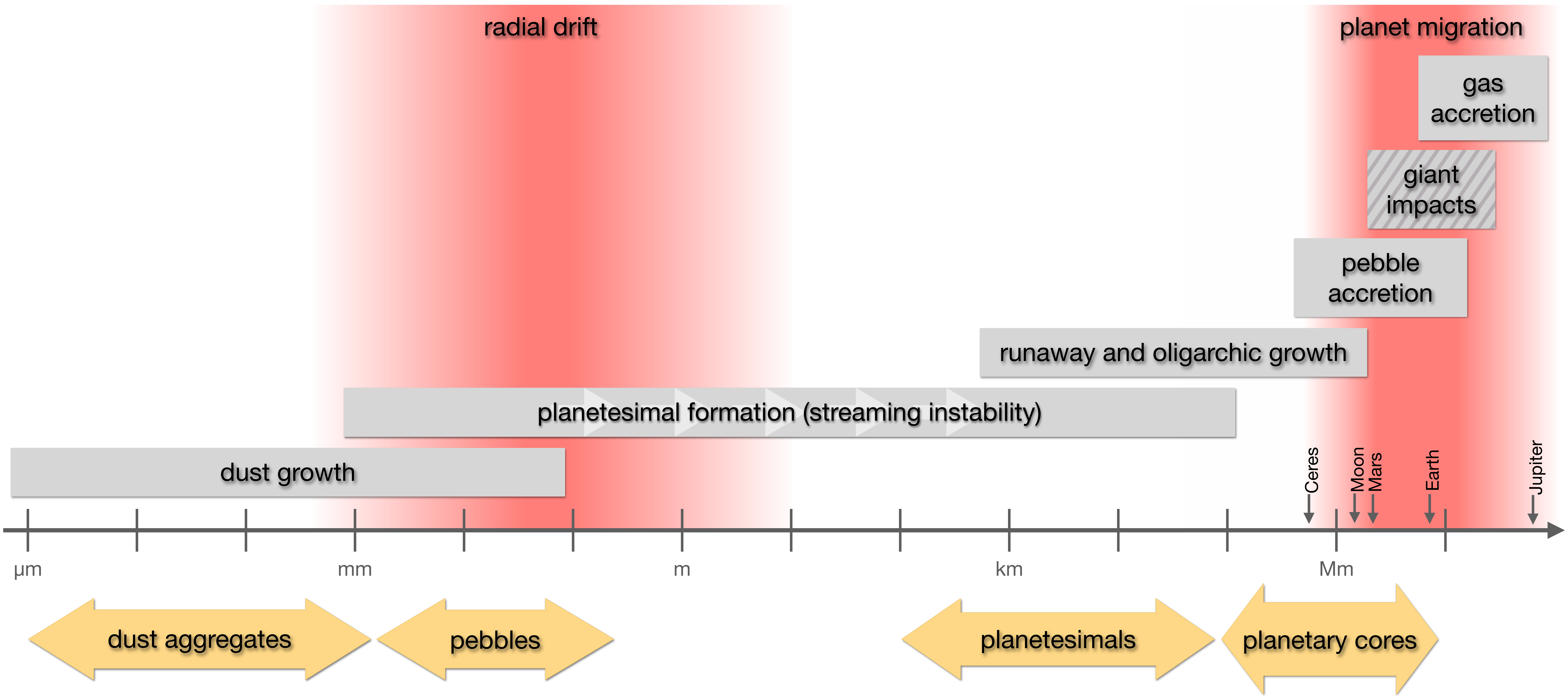


Drążkowska et al. PPVII chapter

pebble population synthesis model by Bertram Bitsch & Michiel Lambrechts

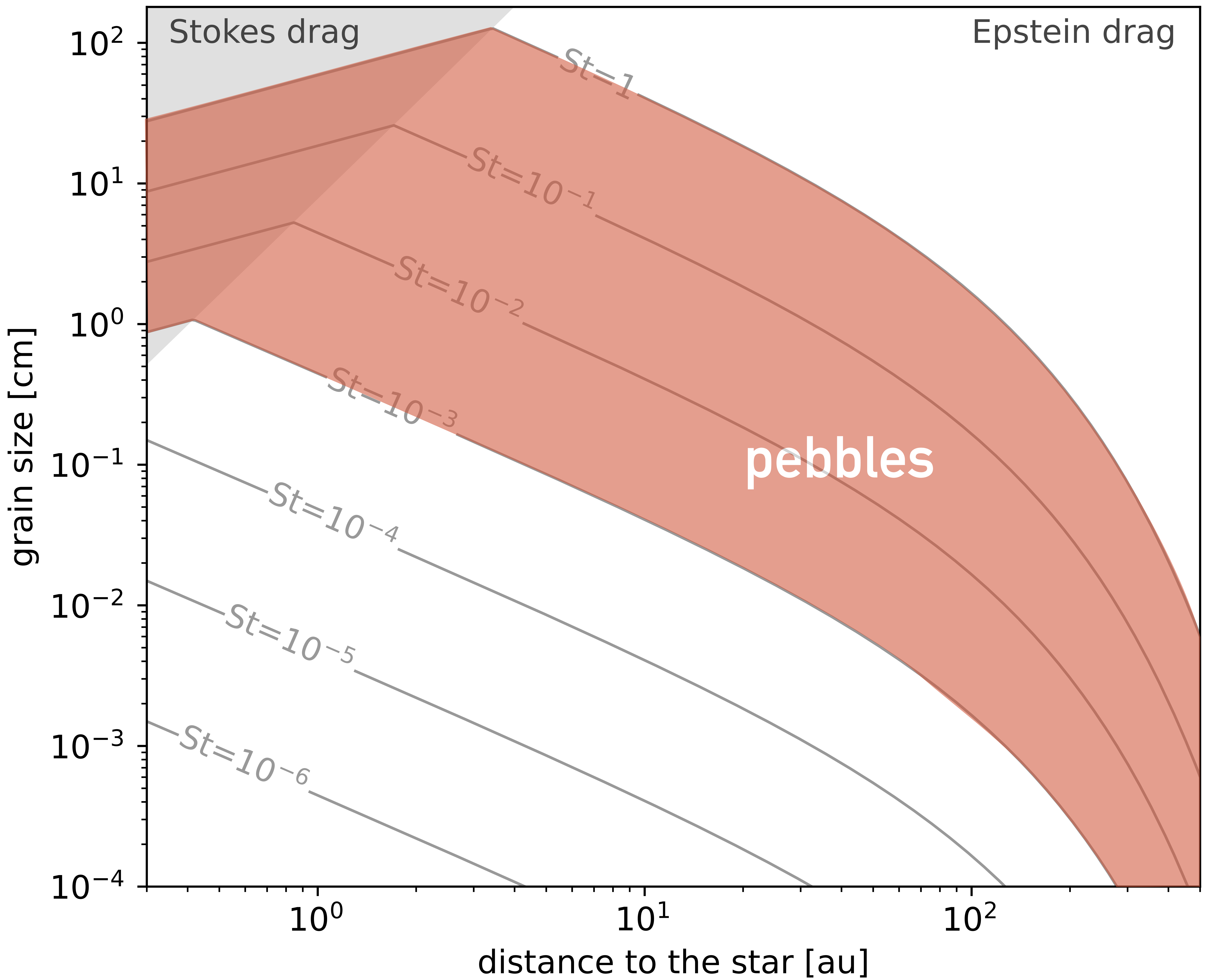
models from Emsenhuber et al. 2020

WHERE DO THE PLANETARY CORES COME FROM?



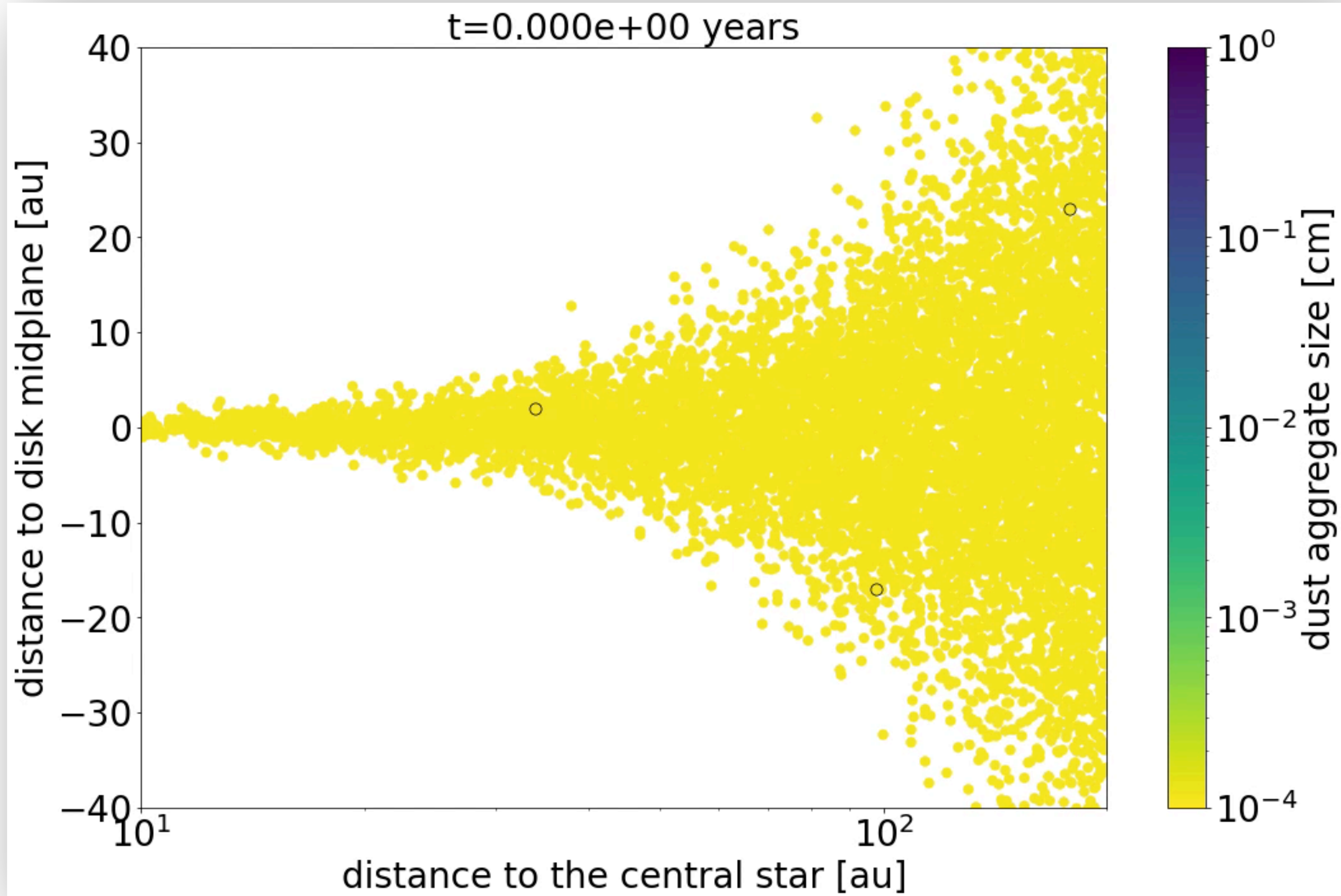
Drążkowska et al, PPVII review chapter, arXiv:2203.09759

THE DEFINITION OF A PEBBLE



DUST COAGULATION MODELS

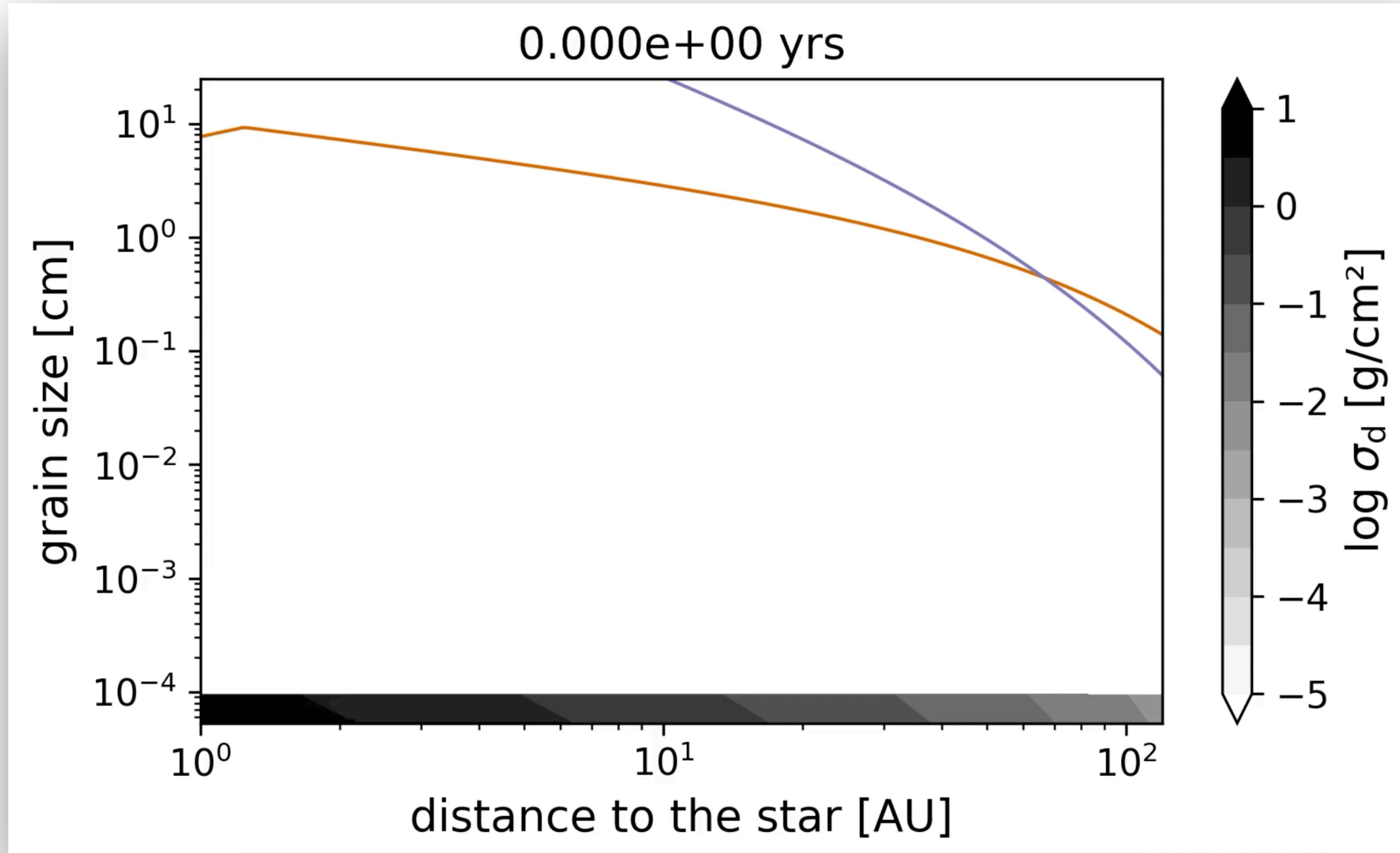
Monte Carlo algorithm with representative particle approach allows for following the evolution of individual particles.



made with the 2-D Monte Carlo code by *<u>Drążkowska</u> et al. 2013*

DUST COAGULATION MODELS

Codes using the fluid approach to dust dynamics and the **Smoluchowski equation solver** allow for long-term integration of a global disk.

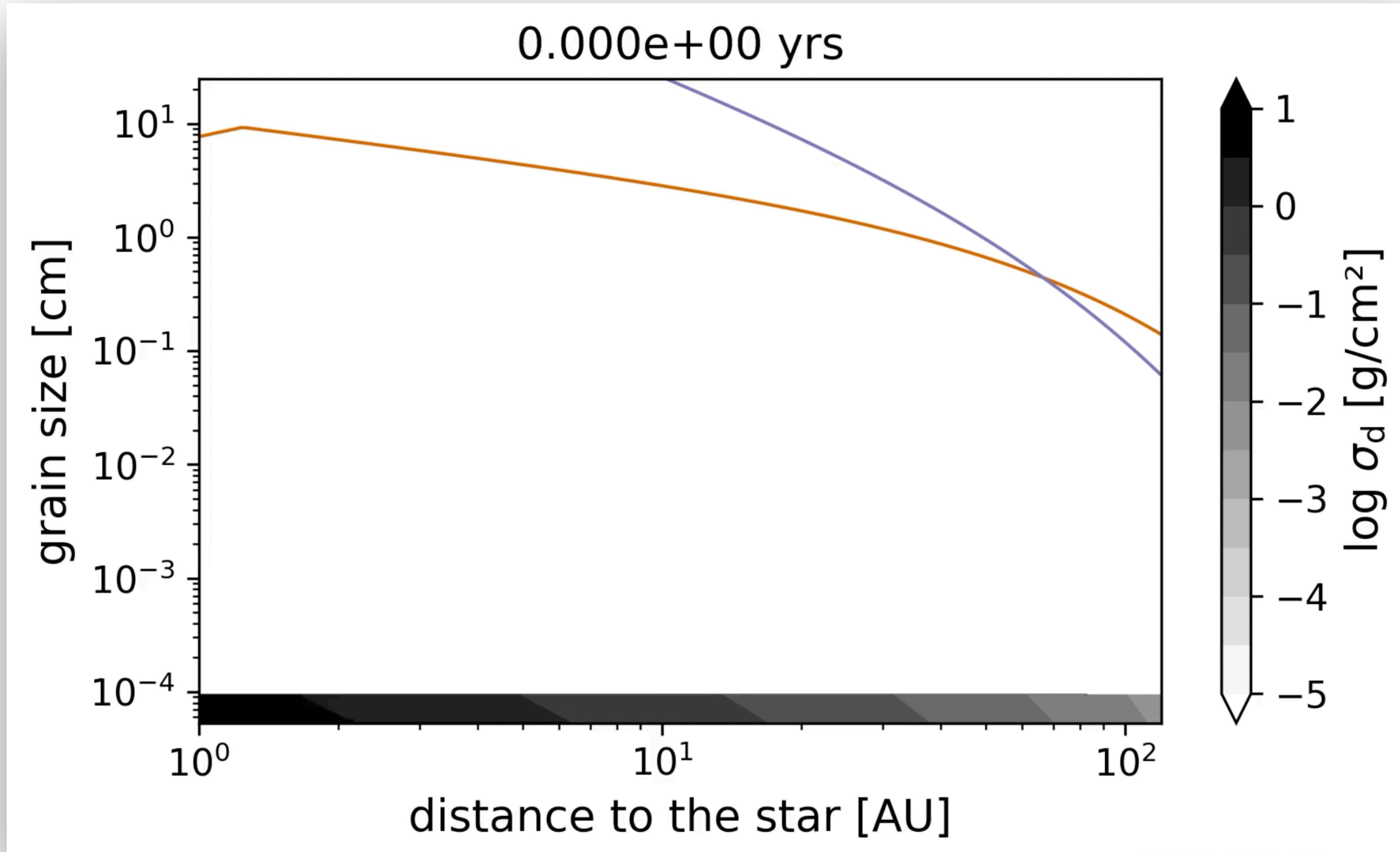


made with the DustPy code, Stammler & Birnstiel, in prep.

DUST DOES NOT GROW TO PLANETESIMALS

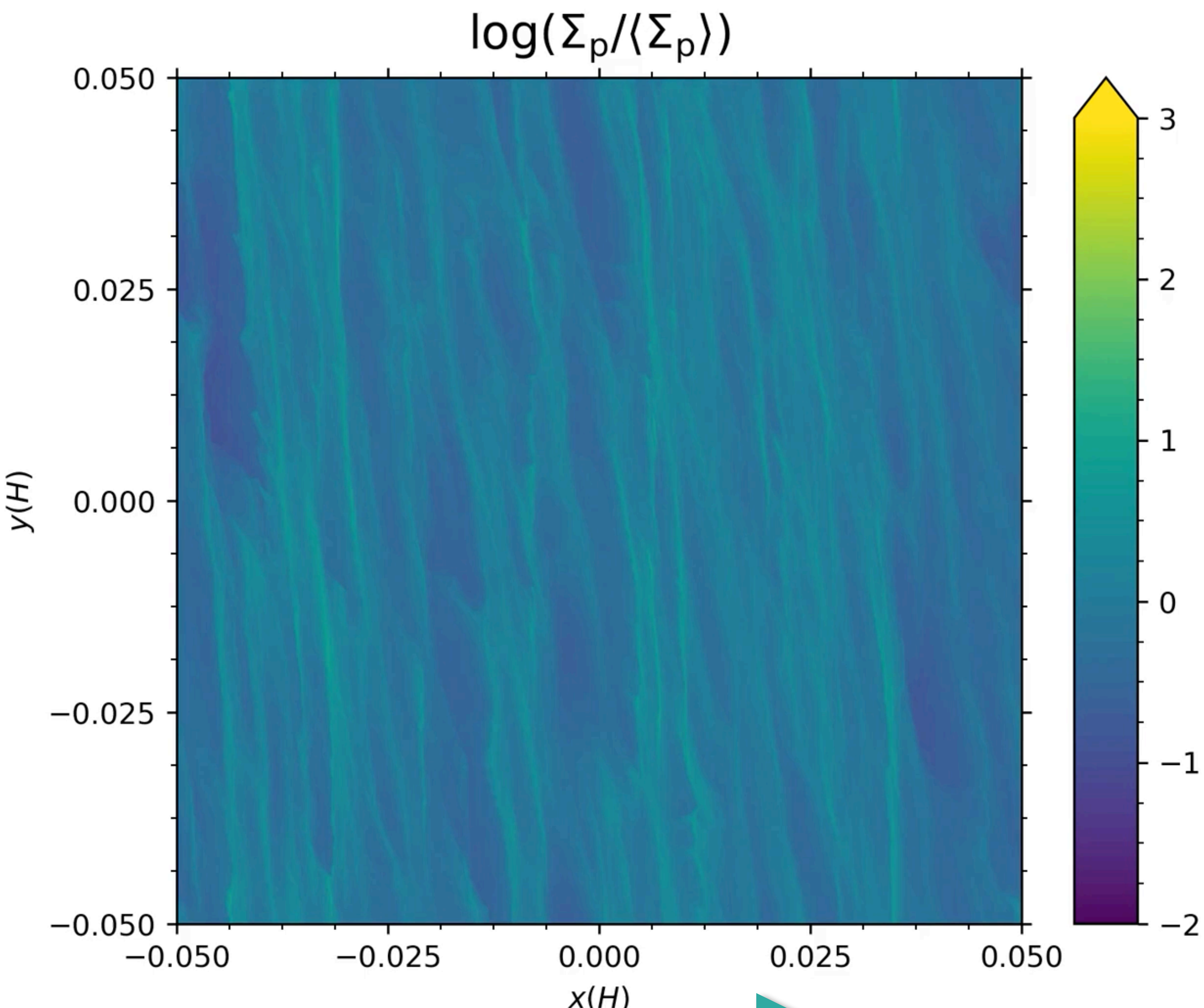
Dust growth is restricted by **radial drift** when the drift timescale is shorter than the growth timescale and by **fragmentation** when the dust aggregates collide with velocities exceeding so-called sticking threshold.

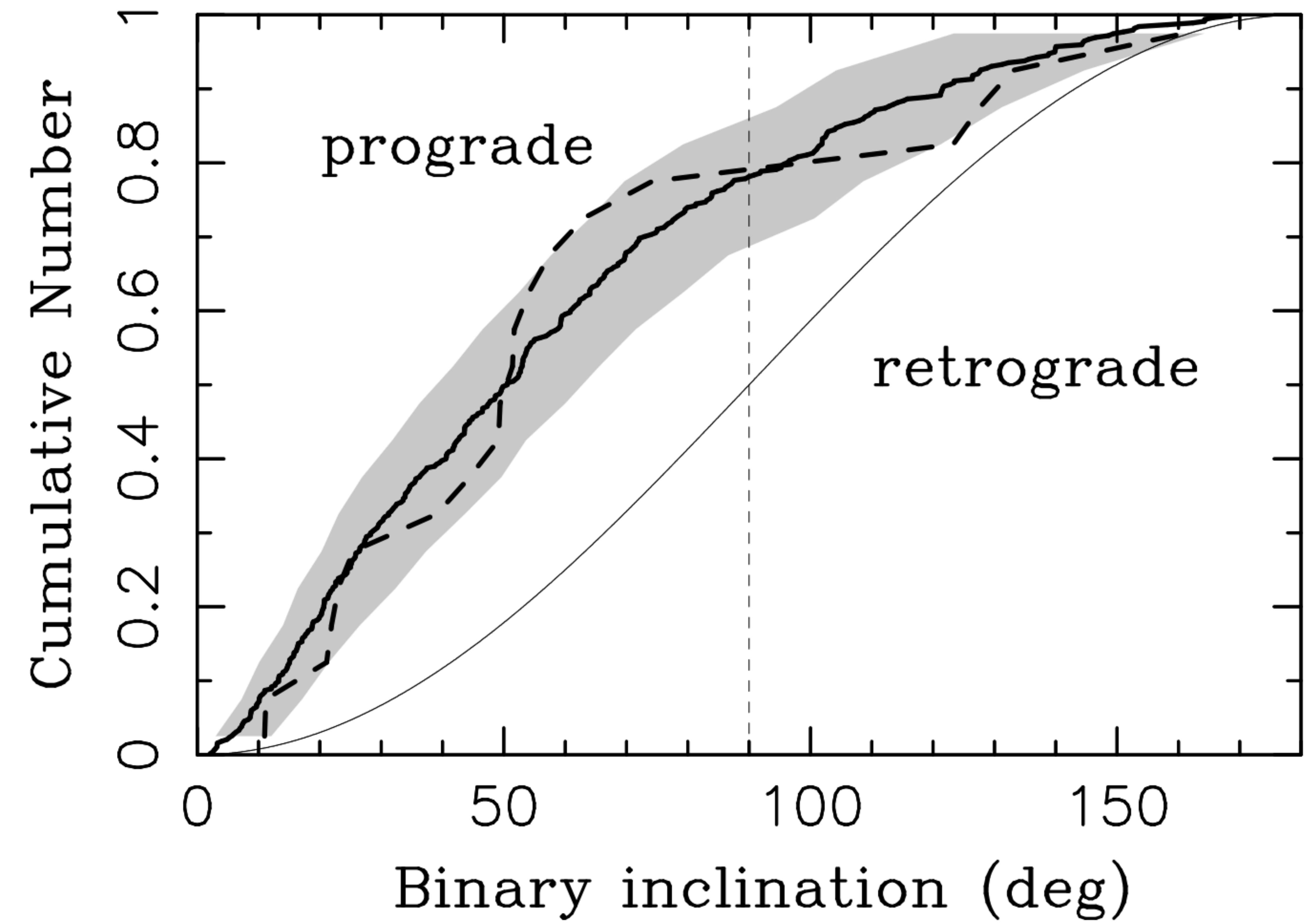
direct comparison between the Monte Carlo approach and the Smoluchowski equation solver: Drążkowska et al. 2014



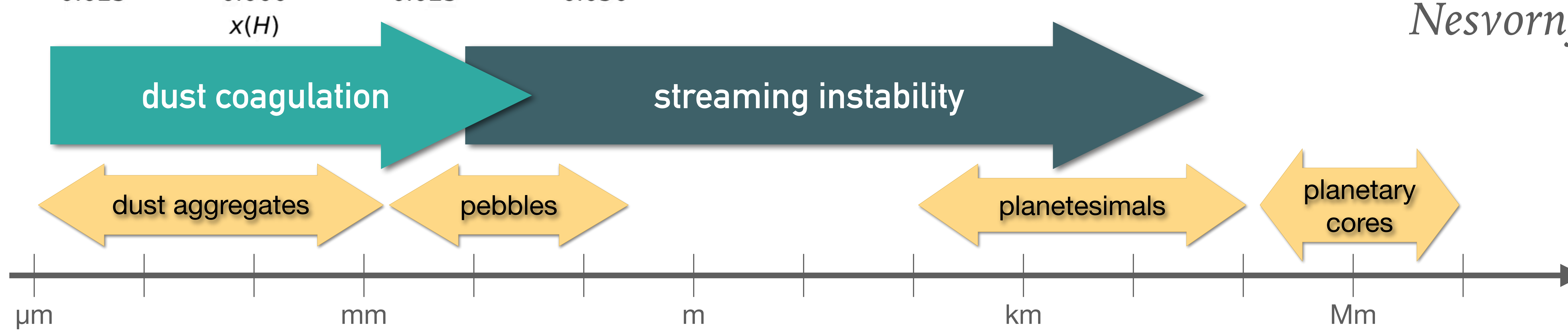
made with the DustPy code, Stammler & Birnstiel, in prep.

PLANETESIMALS FORM VIA THE STREAMING INSTABILITY

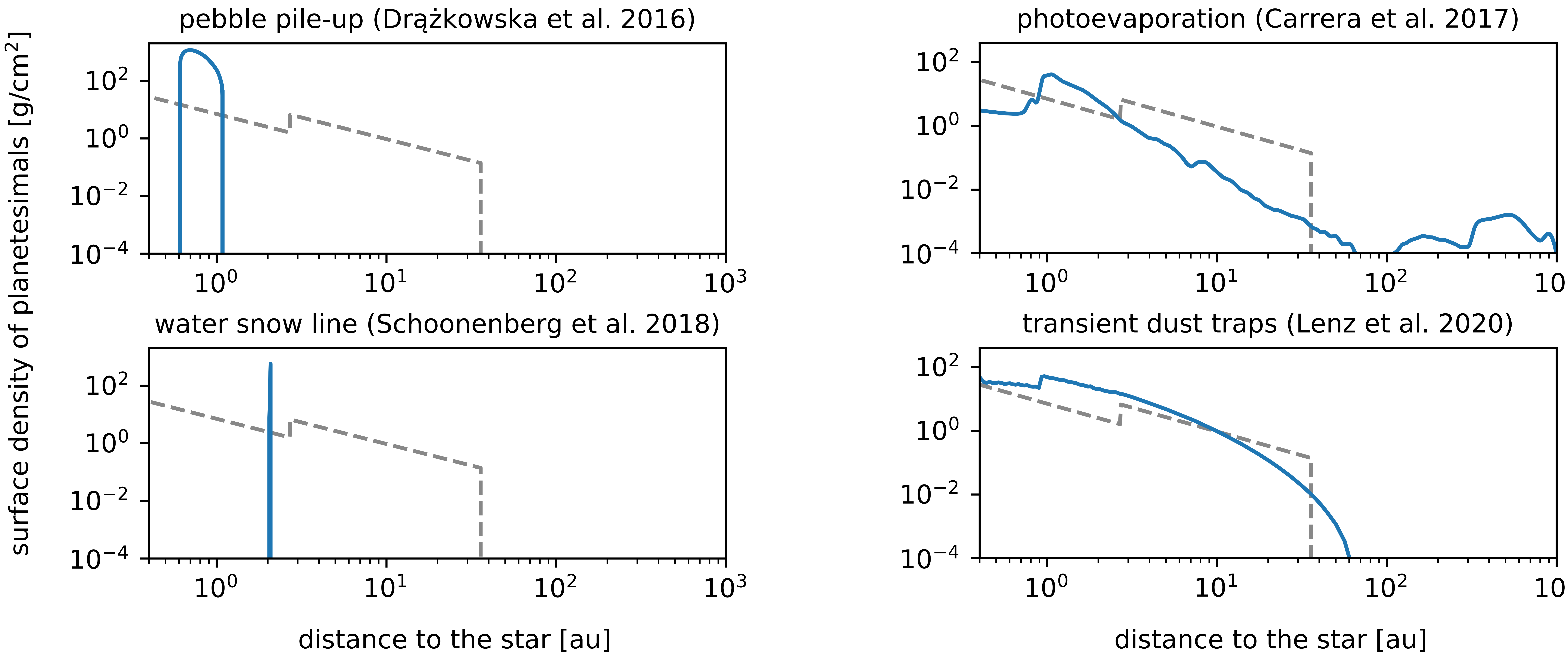




Nesvorný et al. 2019

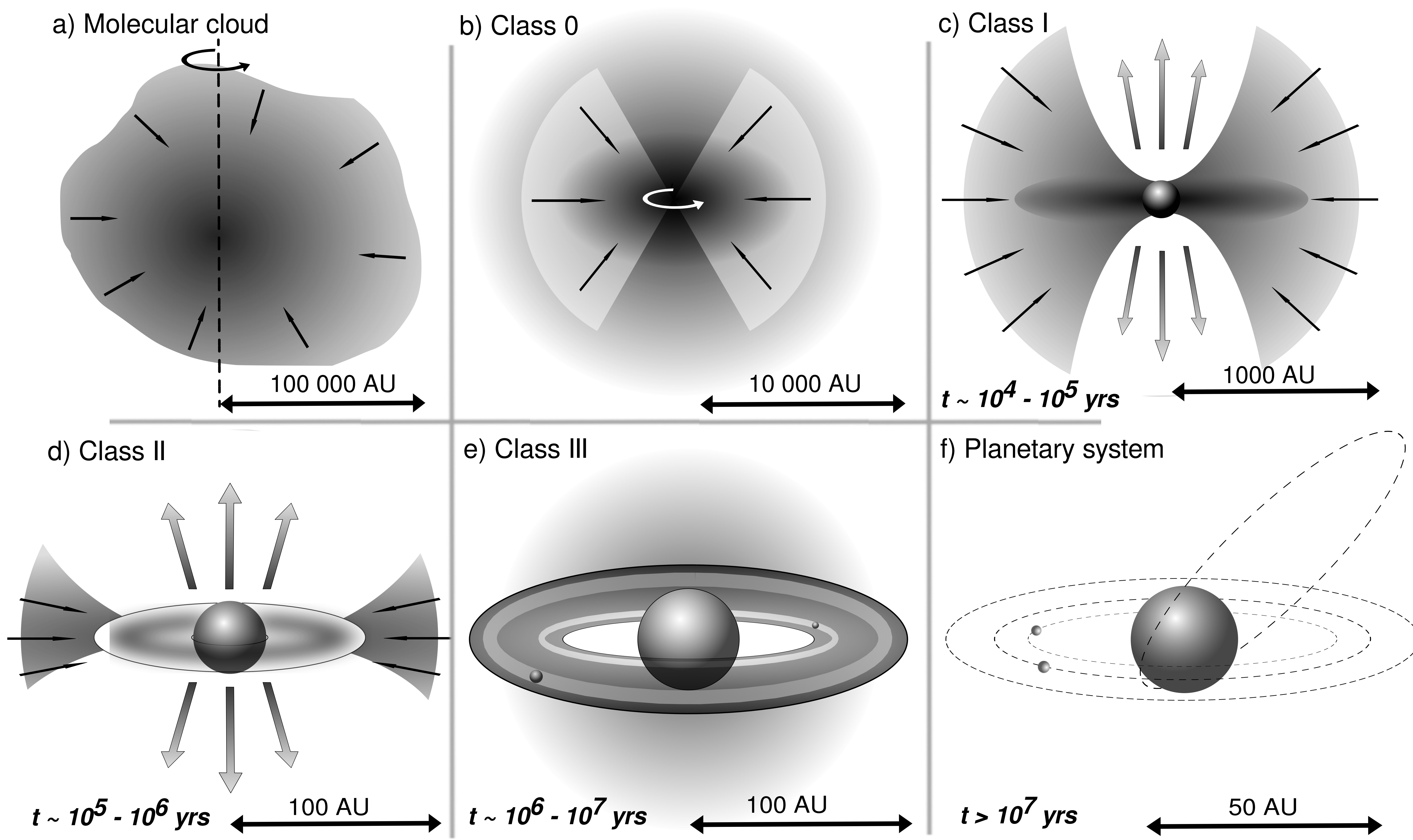


PLANETESIMAL FORMATION DEPENDS ON ASSUMPTIONS

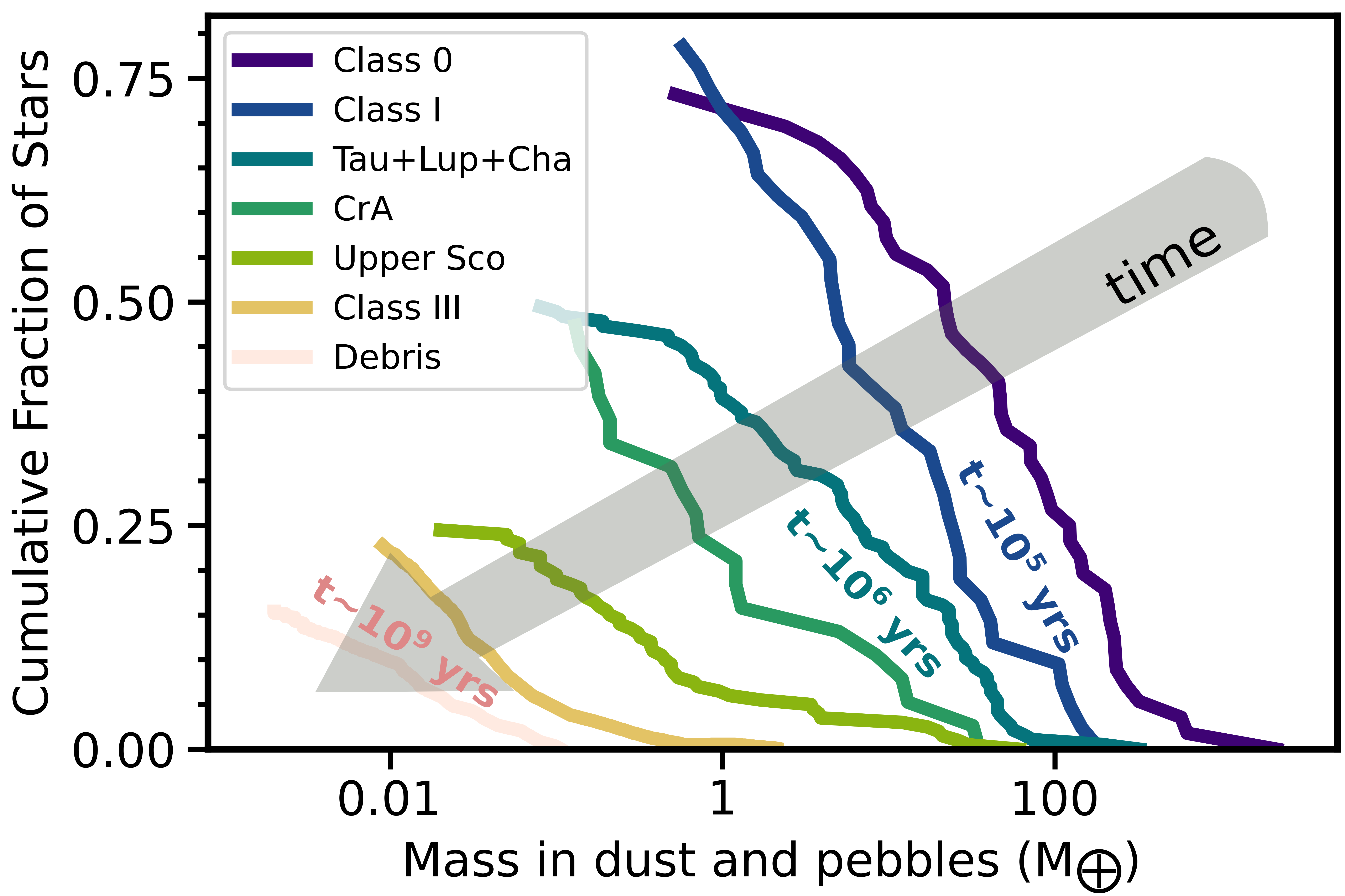


Drążkowska et al, PPVII review chapter, arXiv:2203.09759

MOST OF THE MODELS START WITH CLASS II DISKS…



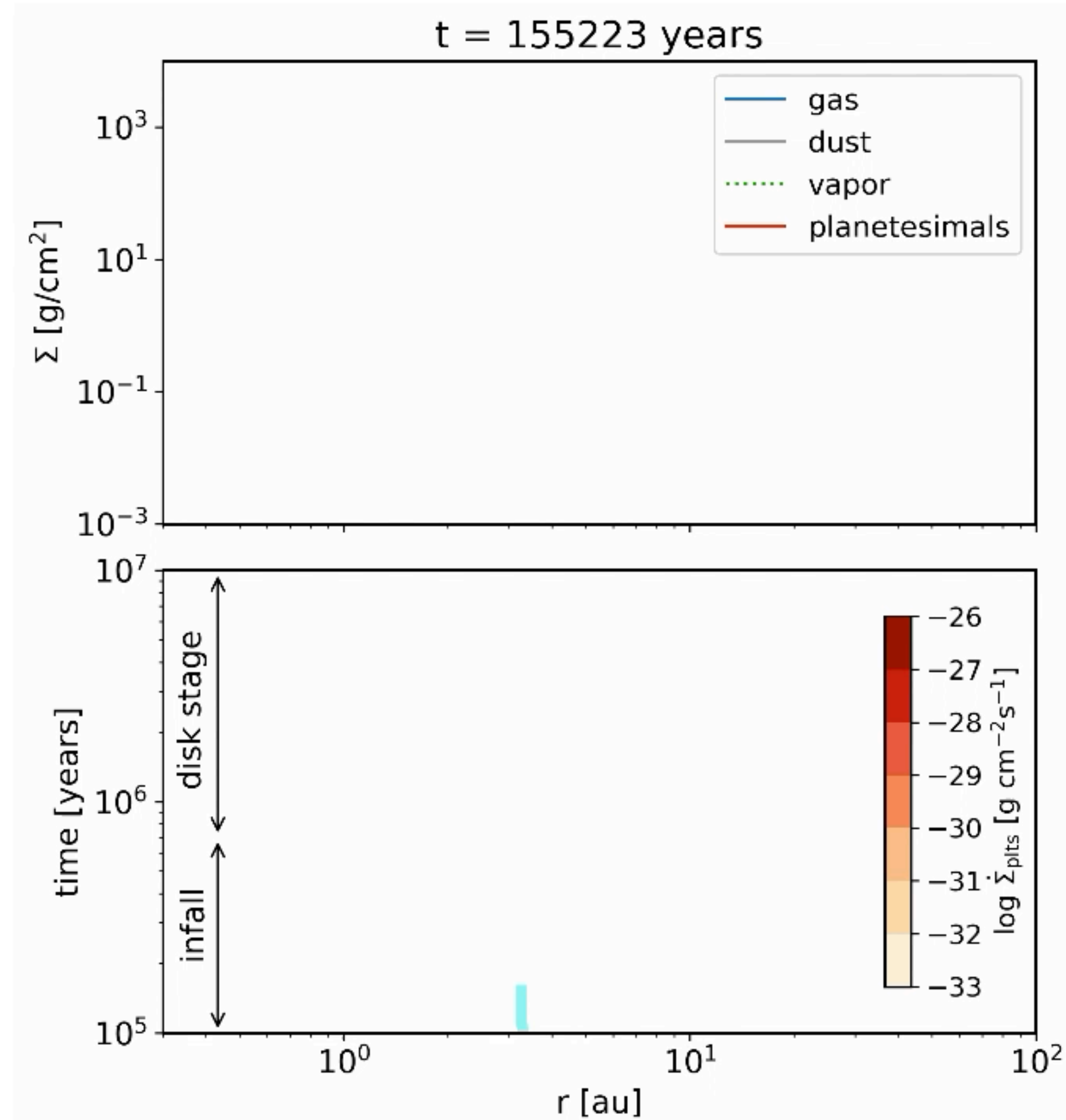
...WHICH DO NOT HAVE ENOUGH MASS



Drążkowska et al, PPVII review chapter, arXiv:2203.09759

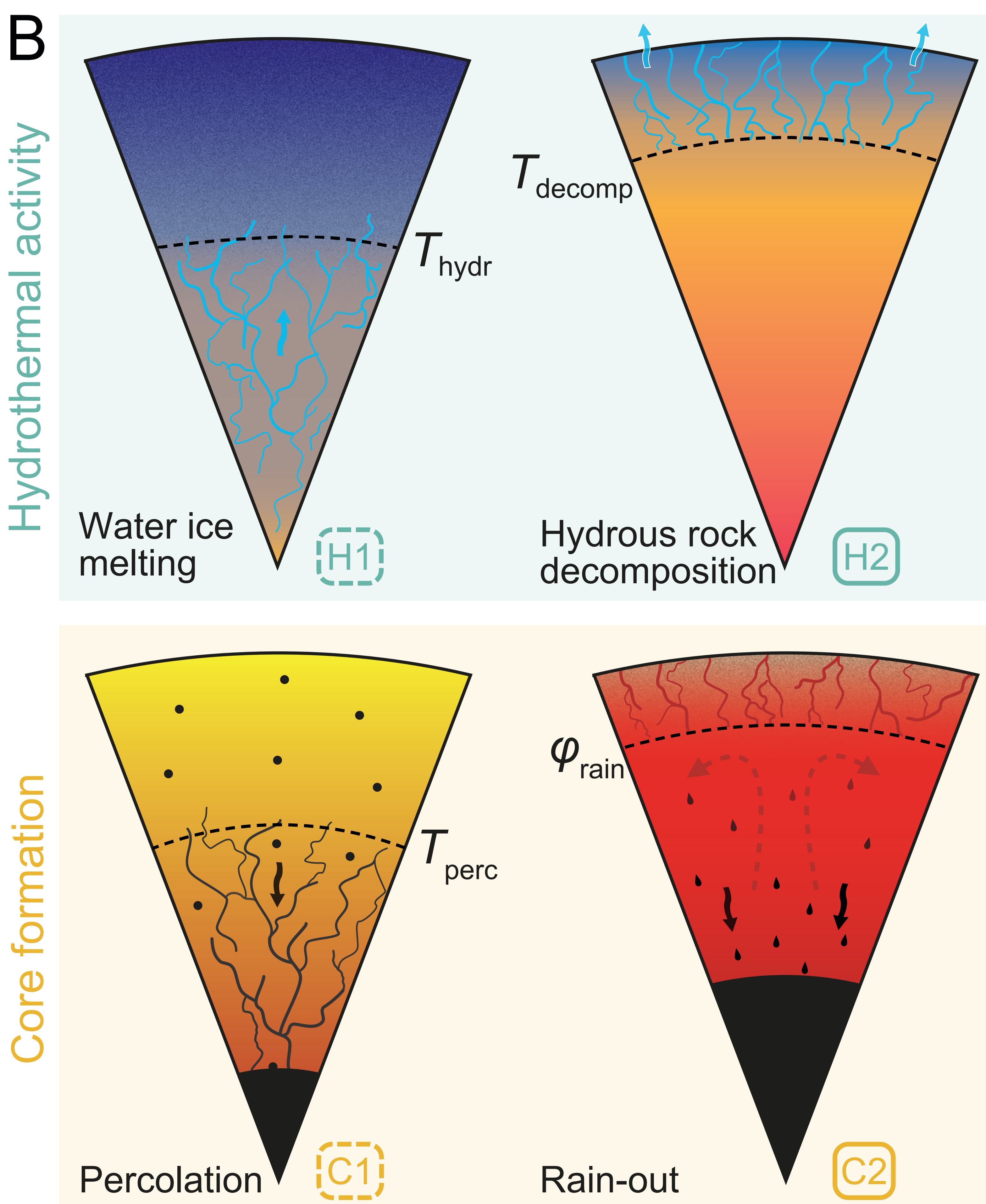
STARTING FROM DISK BUILDUP

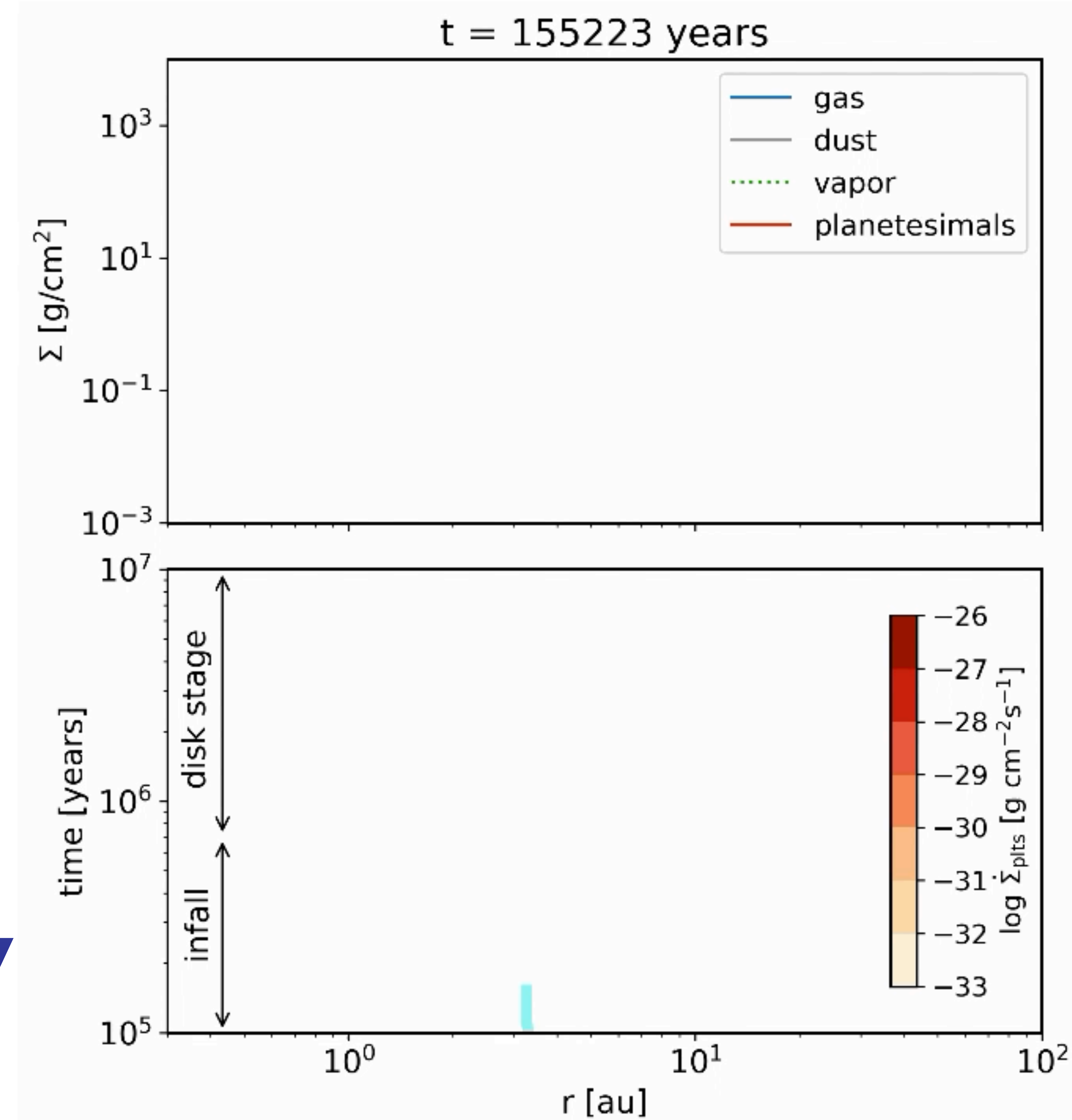
Drążkowska & Dullemond 2018



DIVERGENT INTERNAL EVOLUTION

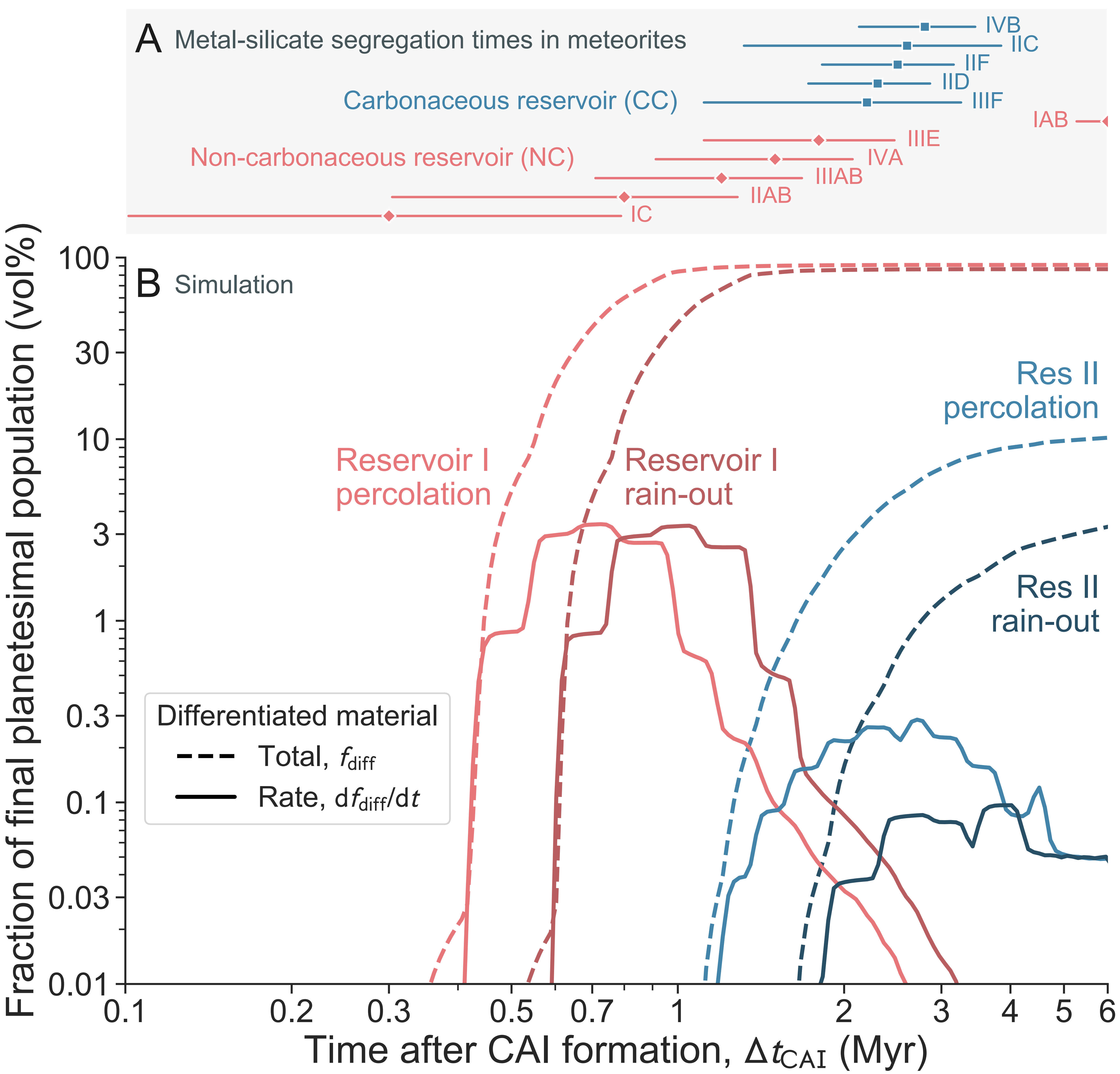
Lichtenberg, Drążkowska et al. (2021)

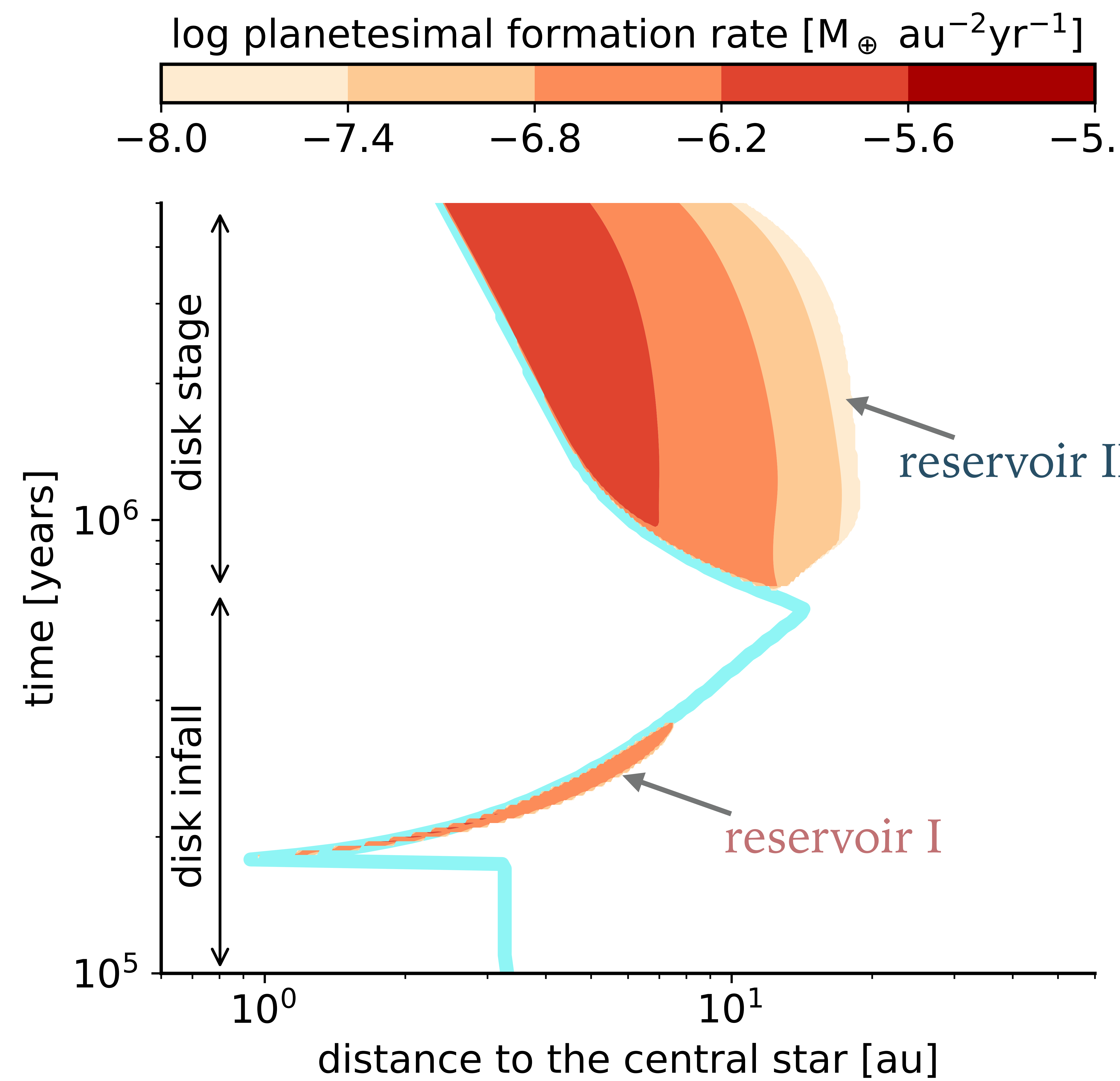




CONSISTENT WITH THE SOLAR SYSTEM METEORITIC RECORD

Lichtenberg, Drążkowska et al. (2021)





TAKE-AWAY POINTS

- Planet formation theory is undergoing major changes driven by the exoplanets discoveries, protoplanetary disks observations, and the Solar System research.
- Pebble accretion paradigm gives overall better fit to the observed exoplanets demographics than the planetesimal accretion paradigm.
- Planetesimals do not form by direct growth of dust aggregates but by the gravitational collapse of pebble clumps driven by the streaming instability.
- Planetesimal formation is not a single burst, planetesimals may form for several Myrs. We need models coupling dust evolution, planetesimal formation, planetary growth, and the internal evolution of planets.