



Finanziato
dall'Unione europea
NextGenerationEU



Ministero
dell'Università
e della Ricerca



Italiadomani
PIANO NAZIONALE
DI RIPRESA E RESILIENZA



Mercury-ArXes: an high-performance n-body code for planet formation simulations

*Diego Turrini (INAF-OATO), Danai Polychroni (INAF-OATO), Paolo Simonetti (INAF-OATS),
Sergio Fonte (INAF-IAPS), Romolo Politi (INAF-IAPS)*

WG2 Code introduction meeting, 14-17/10/2024
COST Action CA22133 PLANETS

Mercury-ArXes – The code



Mercury-ArXes (Turrini+2019, 2021) is the multi-language n-body code of **ArXes**, the INAF suite of planet formation and astrochemistry codes:

- Builds on the Mercury n-body code (Chambers 1999; FORTRAN77) and the WHFAST library (Rein & Tamayo 2015; C99).
- Integrates planet formation libraries to track the growth, migration and interactions with the disk gas of planetary bodies (Turrini+2019, 2021; Fortran2003).
- Parallelized and vectorized (SIMD) with OpenMP, porting designed so that the parallel and serial version produce the same results.
- Porting to GPU computing in the framework of the ICSC - Italian Research Center on High-Performance Computing, Big Data and Quantum Computing
- Ongoing expansion with additional dynamical and physical libraries and satellite codes (Turrini+2019; Bernabò+22; Polychroni+2023)

Mercury-ArXes – The code



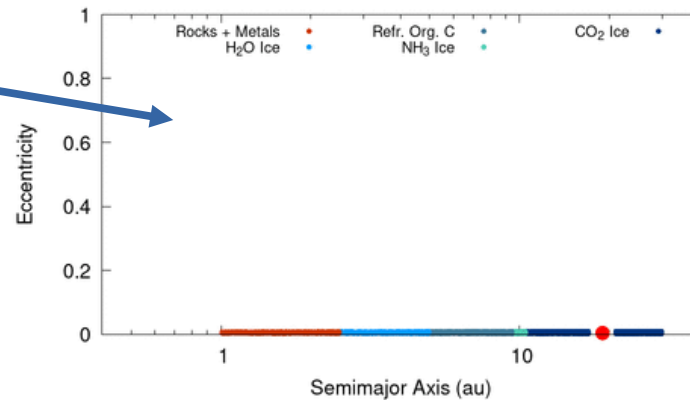
Mercury-ArXes simulates:

- Multi-phase growth tracks (Turrini+2019)
 - core formation and envelope capture + runaway gas accretion (Turrini+2011)
 - growth curves compatible with both pebble accretion and planetesimal accretion
- Multi-phase migration tracks (Turrini+2021)
 - Linear migration regime (Walsh+2011) + power law migration regime (Hahn & Malhotra 2005)
 - based on migration tracks from Mordasini+2015
- Radius evolution of giant planets (Turrini+2021)
 - expanded atmosphere (Lissauer+2009) + envelope contraction (D'Angelo+2021)
- Gas-planetesimal interactions (Turrini+2019,2021)
 - Damping effects of gas drag (Nagasawa+2019)
 - Exciting effects of disk gravity (Ward 1981 + Fontana & Marzari 2016)
- *Incoming*: physically-justified growth and migration tracks (Polichroni+2023)

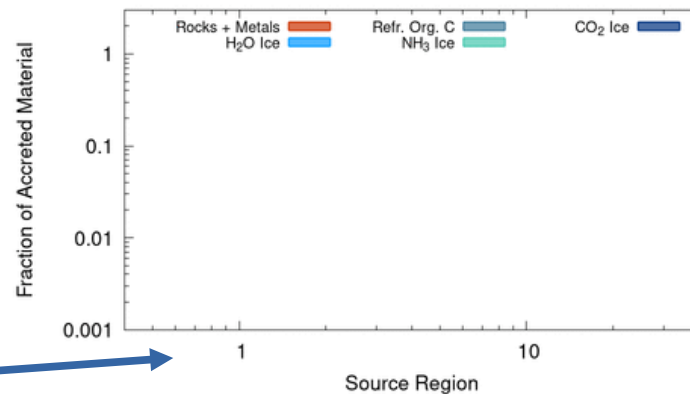
Mercury-ArXes – The simulations



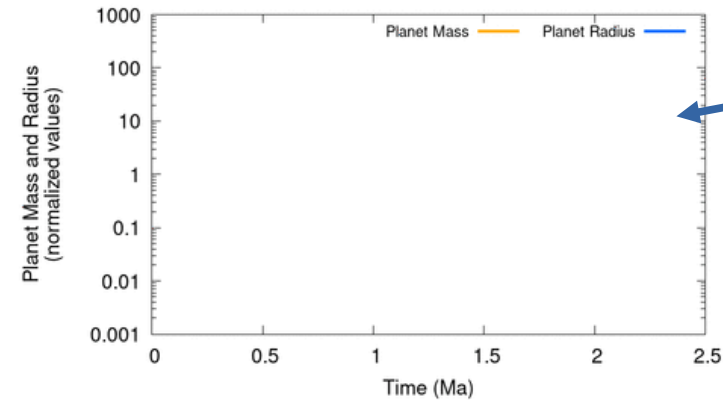
Dynamical state of the
protoplanetary disk



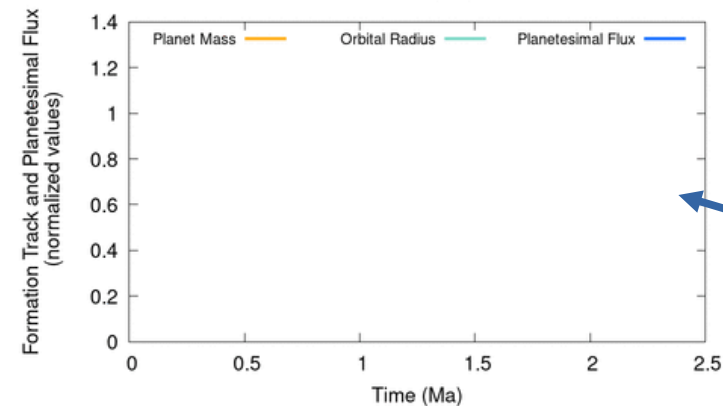
Source regions of the
impact flux over time



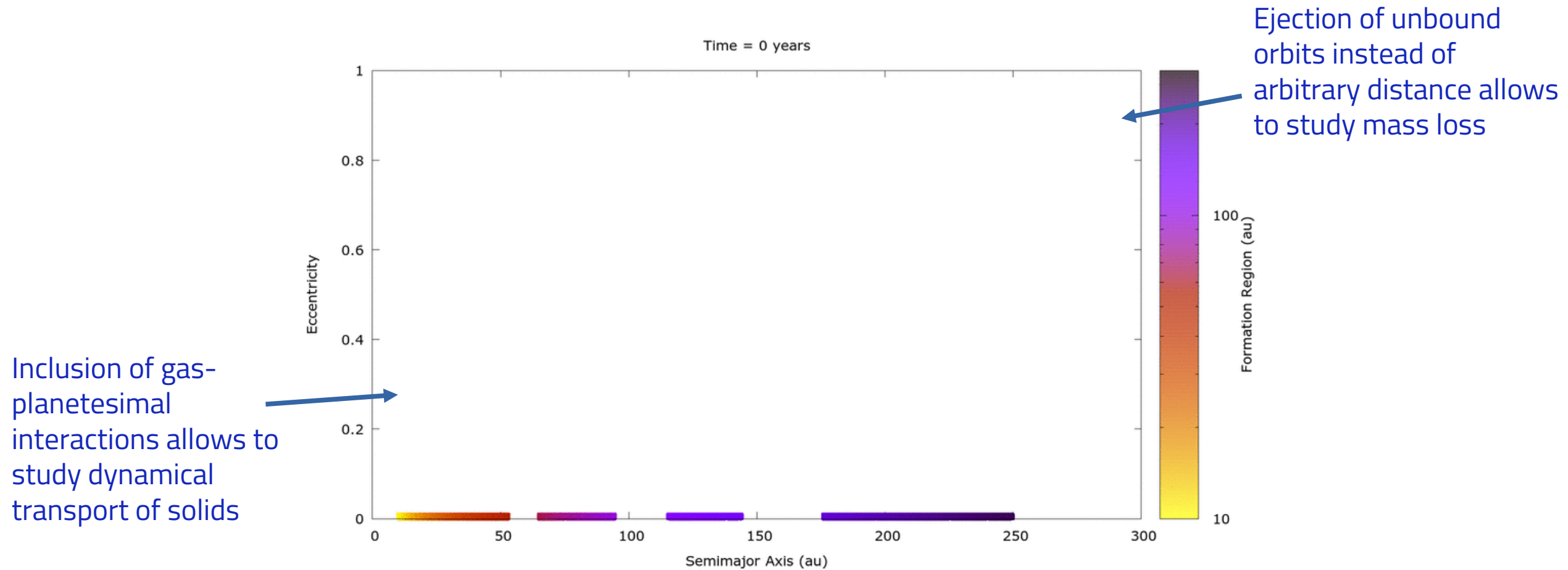
Joint mass and radius
evolution over time



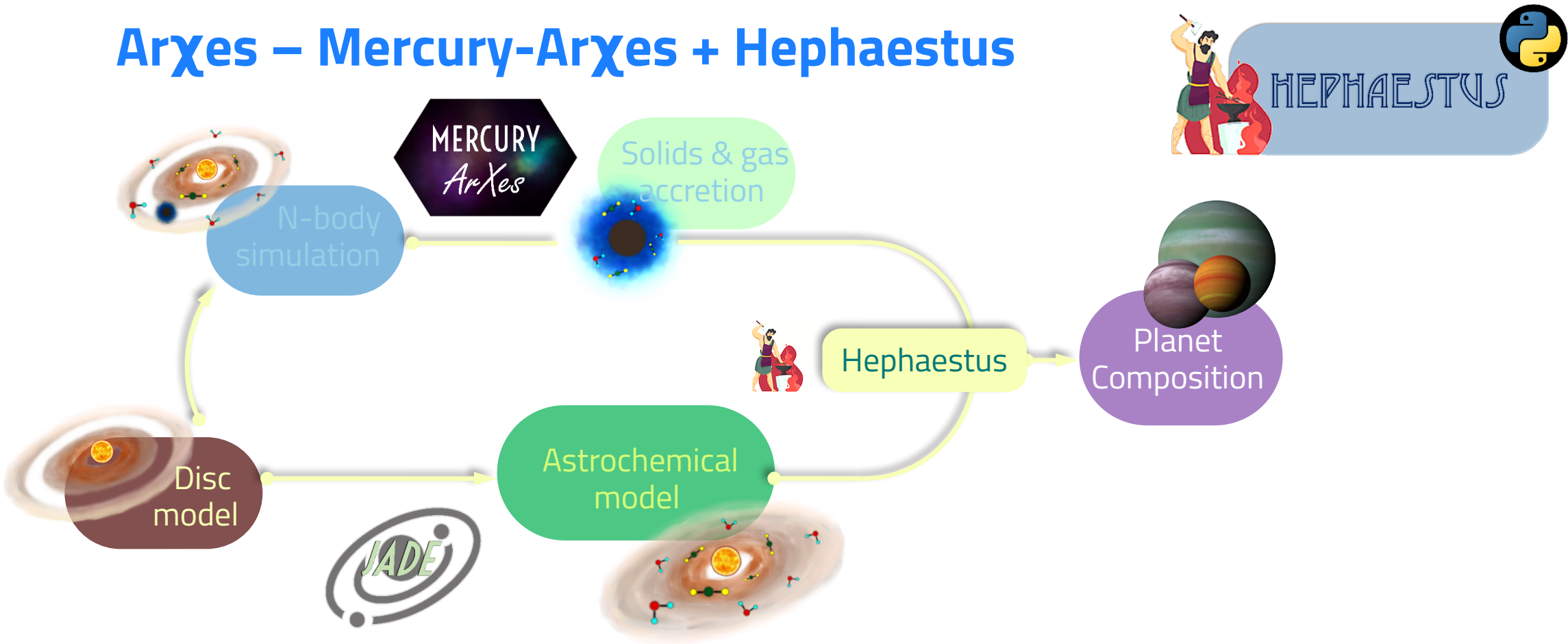
Growth, migration and
impact flux over time



Mercury-Arxes – The simulations

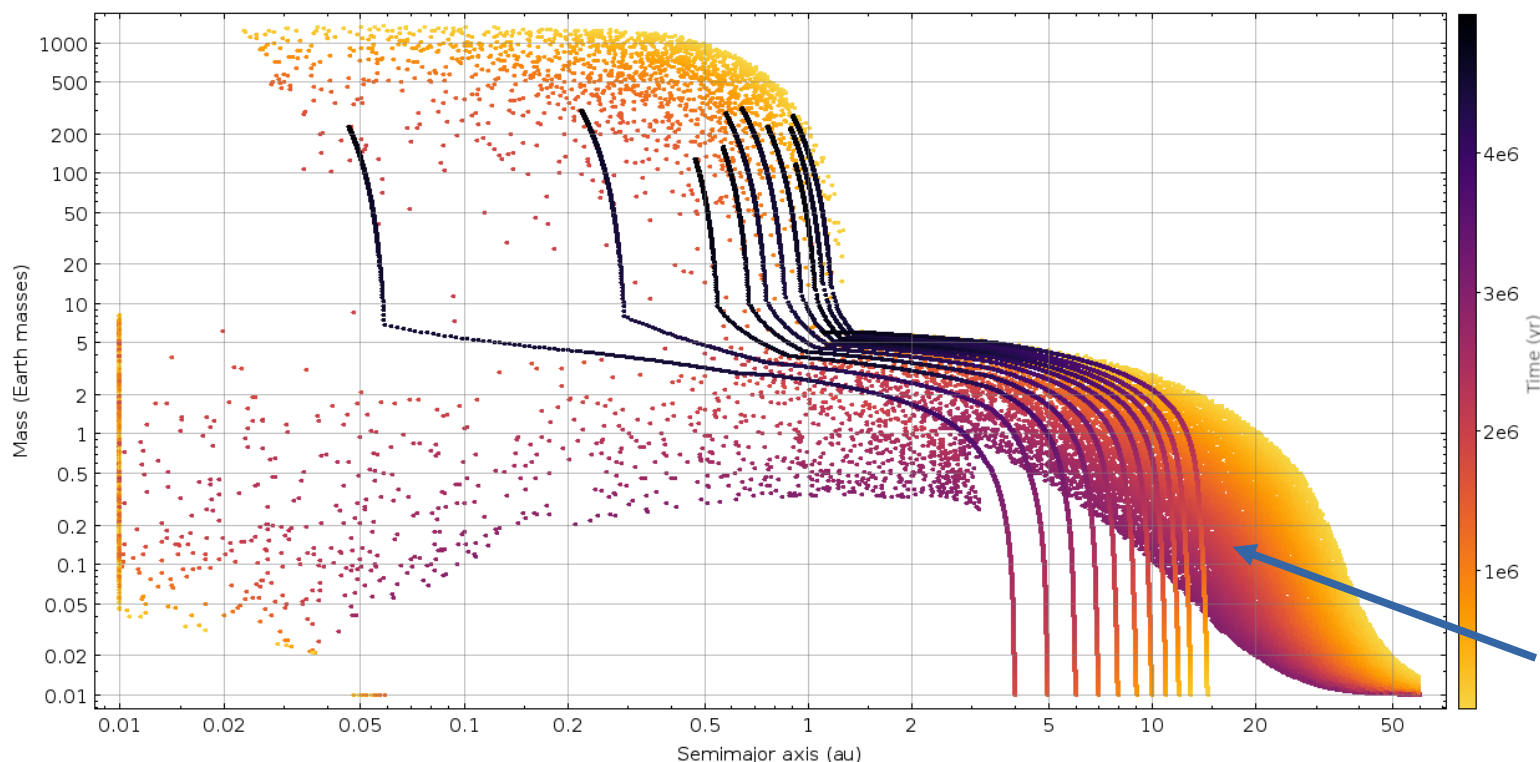


ArXes – Mercury-ArXes + Hephaestus



HEPHAESTUS (Turrini+2021; Pacetti+2022) is the Python compositional post-processing tool that resolves planetary compositions across 20+ elements. It combines the outputs of *JADE* (see presentation by Elenia) and *Mercury-ArXes* to resolve the compositional evolution of the forming planet over time.

Arxes – Mercury-Arxes + GroMiT



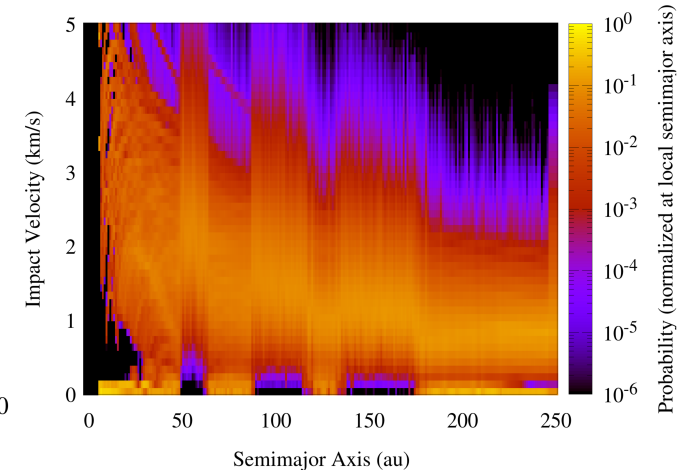
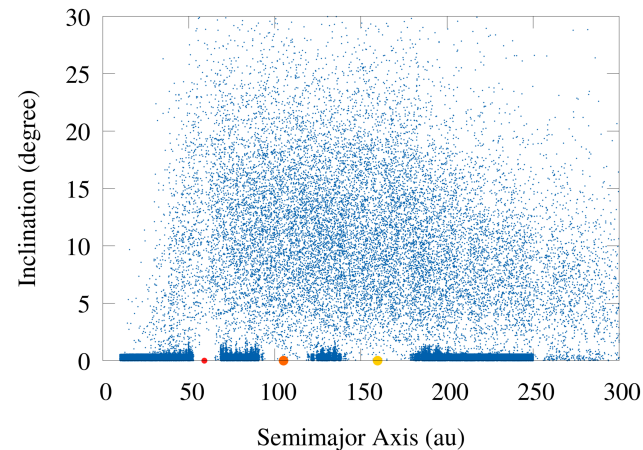
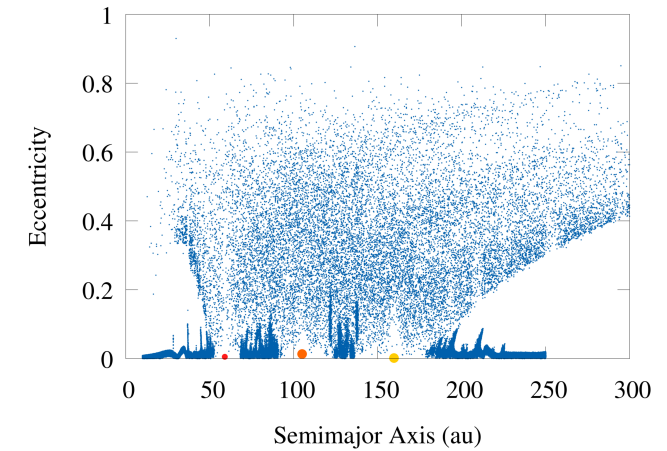
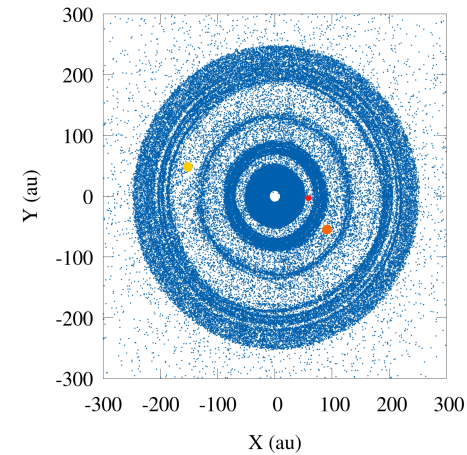
Identification of physically-realistic growth and migration tracks for Mercury-Arxes

GroMiT, the *Growth and Migration Track* code, tracks how a forming planet accretes pebbles and gas as well as how it migrates depending on the local environment of its native circumstellar disk (Polychroni+2023, see presentation by Danaï).

Arxes – Mercury-Arxes + Debris

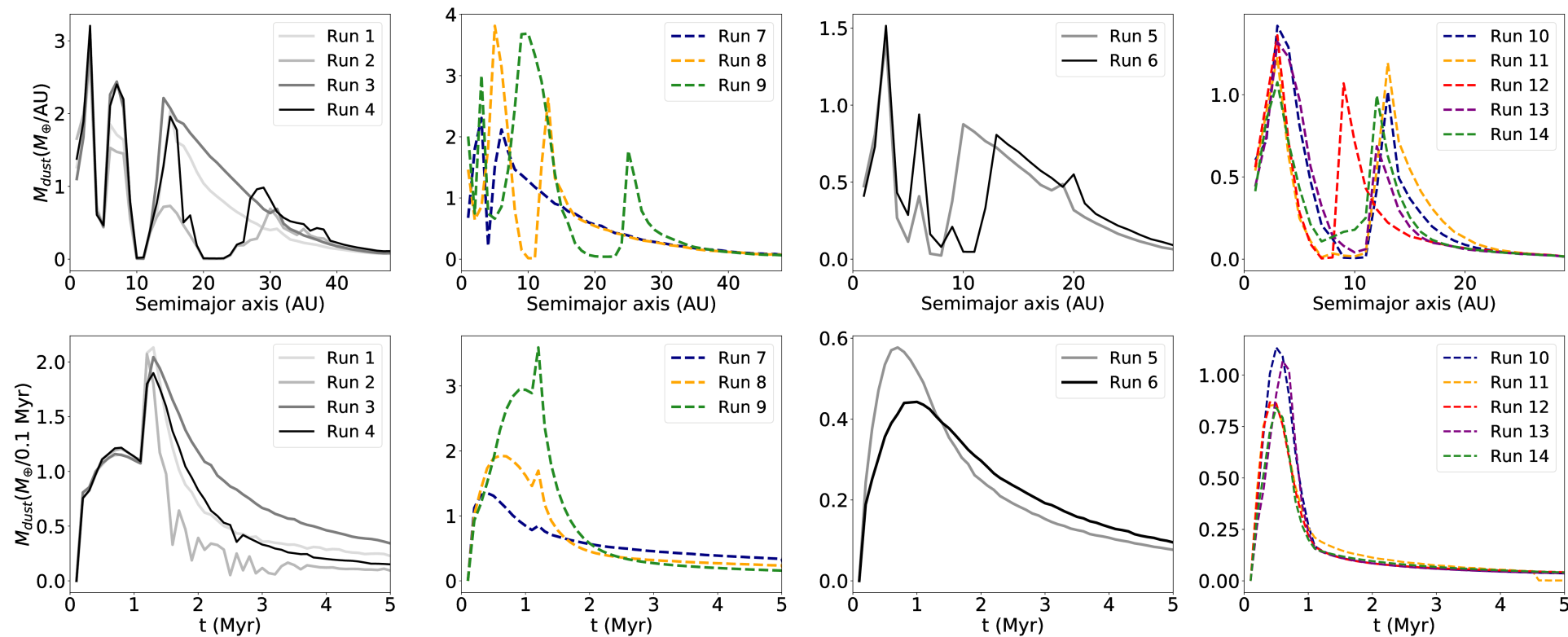
Debris (Turrini+2019, Bernabò+2022) is a parallel statistical collisional code to track the dust production due to planetesimal impacts.

Debris works in combination with the **FARI** collisional probability code (Marzari et al. 1996) to characterize the collisional environment resulting from the outputs of *Mercury-Arxes*.



Mercury-Arxes + Debris – Second-Generation Dust

Collisional dust production creates ring-like structures in discs that are not primordial (Turrini+2019; Bernabò+2022)



The peak of dust production is linked to the runaway growth of giant planets (Turrini+2019, Bernabò+2022)