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OPAL: HPC codes and simulations to unveil the Origins of Planets for the Ariel space mission.

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1. INAF- OATo; 2. INAF-IAPS; 3. INAF-OATs; 4. ICSC

USCVIII – General Assembly, Galzignano Resort, 14-18 Oct



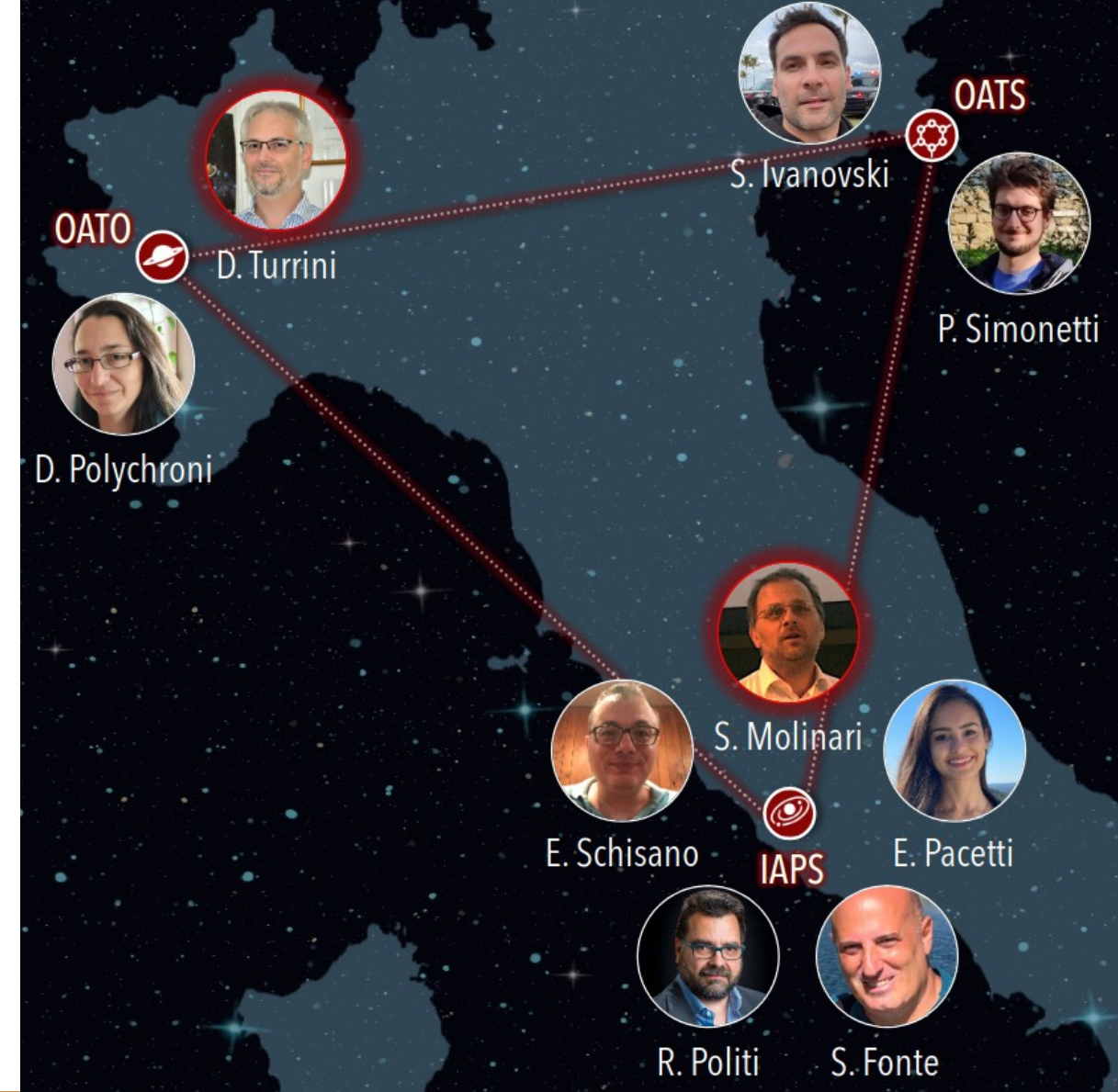
Meet the Arxes Team!

We do:

- Modelling
- Observations
- Computational science

We focus on:

- Star formation
- Planet formation
- Solar system
- Exoplanets



OPAL is:

- A PNRR Key Science Project with two goals:

- produce a *library of detailed synthetic atmospheric models of giant planets* for the Ariel space mission (Tinetti+2018, 2020; Turrini+2018, 2022)
- port the *Arxys* planet formation suite of codes to *HPC*

Takes advantage of allocated time in:

Leonardo (4 million core hours)

Pleiade (2.5 million core hours)

as well as the dedicated cluster GENESIS+.



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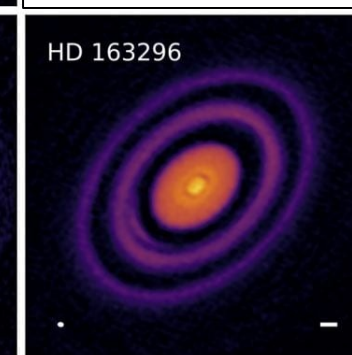
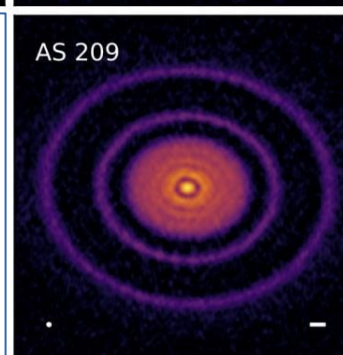
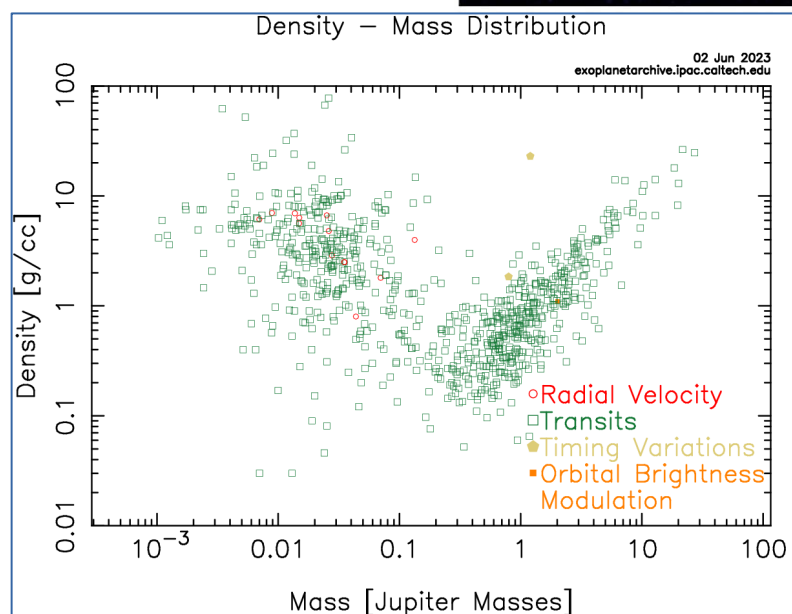
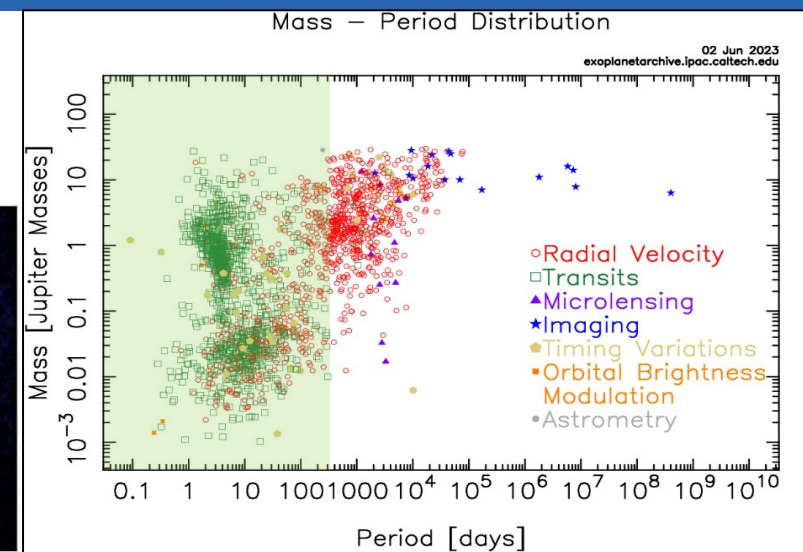
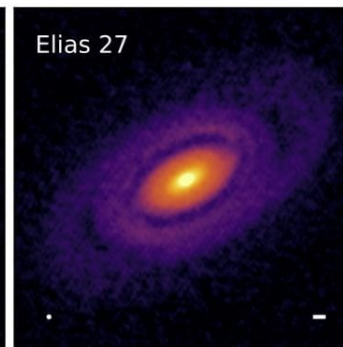
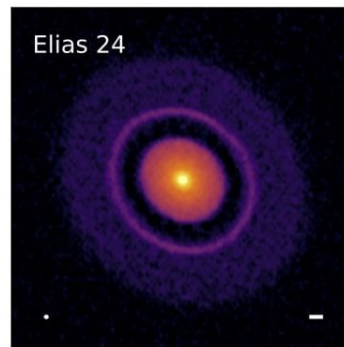


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Why do we need Arxes and OPAL?

- New observational data highlight our limited understanding of where planets form in disks

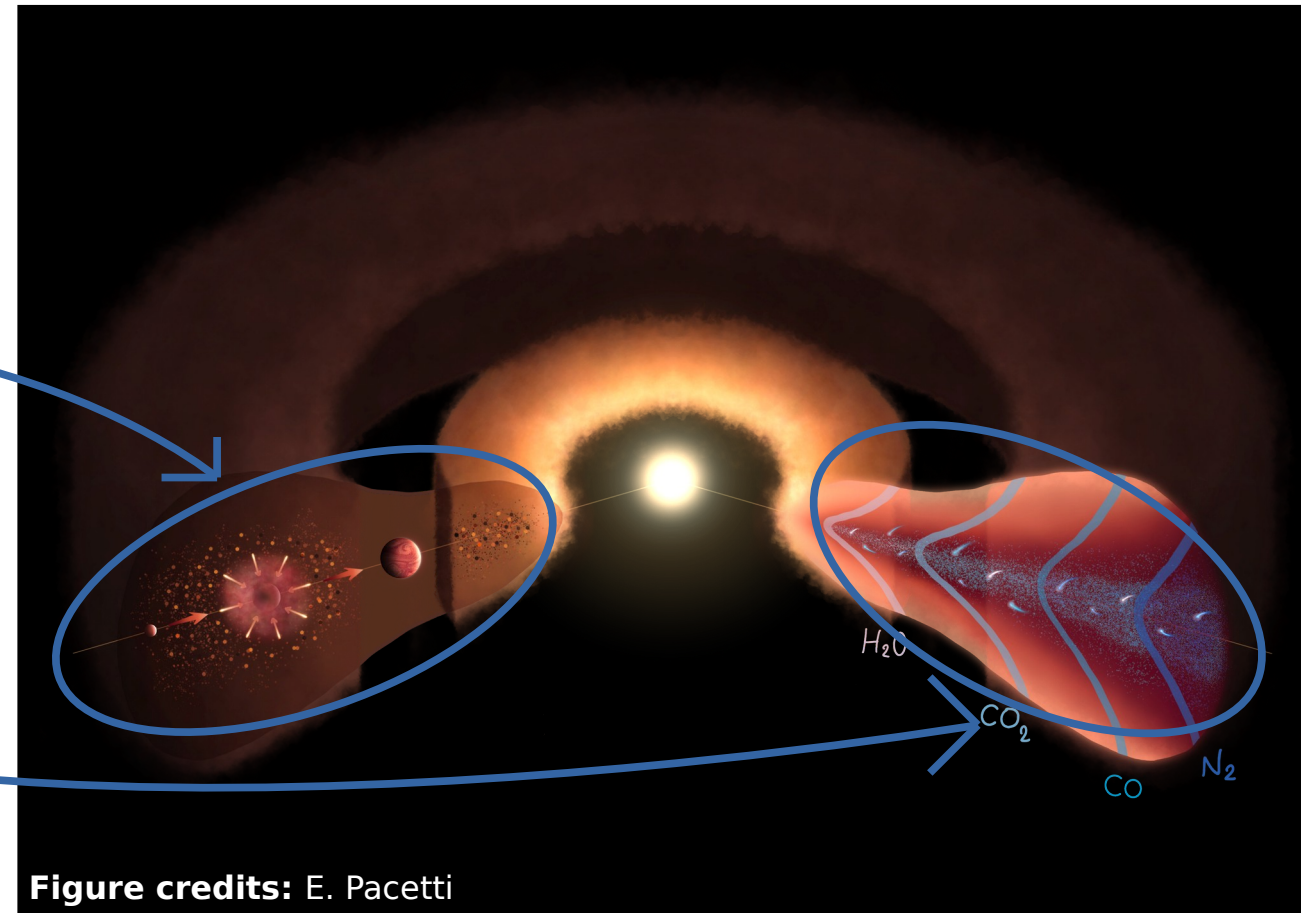


- Planets form and evolve under a wider range of conditions than previously thought.

Modern Challenges in Planetary Formation

Which **processes in disks** shape the **observable properties of planets**?

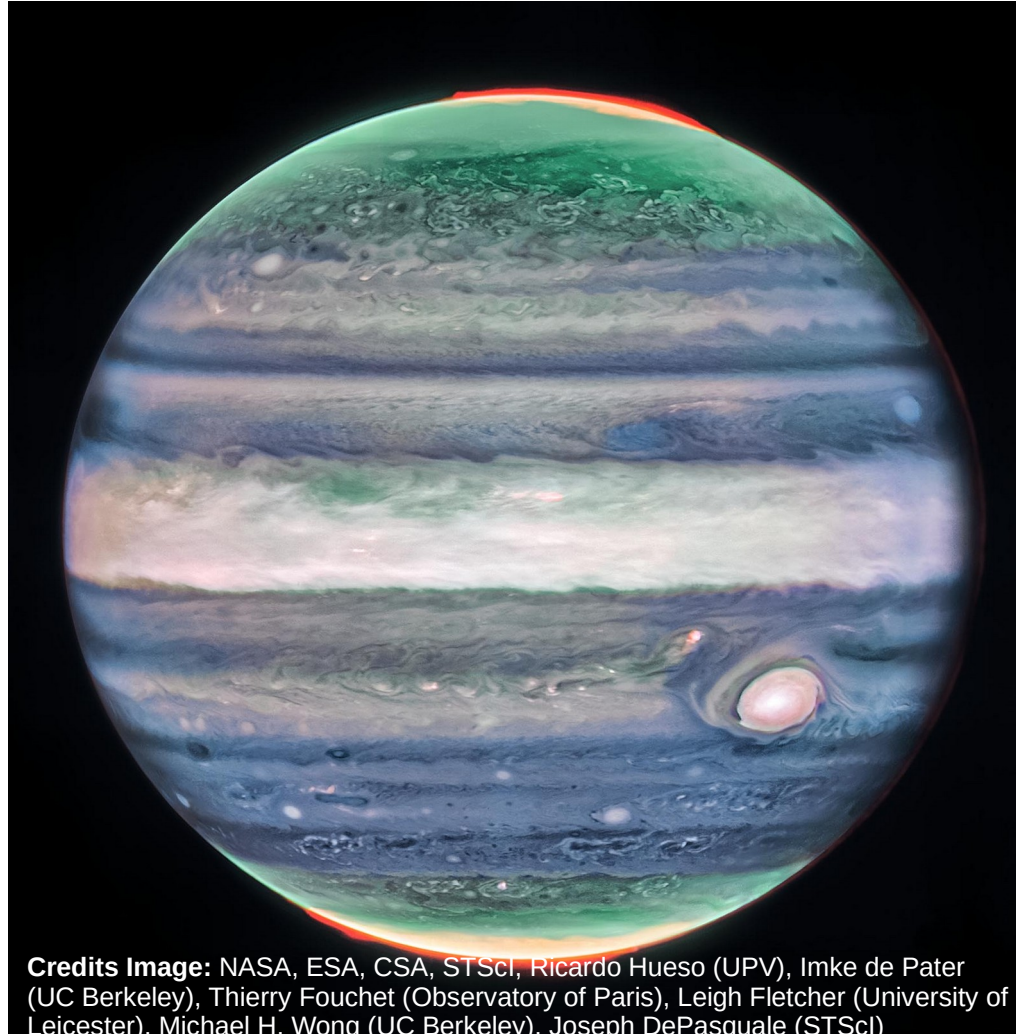
- **Planet formation**
accretion (gas/solid)
orbital migration
- **Planet Composition**
disk evolution
disk chemistry



Modern Challenges in Planetary Formation

What ***can*** we observe?

Modern Challenges in Planetary Formation



Credits Image: NASA, ESA, CSA, STScI, Ricardo Hueso (UPV), Imke de Pater (UC Berkeley), Thierry Fouchet (Observatory of Paris), Leigh Fletcher (University of Leicester), Michael H. Wong (UC Berkeley), Joseph DePasquale (STScI)



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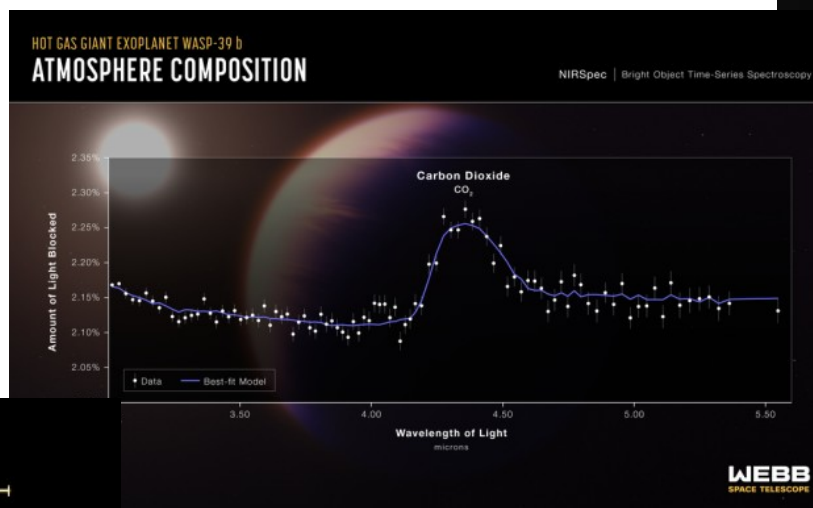


Modern Challenges in Planetary Formation

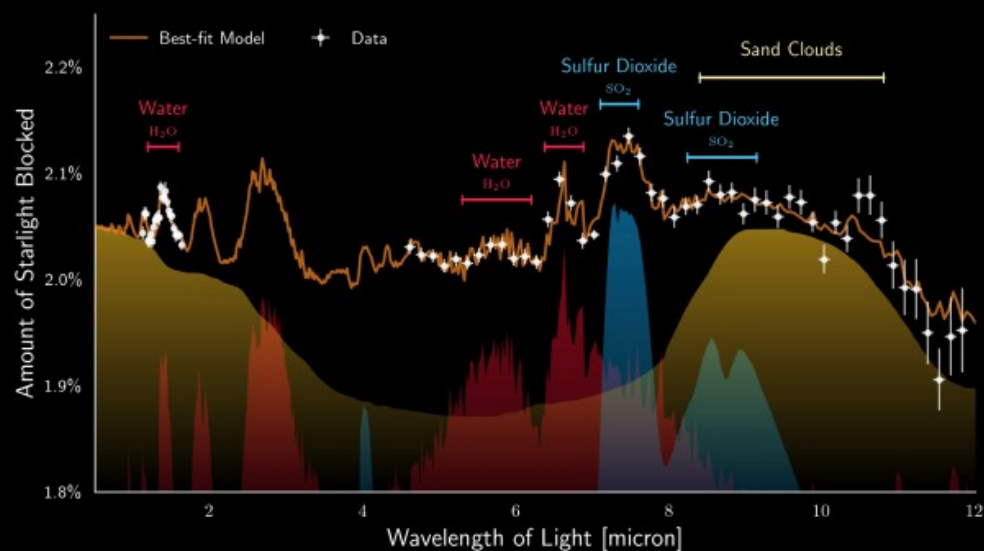
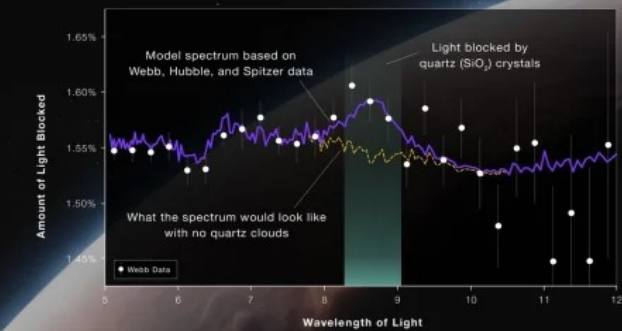


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Atmospheres Basically

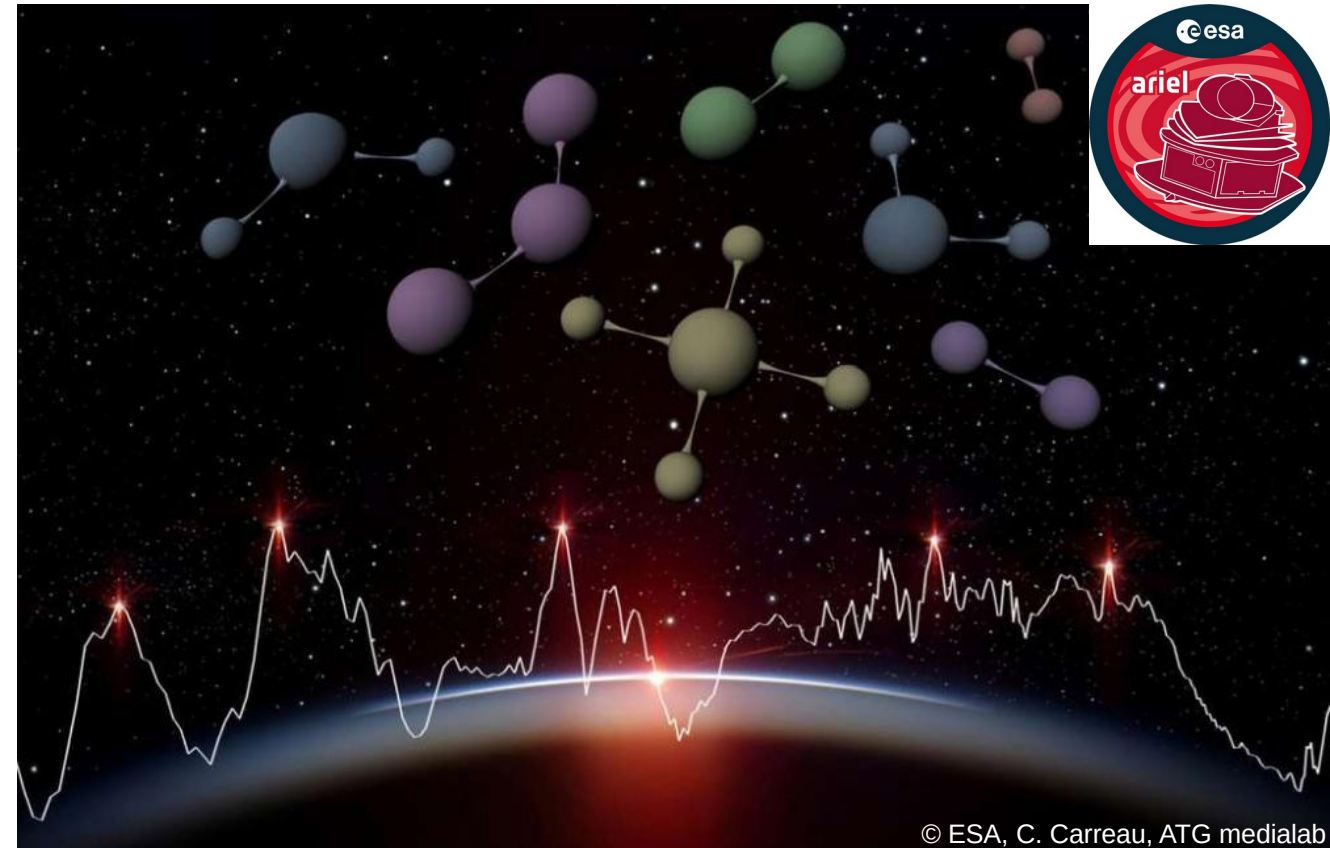


HOT GAS GIANT EXOPLANET WASP-17 b
COMPOSITION OF CLOUD PARTICLES



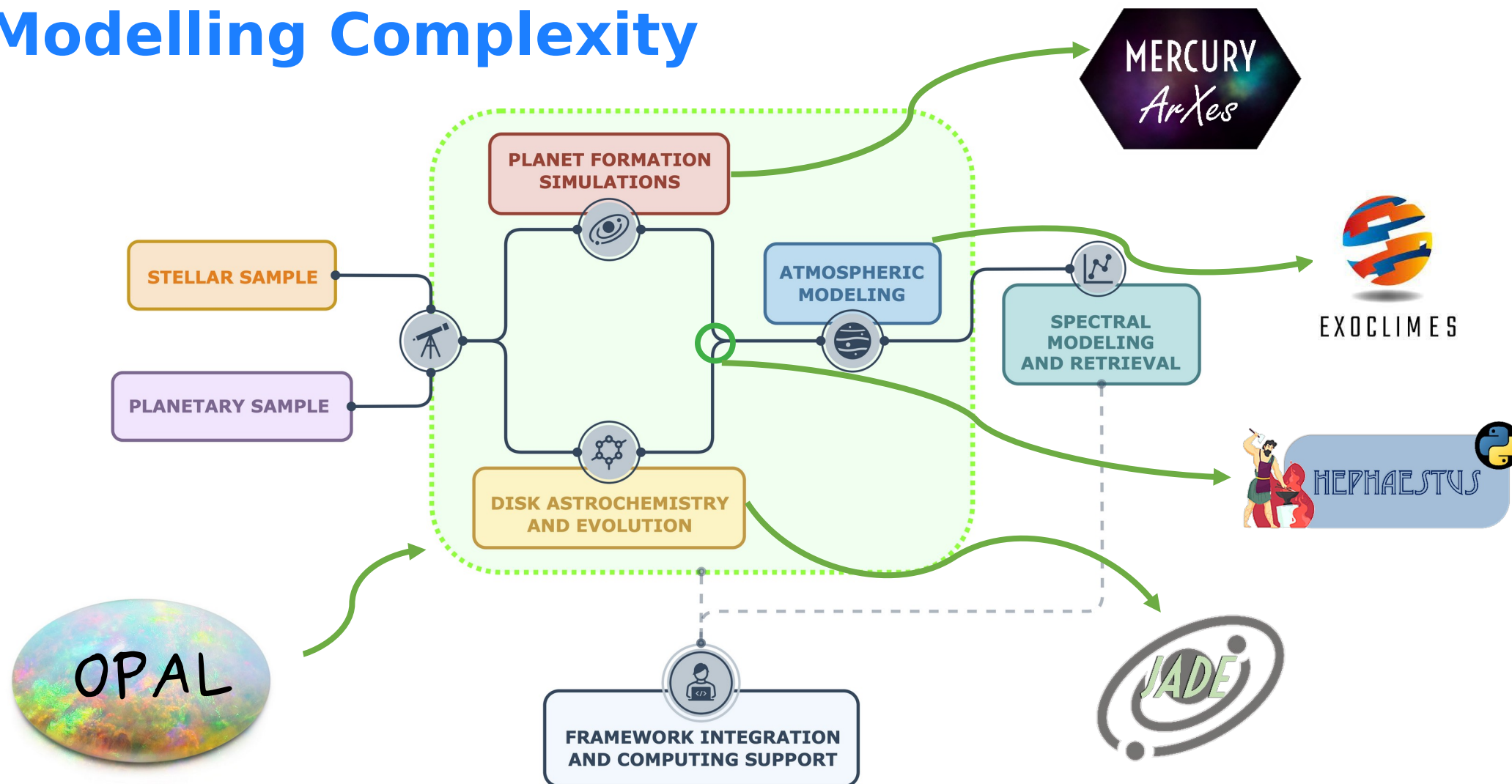
A Library of Synthetic Planetary Atmospheres

OPAL is the ongoing program to create an unprecedented library of end-to-end synthetic (exo)-planetary atmospheres, informed by actual data, using the **Arxes** suite of codes, to predict and consolidate what molecules can be detected in the planetary atmospheres that the **Ariel Space mission** will observe



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OPAL: Modelling Complexity



OPAL: Modelling Complexity



JADE (Pacetti et al. in prep.) is the multi-language (Python + Fortran) data-parallel code to jointly simulate the **physical and chemical evolution of protoplanetary disks** of the Arxes suite.

Mercury-Arxes (Turrini+2019,2021) is the parallel n-body code of the Arxes suite incorporating physical libraries to simulate **planet formation in protoplanetary disks** (see Monday presentation).



HEPHAESTUS (Turrini+2021; Pacetti+2022) is the Python compositional post-processing tool of the Arxes suite that resolves planetary compositions across 20+ elements.

FastChem and **Vulcan** are atmospheric modelling codes from the University of Bern's *ExoClimes* suite that convert Hephaestus' elemental compositions into atmospheric molecular compositions (e.g. Fonte+2023).

GroMiT: The new kid in town!

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 (e.g. Johansen+2019, Ida+2016, Tanaka+2020).

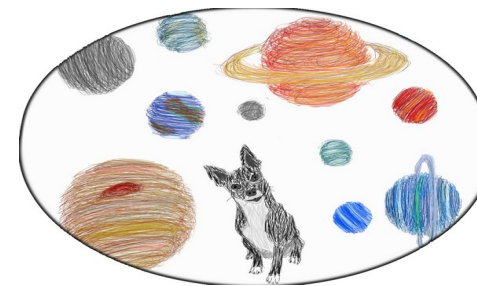
Born as a plug-in for *Mercury-Arxes* to make it self-consistent it found plenty of applications also as a stand-alone code in exploring the formation histories of **observed planets (GAPS)**.

It comes in two flavours!

Single Planet Mode
(Polychroni+2023)

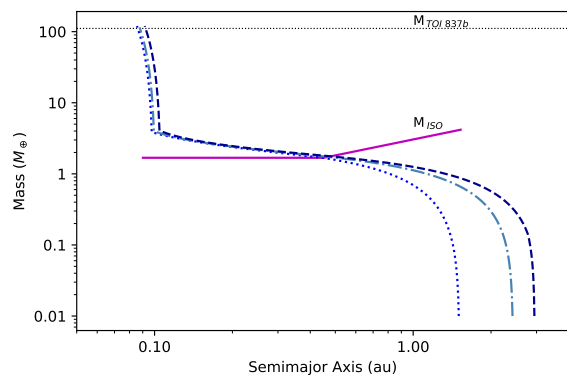


Population Synthesis Mode
(Polychroni+ in prep)

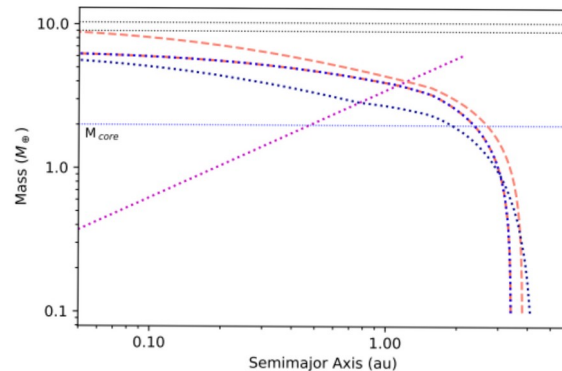


Applications to observed systems

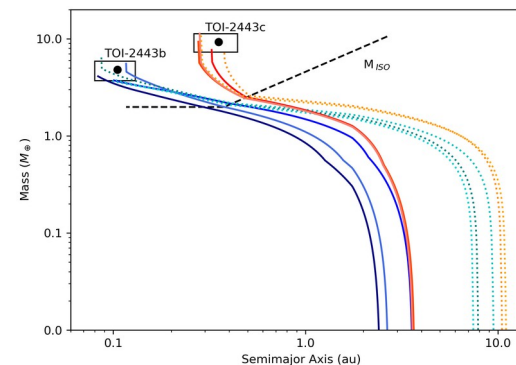
(Mantovan+2023a,b; Damasso+2024; Zingales+2024; Naponiello+sub)



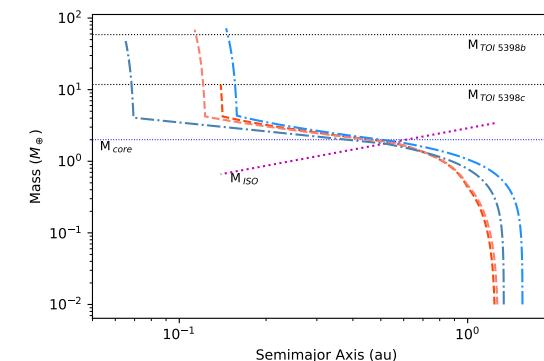
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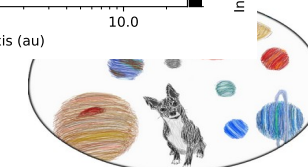
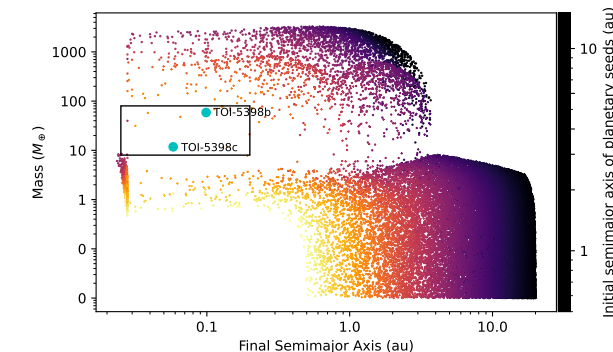
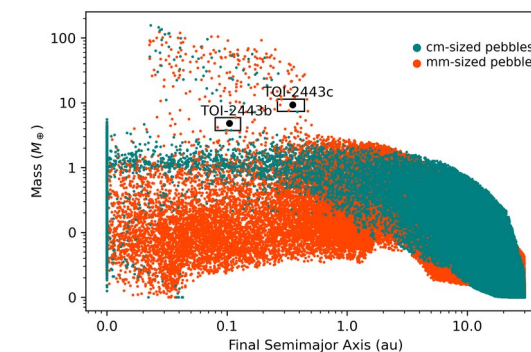
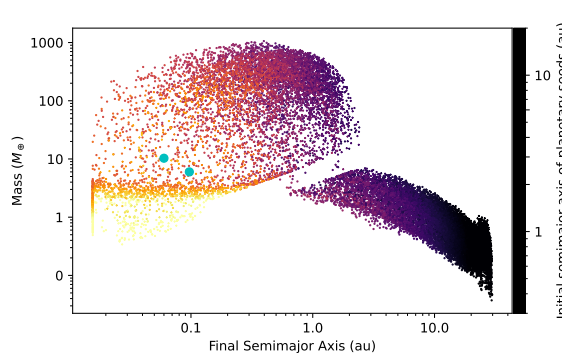
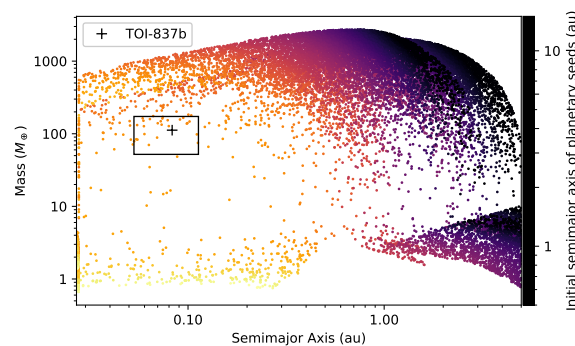
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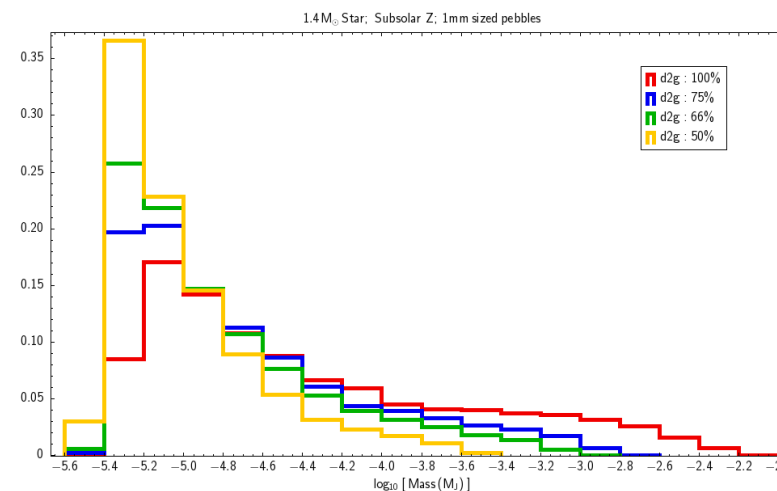
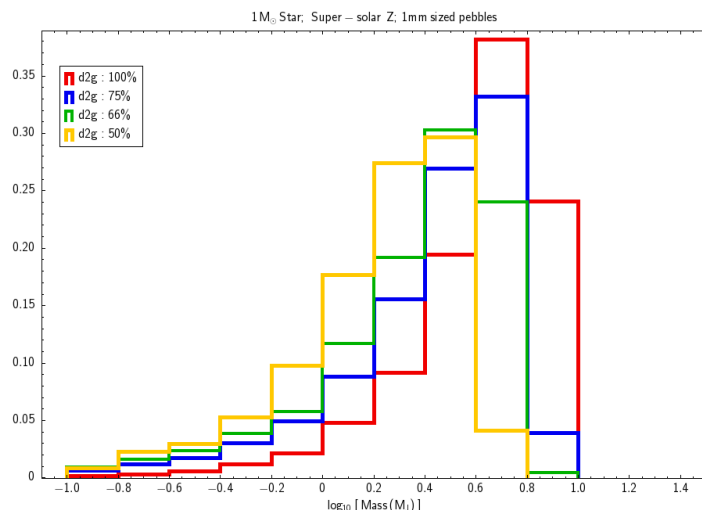
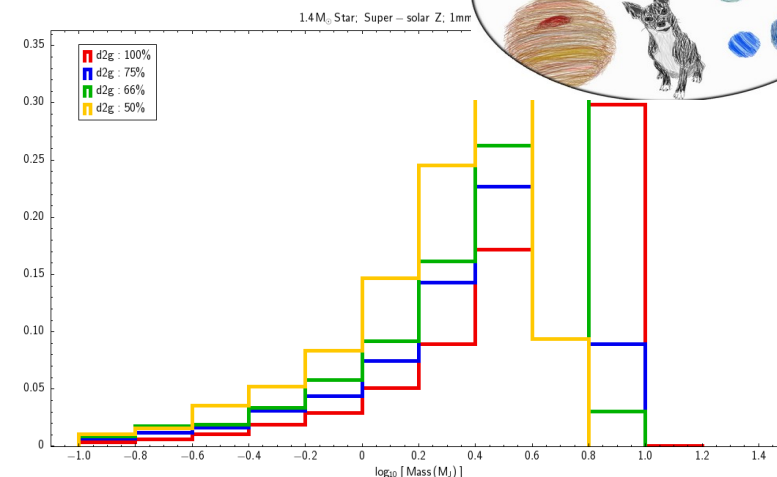
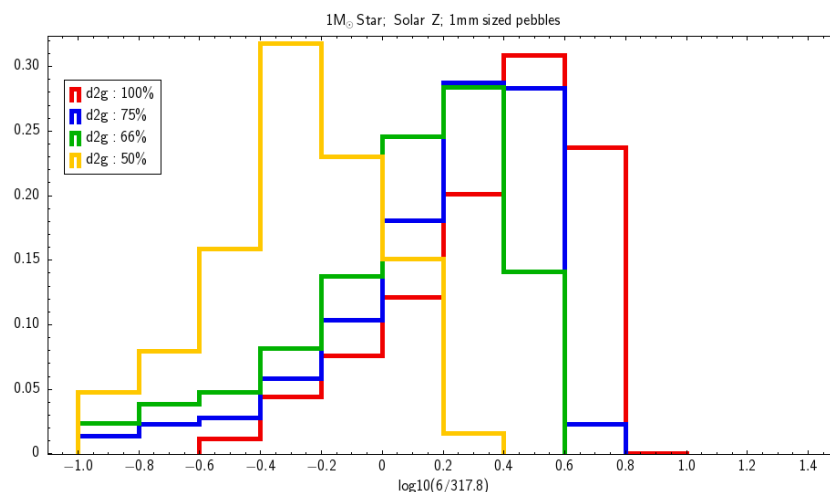
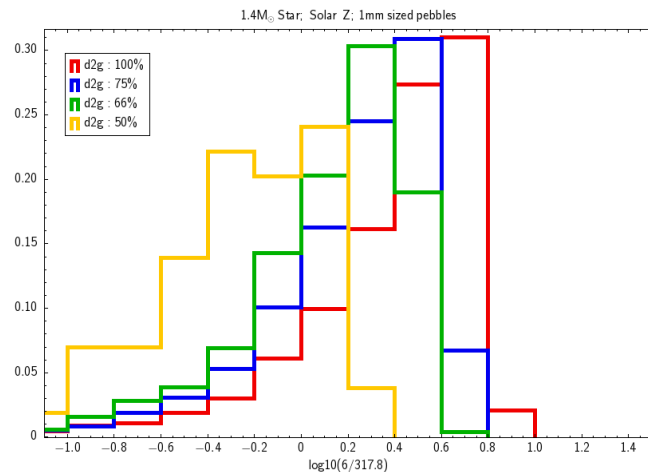
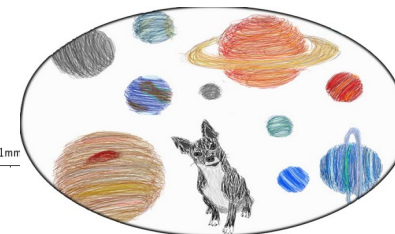


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Synergies with Stellar Characterisation

(Biazzo+2022; Magrini+2022; Filomeno+2024; Tsantaki+ in prep)



OPAL as a Key Science Project

- The **seed of OPAL** is part of the Ariel-IT 2025's activities: its scope and planetary sample are limited as it relies on existing infrastructure (**Genesis cluster** at INAF-IAPS, possible support from **INAF Pleiadi TBD**).
- OPAL is the **next frontier in computational planetary science**: combining multi-domain and multi-physics *ab initio* simulations to fully understand the information encoded into planetary atmospheres.
- **Our community is currently the most advanced** in this integration of expertise and code in a unified scientific and computational ecosystem.
- **OPAL is a coordinated effort between the ARIEL, INAF and the PNRR**