Speeding up cloud models for faster and scalable atmospheric retrievals

Voyer & Changeat (2026)

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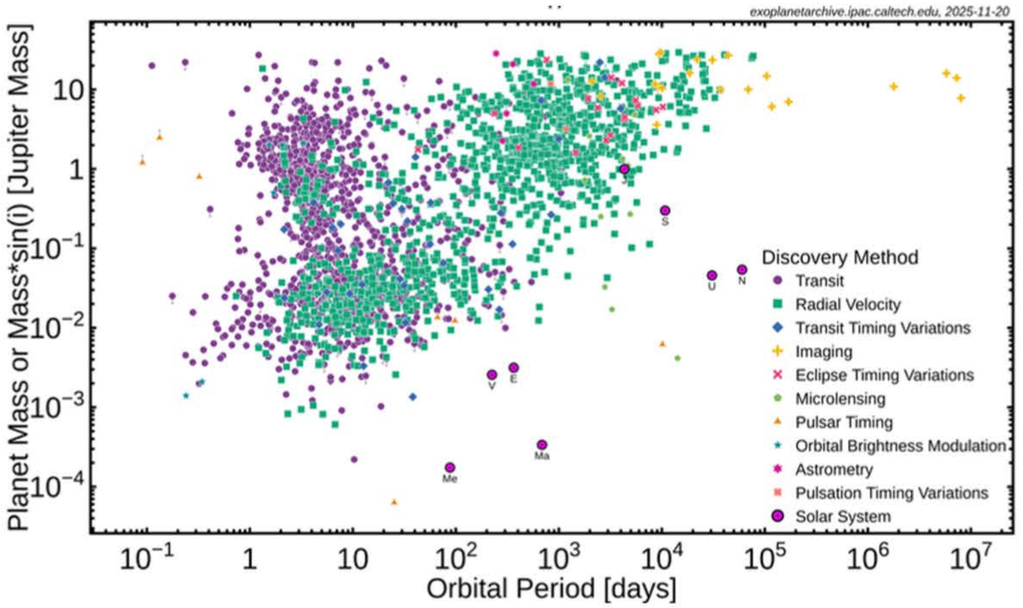
cea

Context

Key questions that drives current research:

- **Which processes govern the structure and composition of exoplanets ?**
- **What is the lasting impact of formation processes on exo-atmospheres ?**
- **How do planets form & evolve?**
- **Which exoplanets/exomoons are habitable and how can we study them ?**

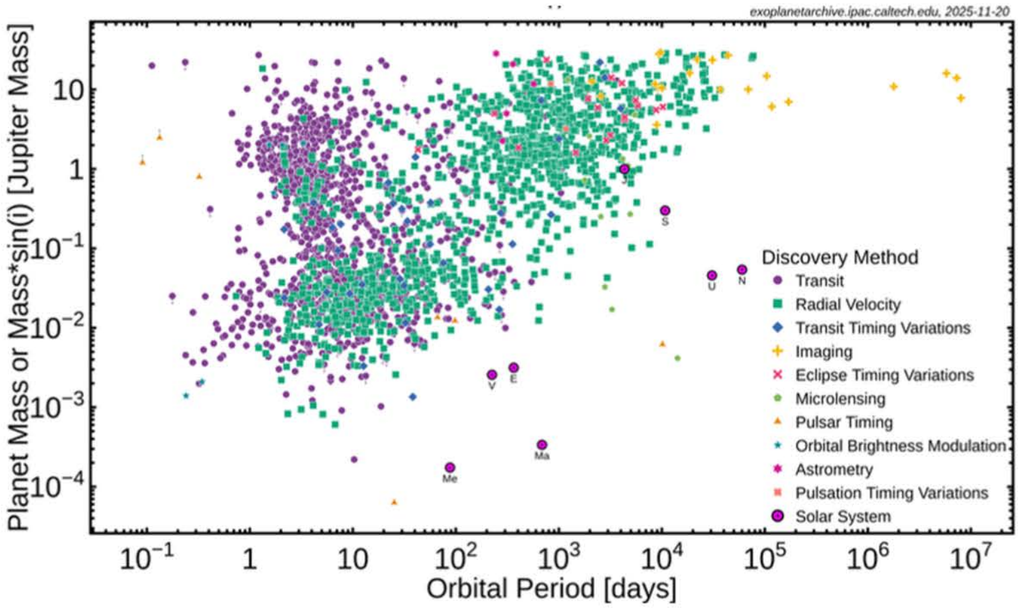


The exoplanet population

Context

My research focuses on two topics:

- **Which processes govern the structure and composition of exoplanets ?**
- What is the lasting impact of formation processes on exo-atmospheres ?
- **How do planets form & evolve?**
- Which exoplanets/exomoons are habitable and how can we study them ?

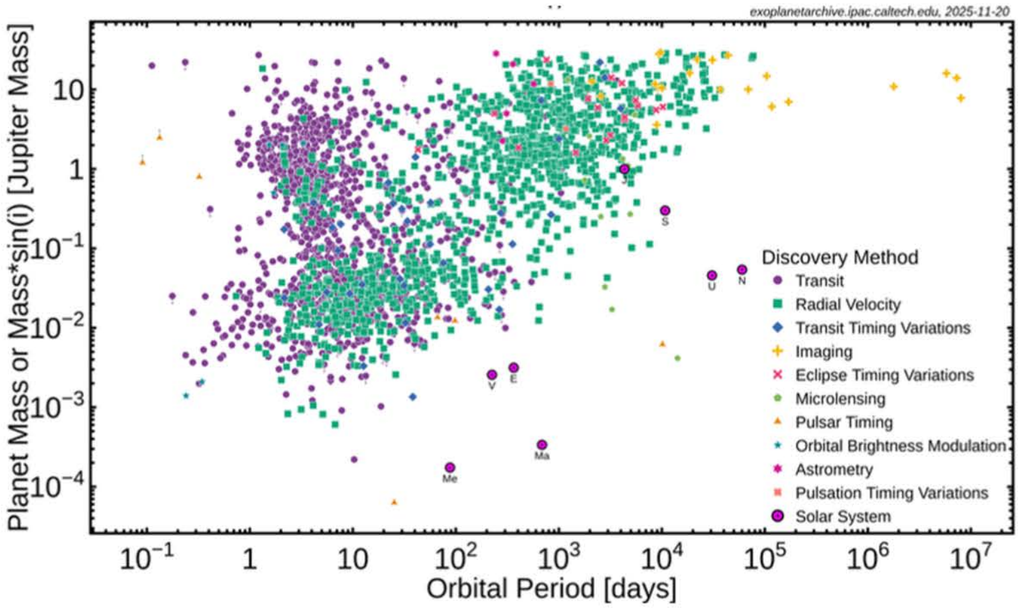


The exoplanet population

Context

Drawbacks of transit spectroscopy:

- Measure of a perturbation, the signal is limited by the poisson noise of the star
- Subject to significant systematics induced by stellar activity (Louca+2023, Thompson+2024, Cristo+2025, ...)



The exoplanet population

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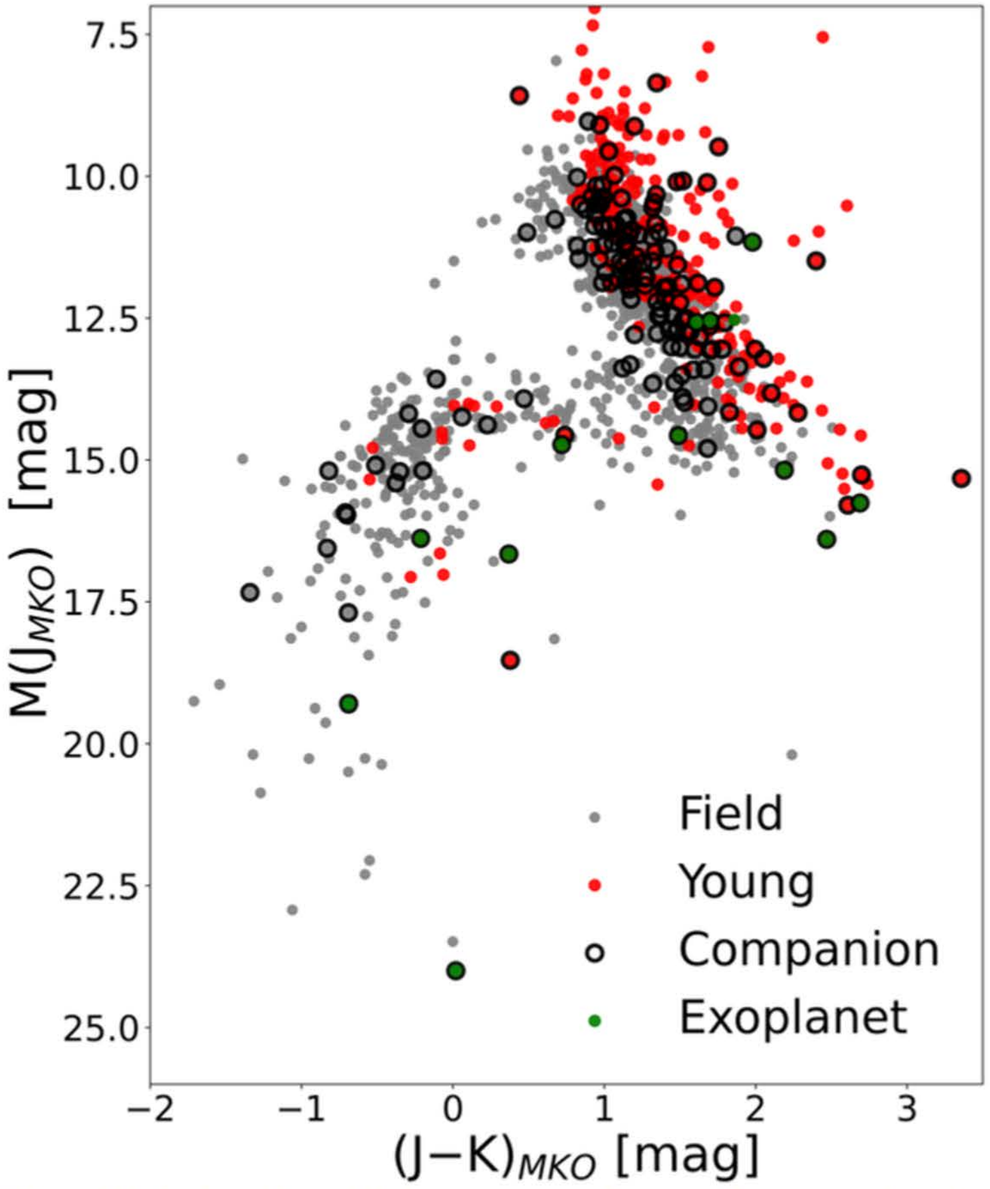
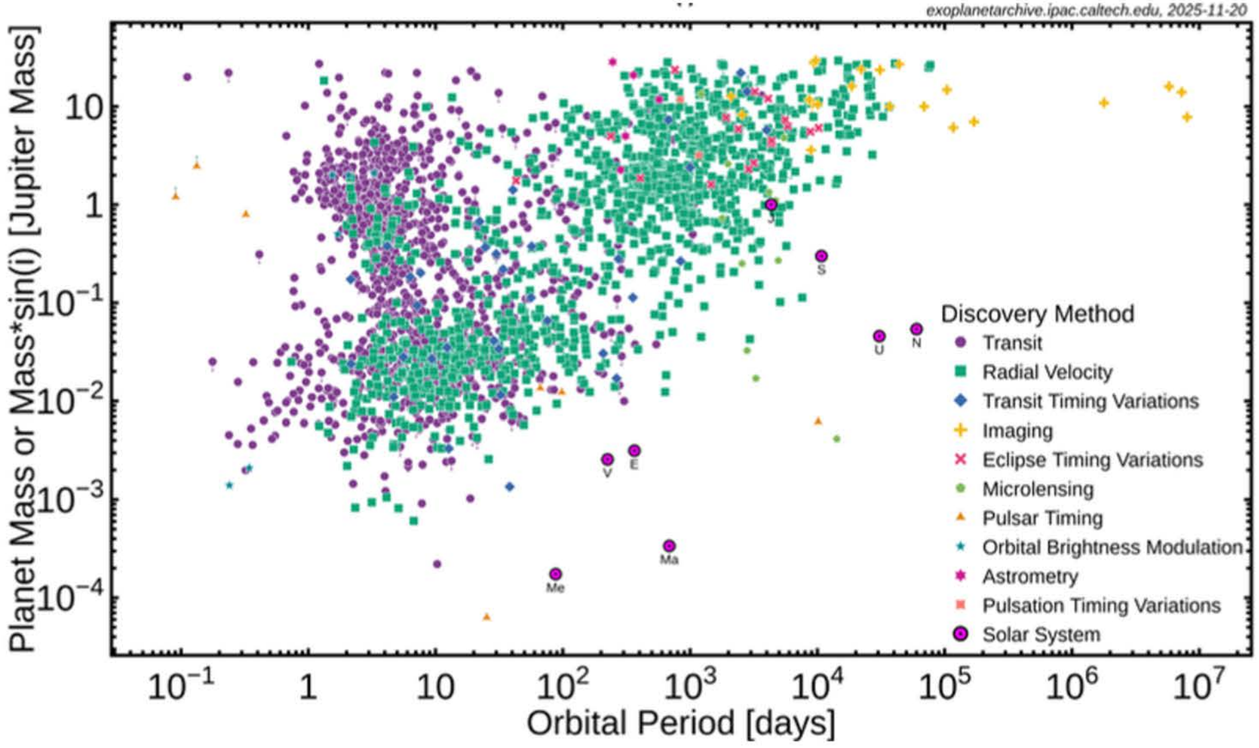


The “historical” brown dwarf population

Data from the UCS, Schneider et al. (2023)



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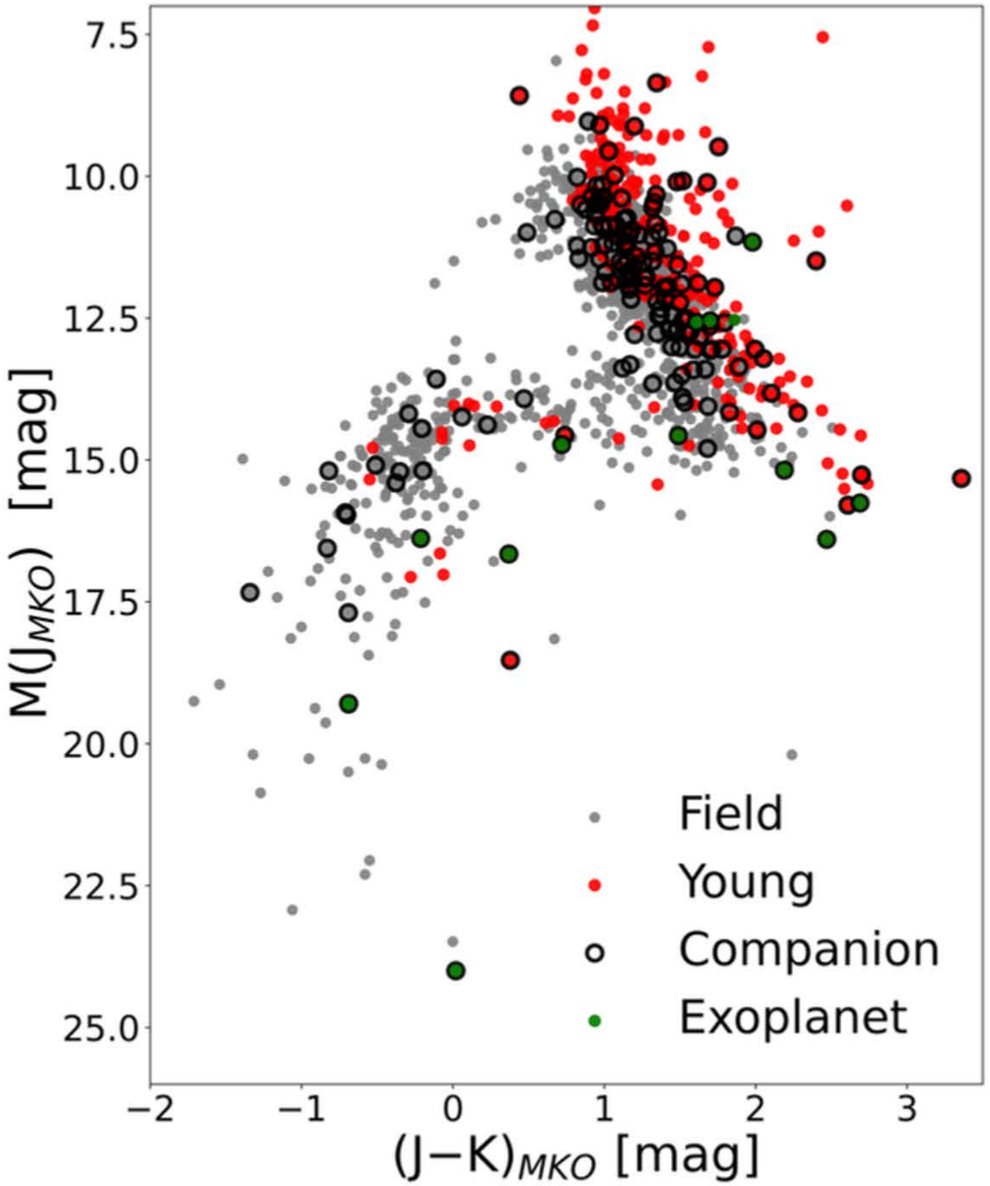


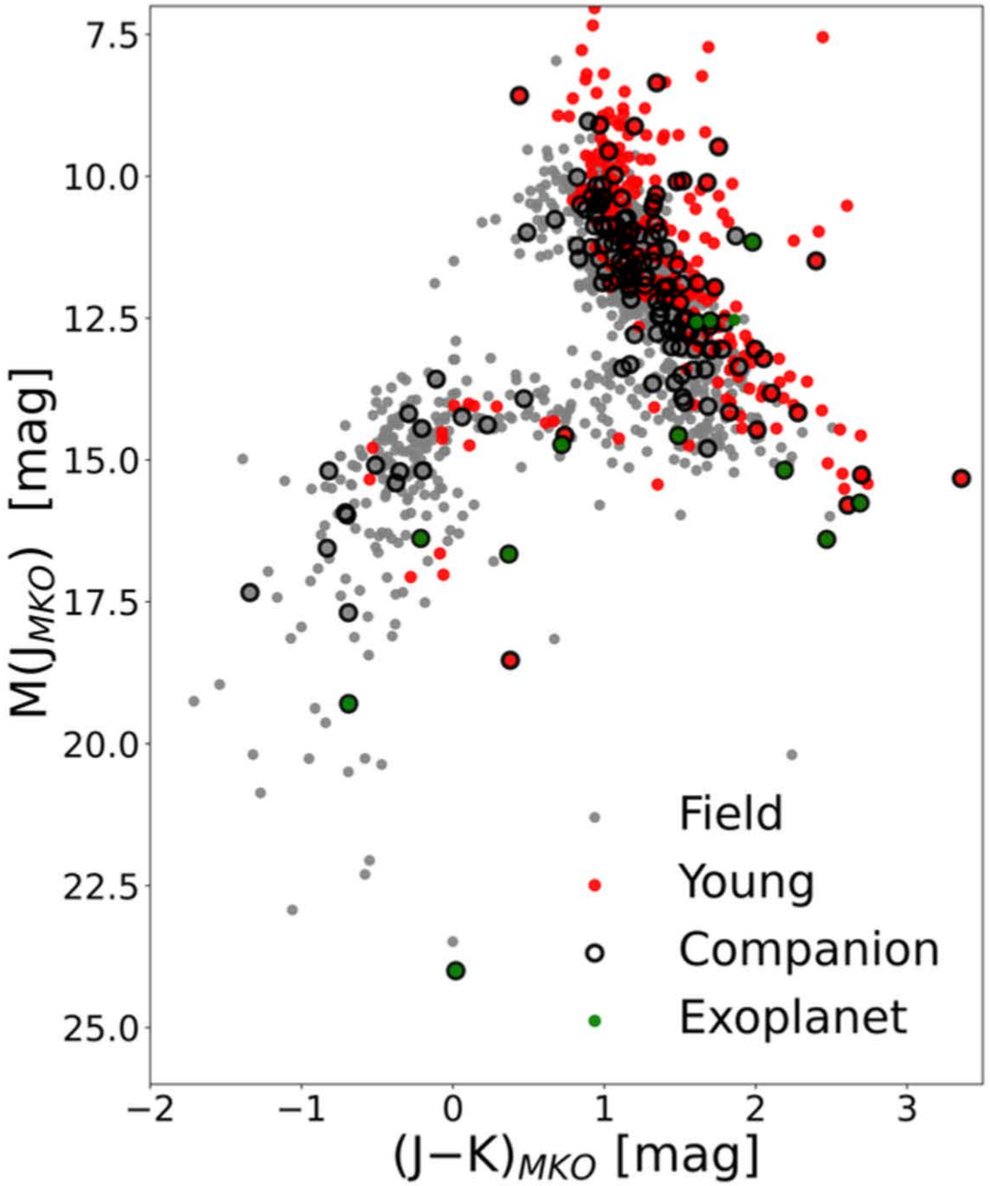
The "historical" brown dwarf population

Data from the UCS, Schneider et al. (2023)

- Covers the **sub-stellar objects** observed in direct imaging
- Ranges from 80 Jupiter Mass to 1 Saturn mass (candidate, Lagrange+2025)
- Effective temperature between 2900 K to 283 K (Deacon+ 2014b, Kühnle+2025)
- Ages ranging from <2 Myr to 9.5 Gyr (Luhman+ 2007d, Faherty+2010)

Context

A mixed population of brown dwarfs, lowest mass stars, planetary mass companions and exoplanets.



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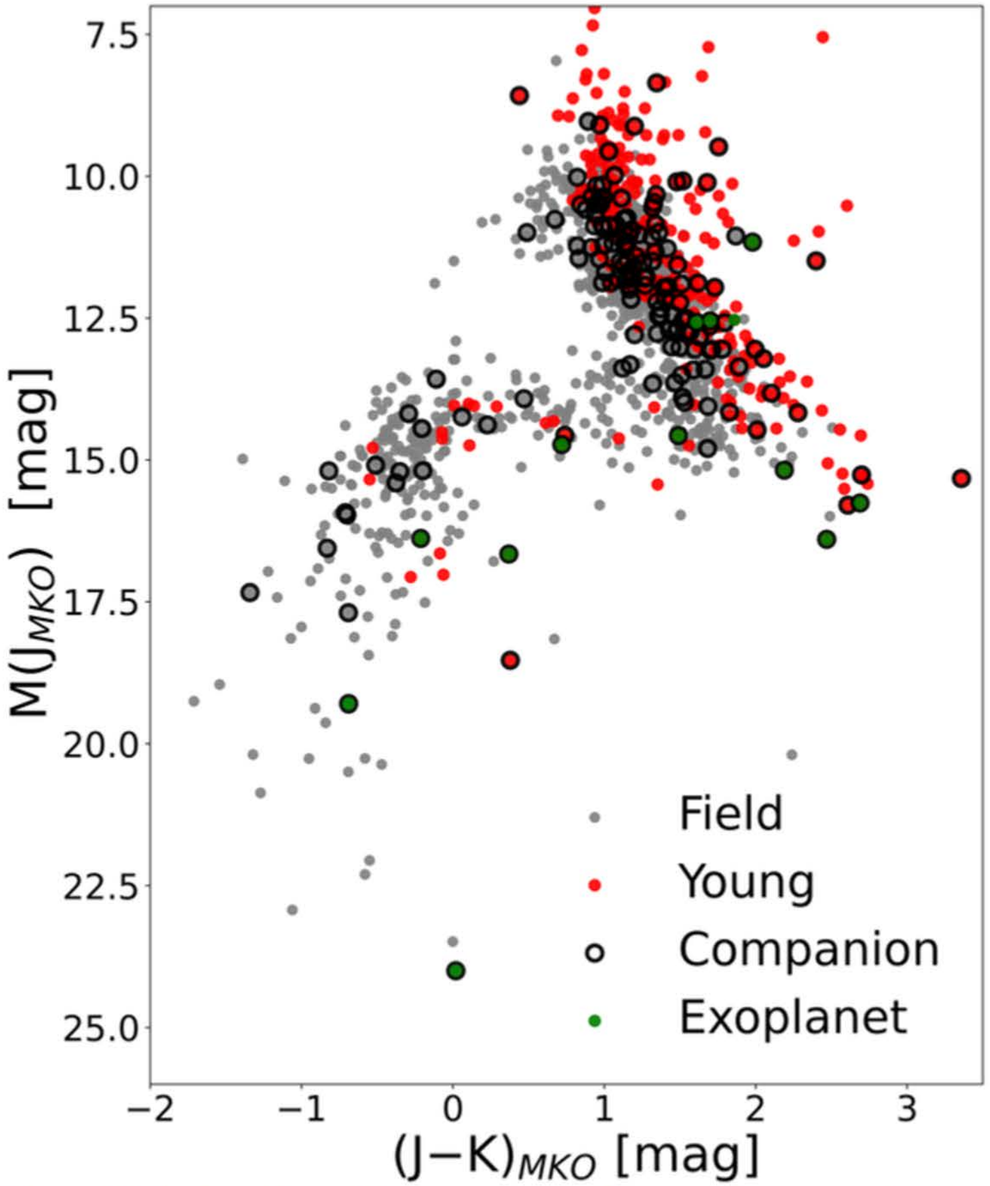

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A mixed population of brown dwarfs, lowest mass stars, planetary mass companions and exoplanets.

These targets provide ideal laboratories to study the evolution and the processes that governs the structure and composition of exoplanets atmospheres.

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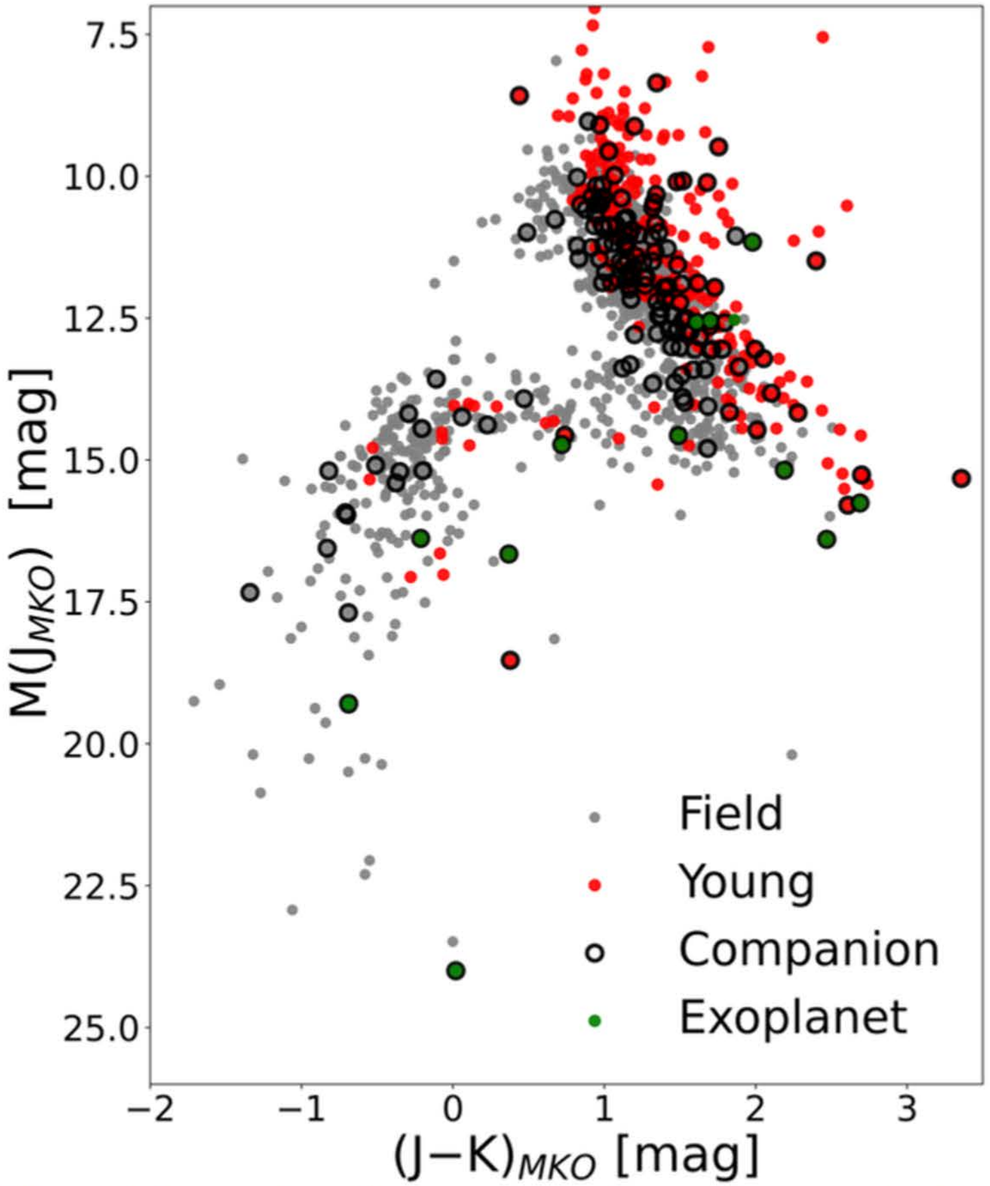

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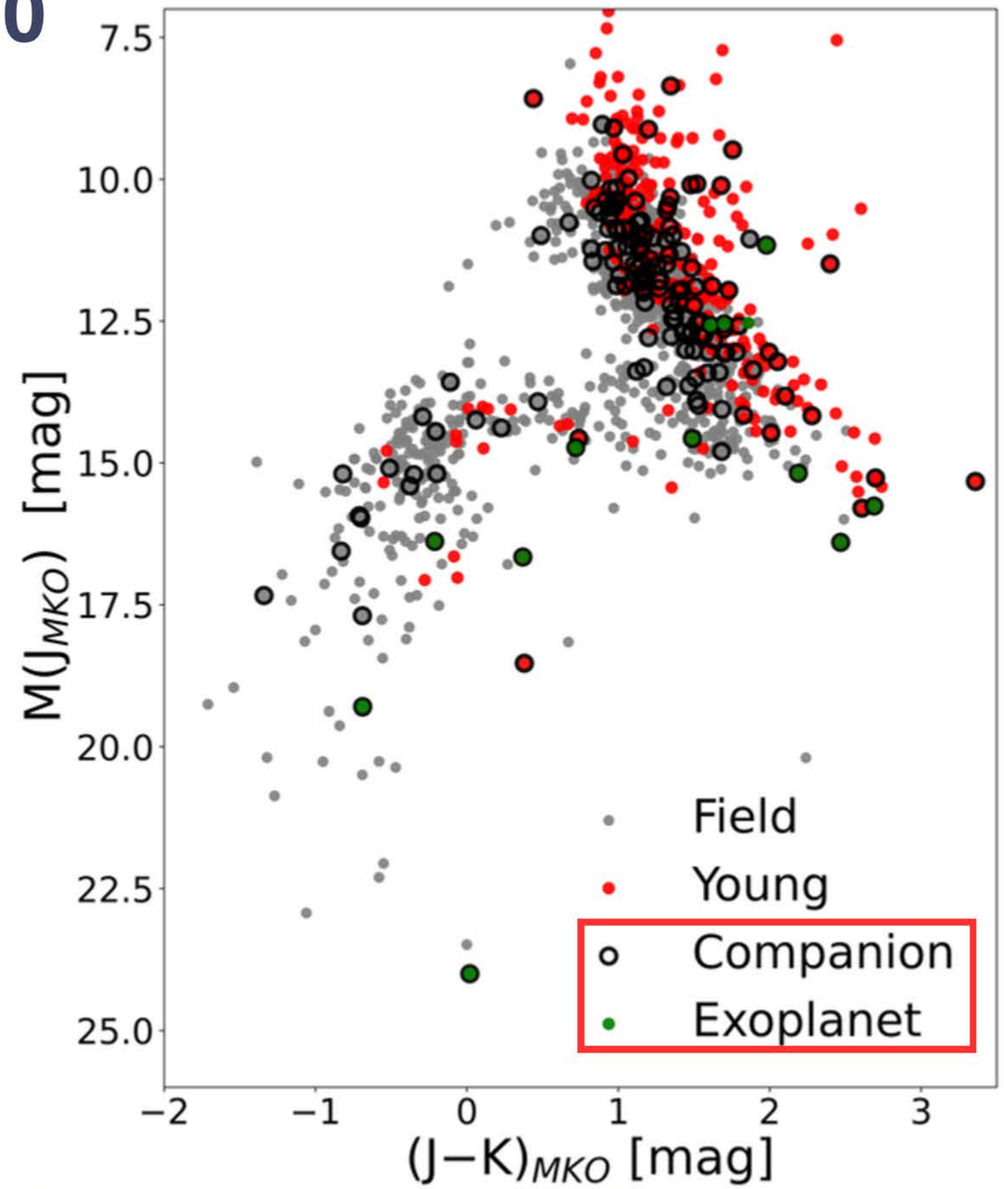
Ideal laboratories because the signal is no longer caped by the poisson noise of the star but the poisson noise of the planet itself.

Context



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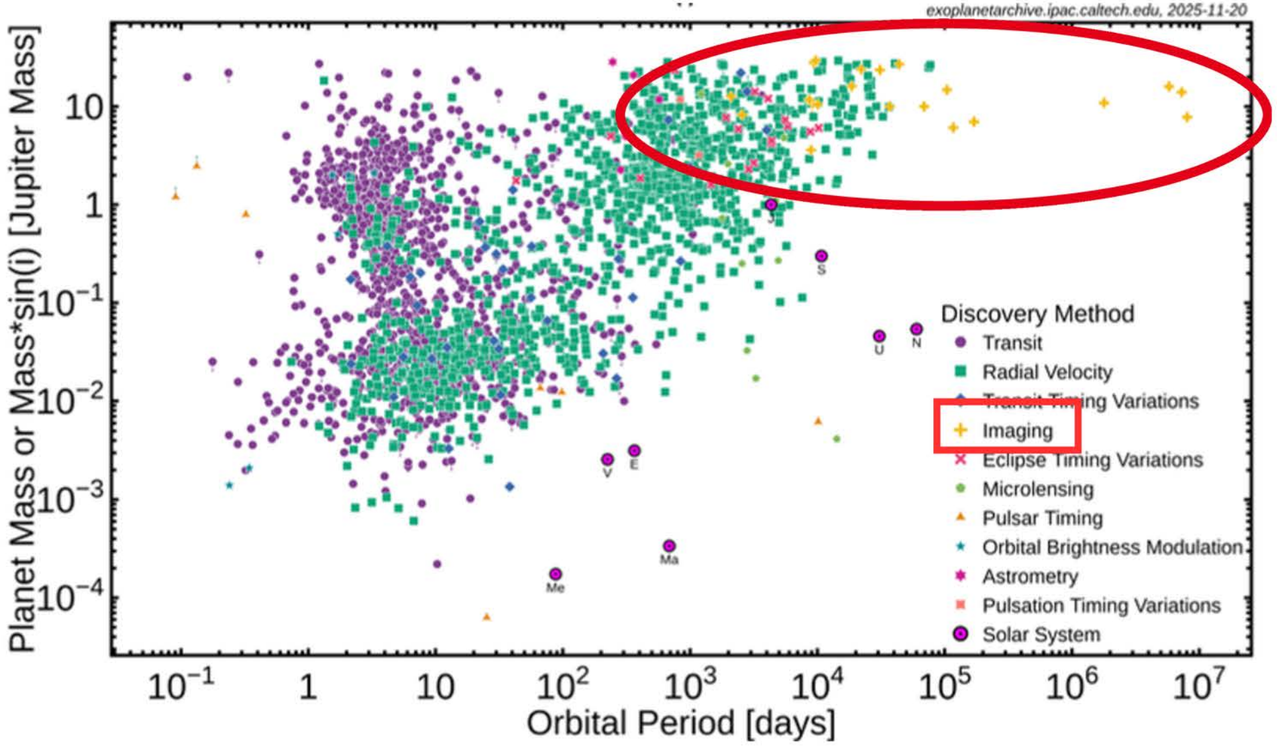
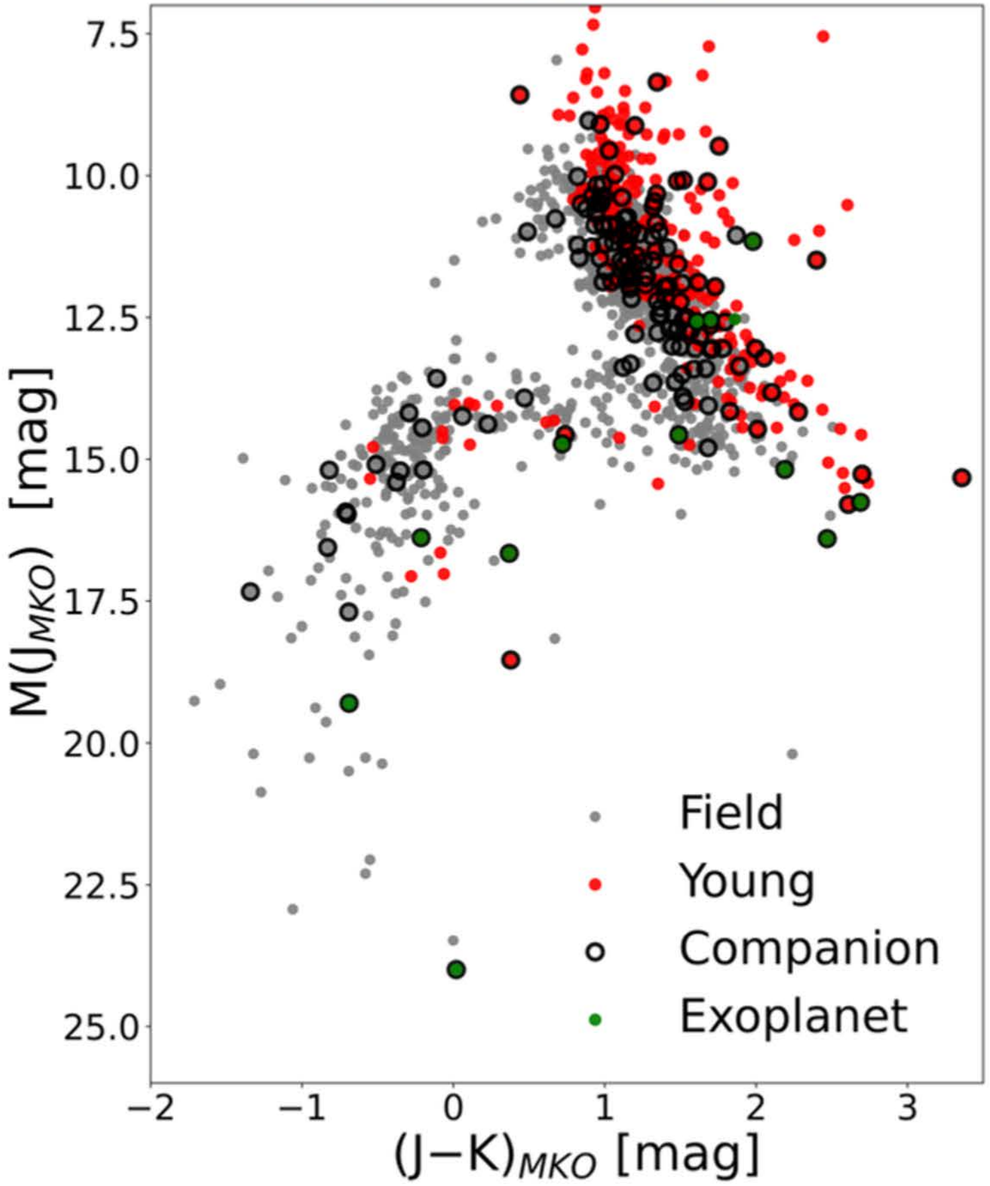


The exoplanet population

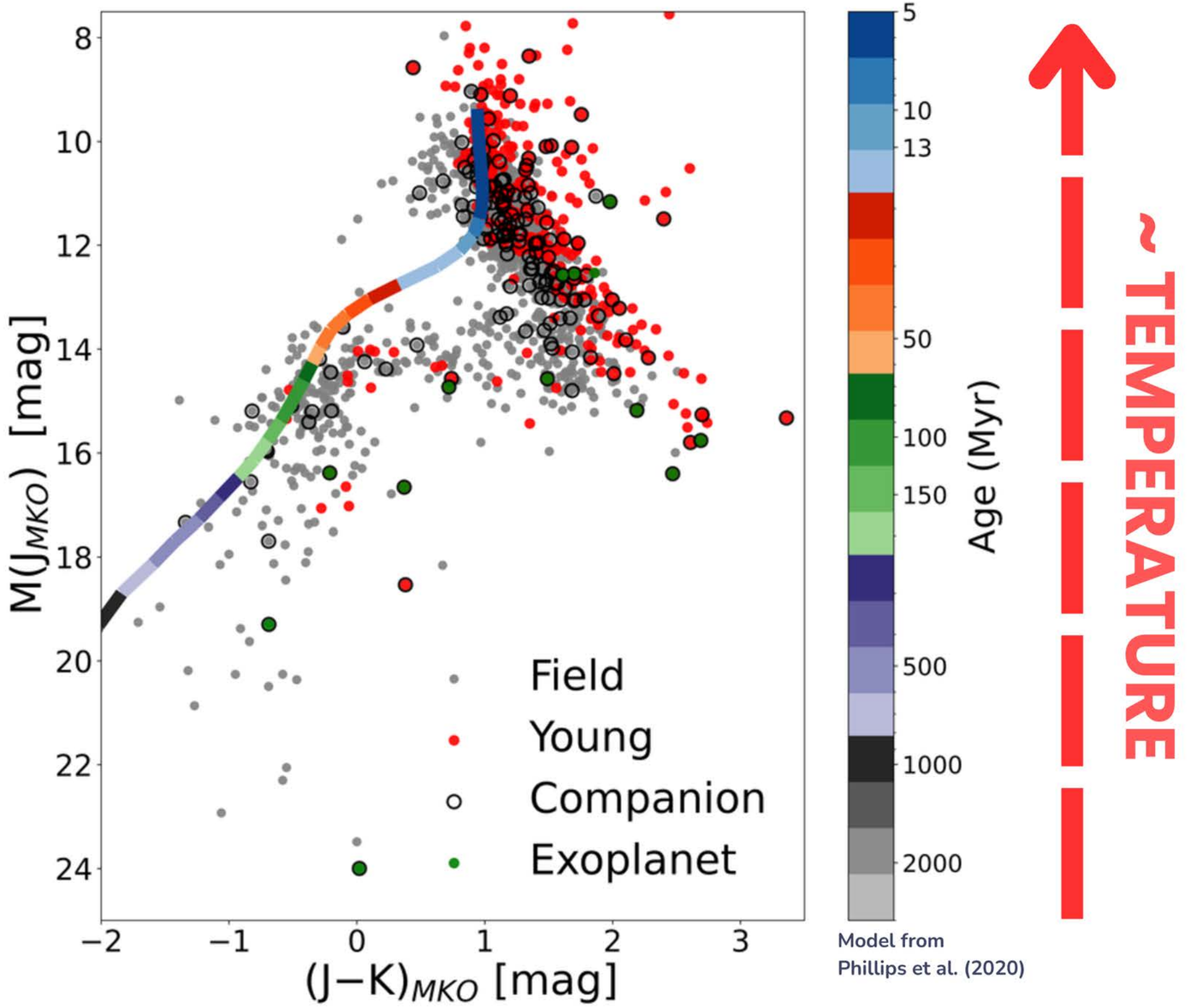
Context

~ AGE



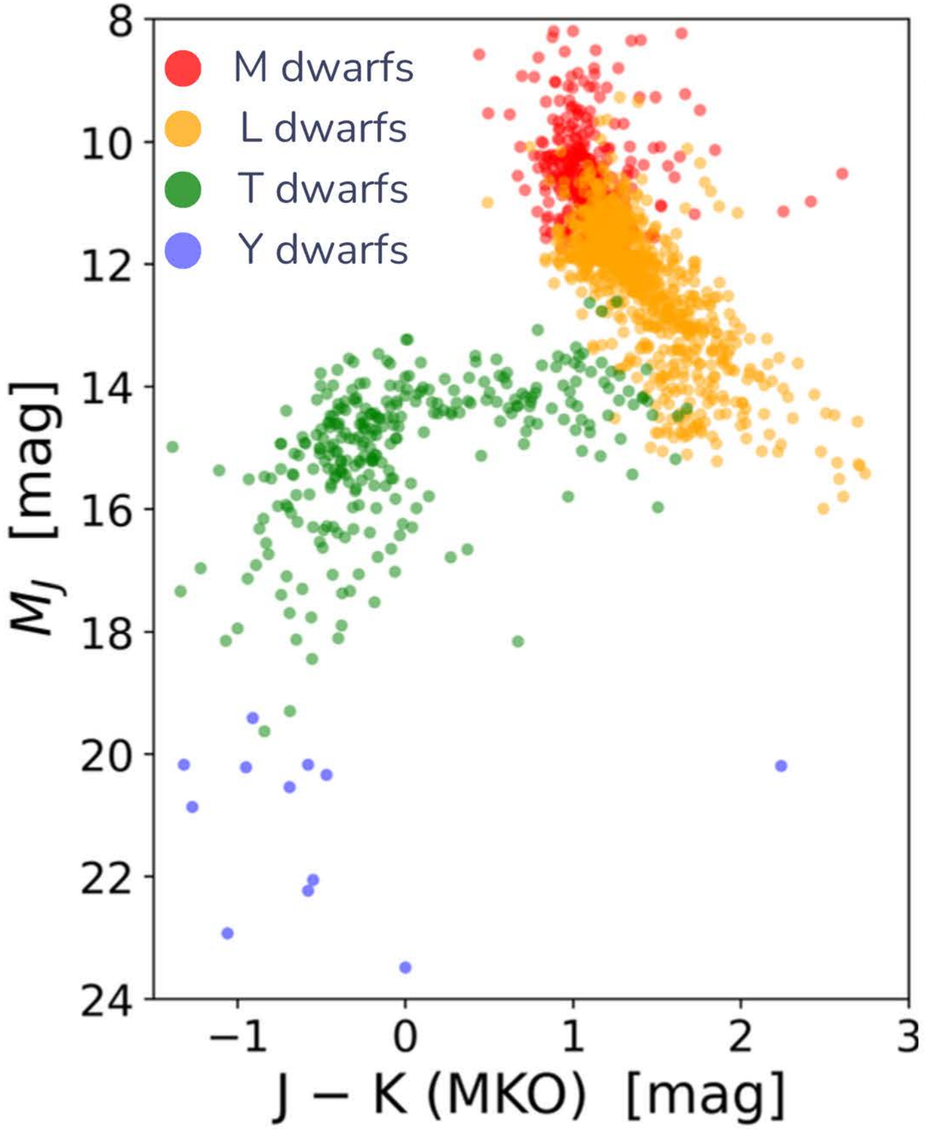
~ TEMPERATURE

Context



Model from
Phillips et al. (2020)

Overview of our sample



My thesis focuses on the **data reduction** and **retrieval analysis** of a sample of **four planetary mass companion** observed in the EXOMIRI guaranteed time program (GTO).

Supervisors: Pierre-Olivier Lagage (CEA) and Quentin Changeat (RUG)

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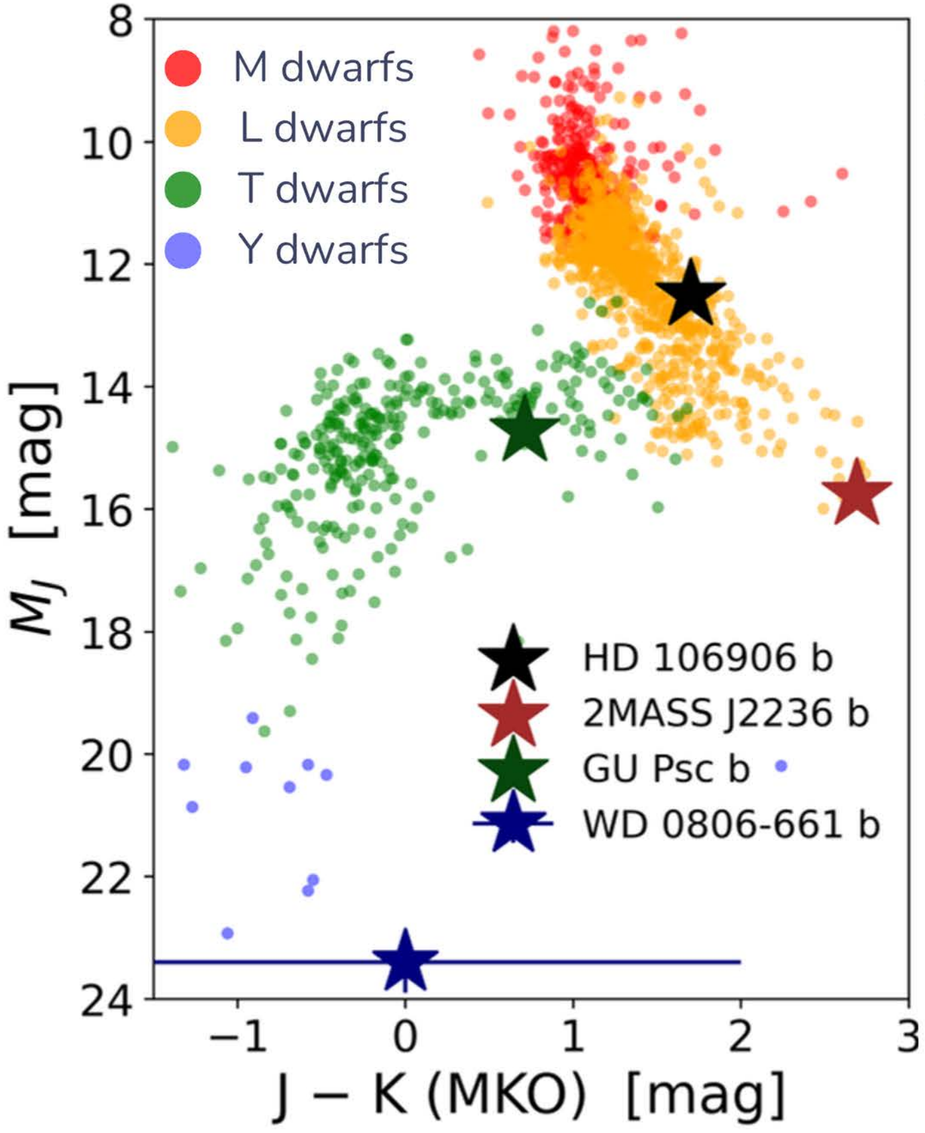

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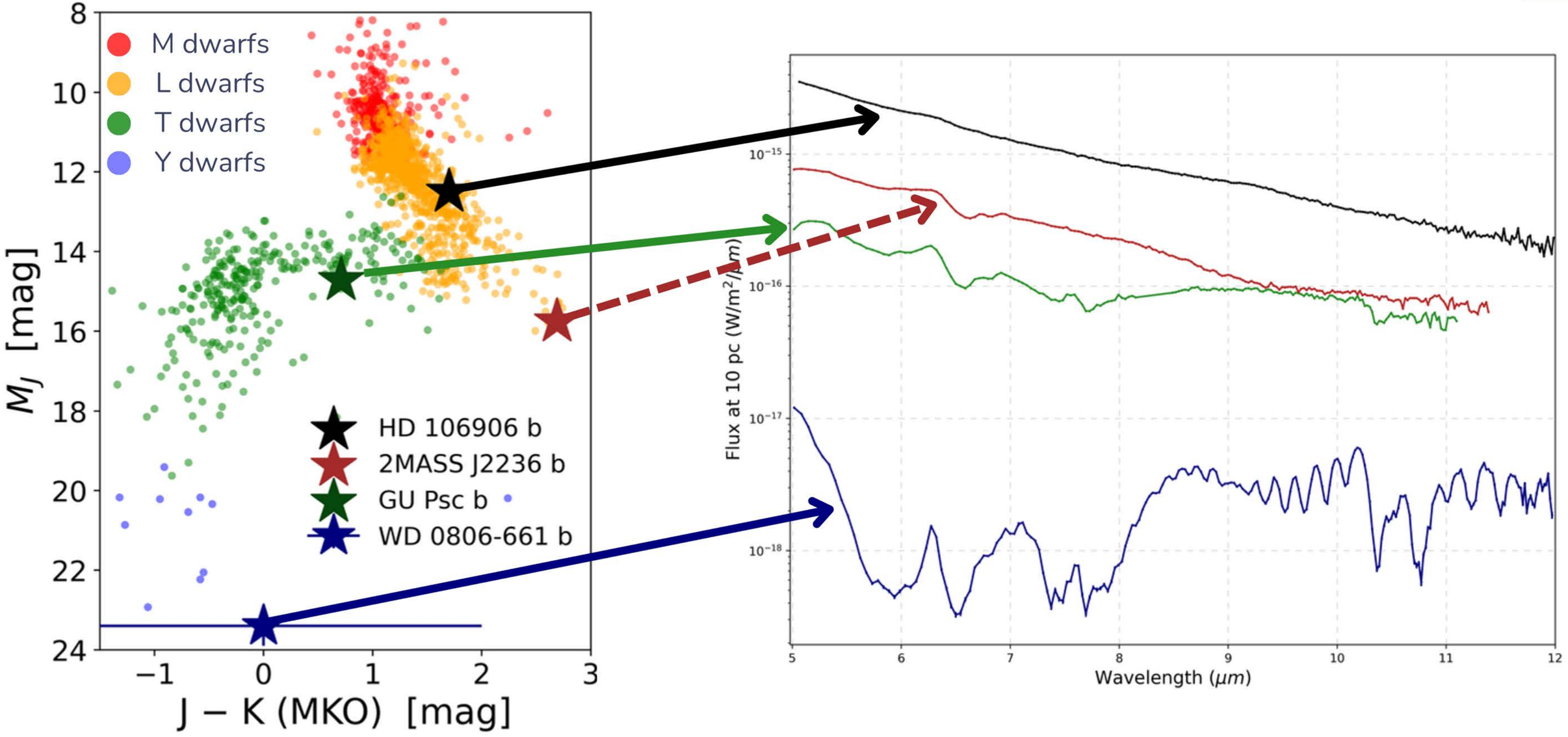
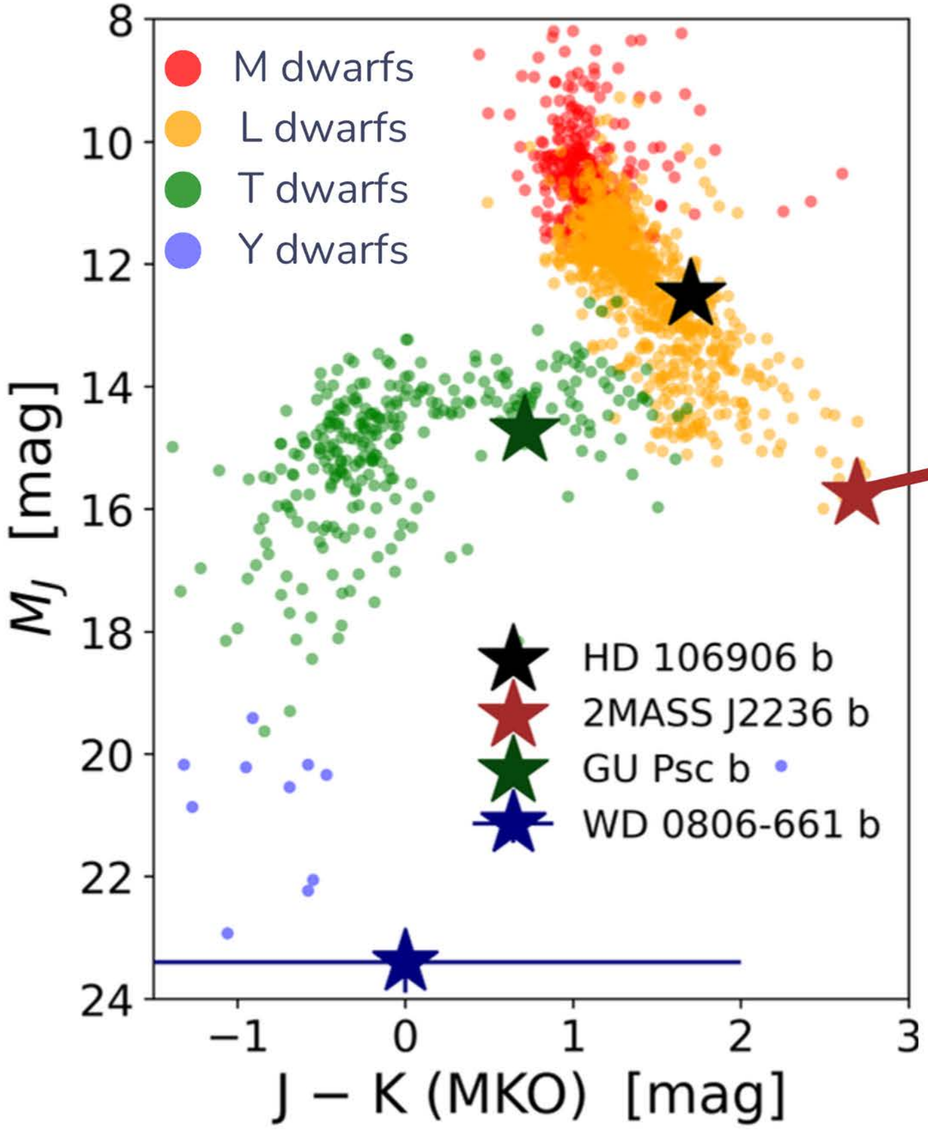
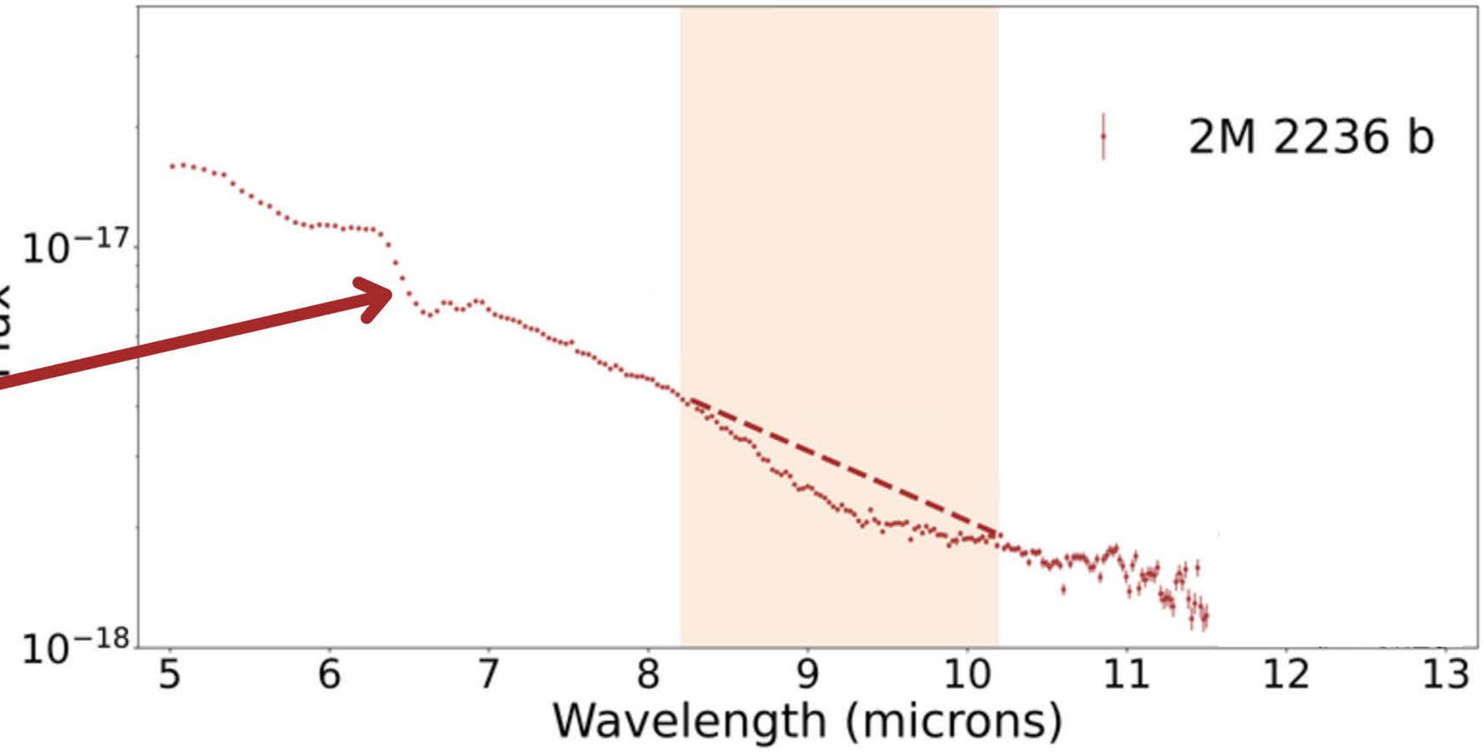


The “clouds” issue

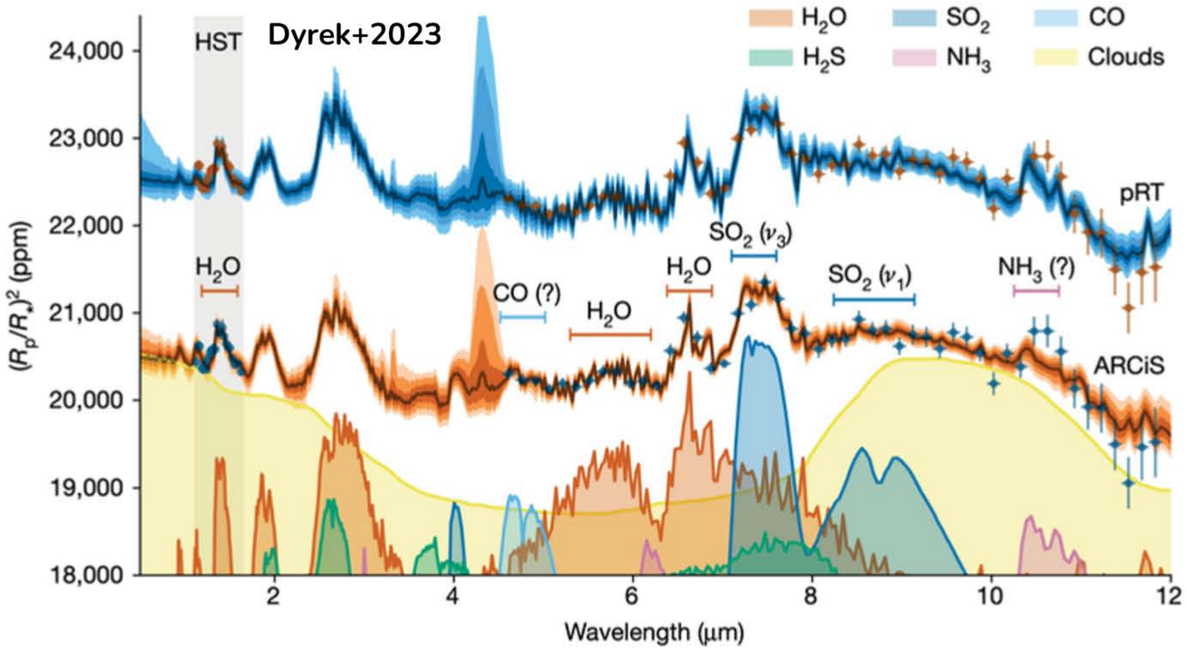


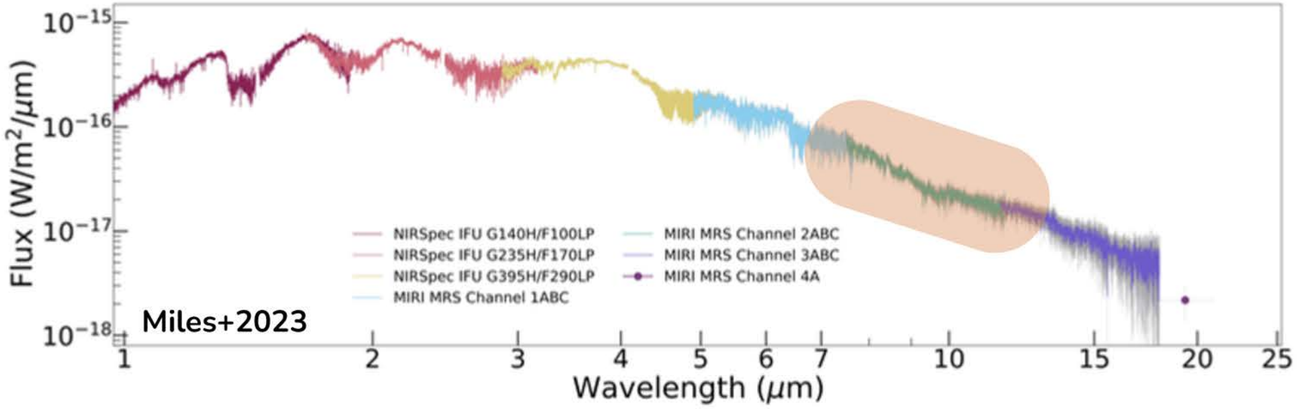


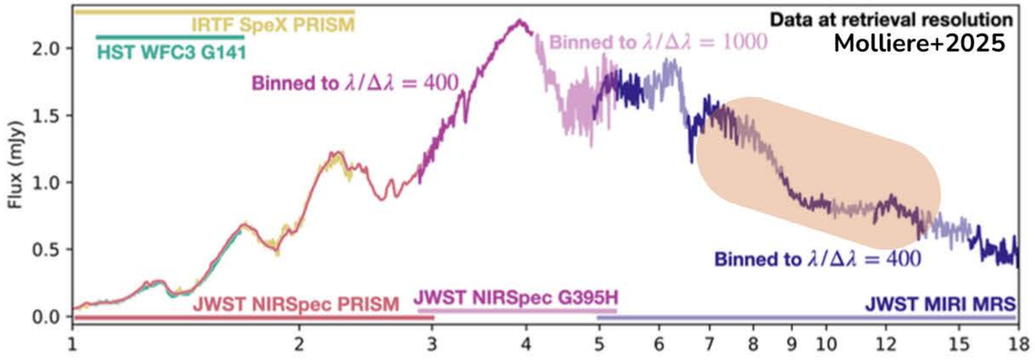
Wide **silicates clouds features**.

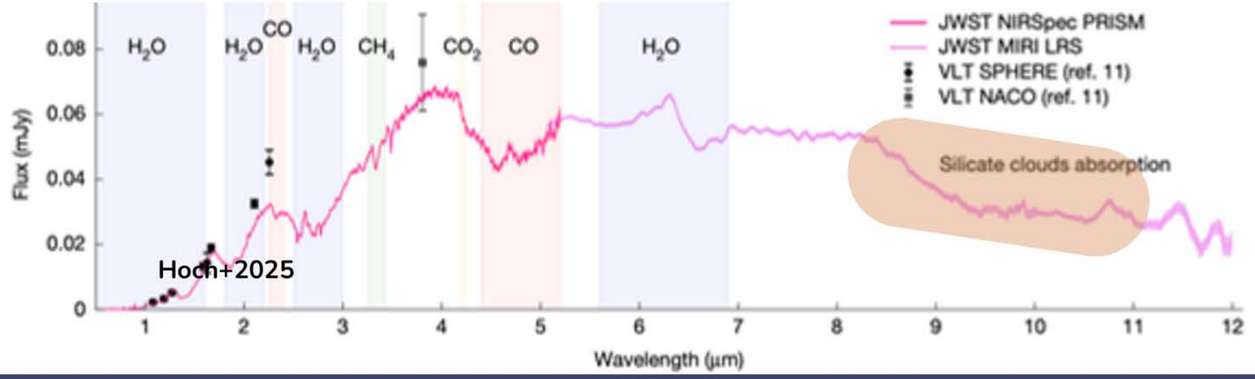
The “clouds” issue

Silicate clouds often present:







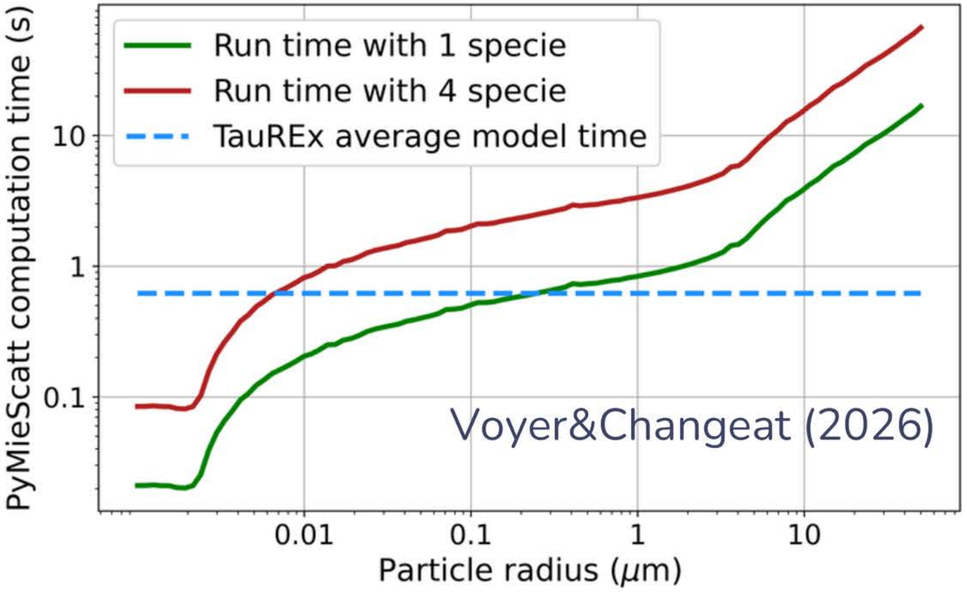


The “clouds” issue

In present free-retrieval framework (TauREx, pRT, …) these clouds are modeled by Mie theory:

Mie theory significantly slows down retrievals because of costly calculations:

$$Q_{ext}(a,\lambda) = \frac{2}{x^2}\sum_{n=1}^{n_{max}}(2n+1)\,\mathrm{Re}\left(a_n(m(\lambda),x) + b_n(m(\lambda),x)\right)$$



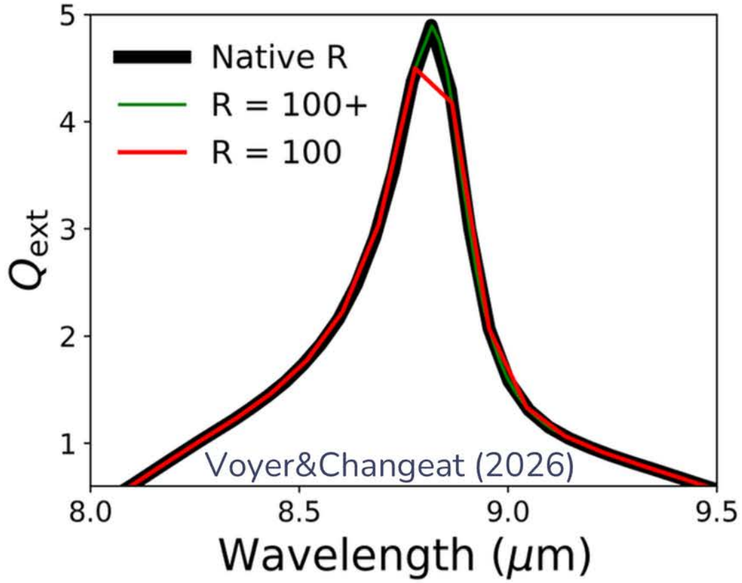
Good news, we can bypass these by precomputing the extinction coefficients !

The “clouds” solution

First consideration is the optical constants

$$Q_{ext}(a,\lambda) = \frac{2}{x^2}\sum_{n=1}^{n_{max}}(2n+1)\,\mathrm{Re}\,(a_n(m(\lambda),x) + b_n(m(\lambda),x))$$

They are the primary source of uncertainty for many species because of low spectral resolution measurements.

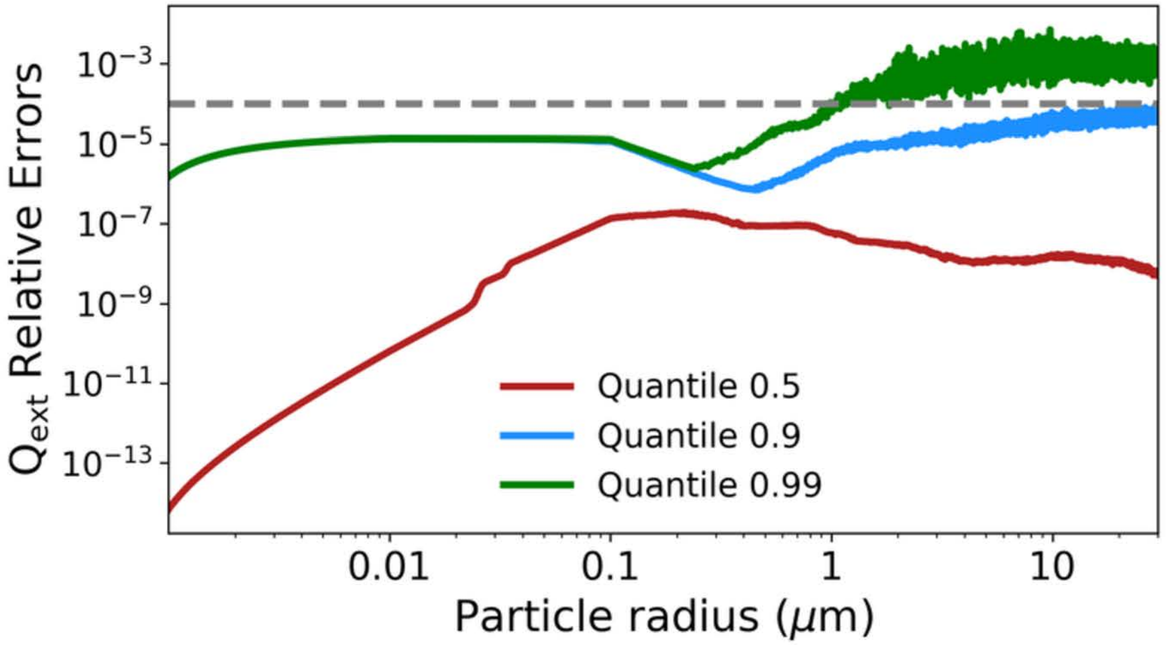


For JWST-level data quality, the optical constant have to be carefully inetrpolated to avoid systematics errors.

The “clouds” solution

We investigated the relative error required on the Qext calculation for JWST-level spectra. Indeed, the optical depth as an exponential impact on the atmospheric flux

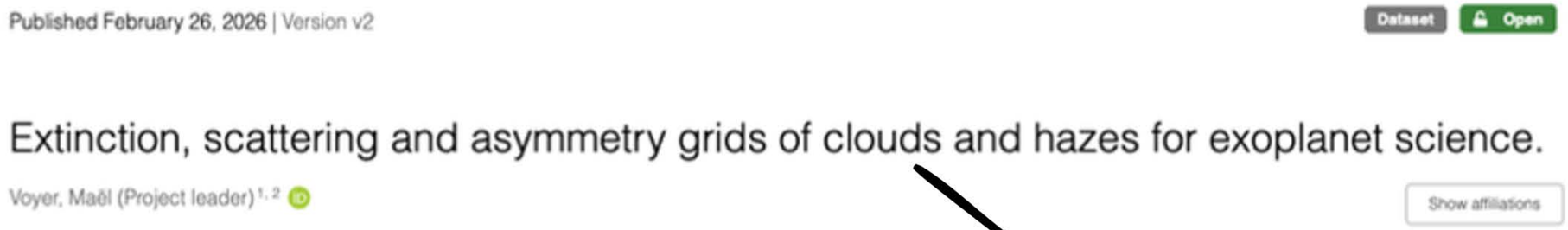
90% of the relative errors below 10^{-4} ensures no impact on retrieval accuracy



The “clouds” solution

We produce precomputed **Qext** but also **scattering** and **asymmetry** grids for :

- **Mg2SiO4**
- **MgSiO3** (amorph glass and solgel)
- **SiO2** (alpha and amorph)
- **SiO**
- **water ice**
- **titan tholins**



For condensed particle radius between 1nm and 30 microns and on the wavelength range 0.3 - 5- microns

Validated for JWST and ARIEL

AEROSOLS GRIDS

The “clouds” solution

We also release a new TauREx plugin **TauREx-PCQ** to use the Qext grids effortlessly.

TAUREX PLUGIN

VOYER & CHANGEAT 2026.

Retrieval acceleration:

- **one cloud → between 1.7 and 3**
- **four clouds → between 15 and 20**

Essential for long (1 week+) JWST retrievals or ARIEL population studies

Standardised format for easy compatibility with other frameworks such as pRT, POSEIDON, etc.

The grids are also applicable for proto-planetary disk retrievals

BACKUP