Mid-infrared interferometry of exoplanets with MATISSE

~~Matisse~~ **Mathis Houllé –** *IPAG (Grenoble)*

with the MATISSE & ExoGRAVITY teams, including:
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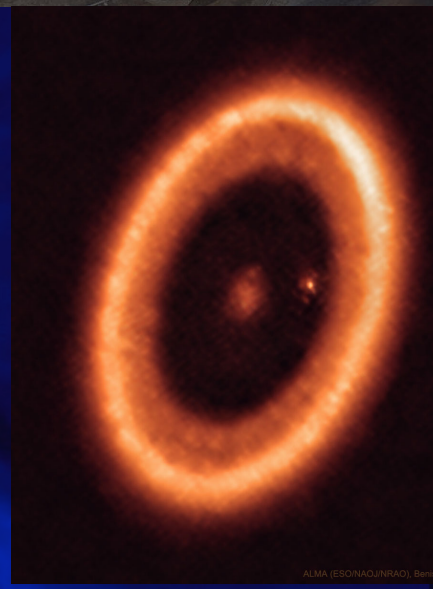

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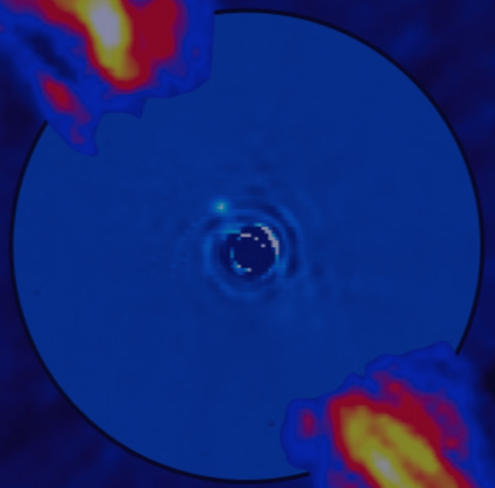

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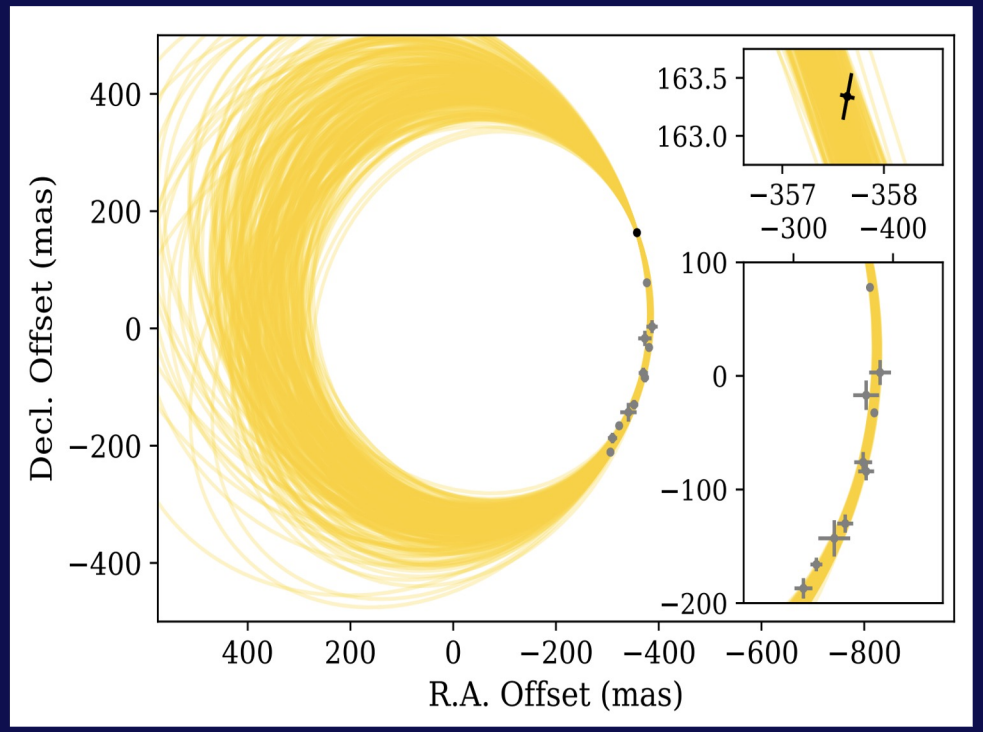
Exosystèmes V – 01/04/2026

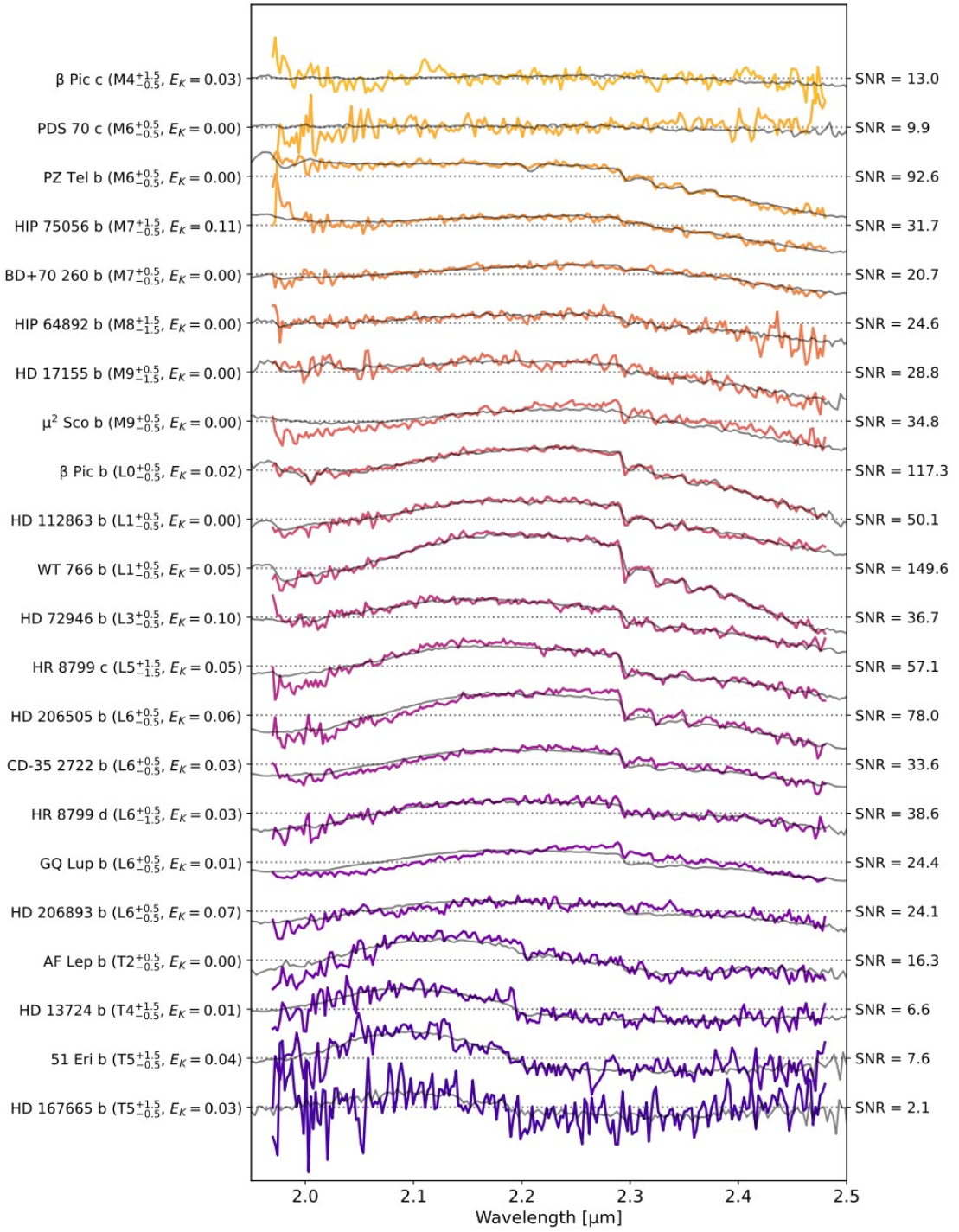
MATISSE

Exoplanet interferometry with GRAVITY

- Ultra-precise **planet astrometry** (~50 μas)
  - orbital fitting & dynamical masses
- Medium-resolution (R = 500) **K-band spectra**
  - T_{eff}, log(g), C/O, M/H constraints



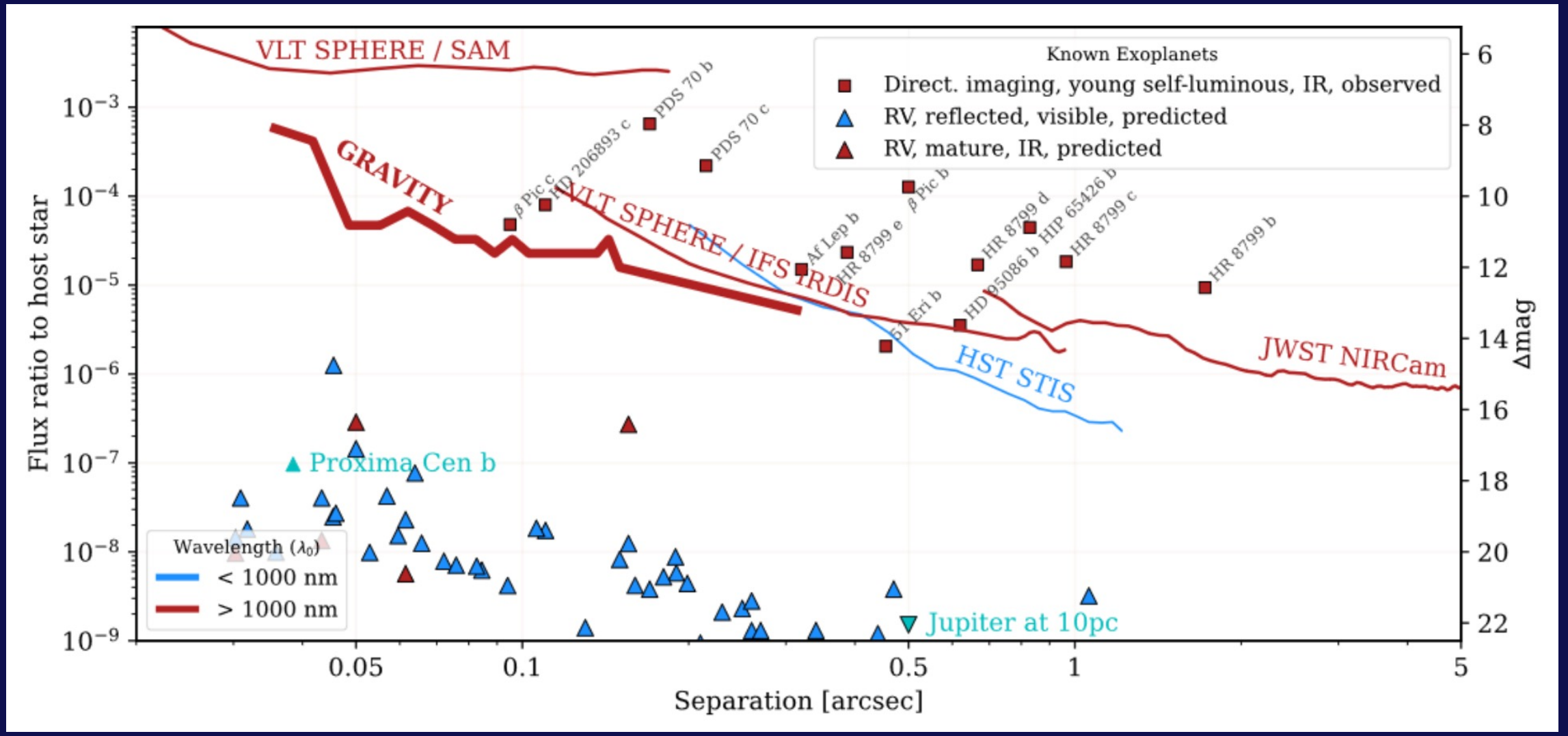
HR 8799 e (GRAVITY Collab.+ 2019)



ExoGRAVITY Spectral Library (Kammerer+ 2025)

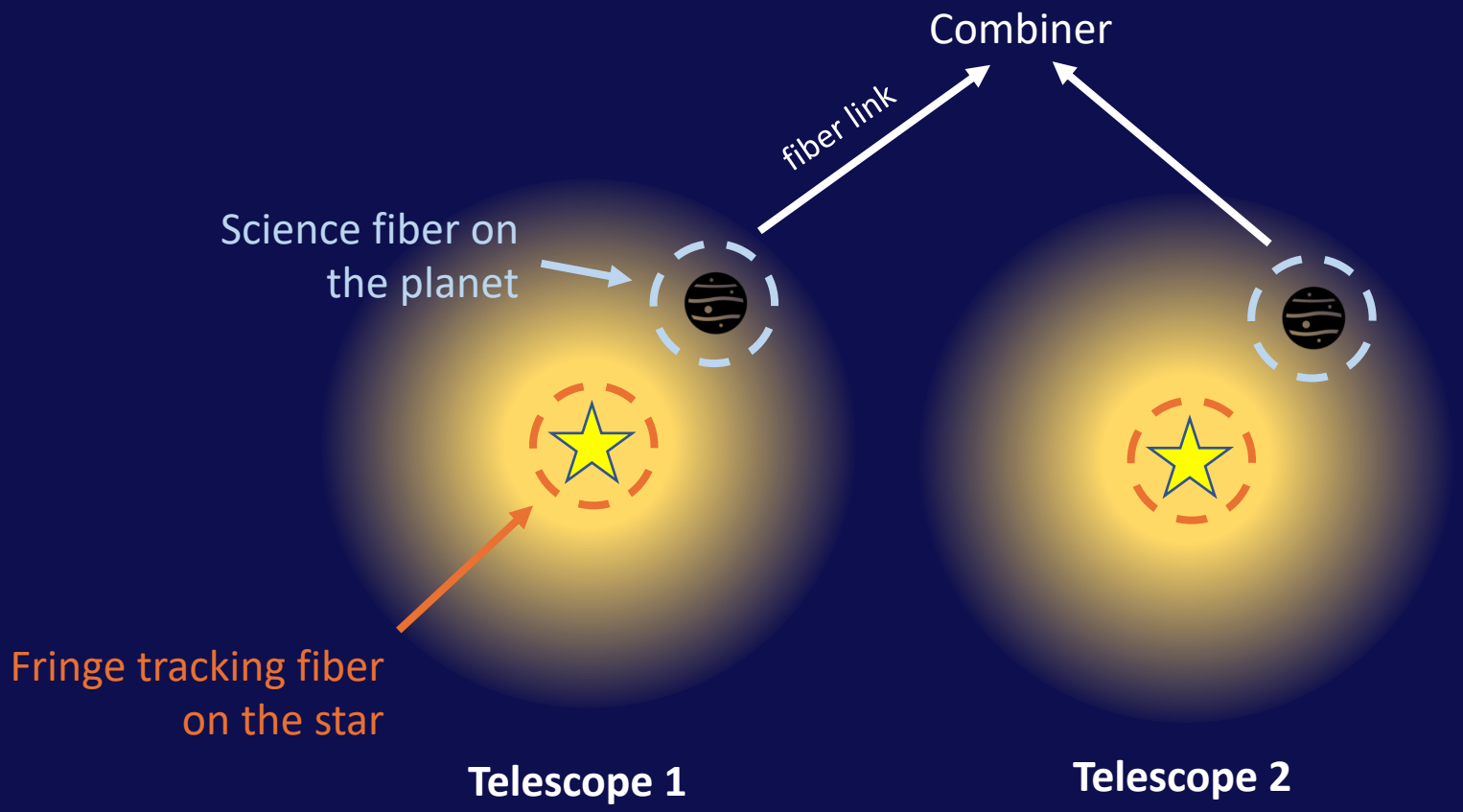
Interferometry & direct imaging

Pourré et al. 2024



Disentangling photons in interferometry

GRAVITY exoplanet observations



Adaptive optics & fringe tracking
MACAO / GPAO + GRAVITY fringe tracker

Spatial filtering
The monomode fiber filters most of the stellar flux

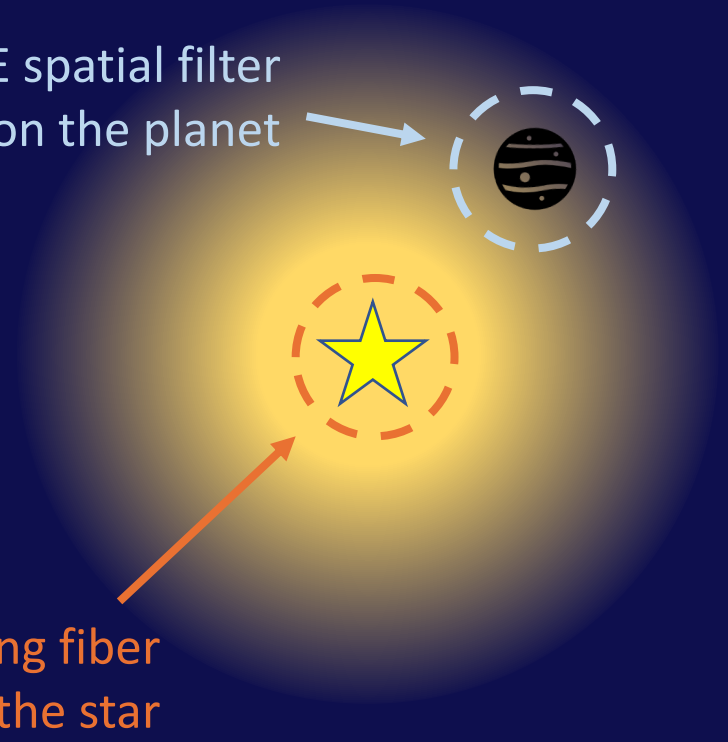
Post-processing
Decoupling stellar and planetary signals thanks to baseline rotation

GRAVITY & MATISSE

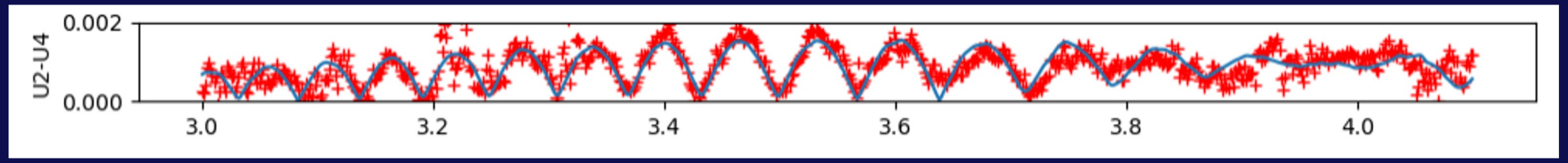
	GRAVITY	MATISSE
Spectral bands	**K** (2.0-2.4 µm)	**LM** (2.7-5.0 µm), **N** (8-13 µm)
Spectral resolution	20, 500, 4000	30, 500, 1000, 3500
Adaptive optics	MACAO, **GPAO** (since 2024, 41x41 actuator DM, 1 kHz)	
Fringe tracking	✓	✓ (since 2021, GRAVITY fringe tracker)
Spatial filtering	Single-mode fiber	Image & pupil stops (1 or 1.5 λ/D)
Off-axis pointing	✓	✓ (since 2022)
Metrology system	✓	✗

First MATISSE exoplanet observations

- MATISSE: L, M and N band (2.8-5.0 µm, 8-13 µm)
- Assisted by the GRAVITY fringe tracker
- First demonstration:
  - β Pictoris b (2022-2023)
  - 4 UTs
  - Medium spectral resolution (R = 500)
  - 45 min on planet
    15 min on star

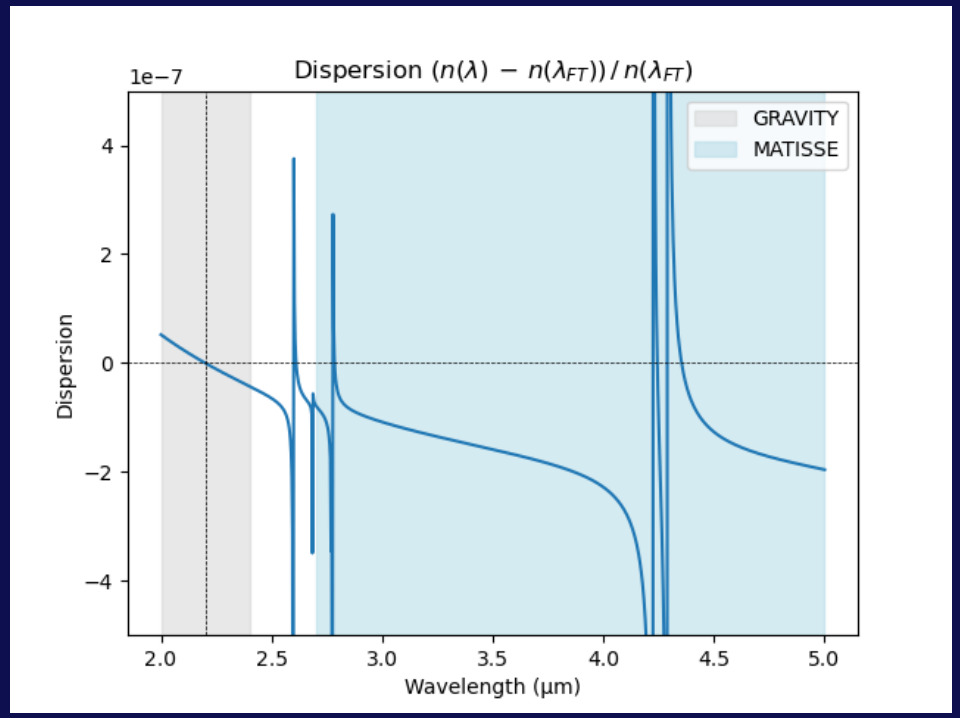


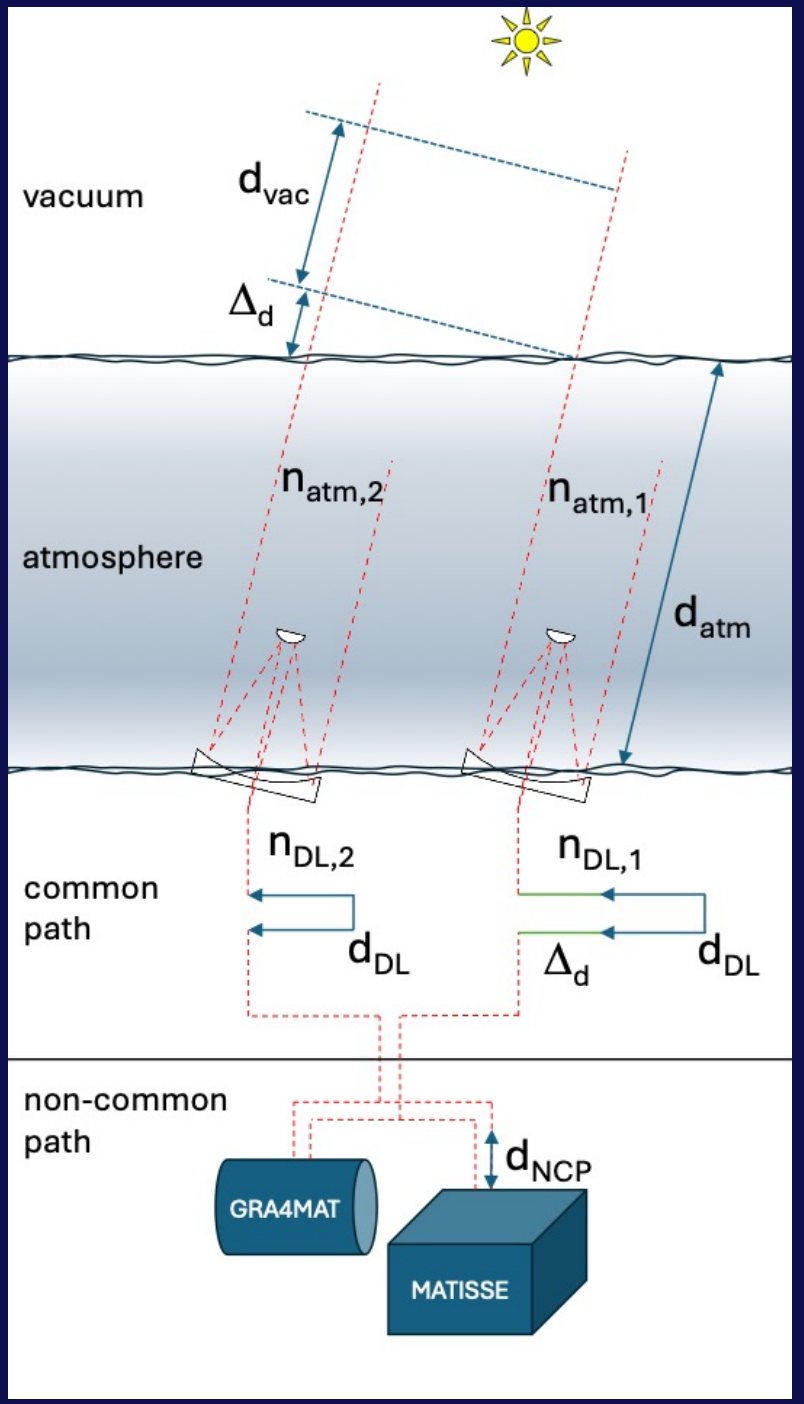
Fringe amplitude in a 1 min exposure



Phase correction

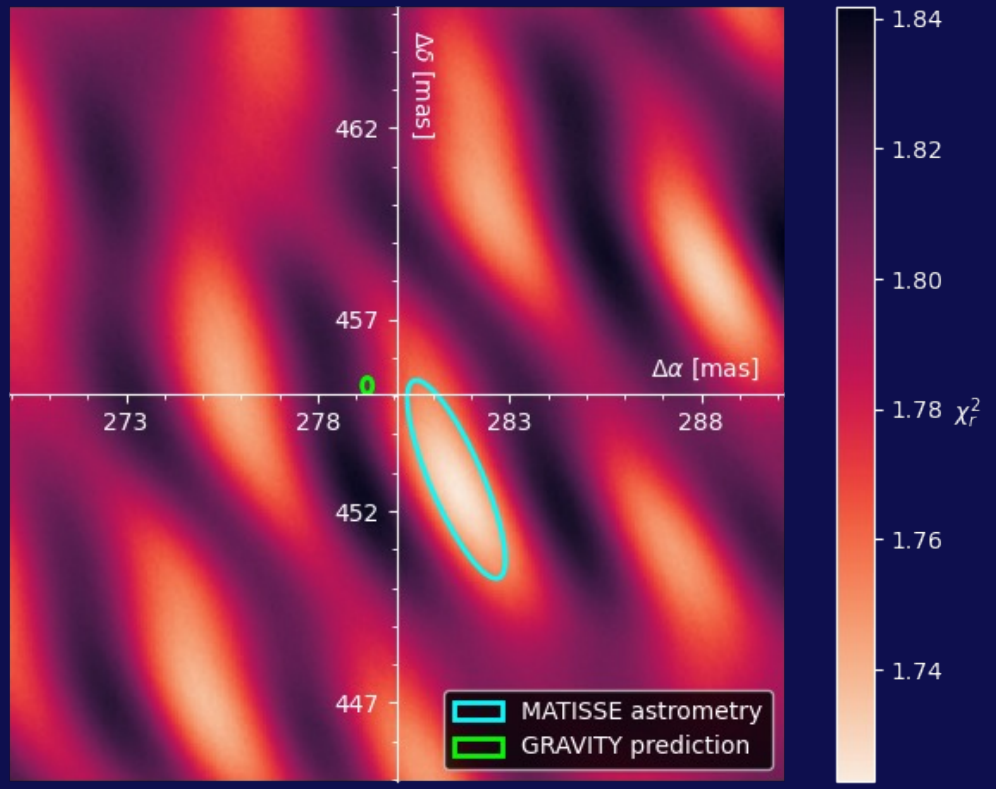
- Optical path difference in vacuum (above the atmosphere) is corrected in air (in the delay lines)
- Fringe tracking & science in different bands (K vs. LMN)
- Creates chromatic dispersion between GRAVITY and MATISSE



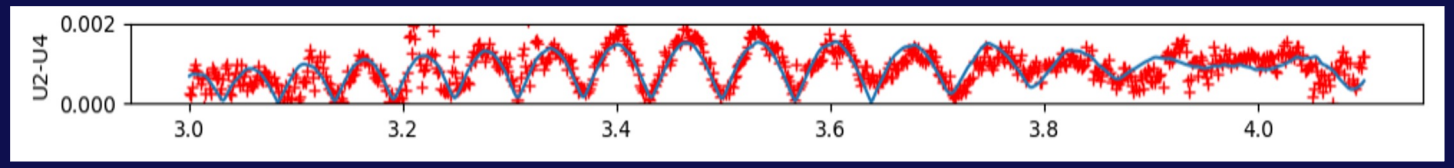


Astrometric fit & stellar contamination removal

Fitting the planet astrometry & stellar contamination

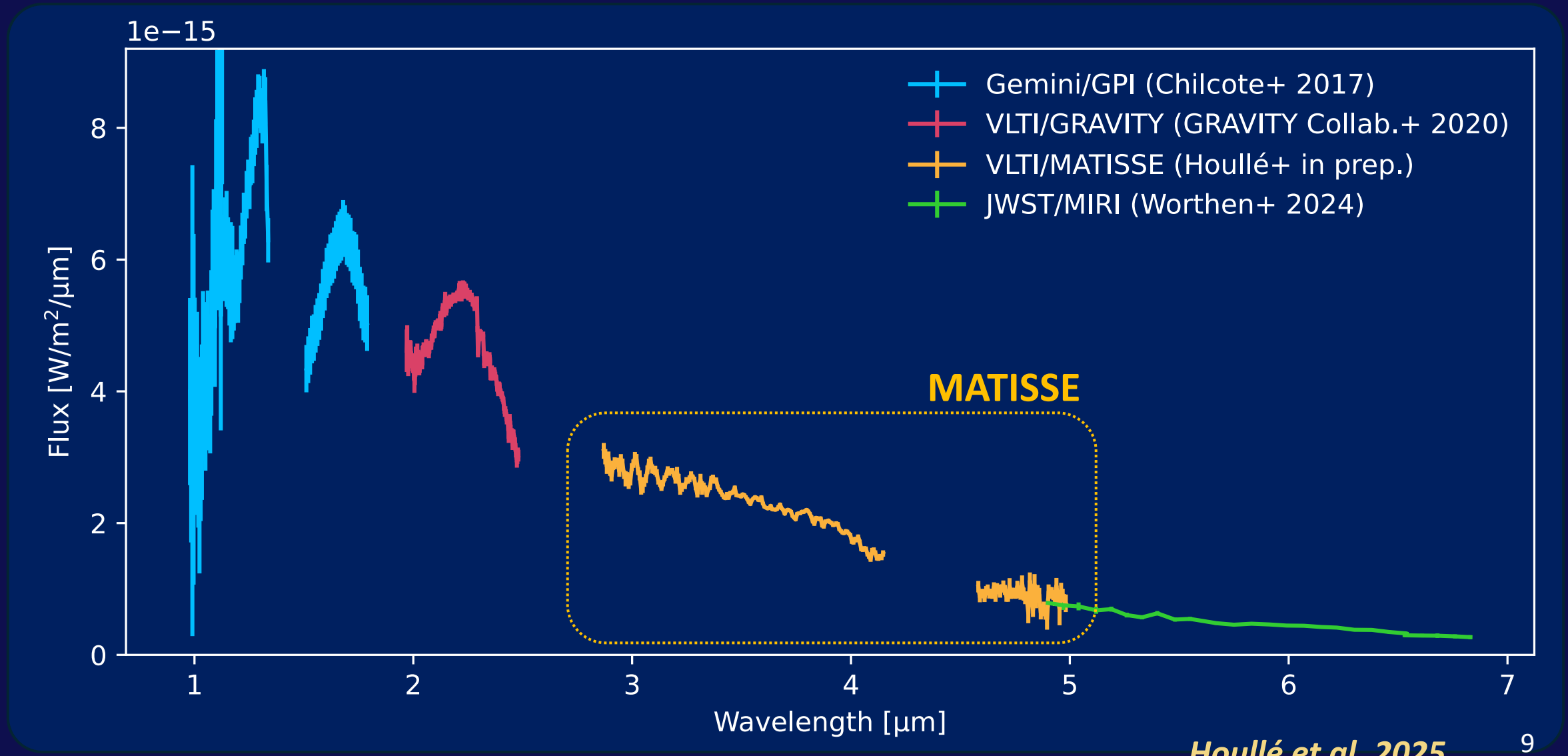


- Planet found ~3.5 mas away from GRAVITY predictions.
- GRAVITY astrometry more reliable thanks to its internal metrology.



Spectrum extraction

β Pic b spectra now covers a range of 1 to 7 µm!



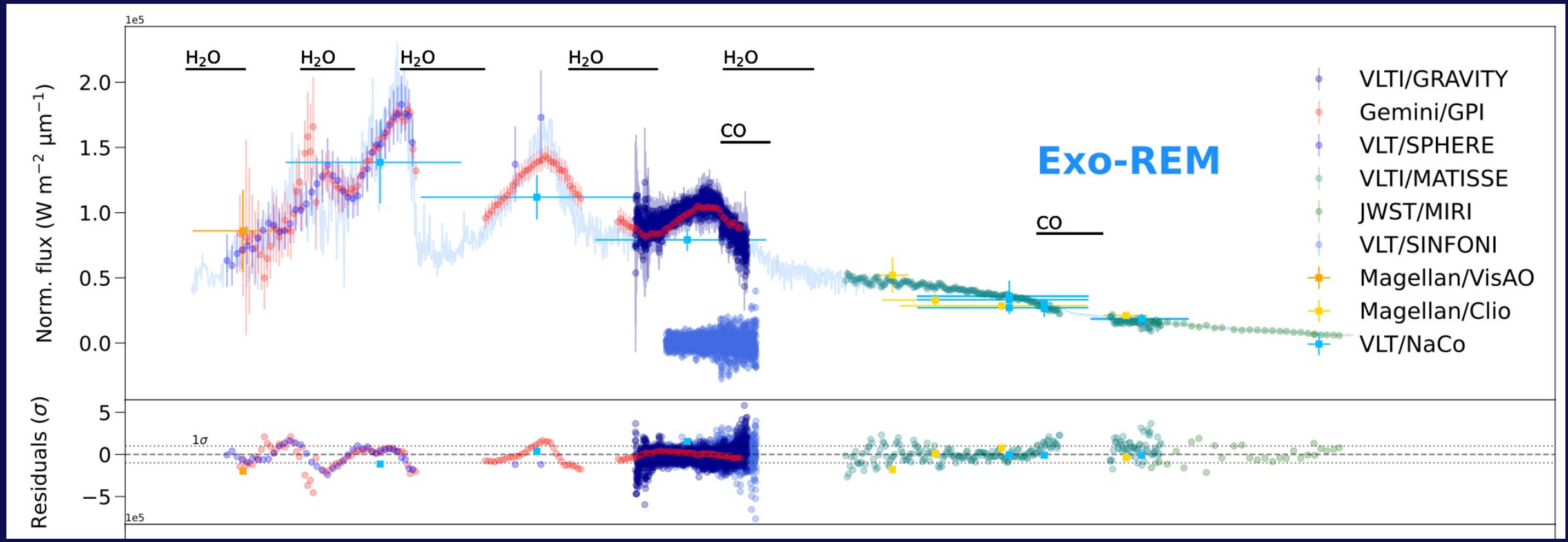
Houllé et al. 2025

Multimodal analysis of β Pic b

Ravet et al. 2026

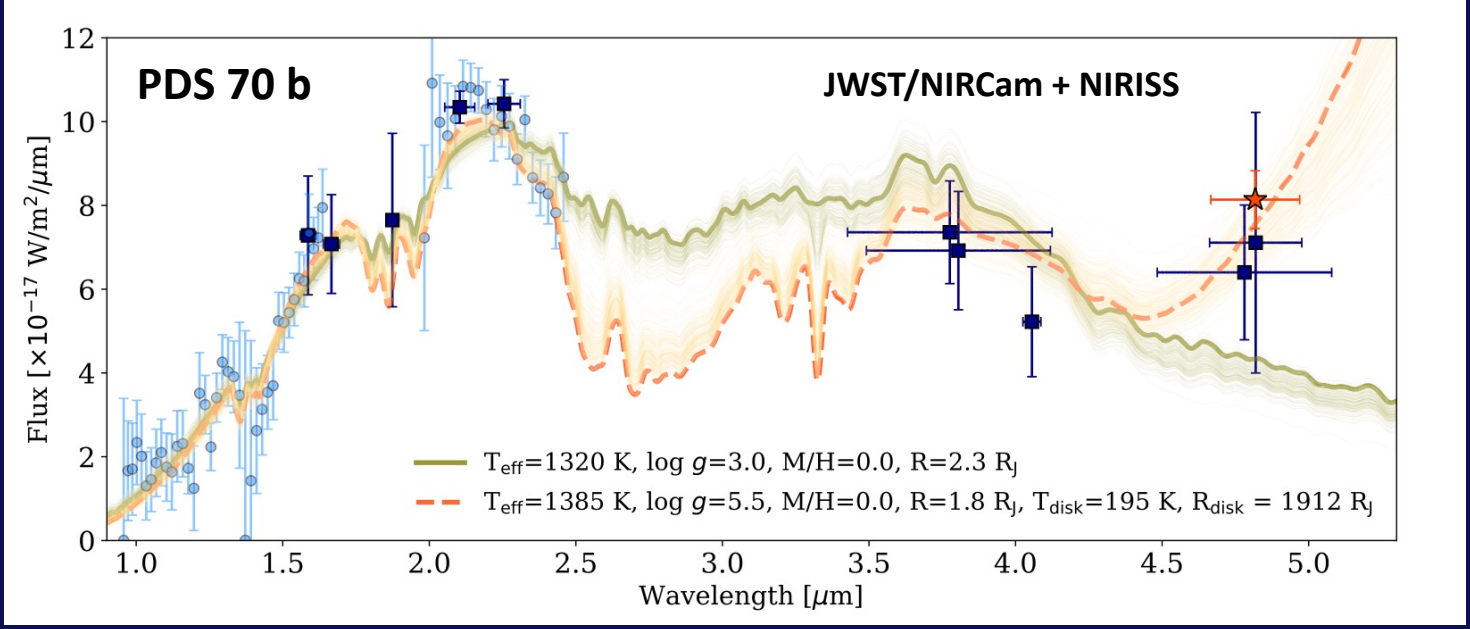
Modelling using all archival photometry and spectra of β Pic b

T_{eff} (K)	log(g) (dex)	[M/H]	C/O	γ	f_{sed}	$\log(^{12}C/^{13}C)$
$1503.38^{+2.30}_{-2.31}$	4.00 ± 0.01	$0.51^{+0.02}_{-0.01}$	$0.552^{+0.003}_{-0.002}$			$1.12^{+0.11}_{-0.08}$



Protoplanet CPDs

- JWST/NIRCam & NIRISS photometry on PDS 70 b and c (Christiaens+ 24, Blakely+ 25)
- Pointing towards mid-IR CPD emission



Blakely+ 2025

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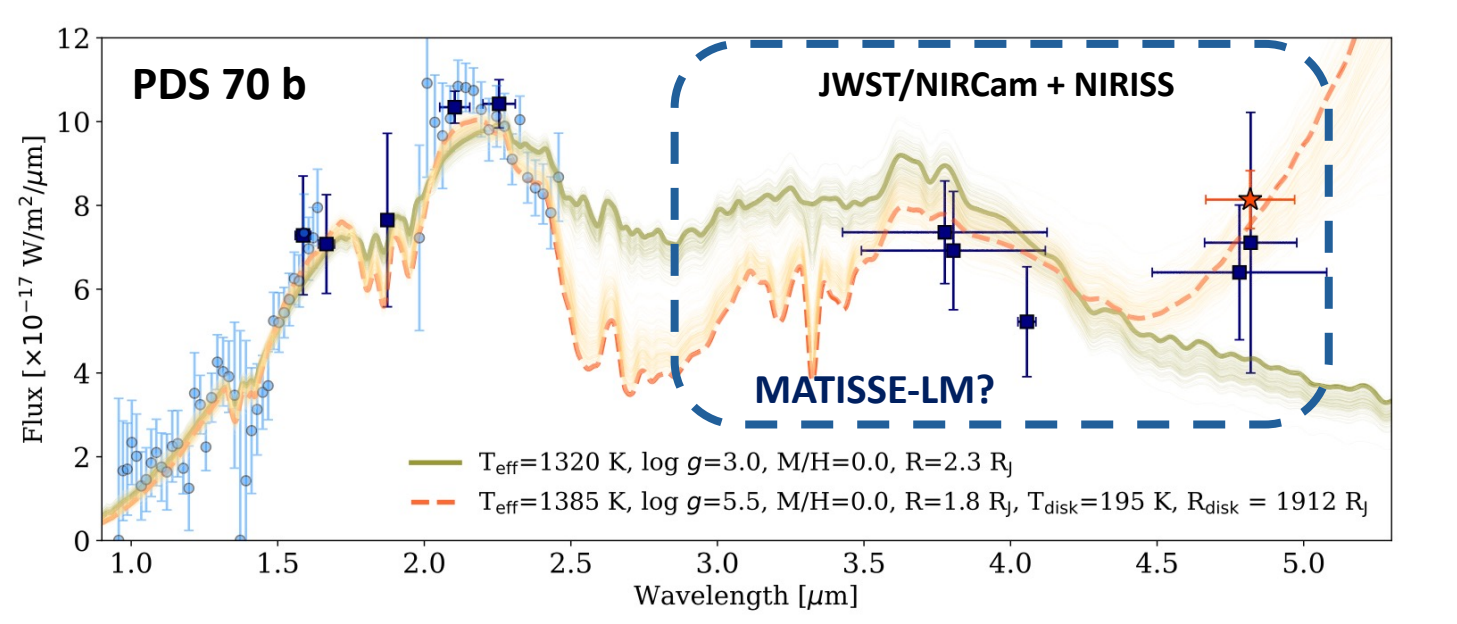


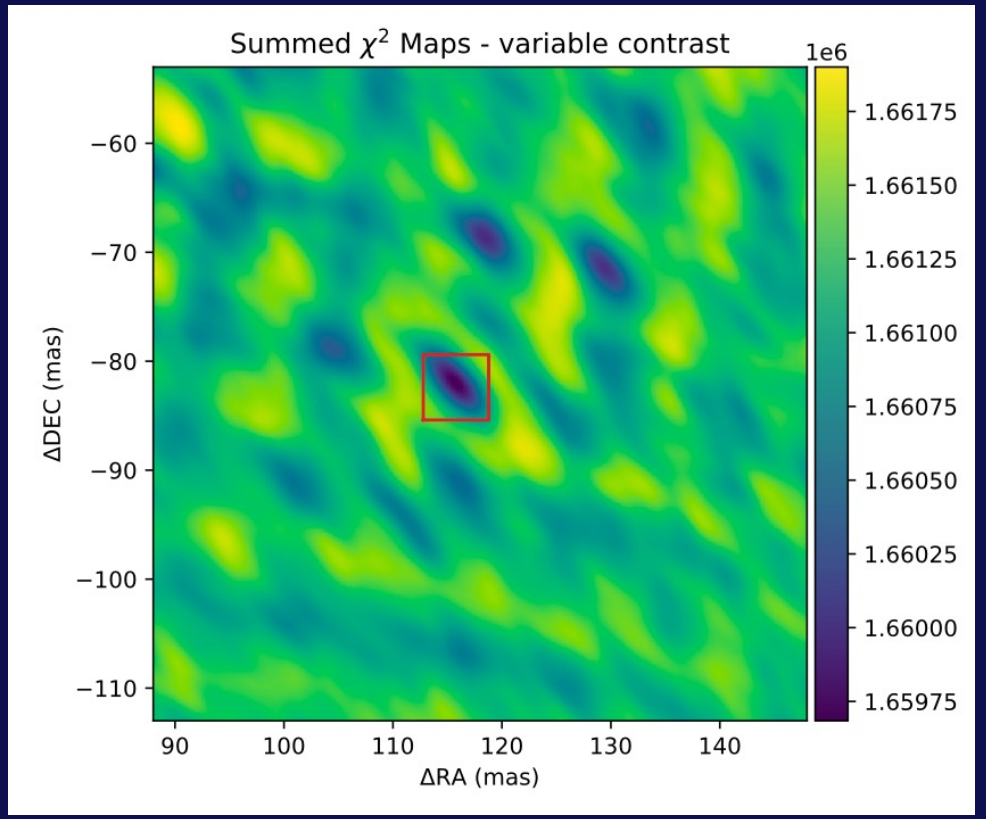
Blakely+ 2025

- MATISSE potential:
  - 3-13 µm spectrum of the protoplanets and their CPDs
  - constrain temperature, mass and radius of the CPDs
  - resolve the CPDs? (λ/B ~ 5 mas)
  - confirm the protoplanetary nature of PDS 70 d?

PDS 70 MATISSE observations

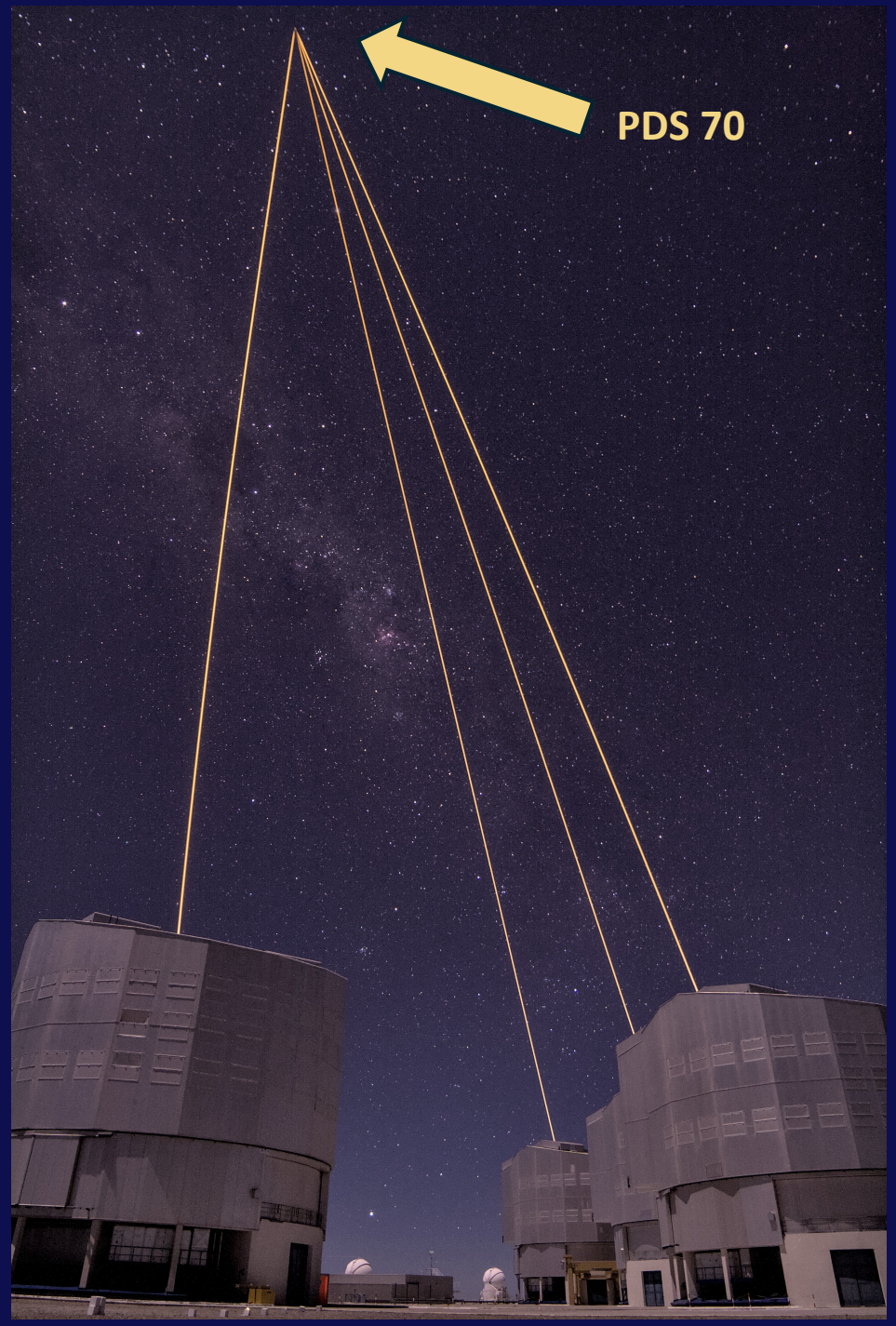
- 2025:
  - Telescope failures & bad conditions, most of time lost
  - Weak detection for both PDS 70 b and c

MATISSE astrometric χ^2 map on PDS 70 b, 2025



PDS 70 MATISSE observations

- 2025:
  - Telescope failures & bad conditions, most of time lost
  - Weak detection for both PDS 70 b and c
- 2026:
  - Reobserved 2 weeks ago
  - Laser Guide Star AO

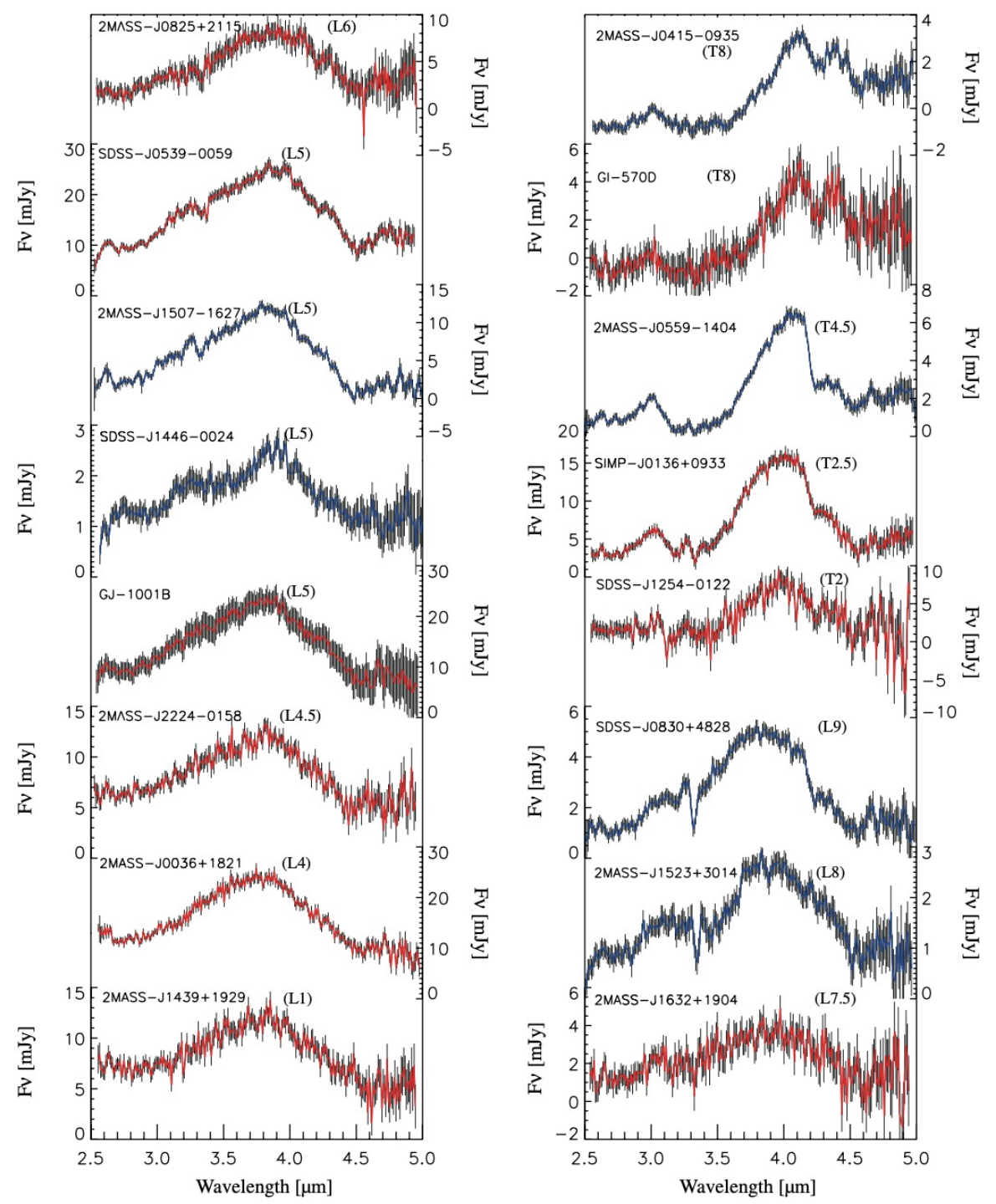


Picture: Matthieu Ravet

The mid-infrared potential

- Few mid-IR spectra
  - Sensitivity of NIRSpec or MIRI-MRS unclear at close separations (< 0.3’’)
- Rich in spectral lines (CH_4, CO_2, CO…)
- Science cases:
  - **cloud scattering** (Mollière+ 20) & **patchiness** (Currie+ 14)
  - **vertical mixing** (Phillips+ 20)
- Peak emission of cold/warm planets (300-1000 K)

Sorahana+ 2012, isolated brown dwarfs

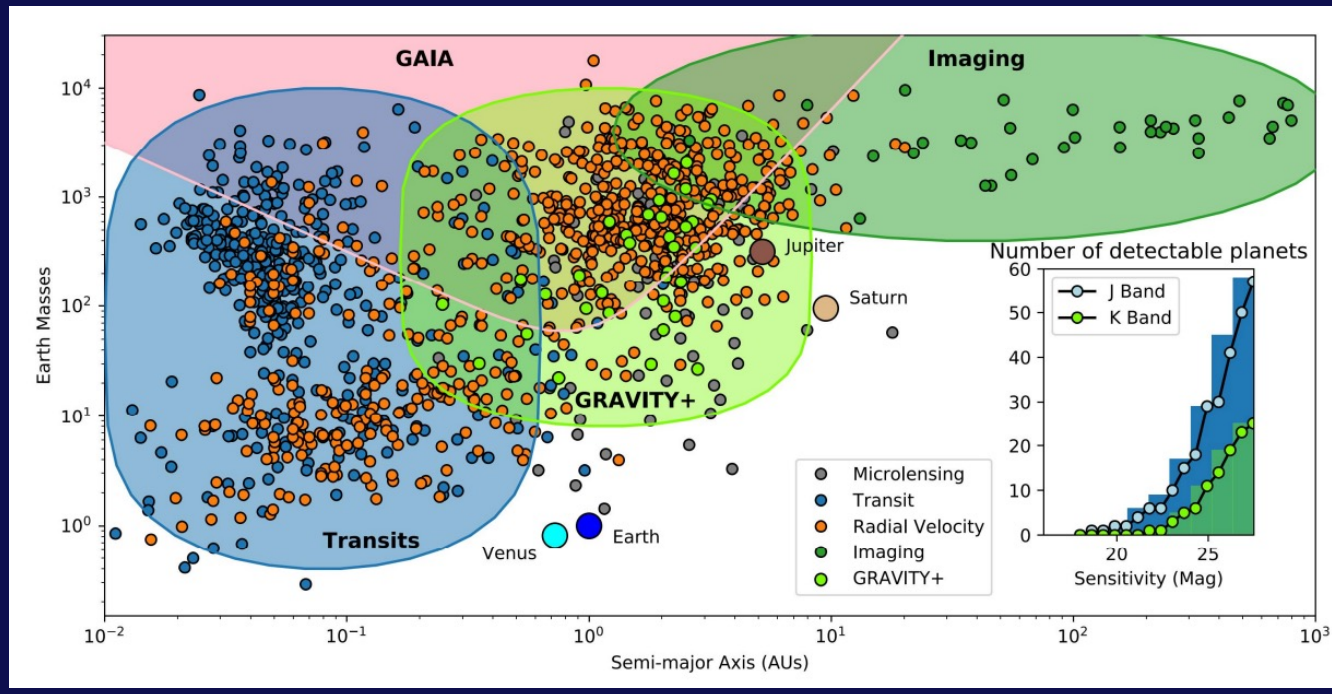


The Gaia-VLTI combination

- A few dozens of Gaia DR4 candidates potentially accessible to GRAVITY and MATISSE
- Large sample of planetary system architectures down to snow line levels (0.1 – 10 au), and constraints on substellar atmospheres

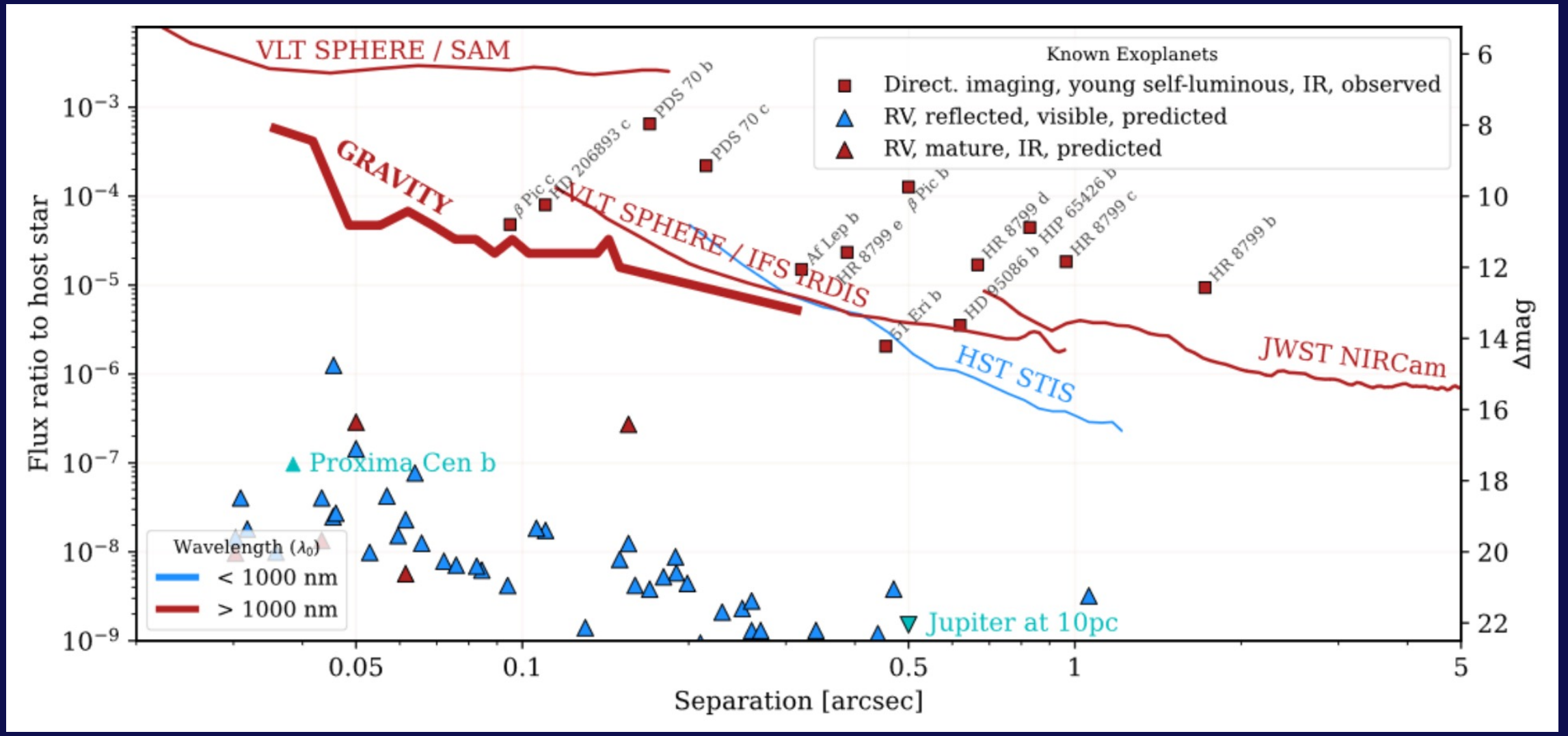
- **Can it solve the mass-age-luminosity degeneracy of evolutionary models?**
  - **Gaia + GRAVITY:** dynamical masses independent of models
  - **GRAVITY + MATISSE + PLANETES/SHARPS:** bolometric luminosity estimates, covering blackbody emission peaks from 1500 K (1.9 µm) to 600 K (4.8 µm)

GRAVITY+ White Paper



Contrast-separation detection limits

Pourré et al. 2024



Summary

- **MATISSE** is now characterizing exoplanets and brown dwarfs
  - High S/N obtained on β Pic b in 45 min
  - First L-band SED of β Pic b
- The **mid-infrared is a great window for exoplanets**
  - Peak emission of 300-1000 K atmospheres and CPDs
- Ongoing developments to access fainter planets and estimate detection limits
- Promising Gaia DR4 + VLTI combination