Mid-infrared interferometry of exo(proto)planets with MATISSE

from Beta Pic b to PDS 70

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with the MATISSE & ExoGRAVITY teams, including:
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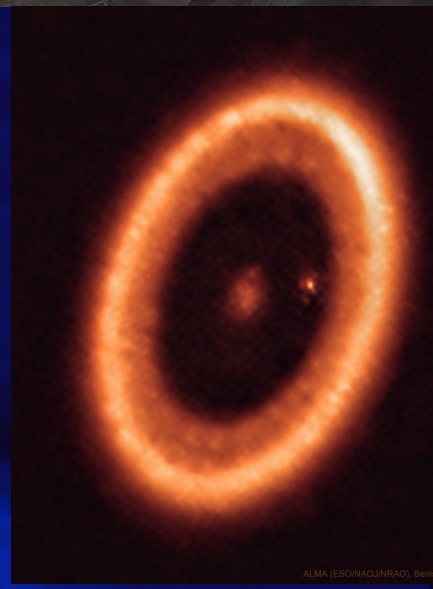

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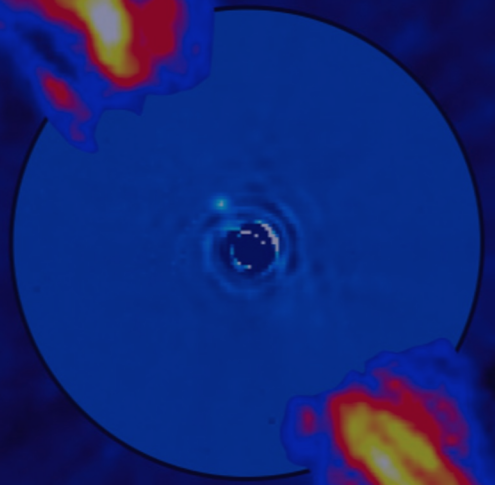

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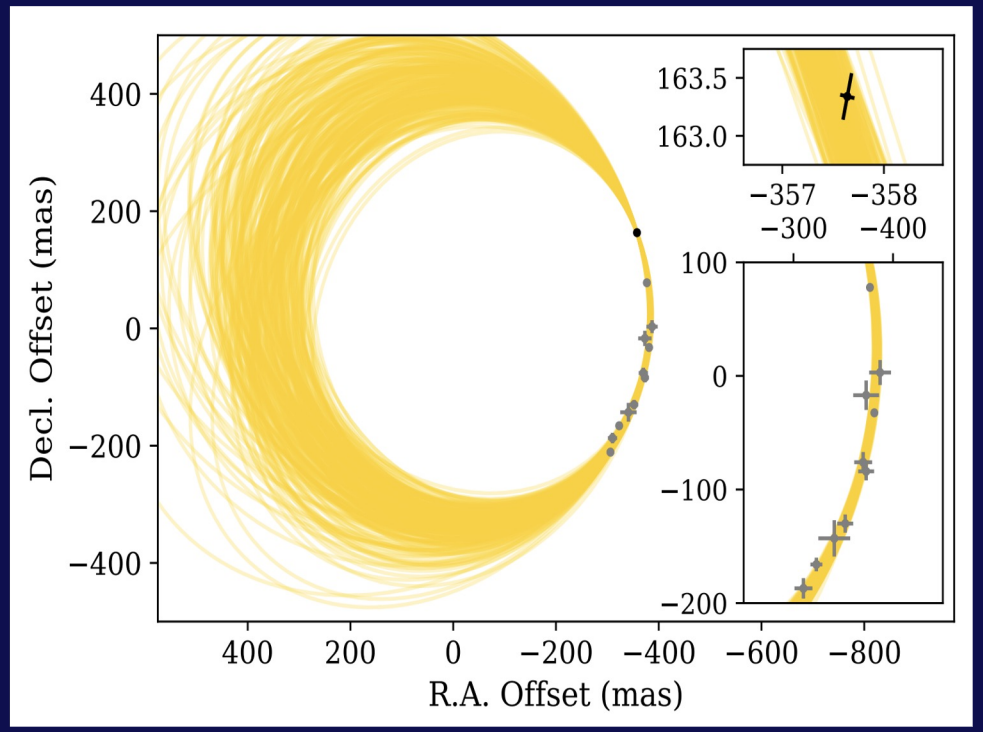
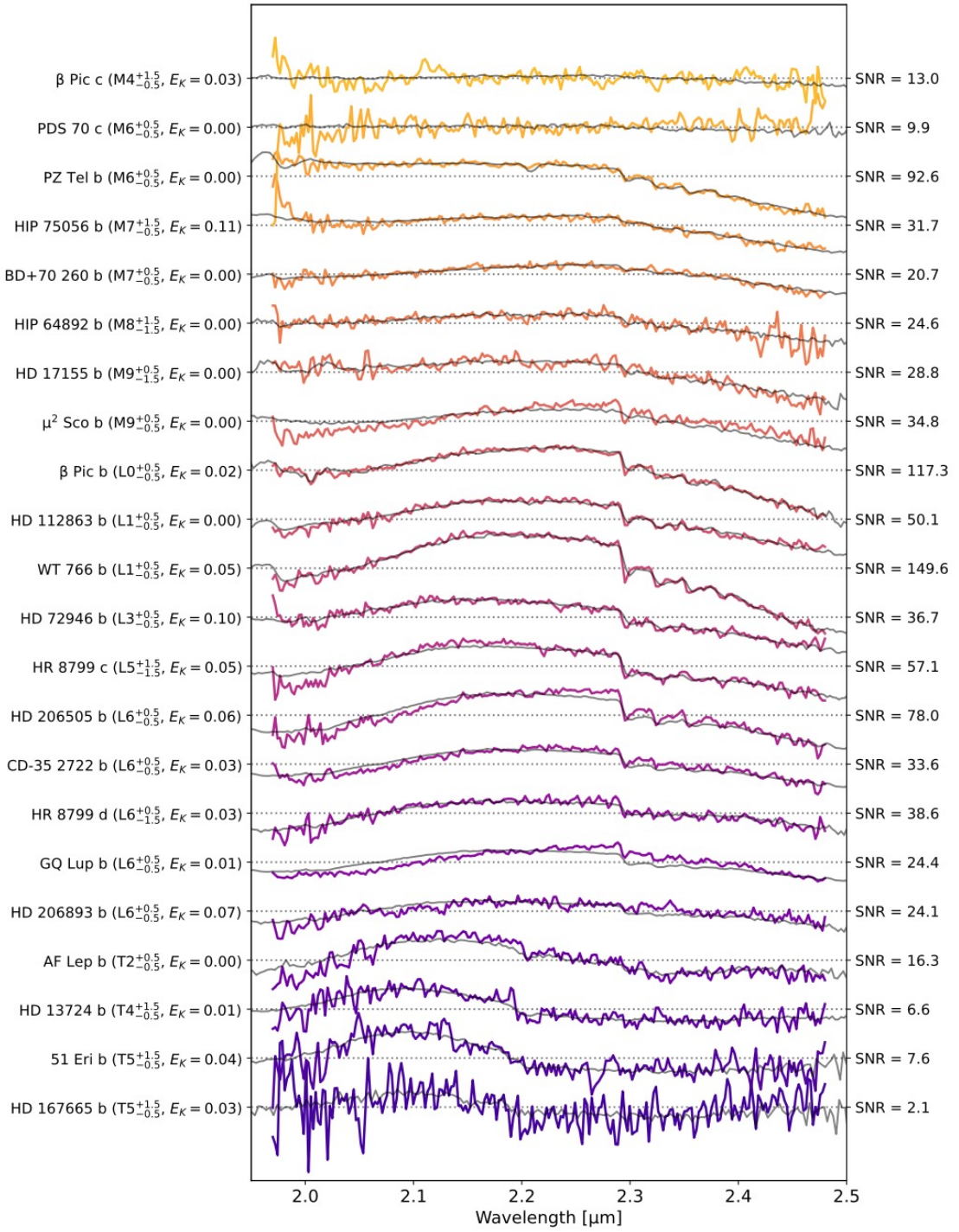
51 Peg b conference – 09/10/2025

Exoplanet interferometry with GRAVITY

- Ultra-precise **planet astrometry** (~50 μas)
  - orbital fitting & dynamical masses
- Medium-res. **near-infrared spectra**
  - T_{eff}, log(g), C/O, M/H constraints



HR 8799 e (GRAVITY Collab.+ 2019)



ExoGRAVITY Spectral Library (Kammerer+ accepted)

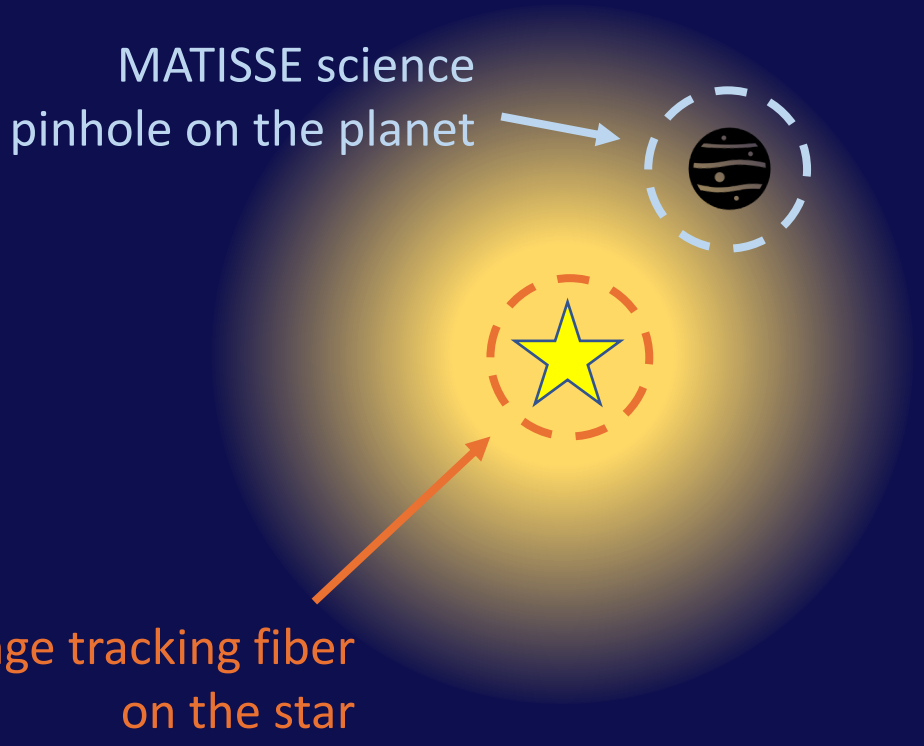
GRAVITY & MATISSE

	GRAVITY	MATISSE
Spectral bands	**K** (2.0-2.4 µm)	**LM** (2.7-5.0 µm), **N** (8-11 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, GRA4MAT)
Spatial filtering	Single-mode fiber	Image & pupil stops (1 or 1.5 λ/D)
Off-axis pointing	✓	✓ (since 2022)
Metrology system	✓	✗

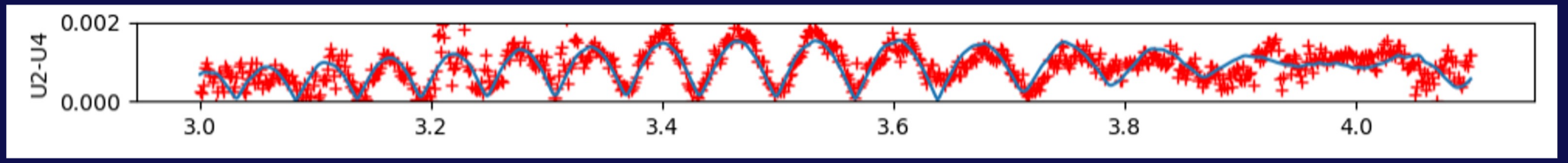
First MATISSE exoplanet: β Pic b

Houllé et al. 2025

- MATISSE: L, M and N band spectro-interferometer
- 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



Coherent flux amplitude in a 1 min exposure



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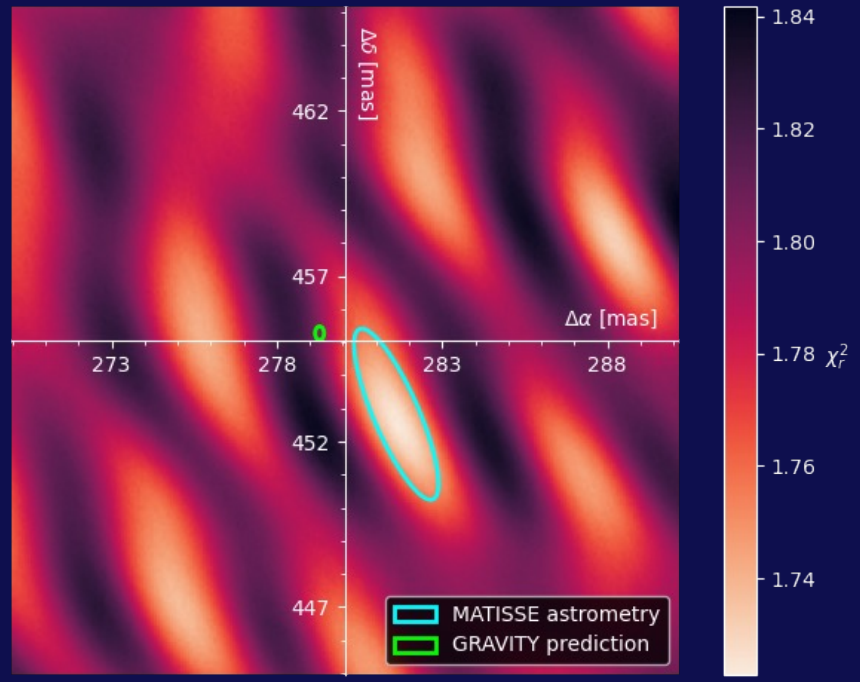
Astrometric χ^2 map



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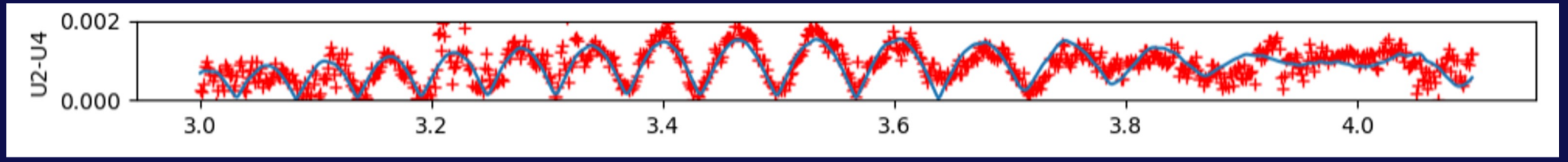
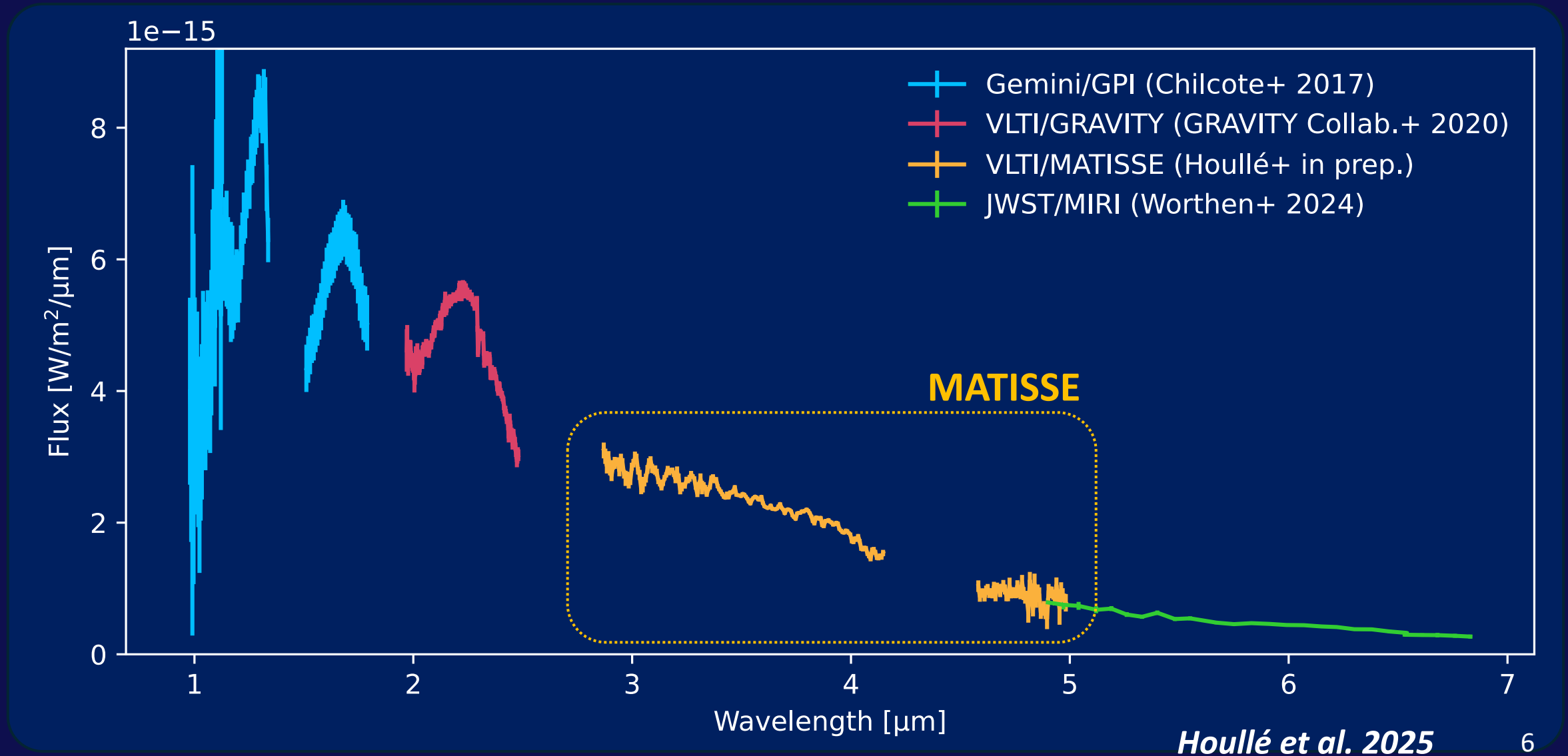


Wavelength [µm]

β Pic b spectrum

Houllé et al. 2025

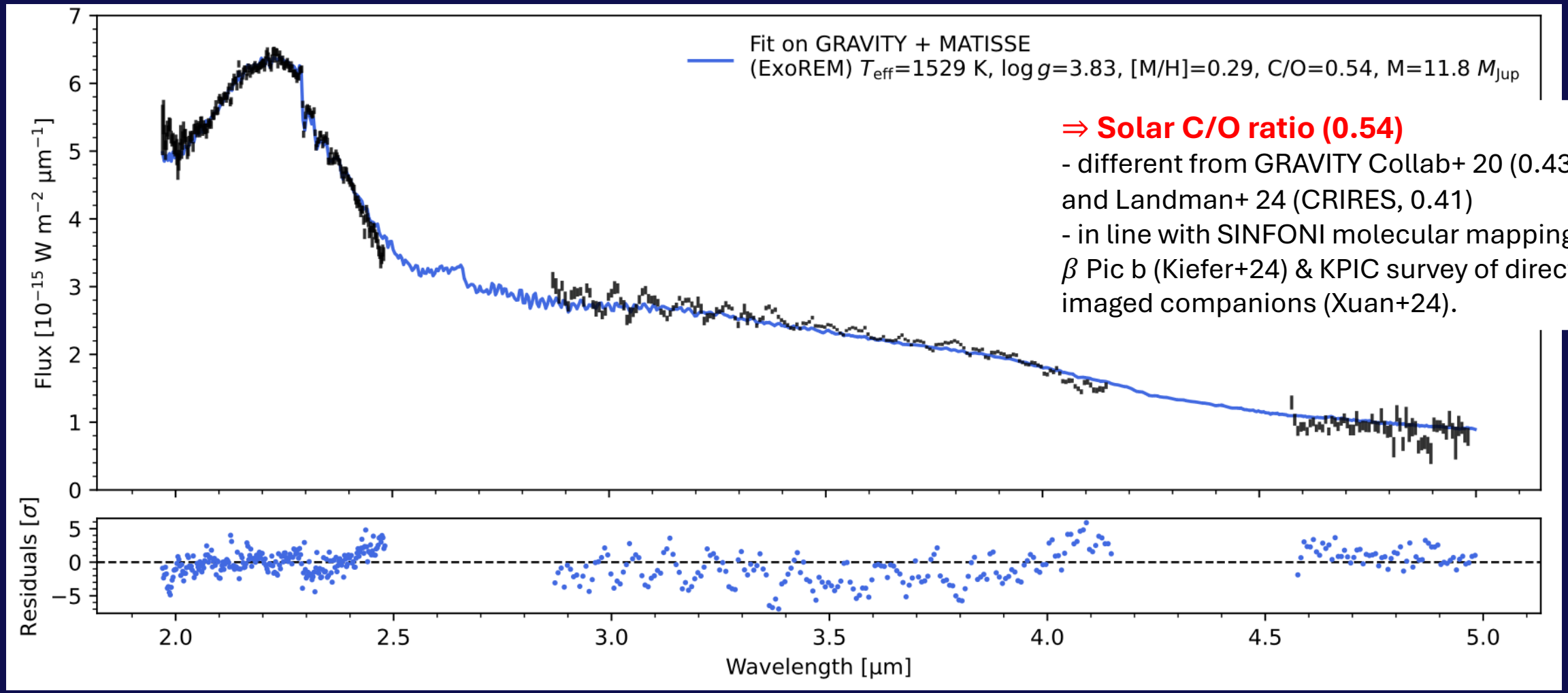
β Pic b spectral coverage now from 1 to 7 µm!



Atmospheric modelling

Houllé et al. 2025

- ForMoSA fitting tool (Petrus+23)
- ExoREM model grid (Charnay+18)



⇒ Solar C/O ratio (0.54)

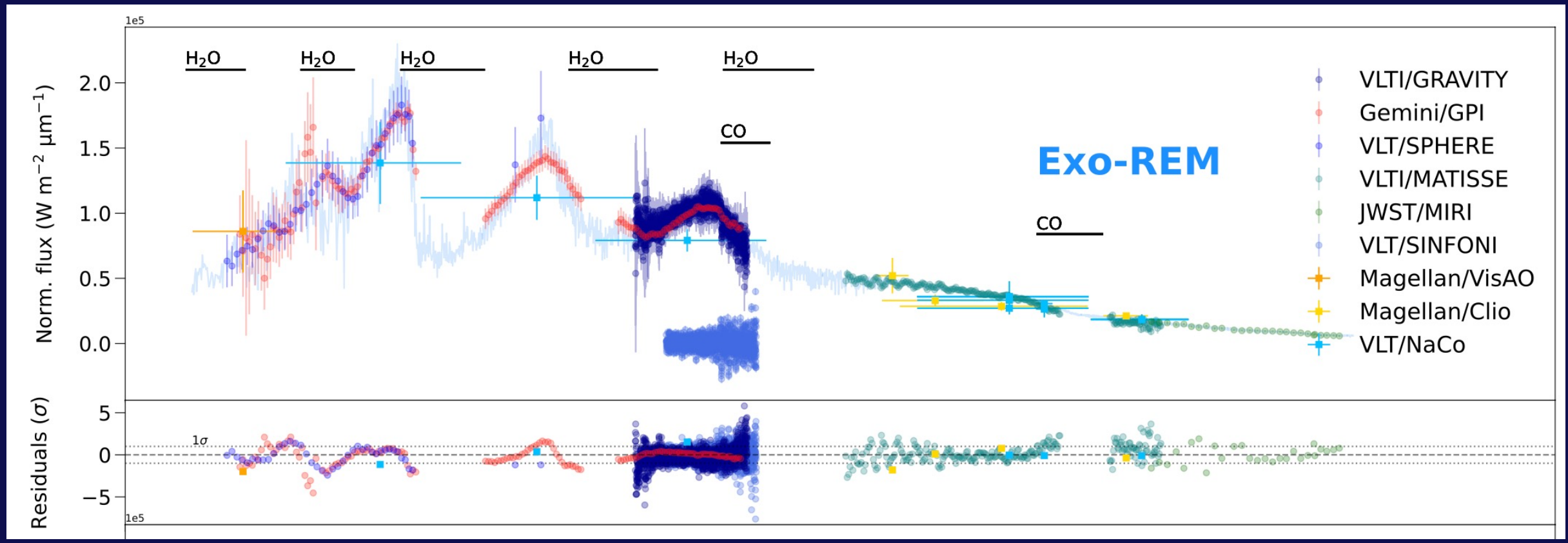
- different from GRAVITY Collab+ 20 (0.43) and Landman+ 24 (CRIRES, 0.41)
- in line with SINFONI molecular mapping on β Pic b (Kiefer+24) & KPIC survey of directly-imaged companions (Xuan+24).

Multimodal analysis of β Pic b

Ravet et al. 2025

Modelling all archival photometry and spectra of β Pic b

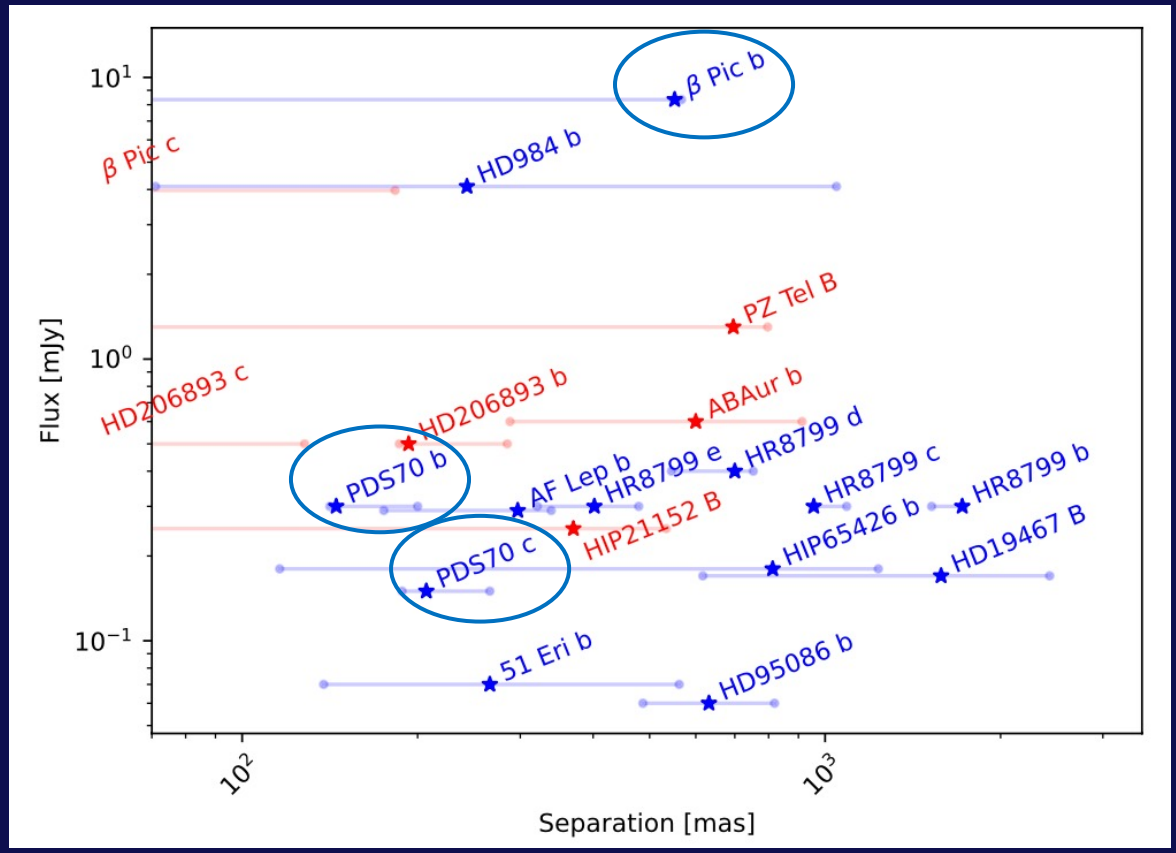
T_{eff} (K)	log(g) (dex)	[M/H]	C/O	γ	f_{sed}	$\log(^{12}C/^{13}C)$
$1503.38^{+2.30}_{-2.31}$	4.00 ± 0.01	$0.51^{+0.02}_{-0.01}$	$0.552^{+0.003}_{-0.002}$			$1.12^{+0.11}_{-0.08}$



From β Pic b to fainter companions

- **β Pic b: brightest L-band planet**
  - **median S/N of 80 per spectral channel with MATISSE**
- Most planets are ~10x fainter

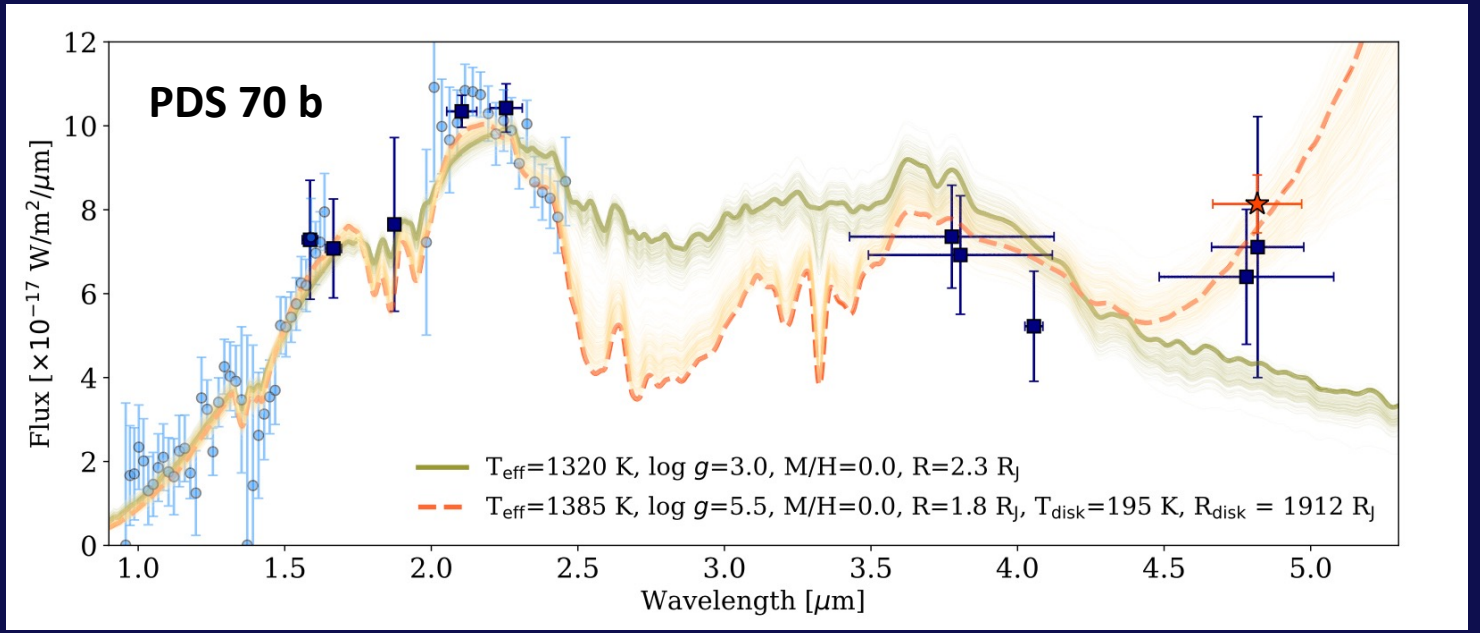
- **How to go fainter?**
  - GPAO (+ planet flux, - stellar contamination)
  - Observational & post-processing improvements
  - Understanding what limits MATISSE narrow off-axis at the moment

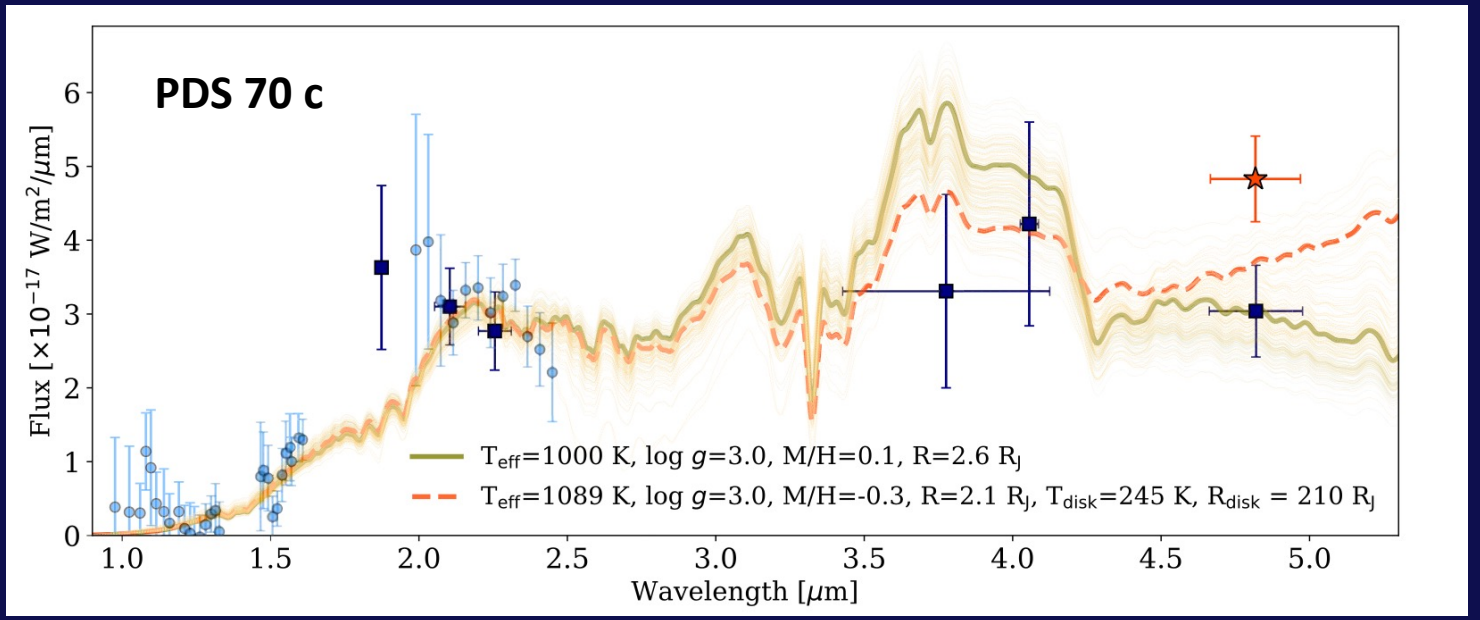


Sample of exoplanet L-band fluxes vs. separations

PDS 70 bc CPDs

- JWST/NIRCam & NIRISS photometry (Christiaens+ 24, Blakely+ 25)
- Pointing towards significant mid-IR CPD emission





Blakely+ 2025

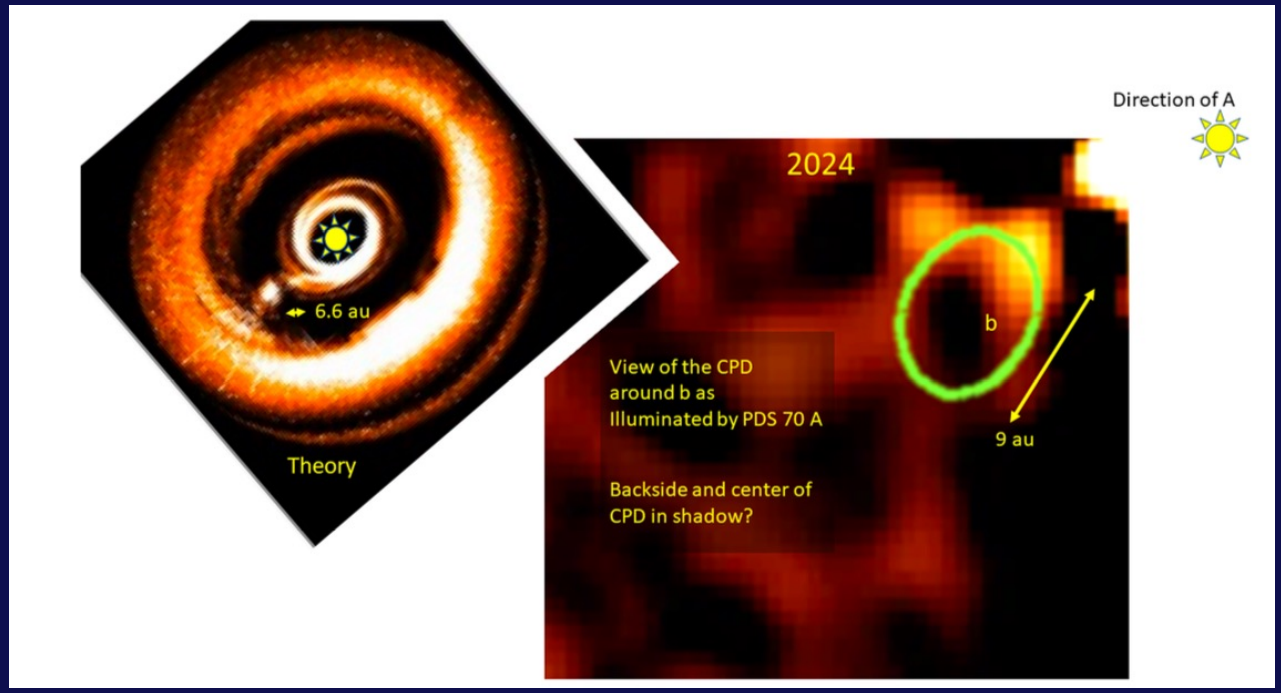
PDS 70 bc CPDs

- CPD scattering observed in the continuum near Hα with MagAO-X?
  (Close et al. 2025)

Hα (Δλ=1nm)

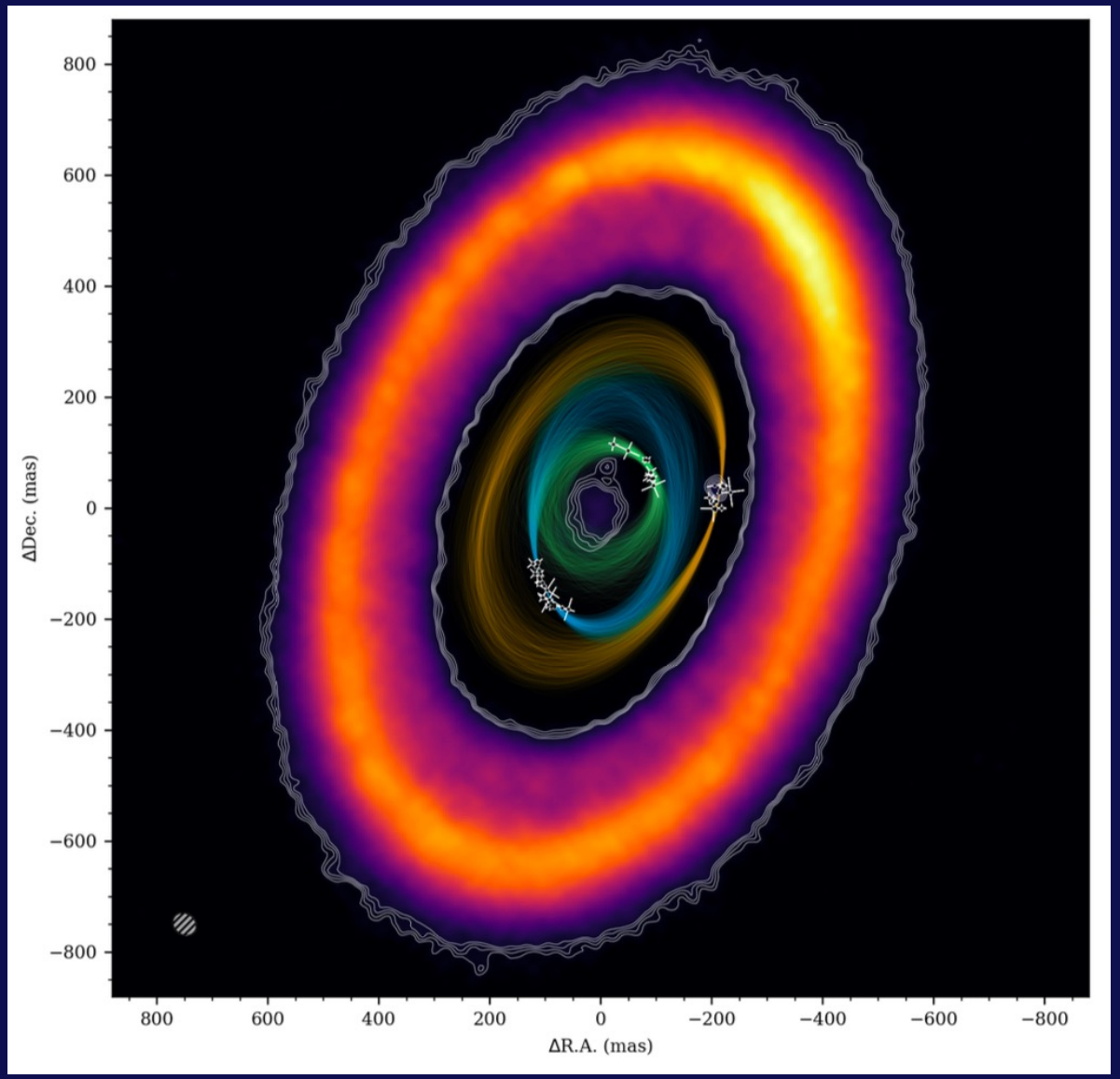
Continuum 668nm (Δλ=8nm)

Close+ 2025



PDS 70 d ?

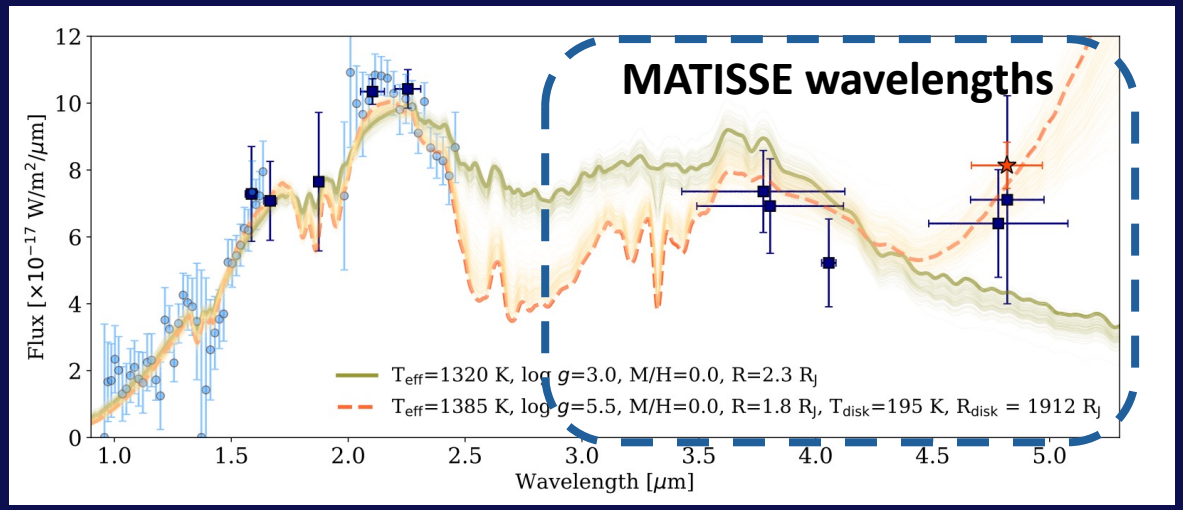
- point source rotating in Keplerian motion near 4:2:1 resonance with b and c (Trevascus+, Hammond+ 2025)
- Protoplanet or disk feature?

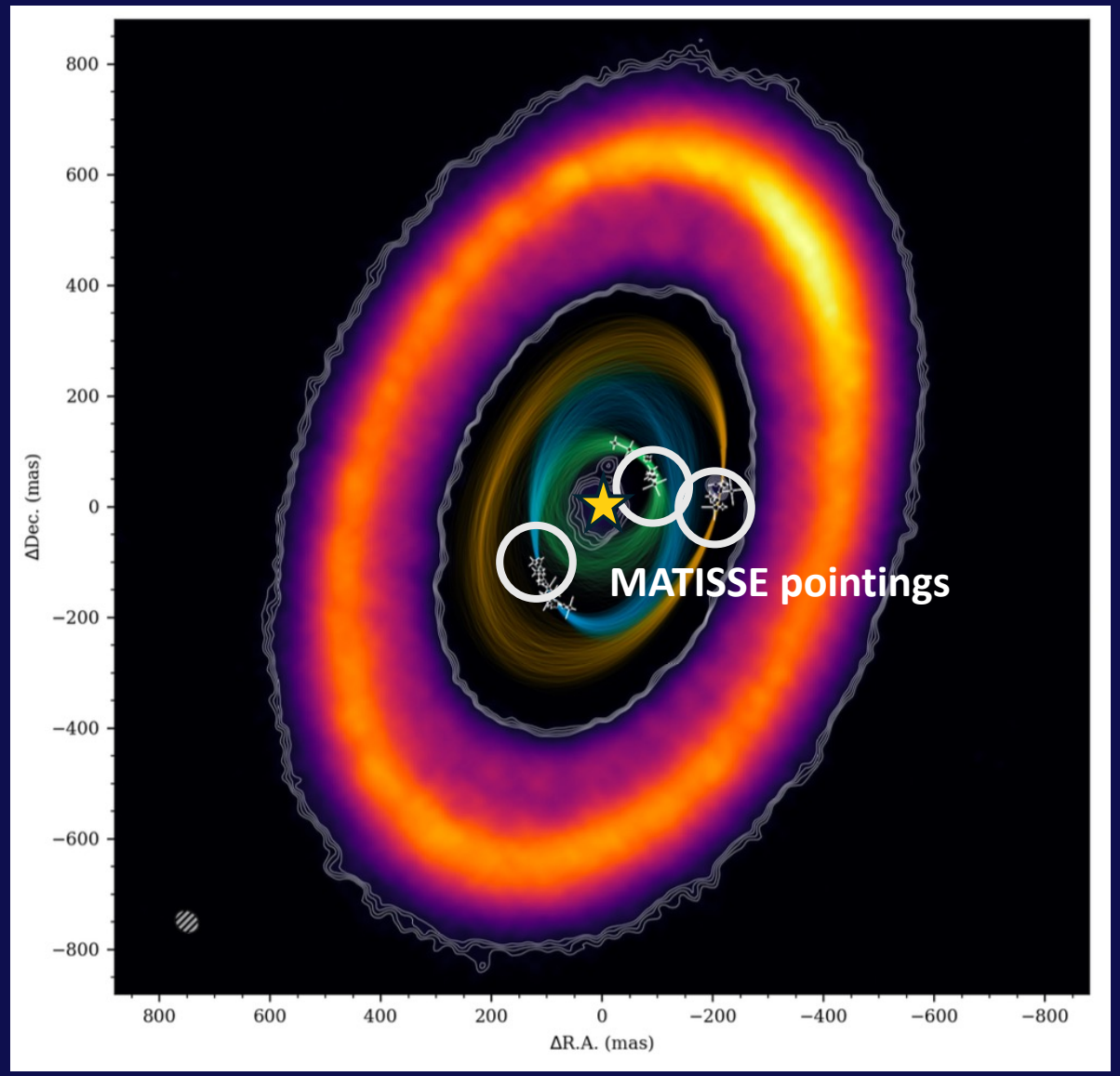


Hammond+ 2025, Trevascus+ 2025

PDS 70 MATISSE observations

- Goals:
  - 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?



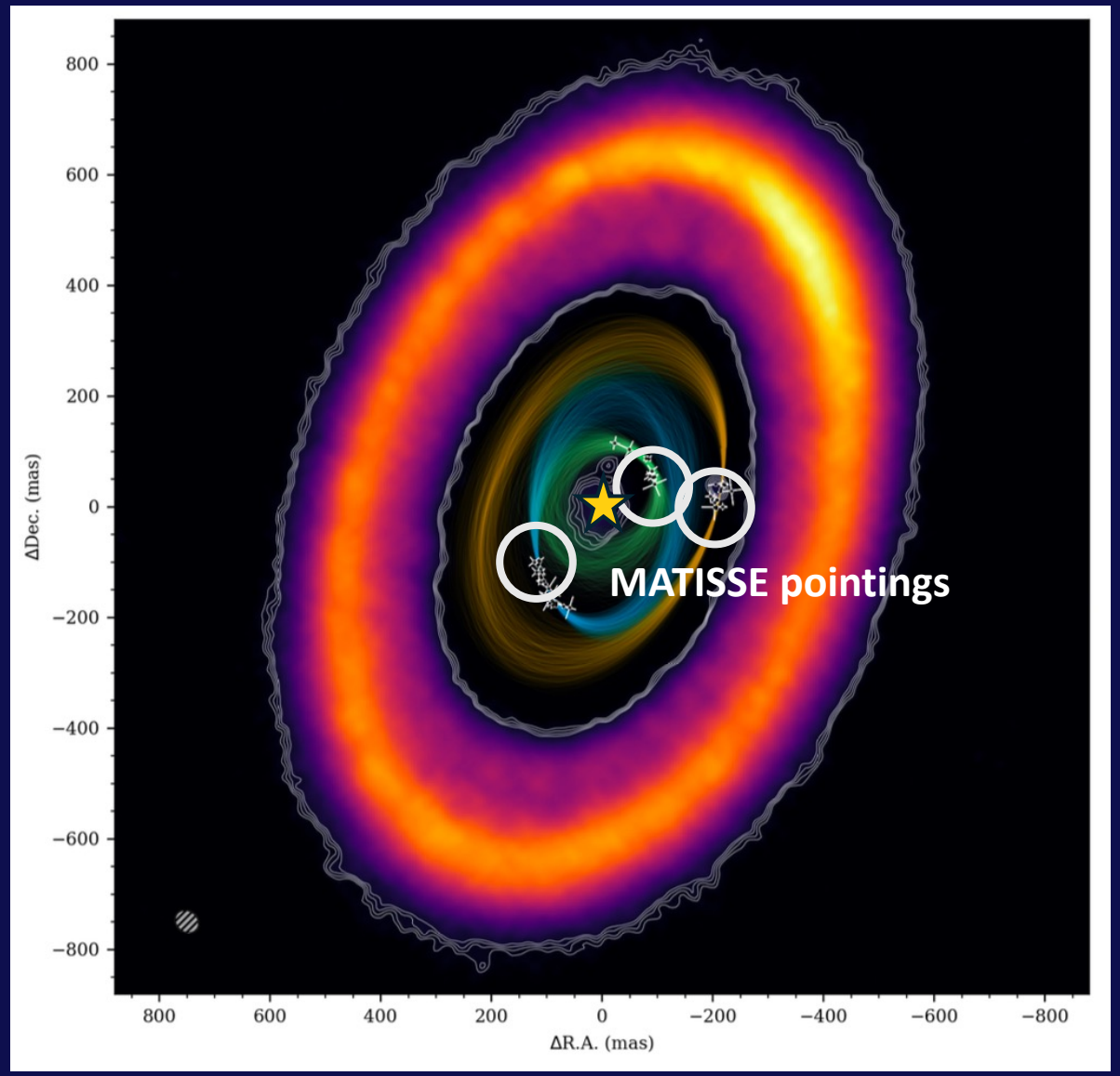


Hammond+ 2025, Trevascus+ 2025

Blakely+ 2025

PDS 70 MATISSE observations

- 3 nights of observations in March 2025
- Pointing PDS 70 A, b, c, d
- Flux optimization:
  - low spectral resolution (R = 30)



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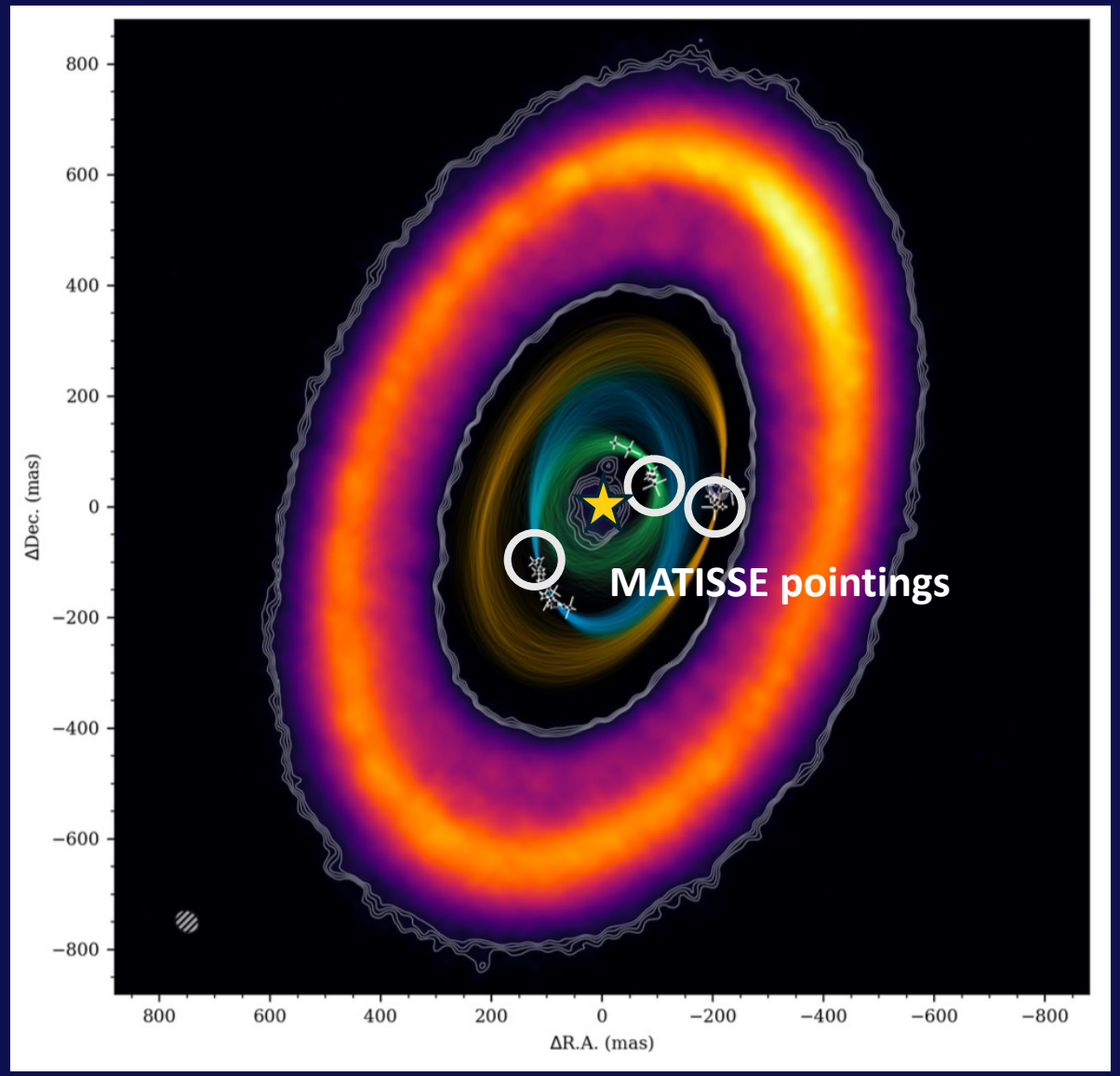

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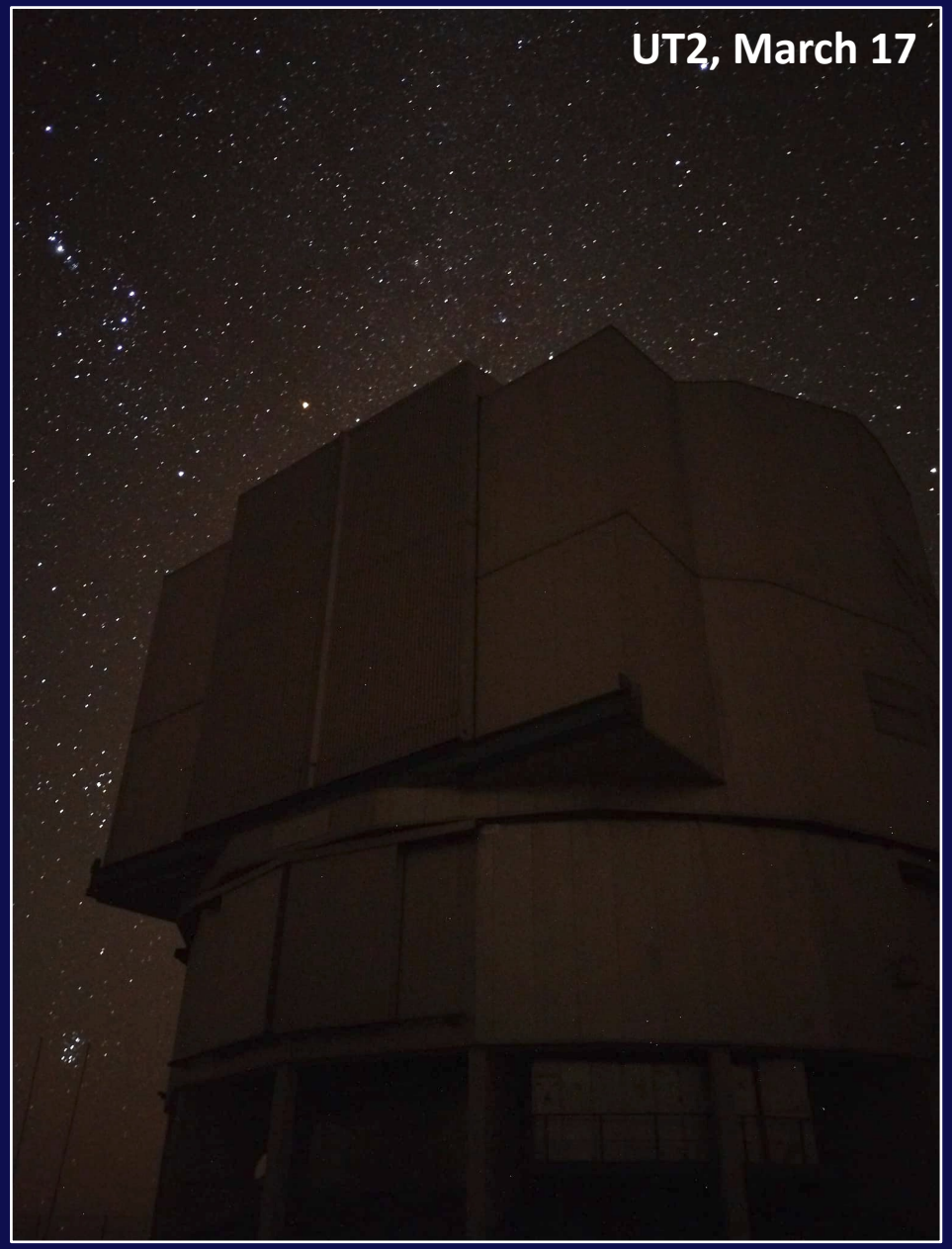
  - Multiple VLTI problems
  - UT2 failure on the 2nd night



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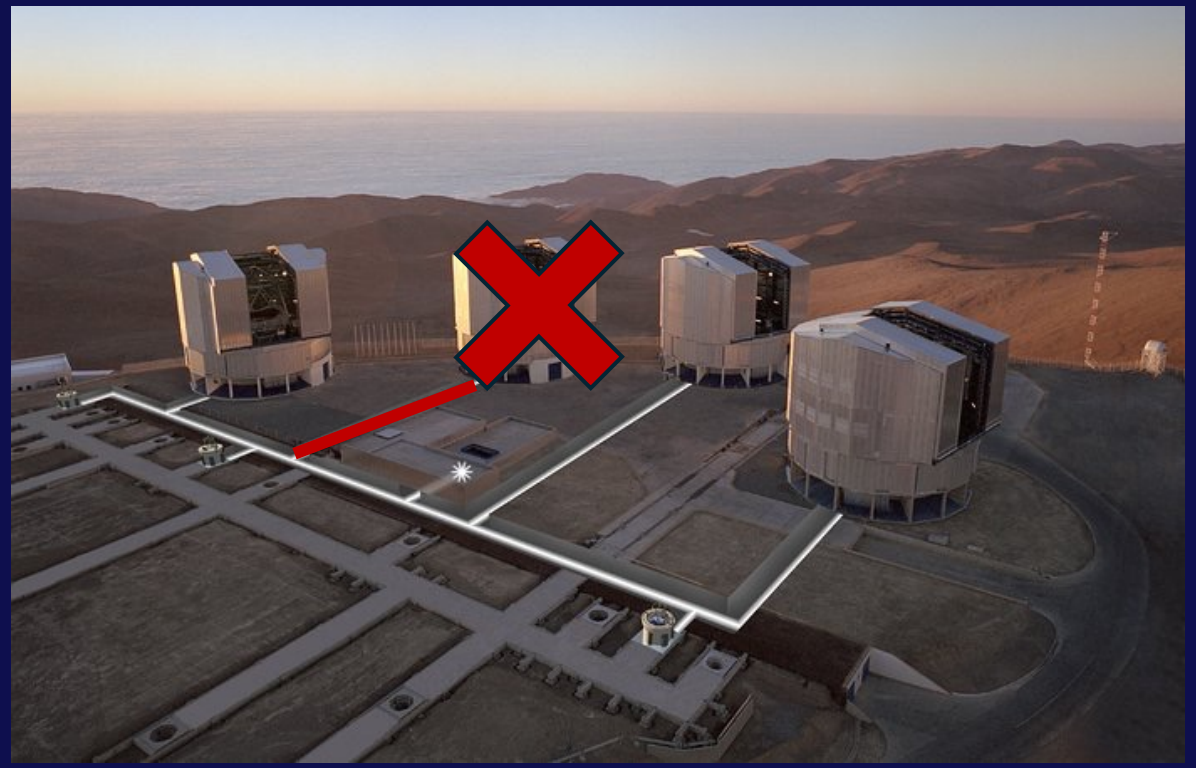

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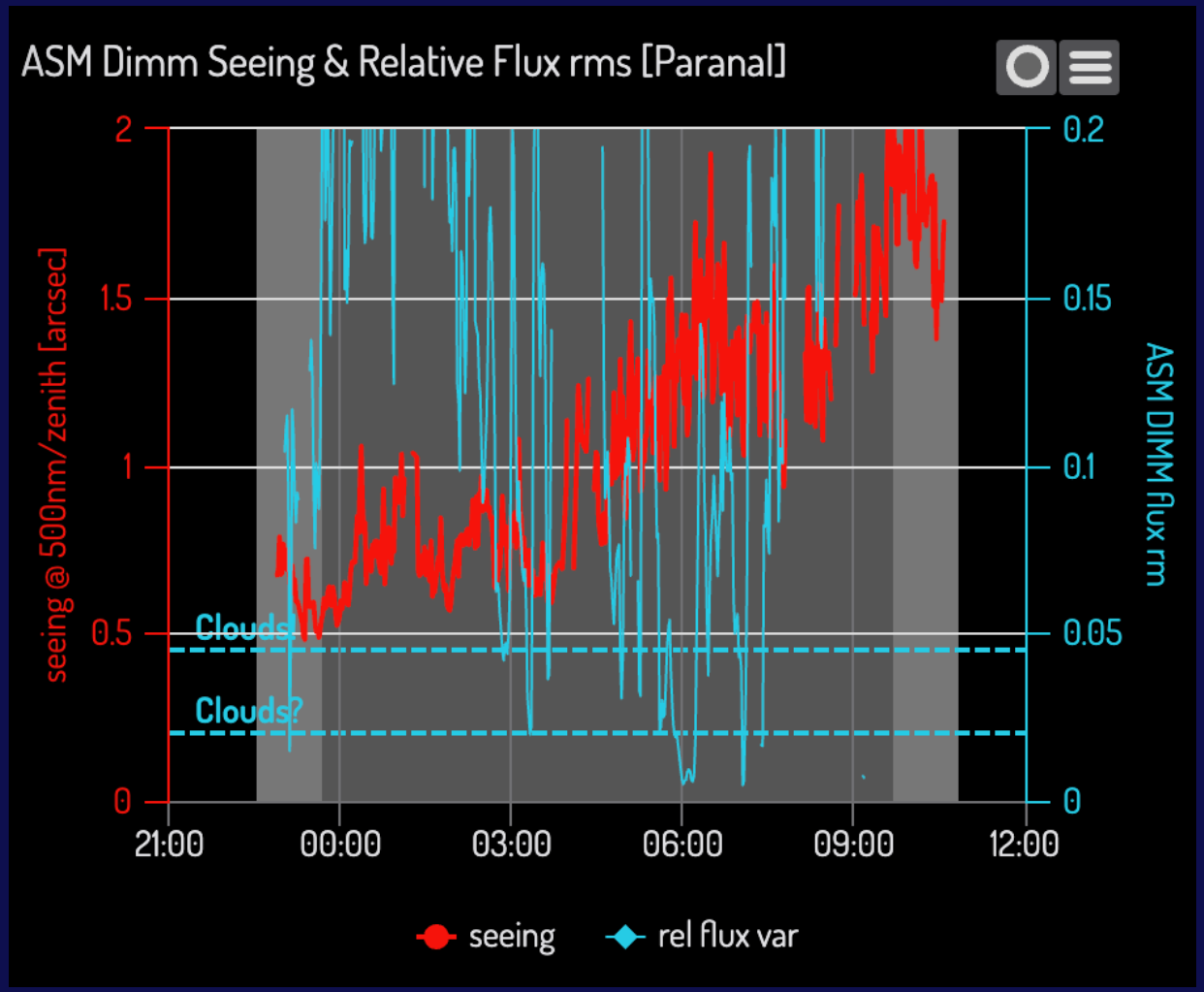

Paranal seeing and cloud coverage, April 17

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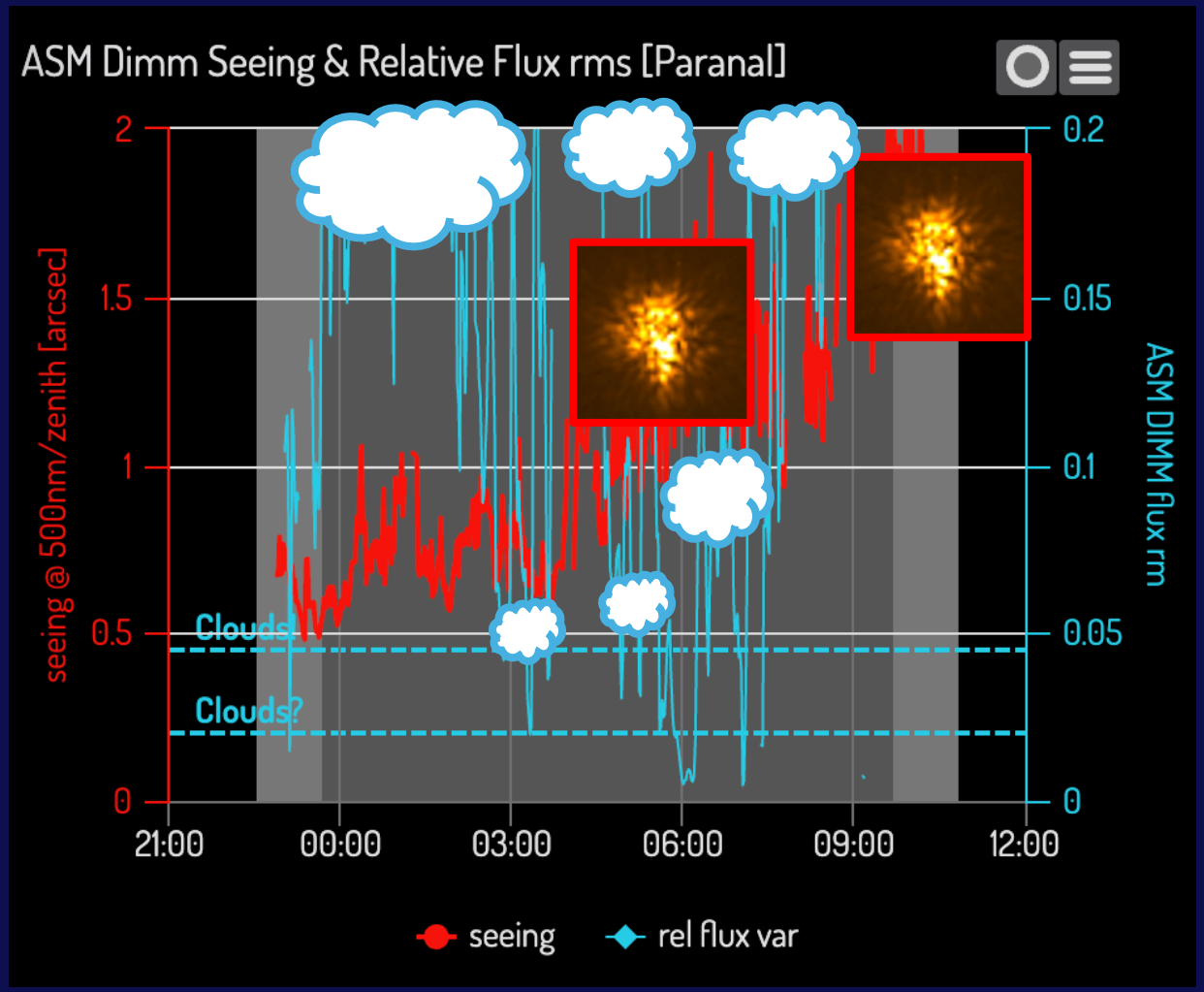
  - smaller spatial filter
    (1 λ/D instead of the standard 1.5 λ/D)
- Eventful nights
  - Multiple VLTI problems
  - UT2 failure on the 2nd night
  - Bad conditions in the April compensation night
- Still a few hours of observations on PDS 70 b & c

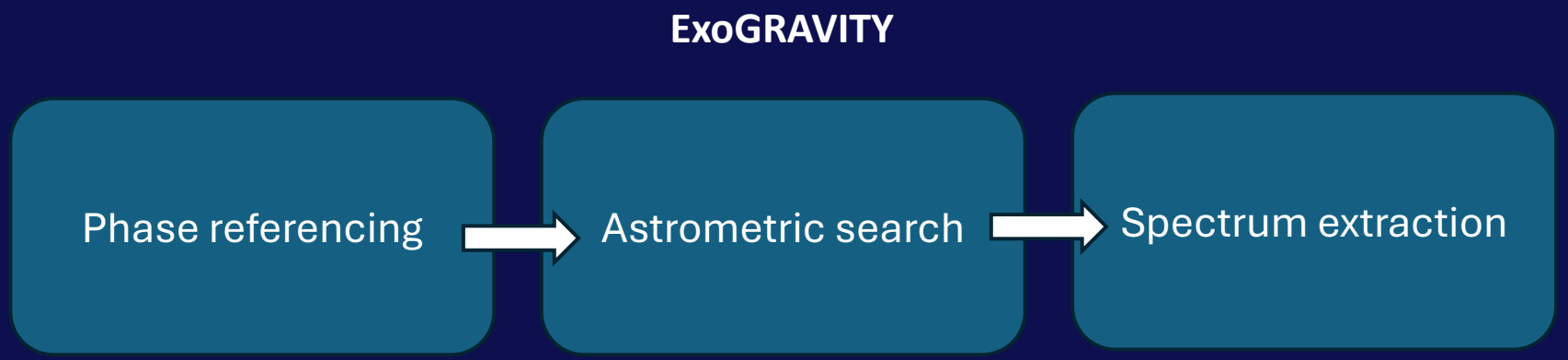


Paranal seeing and cloud coverage, April 17

ExoMATISSE post-processing

- On β Pic b: DIT-by-DIT modelling
  - motivated by the high S/N of the data and the absence of metrology

- Ongoing:
  - processing MATISSE data through the ExoGRAVITY pipeline (differential phases for the moment)
  - improving the phase corrections (chromatic dispersion, non-common path OPD…)
  - co-phasing the DITs together to create absolute phases



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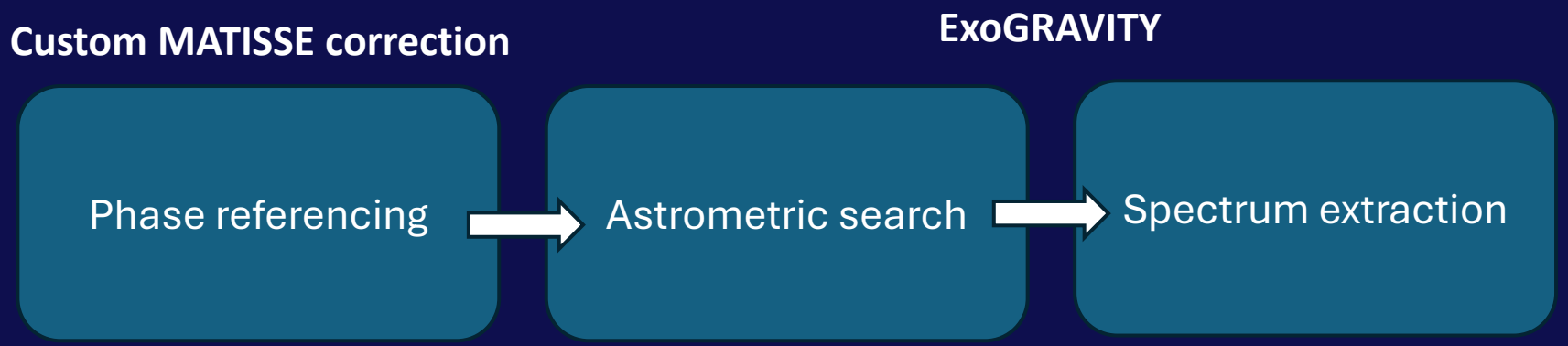
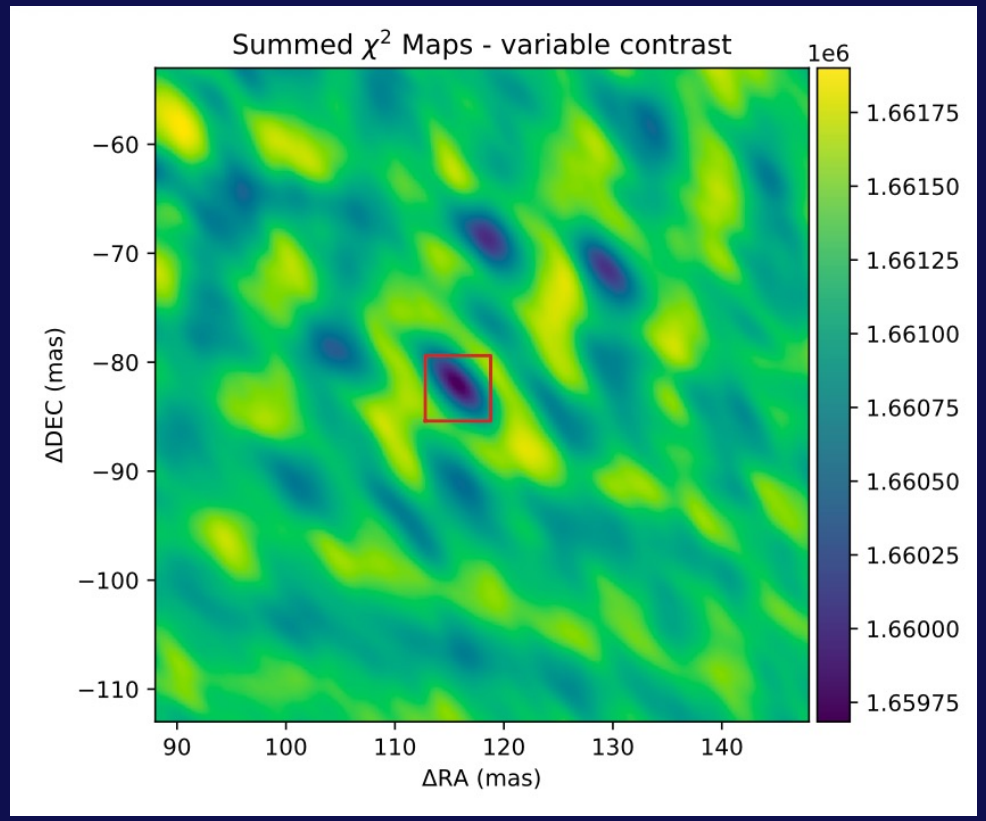
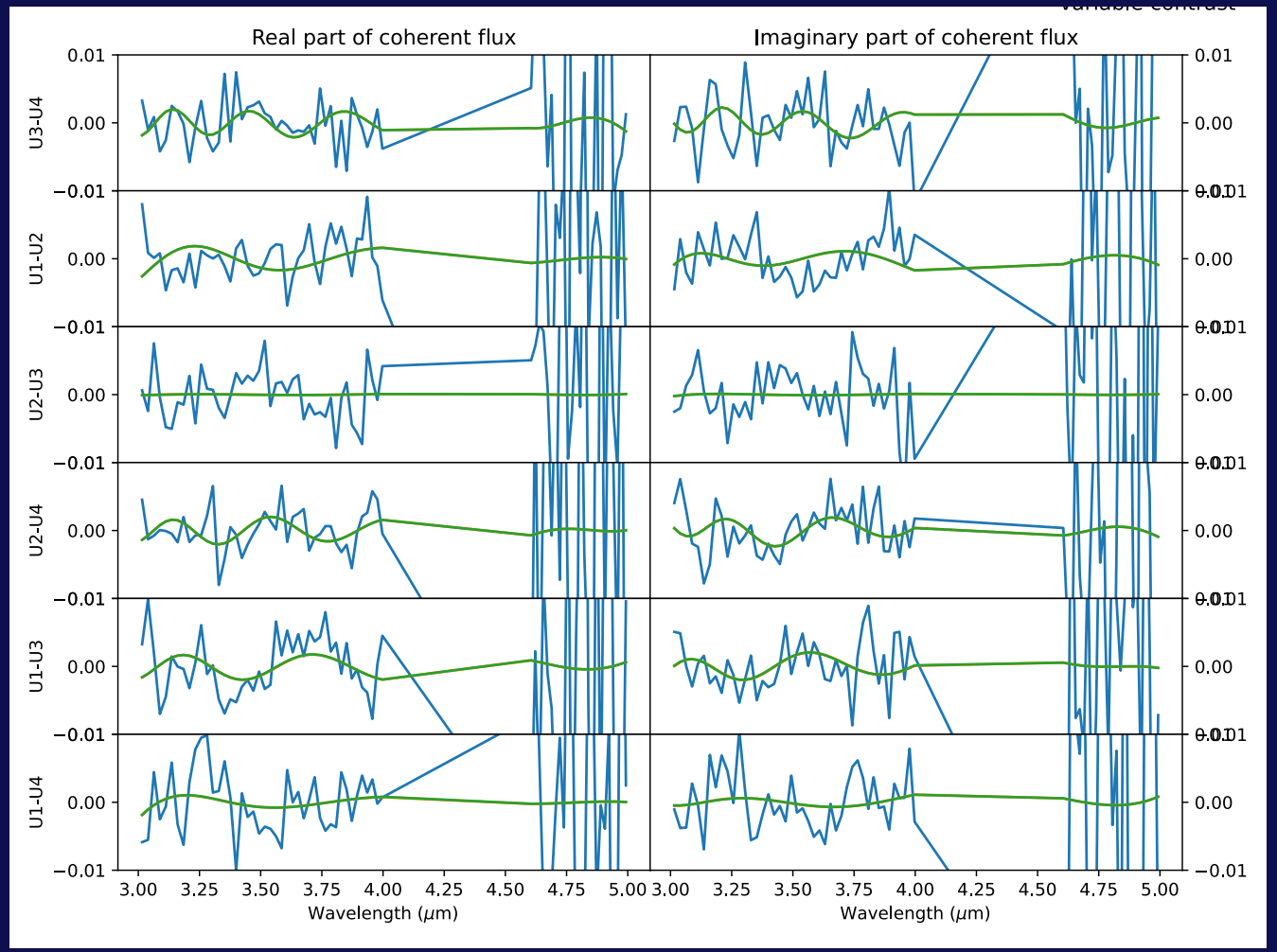


PDS 70 b with MATISSE: preliminary results

ExoGRAVITY chi-2 map

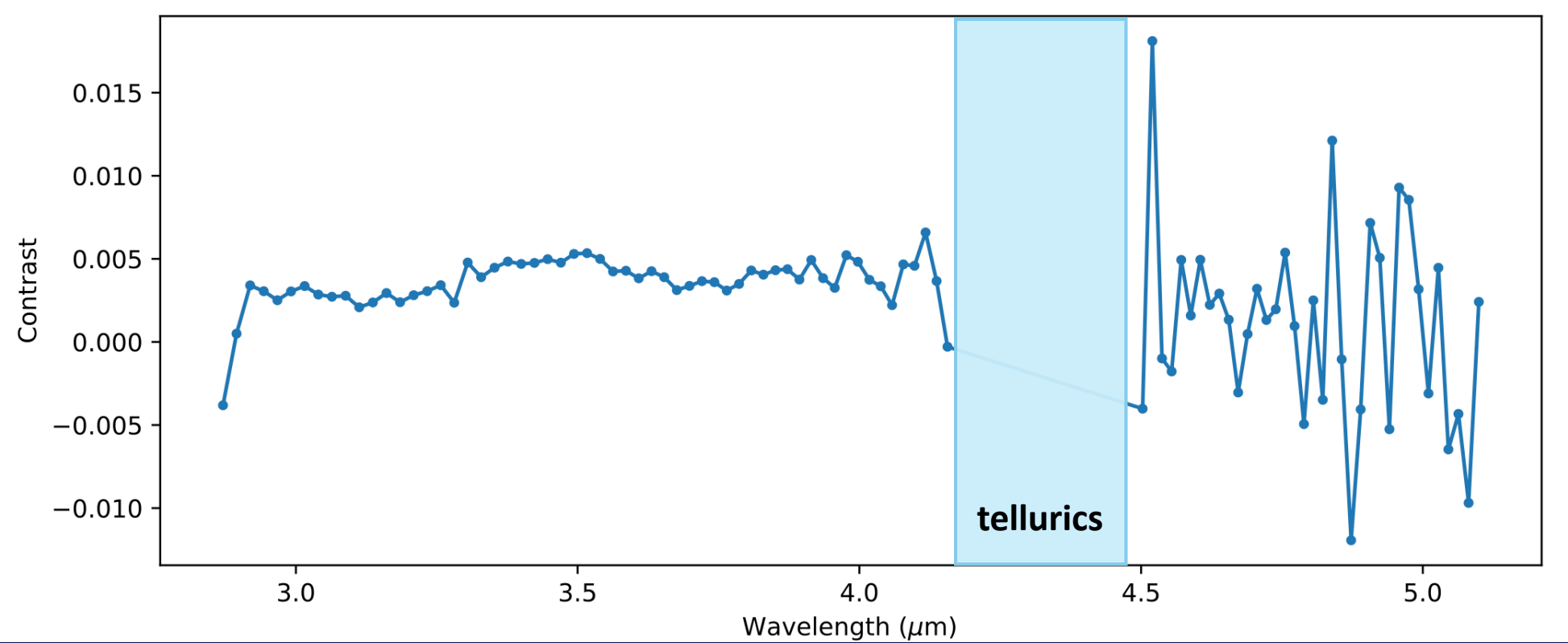


4-min stacked coherent flux + ExoGRAVITY fit



PDS 70 b with MATISSE: preliminary results

Planet-to-star contrast spectrum of PDS 70 b

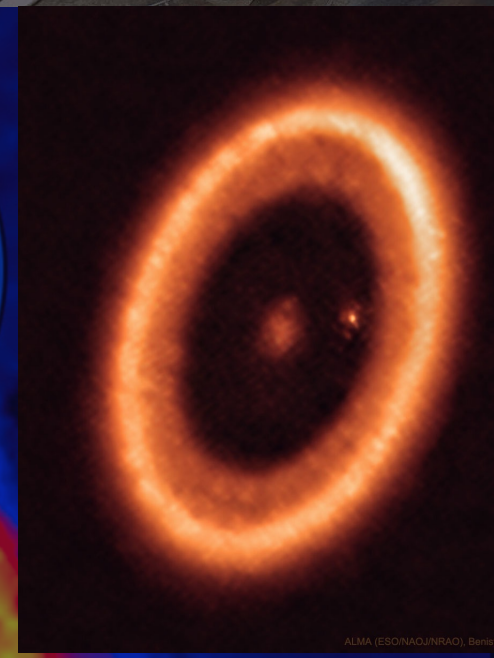


To be done: calibration with the **stellar spectrum** & **stellar visibility**

Summary

- Successful **first MATISSE exoplanet observation** on β Pic b (Houllé et al. 2025)

- PDS 70 bc(d?) with MATISSE: 20x fainter than β Pic b
- Ongoing development to develop a **pipeline for fainter companions**
- Probably not enough data overall
- But **good news!** The program will be **re-observed in March 2026**



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