

*First brown dwarf  
spectrum with MATISSE:*

*HD984B*

**Jules Scigliuto PhD student,**  
**Supervisors: Florentin Millour, Bruno Lopez, Mathis Houllé**  
Laboratoire J.L. Lagrange, Université Côte d'Azur, Observatoire de la Côte d'Azur,  
CNRS, Nice

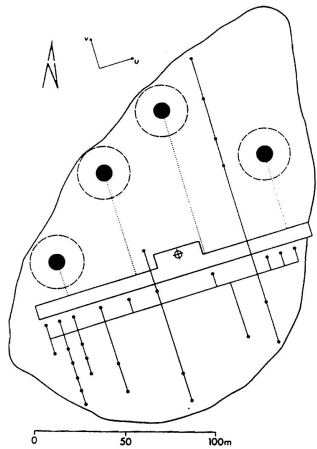
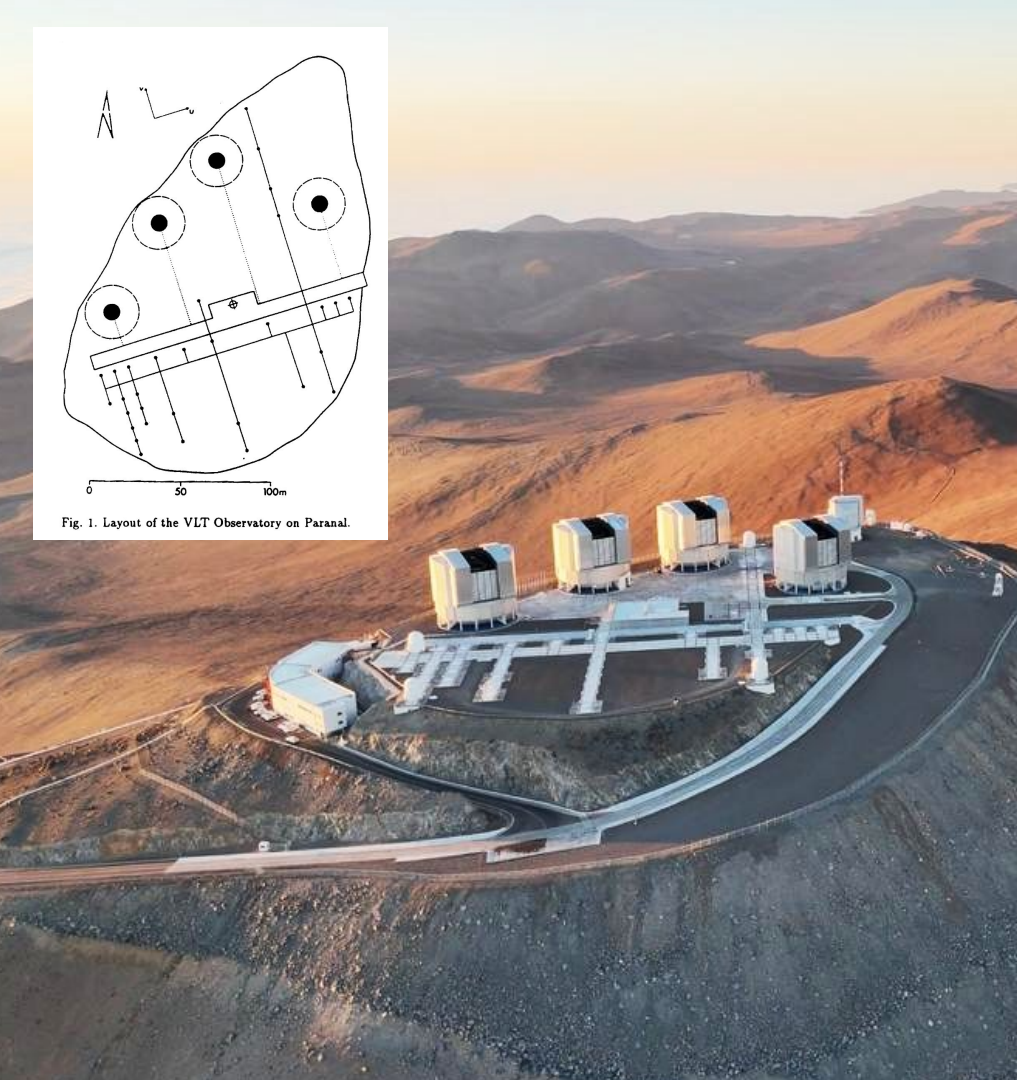


Fig. 1. Layout of the VLT Observatory on Paranal.



→ **Main goal:** To combine the light from multiple telescopes to achieve the angular resolution of a single, giant telescope whose diameter is equal to the separation between them.

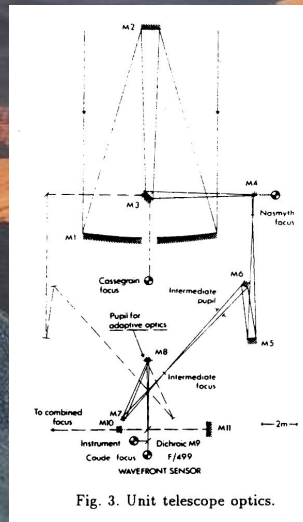


Fig. 3. Unit telescope optics.

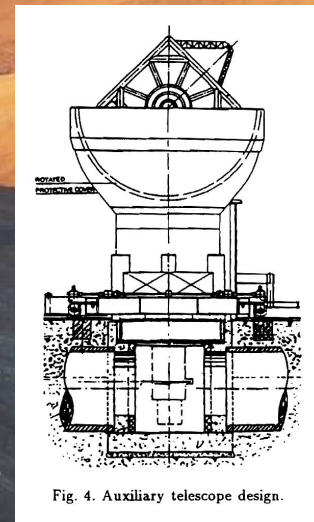
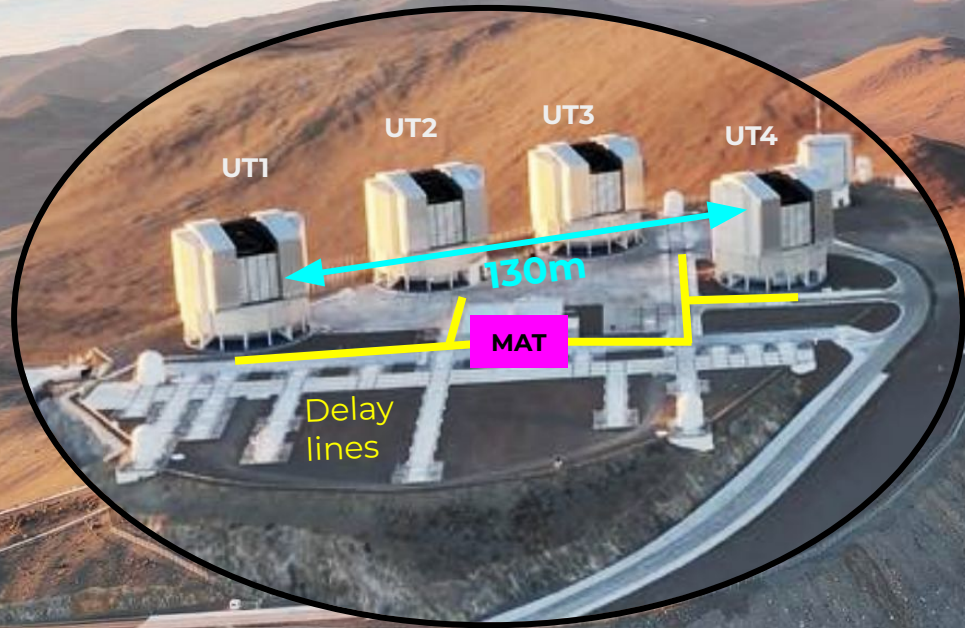


Fig. 4. Auxiliary telescope design.



→ **Main goal:** To combine the light from multiple telescopes to achieve the angular resolution of a single, giant telescope whose diameter is equal to the separation between them.

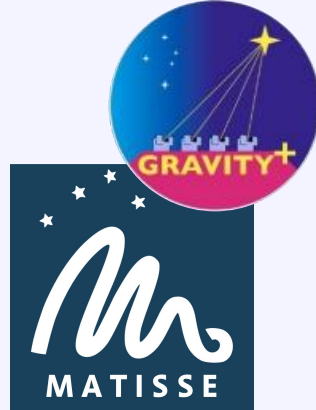
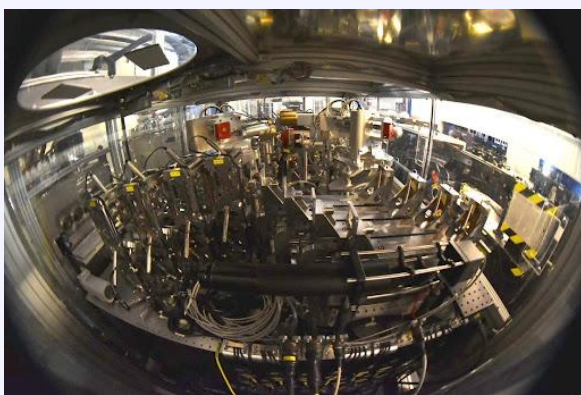
→ Telescope resolution: **70 mas**. The interferometer offers an **angular resolution equivalent to 130m telescope**.

**In the MATISSE wavelengths**  
Interferometer resolution:

- L-band ( $3.5 \mu\text{m}$ ): **5.5 mas**
- M-band ( $4.75 \mu\text{m}$ ): **7.5 mas**
- N-band ( $10.5 \mu\text{m}$ ): **16.7 mas**

To give you an idea:

→ **Probing region ~1-10 au at 100 pc**



Today MATISSE + GRA4MAT :

- GRAVITY = **fringe tracker** (FT)
- Improvement in term of sensitivity
- **Increase the exposure** time to many seconds (DIT: 100ms → 10s)
- Now limited to **telluric background noise**

Photo: Florentin Millour

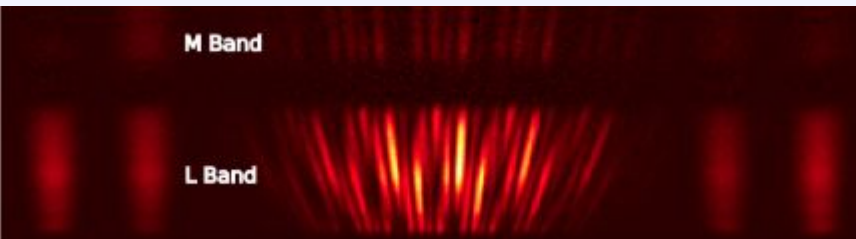
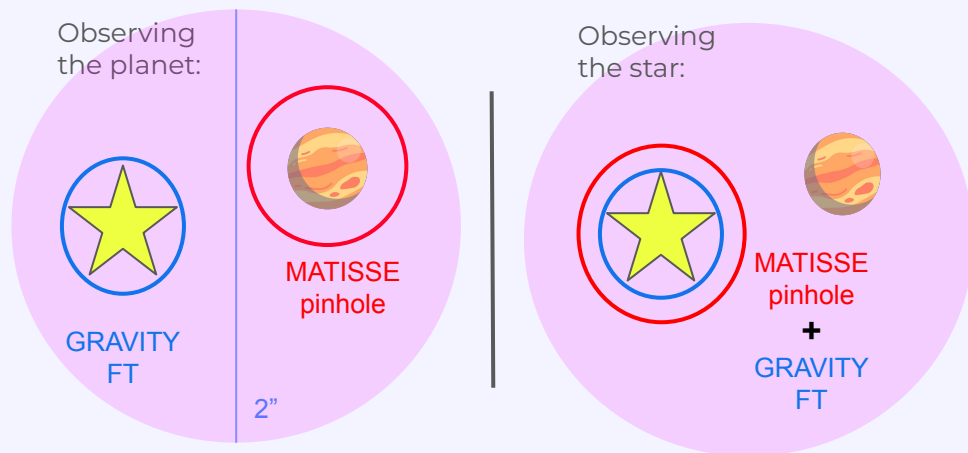
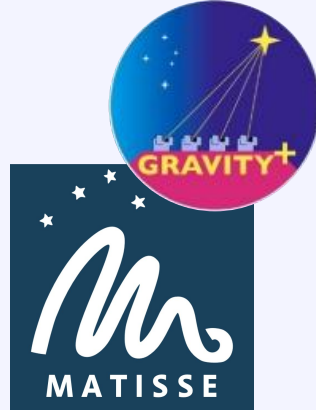
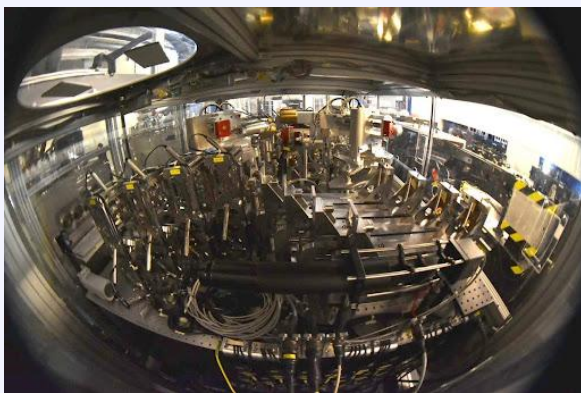


Figure 5: Lopez+2022



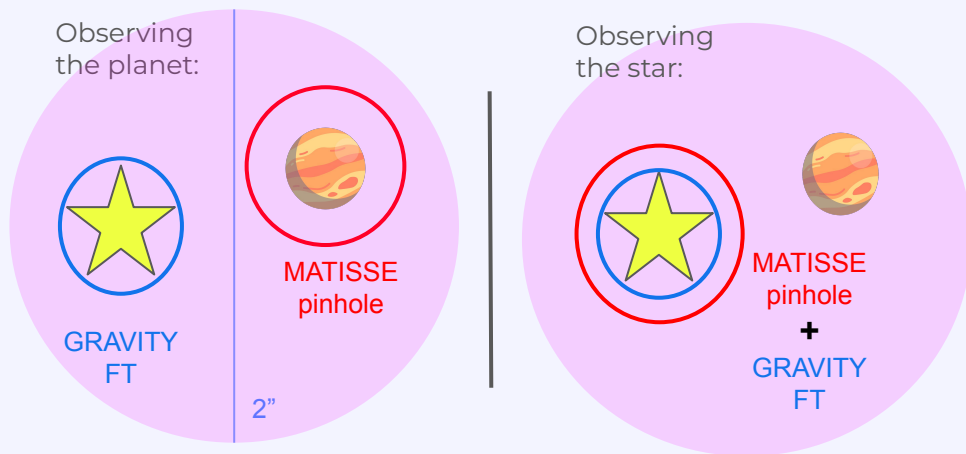
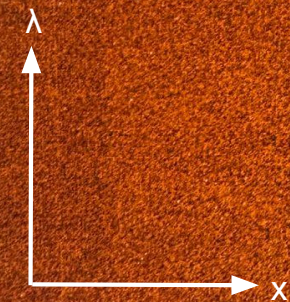


Today MATISSE + GRA4MAT :

- GRAVITY = **fringe tracker** (FT)
- Improvement in term of sensitivity
- **Increase the exposure** time to many seconds (DIT: 100ms → 10s)
- Now limited to **telluric background noise**

Photo: Florentin Millour

Fringes  
( $\beta$  Pic b) visible  
by eyes on the  
RTD



$$\mathcal{F}_\star = T_\star S_\star(\lambda)$$

$$\mathcal{F}_p = T_p \left[ S_p(\lambda) + R(\lambda) e^{i \frac{2\pi}{\lambda} \vec{U} \cdot \vec{\alpha}} \right]$$

$$\frac{\mathcal{F}_p}{\mathcal{F}_\star} = \tau \left[ C(\lambda) + R(\lambda) e^{i \frac{2\pi}{\lambda} \vec{U} \cdot \vec{\alpha}} \right]$$

$$\vec{U} = (u_{ij}, v_{ij})$$

Baseline  
vector

$$\vec{\alpha} = (\Delta\alpha, \Delta\delta)$$

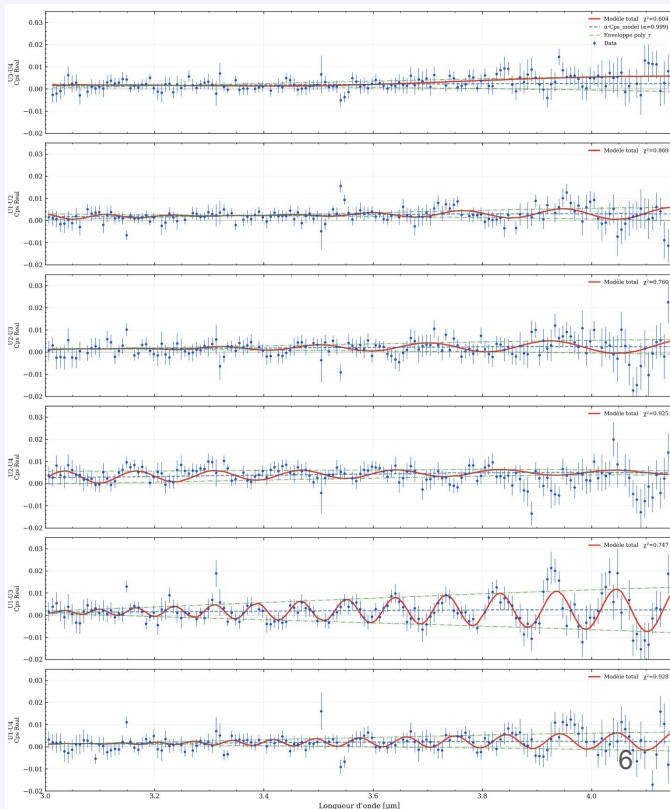
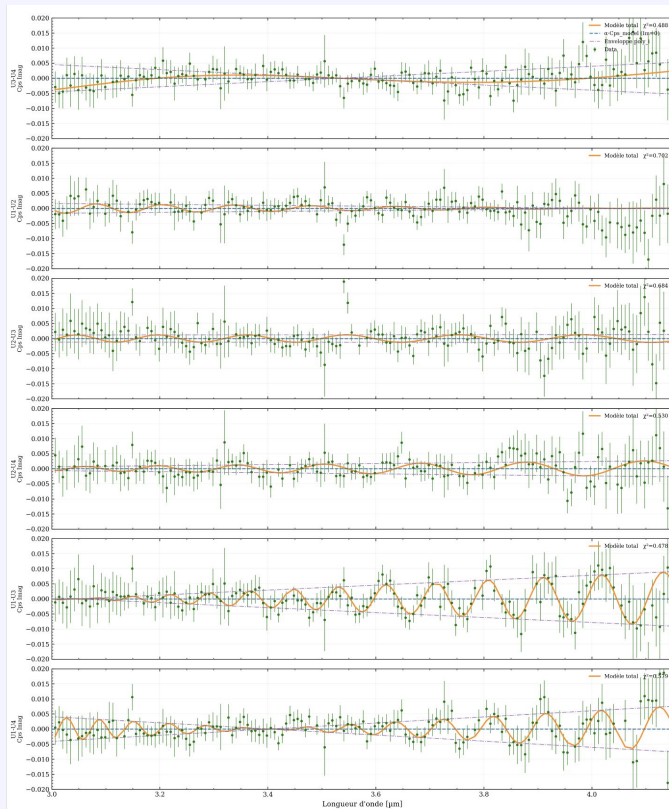
On-sky  
offset

$$C(\lambda) = \frac{S_p(\lambda)}{S_\star(\lambda)}$$

Contrast

$$R(\lambda) = a\lambda + b$$

Speckle  
flux



$$\mathcal{F}_\star = T_\star S_\star(\lambda)$$

$$\mathcal{F}_p = T_p [S_p(\lambda) + R(\lambda) e^{i \frac{2\pi}{\lambda} \vec{U} \cdot \vec{\alpha}}]$$

$$\frac{\mathcal{F}_p}{\mathcal{F}_\star} = \tau [C(\lambda) + R(\lambda) e^{i \frac{2\pi}{\lambda} \vec{U} \cdot \vec{\alpha}}]$$

$$\vec{U} = (u_{ij}, v_{ij})$$

Baseline vector

$$\vec{\alpha} = (\Delta\alpha, \Delta\delta)$$

On-sky offset

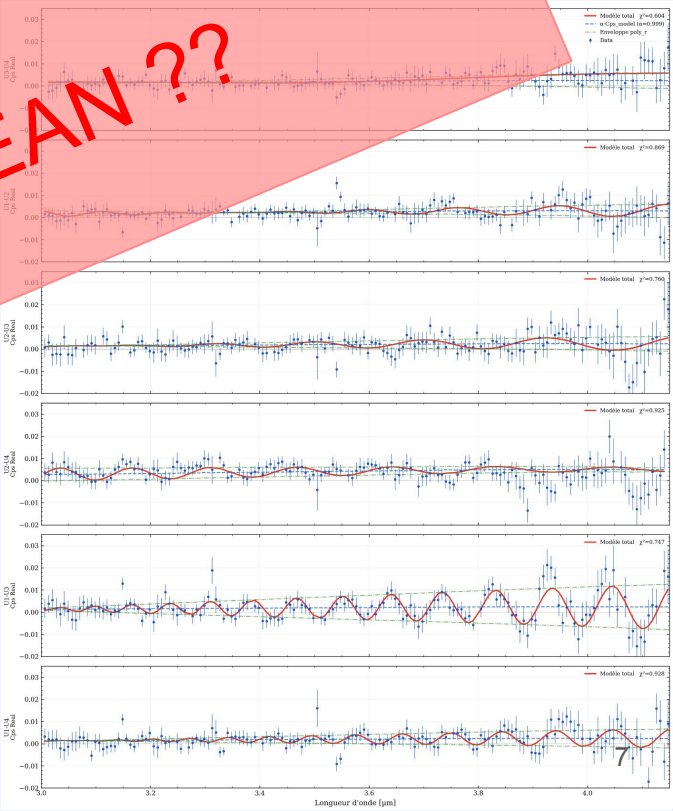
$$C(\lambda) = \frac{F_p(\lambda)}{F_\star(\lambda)}$$

Contrast

$$R(\lambda)$$

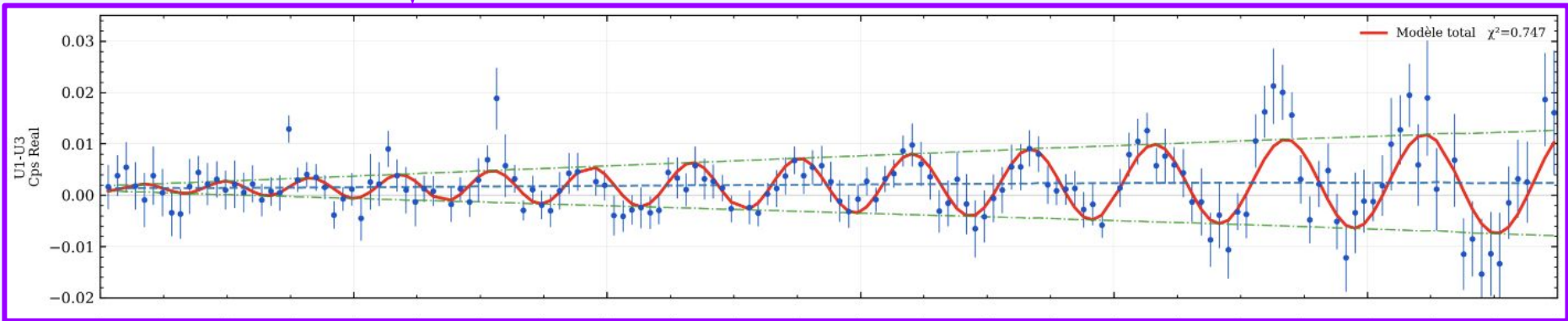
Stellar contamination (Speckle)

WHAT DOES THAT MEAN??



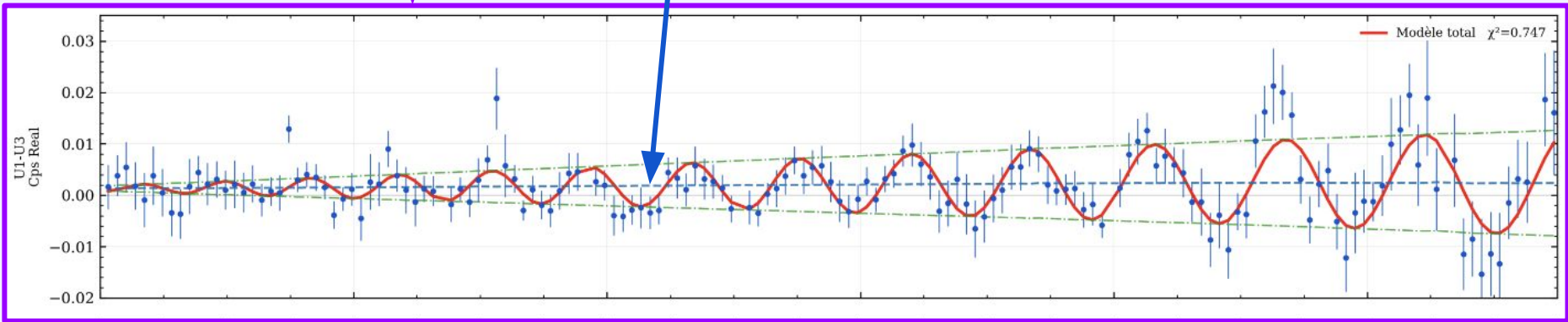
Real part of  
the coherent  
flux ratio

$$\frac{\mathcal{F}_p}{\mathcal{F}_\star} = \tau \left[ C(\lambda) + R(\lambda) e^{i \frac{2\pi}{\lambda} \vec{U} \cdot \vec{\alpha}} \right]$$



Real part of  
the coherent  
flux ratio

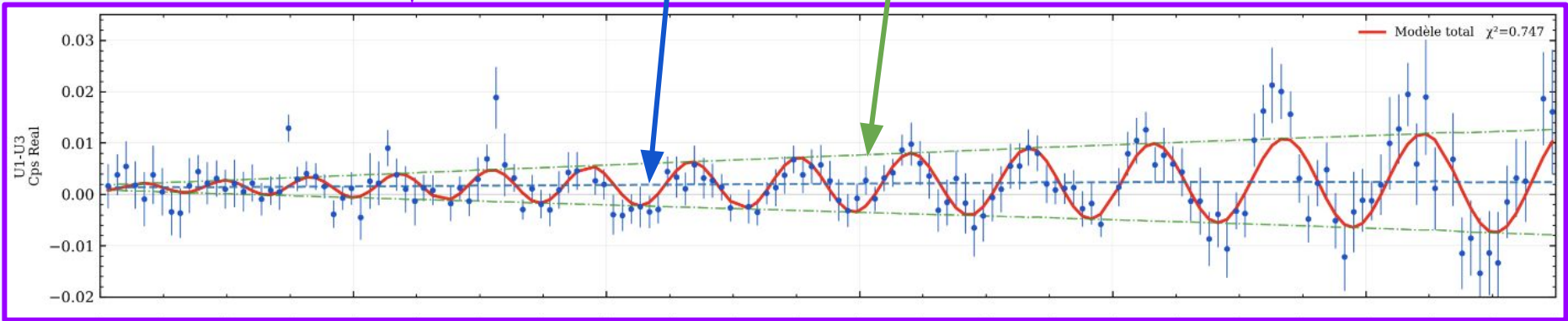
$$\frac{\mathcal{F}_p}{\mathcal{F}_\star} = \tau [C(\lambda) + R(\lambda)e^{i\frac{2\pi}{\lambda}\vec{U}\cdot\vec{\alpha}}]$$



Flux level

Real part of  
the coherent  
flux ratio

$$\frac{\mathcal{F}_p}{\mathcal{F}_\star} = \tau \left[ C(\lambda) + R(\lambda) e^{i \frac{2\pi}{\lambda} \vec{U} \cdot \vec{\alpha}} \right]$$

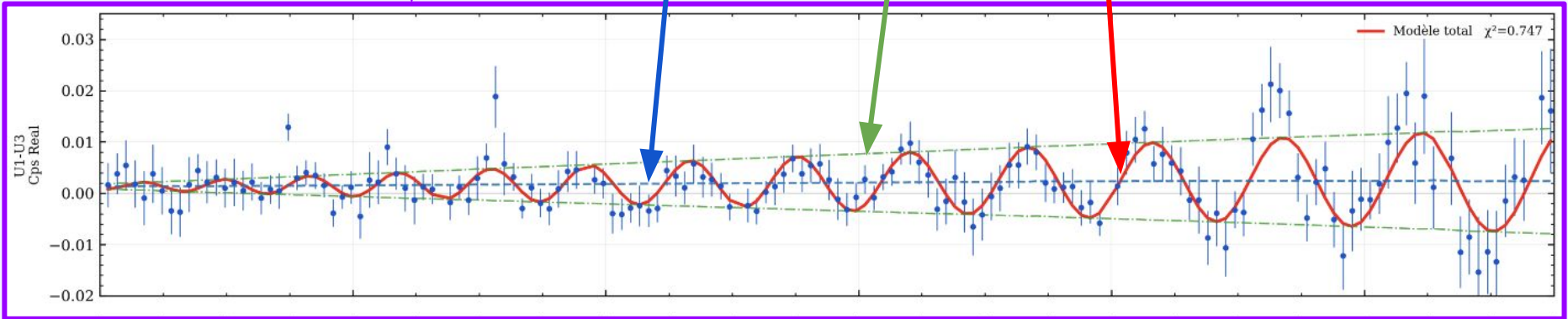


Flux level

Envelope of  
the signal  
hold by the  
speckle flux

Real part of  
the coherent  
flux ratio

$$\frac{\mathcal{F}_p}{\mathcal{F}_\star} = \tau [C(\lambda) + R(\lambda) e^{i \frac{2\pi}{\lambda} \vec{U} \cdot \vec{\alpha}}]$$



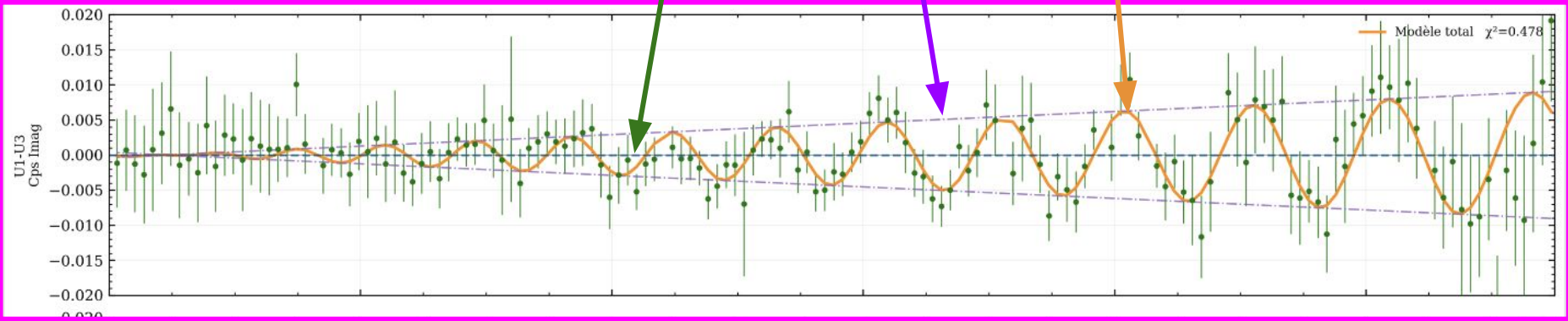
Flux level

Envelope of  
the signal  
hold by the  
speckle flux

Period of  
oscillation  
due to a  
binary signal

Imaginary part of the coherent flux ratio

$$\frac{\mathcal{F}_p}{\mathcal{F}_\star} = \tau \left[ C(\lambda) + R(\lambda) e^{i \frac{2\pi}{\lambda} \vec{U} \cdot \vec{\alpha}} \right]$$

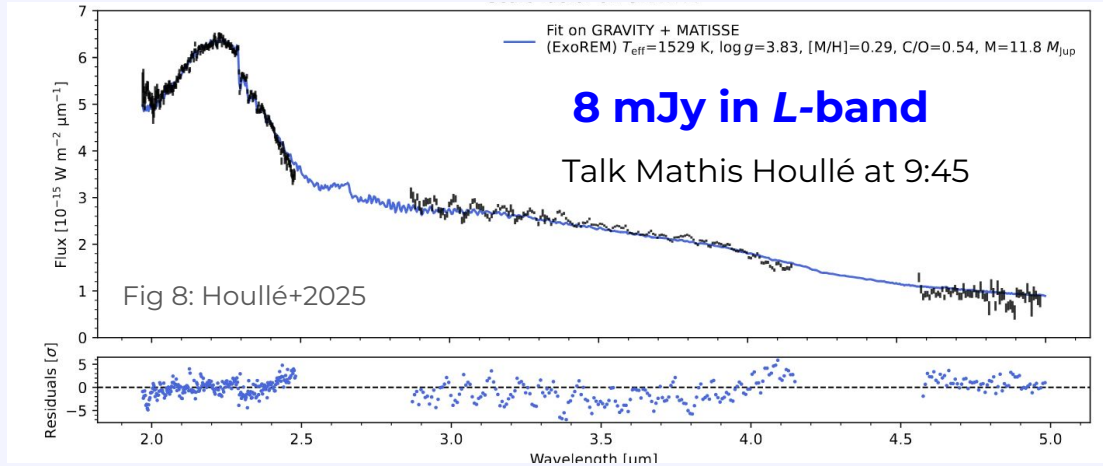


= 0  
(the contrast has no imaginary part)

Envelope of the signal hold by the speckle flux

Period of oscillation due to a binary signal

→ Young brown dwarfs (YBDs) are **good laboratories for young giant planets (YGPs) study**

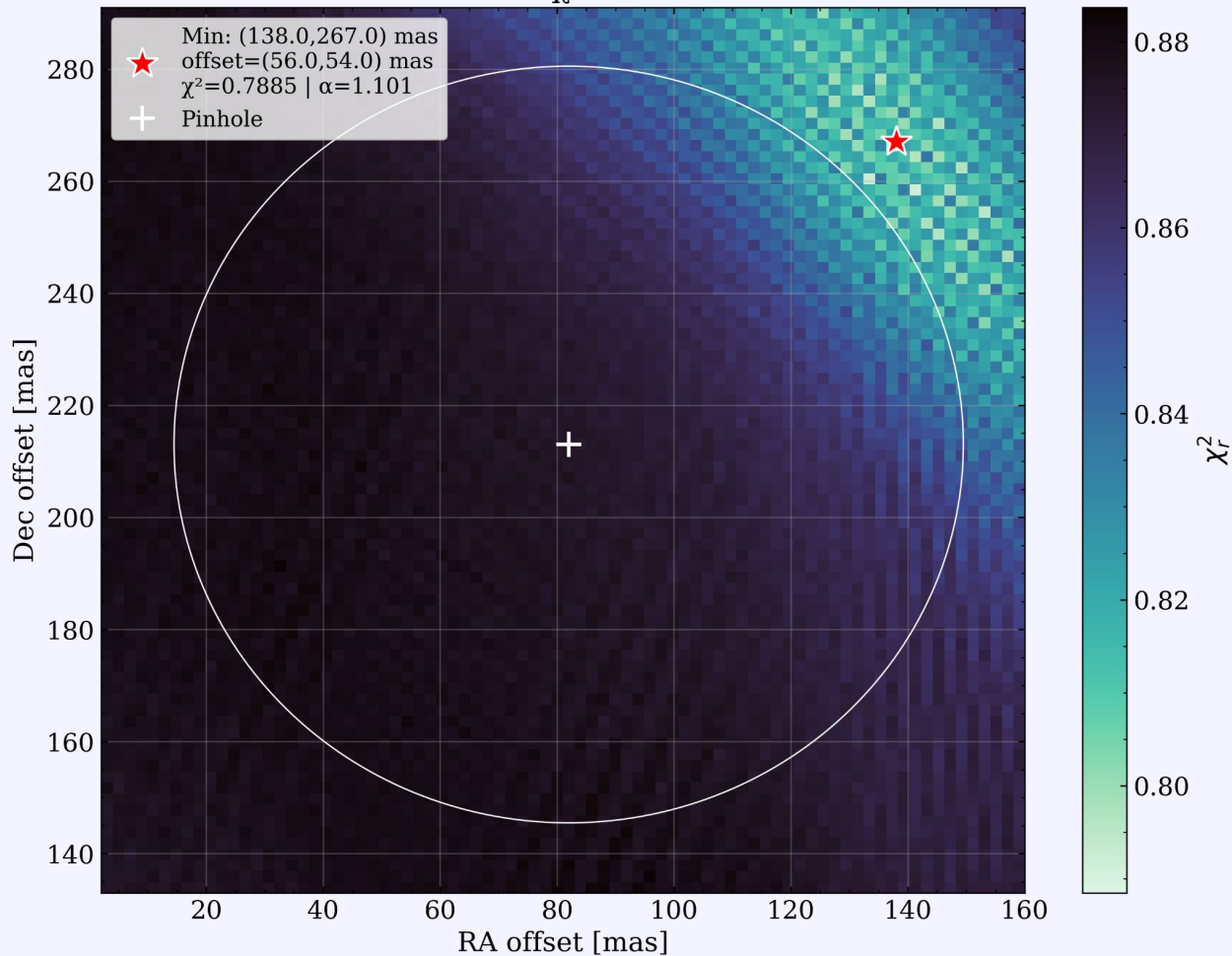


We wanted to go deeper in term of flux.  
HD 984 B is **2 times** fainter than  $\beta$  Pic b and **2 times** closer from its host star

YBDs and YGPs share nearly identical atmospheric properties, such as **effective temperatures**, clouds, and spectra dominated by the same **molecular signatures** (water, carbon monoxide, methane, etc.)

Furthermore, YBDs often form farther from their host stars and are **more massive and brighter** than YGPs, which **improves the SNR**.

Carte  $\chi^2$  L+M

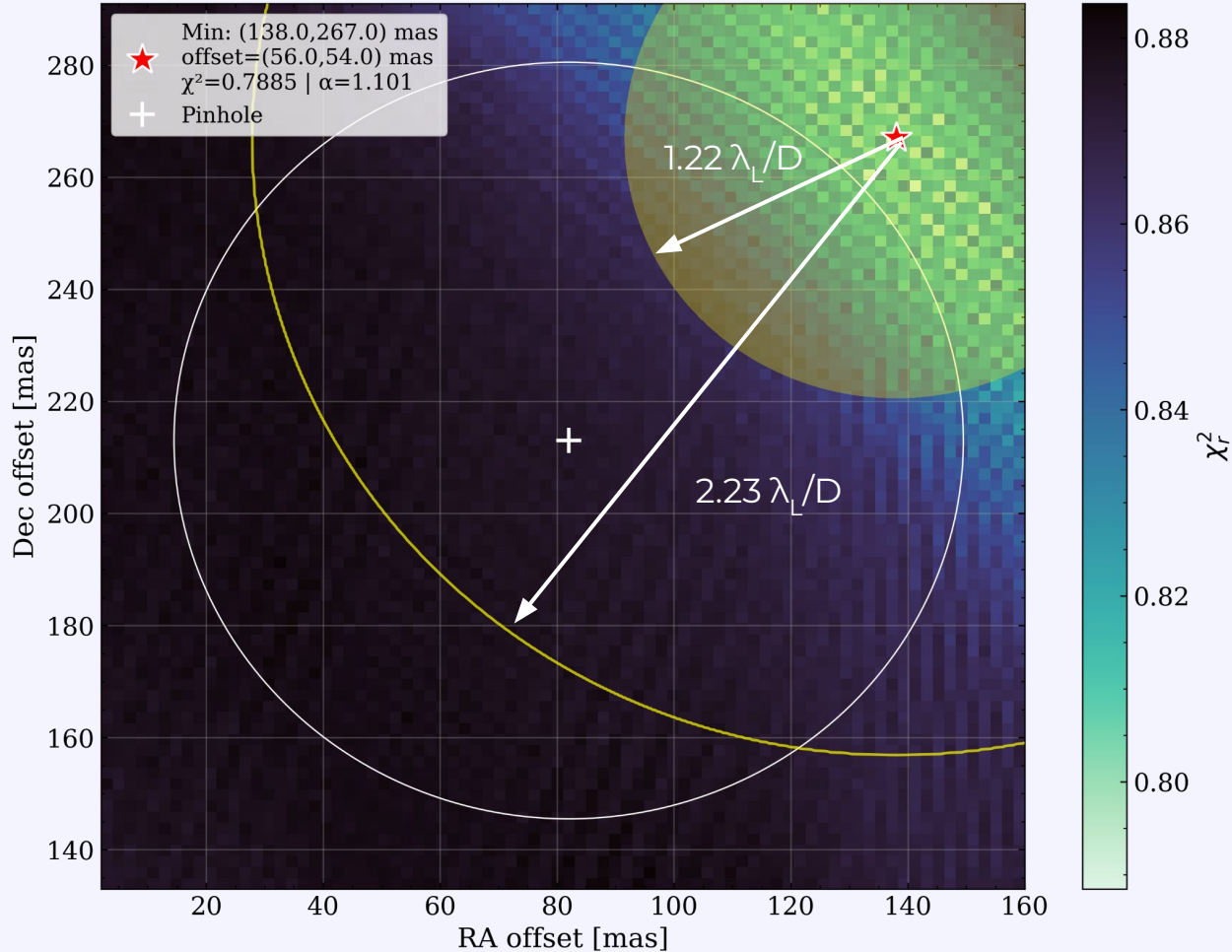


## WHAT ABOUT HD 984 B ?

Brown dwarf aren't faint enough so we point next to the target to be challenged 💪



## Carte $\chi^2$ L+M



→ The companion was out of the pinhole. Reducing its flux by 44%.

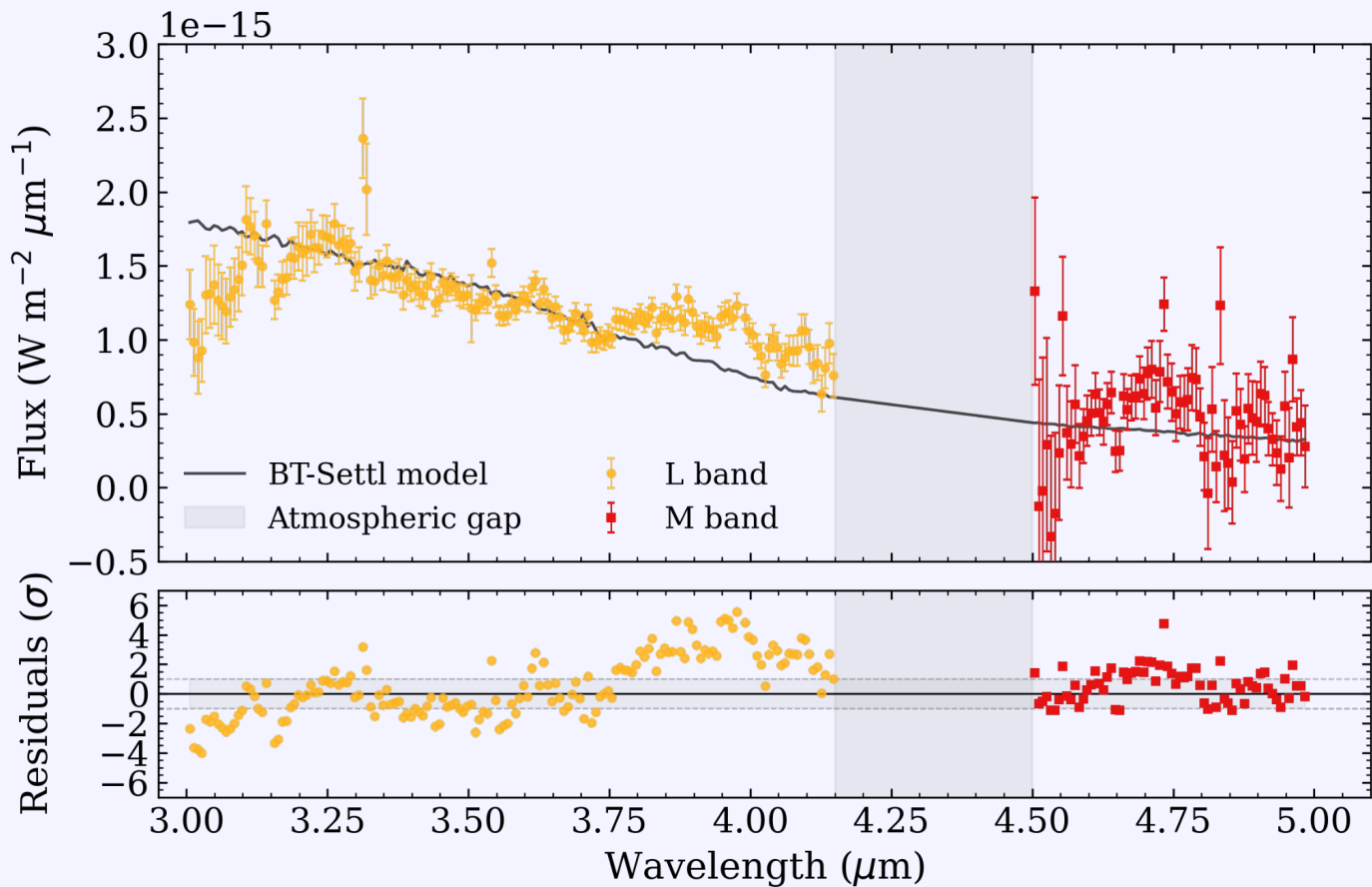
→ Making it **4 times** fainter than  $\beta$  Pic b.

→ Therefore the detection is close to the mJy.

⇒ We fitted the speckle flux and the oscillation in the CF, then we determined the **astrometry of the companion**

$$\vec{\alpha} = (\Delta\alpha, \Delta\delta)$$





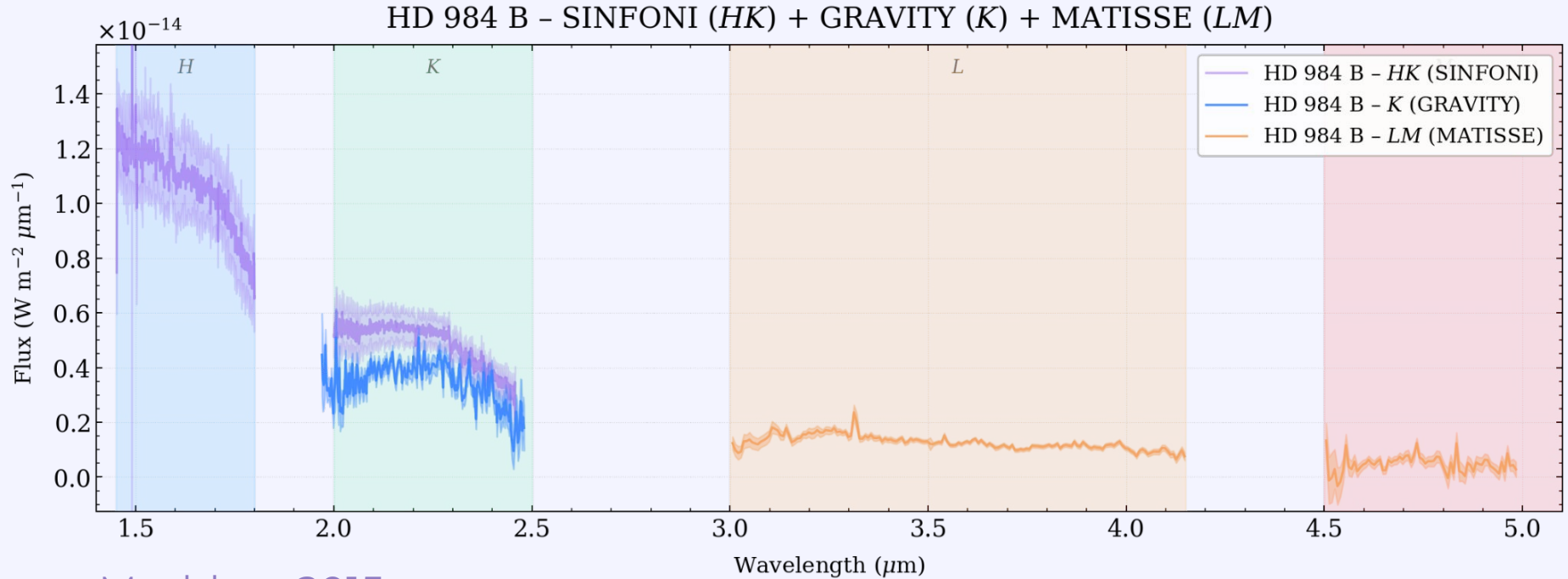
→ In black, the BT-Settl model I used for the proposal

- $T_{\text{eff}} = 2700 \text{ K}$
- $\log(g) = 4.5$

→ MATISSE spectrum in L- & M-band,  
 Resolution = 500,  
 $\text{SNR}_L = 15$ ,  
 $\text{SNR}_M = 2.2$



→ All spectra of HD 984 B (not normalized) covering 5 $\mu\text{m}$  on 4 different bands

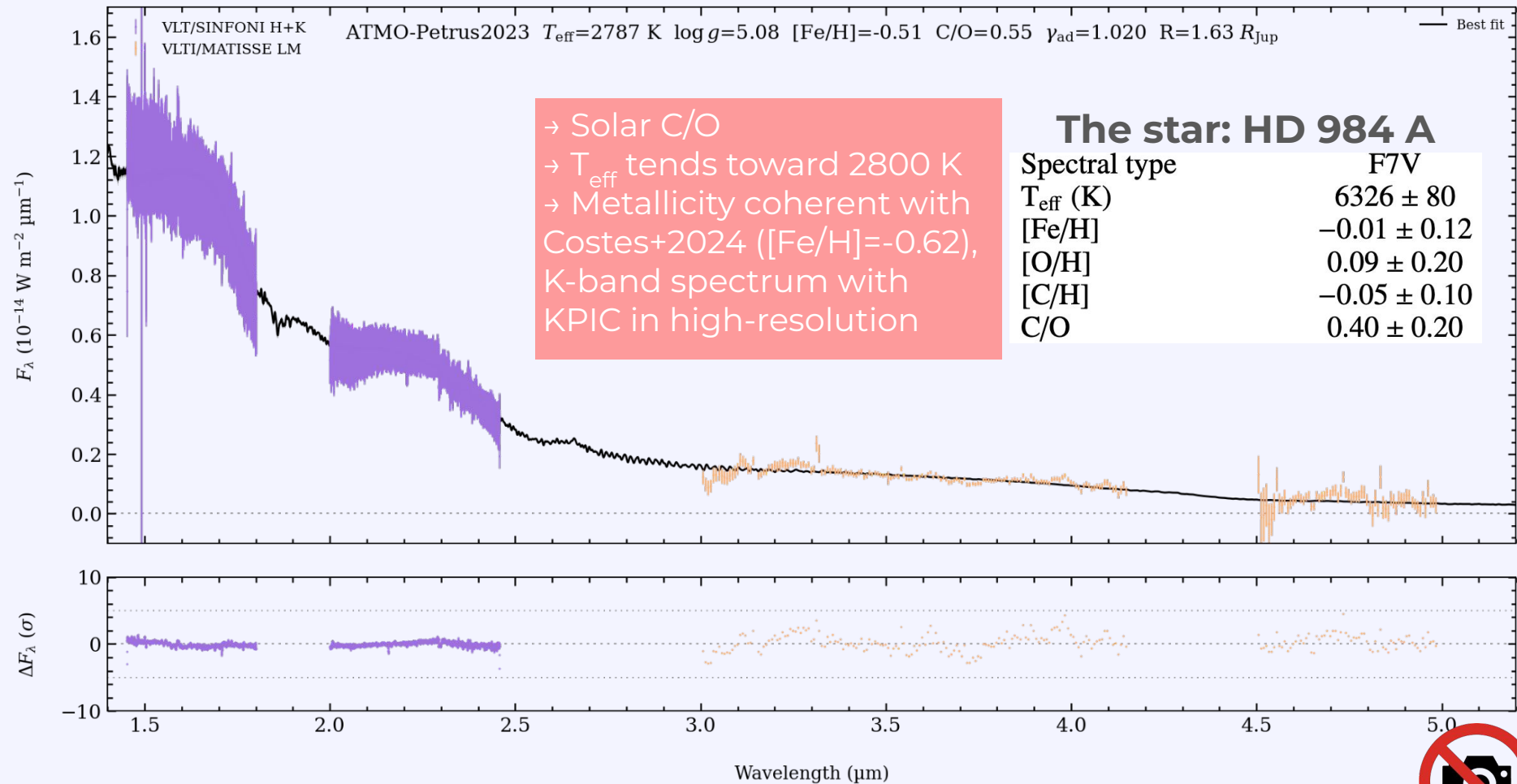


→ Meshkat+2015

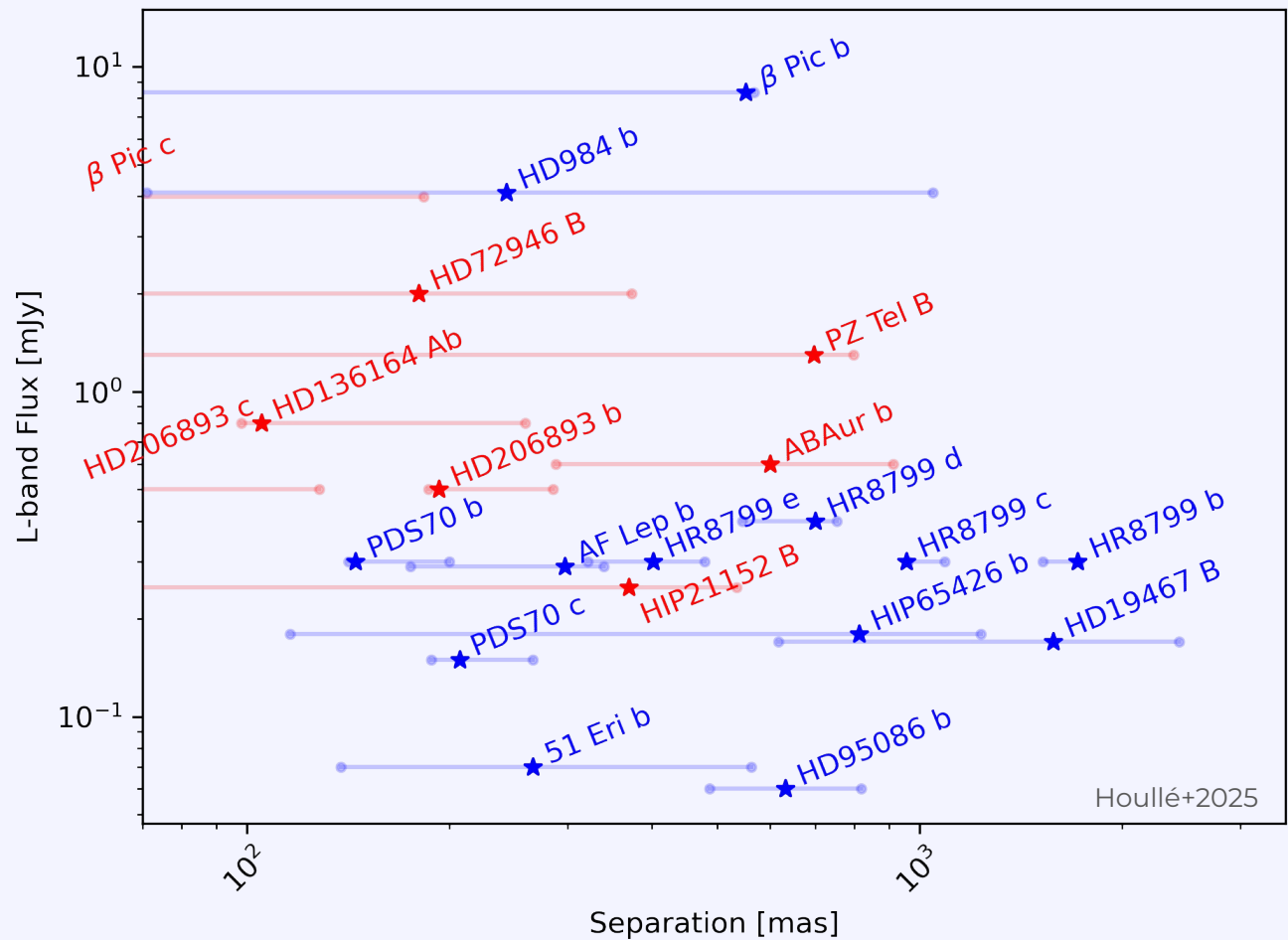
→ Pourré+2024

→ This work





In the near future with MATISSE..





# Take home messages :

- MATISSE can now reach targets around **the mJy**
  - ⇒ Medium-resolution spectra in L- & M-band
- Now we have a **constrain orbit for HD 984 B** (with error bar  $\ll 30$  mas)
  - ⇒ Thanks to MATISSE and GRAVITY accurate astrometry point
- We pushed the detection limit on MATISSE **toward fainter and closer targets**
  - ⇒ Paving the way for multiple other targets to be observed and the **Gaia DR4** at the end of this year !

→ The observable we are interested in is the **correlated flux, C**.

$$V_{ij}(\lambda) \approx 1 + \rho(\lambda) \cdot e^{-2\pi i(u_{ij} \Delta\alpha + v_{ij} \Delta\delta)} \quad \rho(\lambda) = \frac{F_p(\lambda)}{F_*(\lambda)}$$

$\vec{U} = (u_{ij}, v_{ij})$  ← Baseline vector  
 $\vec{\alpha} = (\Delta\alpha, \Delta\delta)$  ← On-sky offset

$$V_{ij}(\lambda) = \frac{C_{ij}(\lambda)}{\sqrt{F_i(\lambda) \cdot F_j(\lambda)}}$$

↑  
Complex visibility

↑ Star flux  
↑ Planet flux

