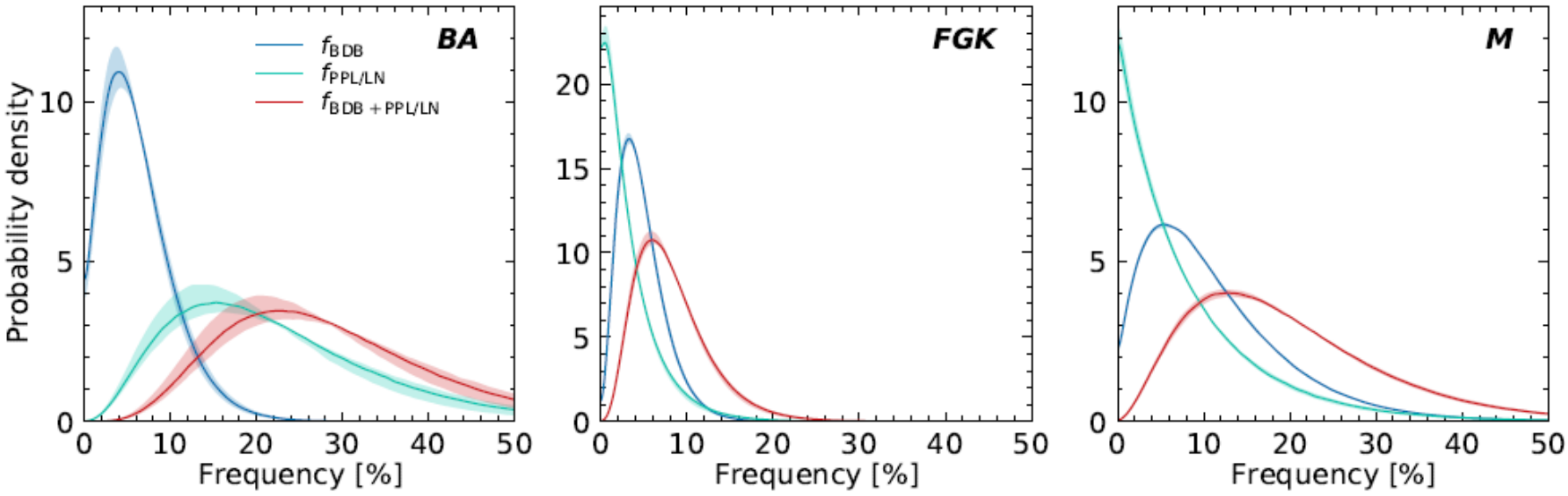
Detection and characterization of planetary mass objects using a multi-technique approach

Dino Mesa – INAF OAPD

Low frequency of substellar objects at large separations

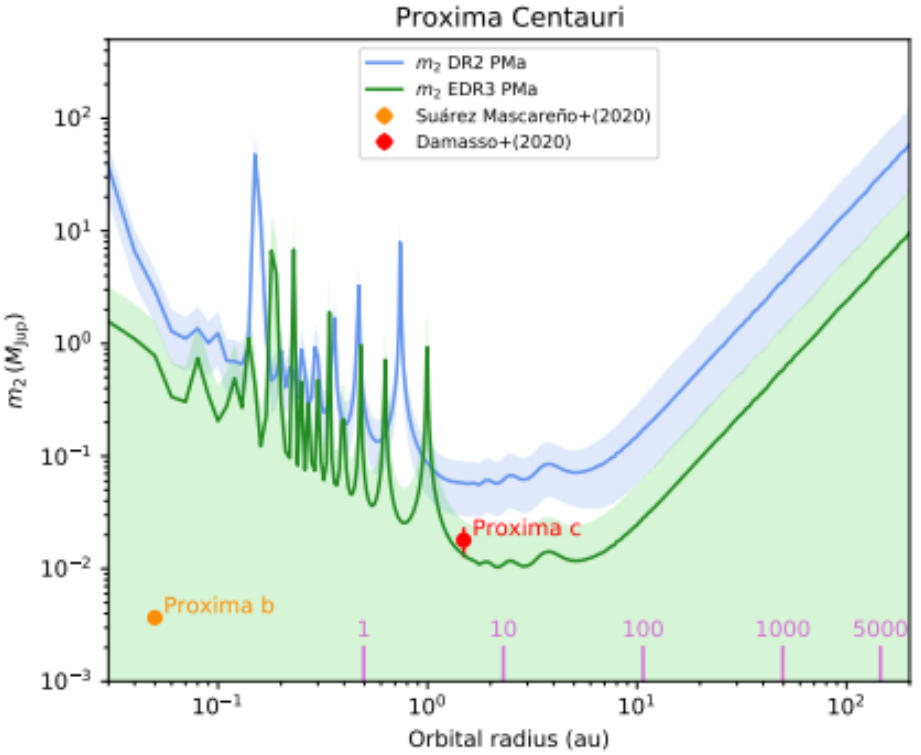
Blind surveys for direct imaging of planetary mass companion at separations larger than 10 au using state-of-the-art instruments (e.g, SPHERE, GPI) have to deal with the low frequency of such objects (e.g., Nielsen+2019, Vigan+2021).



Sample selection based on astrometric data

A way to overcome this problem is to use informed sample selection like using proper motion anomalies (PMa) calculated by comparing different astrometric surveys (e.g., Hipparcos and Gaia, see Brandt+2018,2021, Kervella+2019,2022).

Stars with strong PMa (S/N larger than 3) are indicative of the presence of a companion.



Kervella+2022

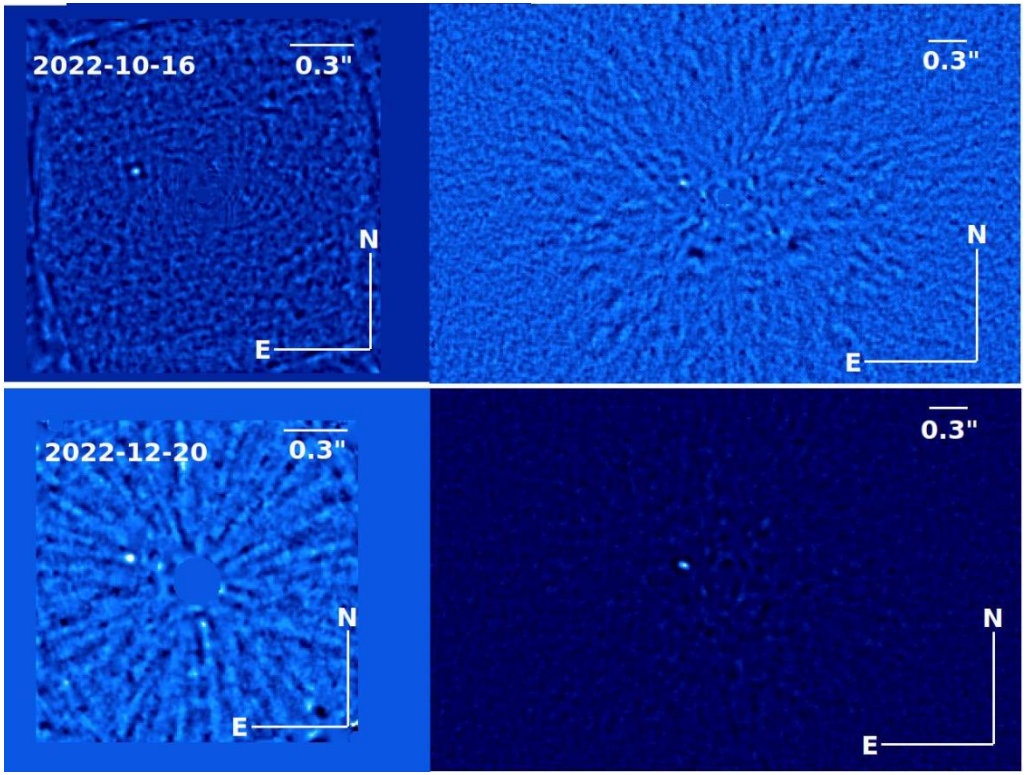
Selection criteria

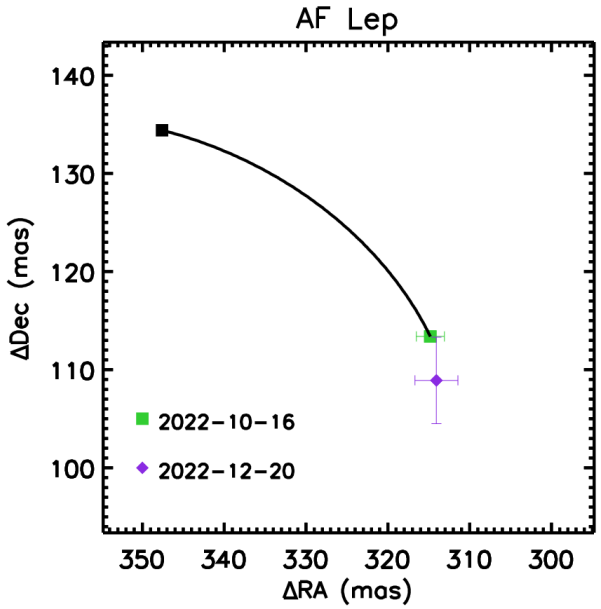
We started from the catalogue from Kervella+2022 and selected a sample following these criteria:

1) **PMa S/N higher than 3 and lower than 20 (to avoid stellar companions).**
2) **Distance from the Sun lower than 50 pc.**
3) **Young stars (less than few hundreds of Myr) to have a good probability to image the planetary mass companions.**

A low mass companion around AF Lep

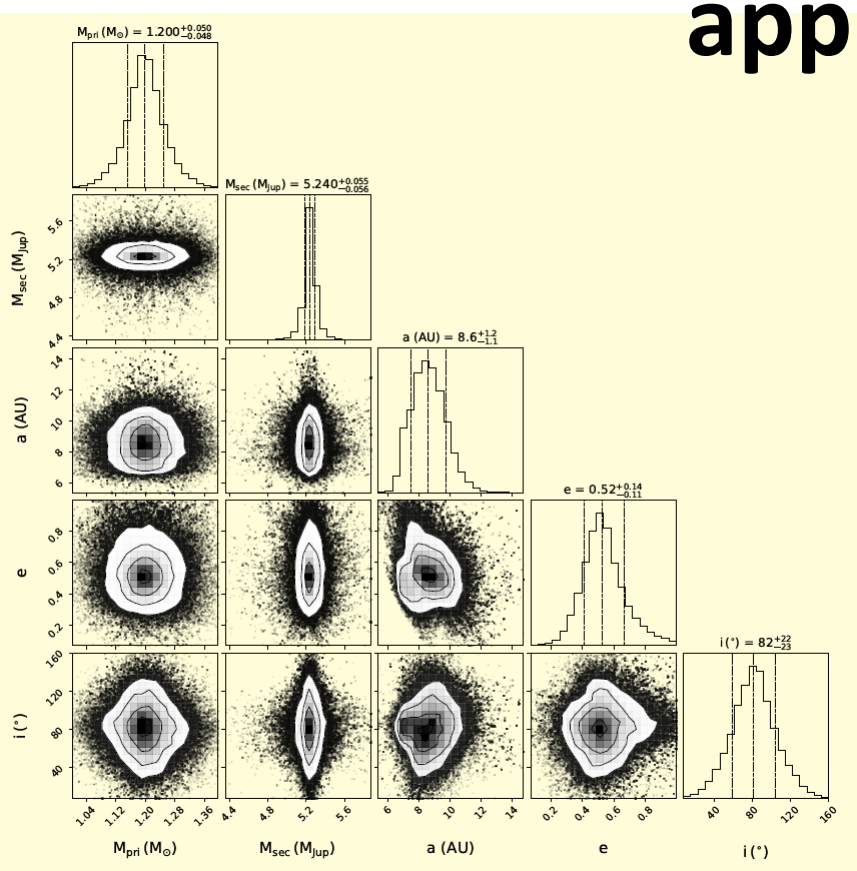
Companion at a separation of ~0.335 arcsec (~ 9 au) from the star and with a PA of 70°-71°. Photometric-mass ranging between 2 and 5 Mjup. Sp.T. : late L-type.

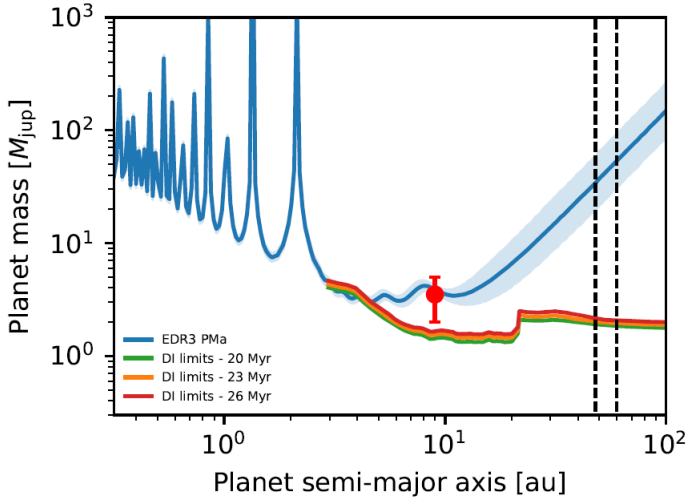




Proper motion confirmation that the companion is gravitationally bound to AF Lep. Mesa+2023 (also in De Rosa+2023 and Franson+2023).

Constraints using a multi-tecnique approach





Parameter	Value
Temperature (K)	1000-1700
Spectral Type	Late L (>L6)
Photometric Mass (M_{Jup})	2-5.5
Dynamical Mass from PMa (M_{Jup})	~5.5
Dynamical Mass from Orvara (M_{Jup})	$5.237^{+0.085}_{-0.10}$
Primary Mass from Orvara ($M_\odot$)	$1.201^{+0.058}_{-0.056}$
Mass ratio	$0.00416^{+0.00022}_{-0.00021}$
Projected separation (arcsec)	0.334±0.001
Position angle (deg)	70.65±0.26
Semi-major axis (au)	$7.99^{+0.85}_{-0.92}$
Ascending node (deg)	249^{+16}_{-12}
Eccentricity	$0.47^{+0.17}_{-0.13}$
Period (years)	$20.6^{+3.4}_{-3.5}$
Argument of periastron (deg)	$46.4^{+9.3}_{-8.9}$
T0 (JD)	2456328^{+1386}_{-503}

Use of the Orvara tool (Brandt+2021) to constrain orbital and physical characteristcs of the companion. Mesa+2023 (comparable results in De Rosa+2023 and Franson+2023).

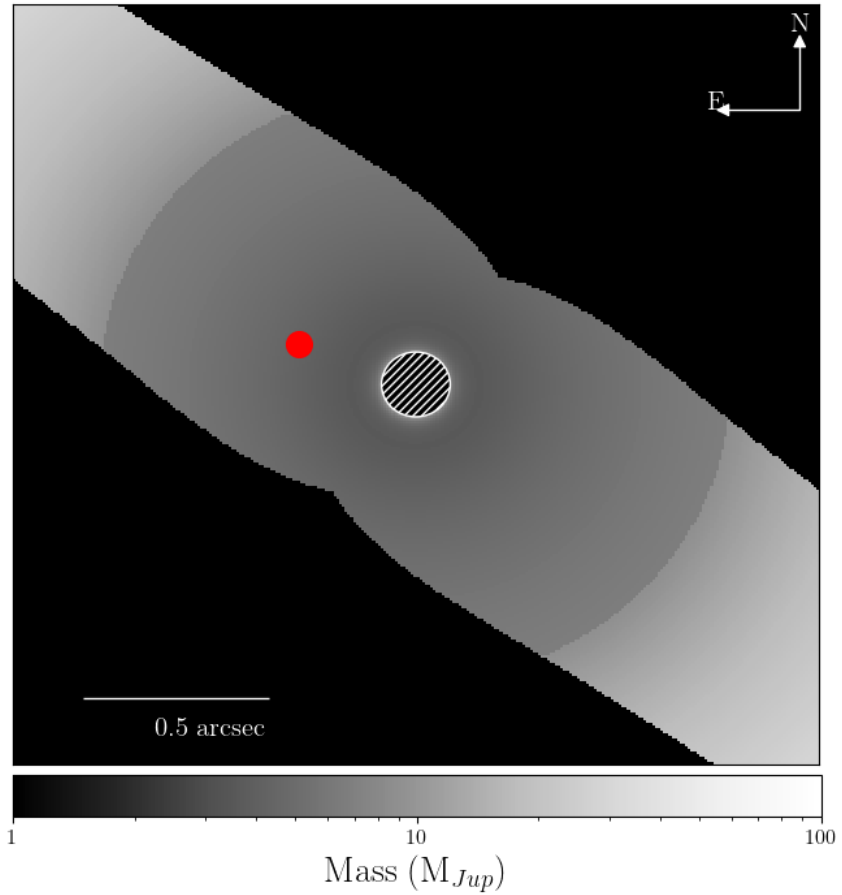
Other detections with the same technique

The same method allowed the detections of other substellar companions (a partial list):

1. **HIP99770B, a low mass (13-16 MJup) BD at a separation of 17 au from the host star (Currie+2023)**
2. **HD 33632 AB, a 46 MJup BD at a separation of ~20 au from the host star (Currie+2024)**
3. **HIP39017 B, a 23 MJup BD at a separation of ~23 au from the host star (Tobin+2024)**
4. **HIP21152 B, a 24 MJup BD at a separation of 16 au from its host star (Bonavita+2022; Franson+2023)**

Exploiting PMa vector informations

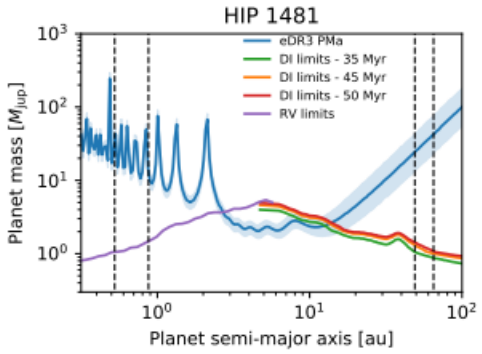
Exploiting the vector informations from the PMa we can define the expected position of a companion generating the PMa signal beside to its mass and separation. To this aim we can use tools like FORECAST (Bonavita+2022) or similar.

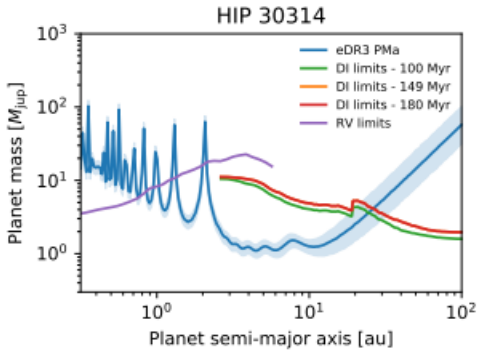


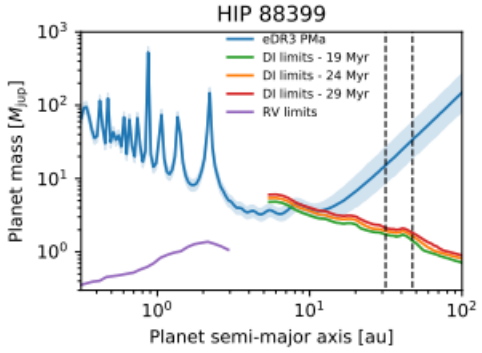
Example of the output of the FORECAST tool in the case of AF Lep (Mesa+2023).

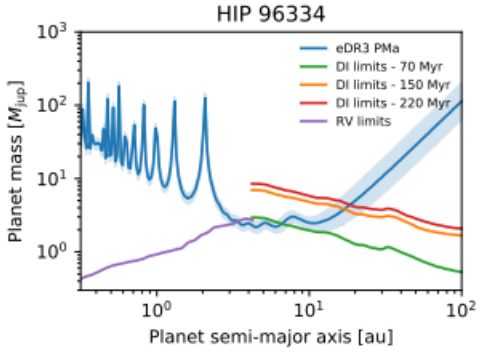
In case of non-detection (1)

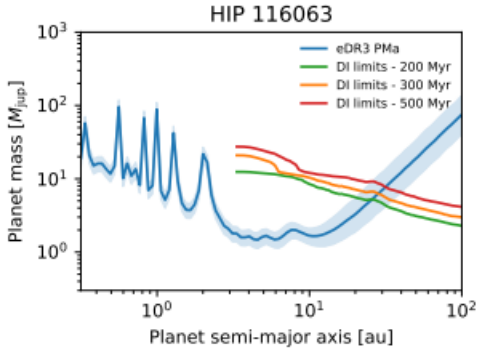
Coupling mass limits from DI and RV with the informations from the PMa can strongly constrains mass and position of the low mass companion causing the PMa signal.
Here an example using DI data from SPHERE SHINE survey (Mesa+2022).





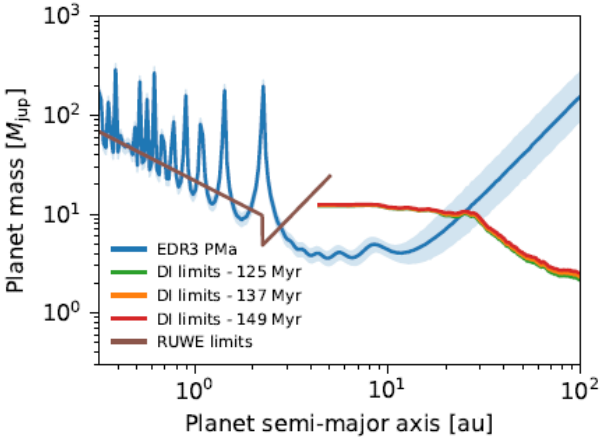


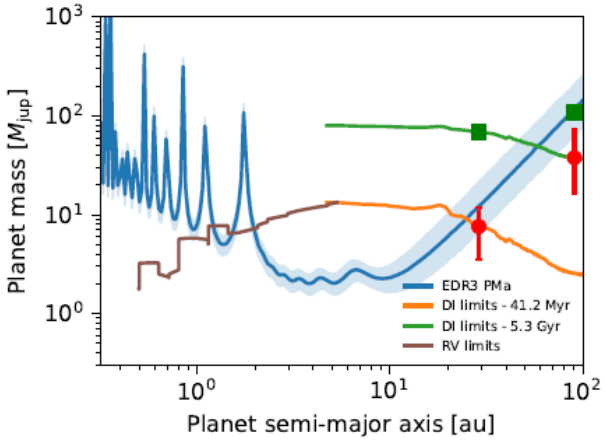


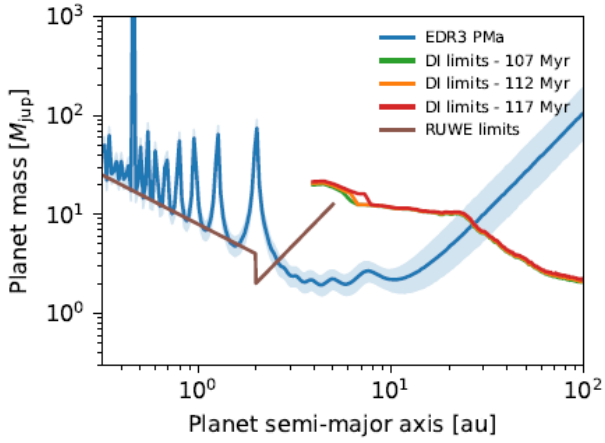


In case of non-detection (2)

New instrumentation is currently allowing to perform the same analysis on a larger scale and on parts of the sky less studied up to now (e.g., the Northern sky). One example is given by the two new instrument SHARK-VIS and SHARK-NIR at LBT.

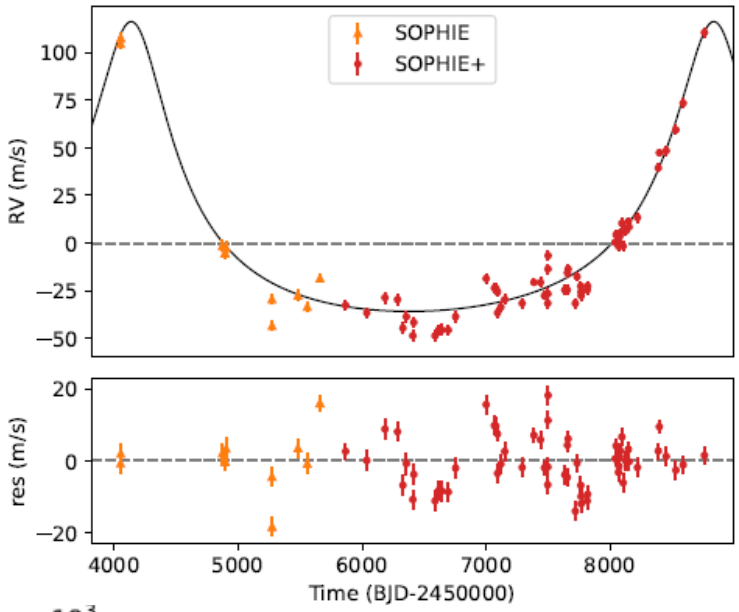


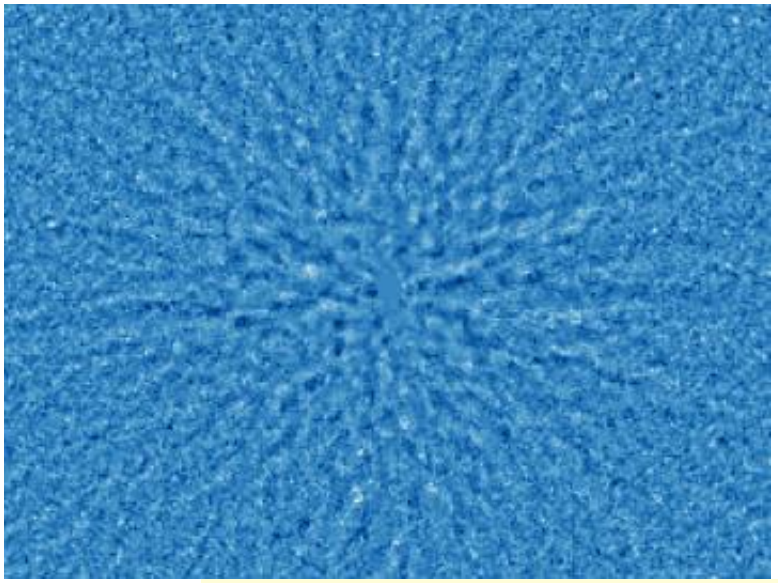


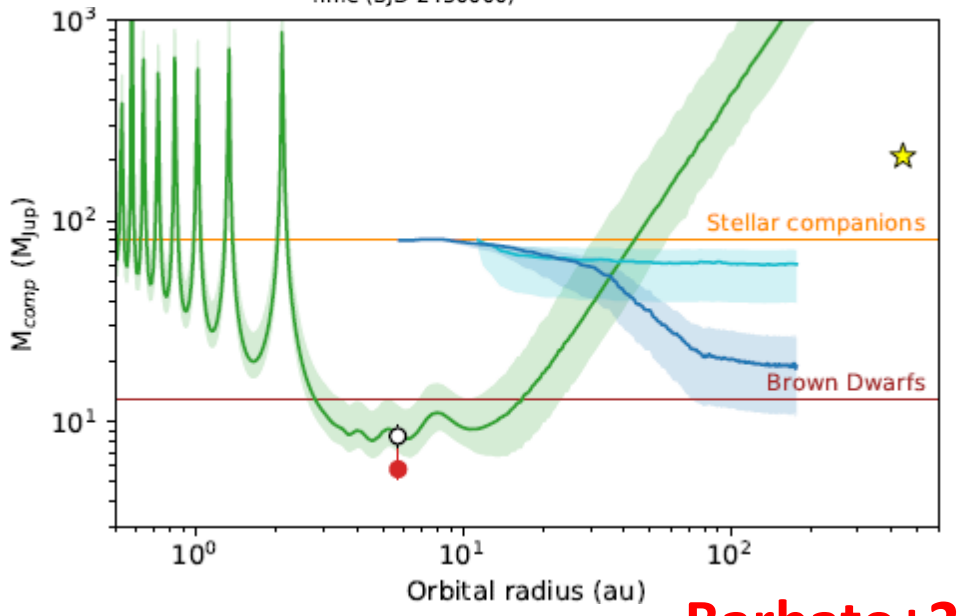


Mesa+2025

A new companion around HD57625







Barbato+2025

Parameter	Priors	Best-fit values
M_b (M_{Jup})	$1/M$ (log-flat)	$8.43^{+1.10}_{-0.91}$
a_b (au)	$1/a$ (log-flat)	$5.70^{+0.14}_{-0.13}$
$\sqrt{e_b}\sin\omega_b$	$\mathcal{U}(-1,1)$	$0.008^{+0.068}_{-0.056}$
$\sqrt{e_b}\cos\omega_b$	$\mathcal{U}(-1,1)$	$0.720^{+0.023}_{-0.026}$
i_b (deg)	$\cos i$, $\mathcal{U}(0,180)$	$43.82^{+14.30}_{-7.22}$
λ_0 (deg)	$\mathcal{U}(0,360)$	$89.4^{+7.1}_{-6.1}$
Ω_b (deg)	$\mathcal{U}(0,360)$	301^{+13}_{-40}
P_b (d)	Derived	4843^{+306}_{-167}
ω_b (deg)	Derived	$9.2^{+349}_{-7.2}$
e_b	Derived	$0.52^{+0.04}_{-0.03}$
j_{SOPHIE} ($m\,s^{-1}$)	$1/j$ (log-flat)	$8.8^{+2.9}_{-2.0}$
$j_{SOPHIE+}$ ($m\,s^{-1}$)	$1/j$ (log-flat)	$6.76^{+0.78}_{-0.68}$

Future work

- **The PMa targets program with SHARK-NIR started in autumn 2023 and it is currently running.**

- **Some of the targets presented here could be interesting for future observations with SPHERE+ and/or ELTs that could be able to detect the companions.**

- **Future Gaia Data Releases will provide better astrometric sensitivity allowing improved definition of the acceleration and of the sample.**