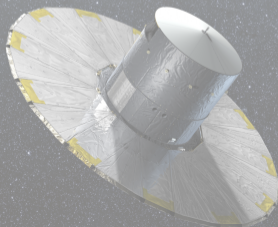


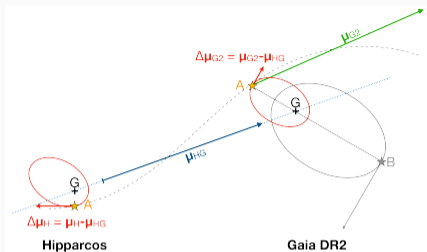
A NEW GOLDEN AGE FOR THE PROPER MOTION ANOMALY TECHNIQUE WITH GAIANIR

D. Barbato, D. Mesa, S. Desidera, A. Ruggieri, A. Zurlo, E. Rigliaco, M. Bonavita, R. Gratton, V. D'Orazi
17 January 2024 - GaiaNIR: gathering the interest of the Italian Community



OSSERVATORIO
ASTRONOMICO DI PADOVA

THE PROPER MOTION ANOMALY TECHNIQUE



Difference between long-term and short-term PM vector hinting at gravitational reflex motion due to unseen secondary body.

Hipparcos and Gaia DR3 baseline of ~ 25 yr best suited for long-period companions.

Kervella et al. 2019, 2022
 $\sim 116\,000$ stars

Brandt et al. 2018, 2021
 $\sim 115\,000$ stars

While mostly limited by Hipparcos catalog size and PM uncertainties ($\sim \text{mas/yr}$), many successful applications especially in synergy with radial velocity and direct imaging search for exoplanets and brown dwarfs.

Damasso et al. 2020, A&A, 642, A31
Makarov et al. 2021, RNAAS, 5, 155
Venner et al. 2021, AJ, 162, 12
Rickman et al. 2022, A&A, 668, A140
Barbato et al. 2023, A&A, 674, A114
Unger et al. 2023, A&A, 680, A16

Brandt et al. 2019, AJ, 158, 140
De Rosa et al. 2019, AJ, 158, 225
Bonavita et al. 2022, MNRAS, 513, 5588
Currie et al. 2023, Science, 380, 198
Mesa et al. 2023, A&A, 672, A93
Franson et al. 2023, A&A, 672, A94

DIRECT IMAGING AND PROPER MOTION ANOMALY

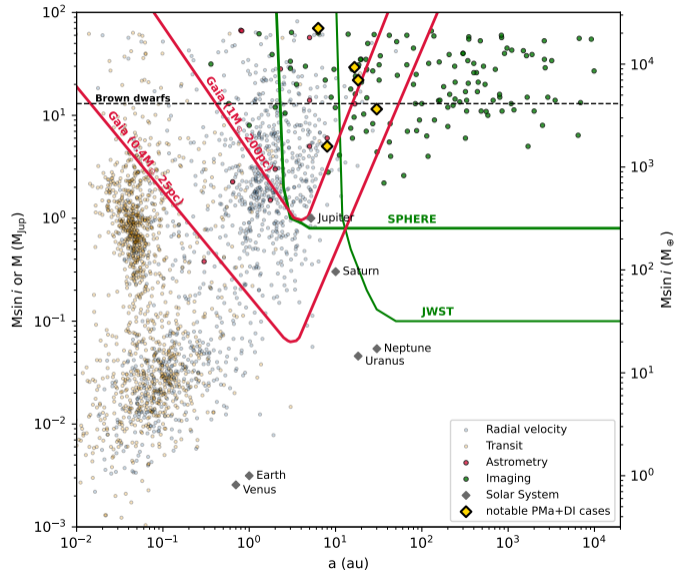
Direct imaging technique searches for massive companions at large separations around young stars.

PMA allows for precise dynamical mass estimation when compared to evolution models.

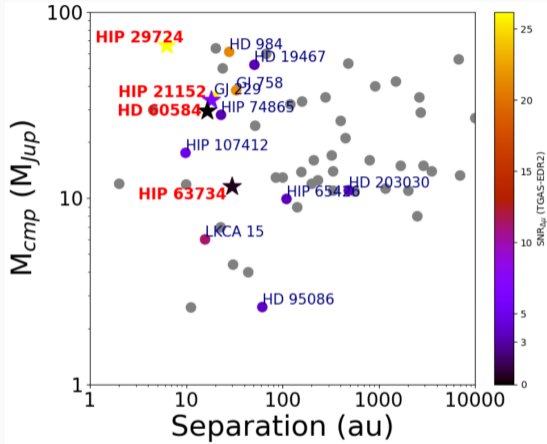
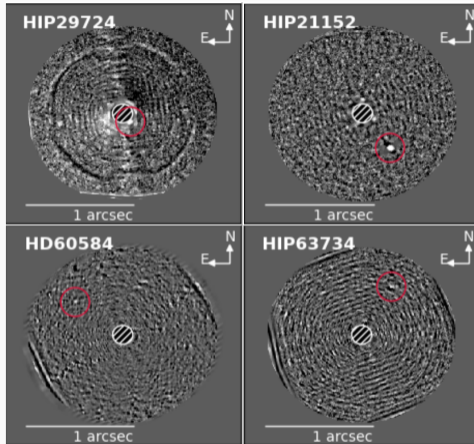
Giant planets >10 au rare around FGK stars (~5-6%, Vigan et al. 2021).

Blind DI searches are time-consuming and with relatively low detection returns.

Preselection criteria required:
stars exhibiting significant PMA

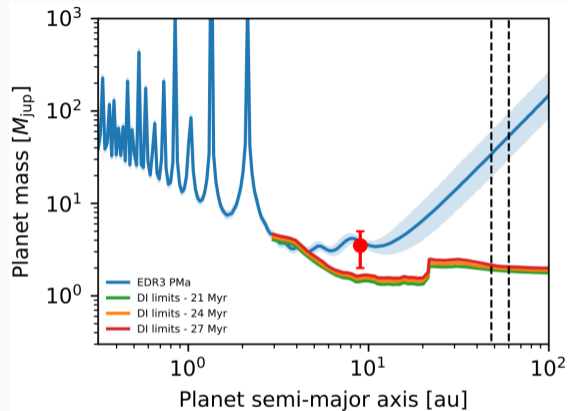
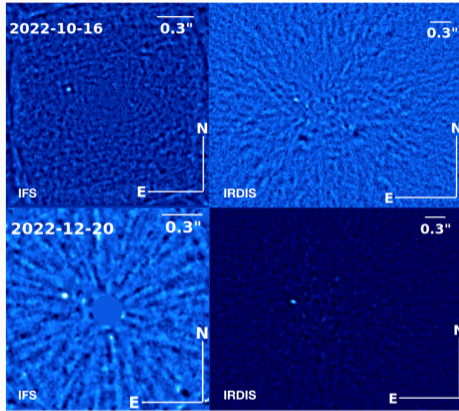


THE COPAIN SURVEY: PMA AS PRE-SELECTION TOOL



Pilot survey with SPHERE@VLT on 25 stars with PMA $> 3\sigma$. Ten new companions including four BDs. Hipparcos-Gaia PMA instrumental in characterising substellar companions and allows for high DI detection rate.

AF LEP B: THE LOWEST-MASS PMA+DI EXOPLANET



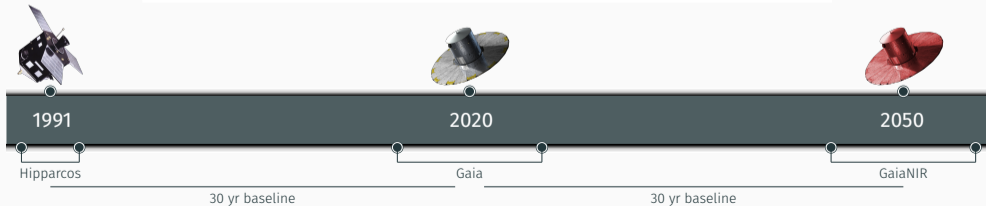
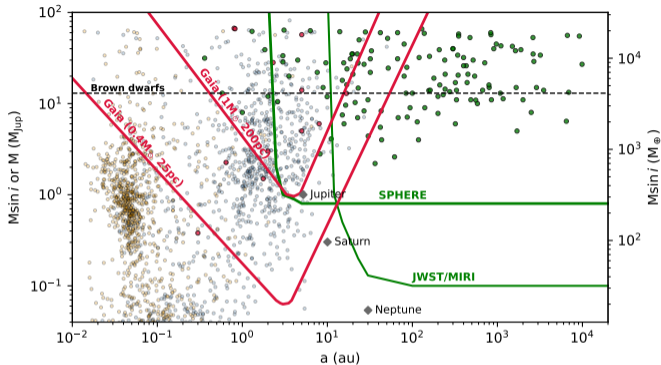
F8 star with PMA S/N=9 observed with SPHERE@VLT in Y-K bands, companion at $8.6_{-1.1}^{+1.2}$ au with $5.24 \pm 0.05 M_{\text{JUP}}$.
First companion below the deuterium burning limit discovered by coupling DI and PMA measurements!

Mesa et al. 2023, A&A, 672, A93, *AF Lep b: The lowest-mass planet detected by coupling astrometric and direct imaging data*

De Rosa et al. 2023, A&A, 672, A94, *Direct imaging discovery of a super-Jovian around the young Sun-like star AF Leporis*

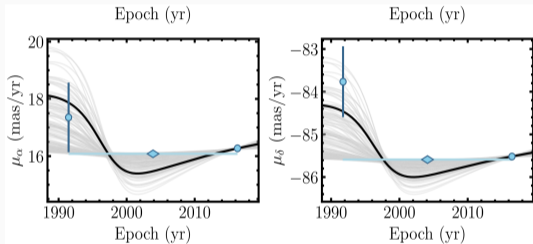
Franson et al. 2023, arXiv:2302.05420, accepted to ApJL, *Astrometric Accelerations as Dynamical Beacons: A Giant Planet Imaged Inside the Debris Disk of the Young Star AF Lep*

THE GAIANIR OPPORTUNITY: EXPLORING LARGER SEPARATIONS



THE GAIANIR OPPORTUNITY: DEEPENING HIPPARCOS-GAIA PMA ANALYSIS

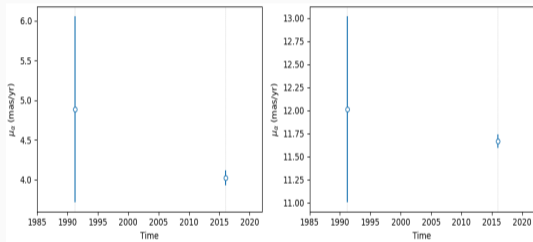
Third PM measurement for $\sim 117\,000$ Hipparcos-Gaia stars, extending baseline and constraining orbits



Franson & Bowler 2023, *Dynamical Mass of the Young Brown Dwarf Companion PZ Tel B*

$$M = 27^{+25}_{-9} M_{\text{Jup}}, a = 27^{+14}_{-4} \text{ au}, P = 120^{+110}_{-30} \text{ yr}$$

High-precision GaiaNIR PM measurement can detect hidden trends and show first signs curvatures



A typical low-SNR PMA as retrieved from Brandt et al. 2021: what's in there?

Expansion and refinement of Hipparcos-Gaia PMA search for unseen companions.

THE GAIANIR OPPORTUNITY: A PMA TREASURE CHEST

High-precision PMA between Gaia-GaiaNIR
with ~ 30 yr baseline: PMs 14 times
more accurate than Gaia DR4

PMA search expanded to full Gaia catalog:
one can look at Kervella catalog to estimate
possible PMA search sample size

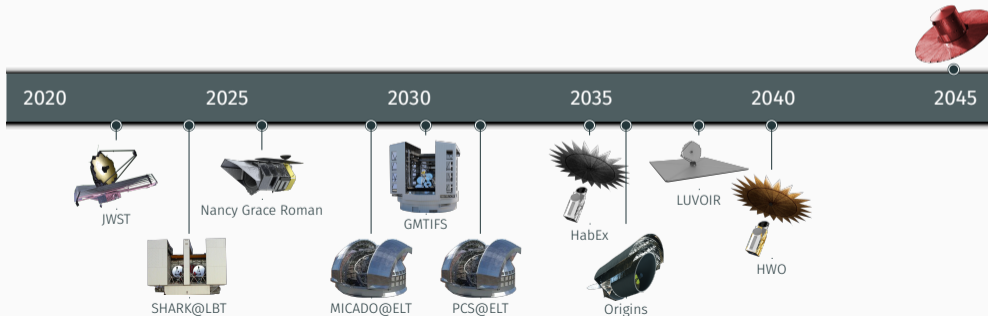
	Kervella et al. 2022	Gaia-GaiaNIR
Full sample	116 000	$1.5 \cdot 10^9$
PMA SNR > 3	37 300 (32.17%)	$4.8 \cdot 10^8$
PMA compatible with possible companion:		
giant at 30au	202 (0.17%)	$2.6 \cdot 10^6$
BD at 30au	3 600 (3.12%)	$4.6 \cdot 10^7$
star at 30au	33 500 (29%)	$4.3 \cdot 10^8$

Depending on stellar distance, parameters, solution quality etc, GaiaNIR would allow for a huge expansion of PMA companion search sample.

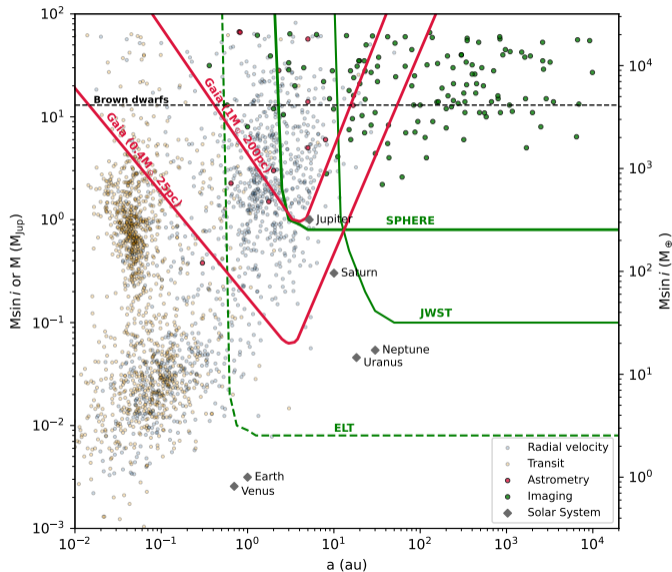
THE GAIANIR OPPORTUNITY: FUTURE DI INSTRUMENTS

Current or near-term DI instruments with future updates, using PMA as preselection and fully exploiting techniques synergies

Future DI instruments aiming at inner low-mass companions complementing PMA and fully investigate systems architecture



TAKE-HOME MESSAGE



GaiaNIR would extend the PMa baseline by ~ 30 yr, allowing to probe larger orbital separations

GaiaNIR PM measurement will sustain current PMa analysis and expand its reach beyond the Hipparcos catalog

The rise of small-separation DI will complement the discovery space of PMa characterization

A new astrometric revolution: the best is yet to come!