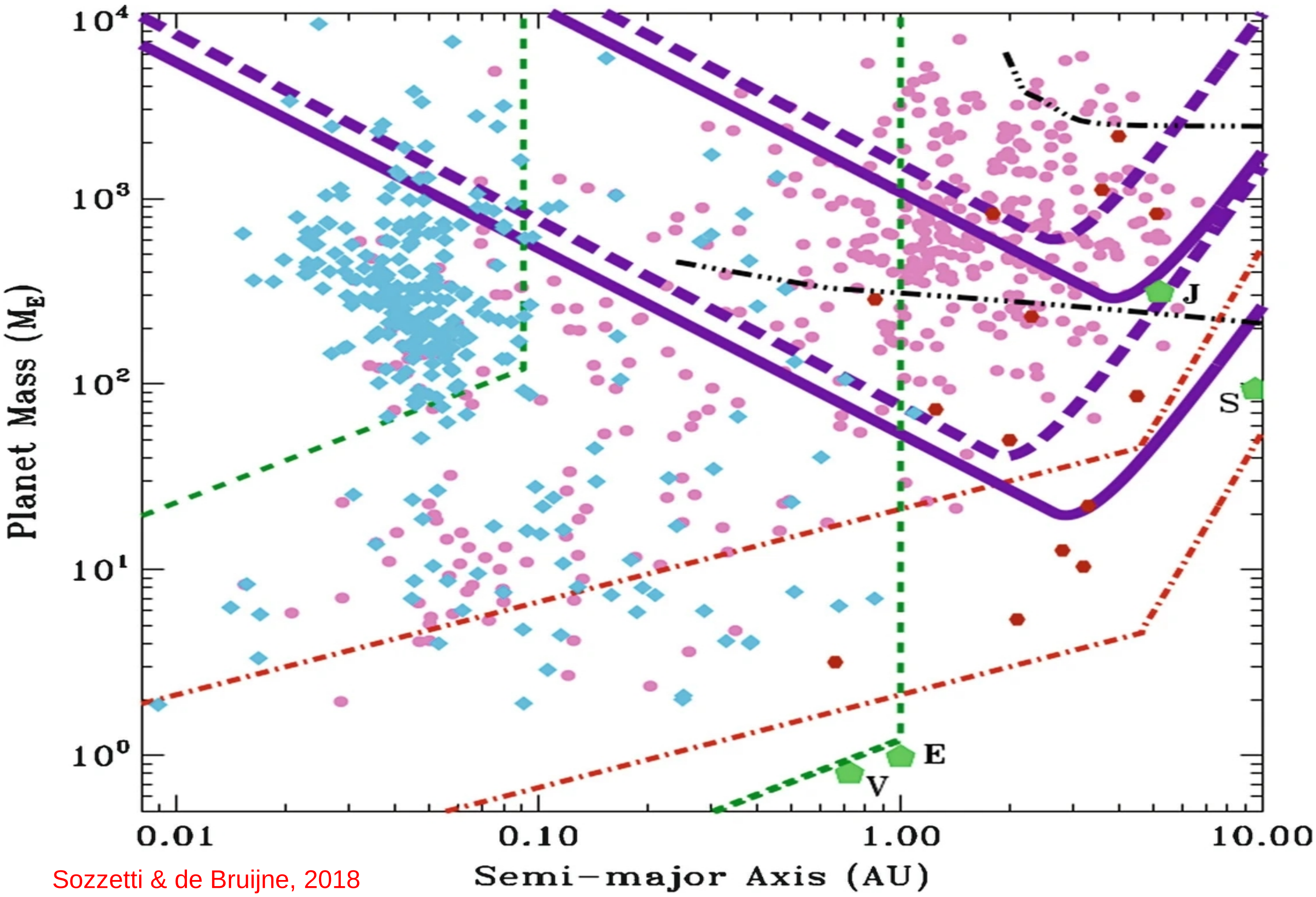
Characterizing long-period exoplanets with high-precision astrometry and RVs: current examples and future prospects

Matteo Pinamonti matteo.pinamonti@inaf.it
A. Ruggieri, A. Sozzetti, S. Desidera, P. Giacobbe

Gaia-NIR: next generation astrometric mission
Bologna, Italy
17-18 January 2024

Context

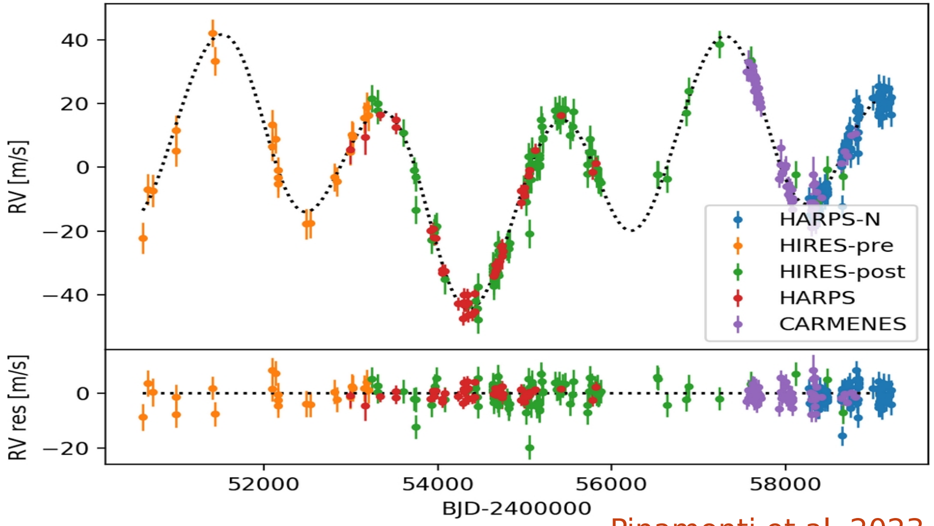


Sozzetti & de Bruijne, 2018

Multiple long-period planets

Discovered with RVs

GJ 849



Pinamonti et al. 2023

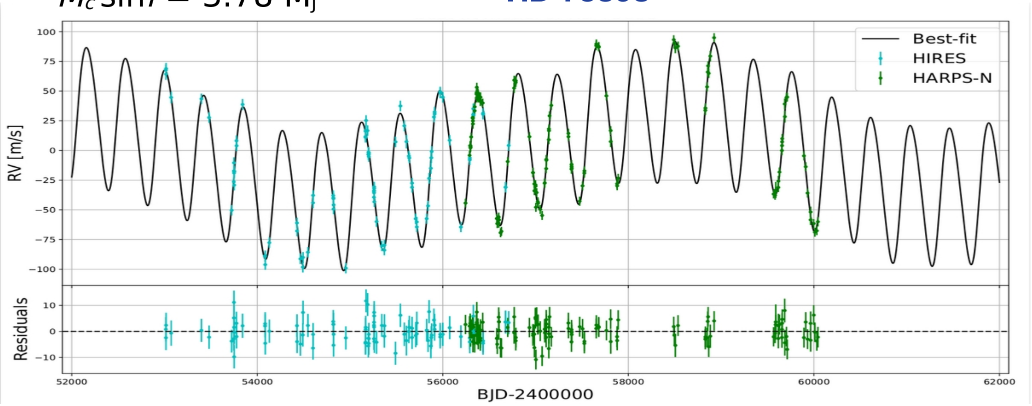
Solar-type survey

Several planets (both short- and long-period) discovered within the GAPS programme in the sample.

P_b = 423 d
$M_b \sin i$ = 2.55 M_J

P_c = 6690 d
$M_c \sin i$ = 3.78 M_J

HD 75898



Ruggieri et al., in prep.

M-dwarf survey

P_b = 1920 d
$M_b \sin i$ = 0.893 M_J

P_c = 5990 d
$M_c \sin i$ = 0.99 M_J

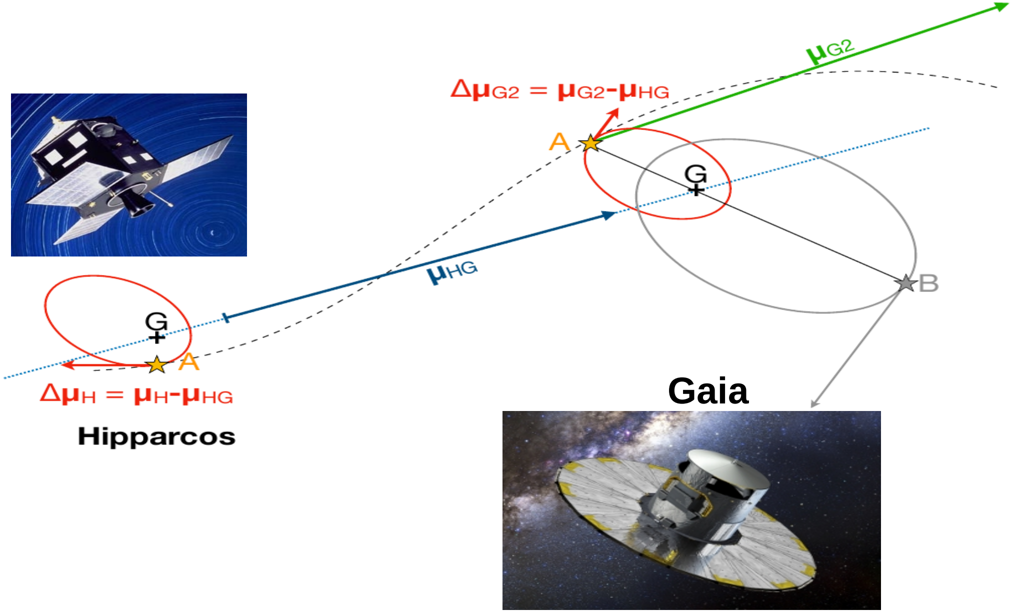
Synergies RV + astrometry

Cold-Jupiters mass determination

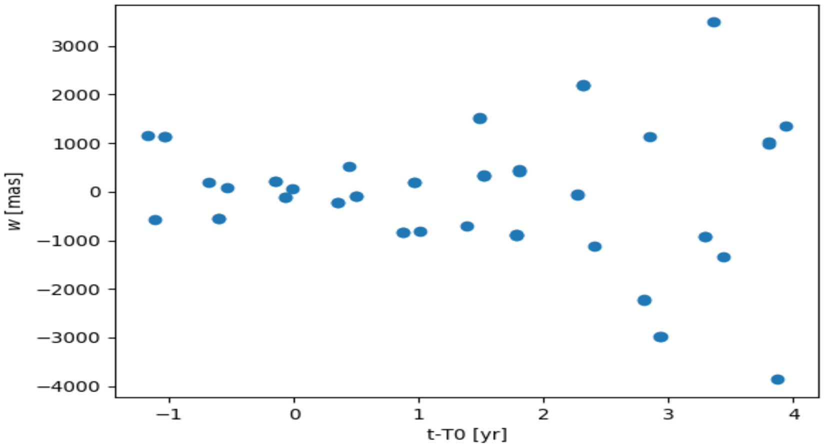
From RVs only $m_p \sin i$ is measured.
No inclination, **no** true planetary mass.

Astrometry can solve this!
Two possible approaches:

1) Proper Motion Anomaly (PMA)

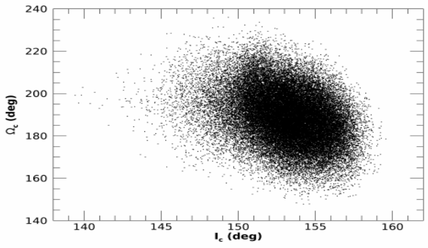


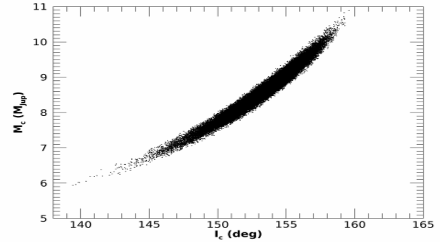
2) Gaia Astrometric time series



GJ 849b (Gaia DR4 timeseries simulations)

Proper Motion Anomaly analysis



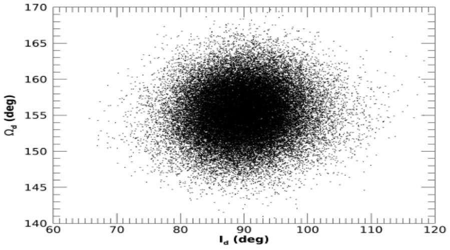


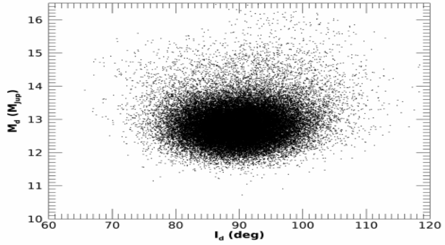
Parameter	Prior	Value
P_c [yr]	$\mathcal{U}(15.0, 25.0)$	$18.39^{+0.12}_{-0.11}$
a_c [au]	$\mathcal{U}(5.0, 10.0)$	$7.39^{+0.04}_{-0.05}$
i_c [deg]	$\cos(i_c)$, $\mathcal{U}(0.0, 180.0)$	153^{+2}_{-3}
Ω_c [deg]	$\mathcal{U}(0.0, 360.0)$	189^{+12}_{-12}
q_c	$\mathcal{U}(0.0, 0.1)$	$0.0063^{+0.0005}_{-0.0005}$
M_c [M_{Jup}]	(derived)	$8.49^{+0.65}_{-0.63}$

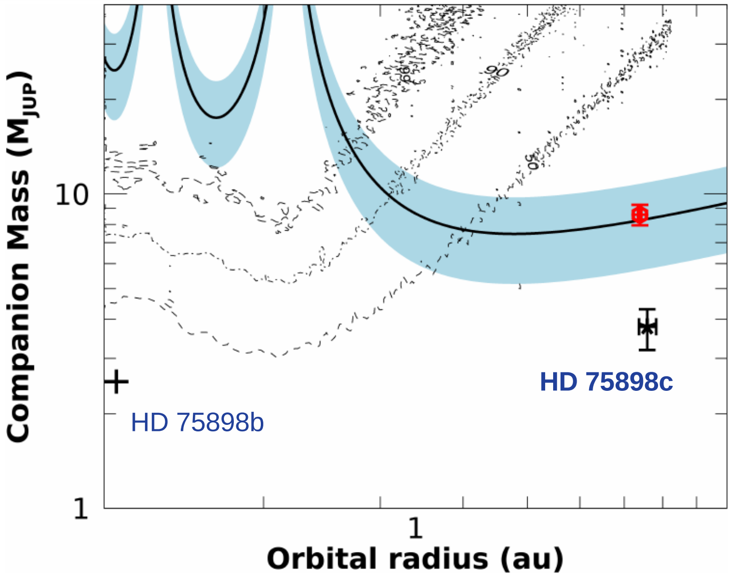
Combined fit: RV + PMA
HD 75898c

Parameter	Prior	Value
P_d [yr]	$\mathcal{U}(30.0, 150.0)$	$72.6^{+0.7}_{-0.8}$
a_d [au]	$\mathcal{U}(10.0, 30.0)$	$18.20^{+0.06}_{-0.09}$
i_d [deg]	$\cos(i_d)$, $\mathcal{U}(0.0, 180.0)$	90^{+6}_{-5}
Ω_d [deg]	$\mathcal{U}(0.0, 360.0)$	155^{+3}_{-4}
q_d	$\mathcal{U}(0.0, 0.1)$	$0.0100^{+0.0005}_{-0.0004}$
M_d [M_{Jup}]	(derived)	$12.8^{+0.6}_{-0.5}$

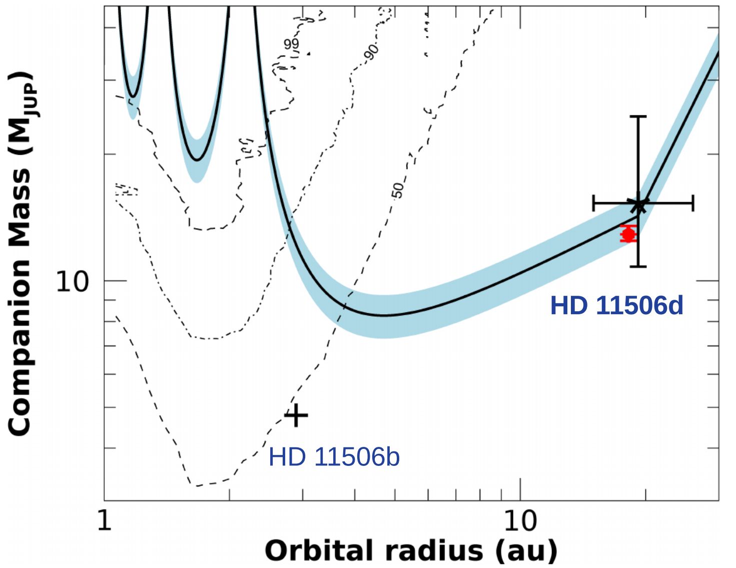
Combined fit: RV + PMA
HD 11506d







⬡ = soluzione RV+PMA
* = soluzione RV



Ruggieri et al., in prep.

Gaia Astrometric time series (simulations)

Cold Jupiters from M-dwarf sample (Pinamonti+23) and Solar-type sample (Ruggieri+ in prep)

7 long-period planets, around early-M dwarfs (4) and G0 stars (3).

Currently no astrometric orbital solution for any of them (GaiaDR3)

c	**GJ 328b**	**GJ 649b**	**GJ 849b**	**GJ 849c**
P [yr]	10.32±0.05	1.64±0.03	5.27±0.02	16.4±0.3
$M_p$sin*i* [MJ]	2.5±0.2	0.26±0.02	0.89±0.09	1.0±0.1
e	0.23±0.02	0.08±0.06	0.03±0.02	0.09±0.04

	HD 75898c	**HD 11506b**	**HD 11506d**
P [yr]	18.3±0.9	4.433±0.005	75±20
$M_p$sin*i* [MJ]	3.8±0.5	4.80±0.08	15±5
e	0.15±0.09	0.379±0.009	0.13±0.11

Simulation setup

Astrometric time series generated for different GaiaDRs, Orbital parameters from RV solution, inclination *i* and longitude of ascending node Ω randomly generated.

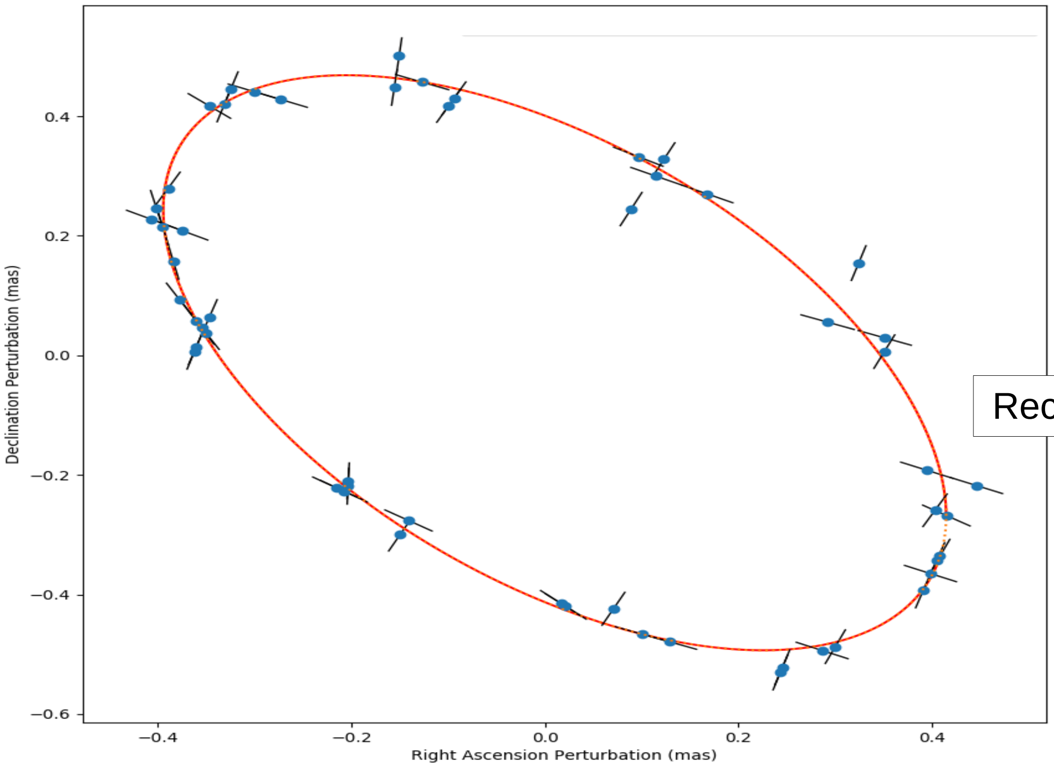
=> test how well the orbit would be recovered.

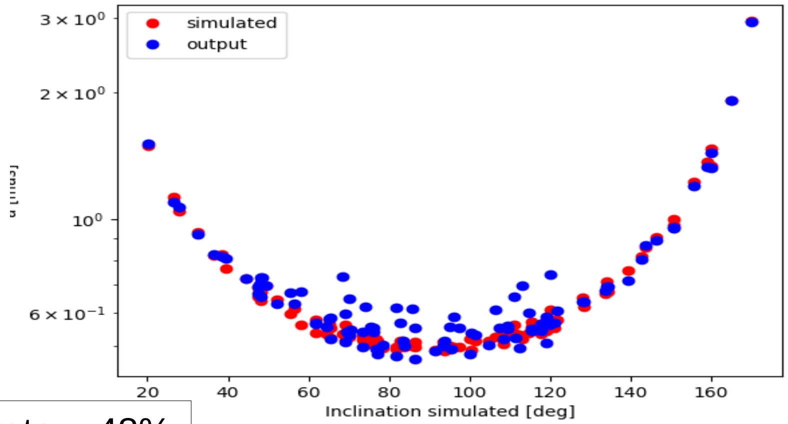
Angular semi-major axis $\propto$ M_p * *a*

Gaia Astrometric time series (simulations)

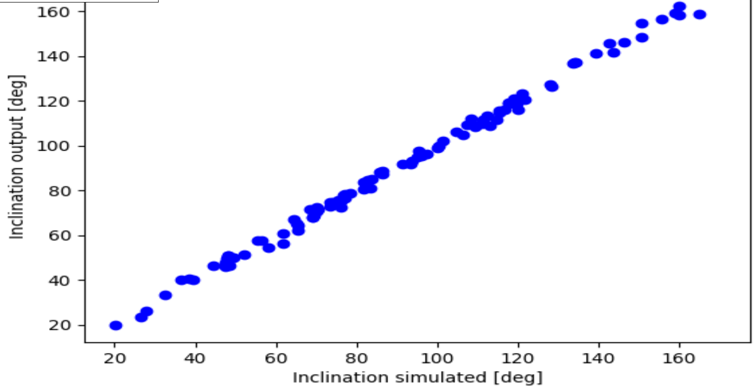
GJ 849b: P_b = 5.27 yr
a_b = 2.3 AU

GaiaDR4





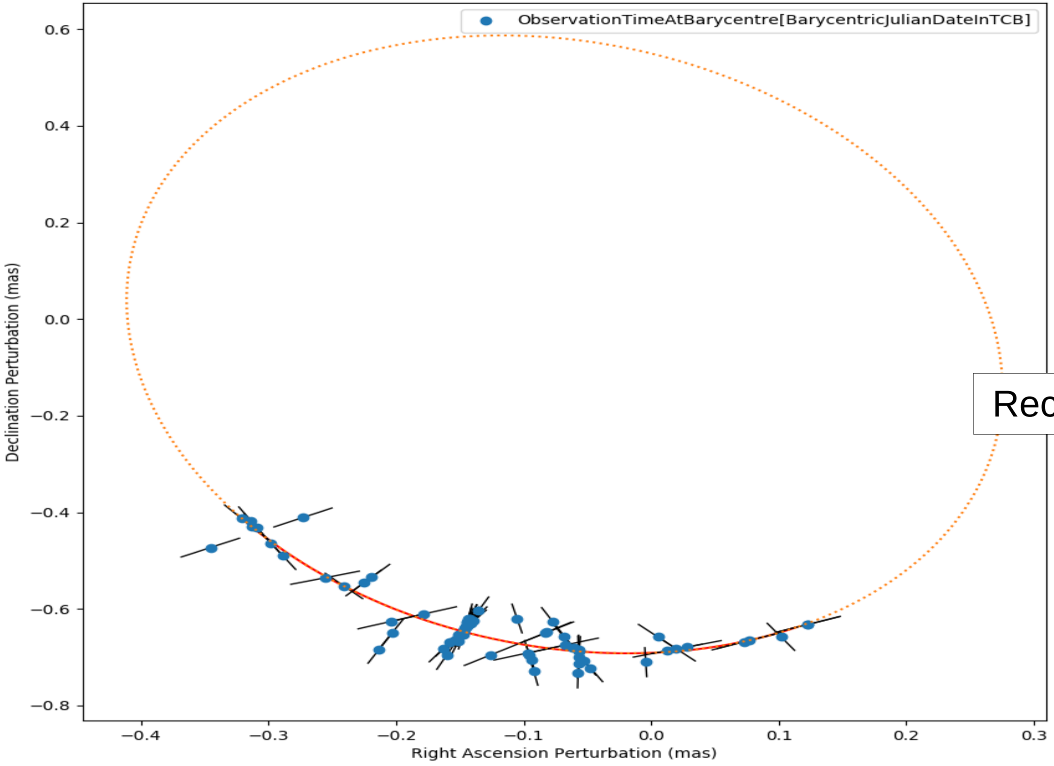
Recovery rate = 48%



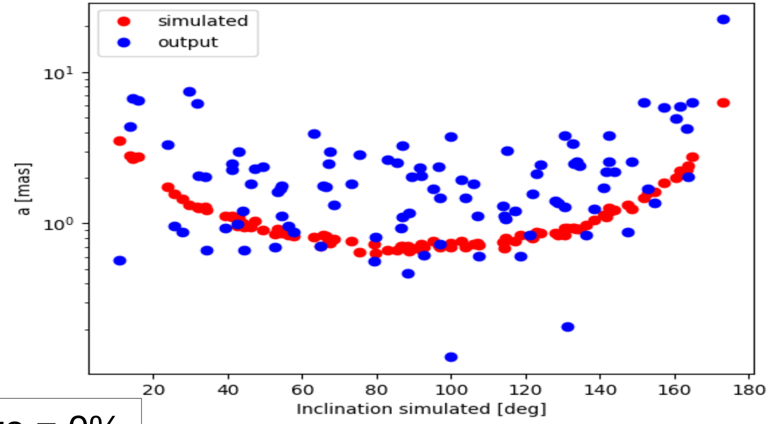
Gaia Astrometric time series (simulations)

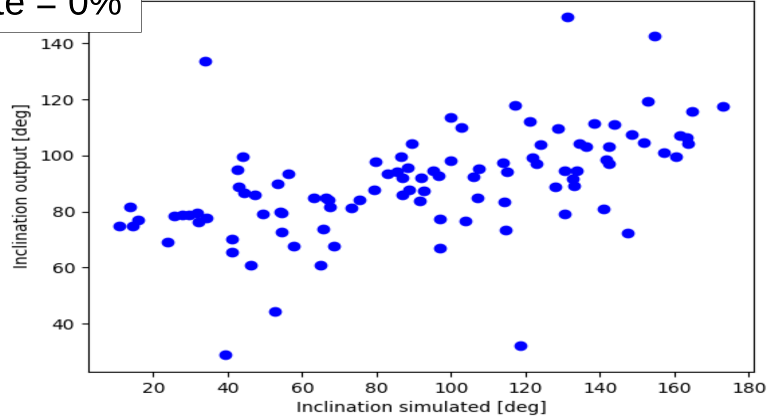
GJ 328b: P_b = 10.3 yr
a_b = 4.1 AU

GaiaDR3



Recovery rate = 0%

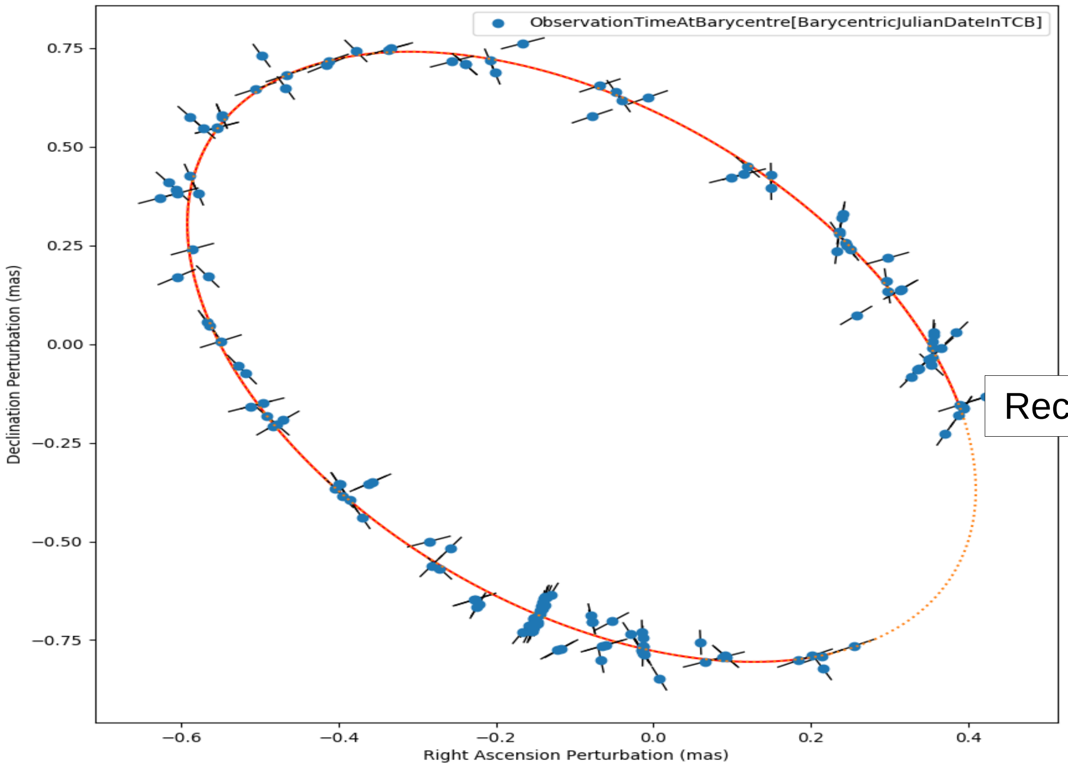




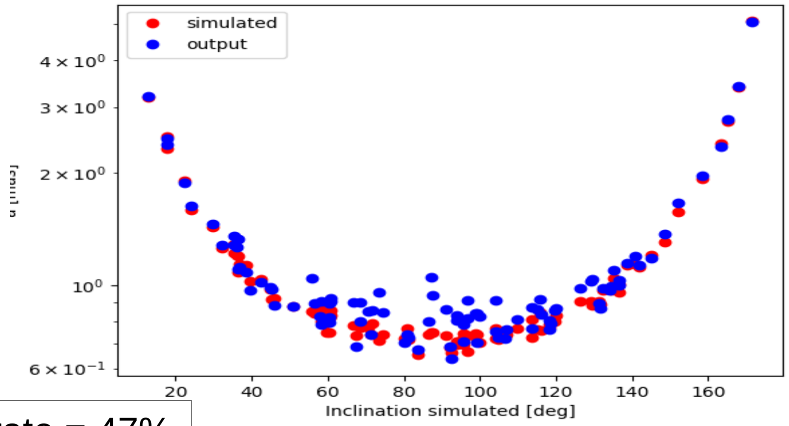
Gaia Astrometric time series (simulations)

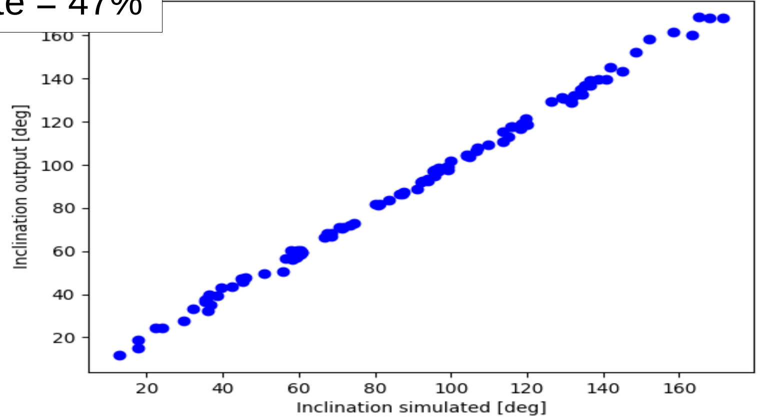
GJ 328b: P_b = 10.3 yr
a_b = 4.1 AU

GaiaDR5



Recovery rate = 47%

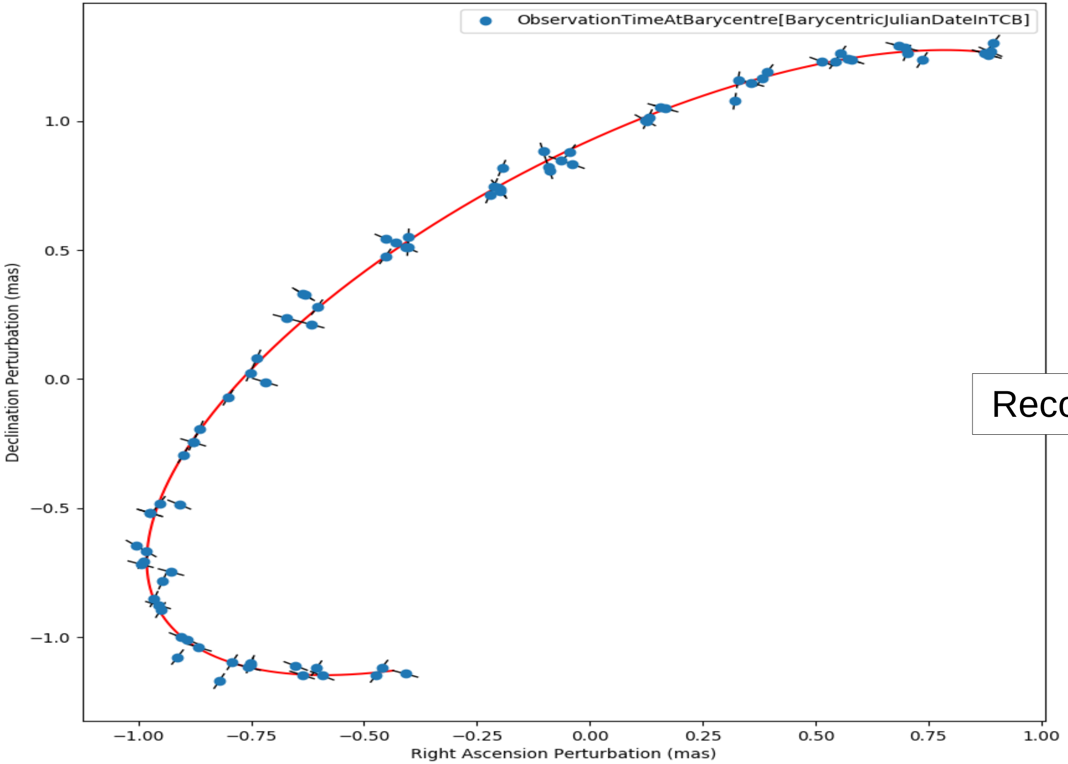


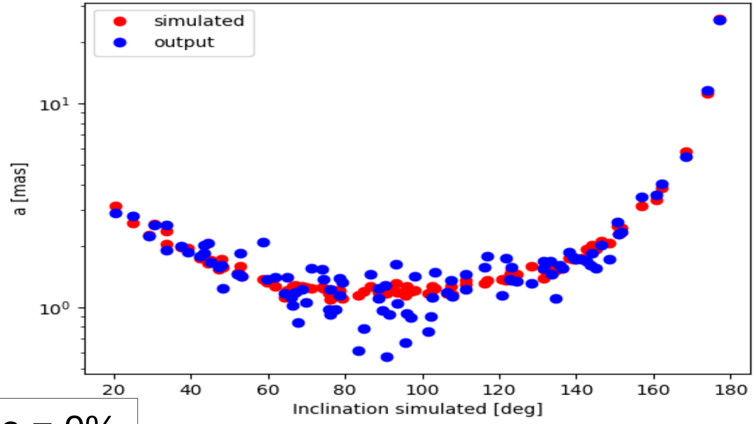


Gaia Astrometric time series (simulations)

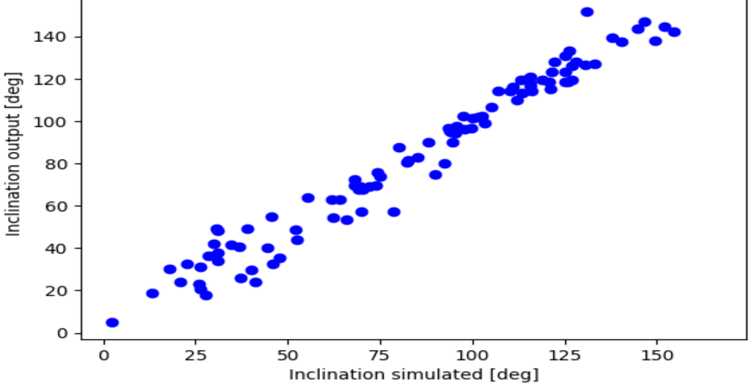
GJ 849c: P_b = 16.4 yr
a_b = 4.9 AU

GaiaDR5





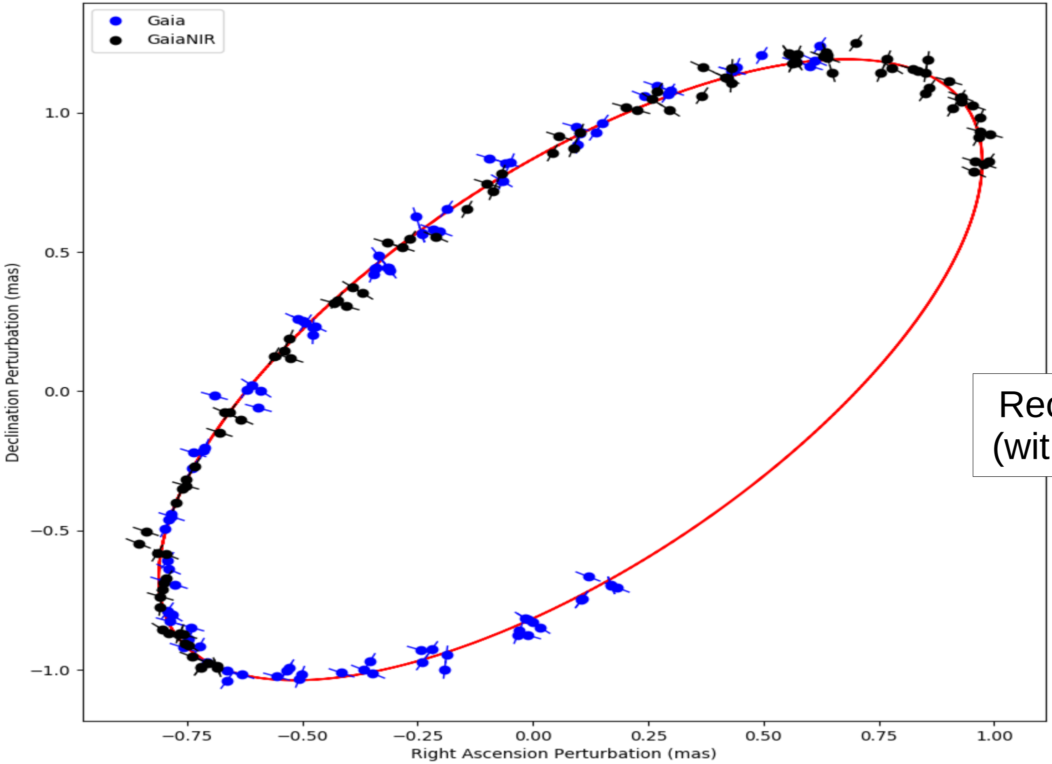
Recovery rate = 0%

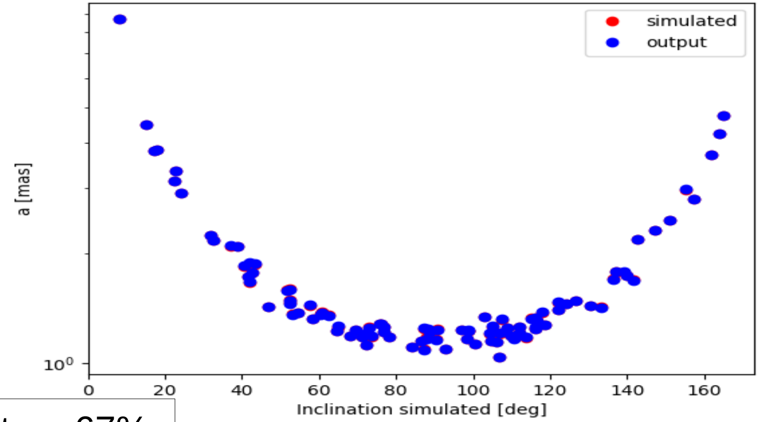


Gaia + GaiaNIR (simulations)

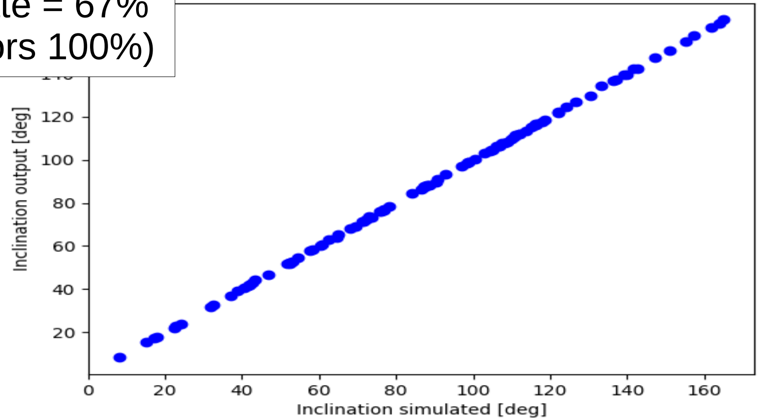
GJ 849c: P_b = 16.4 yr
a_b = 4.9 AU

Gaia + GaiaNIR





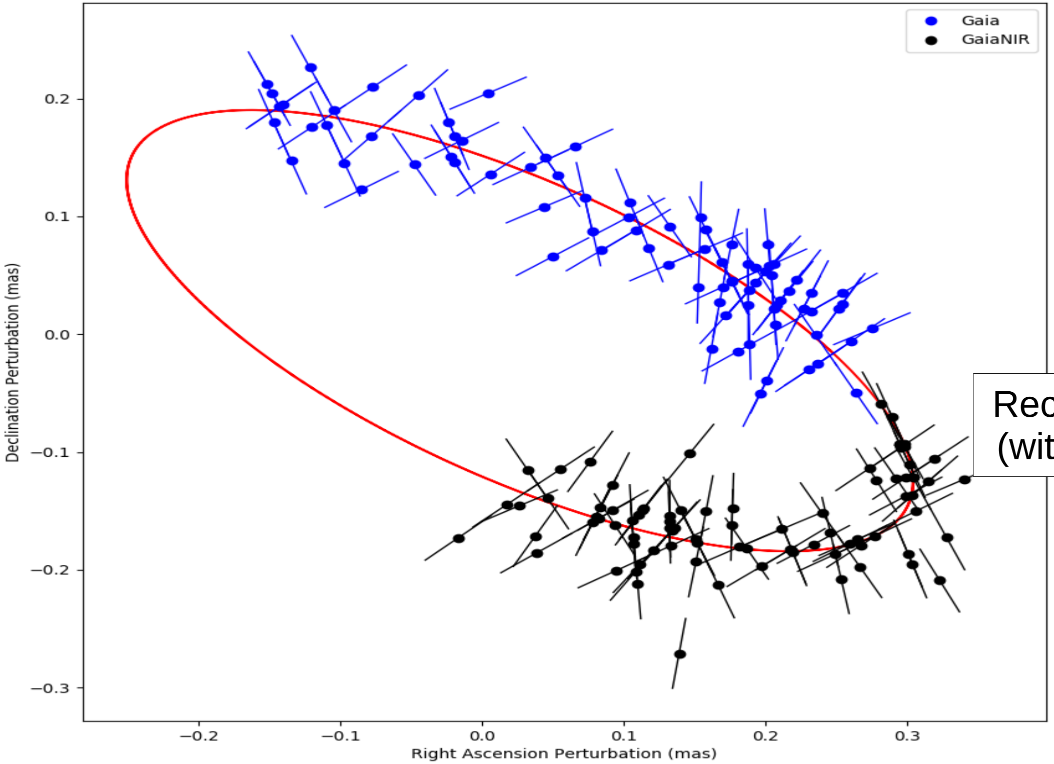
Recovery rate = 67%
(with RV priors 100%)



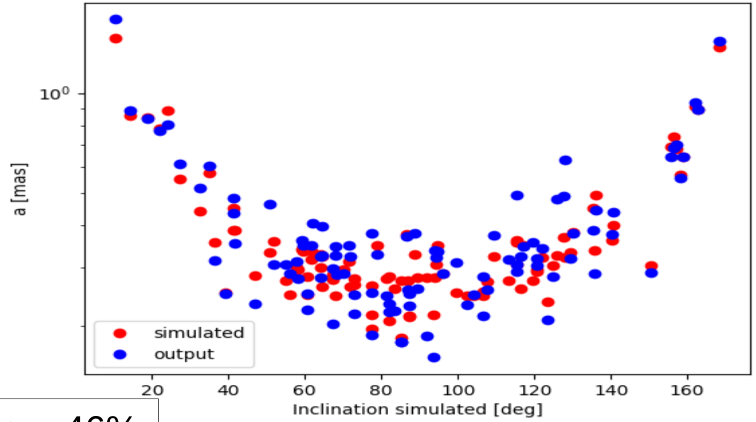
Gaia + GaiaNIR (simulations)

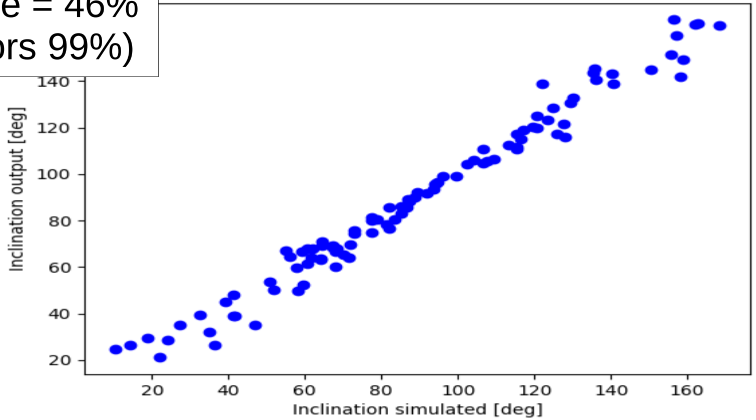
HD75898c: P_c = 18.3 yr
a_c = 7.6 AU

Gaia + GaiaNIR



Recovery rate = 46%
(with RV priors 99%)



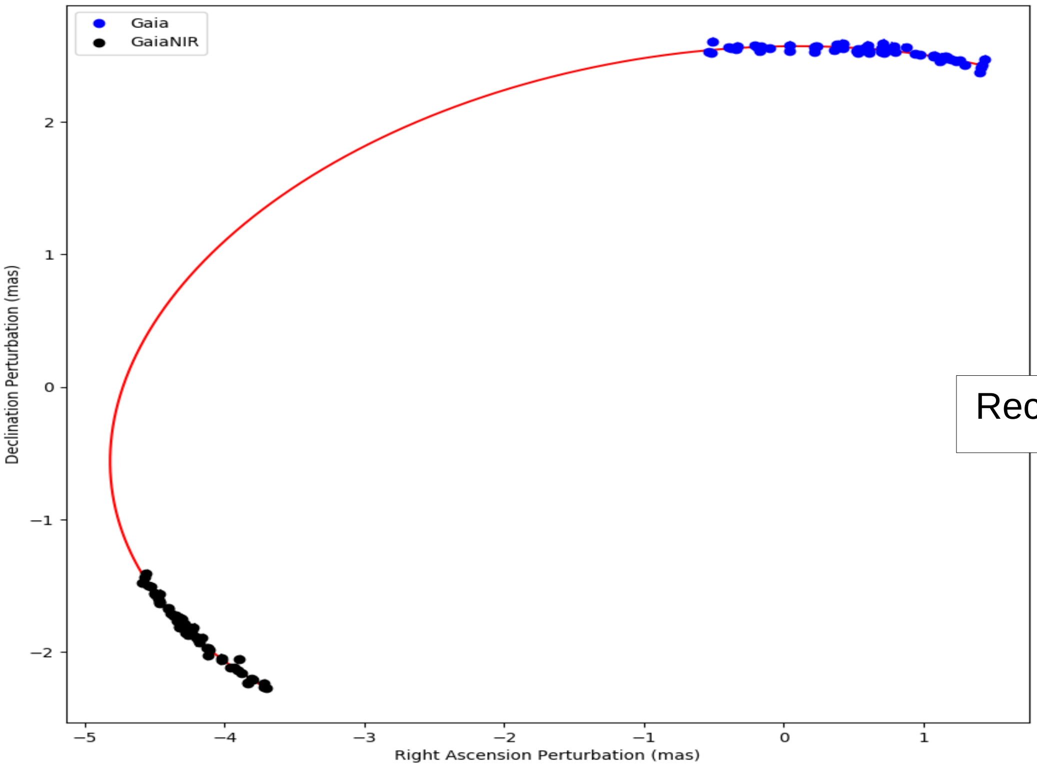


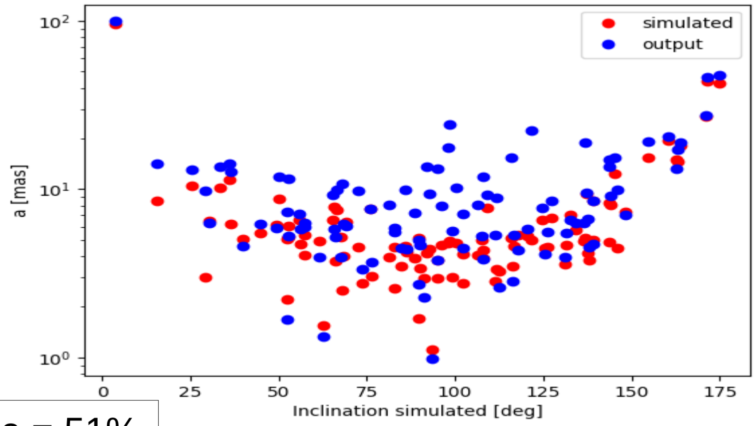
Gaia + GaiaNIR (simulations)

HD 11506d: P_c = 75 yr

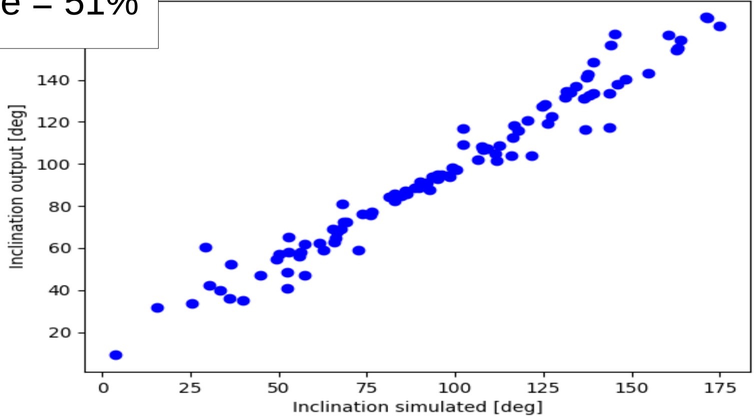
a_c = 19 AU

Gaia + GaiaNIR





Recovery rate = 51%



Summary

- **Combination of RV and astrometry:** different approaches can recover inclination and real mass in different systems. Future GaiaDRs will allow precise measurement of orbit for Cold Jupiters:
  - "short" orbits ($\lesssim$5 yr) will be solved with DR4 data;
  - For Jupiter-like orbits (>10 yr) PMA (not always...), or final DR5.

- **Gaia limited by its timespan:** massive companions on long period orbits have large astrometric signals, but cannot be fully characterized (long-term trends)
  - ➔ **Gaia+GaiaNIR:** realistic simulations of Gaia and GaiaNIR astrometric time series, quantify the great boost in precision in the modeling of long-period companions, even with open orbits. The combination of these well-spaced datasets will greatly help the study of long-period substellar companions.

THANK YOU

BACKUP SLIDES

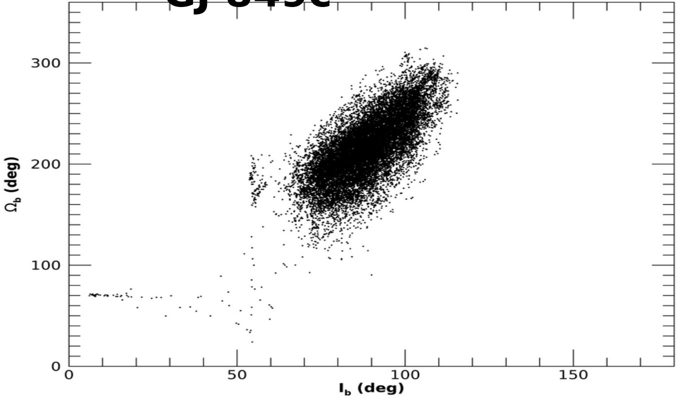
Synergies with astrometry: Gaia+

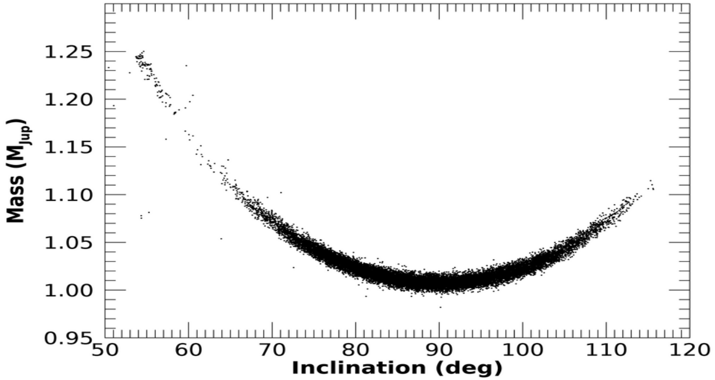
Proper Motion Anomaly analysis

GJ 849

Combined fit: RV + PMA

GJ 849c





PMA Sensitivity from Kervella+2022