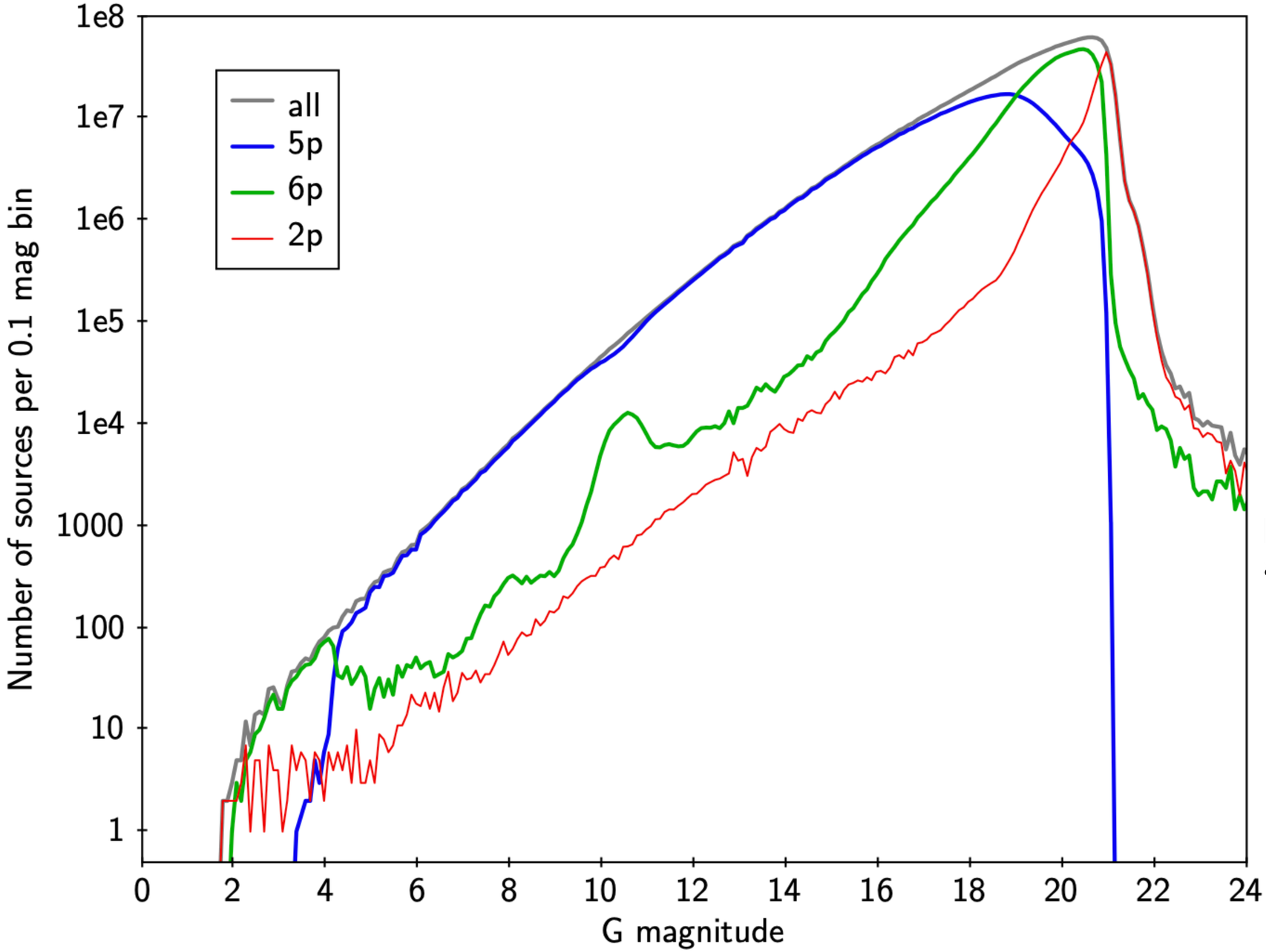
# Gaia-PMEX

## Proper-motion anomaly & astrometric excess noise

**Flavien Kiefer / COBREX meeting / Banyuls / 06-10-2022**

# Datasets, $N_{sources}$ vs magnitude




- 2p : only ra-dec position ;
- **5p : + PLX, PM (the best) ;**
- 6p : + pseudocolor $\nu_{eff}$.

Complicated chromaticity correction:

- bad estimate of effective wavenumber (~colour) ;
- crowded field ...

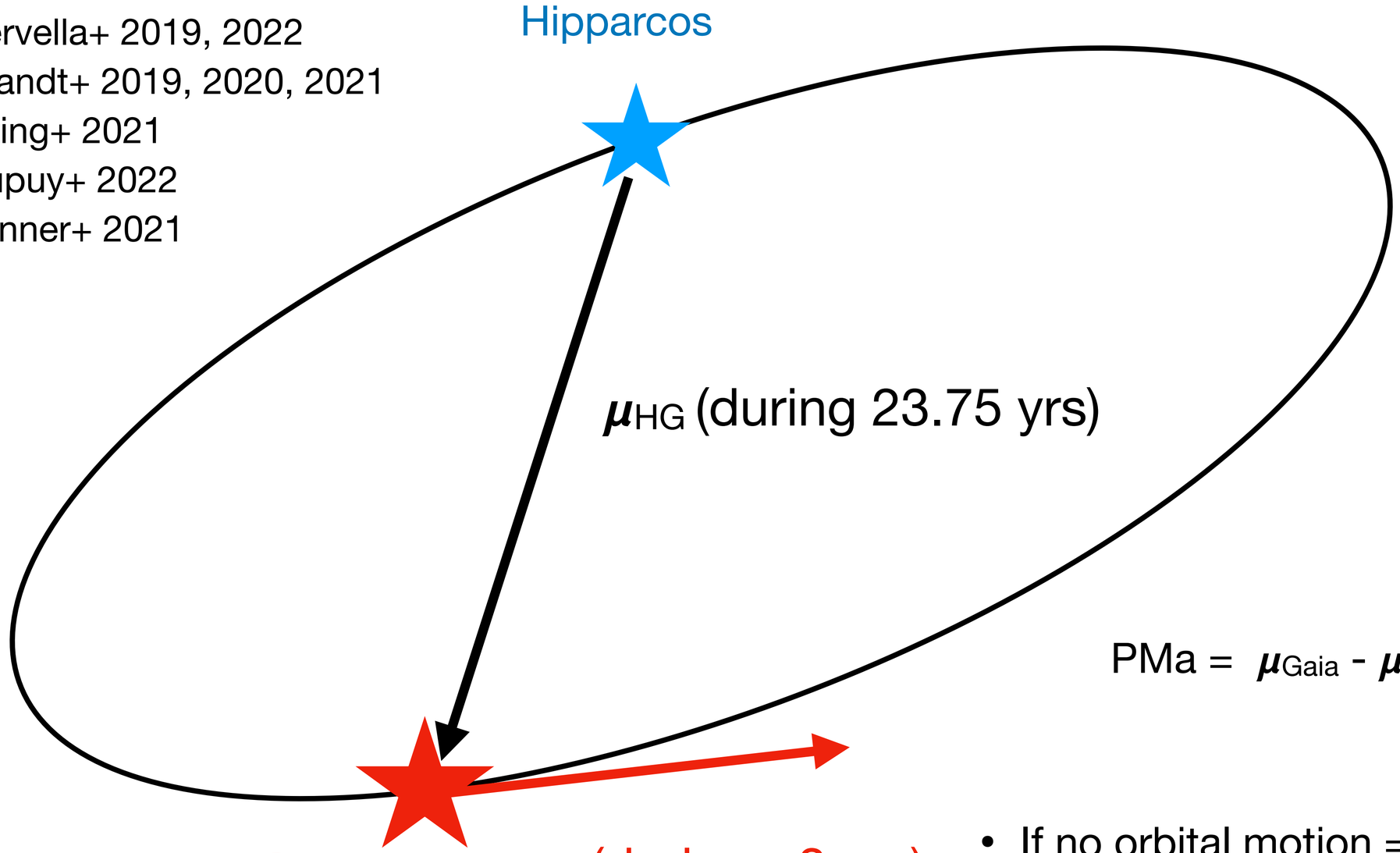
In the Gaia archive, the field **`astrometric_params_solved =`**

- 2p : 3 ;
- 5p : 31, call it **primary** ;
- 6p : 95, call it **secondary**.

Lindegren+ 2021

# Hipparcos - Gaia proper motion anomaly

Kervella+ 2019, 2022
Brandt+ 2019, 2020, 2021
Yiting+ 2021
Dupuy+ 2022
Venner+ 2021
...



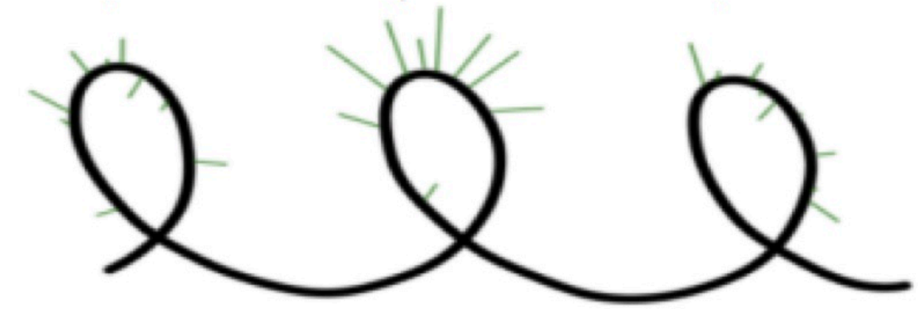

Assume PM = 0
+ orbital motion

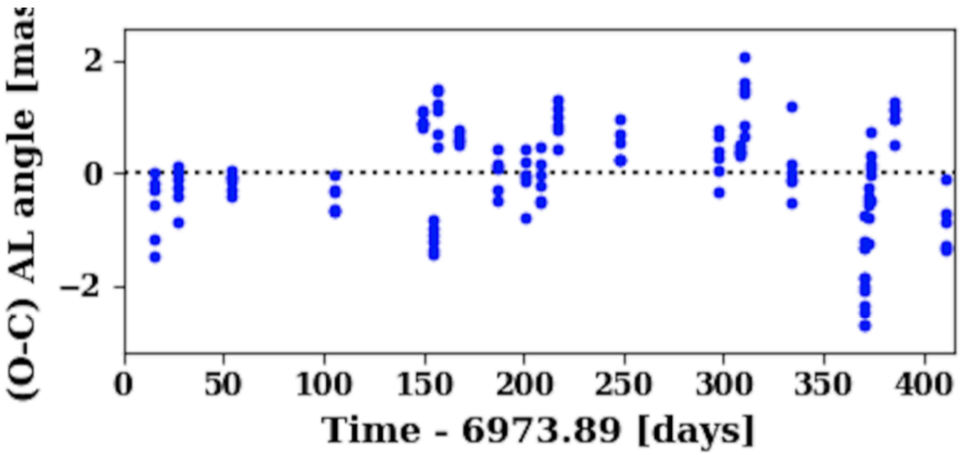
PMa = $\mu_{Gaia}$ - $\mu_{HG}$

- If no orbital motion => PMa=0 mas/yr ;
- 3D for close stars ;

# Astrometric excess noise (AEN) from the Gaia data releases

- Gaia DR3
- 5 parameters (proper motion, parallax, position),
- **Residual scatter**
  - ➡ Measurement noise
  - ➡ + modeling errors
  - ➡ + instrumental noise





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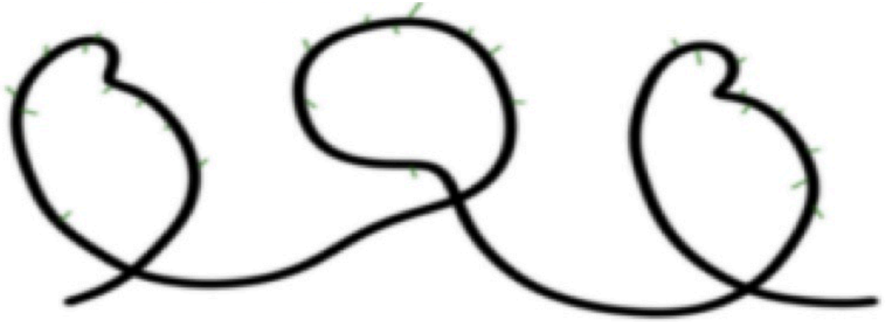
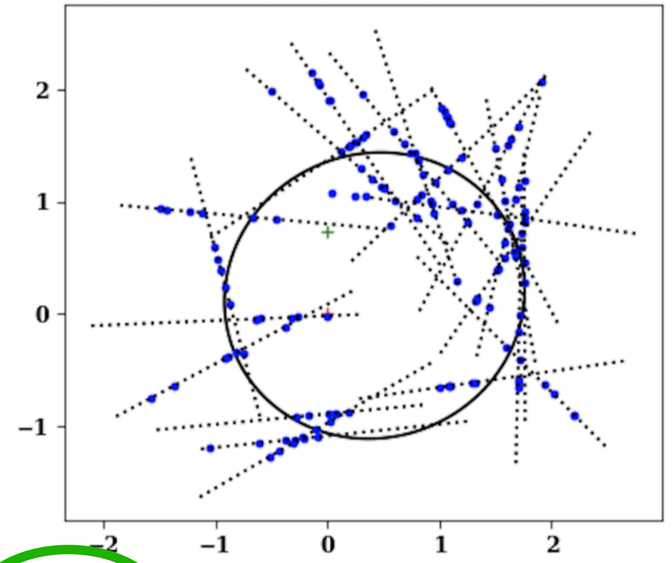
  - ➡ + instrumental noise
  - ➡ **+ more ?**

} **excess noise**






5-param solution residuals

Attitude noise ~ 0.076 mas

$$\varepsilon_{\rm att}^2 + \varepsilon_{\rm DR}^2 + \sigma_m^2 = \frac{\sum_i R_i^2}{N-5}$$

Excess noise

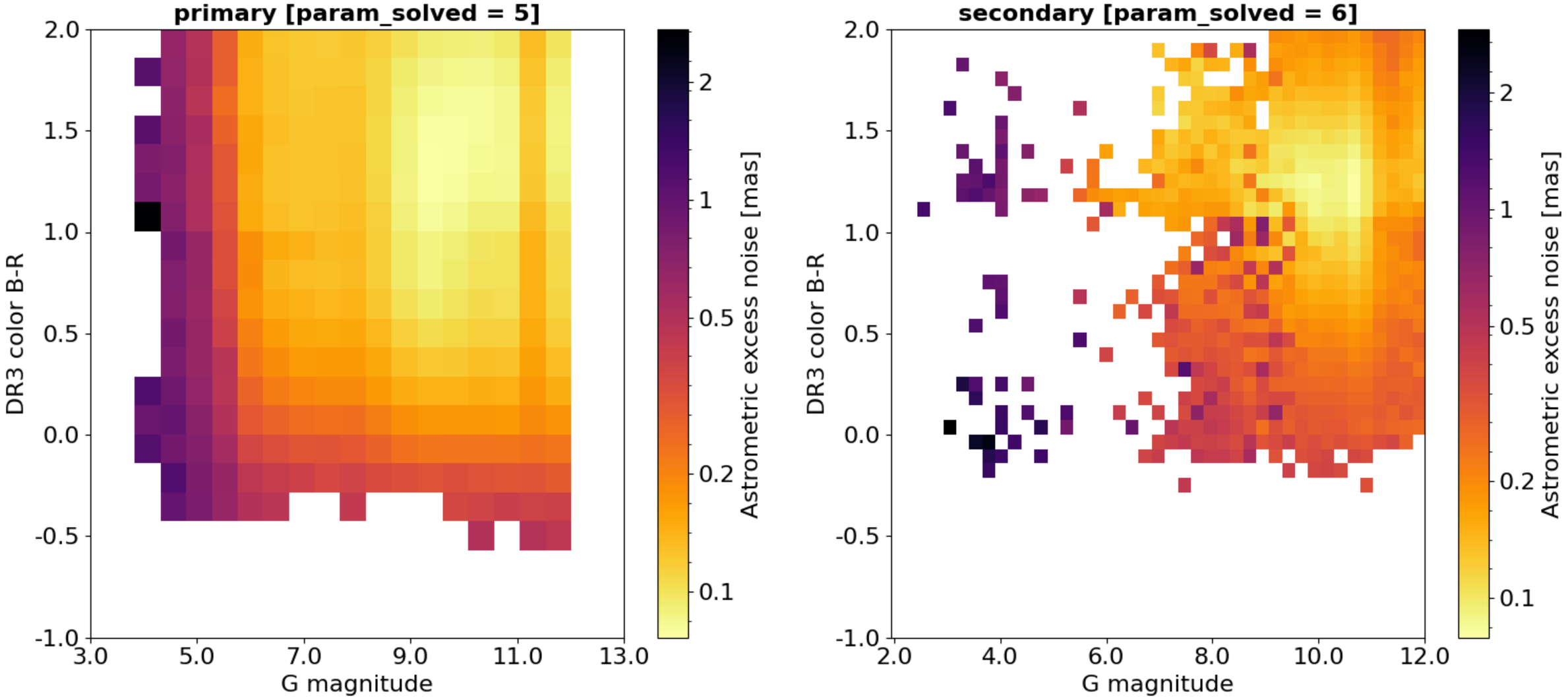
CCD noise
= 0.1 mas

$$\varepsilon_{\rm DR}^2 = \underbrace{\varepsilon_{model}^2 + \varepsilon_{instru}^2}_{} + \varepsilon_{astro}^2$$

DR1 ~ 0.45 mas
DR3 ~ 0.11 mas

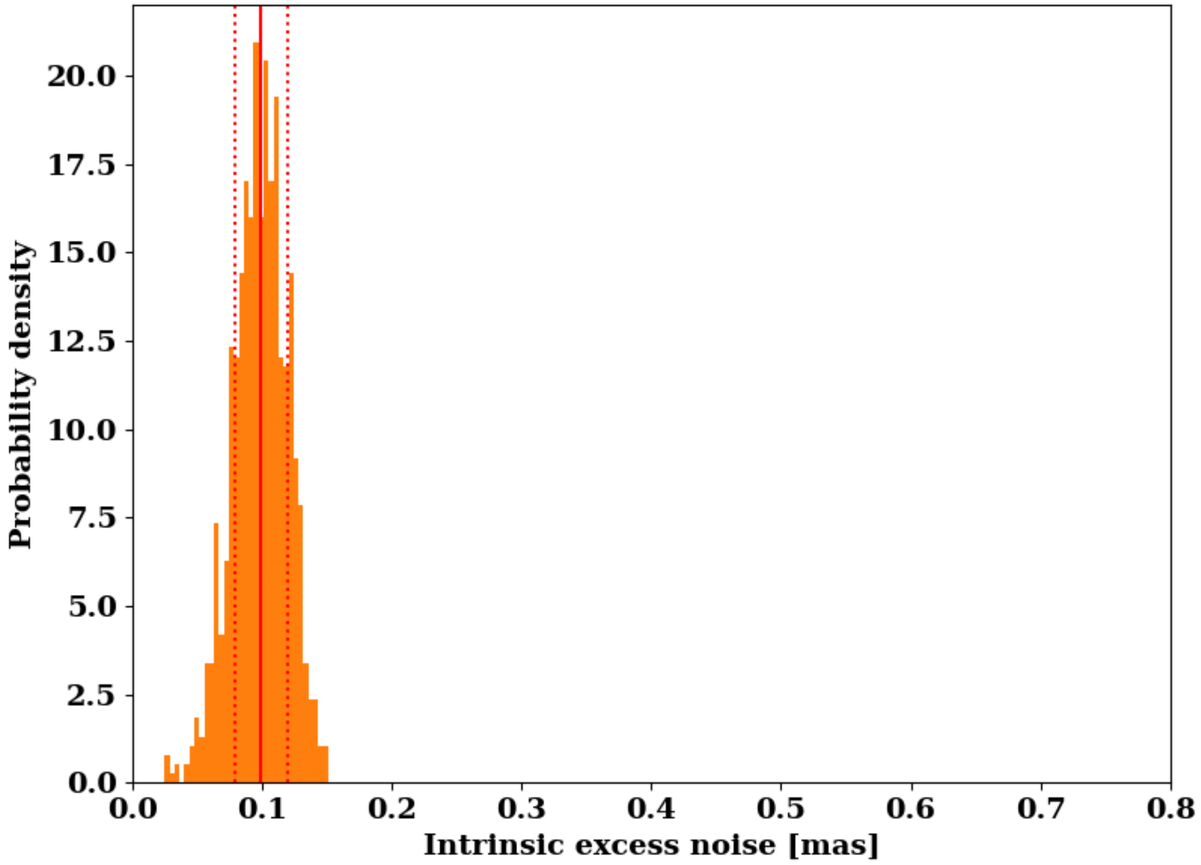
Kiefer+ 2019, 2021
Dalal+ 2021
Demangeon+ 2021
Lagrange+ 2022, submitted

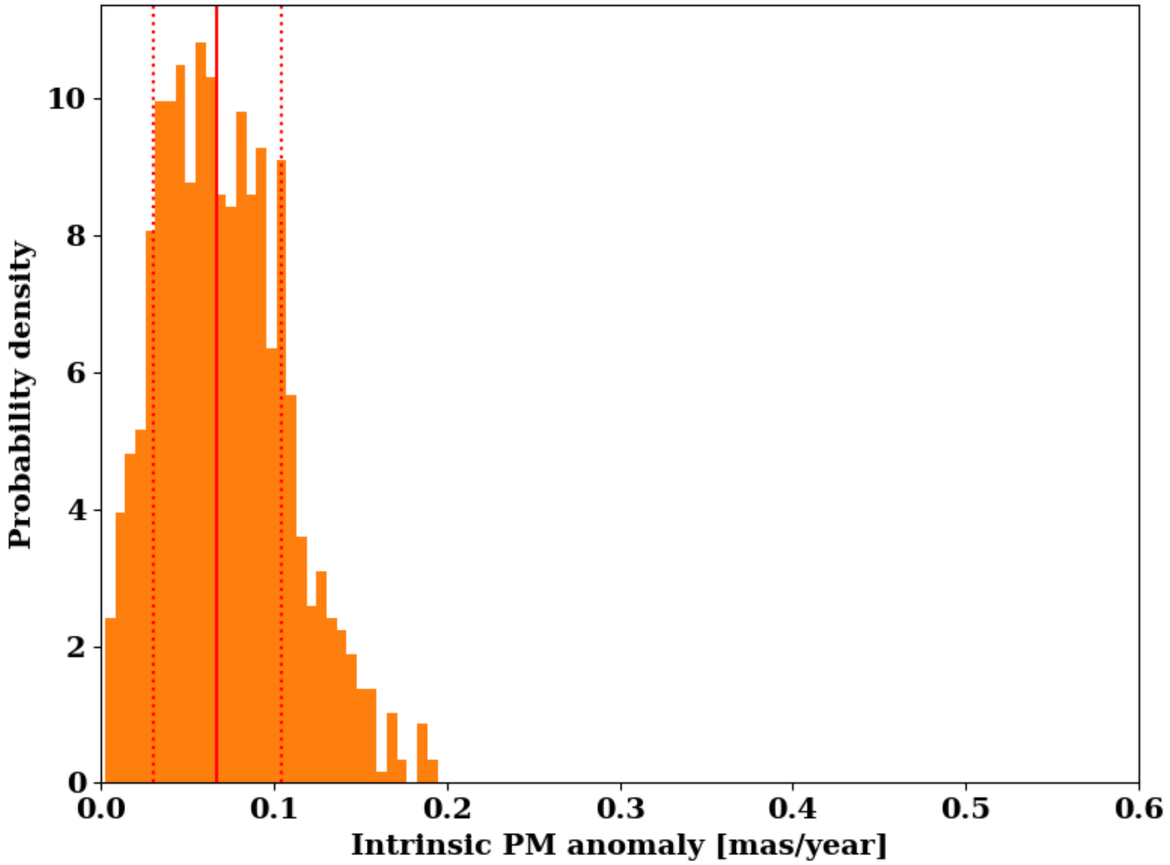
# Median AEN in Gaia data



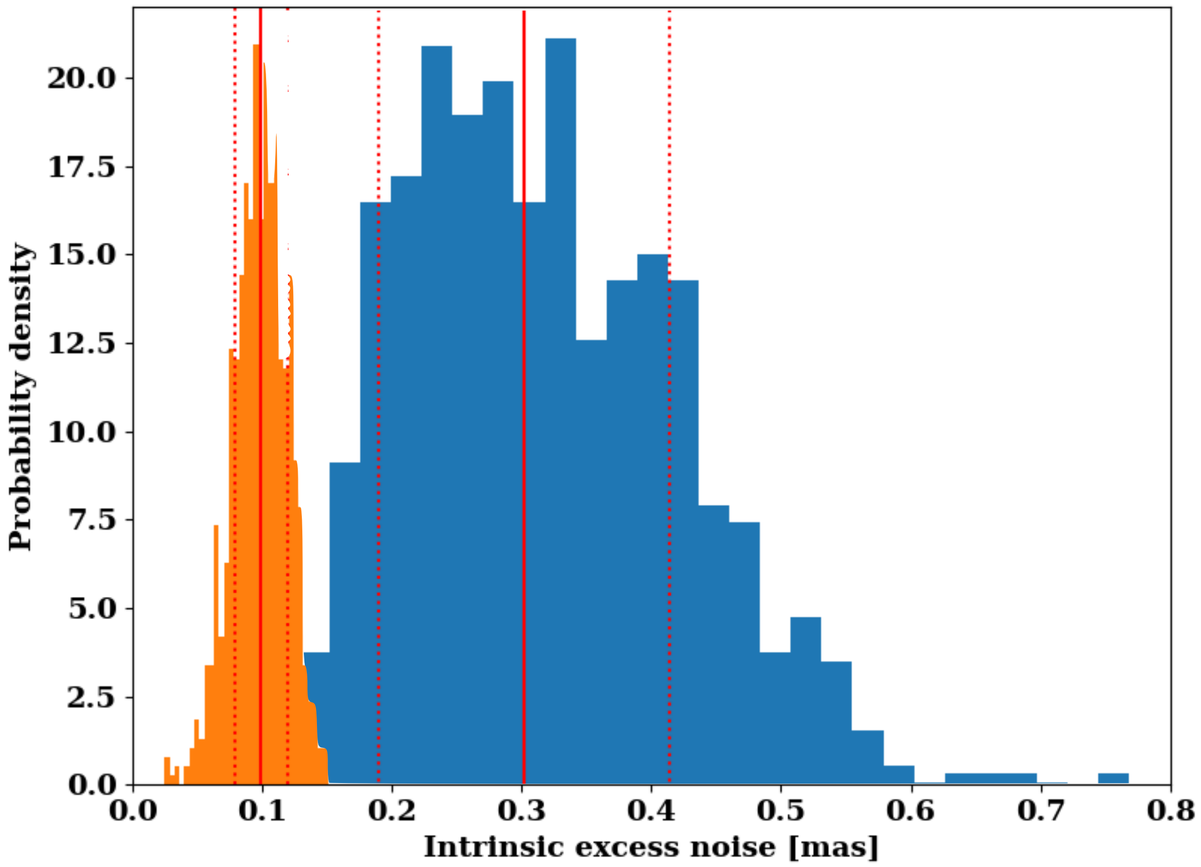

- Less sensible to multiplicity (<50% of stars are multiple);
- Proxy to the instrinsic noise in Gaia meas + reduction;
- Best accuracy for FGK stars: noise < 0.1 mas.

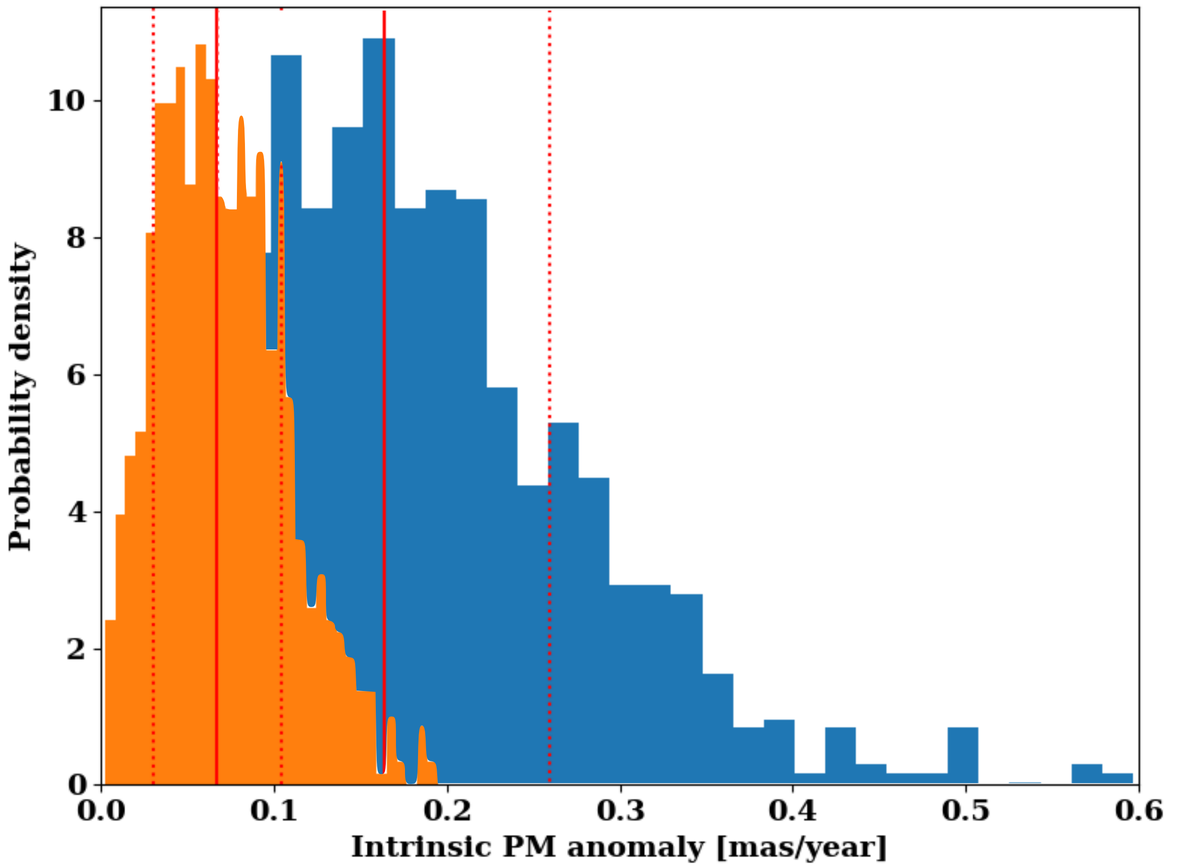
- Star w/ G-mag=9, GB-GR=0.5, DEC=45, HIPerr=1mas, PLX=10 mas;
- **Single** ;
- Only composition of position + proper motion + parallax + Gaia intrinsic noise;



- Same star w/ G-mag=9, GB-GR=0.5, DEC=45, HIPerr=1mas, PLX=10 mas;
- **With a companion (sma=1au; Mp=100 MJup)**
- Composition of position + proper motion + parallax + Gaia intrinsic noise + **astrometric orbit**

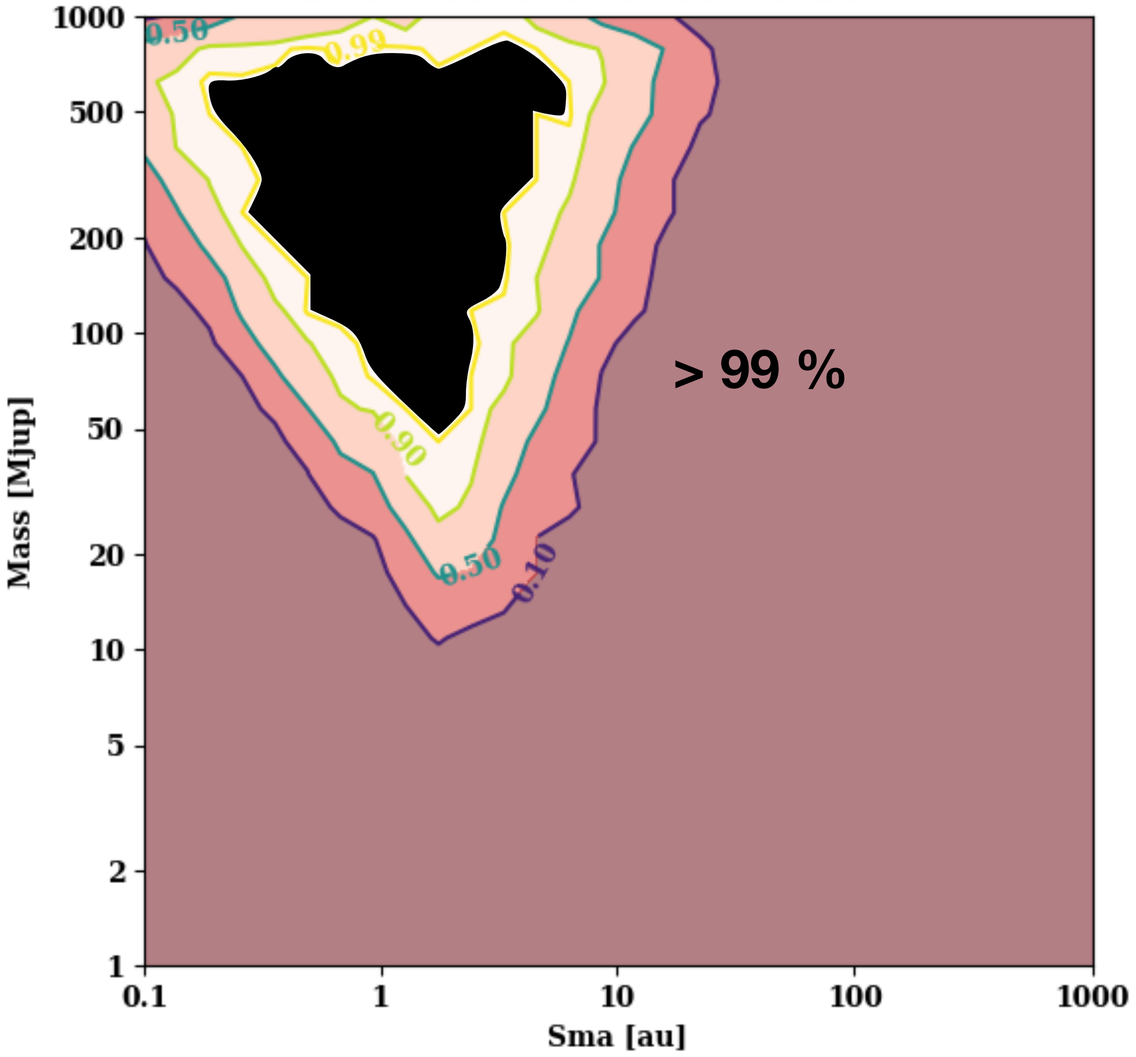


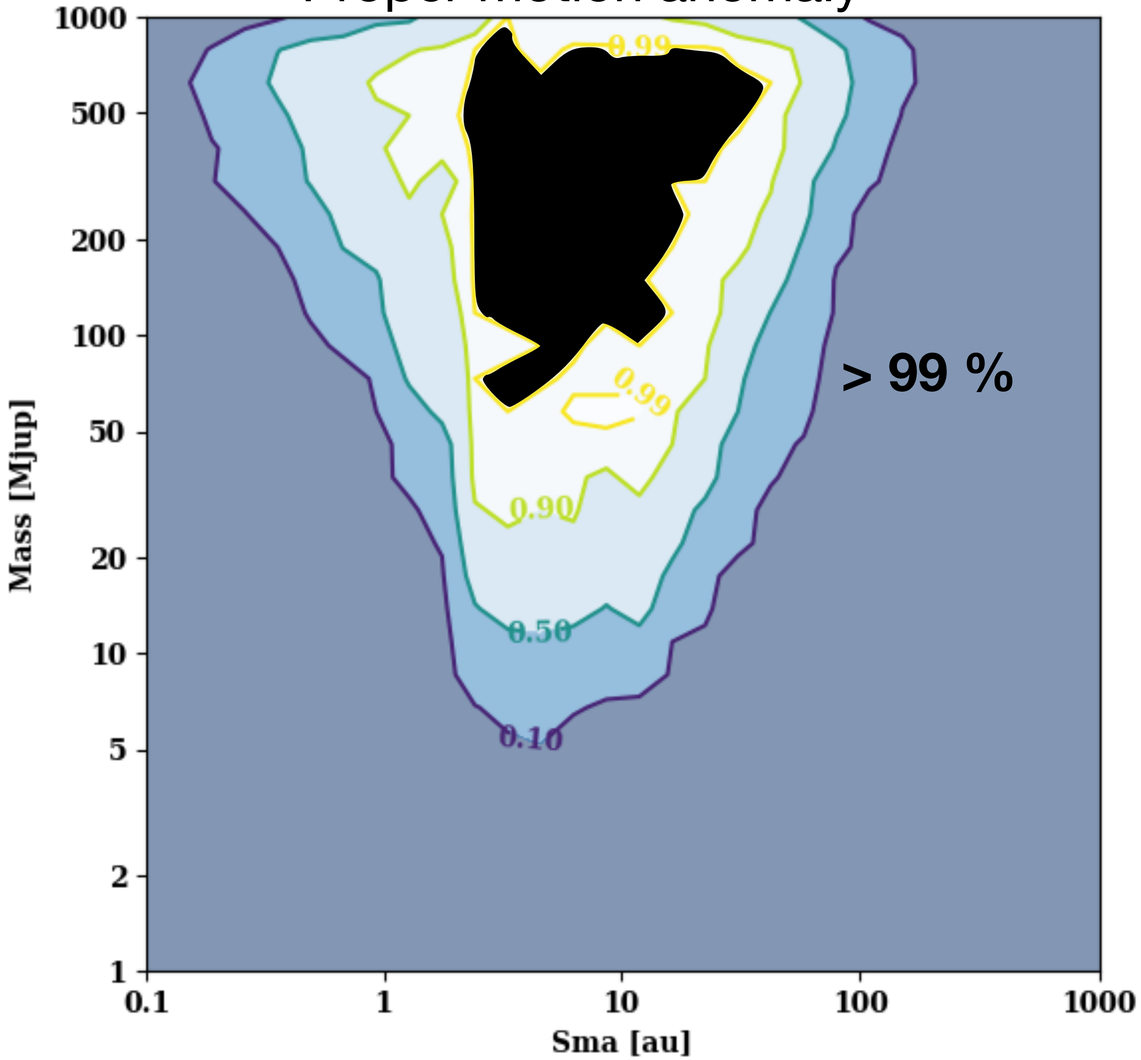
# At given M & sma, how many simulations are > 3-sigma from single star + noise

G-mag=9, GB-GR=0.5, DEC=45, HIPerr=1mas, **PLX=10 mas**

Astrometric excess noise



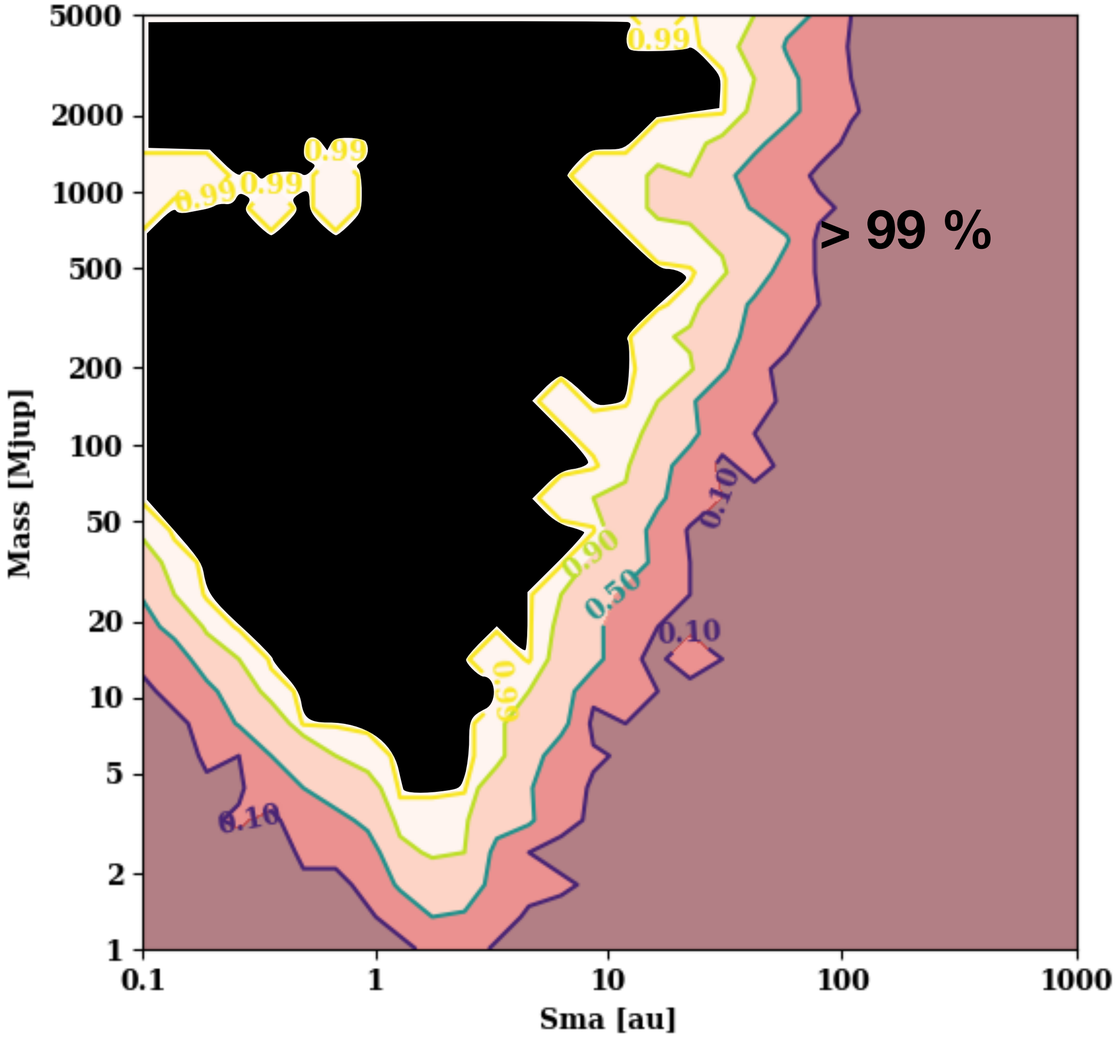

Proper motion anomaly



# At given M & sma, how many simulations are > 3-sigma from single star + noise

G-mag=9, GB-GR=0.5, DEC=45, HIPerr=1mas, **PLX=100 mas**

Astrometric excess noise

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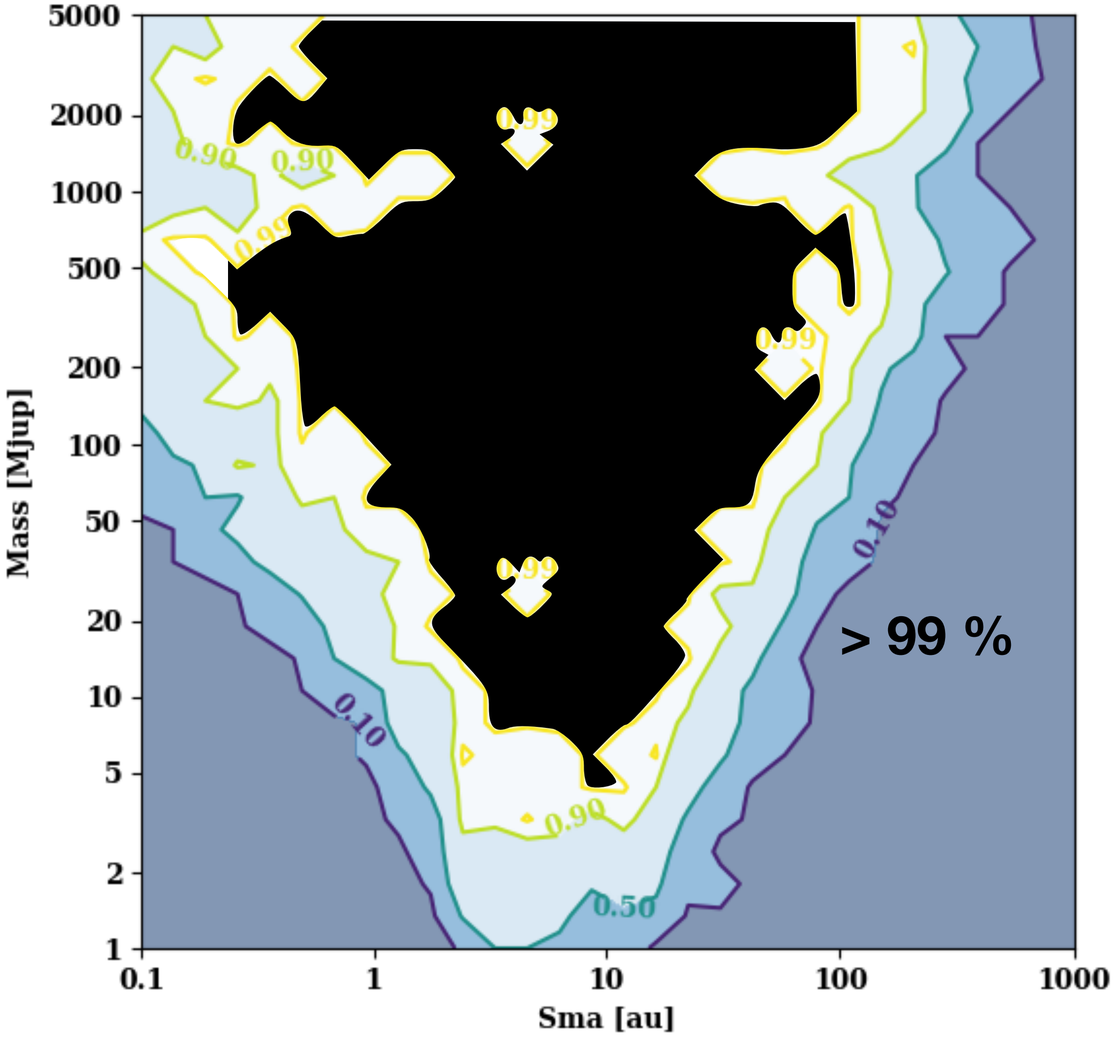

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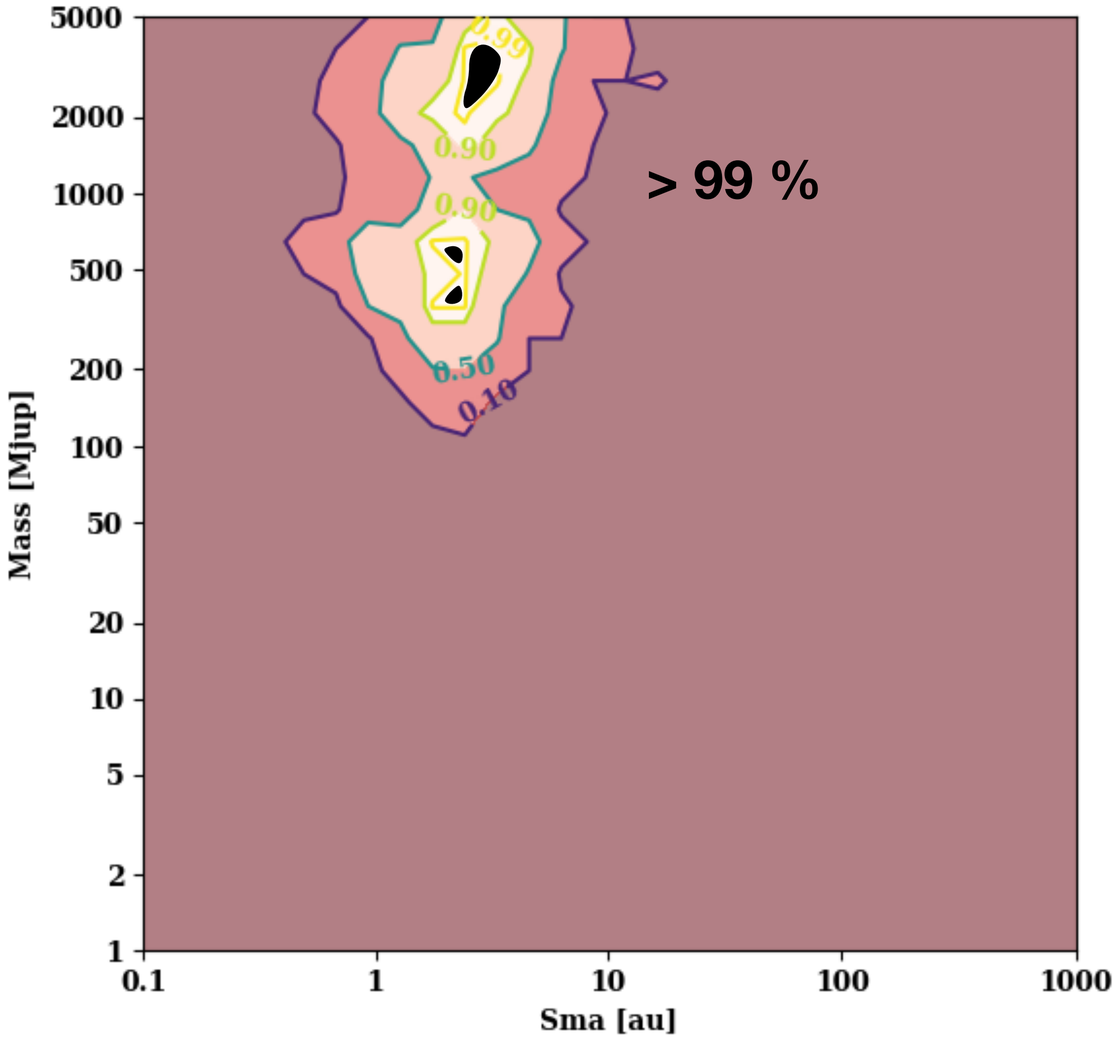
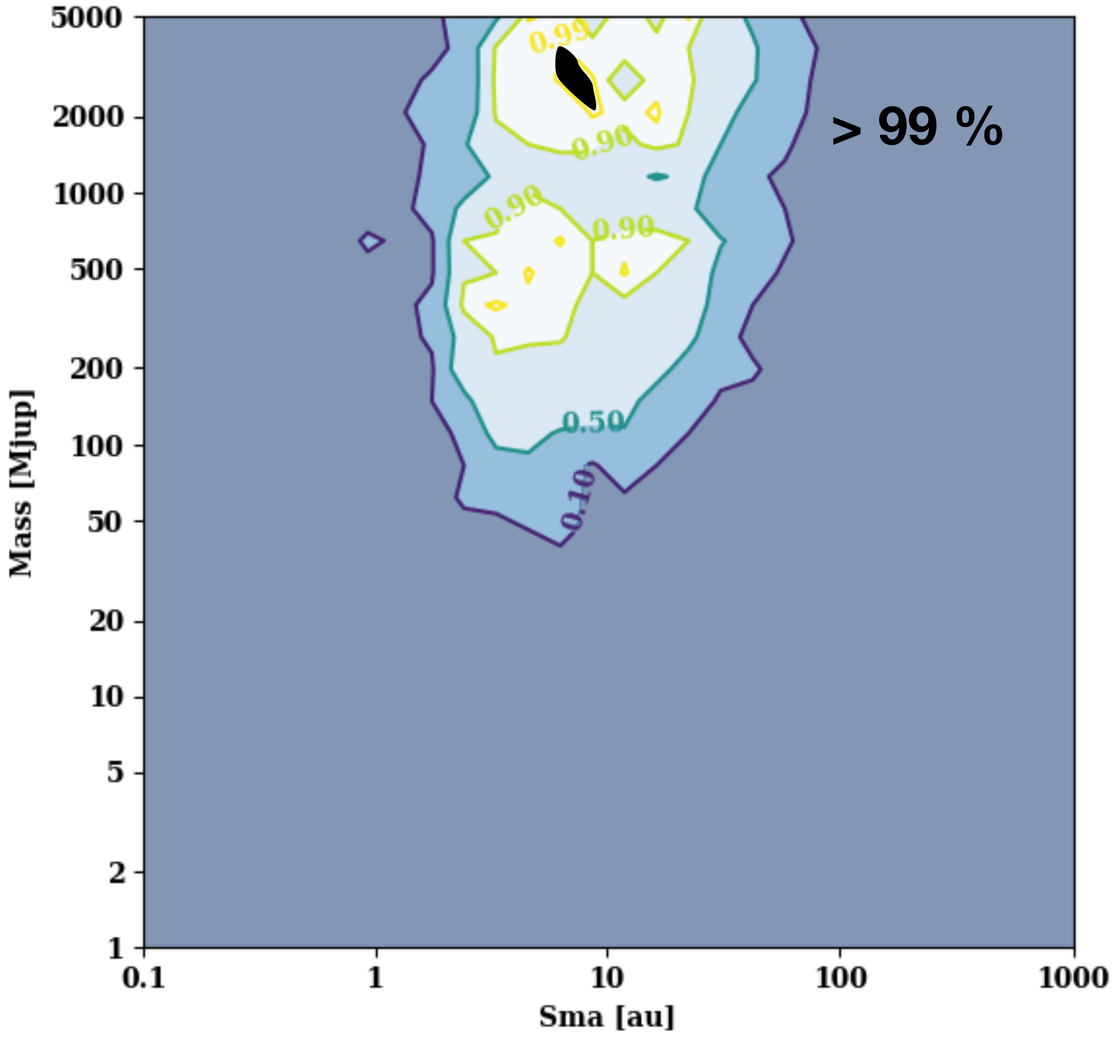
G-mag=9, GB-GR=0.5, DEC=45, HIPerr=1mas, **PLX=1 mas**

Astrometric excess noise




Proper motion anomaly



# Sensitivity maps

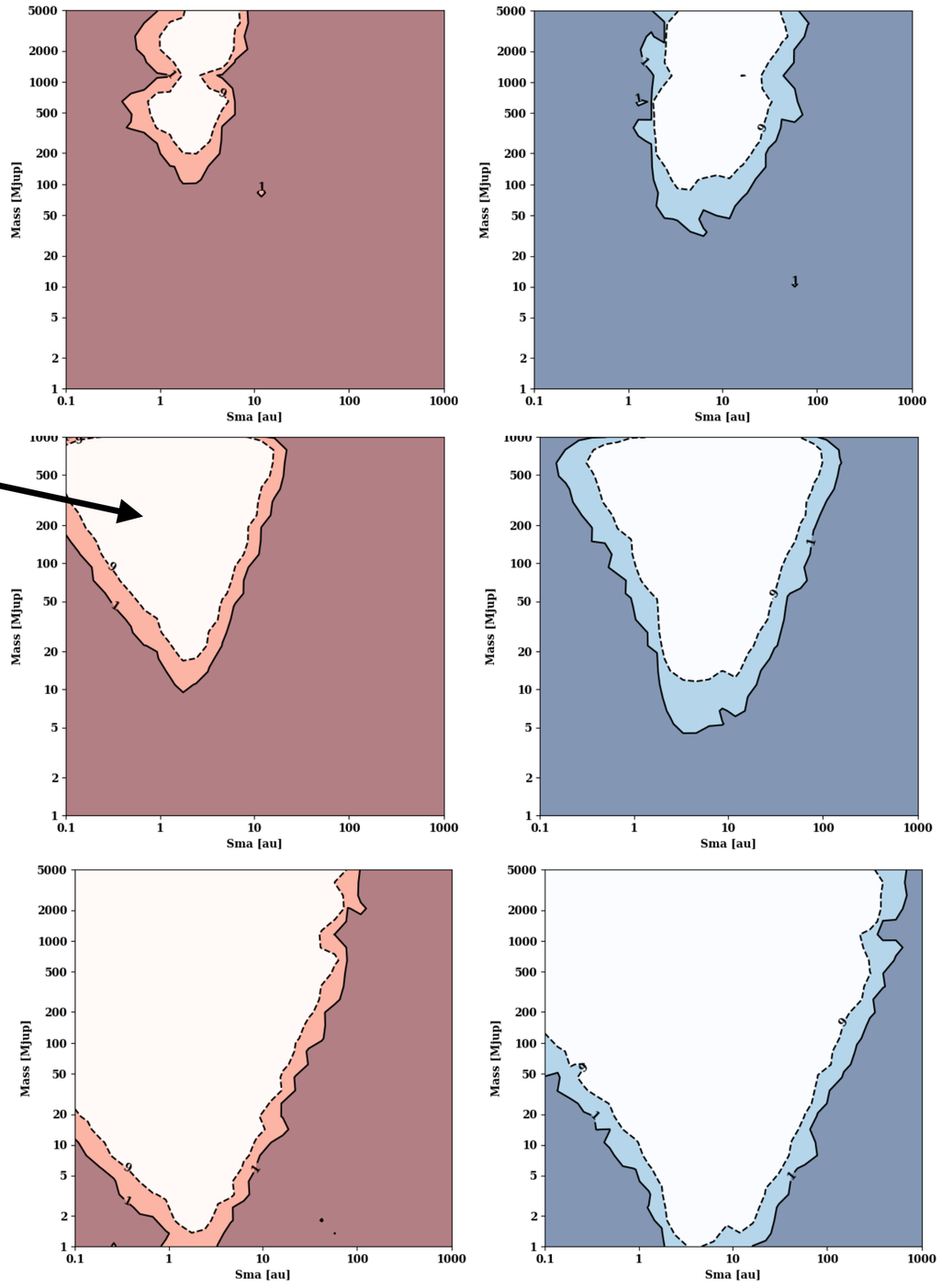
G-mag=9, GB-GR=0.5, DEC=45, HIPerr=1mas

PLX=1 mas

*In average we can expect that companions with (M,sma) in this region will lead to a 3-sigma significant AEN or PMa*

PLX=10 mas

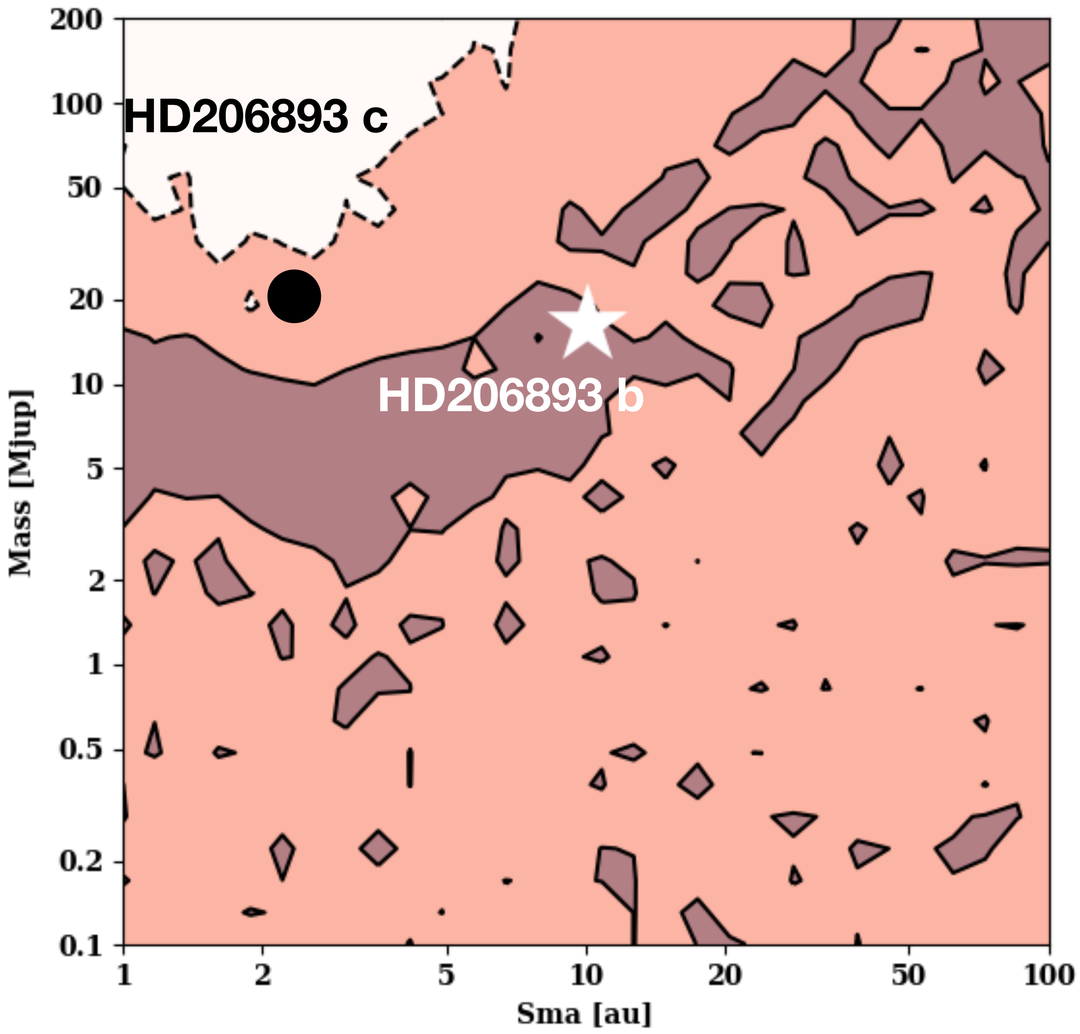
PLX=100 mas



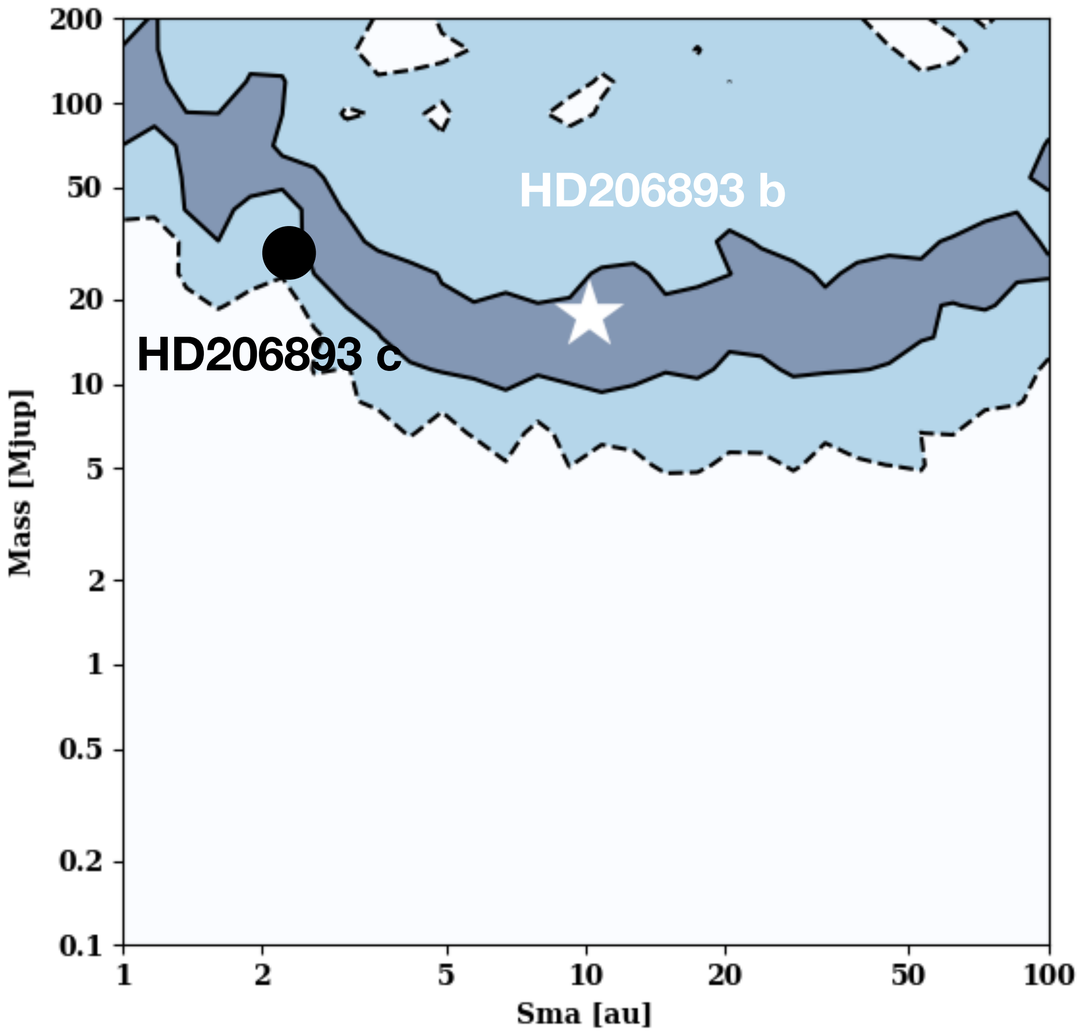
# HD206893 - constraints from actual measurements

epsilon_DR3 = 0.17  (mas)
PMa = 0.58+/−0.03  (mas/yr) (from Kervella+ 2022)

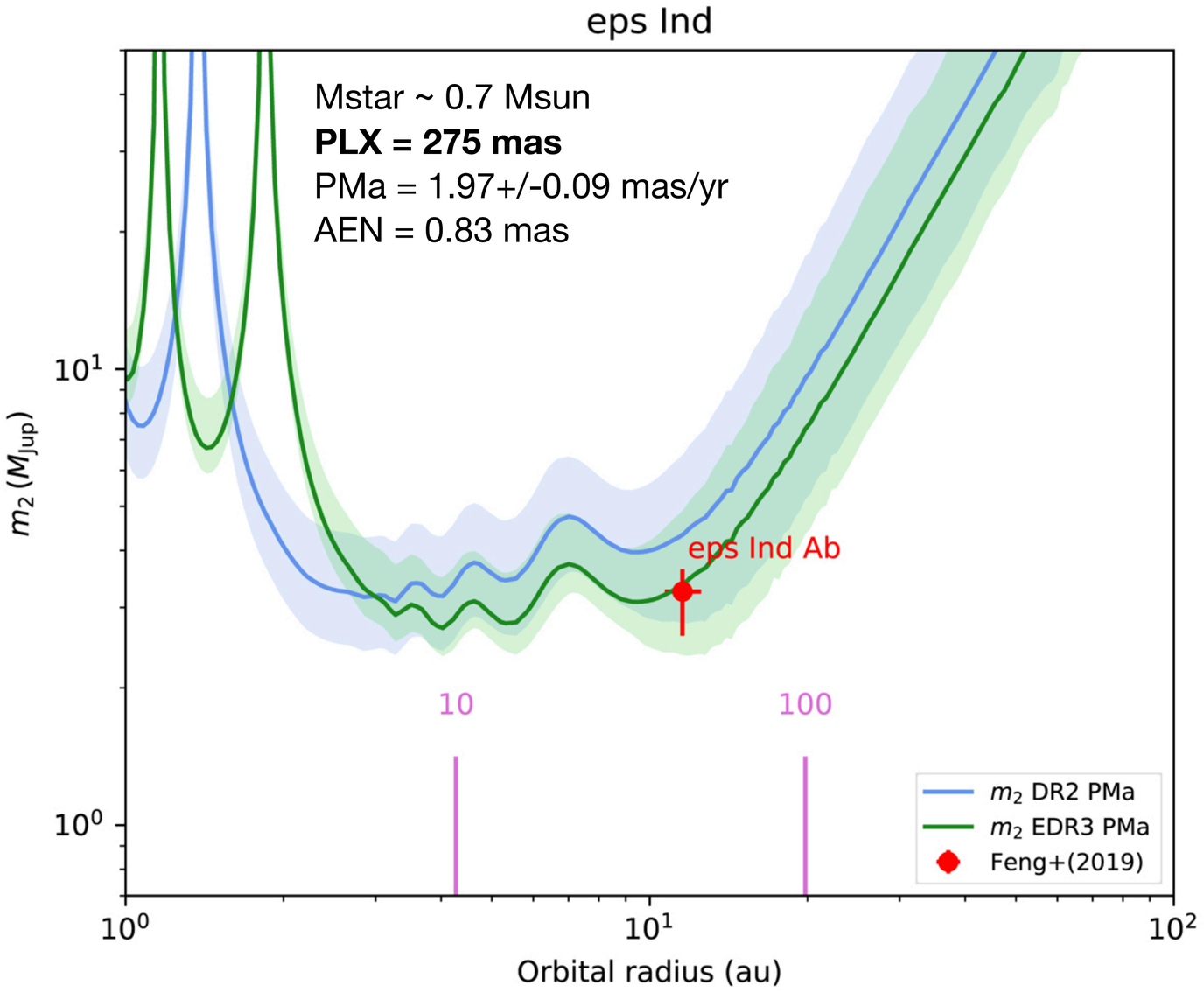
AEN



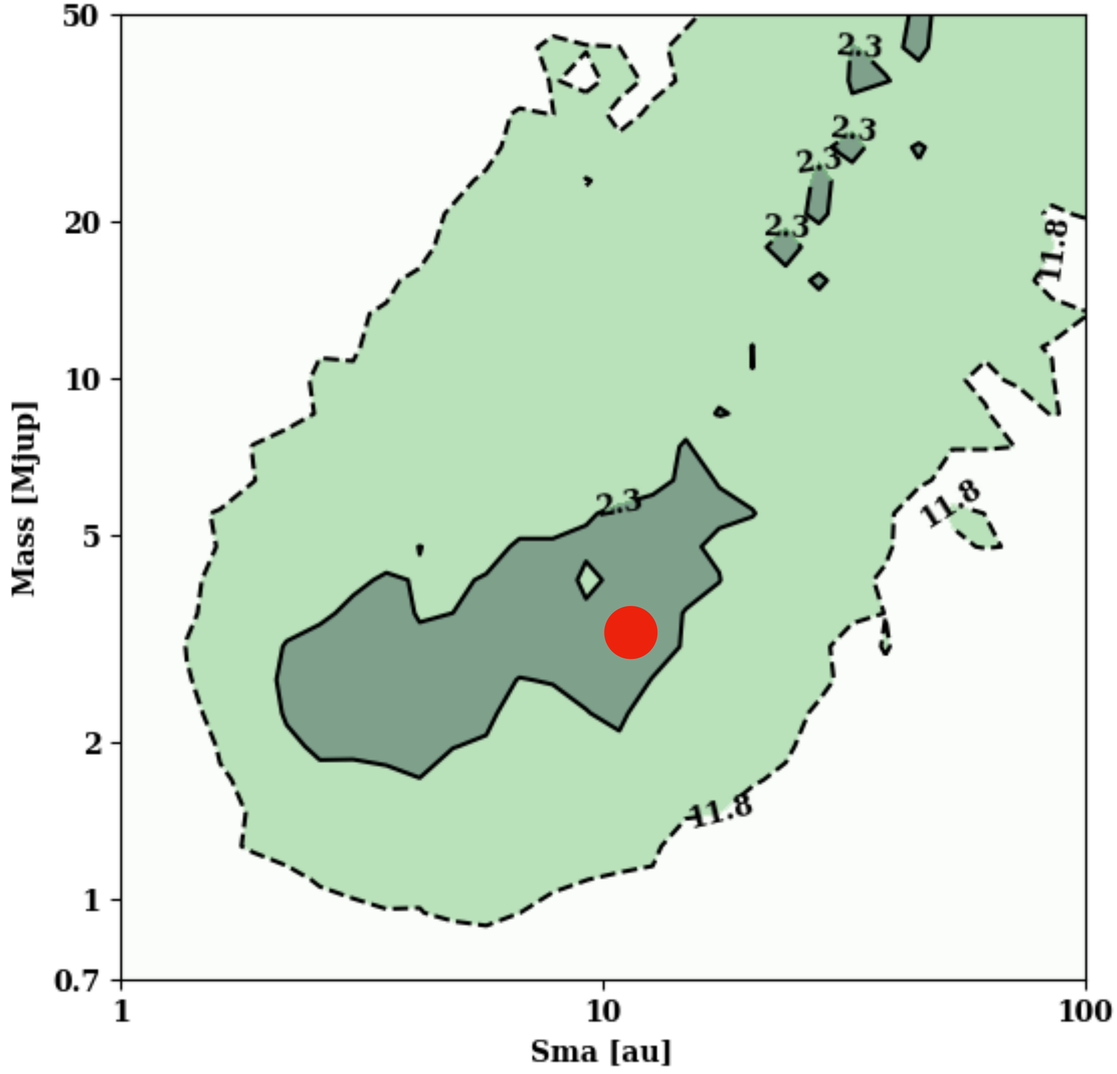

PMa



# Comparing to theoretical curves of Kervella+ 2022




AEN + PMa

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Intrinsic AEN (no companion) = 0.730+/-0.088 mas
Intrinsic PMa (no companion) = 0.303+/-0.176 mas/year
```

# Gaia-PMEX

- The tool is named Gaia-PMEX
- It is available in GitHub here: https://github.com/FlavienKiefer/GaiaPMEX
- It requires only a few inputs:
  - Star name (that SIMBAD is able to recover);
  - Estimated star mass;
  - File w/ the noise map % G-mag and GB-GR;
  - Config file w/ few parameters to fix (e.g. ticks, grid points, Nsimu, using sma or P...);
- Simulate many star orbits as observed w/ Gaia (epochs taken from GOST);
- Testing different values of M & P (N x N grid points);
- For each M & P, it will draw values of e, omega, Ic, big-omega, Tp etc. and simulate Nsimu orbits;
- Compare the average simulated AEN and PMa to the observed value (Gaia-DR3 / Kervella+2022);
- Calculate a log-likelihood and trace contour maps of delta log-likelihood (2.3=1-sigma ; 11.8 = 3-sigma)