Searching for planetary companions around nearby solar-type stars using *Gaia* astrometry

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Image Credit: *ESA*

erc COBREX Conférence ELBERETH des doctorants en astronomie et astrophysique en Ile de France cnrs LIRA Observatoire de Paris | PSL

Basics of Astrometric Detections

Image Credit: *ESA*

Astrometric technique

The Concept

- The position of stars in the sky changes due to several factors
- **Track the positions** of stars very precisely to check if there are companions
- Stars that have stellar or planetary companions will **move differently** compared to single stars
- Use the **measured path** to calculate the properties of the companion

Astrometric signals

For single stars

The path of single stars in only affected by two factors:

Proper Motion
Movement of stars relative to the Sun

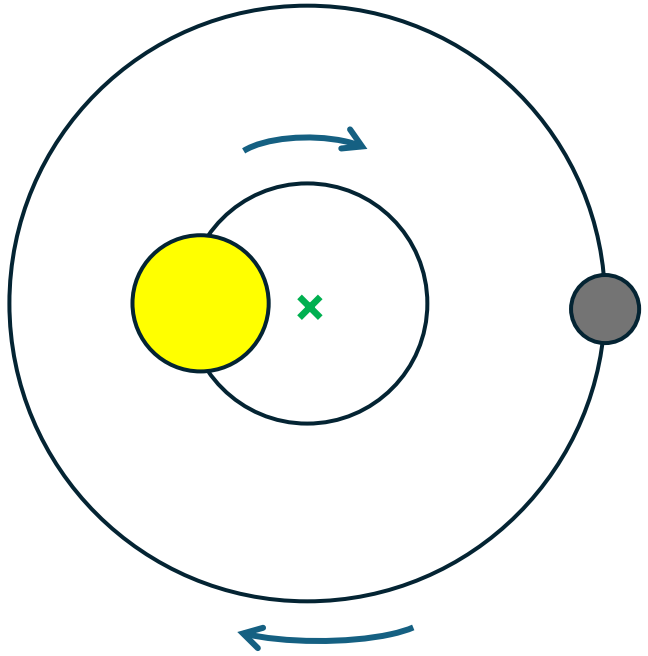
Parallax
Caused by Earth's orbit around the Sun

Observed motion

Astrometric signals

For stars with companions

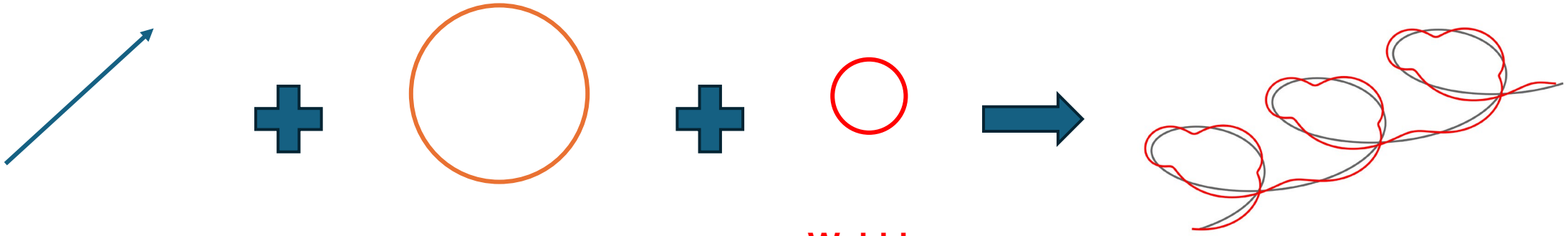
- A companion will cause the star to orbit around the system's barycentre
- The photocentre (the host star) will appear to "wobble" around the barycentre



Astrometric signals

For stars with companions

The presence of a companion will add an additional periodic motion:



Proper Motion
Movement of stars relative to the Sun

Parallax
Caused by Earth's orbit around the Sun

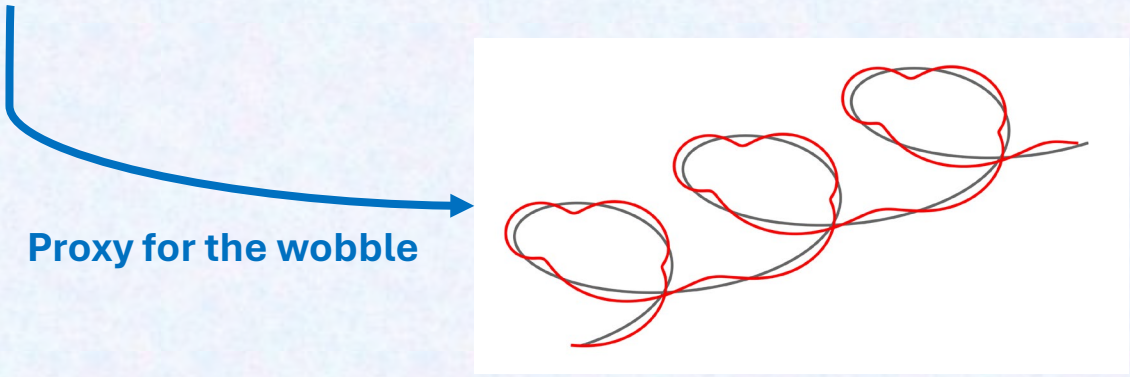
Wobble
Star's orbit around the barycentre

Observed motion

Astrometric signals

Measurement with *Gaia*

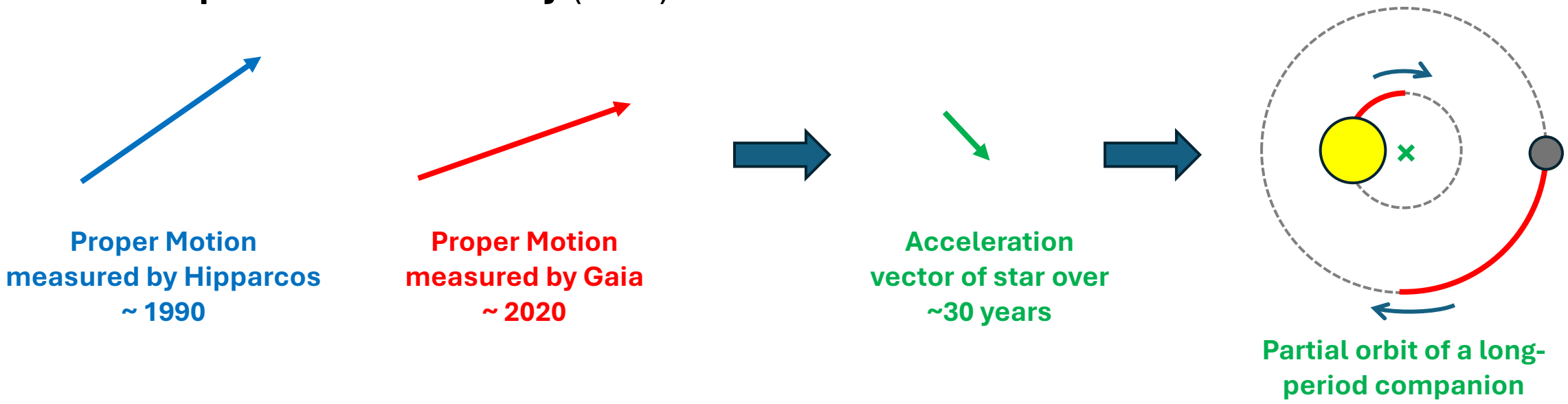
- *Gaia* is a space telescope measuring positions of billions of stars
- The key parameter: **renormalised unit weight error** (RUWE)
  - Normalised reduced χ^2 fit for a **single-star model**
  - Accounts for colour and magnitude → allows **comparison across stars**
- Targets with a high RUWE are good candidate host stars



Astrometric signals

Hipparcos-Gaia Proper Motion anomaly

- The *Hipparcos* space telescope was a similar mission from the 1990s
- Compare the **proper motion vectors** between Hipparcos and Gaia
  - The difference shows the **acceleration of the star** over 30 years → useful for detecting **long-period** companions
  - **Proper Motion anomaly** (PMa)



Methodology

Image Credit: *ESA*

Selecting a sample of stars

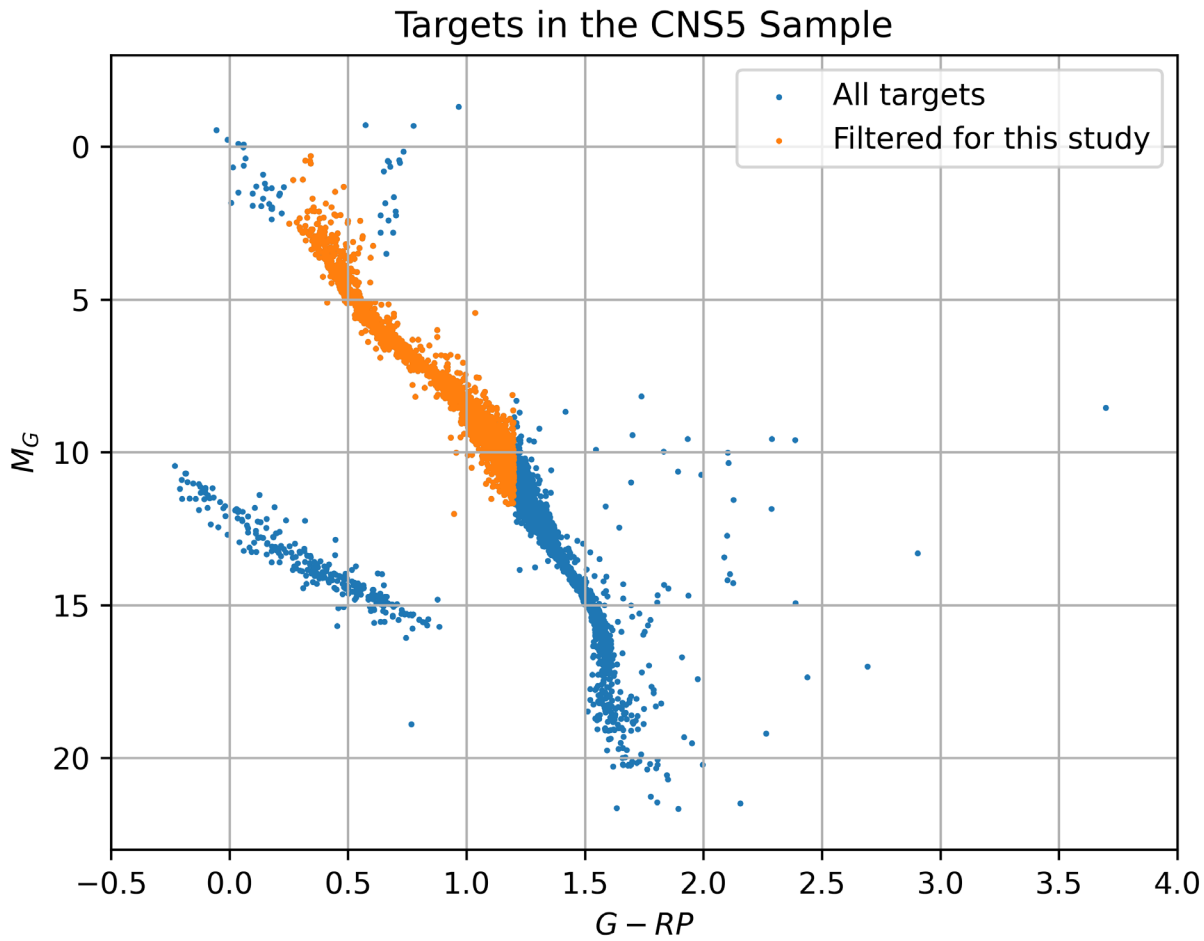
Nearby solar-type stars

Golovin et al. 2023

- The Fifth Catalogue of Nearby Stars (CNS5) is used to select **solar-type stars** within 25 pc
- Filter based on spectral type to select **F, G, K stars**
- Filtering condition used:

  0.25 < G – RP Colour < 1.2

  ➢Sample of ~1300 stars



Analysis with GaiaPMEX

Kiefer et al. 2025

Identifying stars with companions

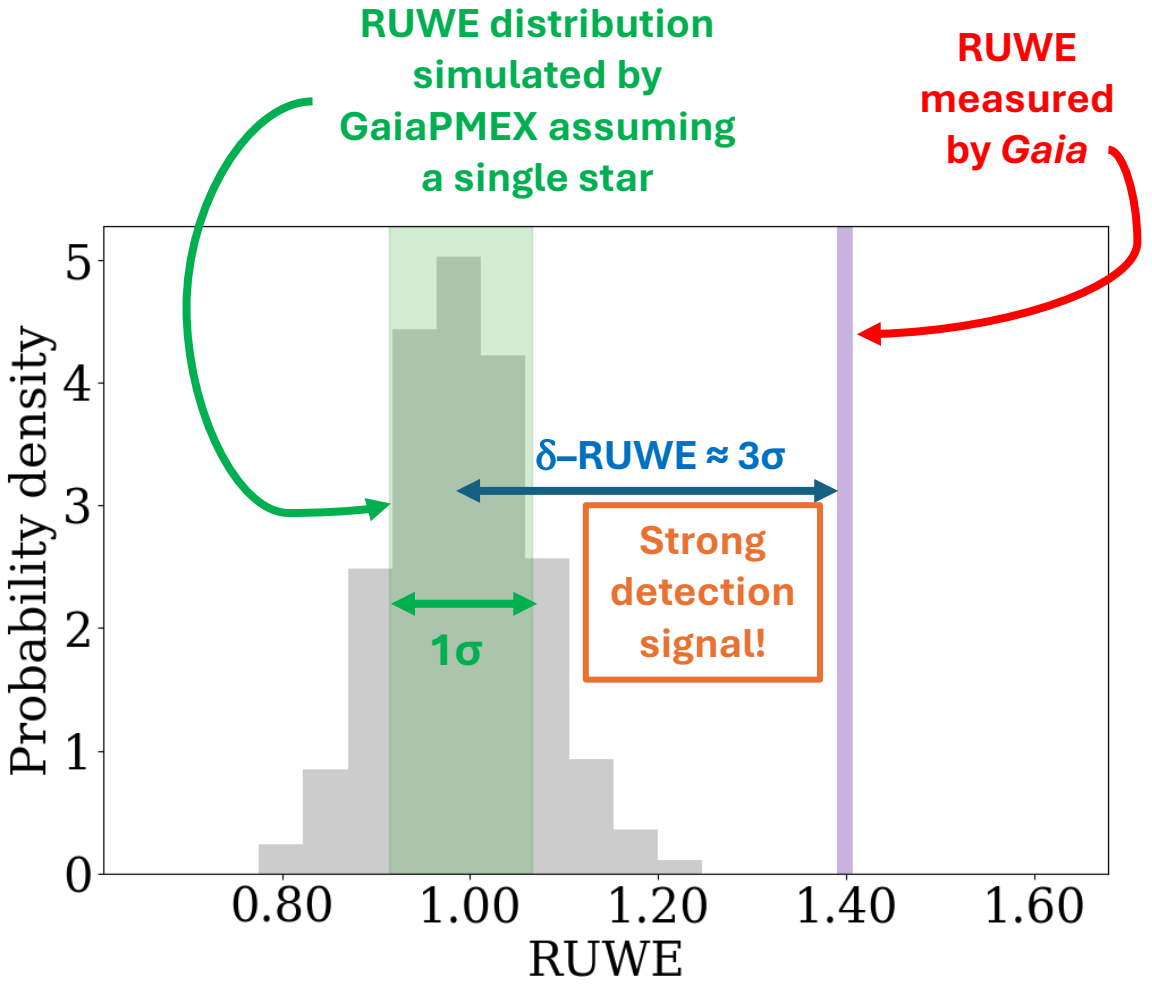
- Search for bound companions using the **GaiaPMEX** tool

➢ Makes use of the **RUWE** from *Gaia* and the *Hipparcos–Gaia* **PMa**

- Filtering condition used:

  δ–RUWE > 2.0 *OR* δ–PMa > 2.0

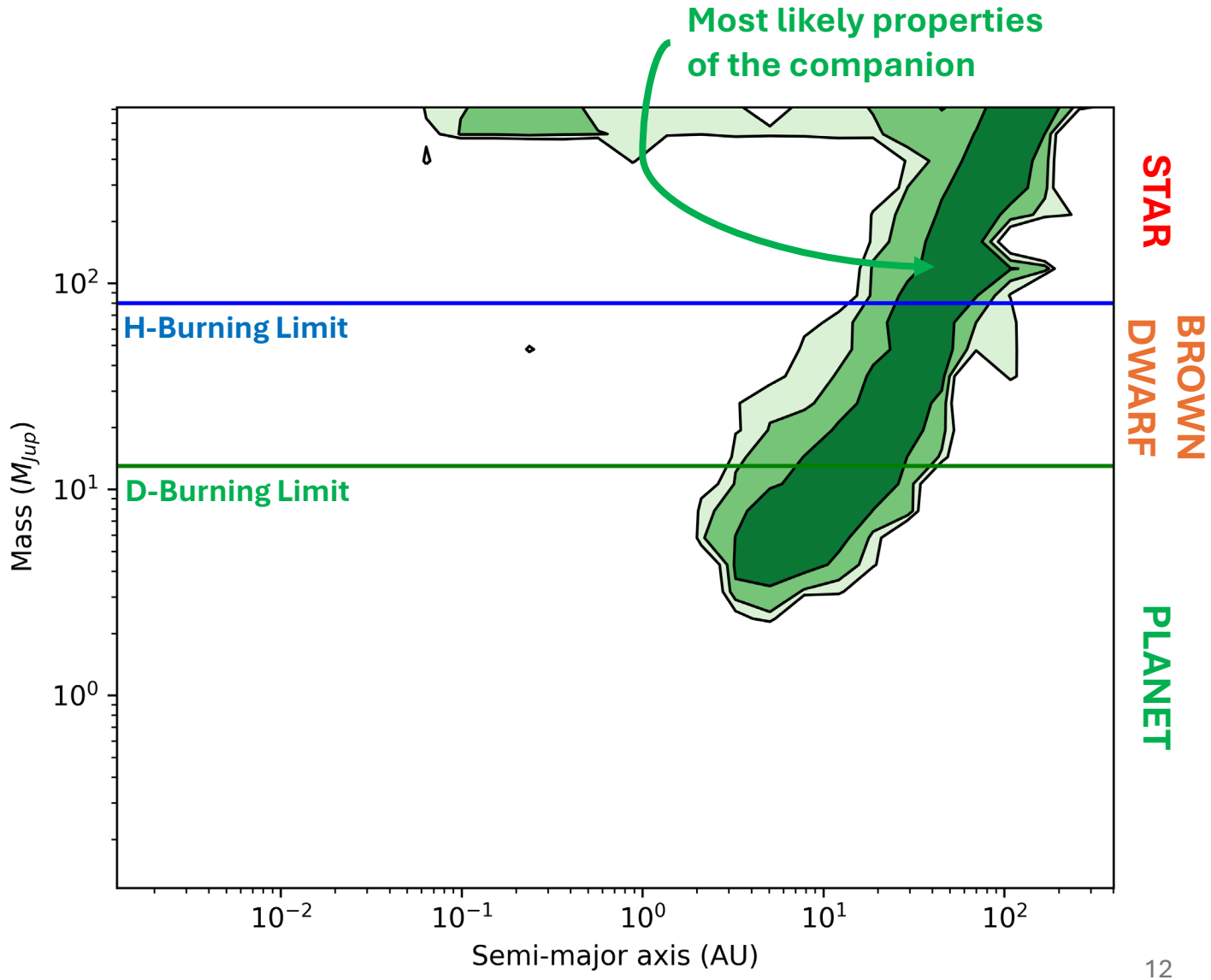
245 stars in our final sample
⟹ **Solar-type stars within 25 pc that have companions**



Analysis with GaiaPMEX

Detection maps

Obtain the possible **mass and semi-major axis** of a companion that **agrees with the observed astrometric signals**



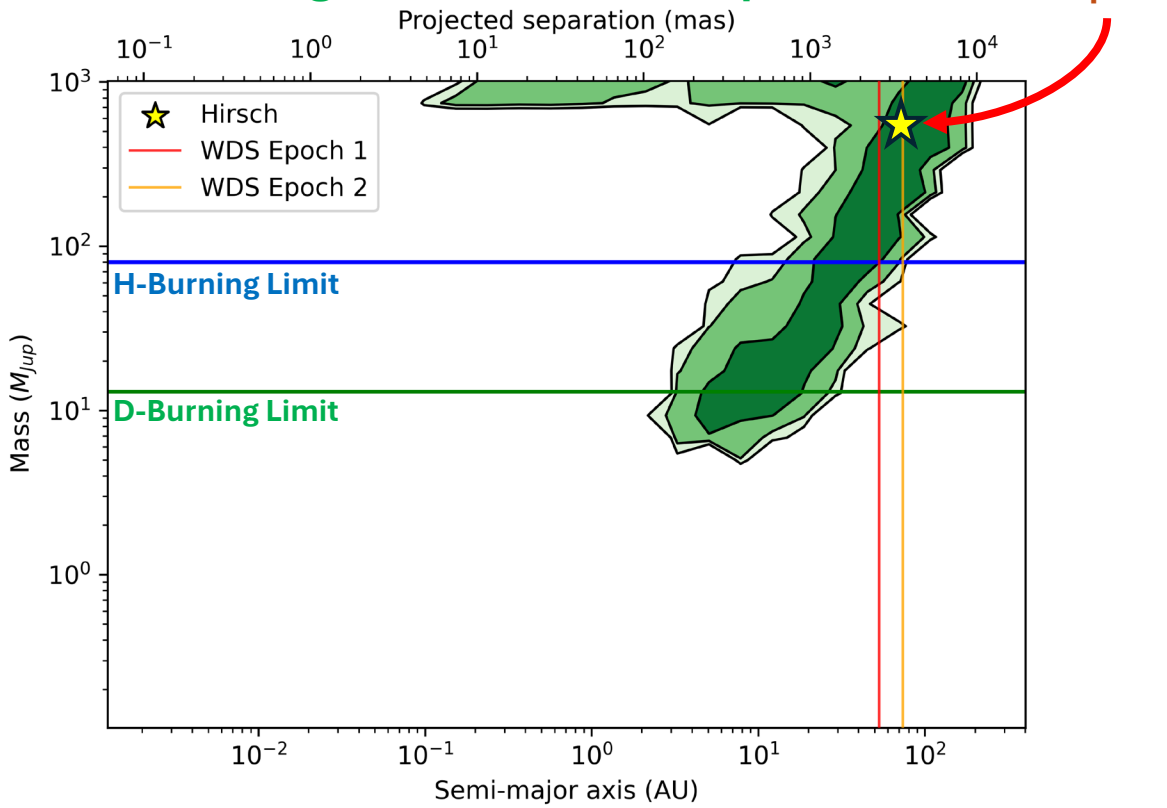
Cross-match with catalogues of known companions

Compare with catalogues of stellar and planetary companions to **exclude known companions** (136 targets removed)

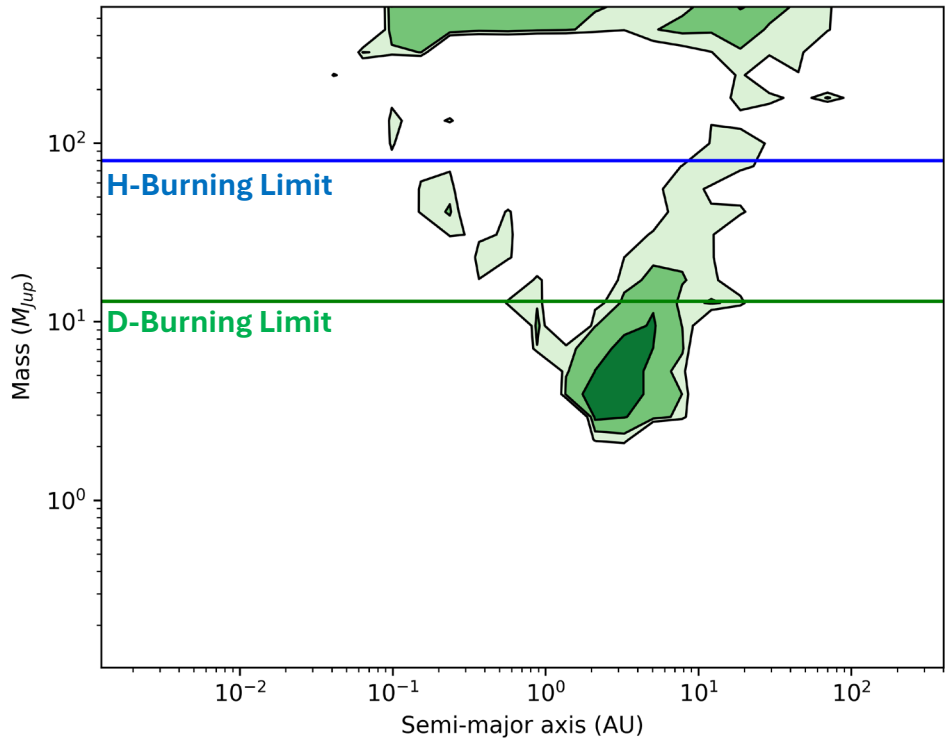
Schneider et al. 2025
Hirsch et al. 2021
Mason et al. 2001
Tokovinin et al. 2020

Target with known companion

Stellar Companion



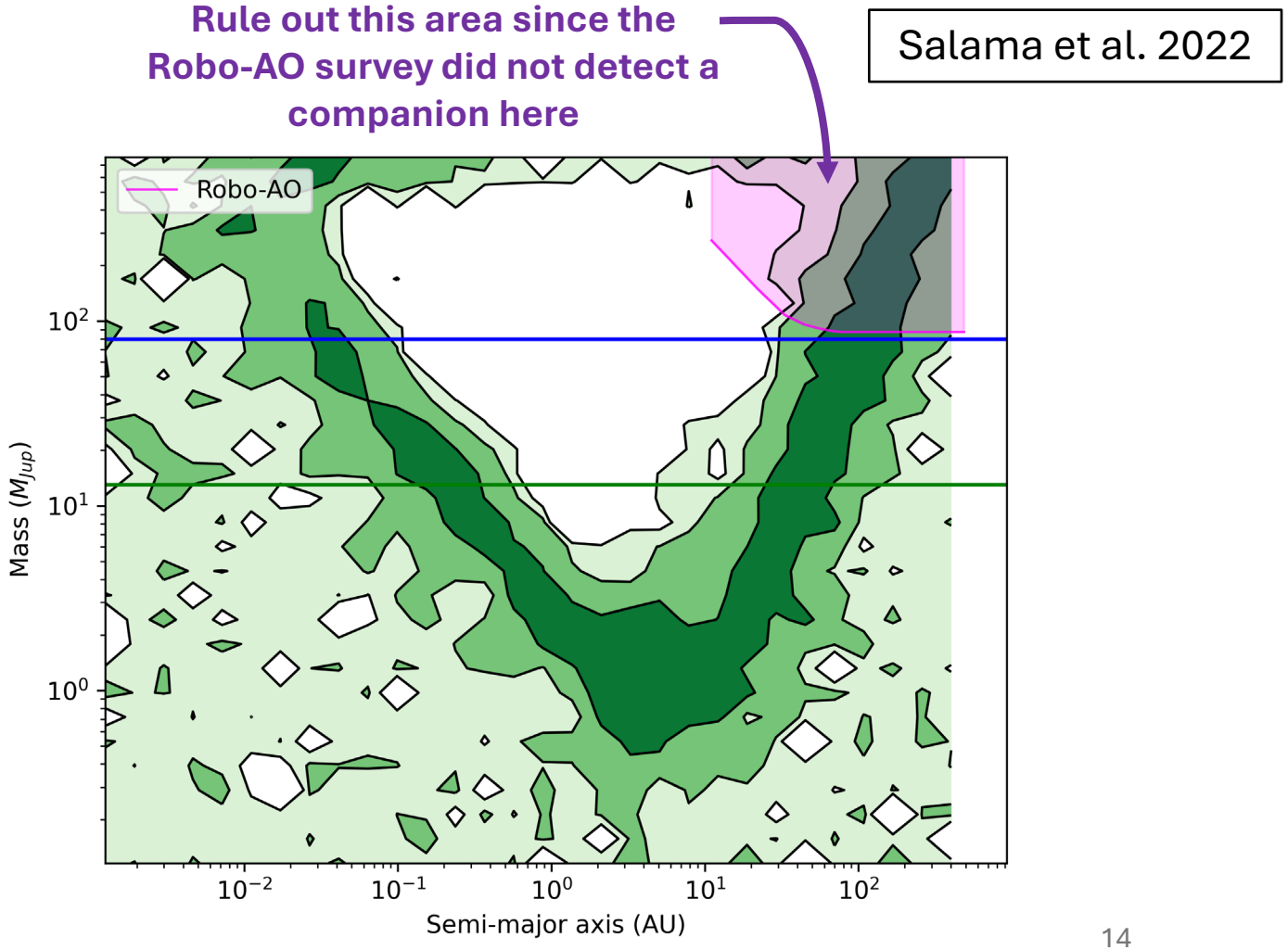
Target with new planetary candidate!



Detection limits using direct imaging

Current work

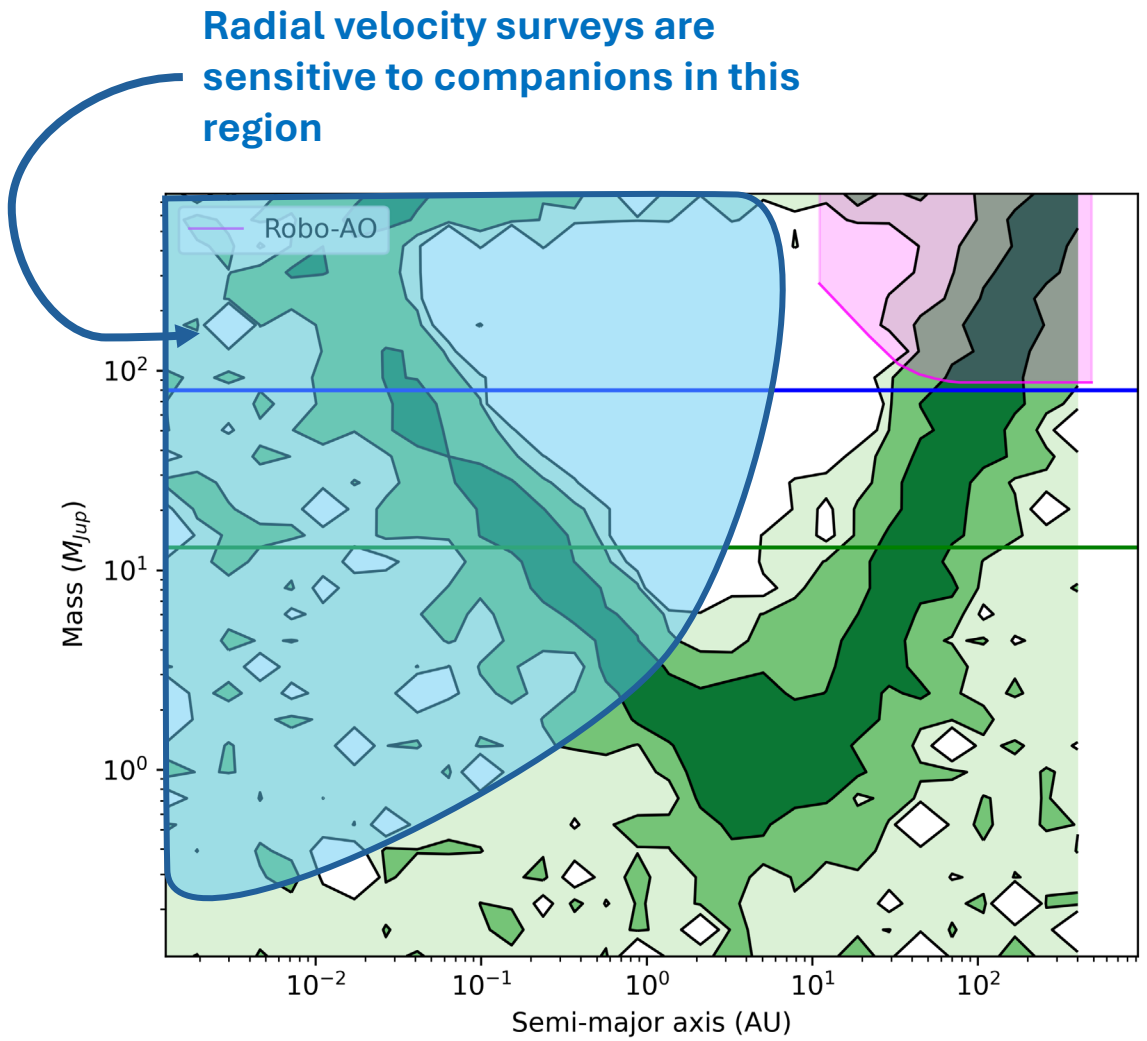
- We use direct imaging surveys to **set constraints** on the parameter space
- **Non-detections** in imaging can be used to **exclude** parts of the possible parameter space
- The sensitivity of the instrument can be converted to **upper detection limits in masses**



Future Work

Radial Velocity surveys

- Use radial velocity data of the stars to rule out **high-mass** and **low-period** companions
- Set **tighter constraints on the properties** of the new companions



Future Work

Follow-up observations

- Perform observations for targets that don’t yet have direct imaging or radial velocity data
- Confirmed detections will be prime targets for follow-up observations with the upcoming Extremely Large Telescope (ELT) and Habitable Worlds Observatory (HWO)

Image Credit: *ESO*

Conclusions

- Aim to detect planets around **nearby solar-type stars**
- The **astrometric signals** of stars can be used to detect the presence of a companion
- **GaiaPMEX** uses the **RUWE** and **PMa** to calculate the possible mass and semi-major axis of the companion
- **Constrain the properties** using direct imaging and radial velocity surveys
- **Follow-up imaging** in the future to study new candidates

Thank you!

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Image Credit: *NASA*

Supplementary Slides

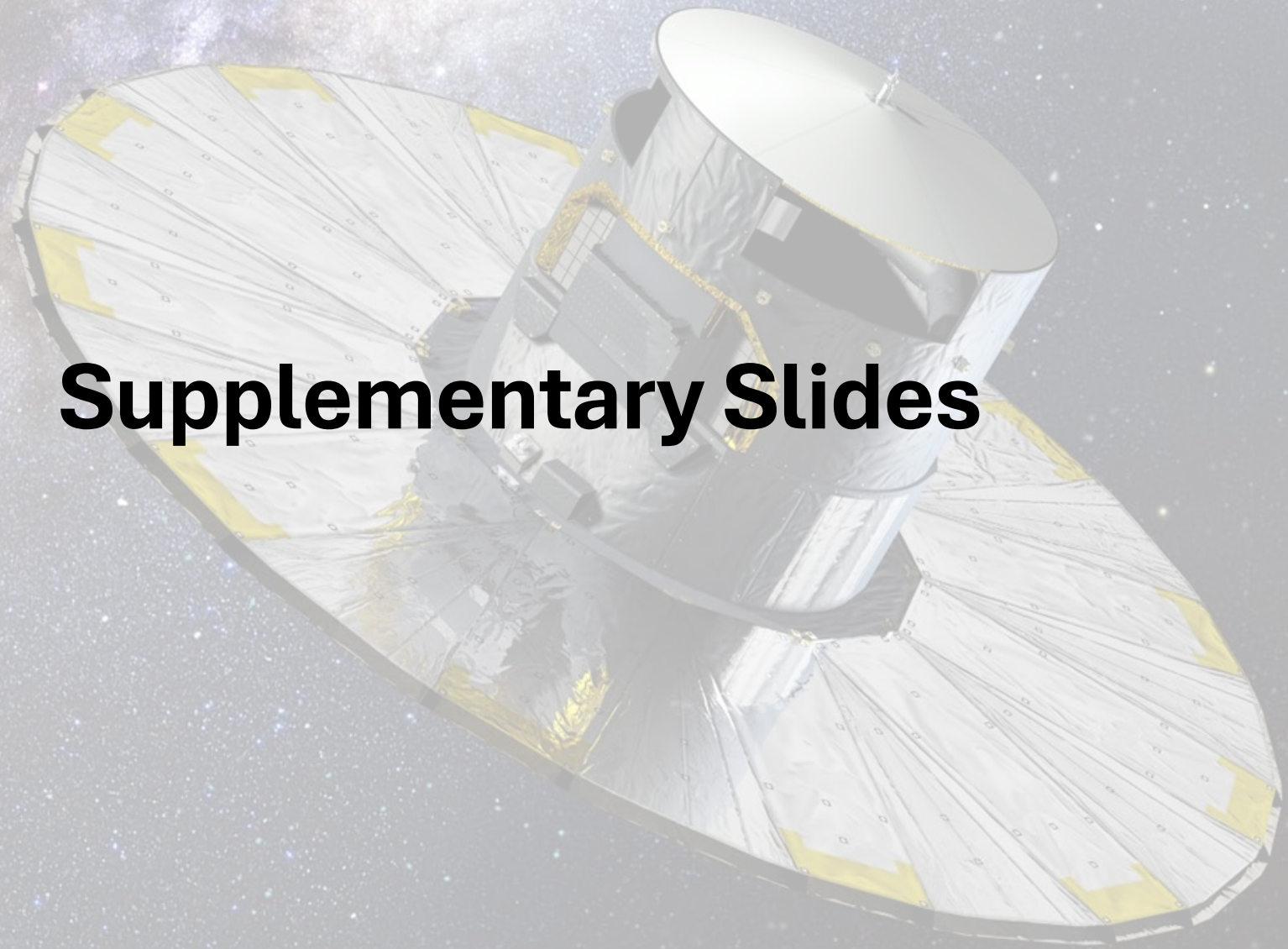
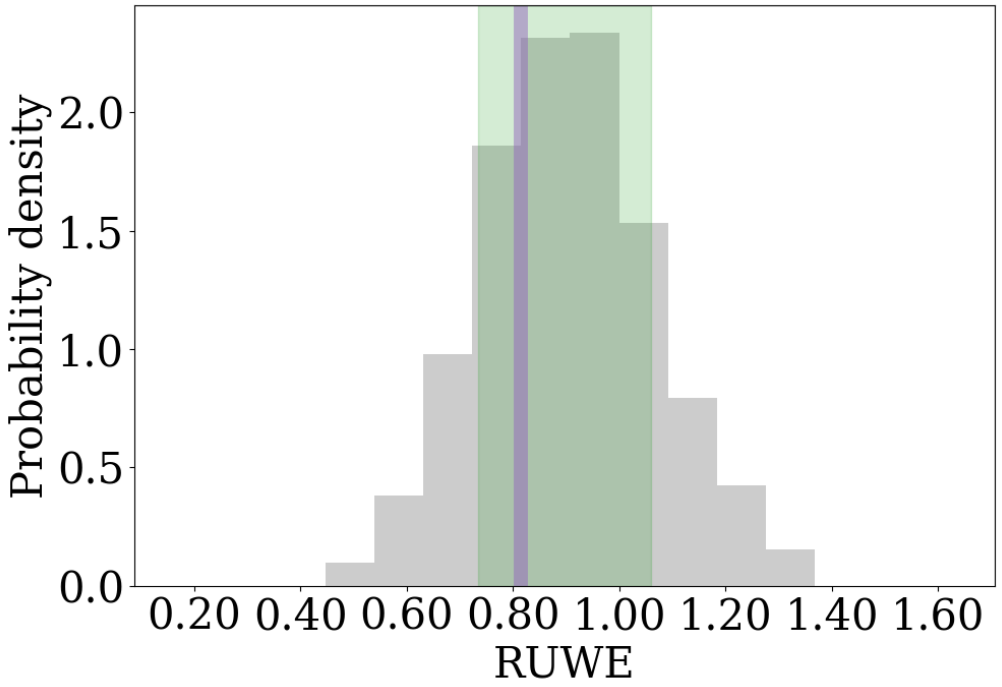
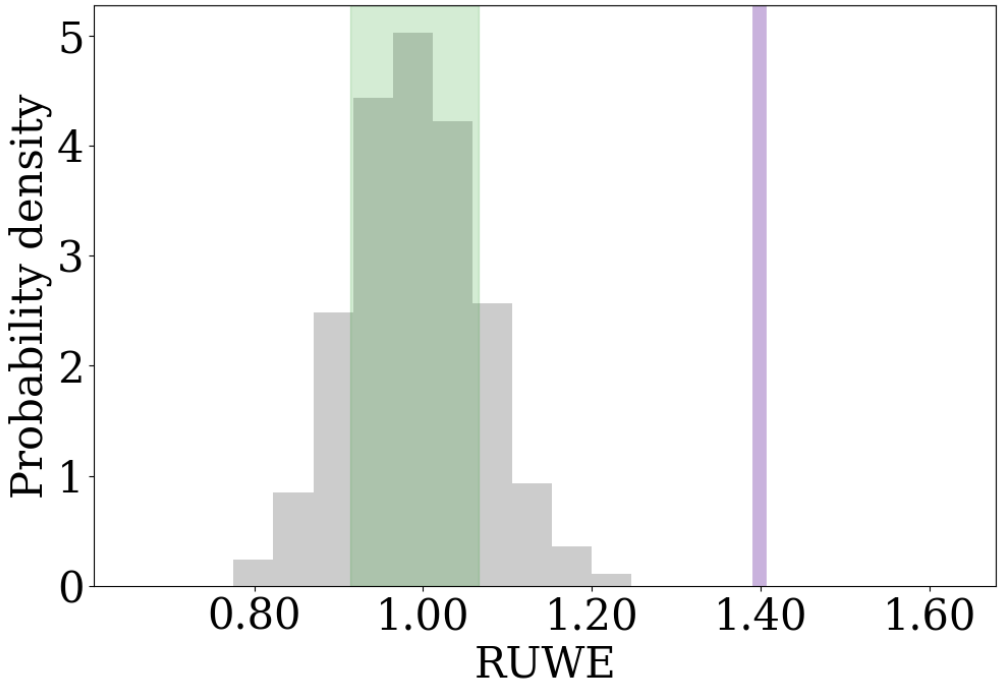


Image Credit: *ESA*

δ–RUWE Plots

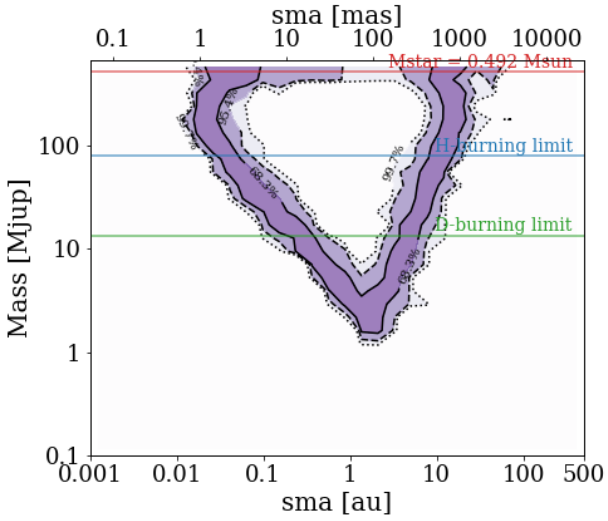


δ–RUWE < 1σ

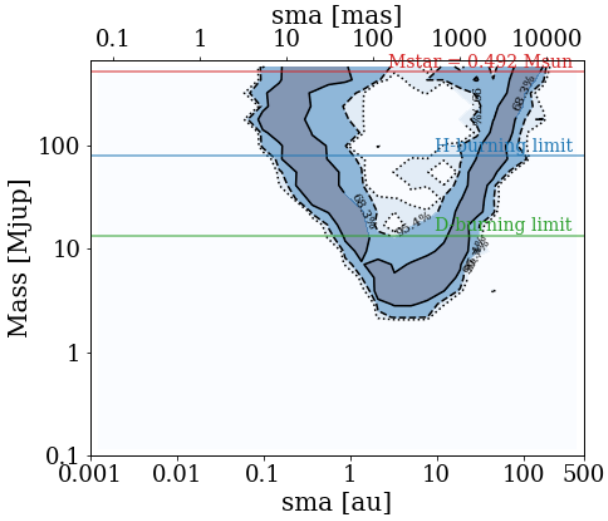


δ–RUWE ≈ 3σ

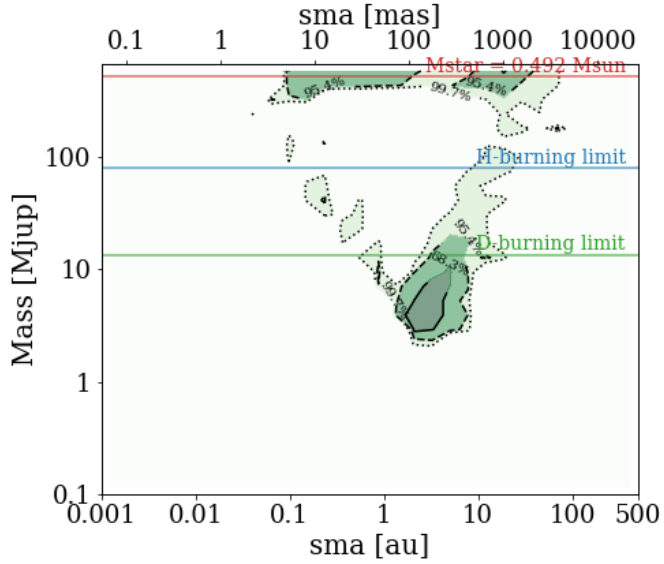
Combining detection maps for RUWE and PMa



RUWE



PMa



Combined