

# Multi-scale Extrasolar Systems: from within Mercury's orbit to beyond Neptune

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## Abstract

We are targeting the detection and the characterisation of exoplanets and brown dwarfs, as well as very low mass stellar (VLMS;  $<150 M_J$ ) companions, around Milky Way Sun-like stars close to the Sun. With the collection of radial velocity datapoints from ground-based spectrograph, such as OHP/SOPHIE, and the publication of the Gaia DR3 astrometric data, and photometry, we are able to detect companions on orbits with periods from very short, day-long, up to, Neptune-like, hundreds-of-years-long. This enabled us to further fully characterize 2-companion systems containing planets.

## Sample Selection and Observations

- Two programs on SOPHIE to reveal Giant Planets and Brown Dwarfs, in service for more than 9 yrs
- Targeting an ensemble of  $> 3000$  systems around FGK main-sequence stars at  $<60$  pc, observed in the North ( $\delta > 0$ ) with OHP/SOPHIE and ELODIE along a baseline  $> 30$  years

## Methods

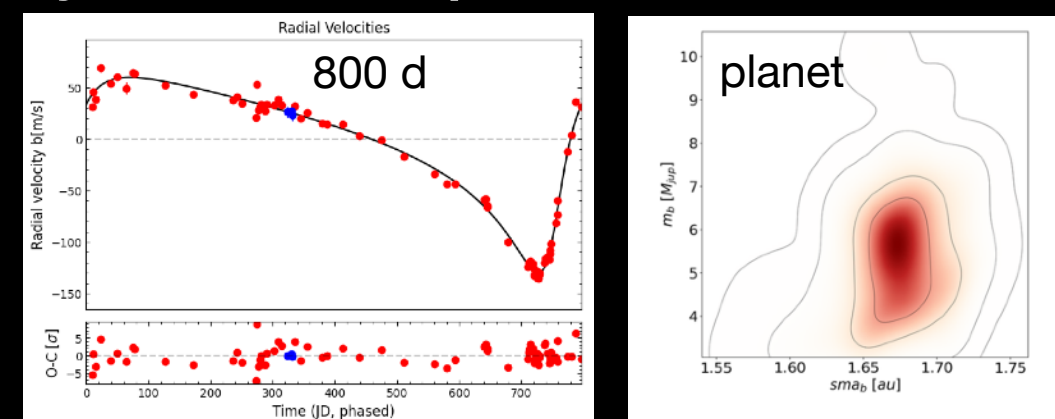
- RV analysis, including activity signal search and correlations study, with e.g. Log R'HK, H-alpha, CCF bisector span, and FWHM
- Coupling with Gaia-Hipparcos using **GaiaPMEX** and **emcee-fit** MCMC (Papers I-V: Kiefer et al. 2025 a-b; Lagrange et al. 2025; Lagrange et al. 2026; Destriez et al. 2026, sub.) incl. astrometry and G-band photometry by modeling the photocenter motion and flux
- 1-companion and 2-companion systems characterisation by solving all parameters for multiple companions

## Results [Kiefer et al., in prep.]

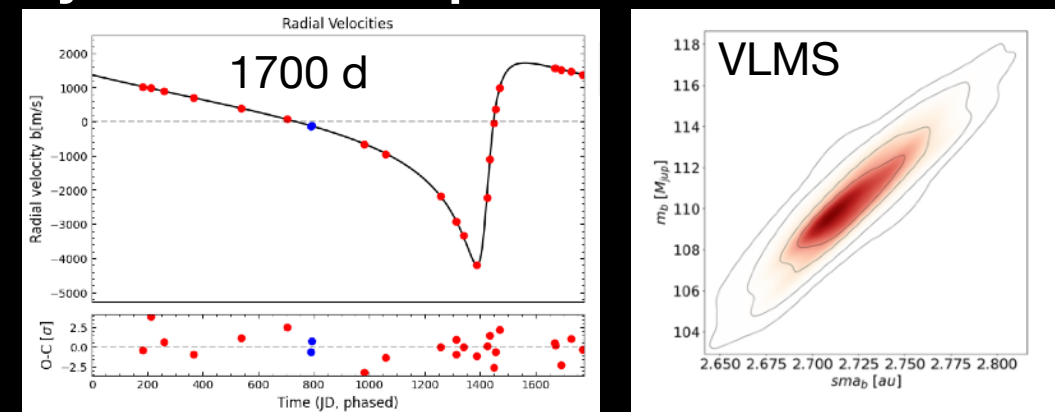
- Orbital motions of 67 systems seen with RV and astrometry
- Periods: 17 days to 30 years.
- $M \sin(i)$ : 3 to  $500 M_J$
- True masses measured + full 3D orbital motion resolved
- 4 planets, 1 BD, 8 VLMS and  $>34$  binaries
- Three **2-companion systems in both RV+astrometry**

## Inner to Jupiter orbit detection RV + astrometry

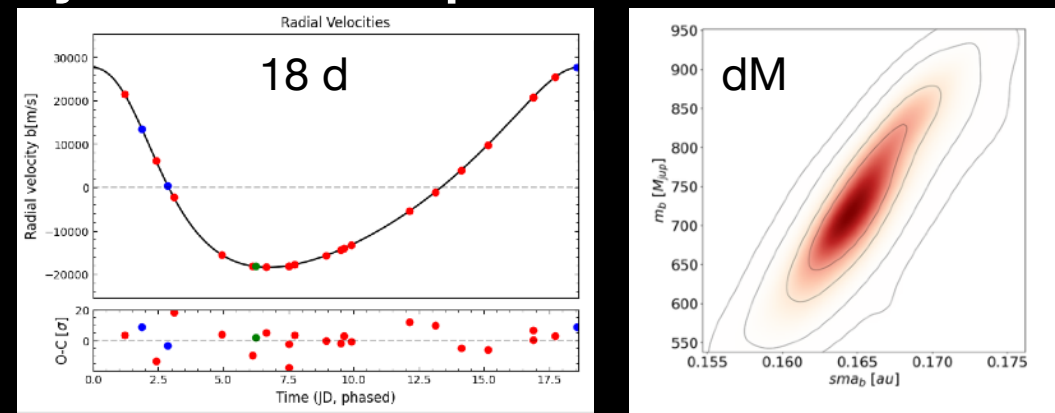
### System #1 - component b



### System #2 - component B



### System #3 - component B

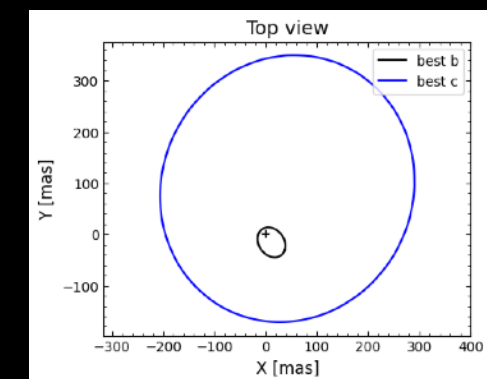
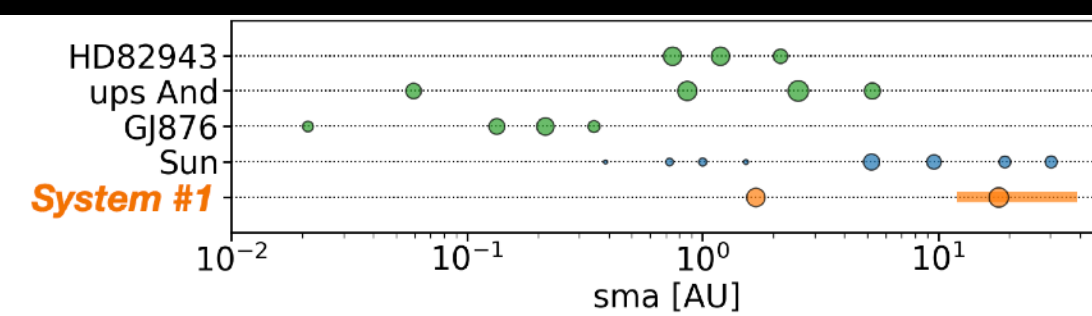


## A Solar System Analog among three 2-companion systems

Detections and characterisation of two orbital signals in both astrometry and RV at various scales from within Mercury –tens of day– to beyond Neptune –hundred's of years. The astrometry and the RV detect the signal of both components, the inner one (look left) and the outer one (look right) in these systems.

### System #1: a Solar System analog?

- An architecture resembling that of the Solar System
- Other RV+astrometry multiple systems are more compact (below)

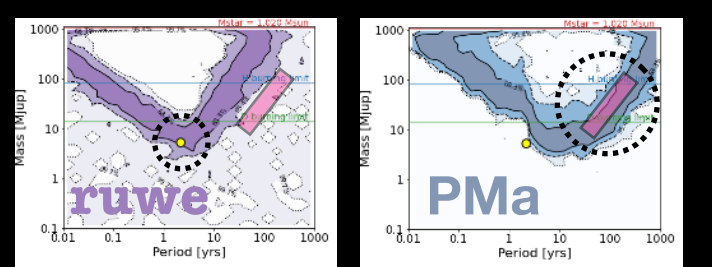


- ➔ planet b ~ orbit of Mars
- ➔ planet c ~ orbit of Saturn → Neptune

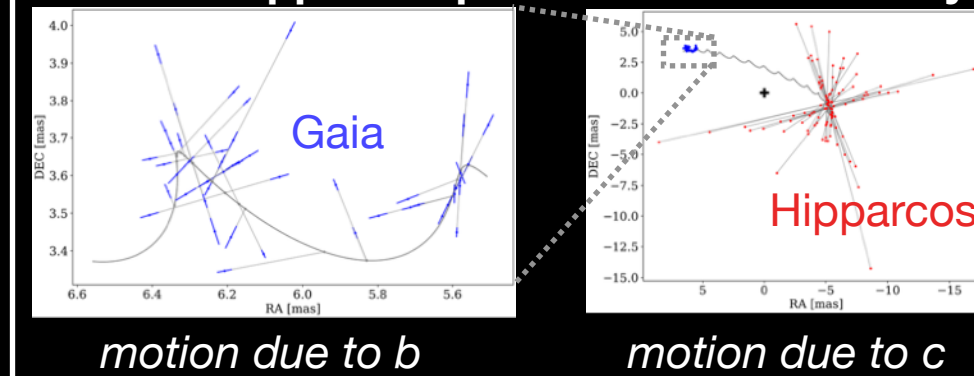
## A Gaia–Hipparcos joint detection of component c

GaiaDR4 will definitely detect *planet b*, but combining to Hipparcos will be needed to fully assess *candidate planet c*, one of the longest orbit ever characterised through RV + astrometry

The signal of **b** is detected by Gaia only (RUWE) while component **c** is revealed through Gaia-Hipparcos coupling (PMA)



### Reconstructed Gaia-Hipparcos photocenter astrometry



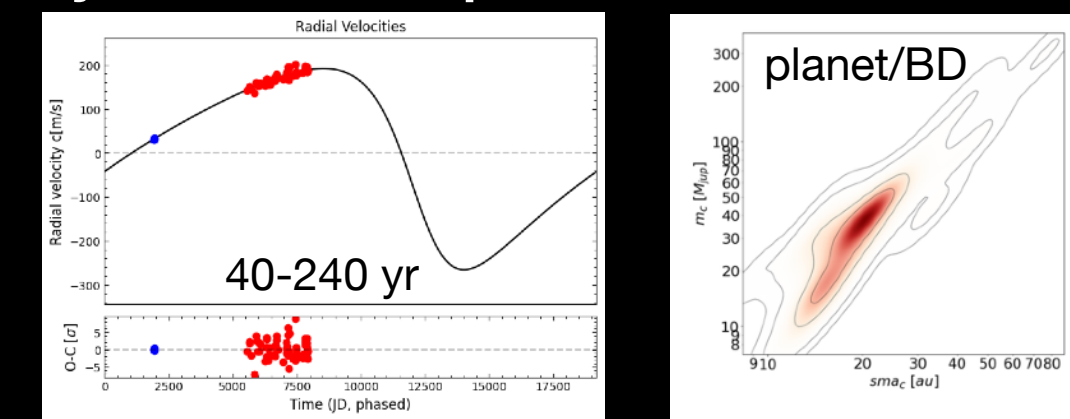
**CONCLUSION**

A new capability of combined RV & Gaia-Hipparcos astrometry, for revealing and characterising exoplanets on **Solar System scales**

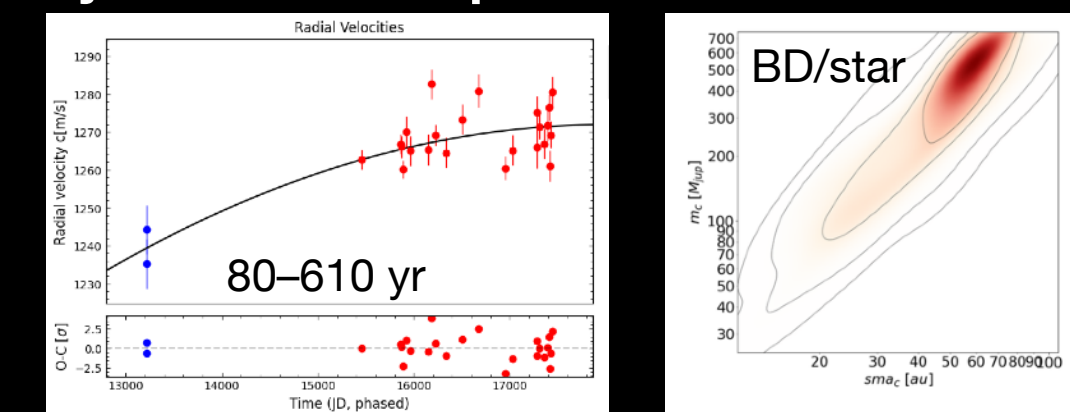
Kiefer+ 2025 A&A 702 A76 / A77  
 Lagrange et al. 2025, 2026, A&A  
 Destriez et al. 2026, A&A, sub.  
 Kiefer et al., in prep.

## Outer to Saturn orbit detection RV + astrometry

### System #1 - component c



### System #2 - component C



### System #3 - component C

