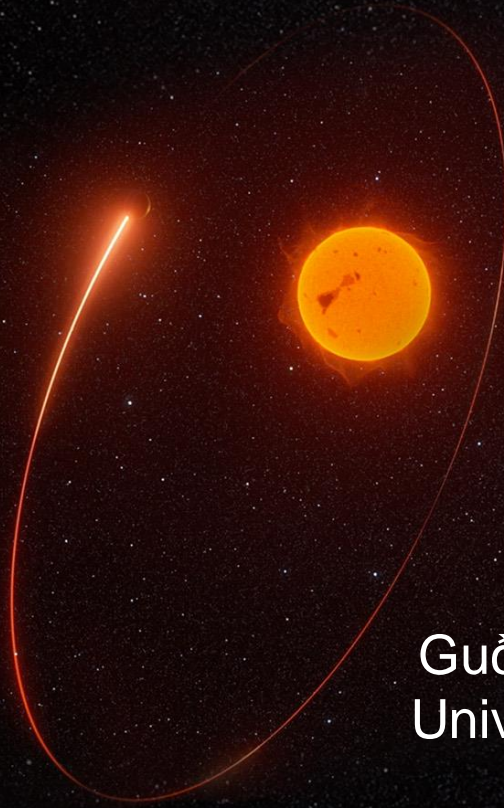
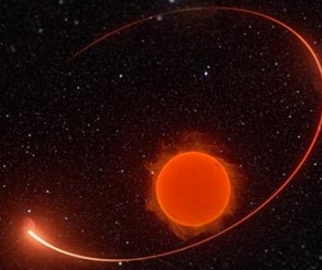


Spectroscopic Confirmation of Gaia Astrometric Exoplanet Candidates

Gaia-4b



Gaia-5b



Guðmundur Stefánsson
University of Amsterdam

Feb 4, 2025

Know Thy Star Know Thy Planet 2



G. Stefansson, S. Mahadevan, J. Winn, M. Marcussen, S. Kanodia, S. Albrecht, E. Fitzmaurice, O. Mikulskitye, C. Cañas, J. Espinoza-Retamal, Y. Zwart, D. Krolikowski, A. Hotnisky, P. Robertson, J. A. Alvarado-Montes, C. Bender, C. Blake, J. Callingham, W. Cochran, M. Delamer, S. Diddams, J. Dong, R. Fernandes, M. Giovanazzi, S. Halverson, J. Libby-Roberts, S. E. Logsdon, M. McElwain, J. Ninan, J. Rajagopal, V. Reji, A. Roy, C.



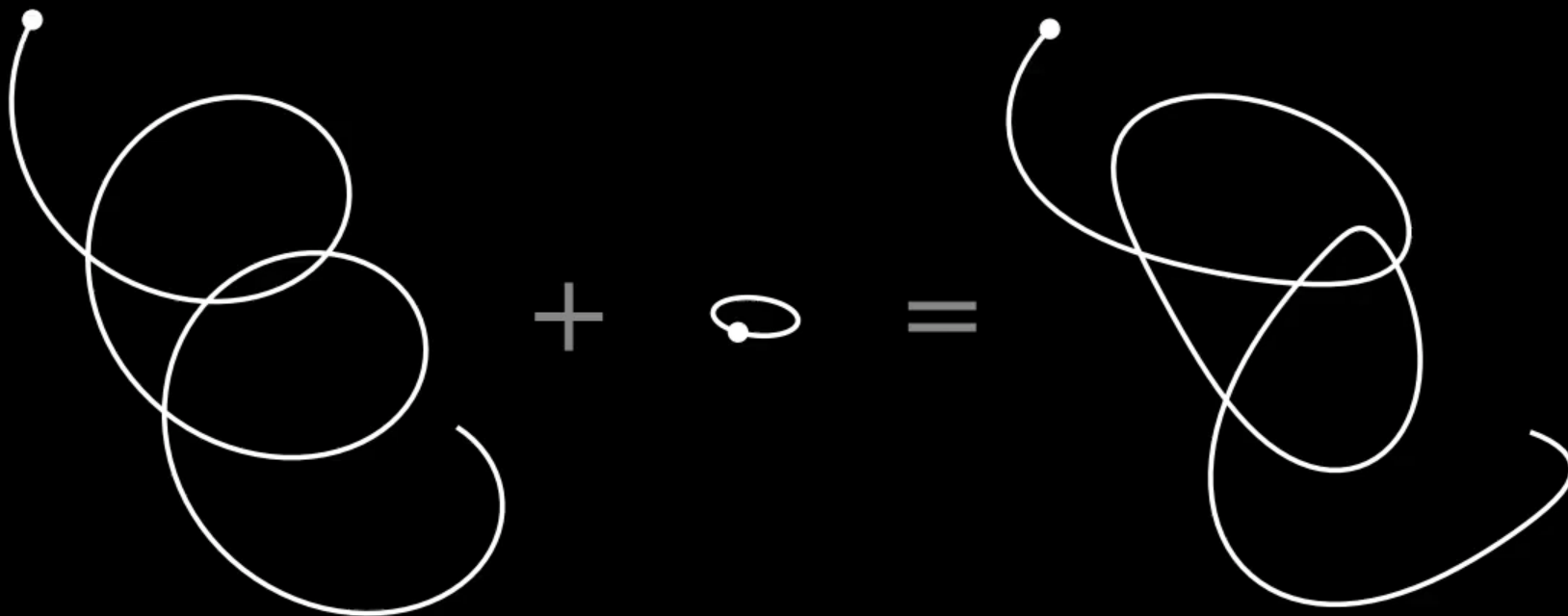


Gaia is expected to detect hundreds-thousands of planets with the astrometric technique





The **astrometric technique** relies on measuring the gravitational wobble of a star due to an orbiting companion

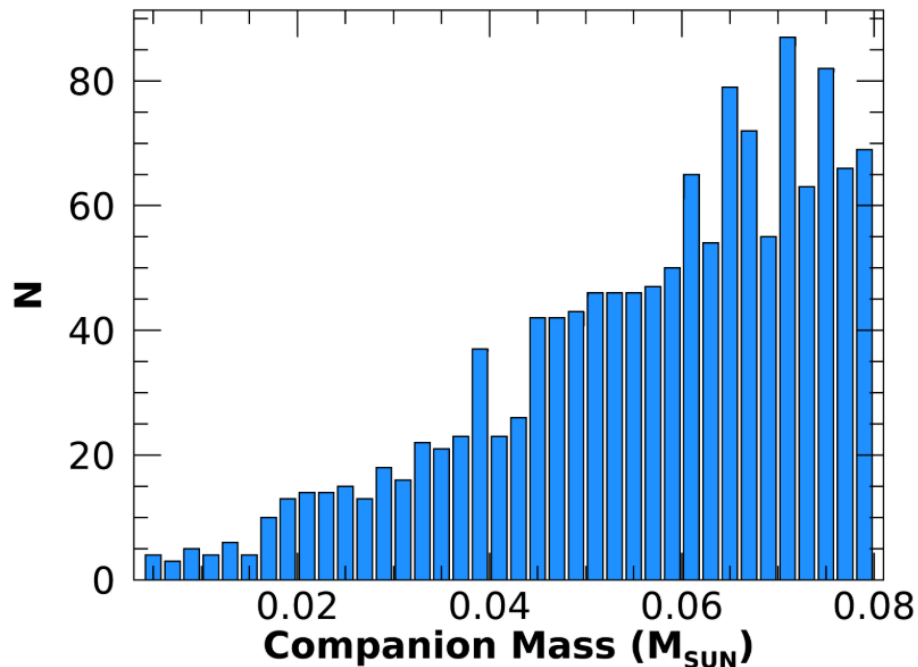


Can constrain **virtually all orbital parameters** of a planet

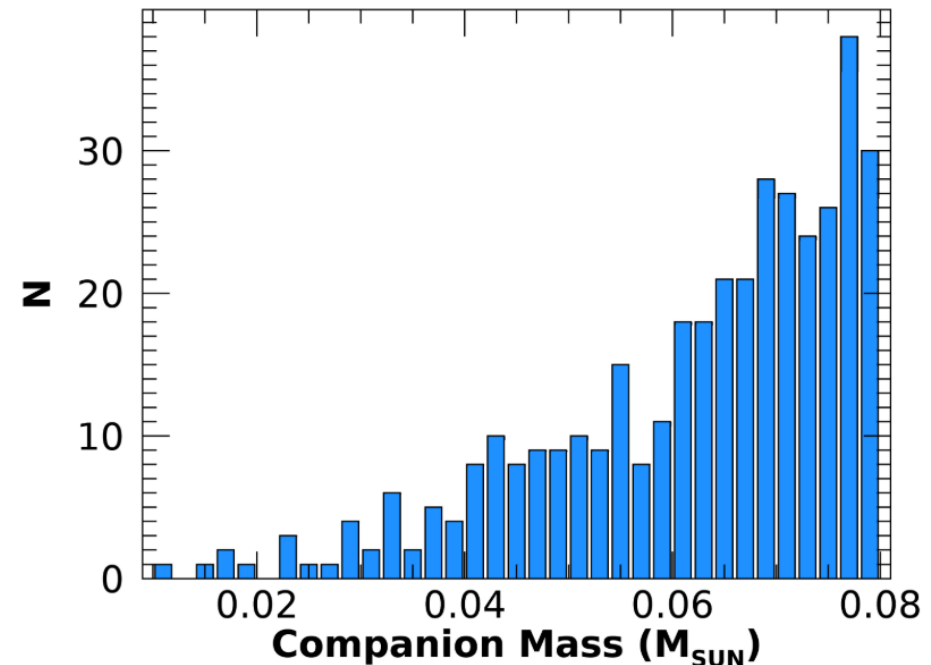
Gaia is expected to detect **thousands of planets** at intermediate orbital periods

As part of Gaia DR3, Gaia released astrometric orbital solutions for the first time—some of which are substellar

Orbital sample: $M_* < 0.6 M_{\text{SUN}}$



Orbital sample: $M_* > 0.6 M_{\text{SUN}}$

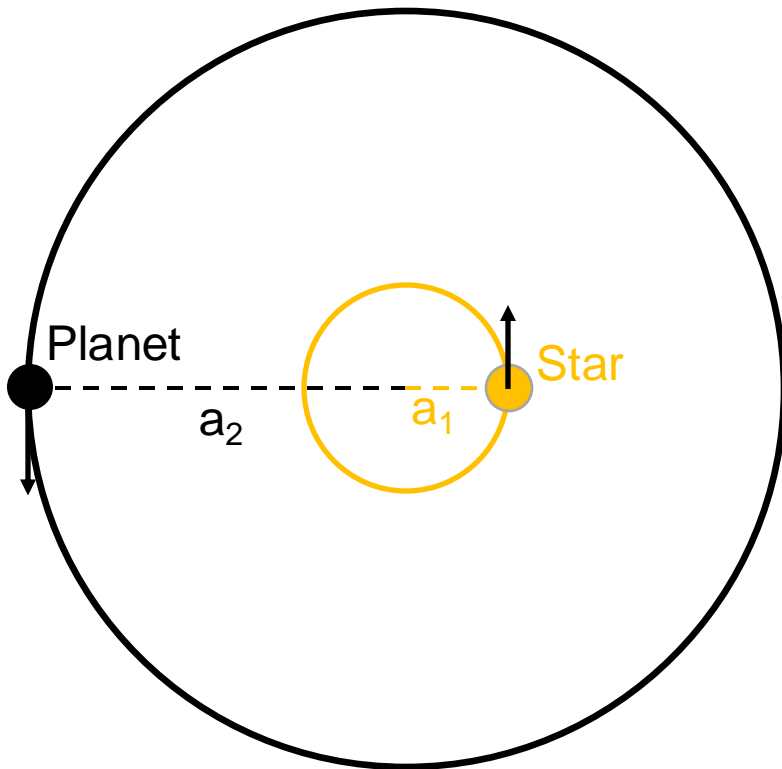


Arenau et al. 2022

72 Gaia **A**strometric **O**bjects of **I**nterest (Gaia-**ASOI**) Exoplanet Candidates

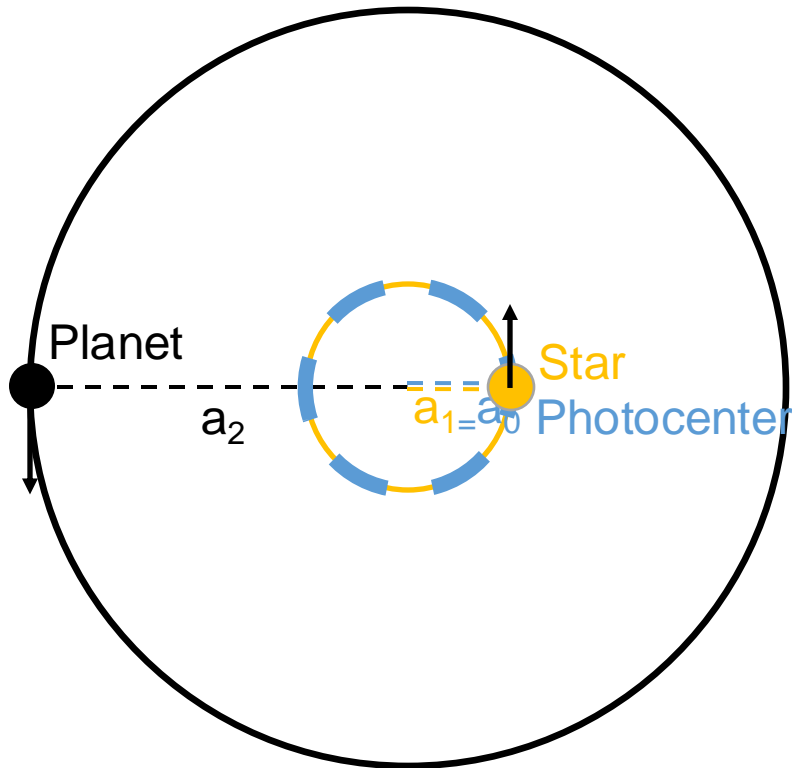
False positives: Close-to-equal mass stars can generate small photocenter motions

Dark Planet Companion



False positives: Close-to-equal mass stars can generate small photocenter motions

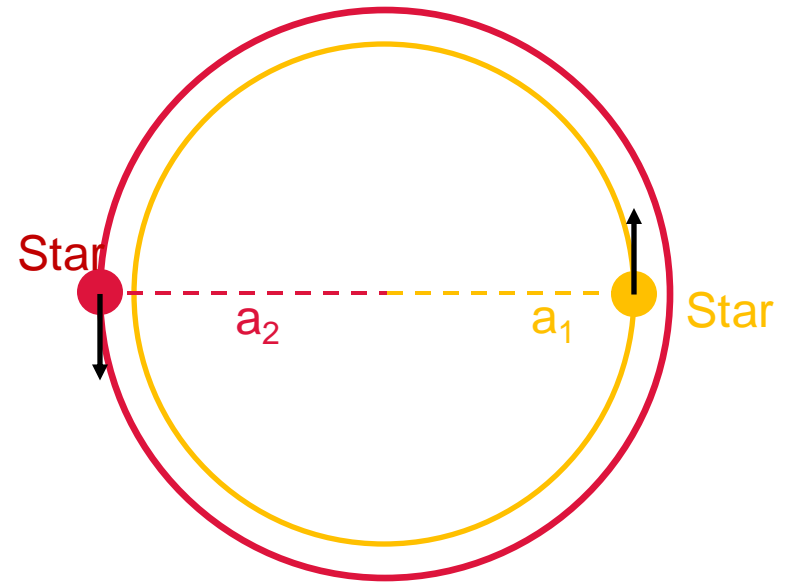
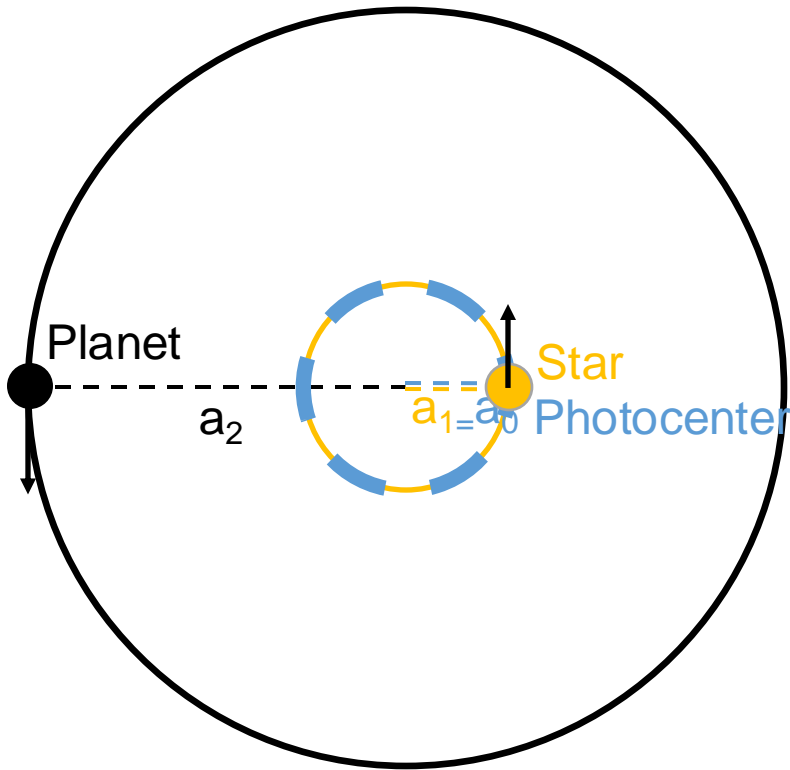
Dark Planet Companion



False positives: Close-to-equal mass stars can generate small photocenter motions

Dark Planet Companion

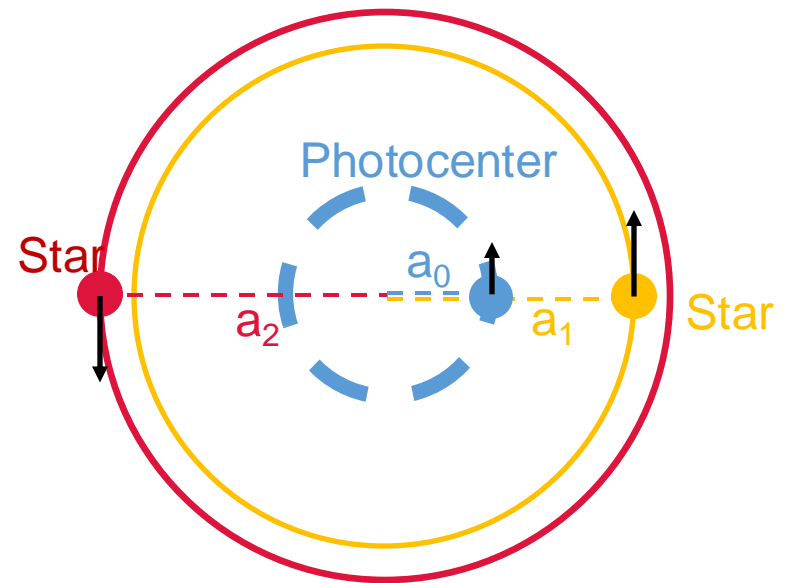
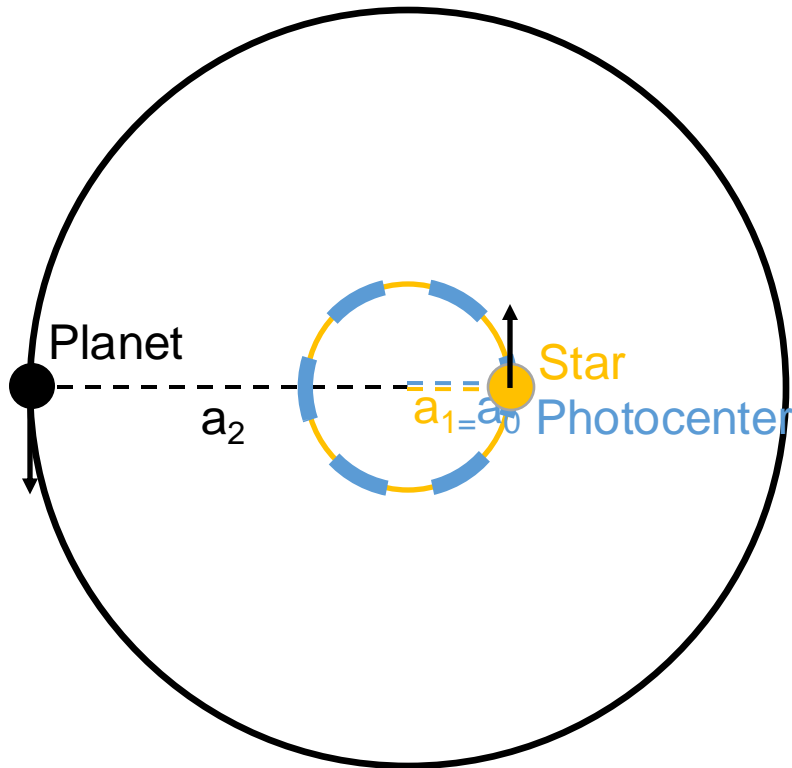
Close-to Equal-mass binaries
mass ratio \sim flux ratio



False positives: Close-to-equal mass stars can generate small photocenter motions

Dark Planet Companion

Close-to Equal-mass binaries
mass ratio \sim flux ratio

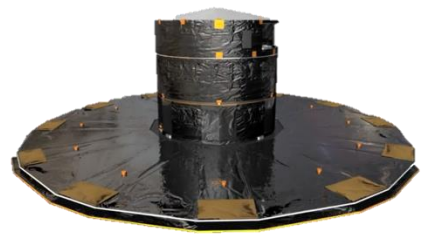


Marcussen & Albrecht 2023

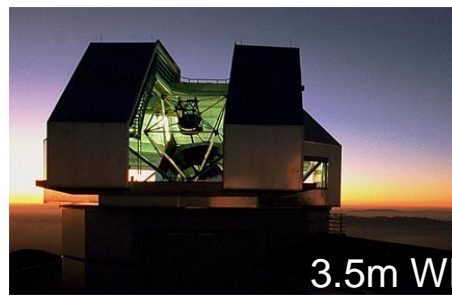
Essential to **Know Thy Host Star** to rule out false-positive scenarios

We are following up Gaia ASOIs with RV facilities to confirm and characterize them

Gaia



HPF



FIES

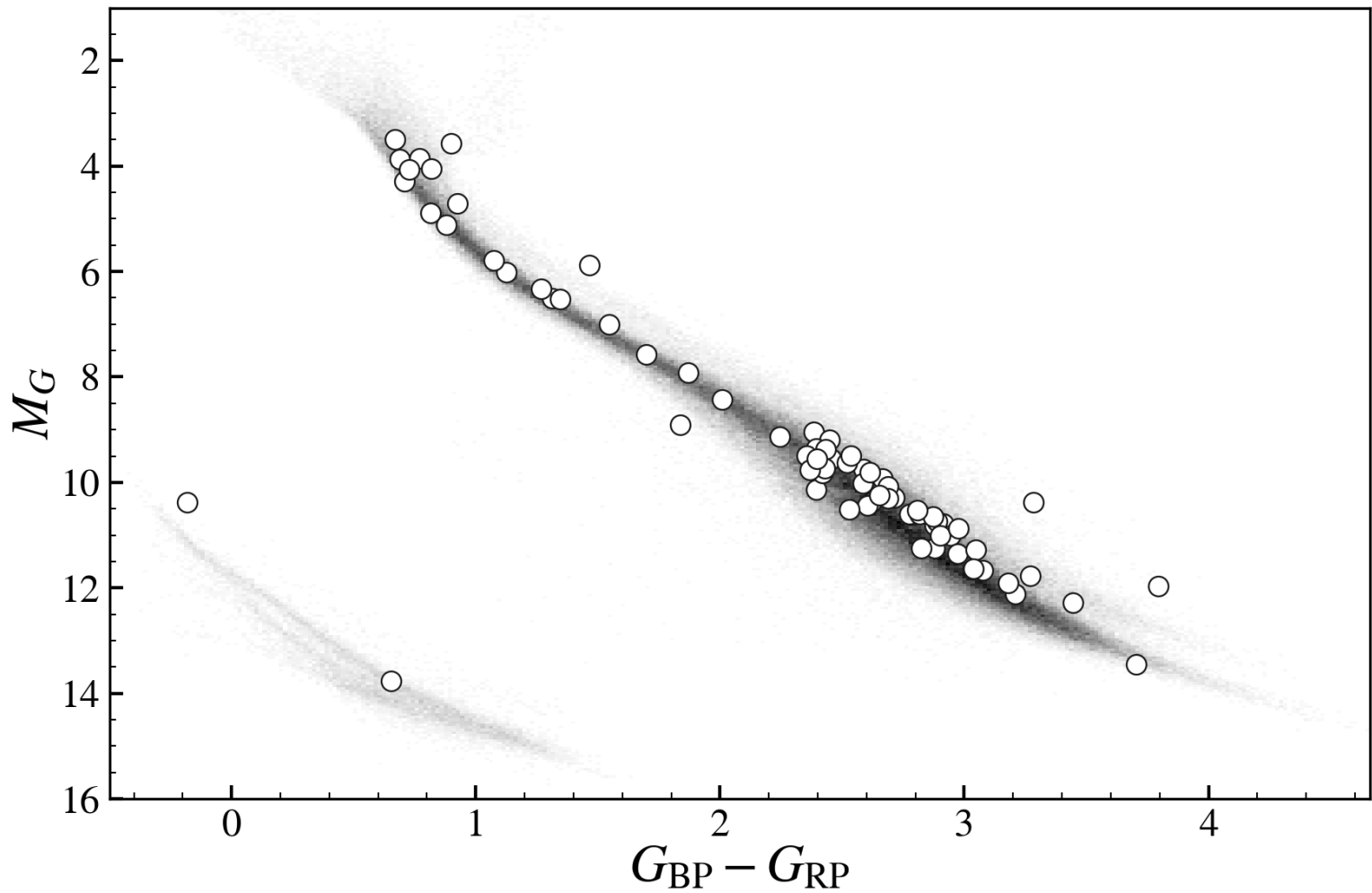


HARPS/N
IRDS

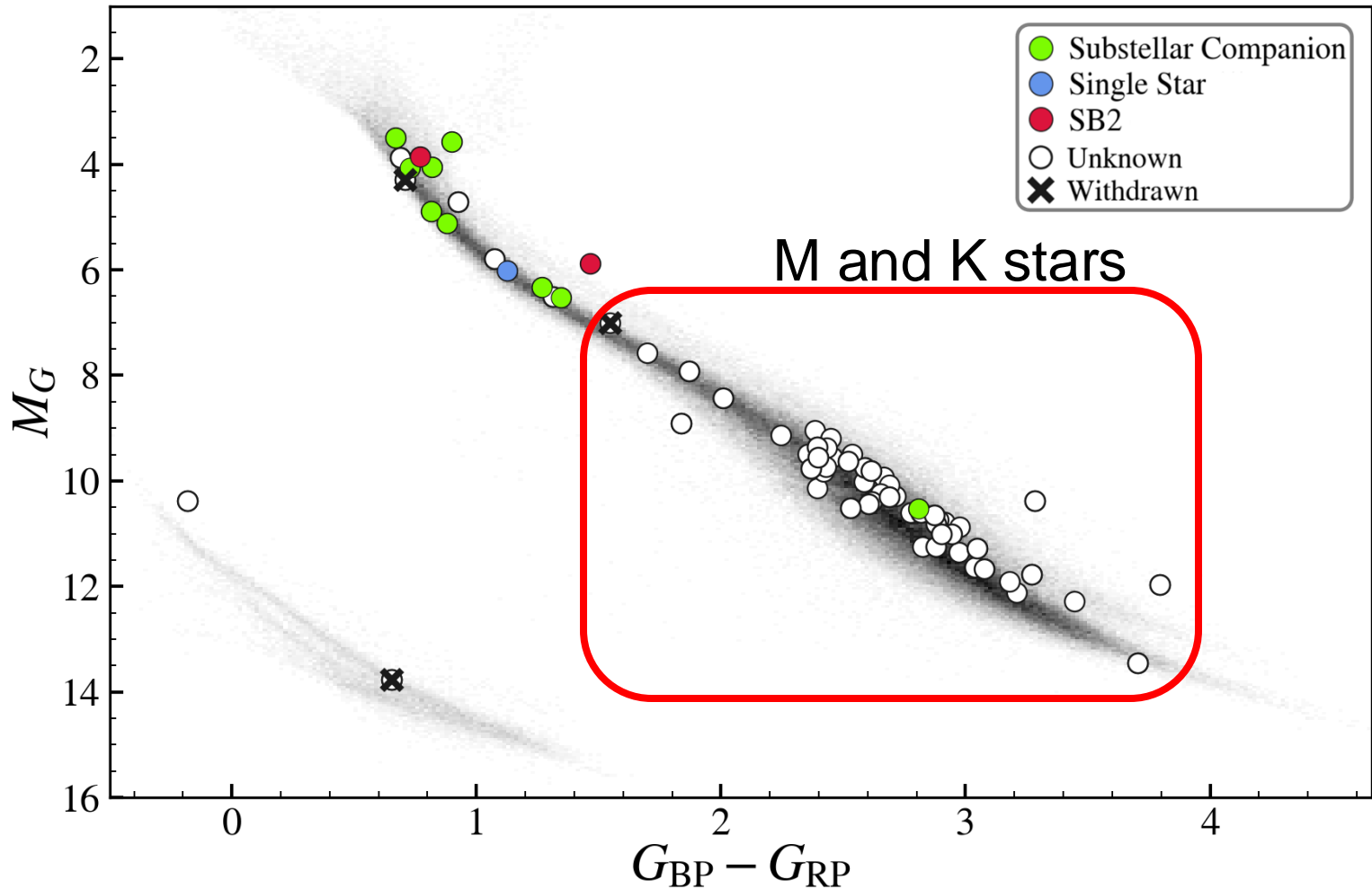




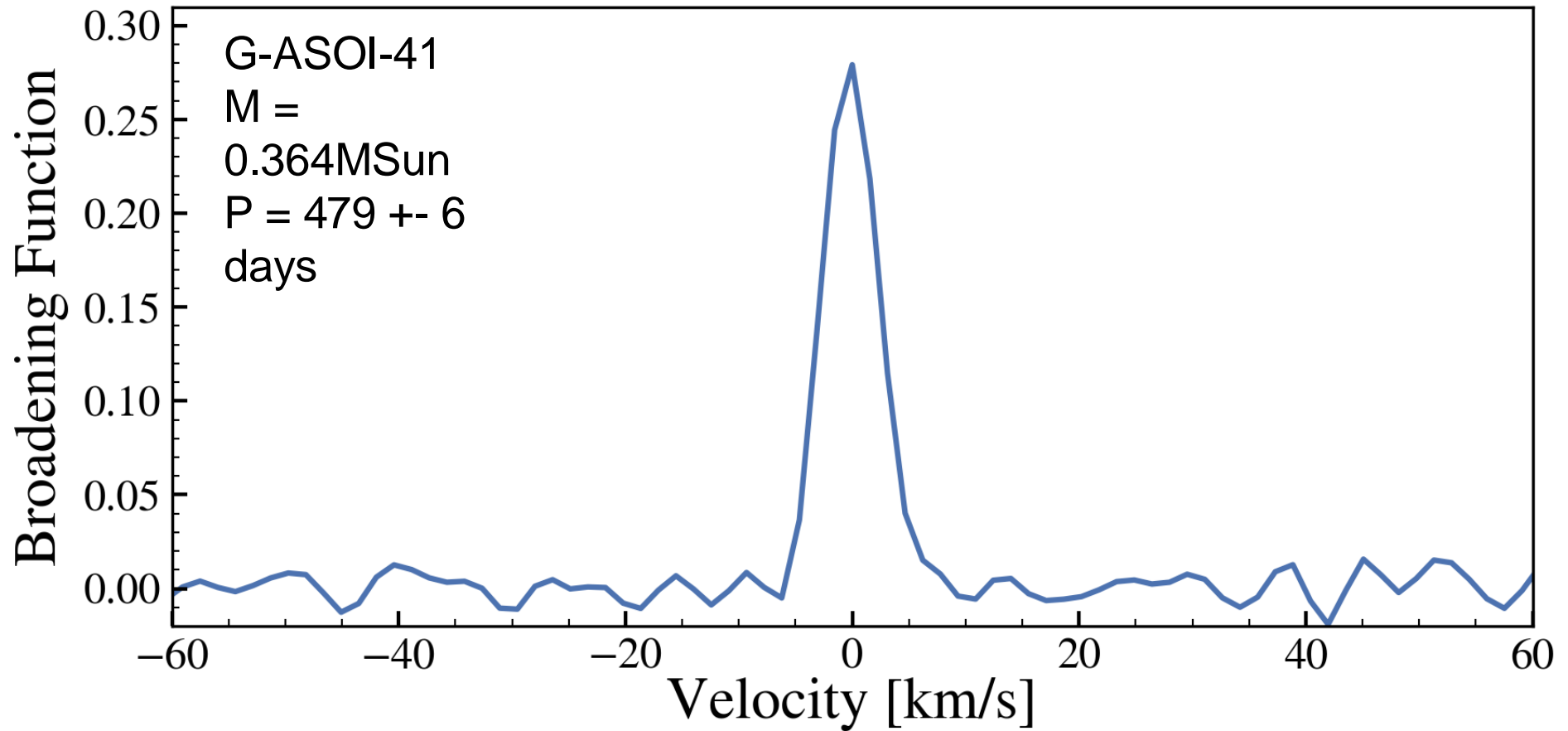
Gaia astrometric exoplanet candidates from DR3



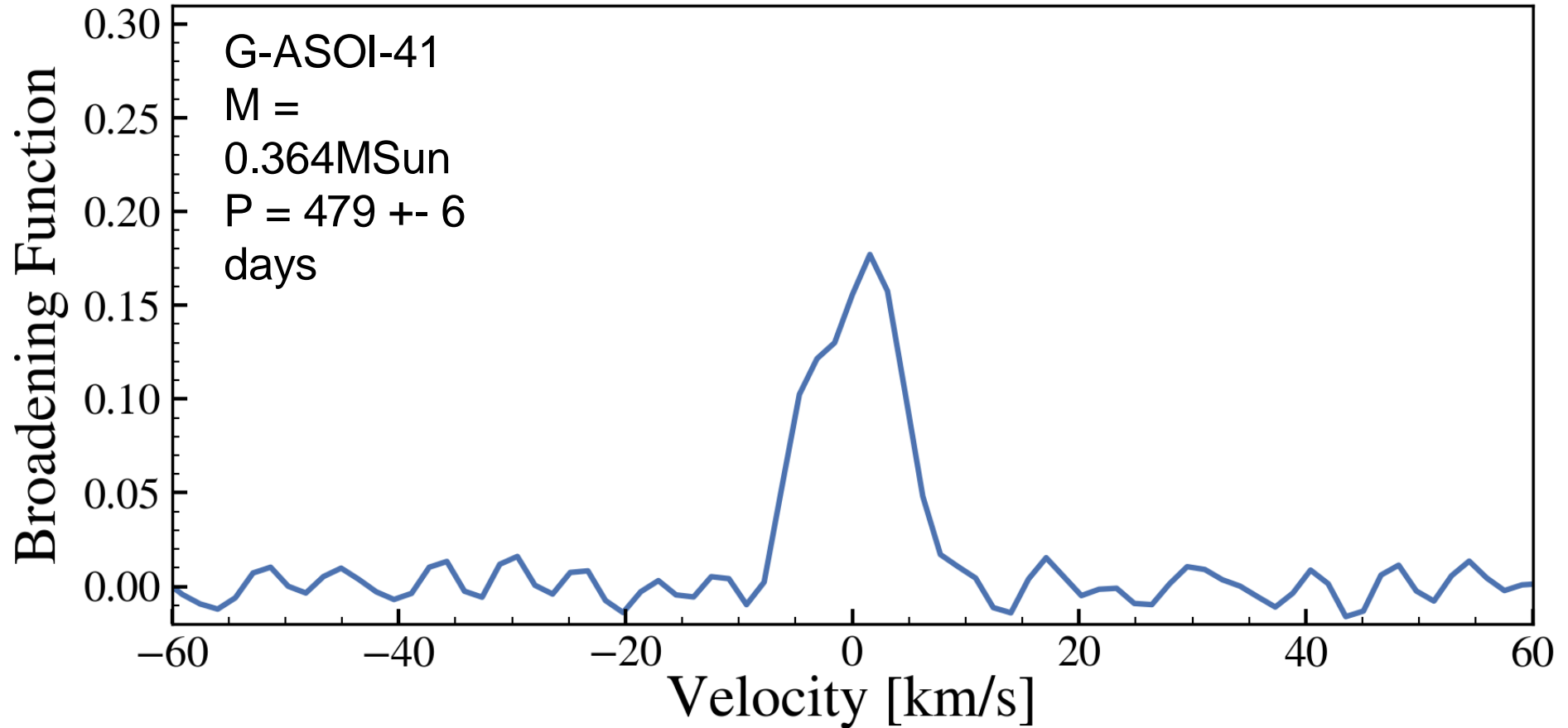
Gaia astrometric exoplanet candidates from DR3



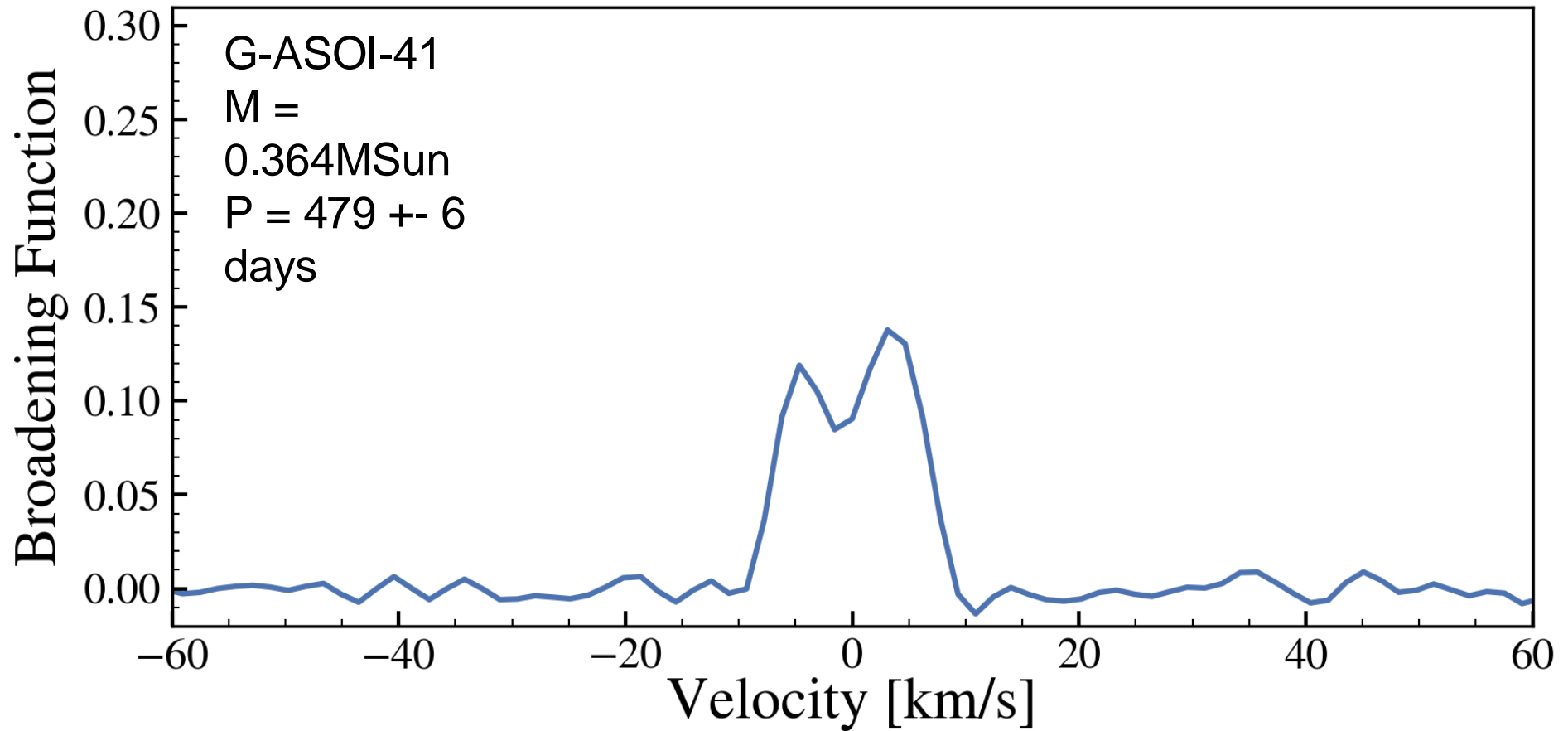
Spectroscopic follow-up observations reveal false positives



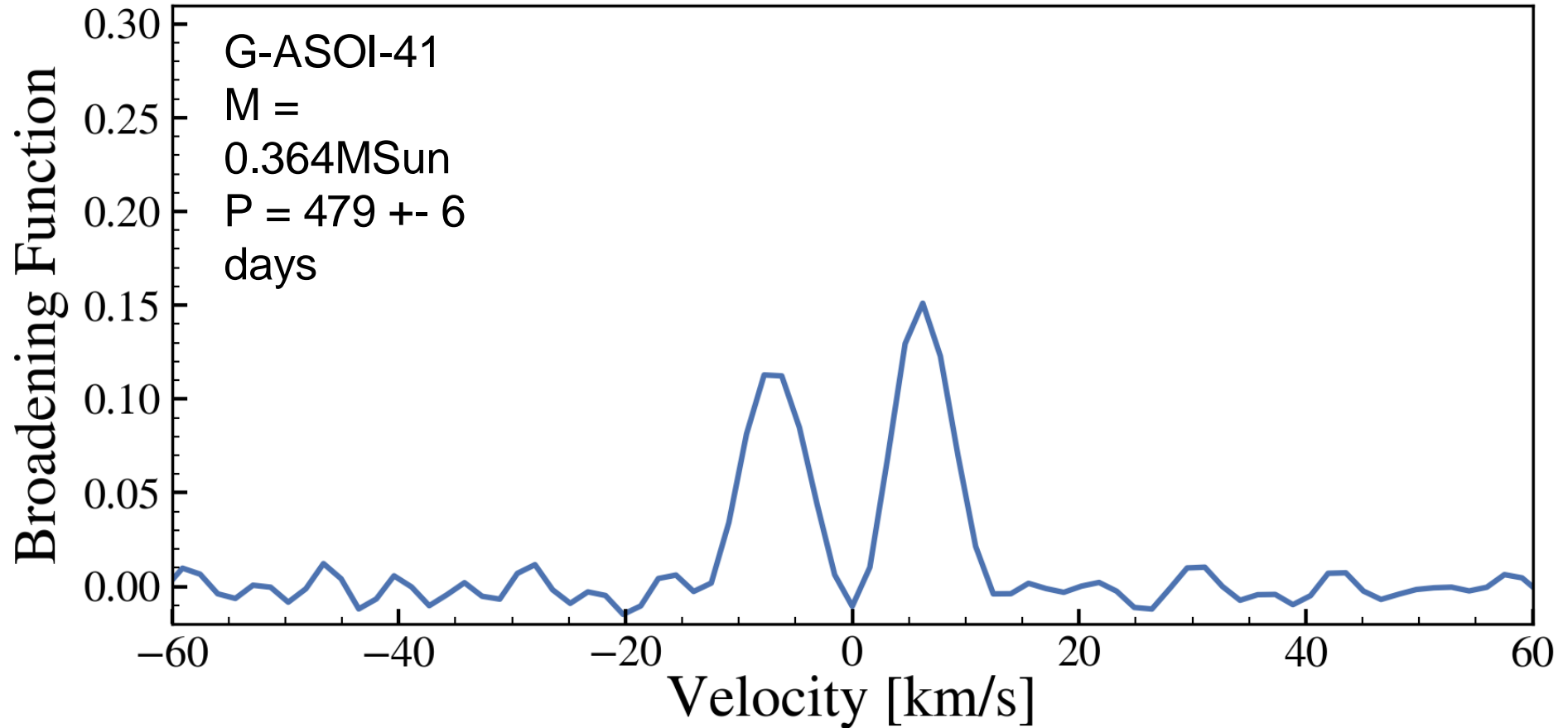
Spectroscopic follow-up observations reveal false positives



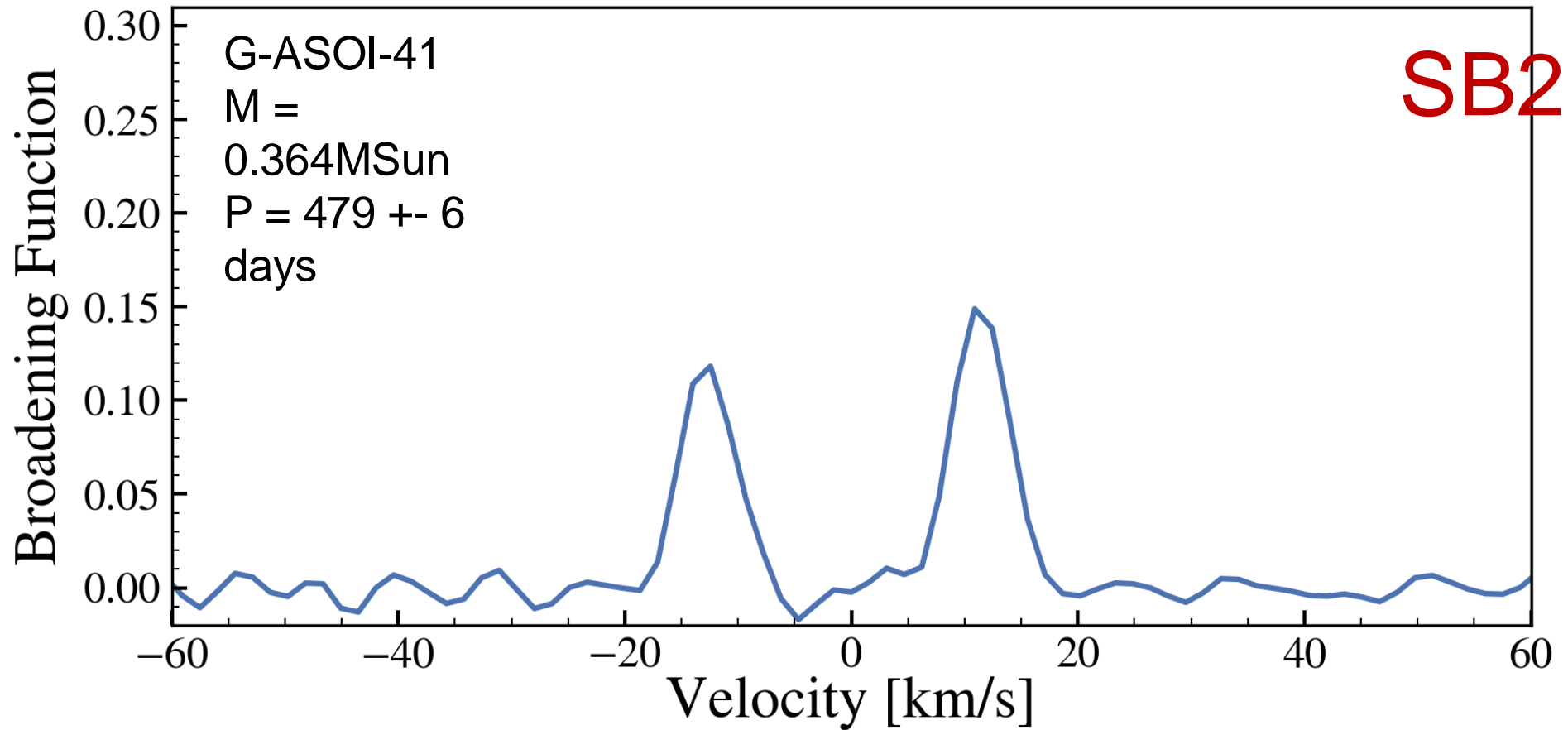
Spectroscopic follow-up observations reveal false positives



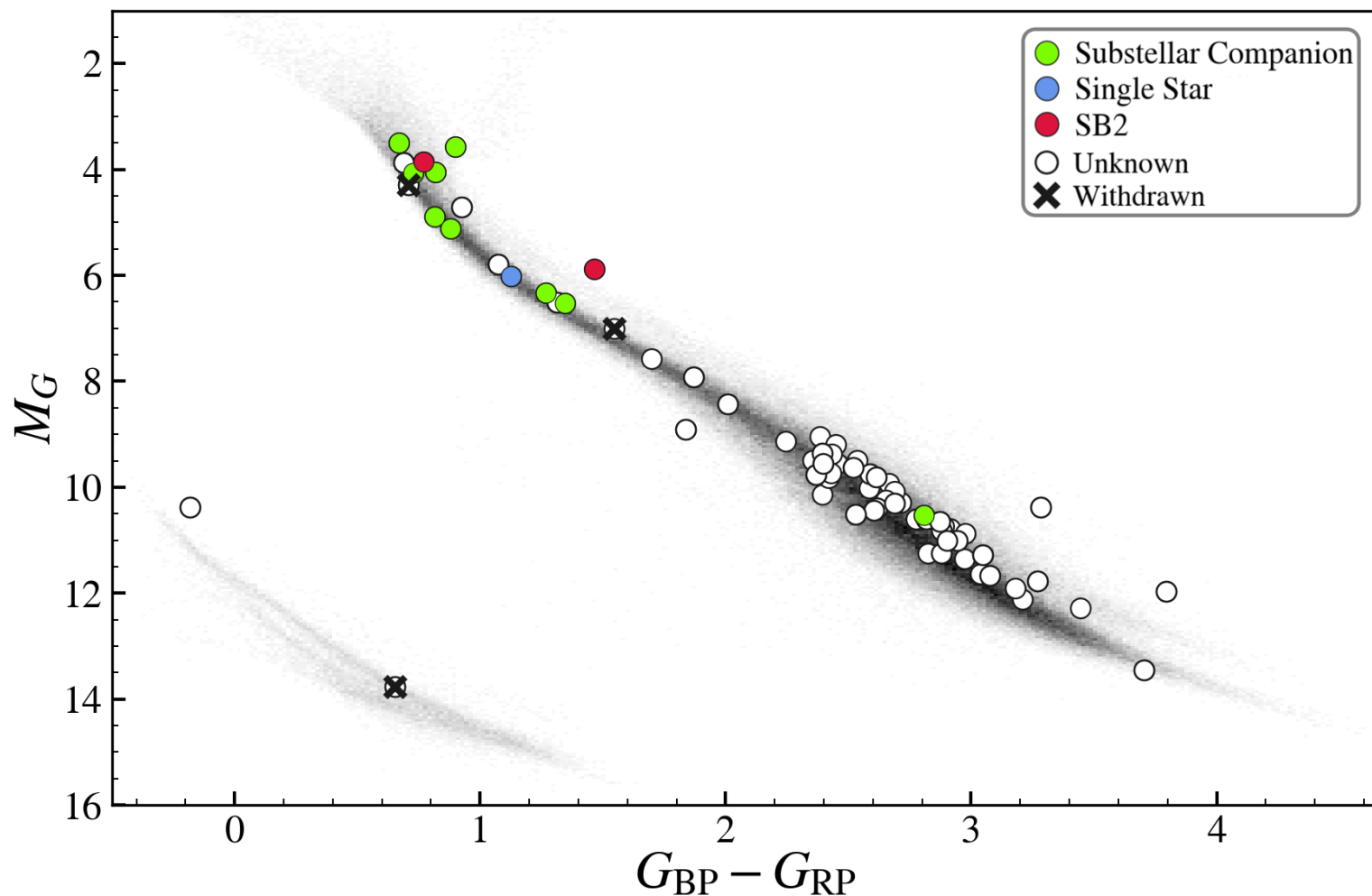
Spectroscopic follow-up observations reveal false positives



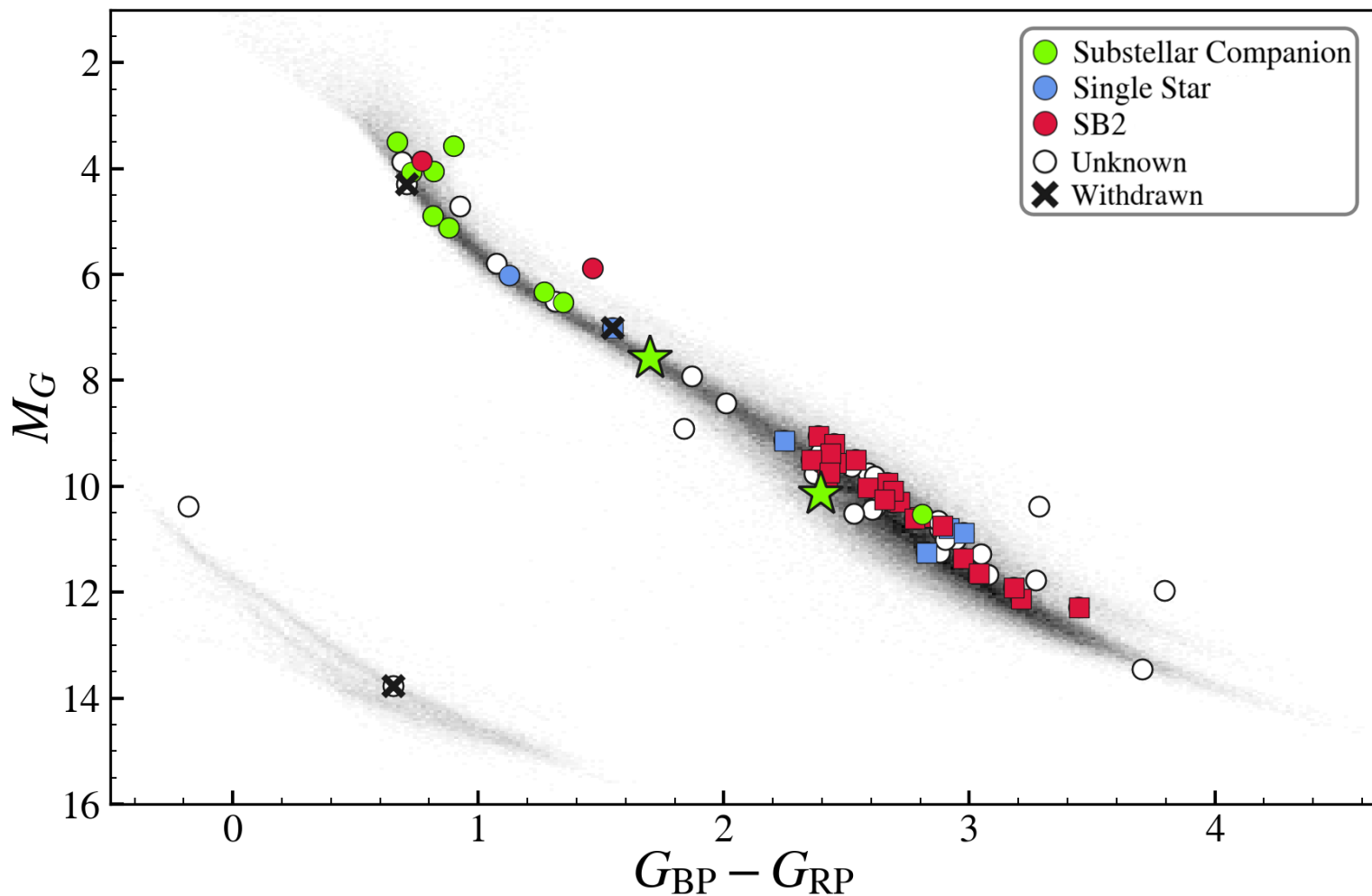
Spectroscopic follow-up observations reveal false positives



RVs reveal a high false positive rate: 21/28 are binaries

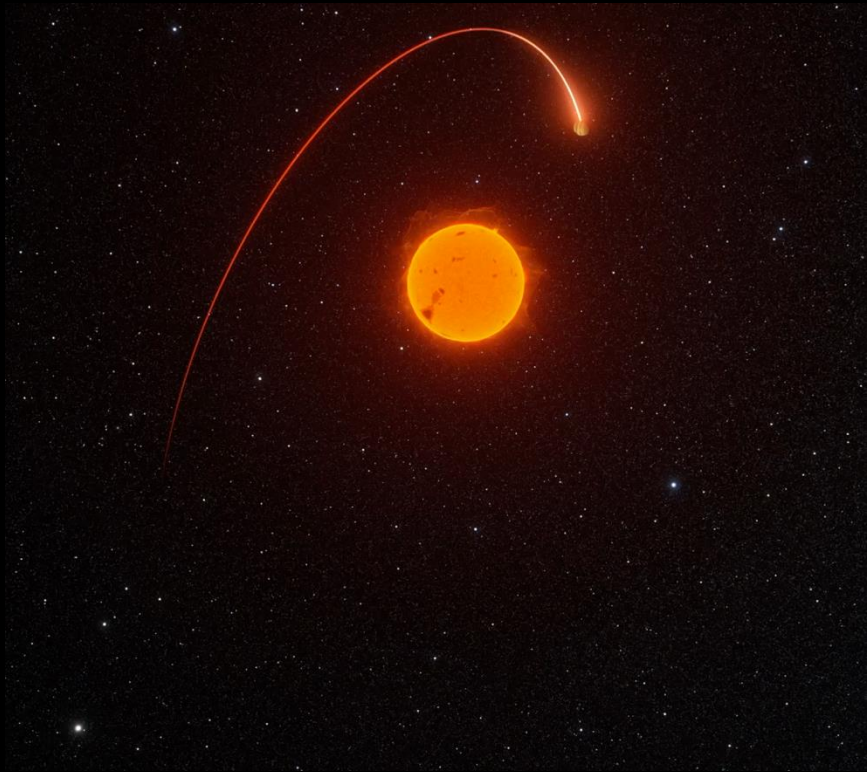


RVs reveal a high false positive rate: 21/28 are binaries



First two discoveries

Gaia-4b



$P = 570$ day
 $M = 12 M_{\text{Jup}}$

Gaia-5b

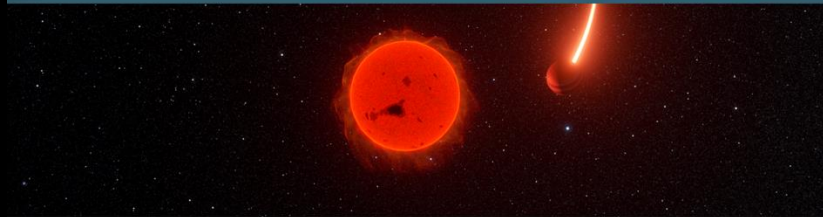


$P = 360$ day
 $M = 20 M_{\text{Jup}}$

Video credit: M. Marcussen

Gaia-4b is the **first confirmed astrometric planet** from Gaia




Stefánsson et al






SCIENCE & EXPLORATION

Wobbling stars reveal hidden companions in Gaia data

04/02/2025 160 VIEWS 1 LIKES


 **ESA Gaia**  
@ESAGaia

Another 1st for Gaia! 🎉 Using purely Gaia astrometry, the presence of exoplanet Gaia-4b was revealed! 🤖 #GaiaDR4, expected in 2026, could uncover 100s, if not 1000s of exoplanets in this way. They will bring a deeper understanding of the diverse planetary systems populating our Milky Way.

 **ESA Science**  
@esascience · 25m

. @ESA_Gaia reveals two mysterious objects: a huge exoplanet & a brown dwarf, both orbiting low-mass stars, a scenario thought to be extremely rare.

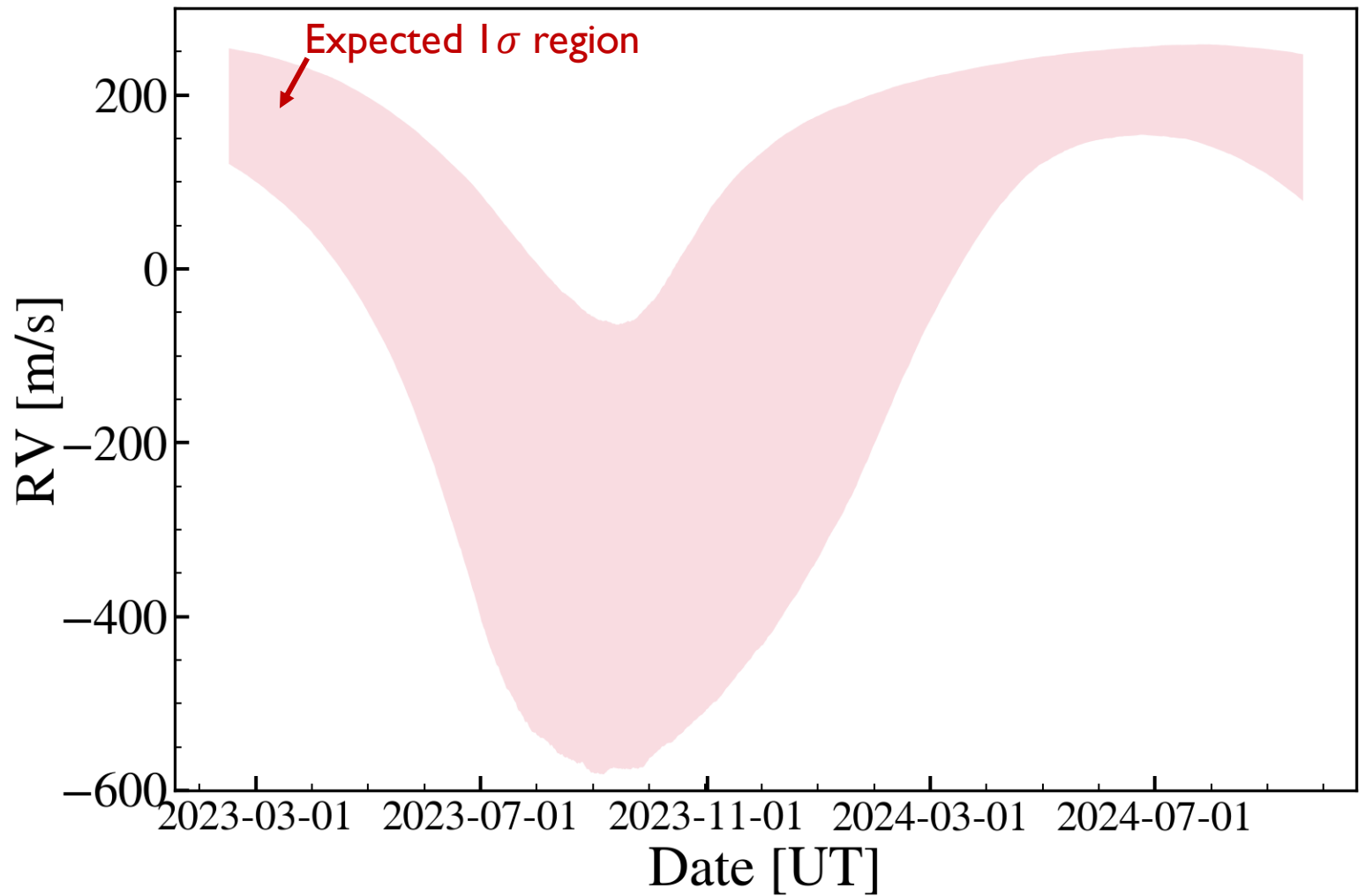
This is the first time a planet has been discovered by Gaia's ability to sense wobbling stars 🌟 esa.int/Science_Explor...



6:18 AM · Feb 4, 2025 · 266 Views

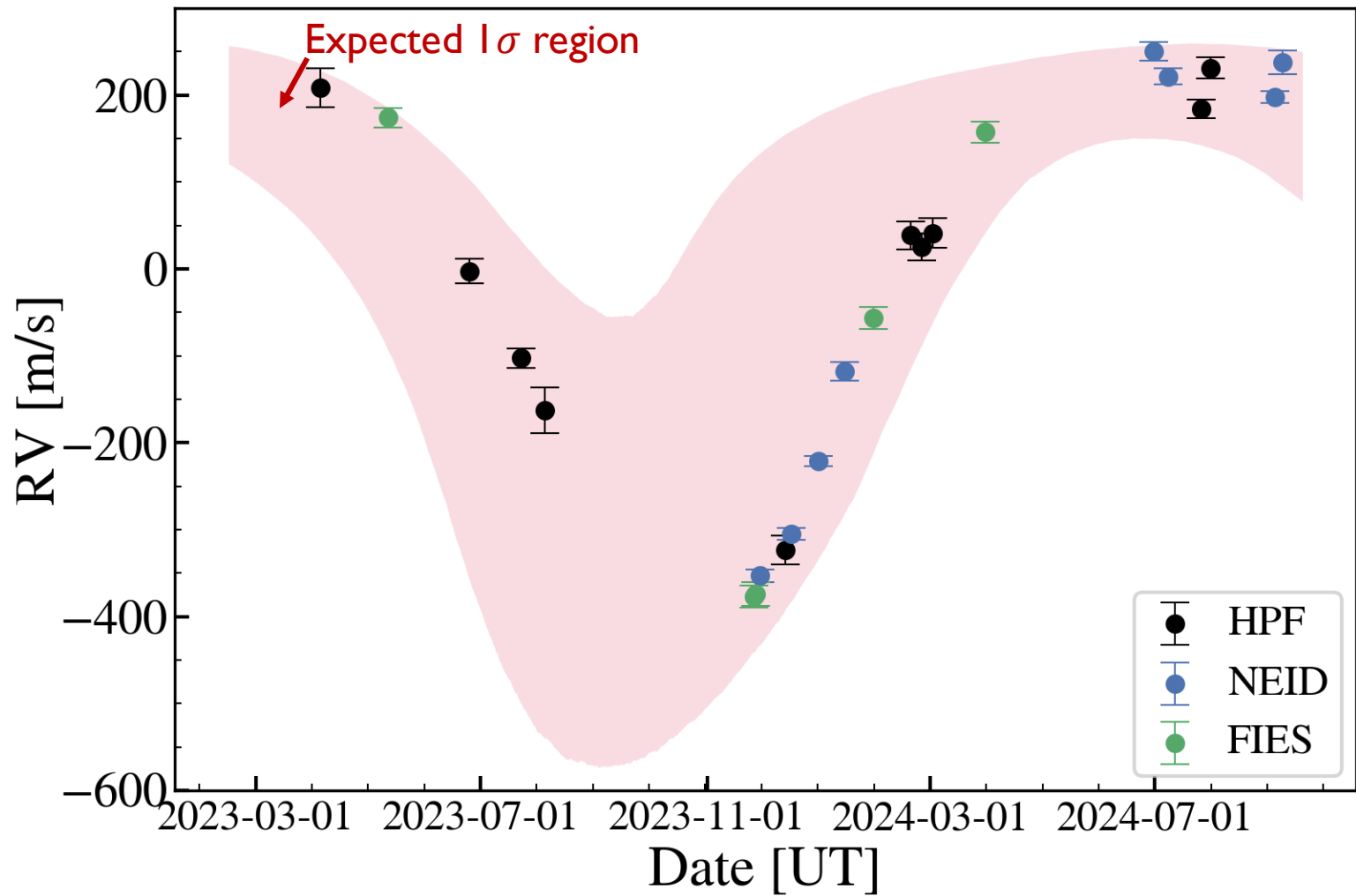


Gaia-4b: Expected RV orbit from Gaia astrometry



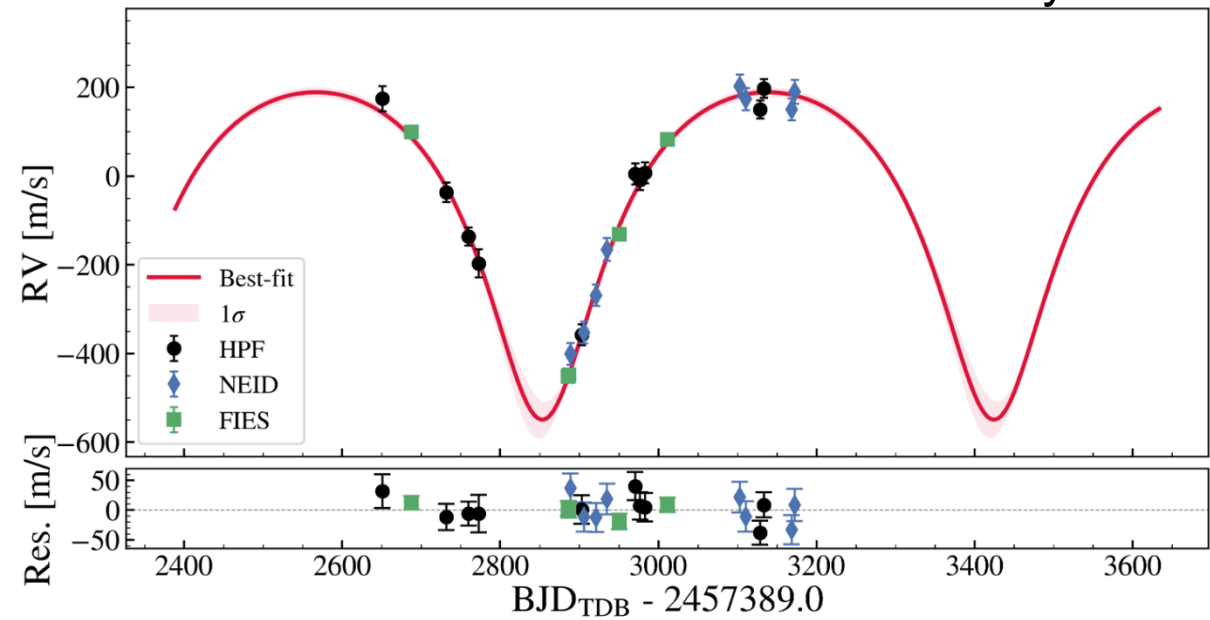


Gaia-4b: Expected RV orbit from Gaia astrometry

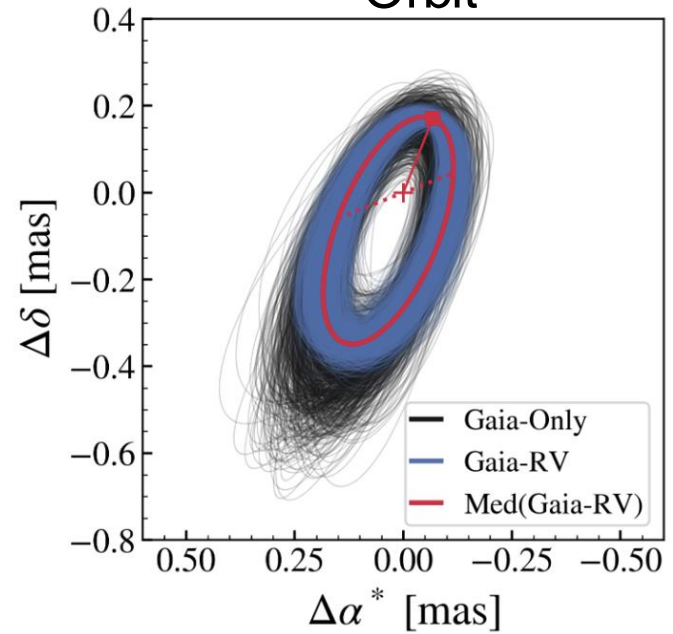


Gaia-4b is a $M = 1.6 \pm 0.9 M_J$ planet in a 571 ± 1.5 day orbit around a $0.64 M_{\text{Sun}}$ star

Joint fit: RVs + Astrometry



Orbit



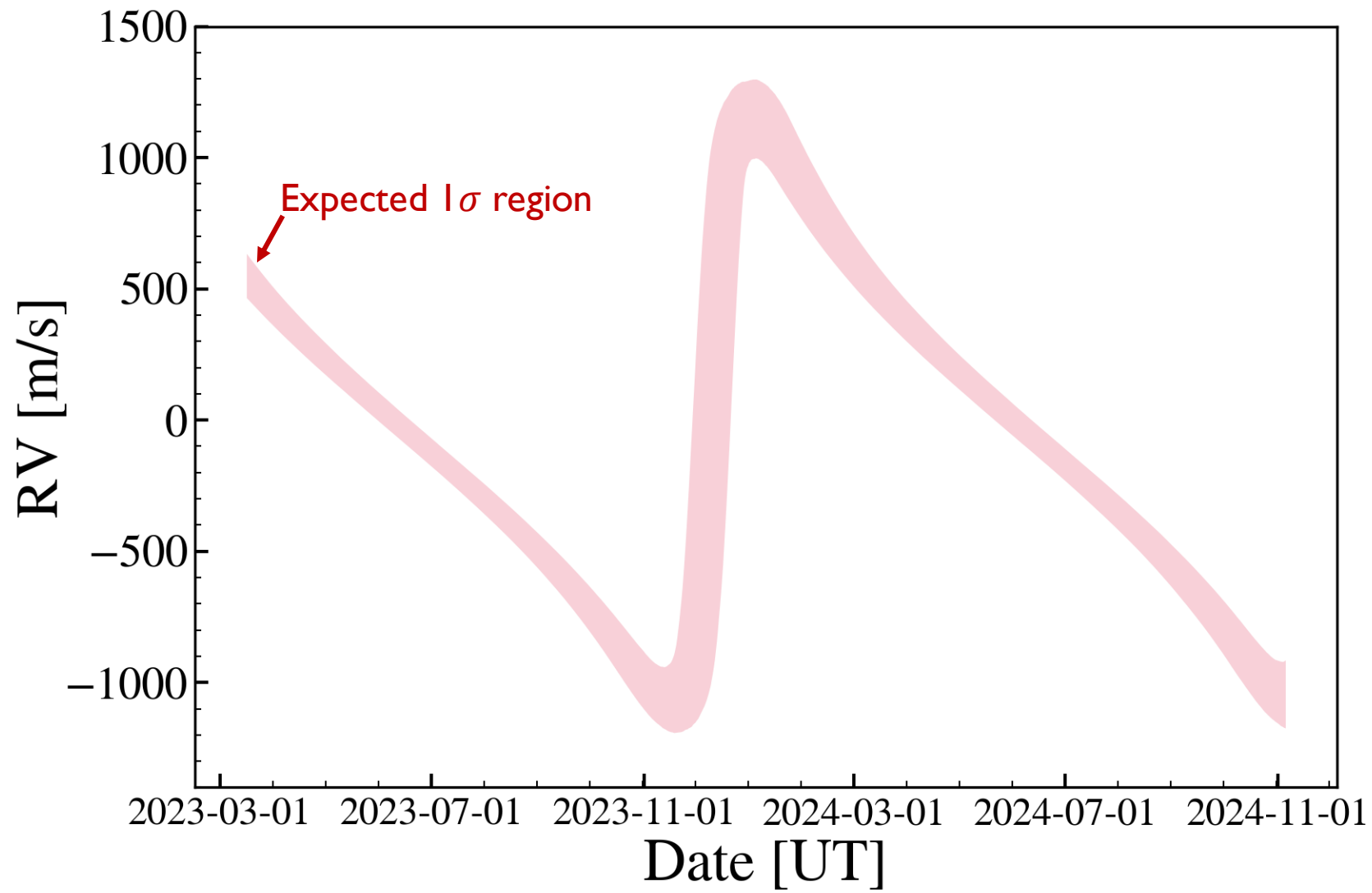
$$\log \mathcal{L}_{\text{tot}} = \log \mathcal{L}_{\text{RV}} + \log \mathcal{L}_{\text{Astrometry}}$$

Standard RV likelihood

$$\mathcal{L}_{\text{Astrometry}} \propto \exp \left[-\frac{1}{2} (\Theta^T C^{-1} \Theta) \right]$$

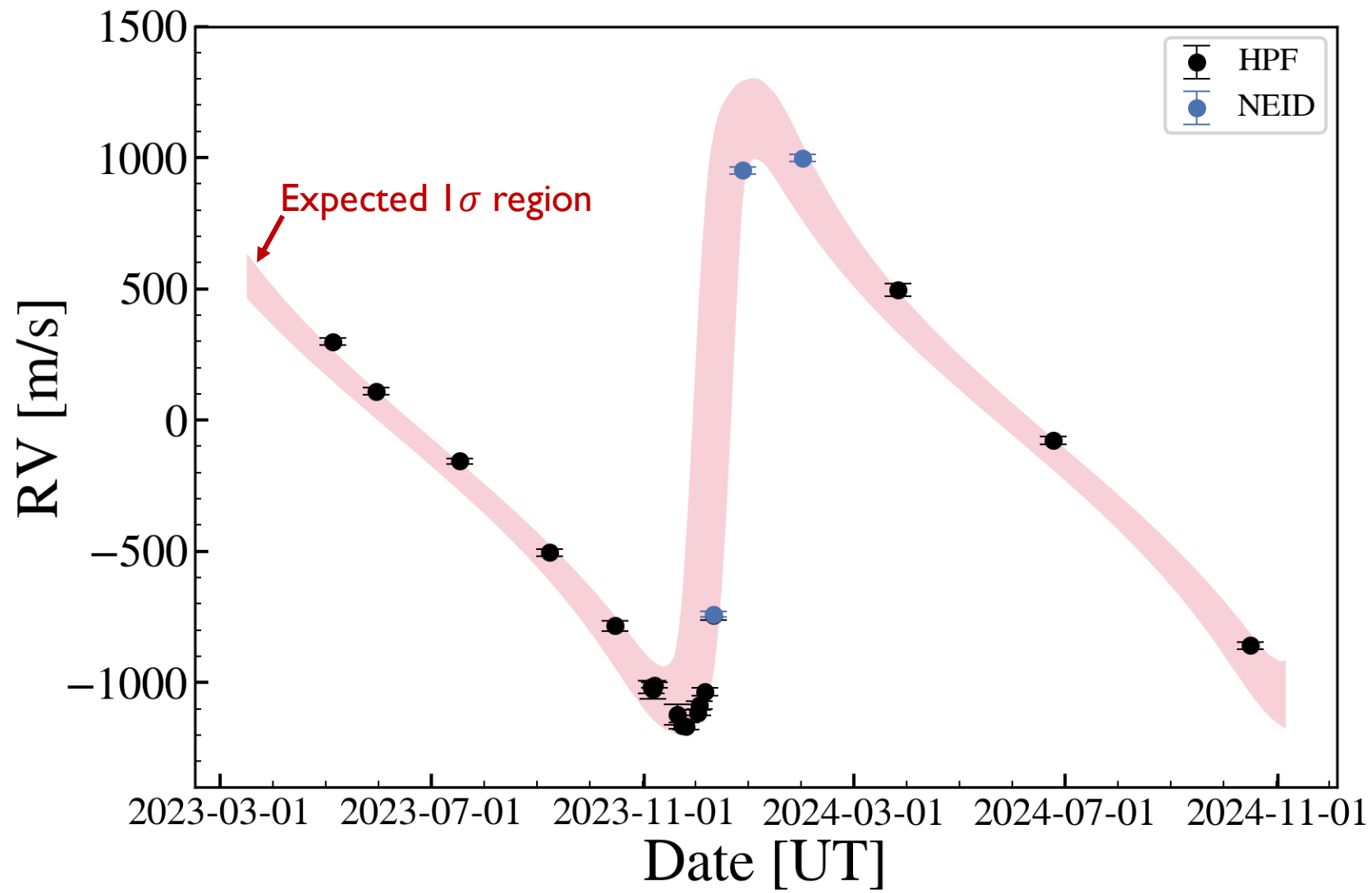


Gaia-5b: Expected RV orbit from astrometry

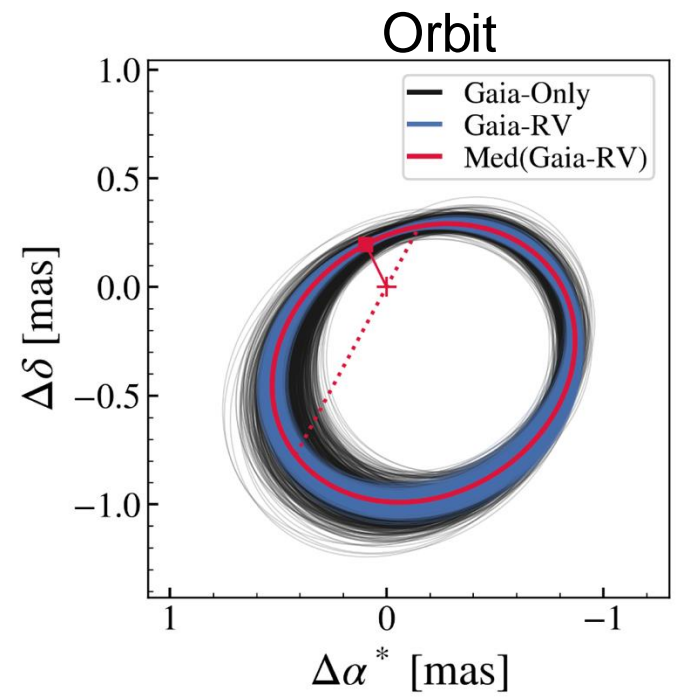
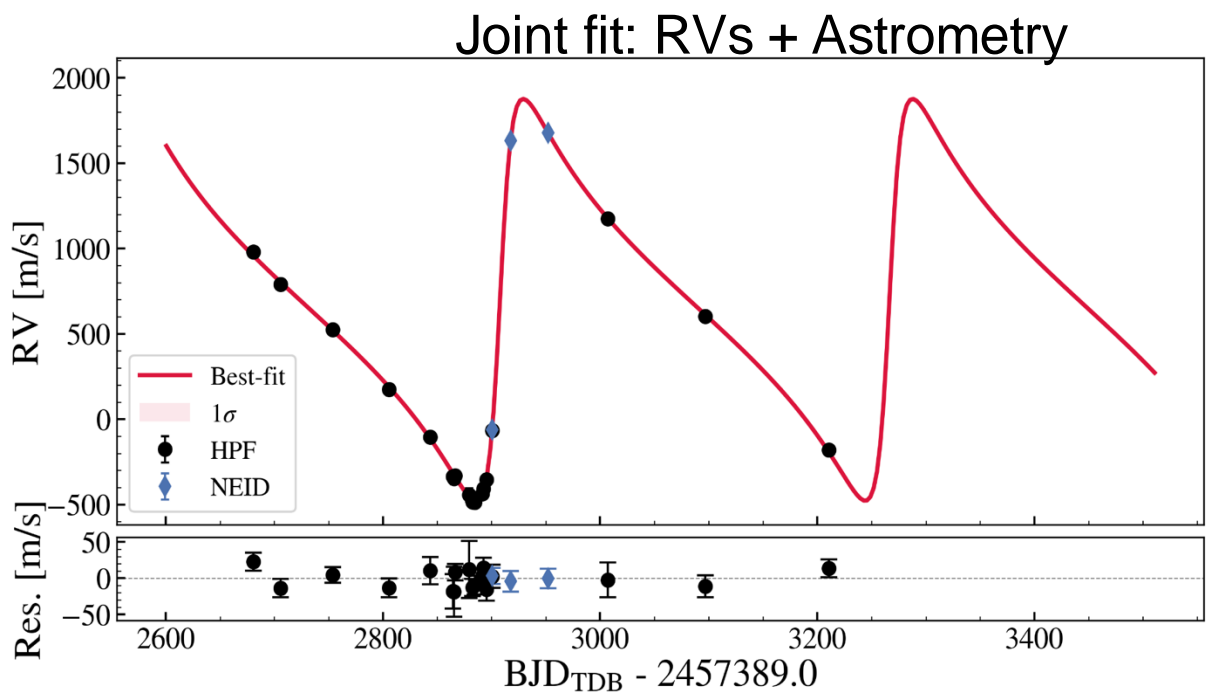




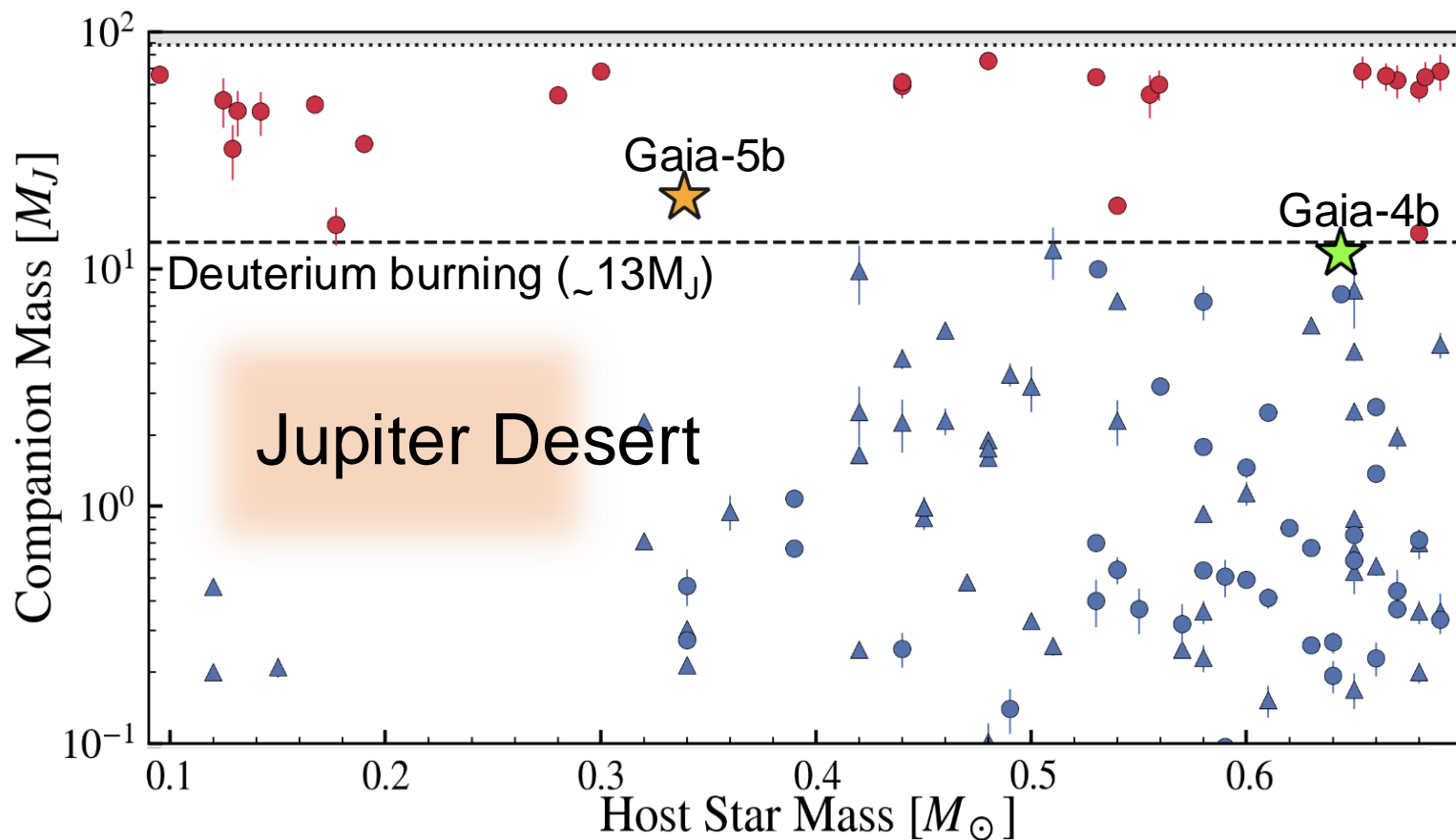
Gaia-5b: Expected RV orbit from astrometry



Gaia-5b is a $M=20.9\pm 0.5M_J$ brown dwarf in a 358.6 ± 0.2 day eccentric orbit around a $0.33M_{\text{Sun}}$ star

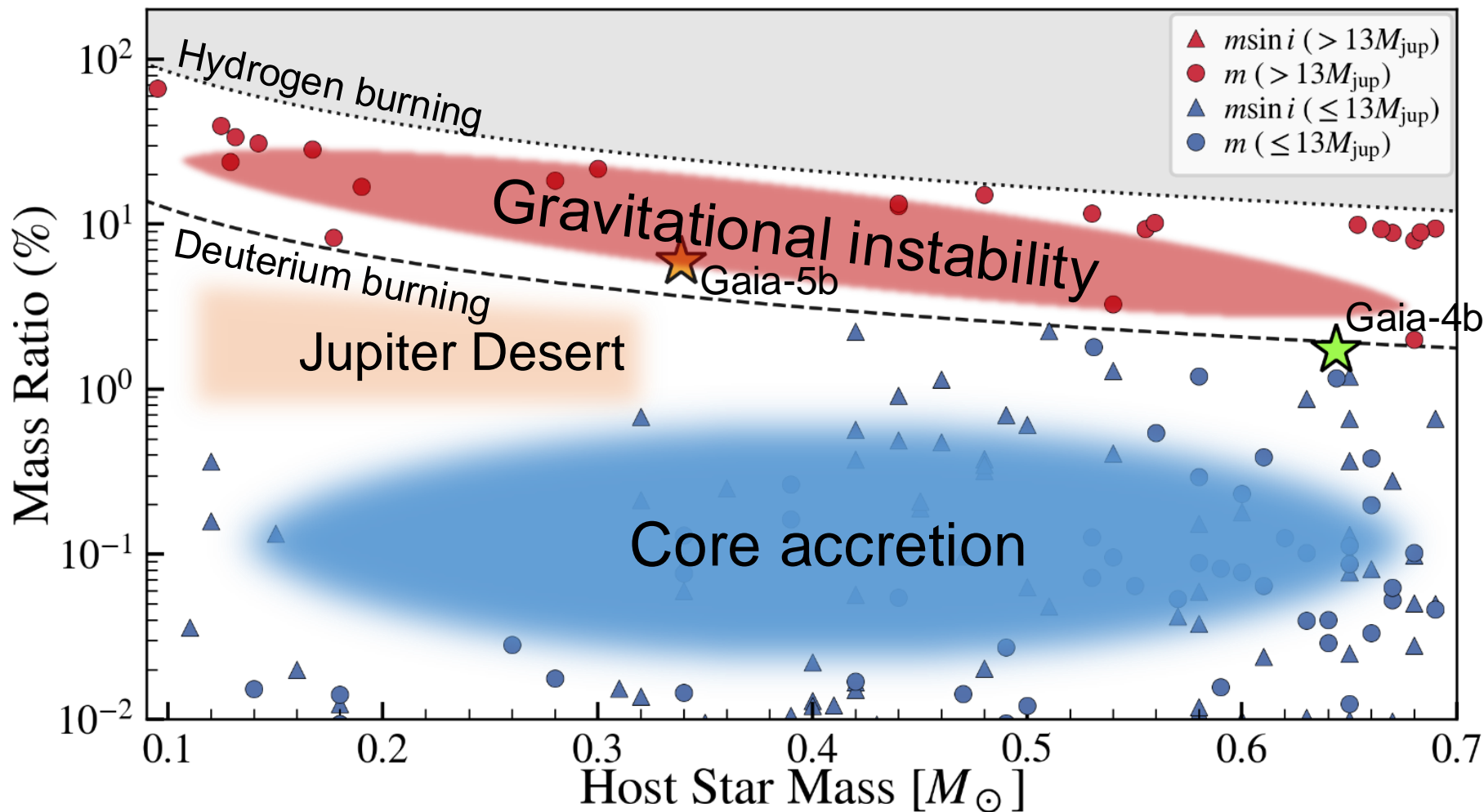


Gaia-4 and Gaia-5 in context of other brown dwarfs and planets around low-mass stars



Currently no known Jupiters around mid-to-late M stars

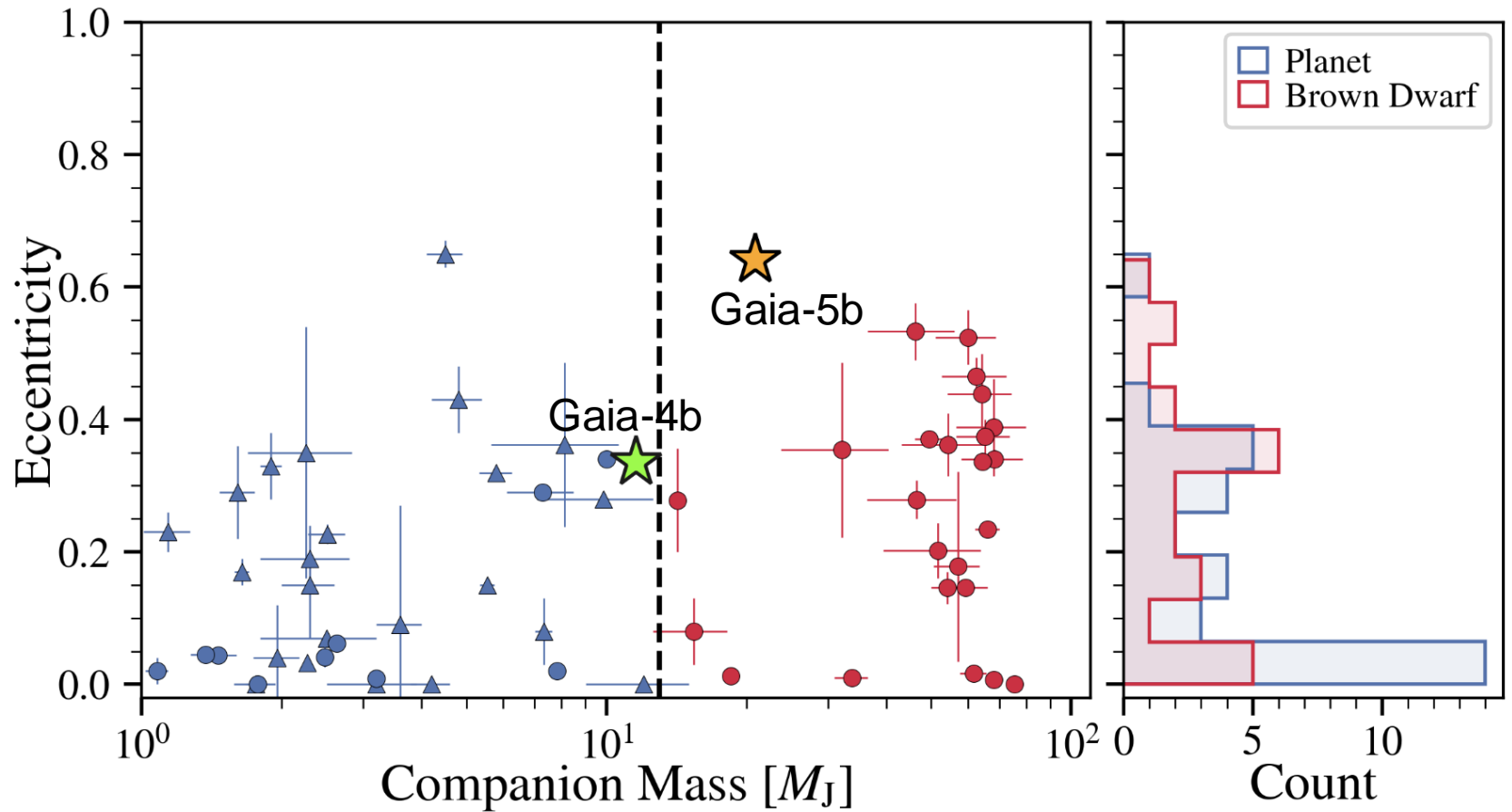
Gaia-4 and Gaia-5 in context of other brown dwarfs and planets around low-mass stars



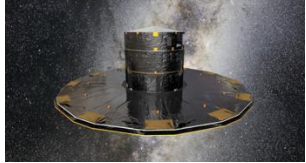
Observational signature of **different formation mechanisms?**

Gaia will be uniquely sensitive to such systems

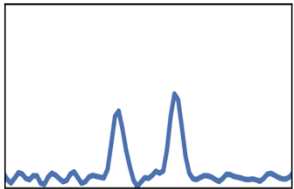
Observed eccentricity distributions for massive planets and brown dwarfs around M stars



Summary



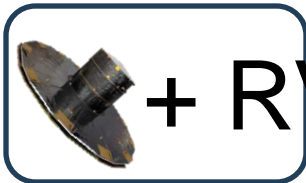
We are characterizing Gaia AStrometric Exoplanet candidates of Interest (**G-ASOIs**) with RVs



We show that **21/28 G-ASOIs** we observed are **SB2s**



Gaia-4b is Gaia's first confirmed astrometric exoplanet



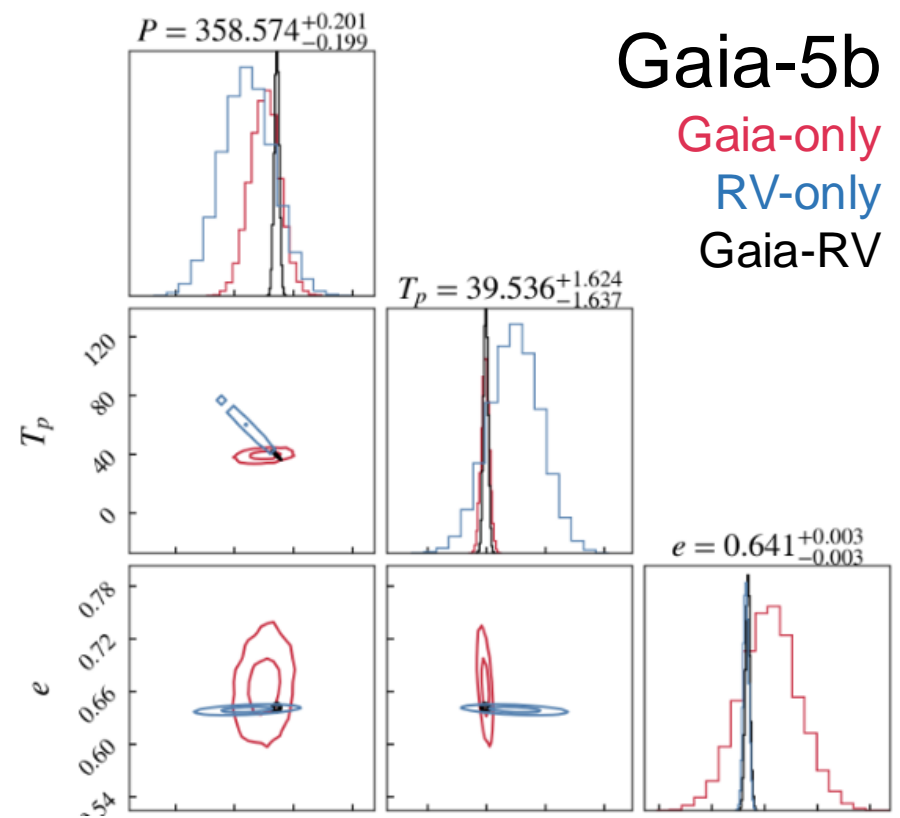
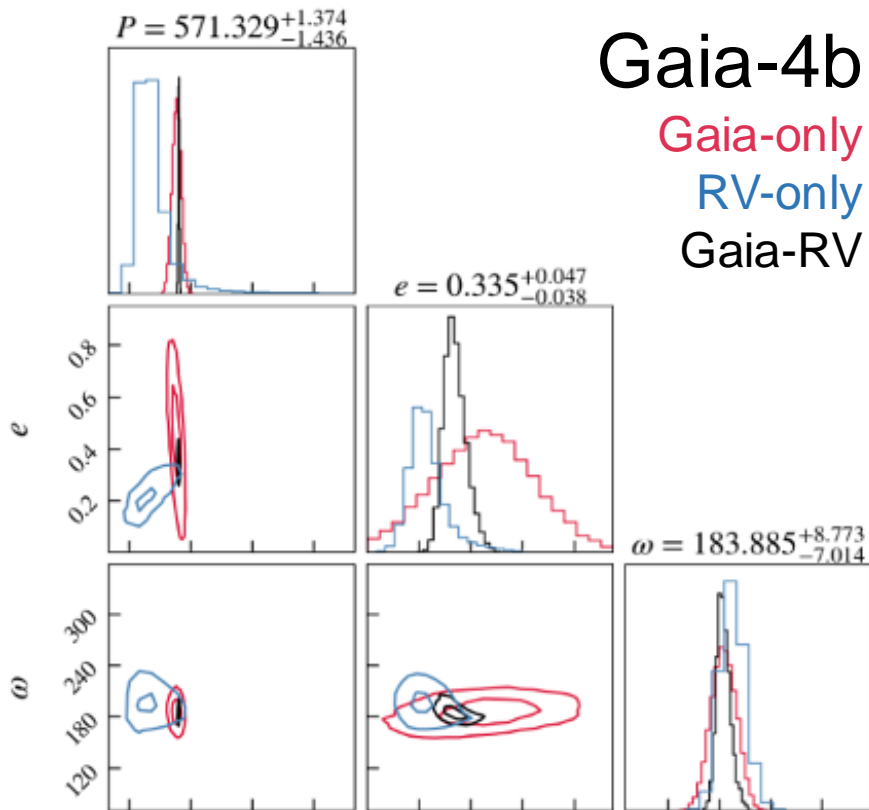
RV observations will be key in confirming Gaia ASOIs in the DR4 era

Thank you !



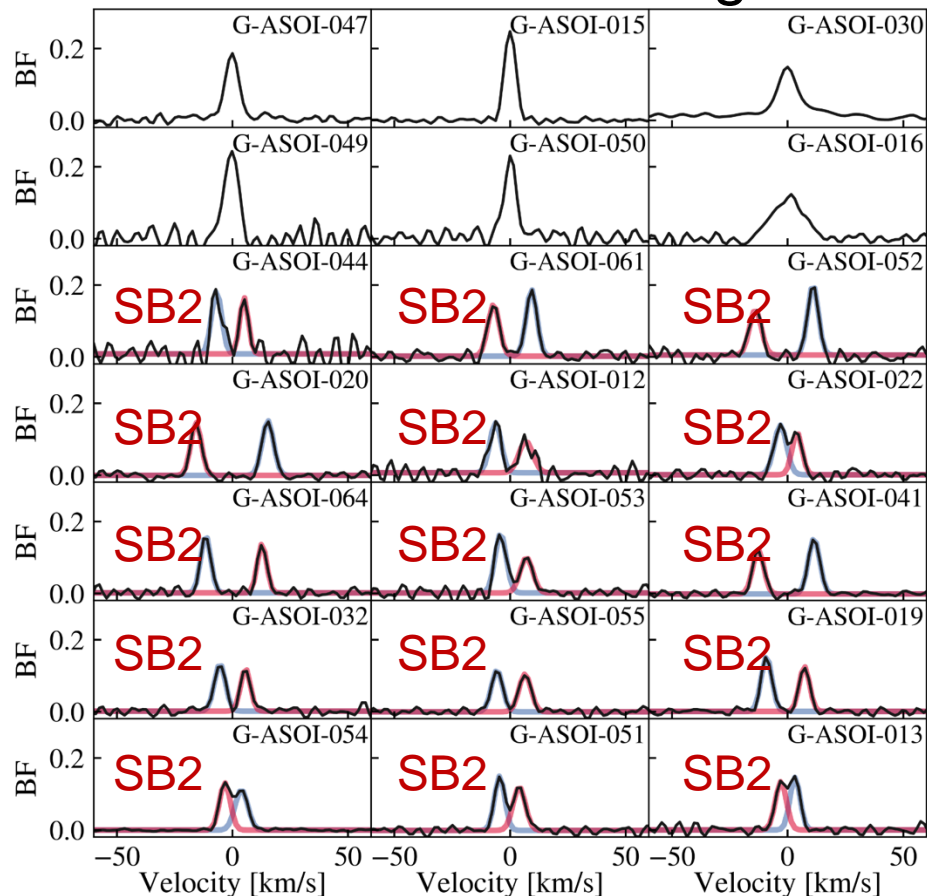
Extra

RV orbits agree well with the astrometric orbits

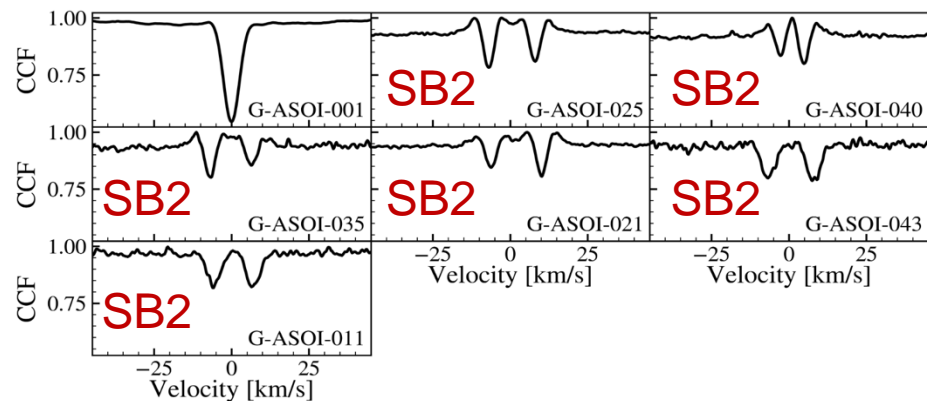


In 28 M and K star G-ASOIs, we show that 21 are binaries

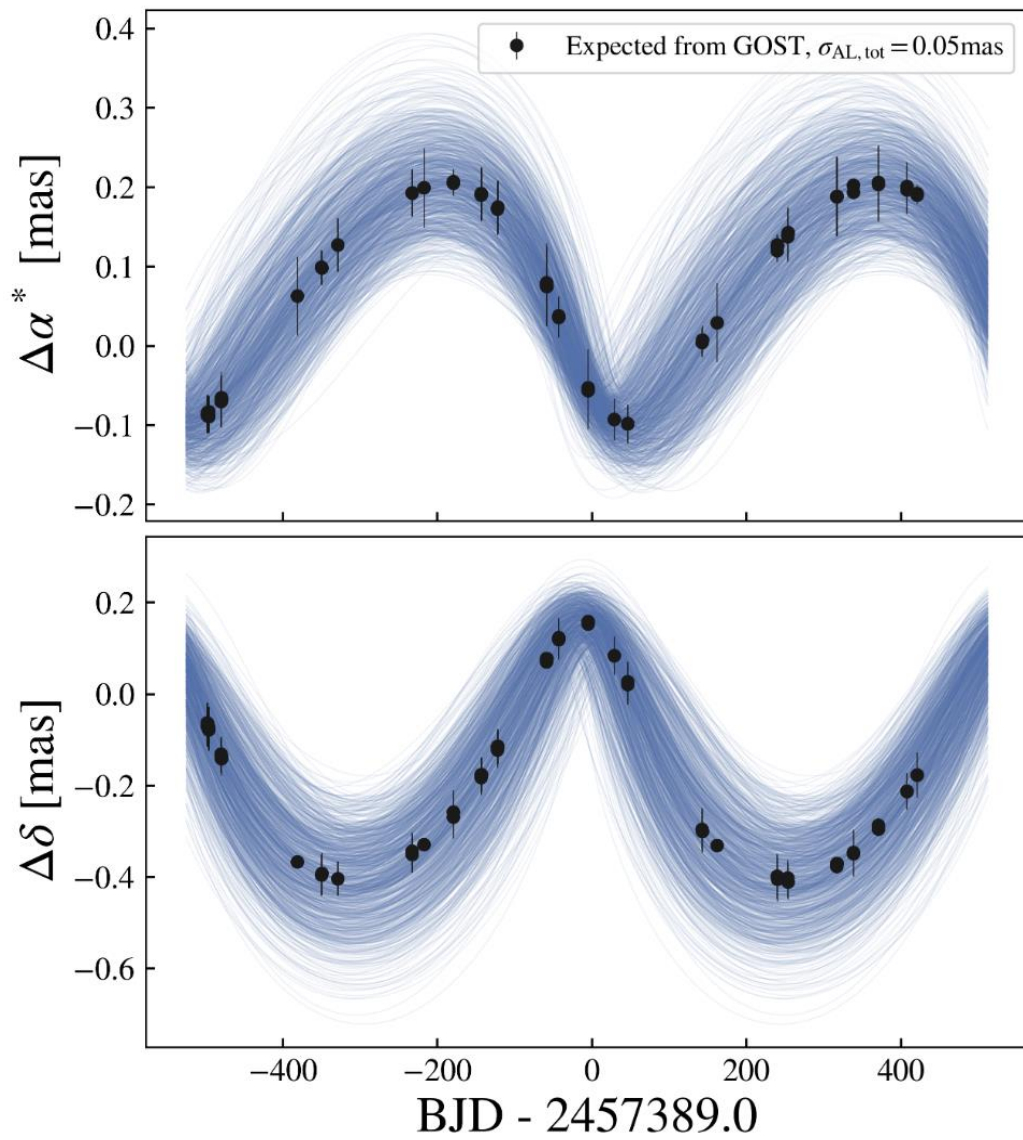
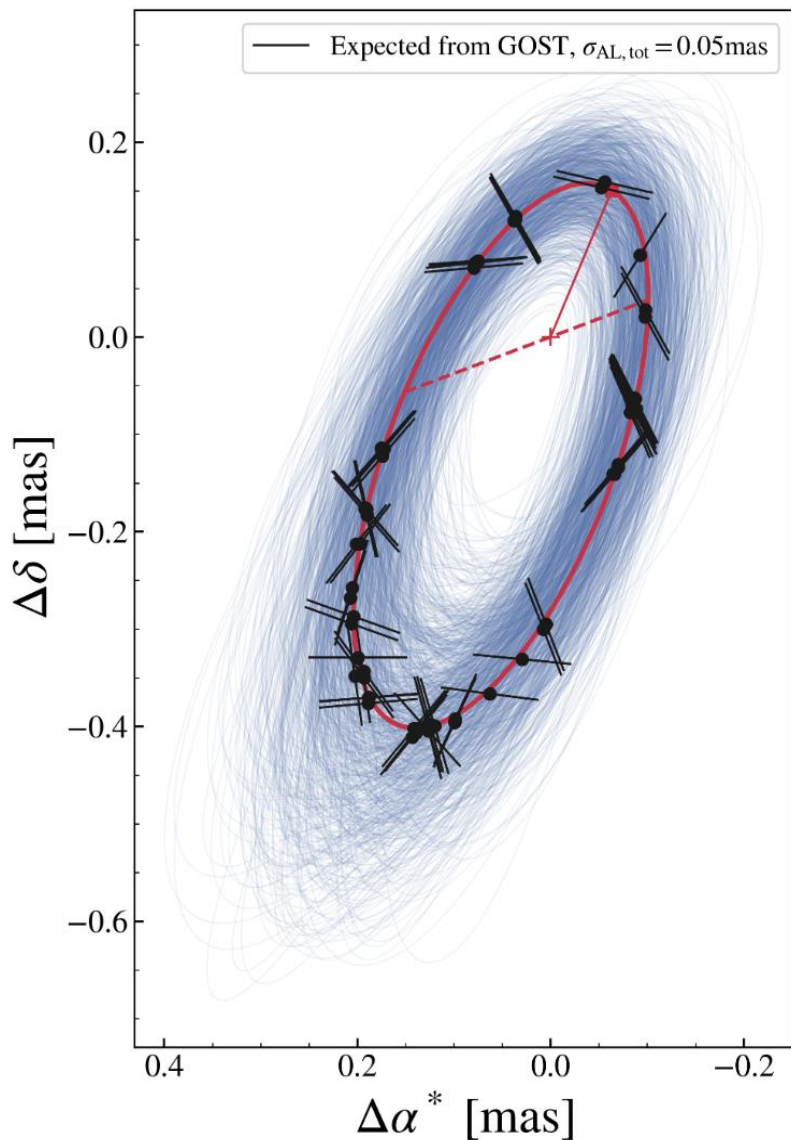
HPF Broadening functions



NEID CCFs



Gaia-4b: Gaia shows even time sampling of the orbit



Gaia-5b: Gaia shows even time sampling of the orbit

