False Positive sources and validation potential in the PLATO dataset

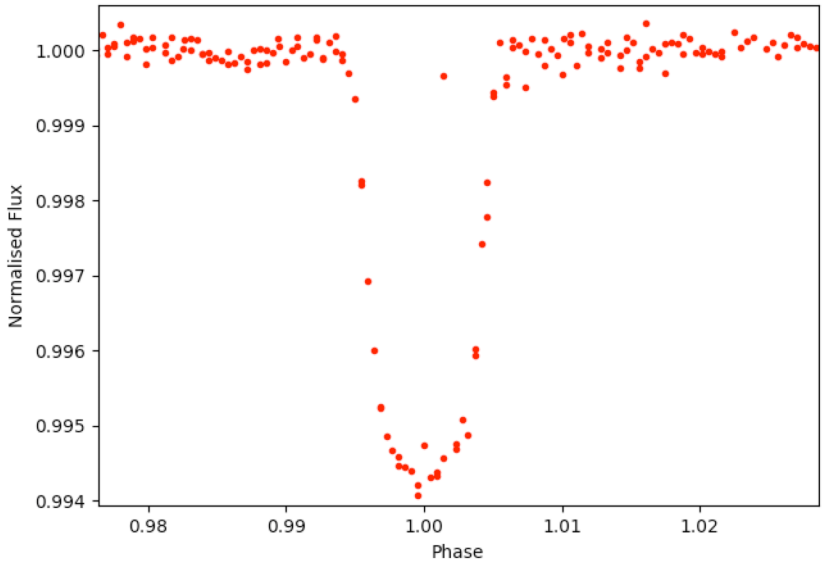
David Armstrong, Marina Lafarga Magro, A. Hadjigeorghiou, Kaiming Cui, Rodrigo Diaz

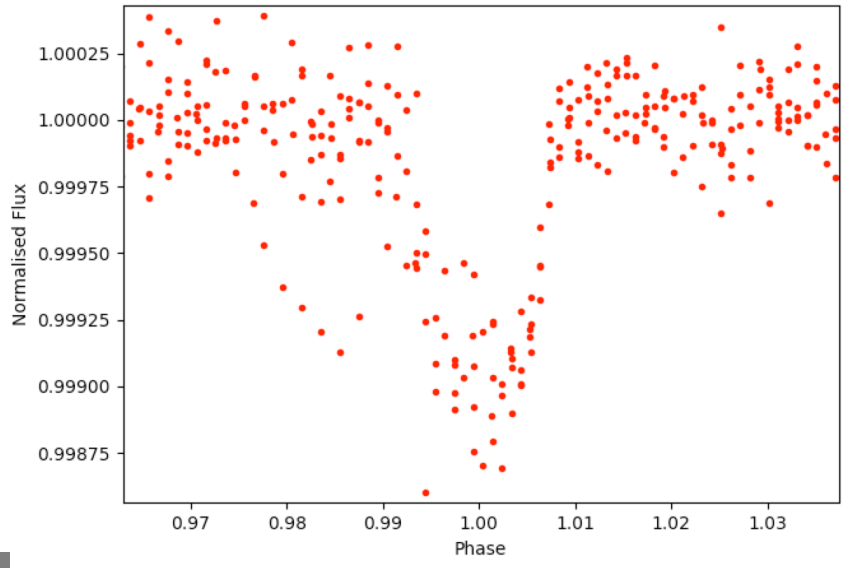
Overview

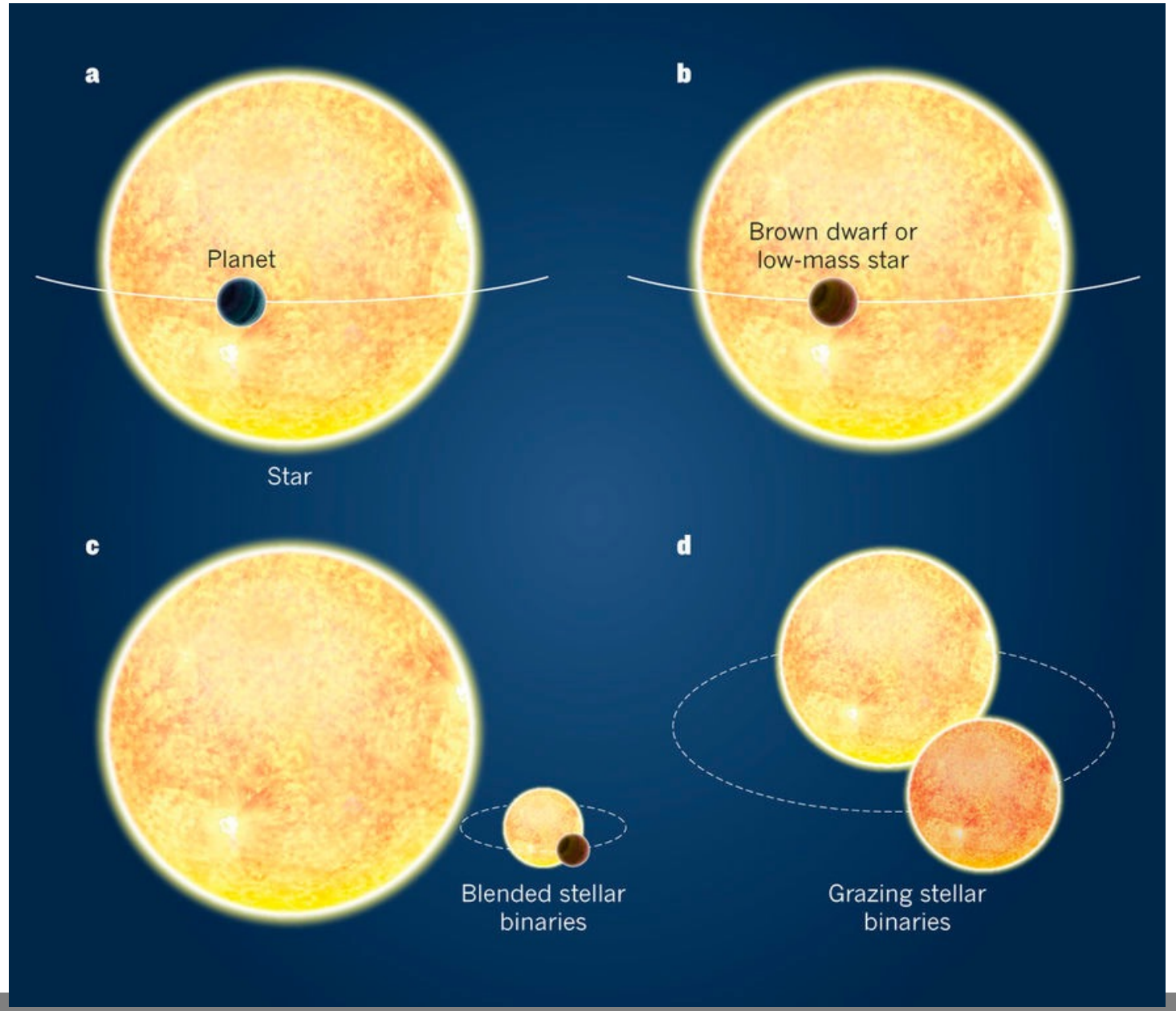
1. Context and false positive scenarios.

2. False positive distributions, priors, and implications.

3. Solutions and expectations for PLATO.


Normalised Flux
1.000
0.999
0.998
0.997
0.996
0.995
0.994
0.98
0.99
1.00
1.01
1.02
Phase


Normalised Flux
1.00025
1.00000
0.99975
0.99950
0.99925
0.99900
0.99875
0.97
0.98
0.99
1.00
1.01
1.02
1.03
Phase


a
Planet
Star
b
Brown dwarf or
low-mass star
c
Blended stellar
binaries
d
Grazing stellar
binaries

Candidate scenarios

Planets

- Transiting planet TP
- Background transiting planet BTP
- Hierarchical transiting planet BTP
- Nearby transiting planet NTP
- Data/ instrumental artefacts

Stars

- Eclipsing binary EB
- Background eclipsing binary BEB
- Hierarchical eclipsing binary HEB
- Nearby eclipsing binary NEB
- Nearby hierarchical eclipsing binary NHEB

Understanding false positive sources

Training sets / Test Samples

Train/develop vetting algorithms

Test completeness / performance of planet finding pipelines

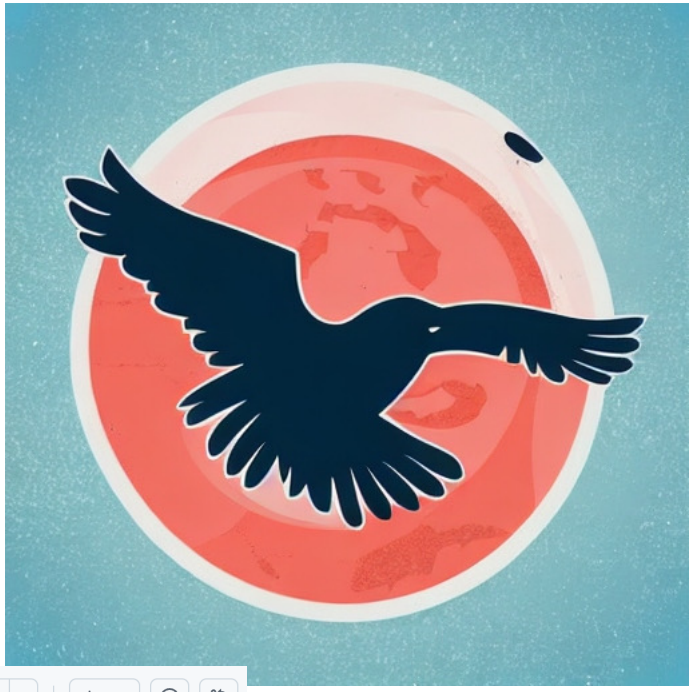
Planet Validation

Probabilistic assessment of candidate nature.
Depends critically on false positive priors.

e.g. vespa, TRICERATOPS, Exominer, …

Often simple, but there is a wealth of research on stellar distributions available.

RAVEN pipeline



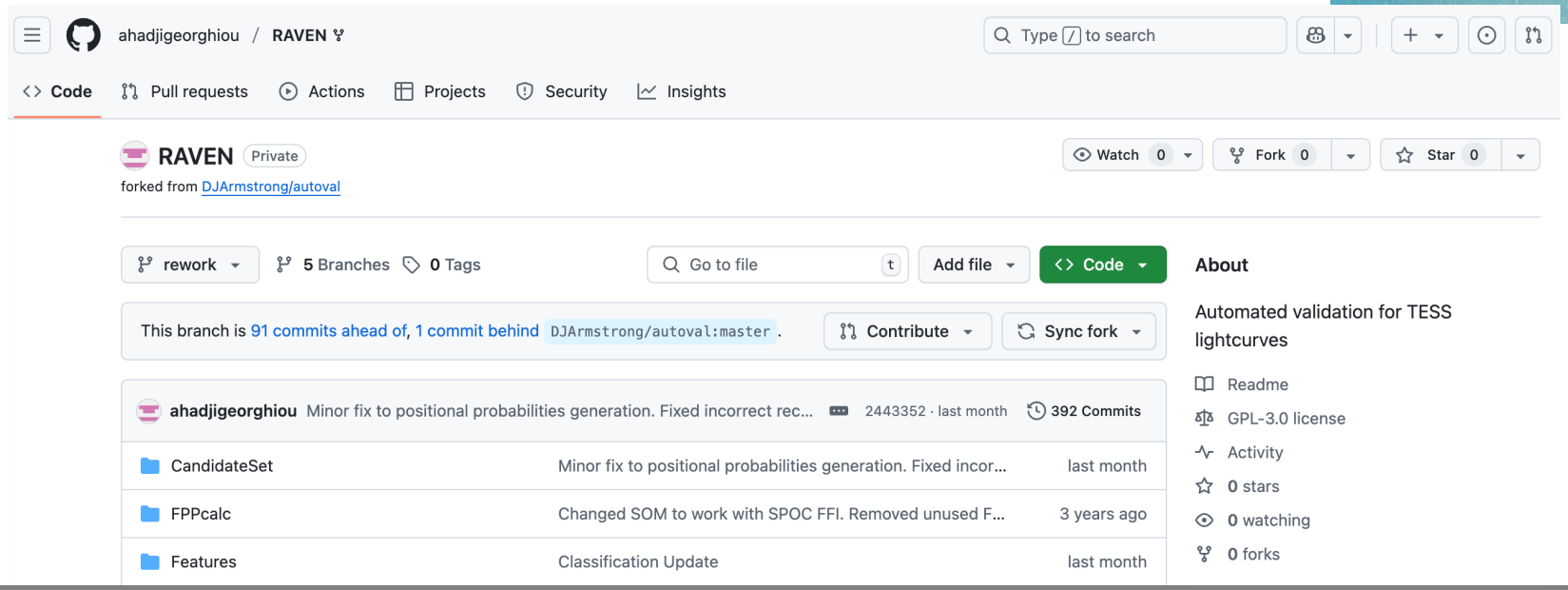
JOURNAL ARTICLE

The positional probability and true host star identification of *TESS* exoplanet candidates

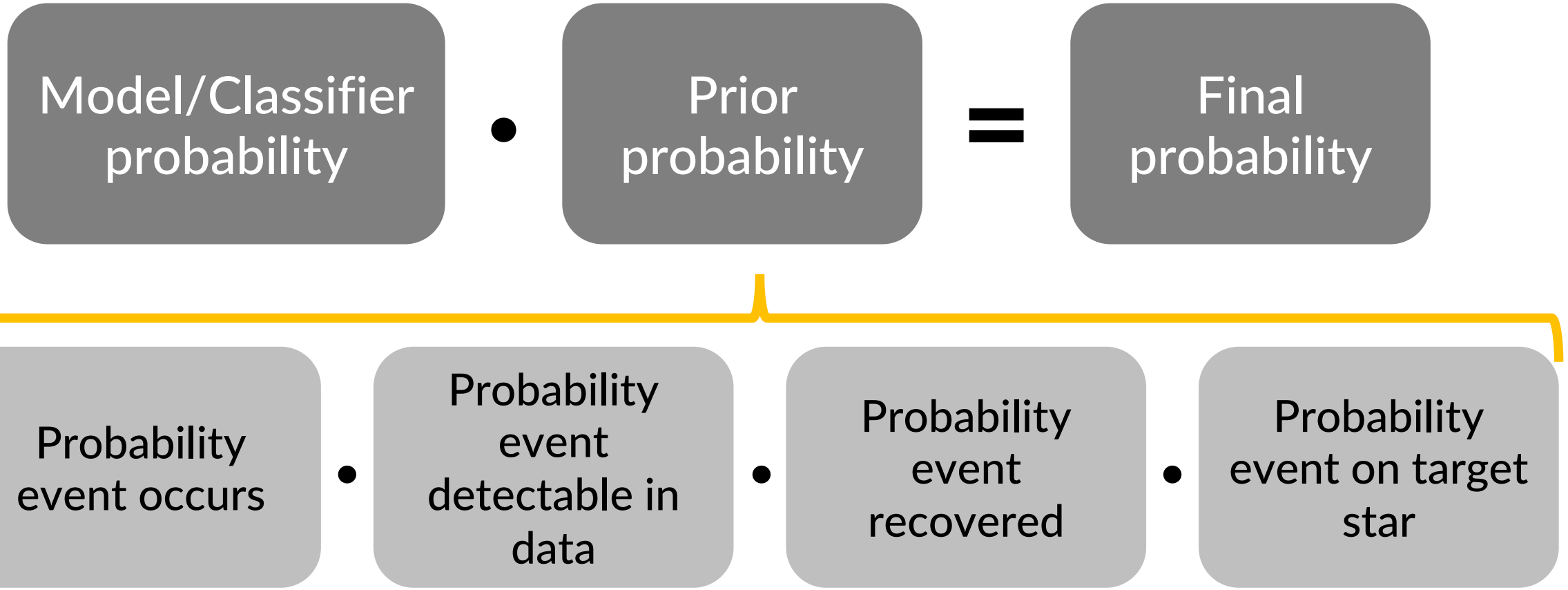
Andreas Hadjigeorghiou ✉, David J Armstrong

Monthly Notices of the Royal Astronomical Society, Volume 527, Issue 2, January 2024, Pages 4018–4030, https://doi.org/10.1093/mnras/stad3286

Published: 26 October 2023 **Article history** ▾



Validation components



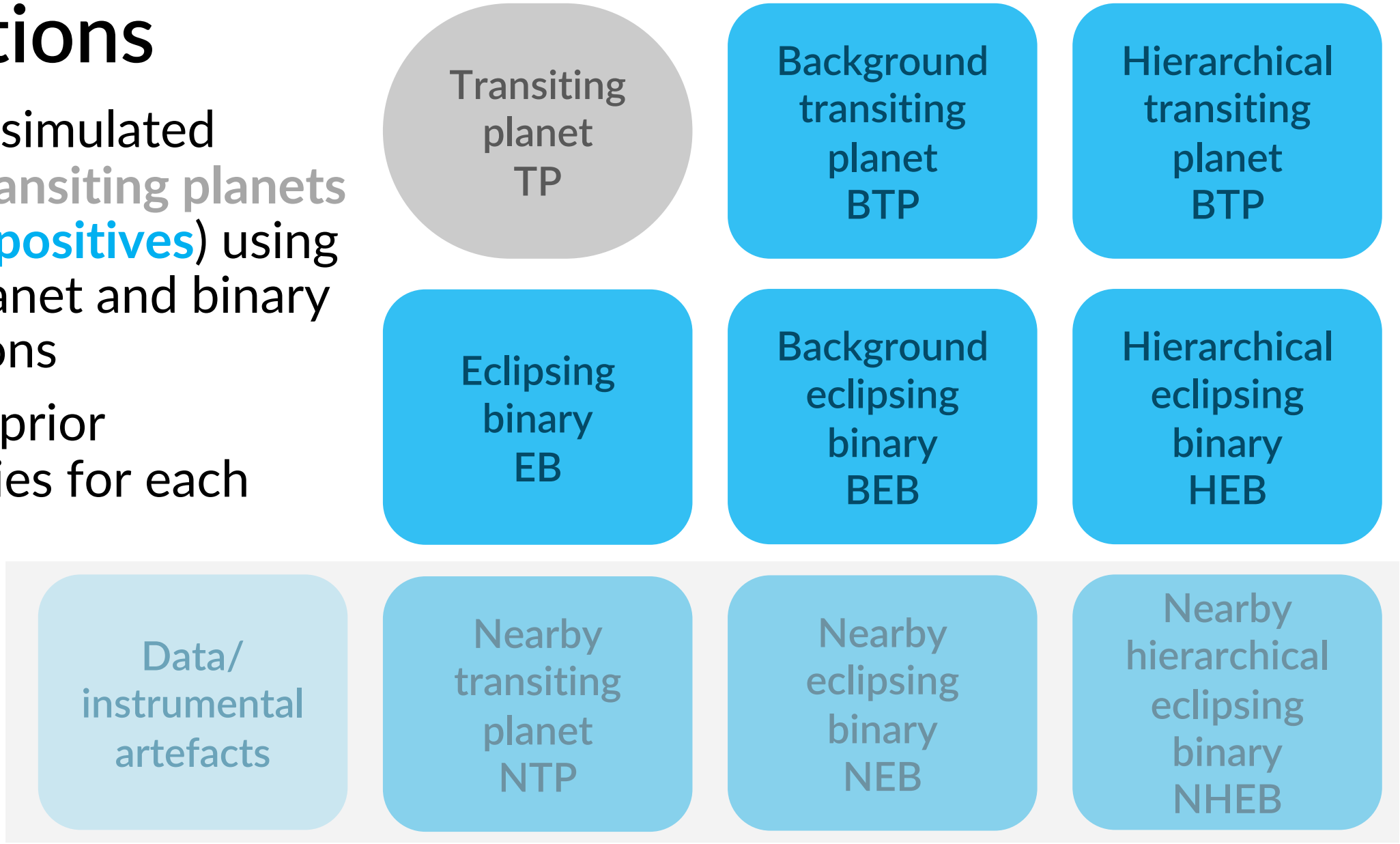
Priors from literature

From transit search on injections

From centroid COB - Hadjigeorghiou & Armstrong 2024

Simulations

- Generate simulated events (transiting planets and false positives) using known planet and binary distributions
- Calculate prior probabilities for each scenario

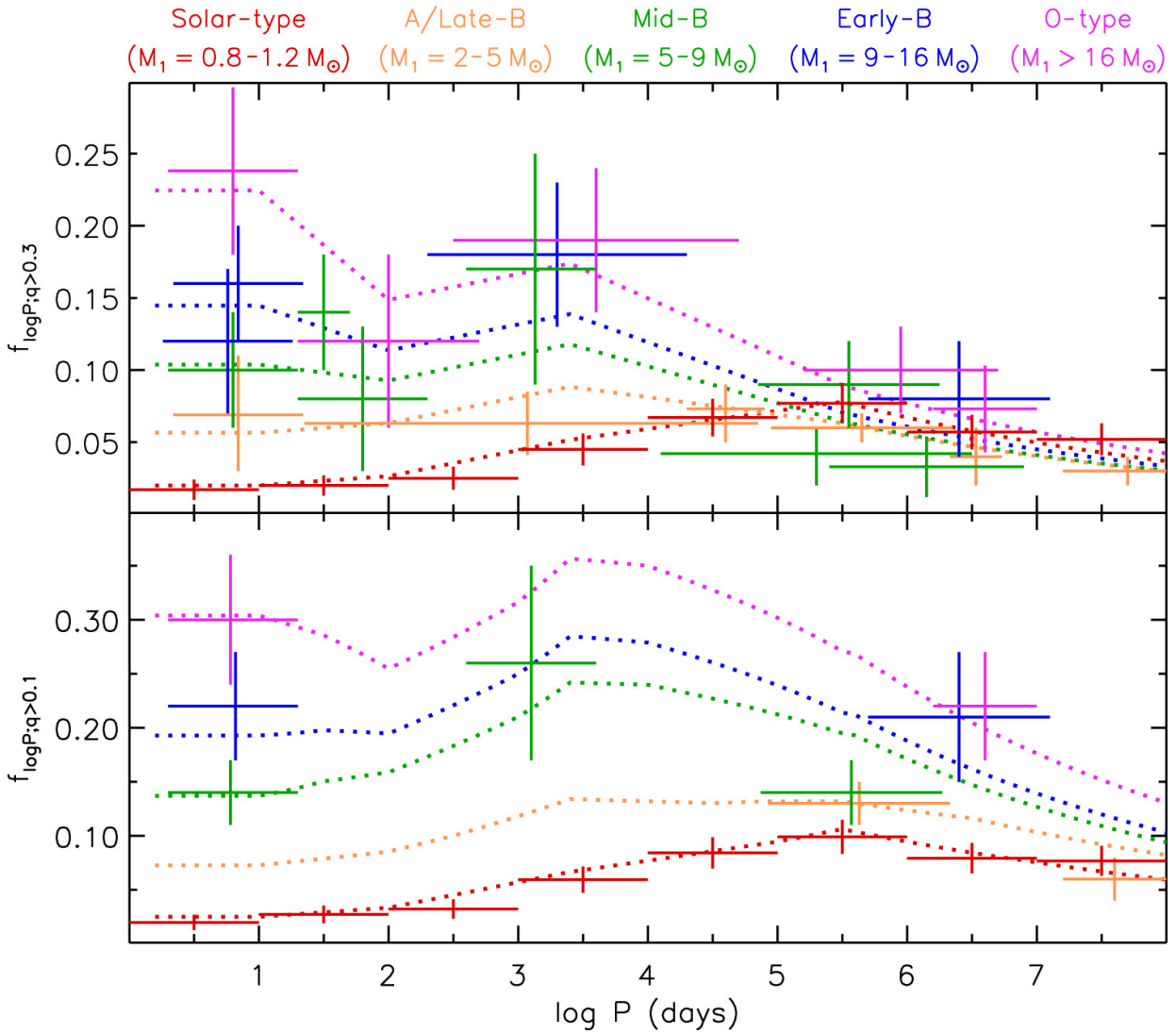


Simulation distributions

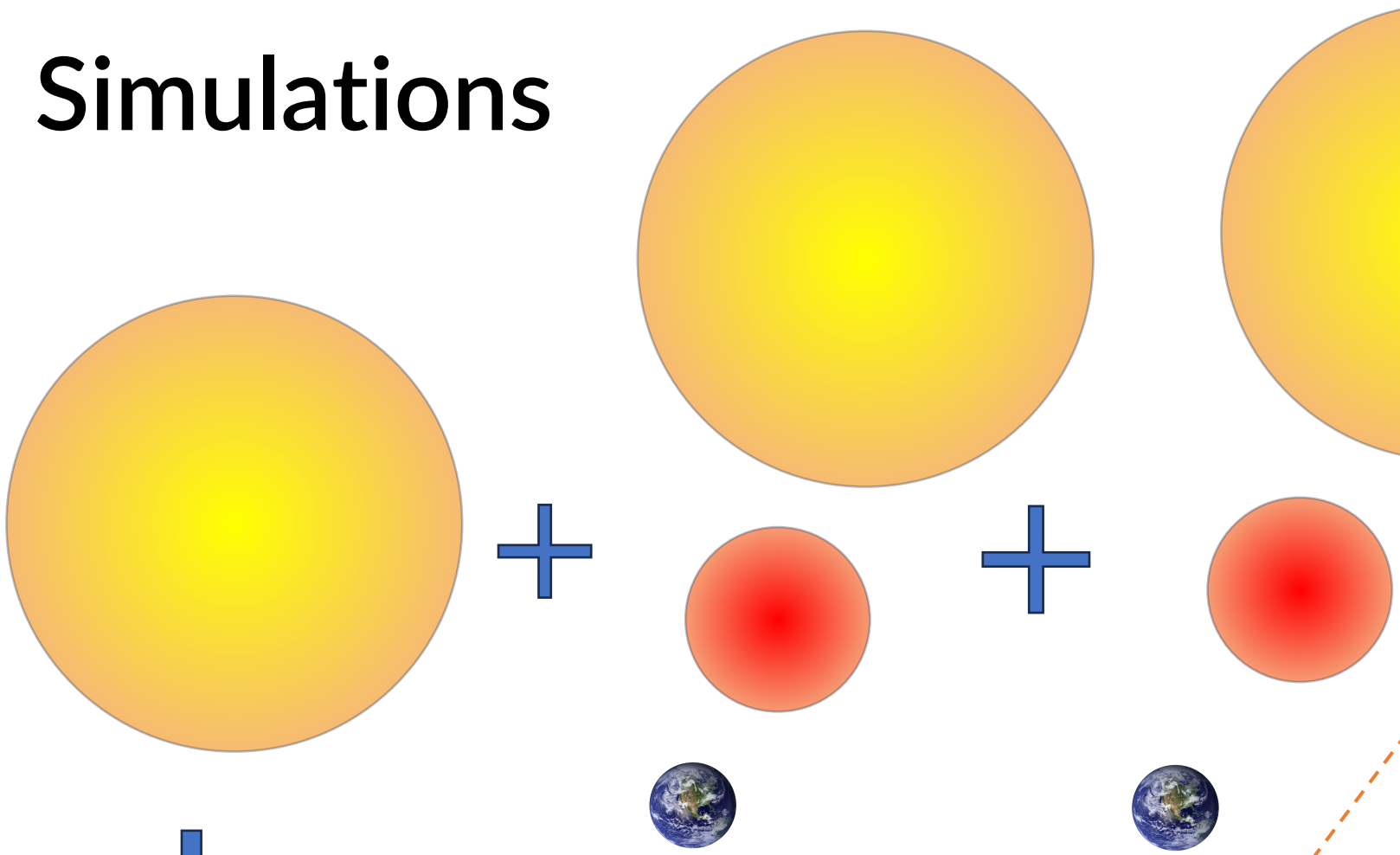
Stellar distributions mostly from Moe + di Stefano 2017

Orbital period, mass ratio, overall multiplicity

Planet distributions mostly from Hsu et al 2019 (Kepler - very uncertain for long period Earths, of course)



Simulations



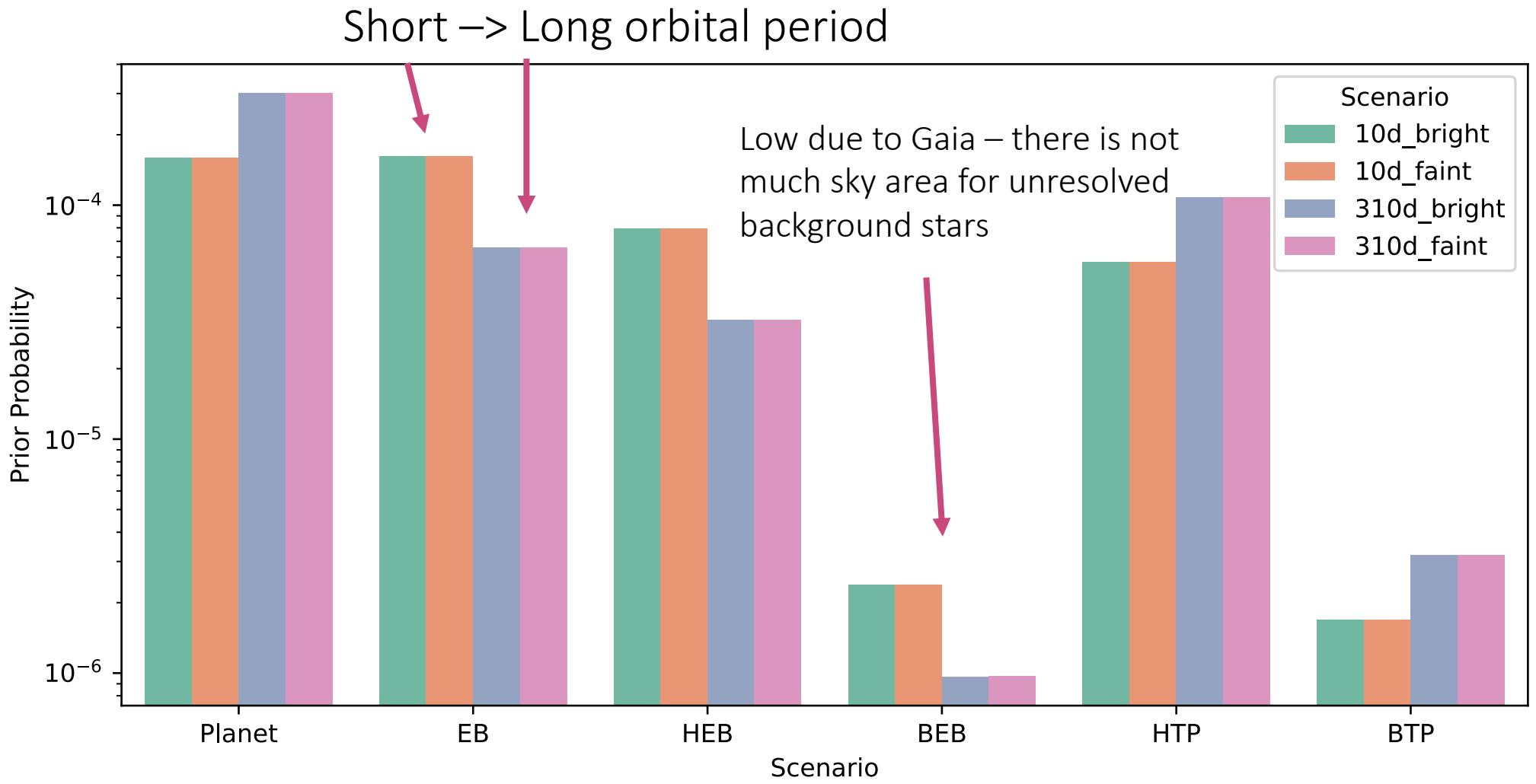
Orbits, Distances, e (if wanted)

Specific host star, orbital period, …

Full system data

Multi-color transit lightcurves(!), Expected RV signal, Astrometry…

Priors Comparison



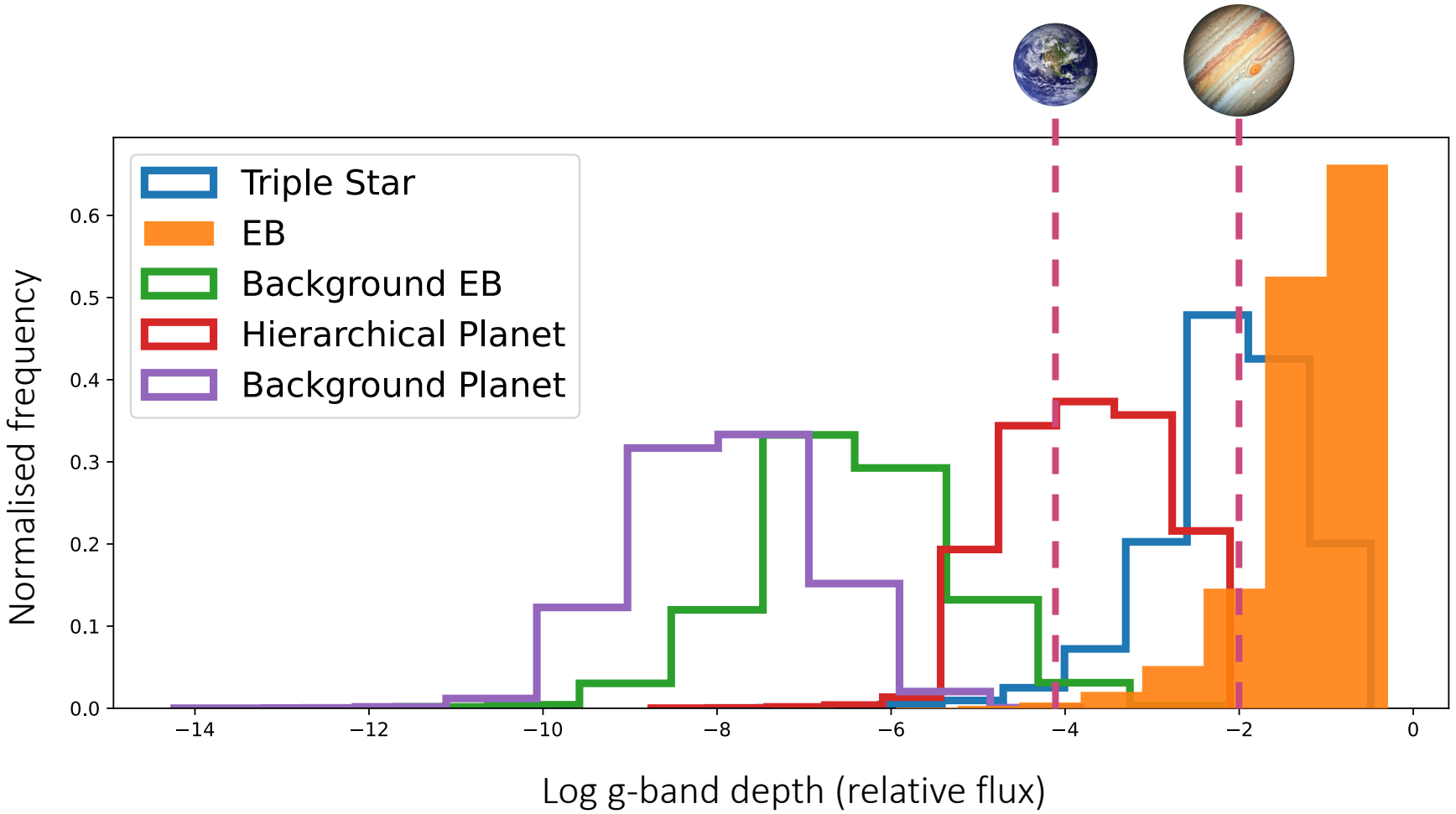
V= 7.9

V=12.6

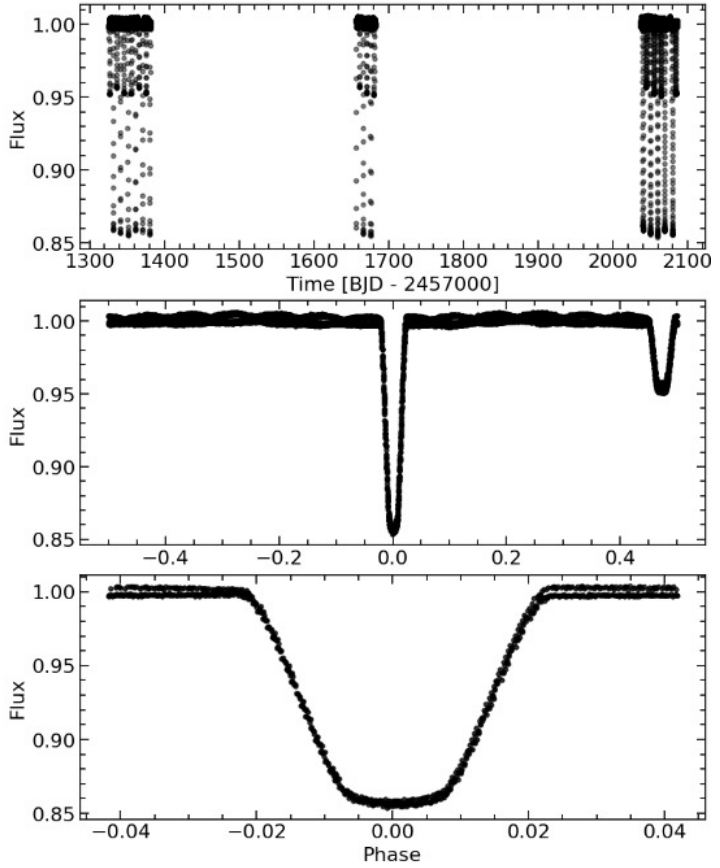
Appropriate distances

This is probability to happen at a given orbital period – not probability to be detectable

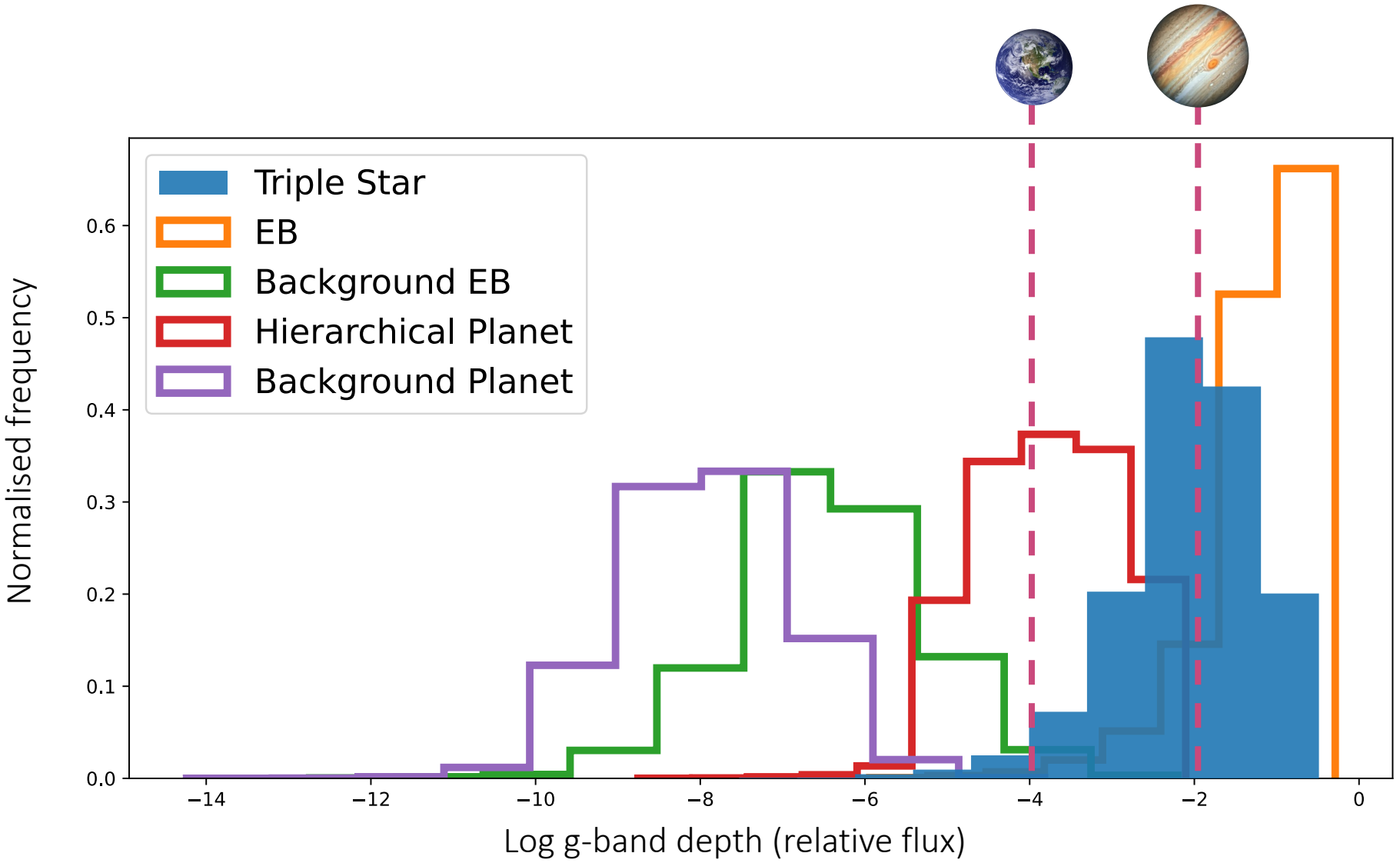
Eclipse depth distributions



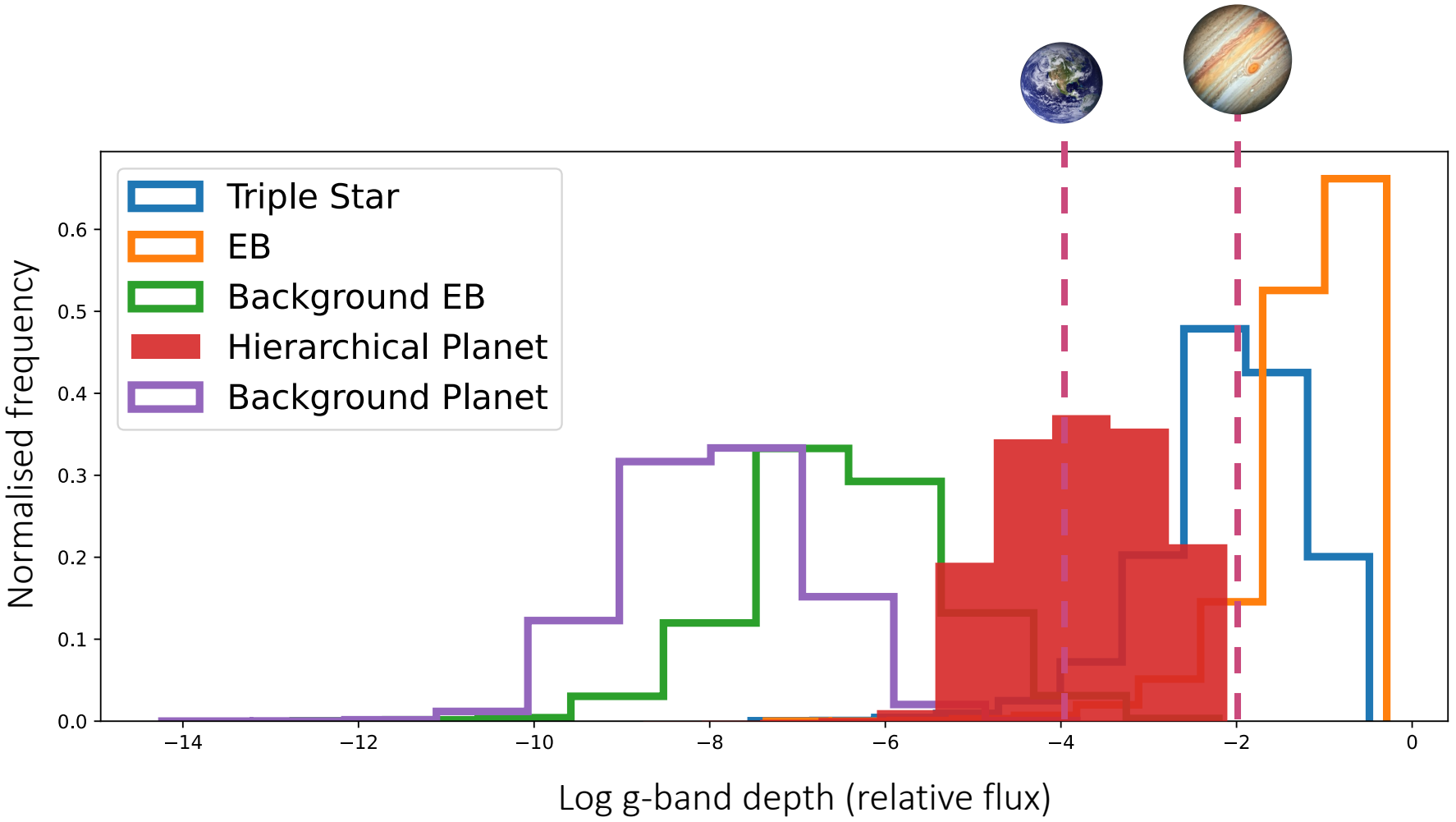
Eclipsing binary

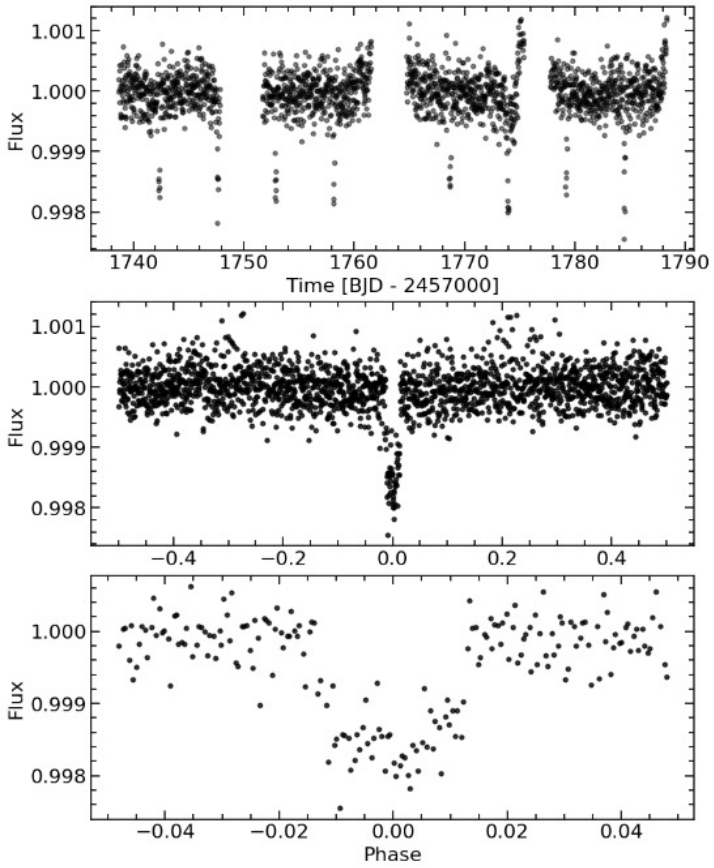


Hierarchical Triple Star

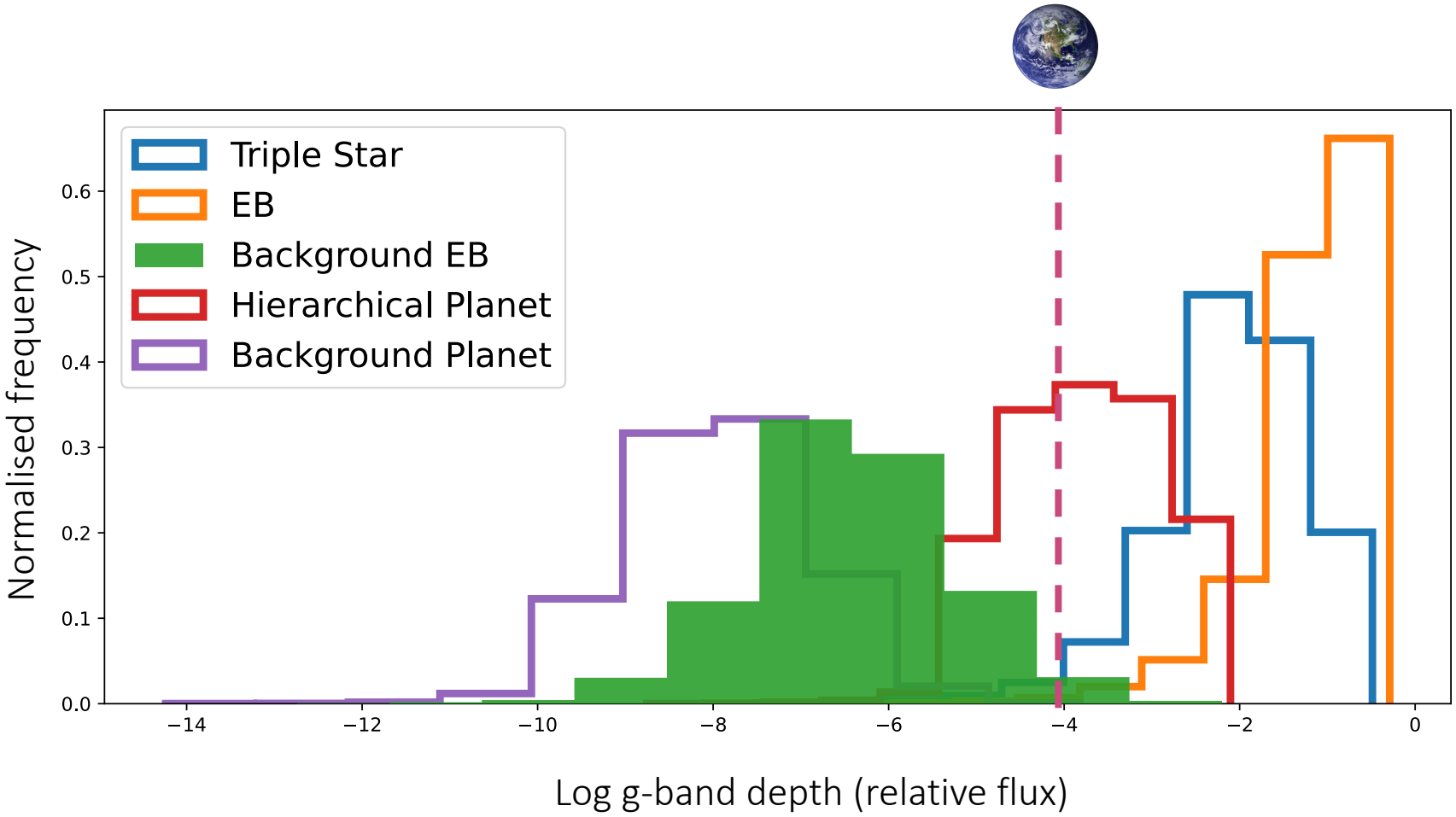


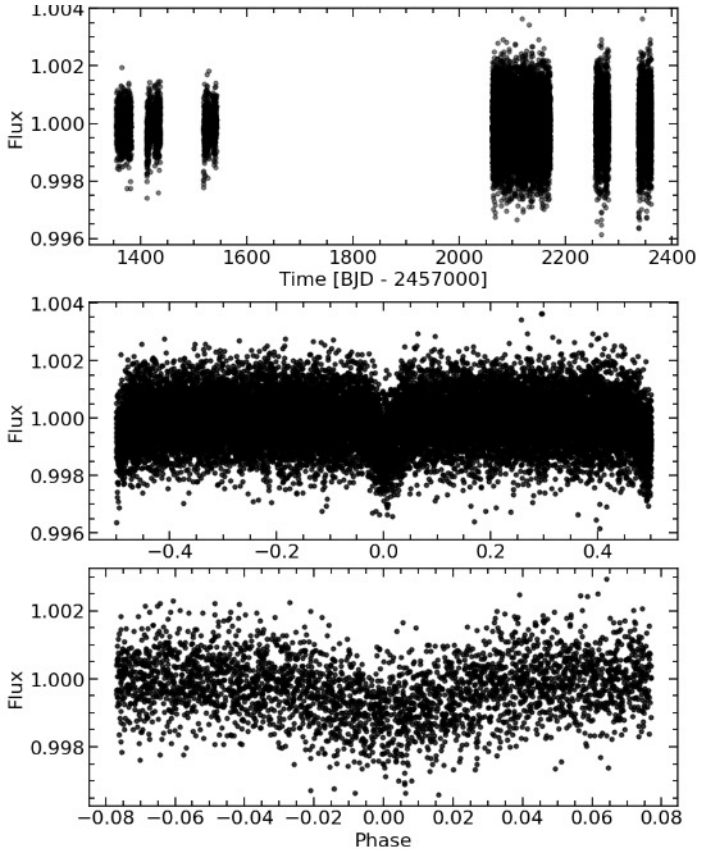
Hierarchical transiting planet



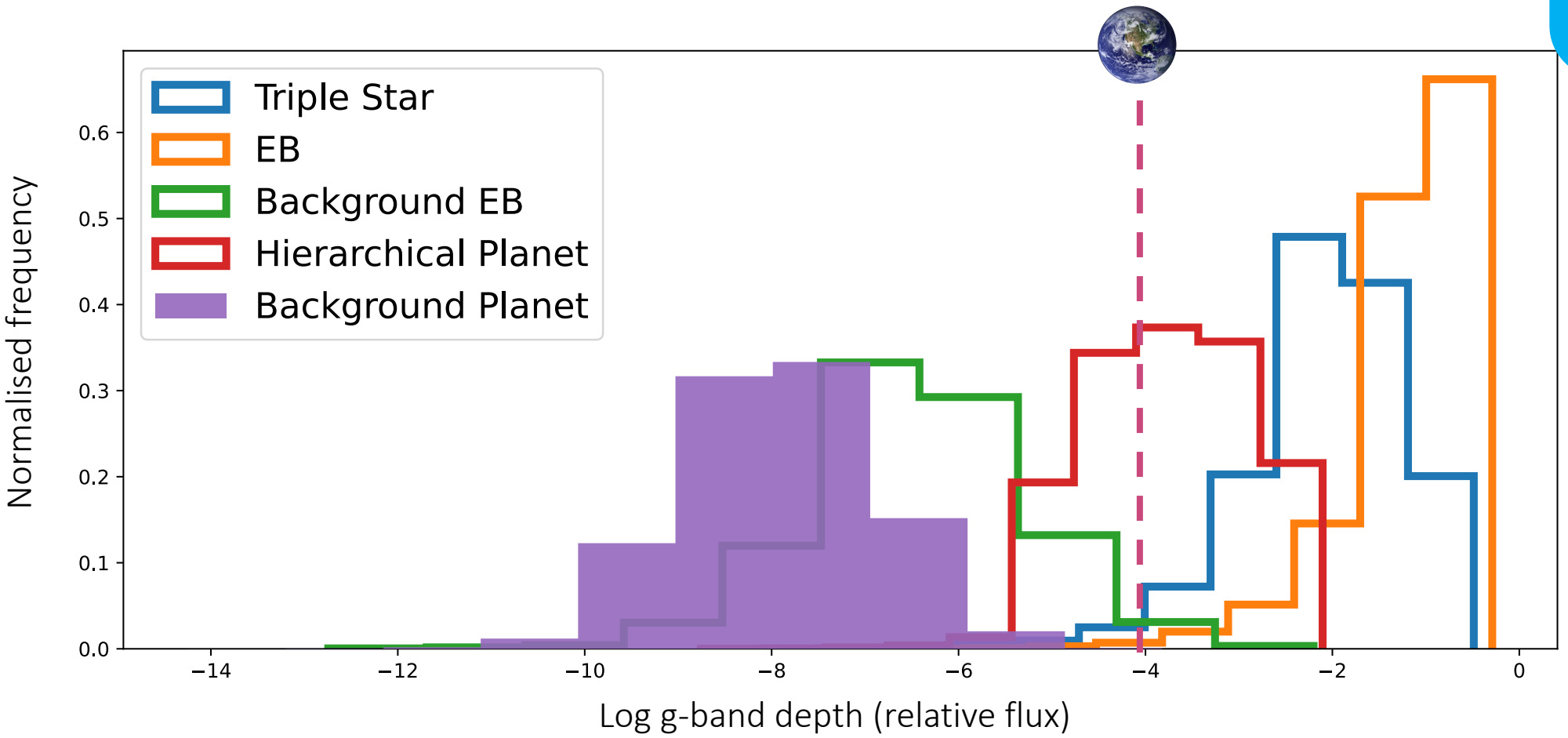


Background eclipsing binary



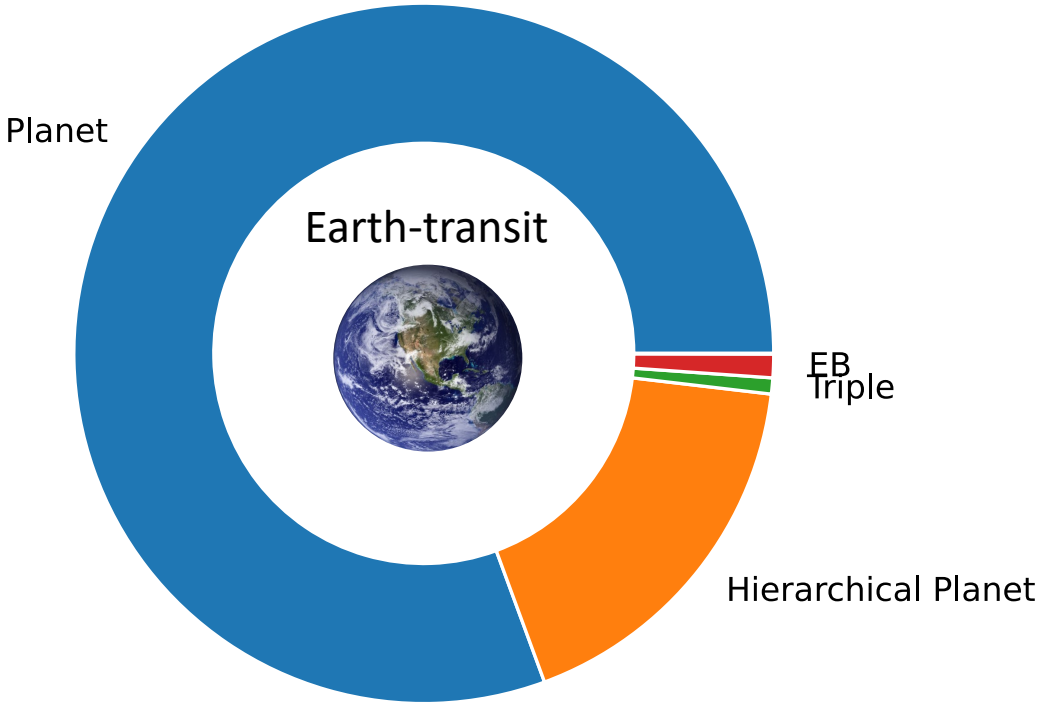


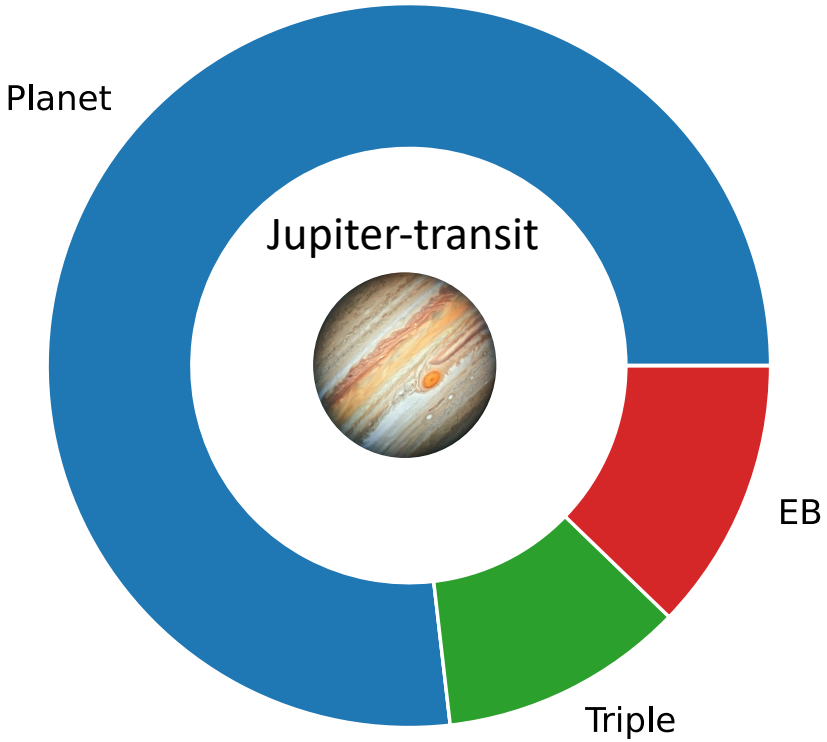
Background transiting planet



Overall distributions for a given candidate

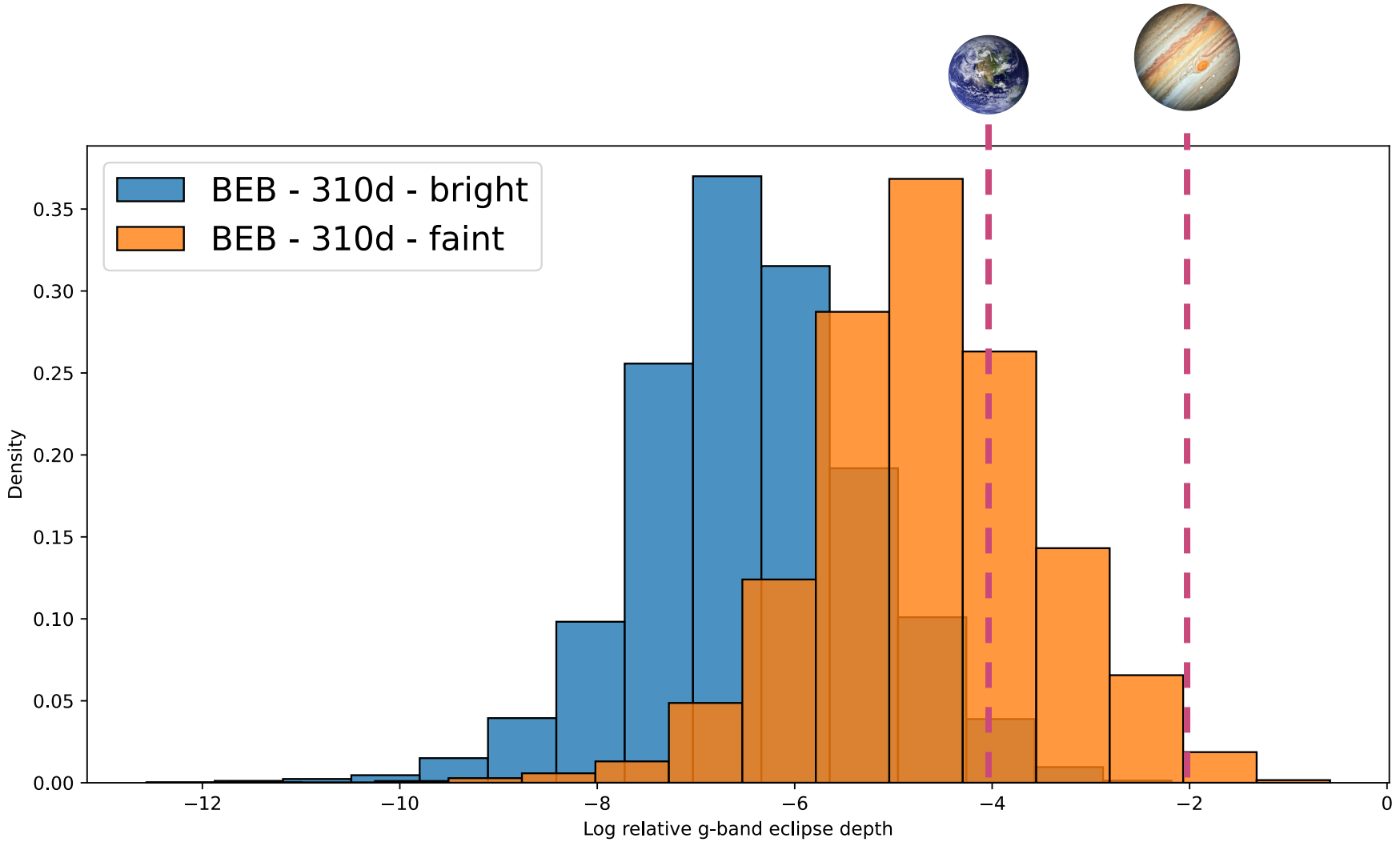
V=7.9, Solar host star, 310d candidate period



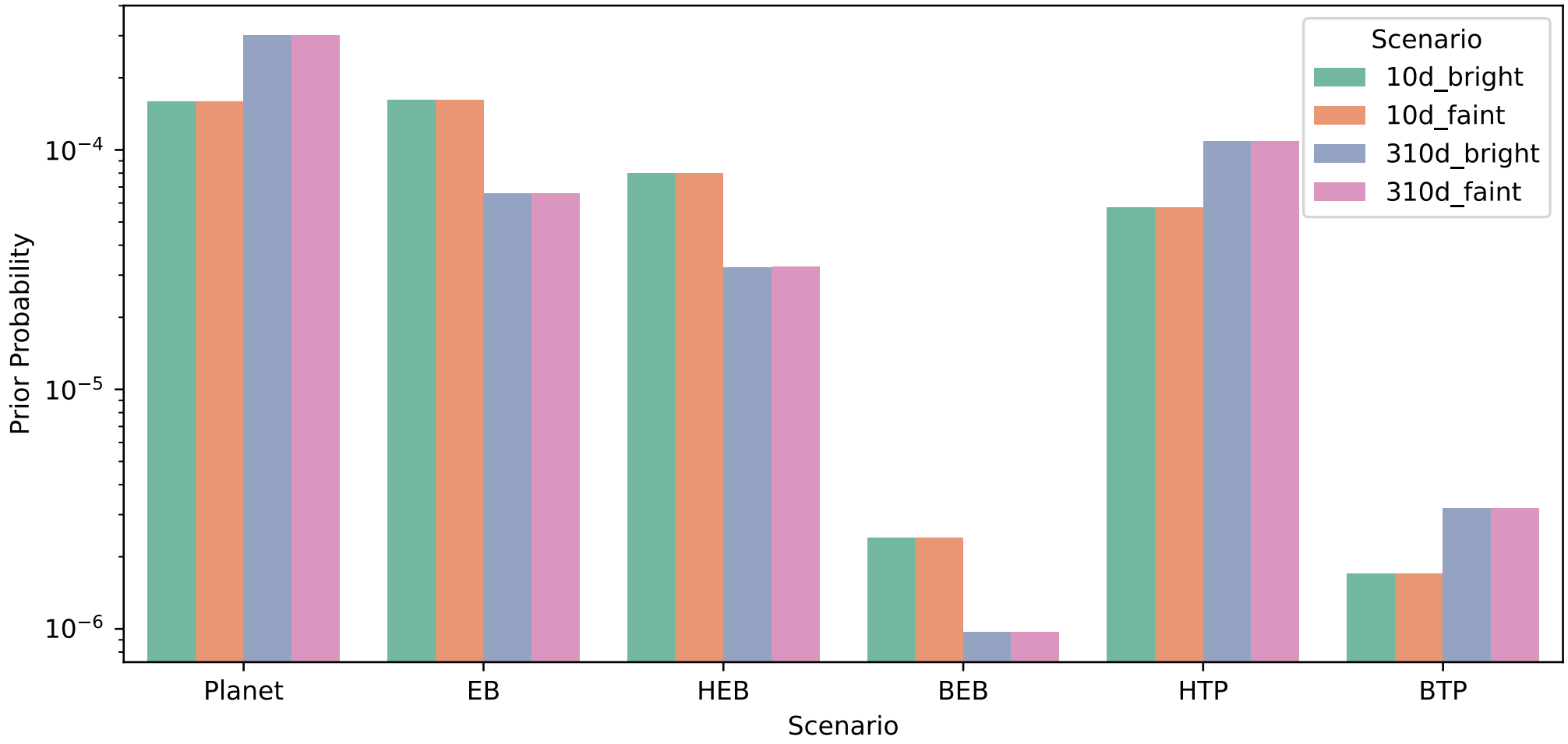


Warning! Eclipses on **nearby resolved stars** and **instrumental artefacts** not included here.
(also assumes Gaia resolves every contaminant at >2” separation)

Effect of brightness



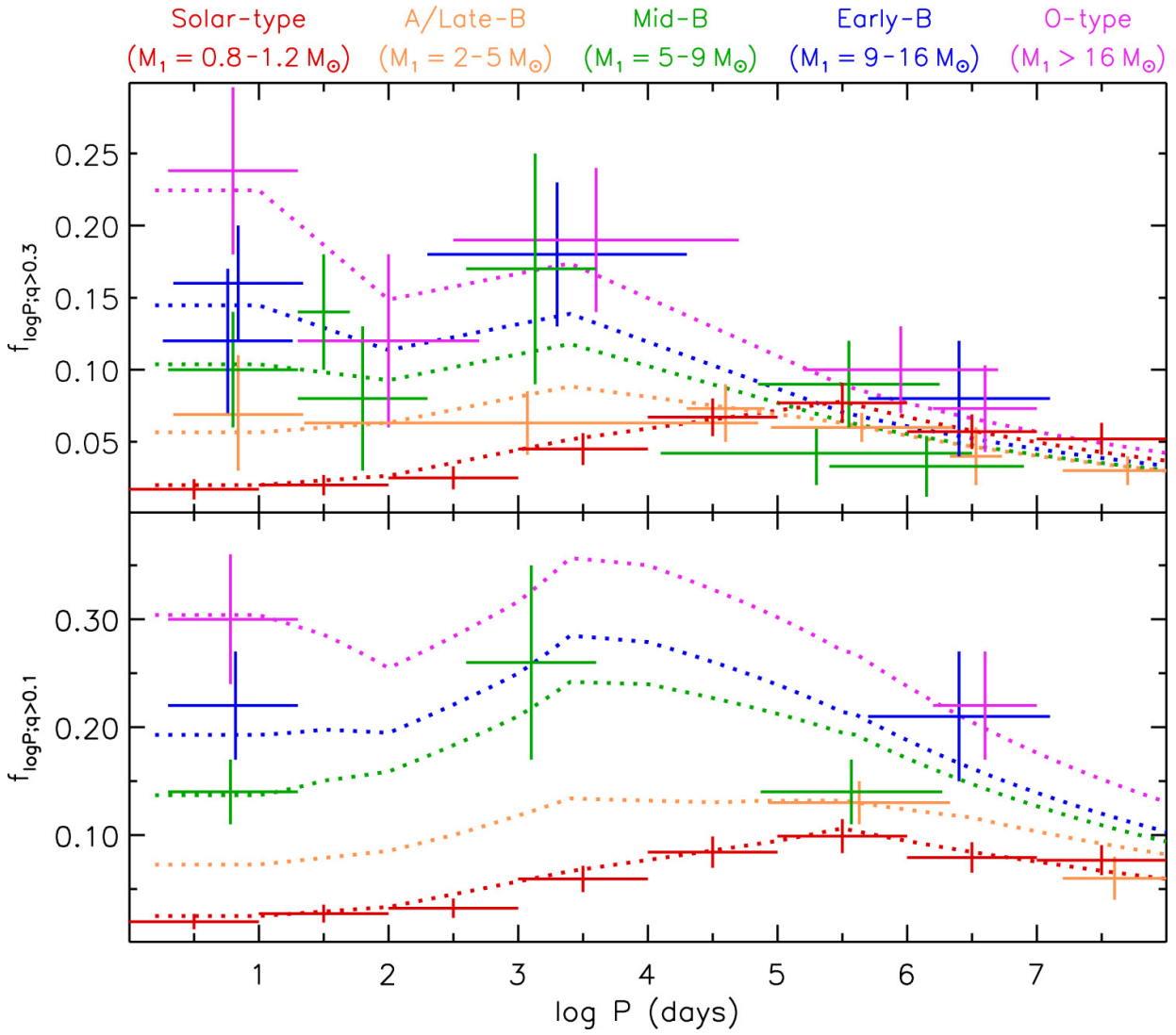
Effect of orbital period



Effect of host star

Stellar multiplicity – all scenarios involving multiple stars (which is most of them) increase for hotter host stars.

Prime Sample has stars up to $1.5M_{\odot}$ - approx. double rate of companion stars compared to $1.0M_{\odot}$



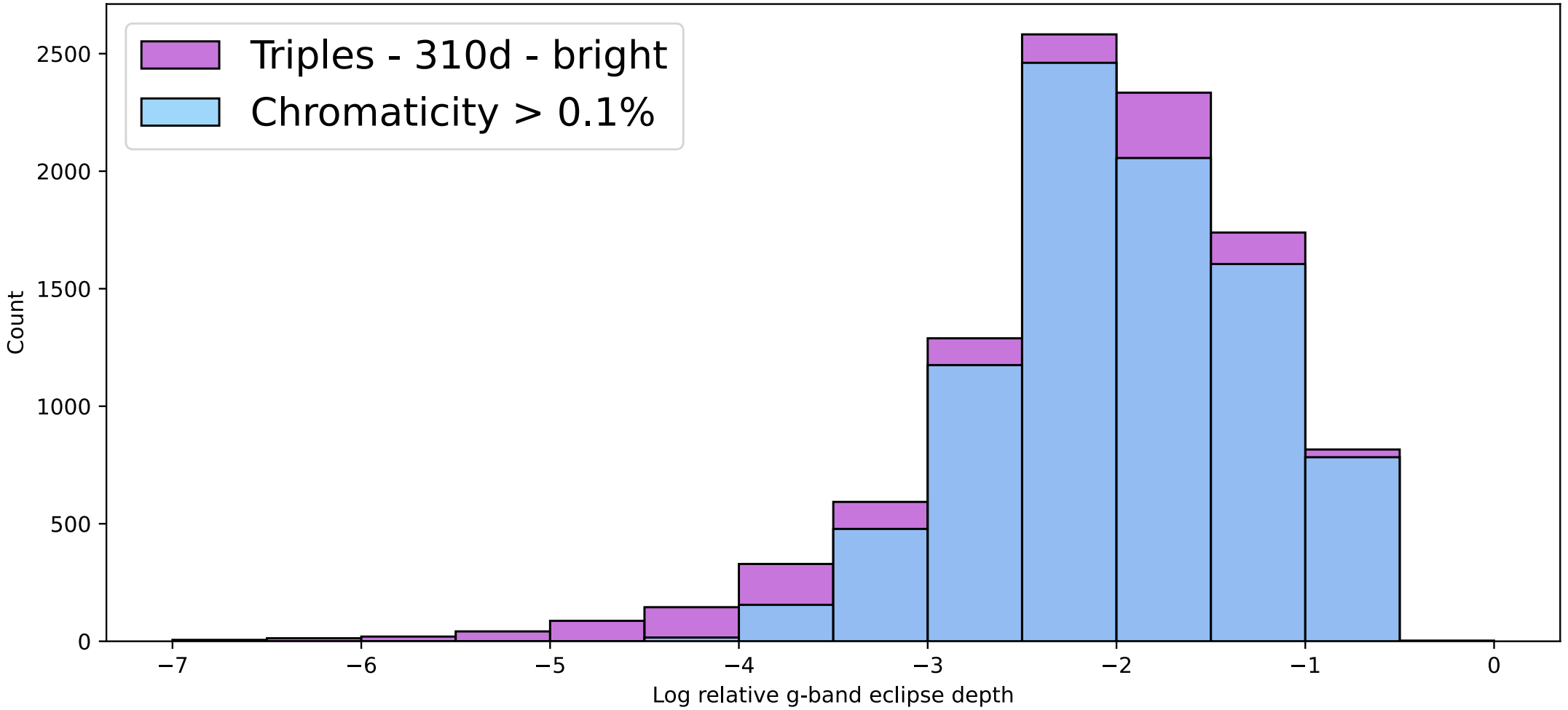
Caveats- Nearby stars, instrumental artefacts

- Planet distributions are uncertain! But planet-related false positive scenario priors scale with true planets.

- EBs and planets on resolved, separate stars from the host not included here. These are a significant source of false positives, but (in theory!) identifiable through centroids, ground-based follow-up, or avoidable.

- Understanding instrumental artefacts critical for small few-transit signals. E.g. Kepler rolling-band noise.

Solutions - Chromaticity

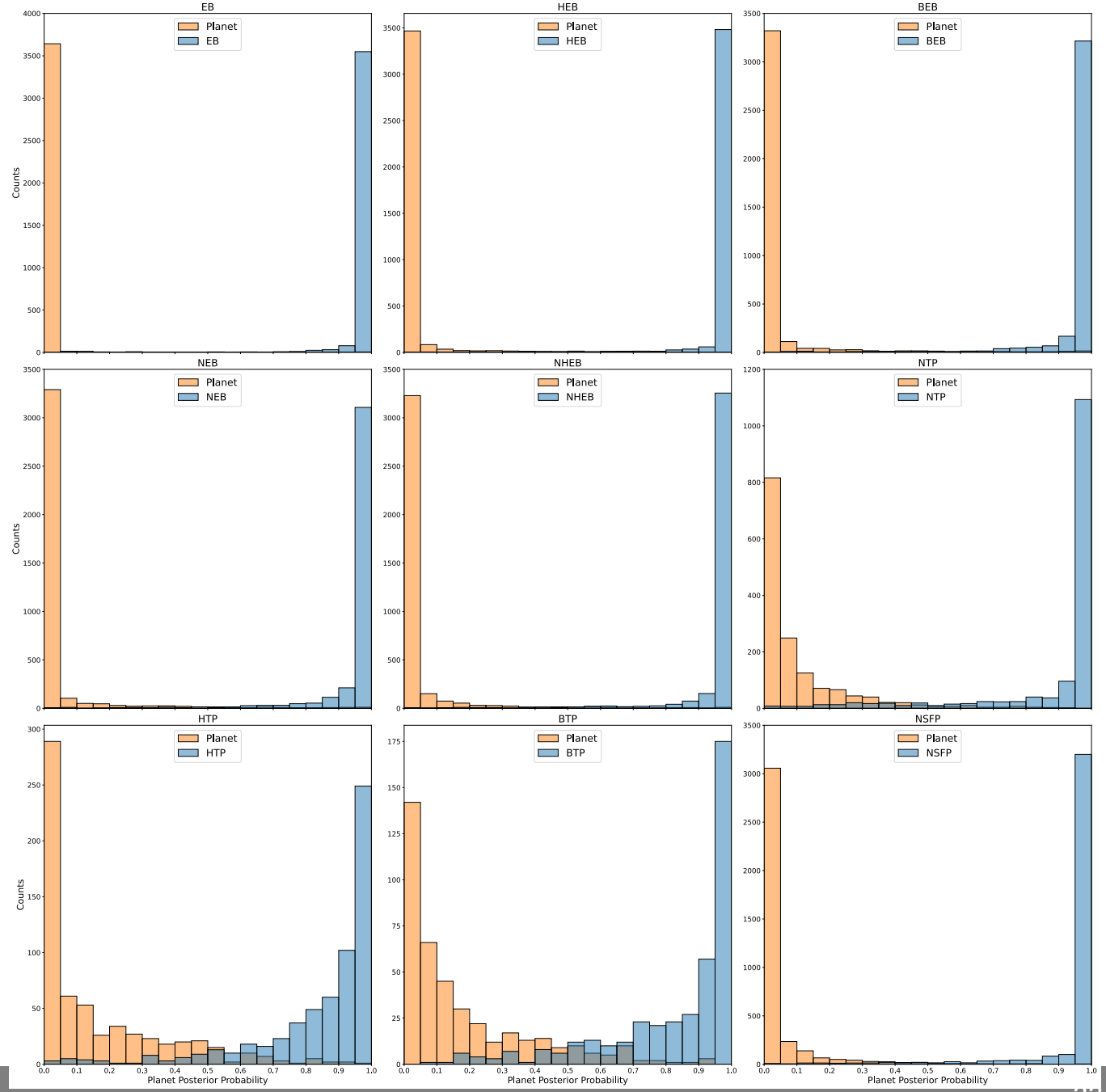


Solutions - Vetting

Vetting methods well established

Typically not tested per false positive scenario

These simulations allow detailed testing



Solutions – Gaia, NEB screening, AO imaging

- **Gaia** – Astrometric orbits for bound stars. Can detect some(most?) HTPs/Triple stars.
- **High contrast imaging** to reduce sky area for bound or background stars
- **Complete NEB screening** – or ignore candidates with potential contaminants
- Most critical, and hard to predict – understand **instrumental noise.**

Summary

- We can simulate lightcurves for a wide range of scenarios – get in touch!

- Prior distributions imply sources of false positives shift from blended stars to blended planets, for small, long period transits. Instrumental artefacts are critical

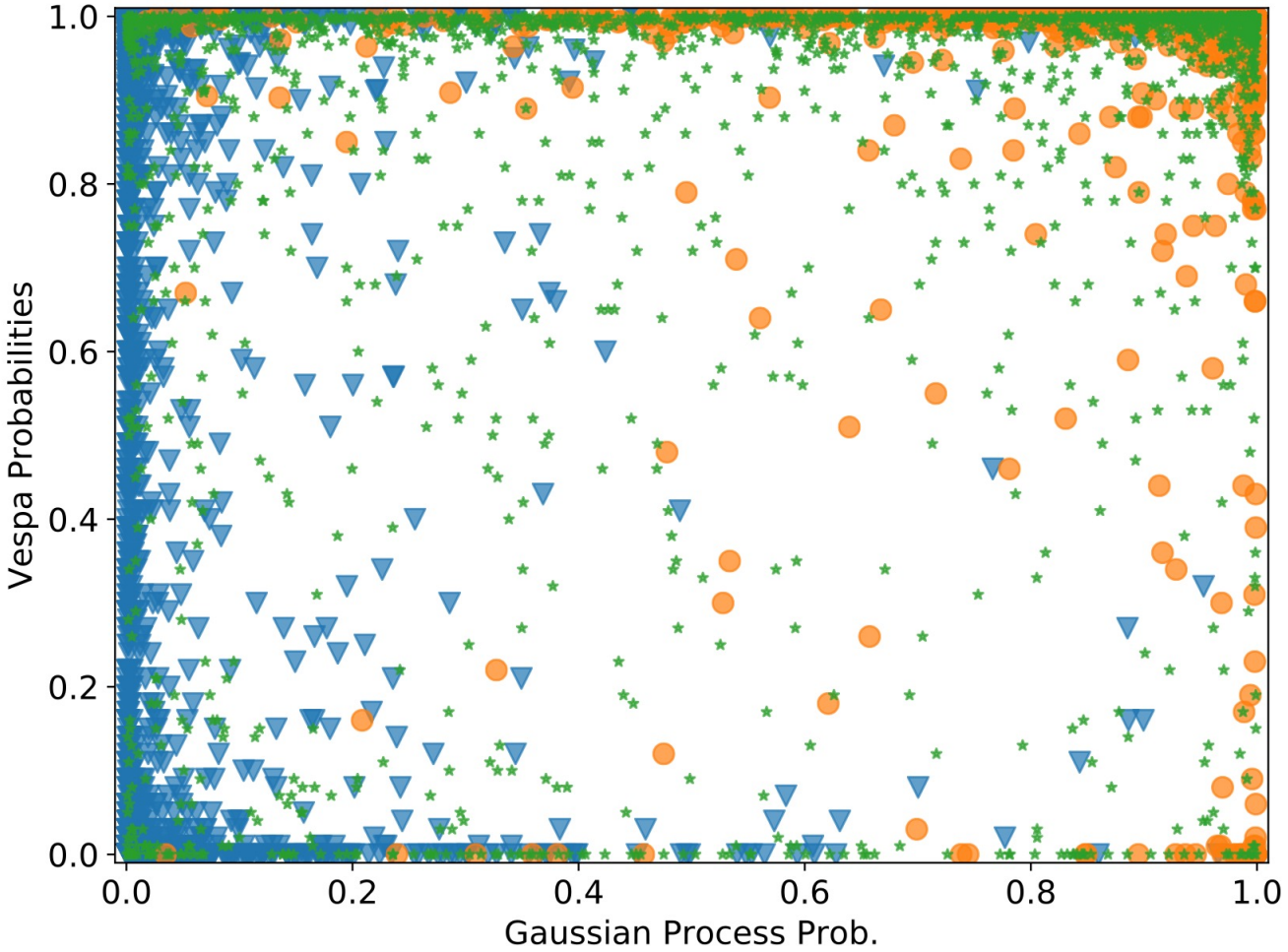
- Gaia knowledge of bound stars in system, plus nearby contaminants, can completely change FP scenarios

Aside - validation

- In Kepler and TESS, often different validation methodologies disagree.
  - This can be due to data, choices of priors and distributions, methodology..

Aside - validation

- In Kepler and TESS, often differ
  - This can be due to data, choices



Armstrong+, 2021

Summary

- We can **simulate multi-color lightcurves** for a wide range of scenarios – get in touch!

- Prior distributions imply sources of false positives shift from blended stars to blended planets, for small, long period transits. Instrumental artefacts are critical.

- Gaia knowledge of bound stars in system, plus nearby contaminants, can completely change FP scenario prior probability.

- Validation outcomes can be highly variable and dependent on distribution choices – be careful, and **please don’t treat validated planets as equal to ‘confirmed’.**