Orbits and Masses from RV and Astrometry

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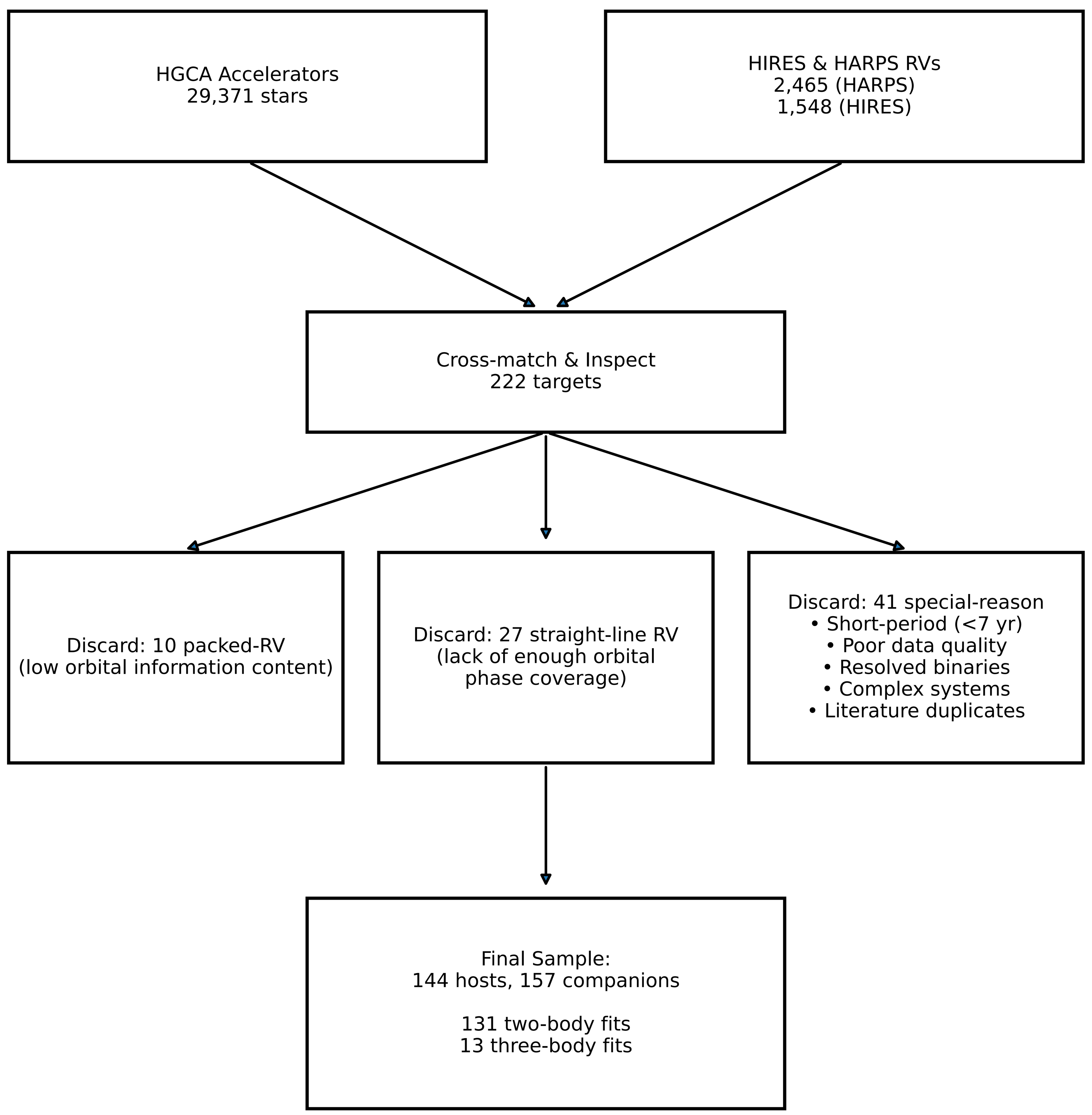
Motivation & Intro

One of the central aims of exoplanetary science is to understand how substellar companions—from giant planets to brown dwarfs—form and evolve within their host systems. Precise measurements of companion masses and orbits are the key to distinguishing whether these objects arise via a star-like collapse of molecular clouds or a planet-like assembly within protoplanetary disks. In particular, the observed paucity of brown dwarfs at small separations—the so-called "Brown Dwarf Desert" between roughly 25–65 MJup—hints at distinct formation channels on either side of this mass gap . Dynamical, model-independent mass measurements that combine radial velocities (RVs) with long-baseline astrometry offer the most robust route to characterizing this regime and calibrating substellar evolutionary theory.

Target Selection & Data



Orbit fit & Result

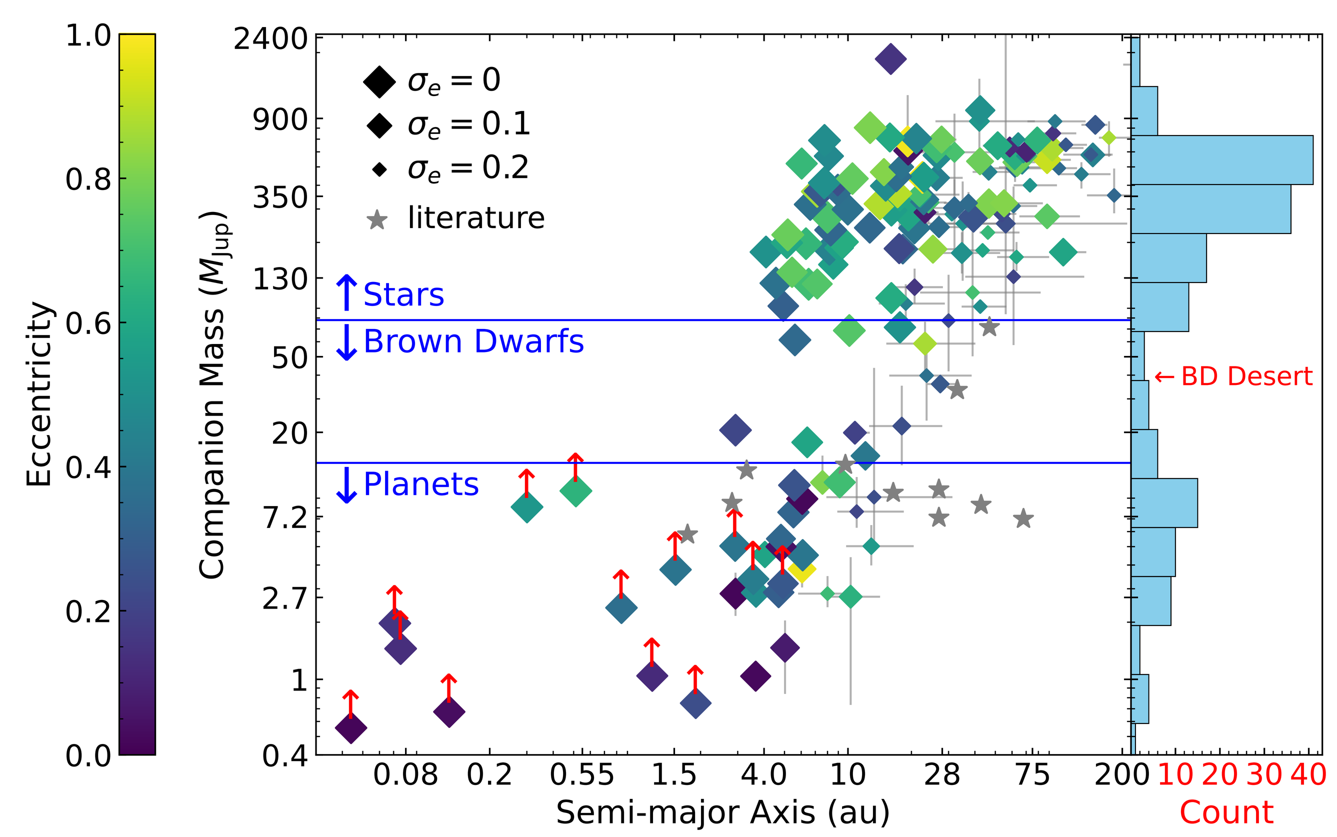
Orbit Fit:

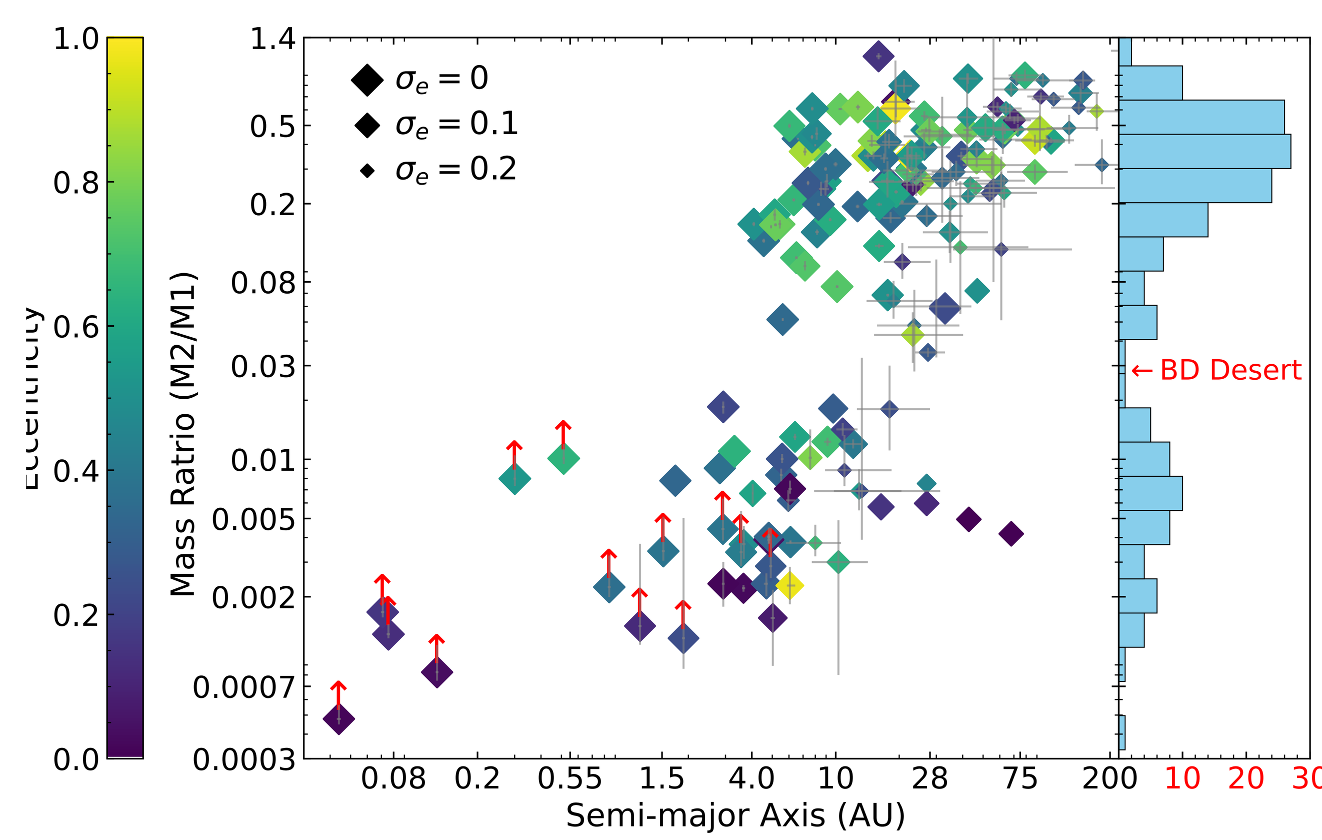
We jointly fit RV, HGCA astrometry, and—when available—relative astrometry using **orvara** (the open-source python package)

- **Priors**: Gaussian on host star mass **M1**; log-flat on companion mass **M2**, semi-major axis **a**, and RV jitter **σ_jit**; uniform on eccentricity **e**, argument of periastron **ω**, mean longitude **λ**, and longitude of ascending node **Ω**; geometric (sin i) on inclination **i**.
- **Sampling:** Parallel-tempered MCMC (100 walkers × 20 temperatures, ≥200 000 steps; 50 % burn-in).

Key Results:

- **157 orbits solved:** 34 planets, 12 brown dwarfs, 111 stellar companions
- **Brown-dwarf desert:** pronounced deficit of companions from 25–65 MJ, centered near ≈40 MJ in mass–separation and at mass ratio ≈0.03 in mass-ratio–separation regime.

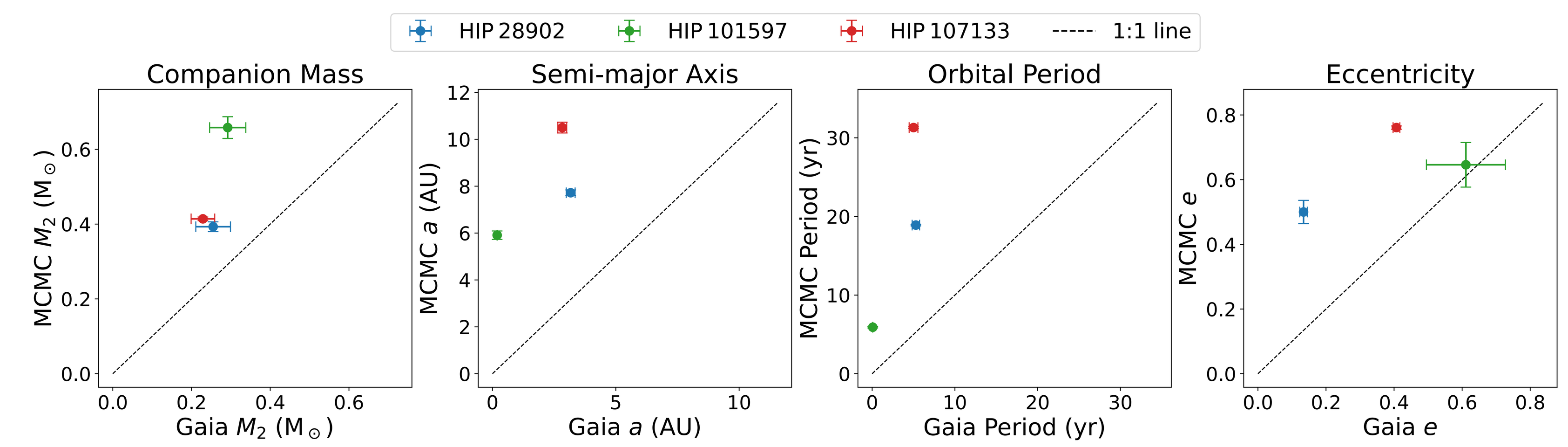




Compare with Gaia DR3 NSS Solutions

Two Body Orbit:

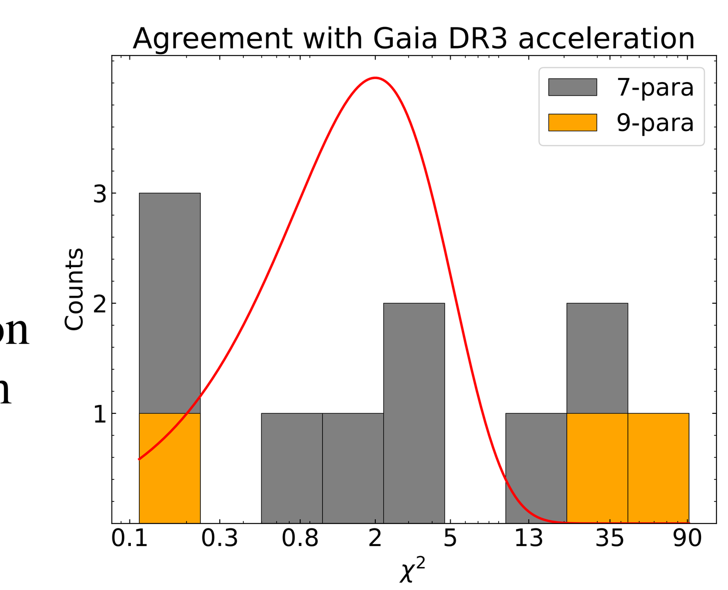
Assuming the companion's luminosity is negligible; M1 is adopted from **orvara** fit; Gaia sma is converted to enable direct comparison with our results.



Takeaway: The systematic offset between our results and the Gaia two-body solutions stems from the Gaia binary pipeline's period grid. Gaia DR3 searches periods only up to twice the observational baseline (~2000 days or ≈5.5 years), so orbits with P ≳ 5 years are poorly sampled and the resulting two-body fits become unreliable. Researchers should treat Gaia DR3 orbital solutions with caution for long-period systems near or beyond this threshold.

Astrometric Acceleration:

Using each of the **orvara** chains, we propagate the orbit with **htof** through the GOST scanning law to predict Gaia-frame accelerations. The probability density function for the distribution with 2 degrees of freedom is plotted in red curve for reference.



Takeaway: Our predicted Hipparcos–Gaia proper-motion accelerations agree with Gaia DR3 NSS values to within 1–2 σ for the vast majority of systems, with no detectable systematic offset; outliers are confined to low-S/N NSS solutions, highlighting the reliability of high-S/N Gaia accelerations and the need for caution when using marginal NSS results.

Conclusion

- By combining long-baseline RVs with absolute astrometry (HGCA) and, where available, relative astrometry, we measure 157 companion masses (34 planets, 12 brown dwarfs, 111 stars) across 144 systems.
- We confirm the brown-dwarf desert exists in both mass–separation and mass-ratio–separation space.
- Our predicted proper-motion accelerations and orbital parameters agree with Gaia DR3 NSS for well-sampled systems, but Gaia's two-body fits become unreliable for periods ≳5 yr.