The Unexpectedly Divergent Fates of Hot Jupiters and Ultra-short-period Planets

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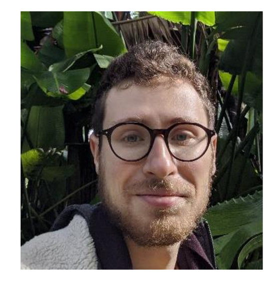
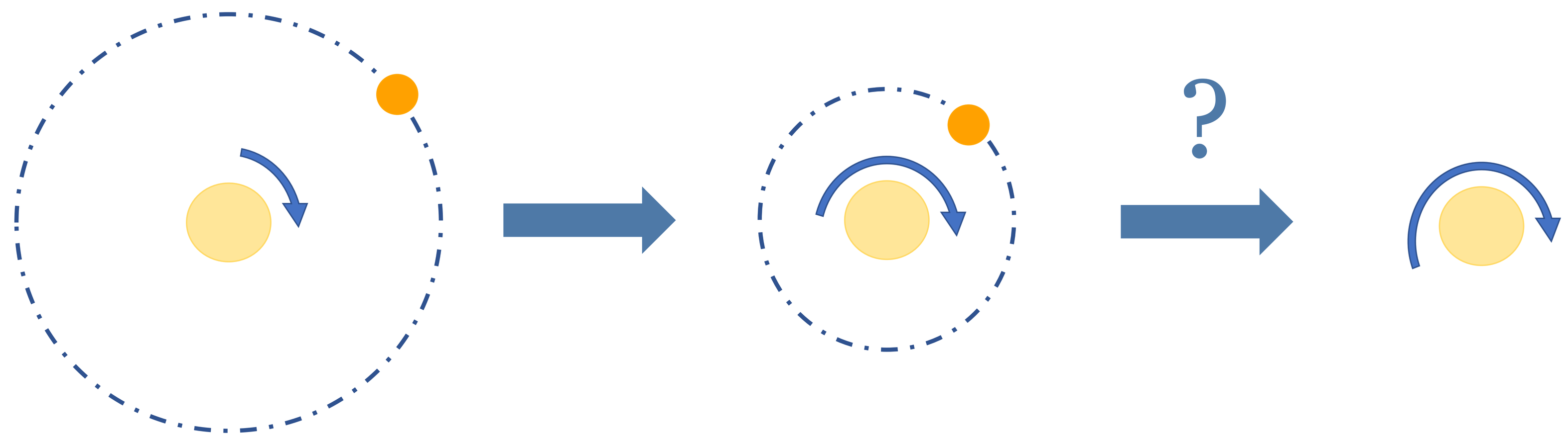
Hamer & Schlaufman (2019), Hamer & Schlaufman (2020, in press)



Abstract

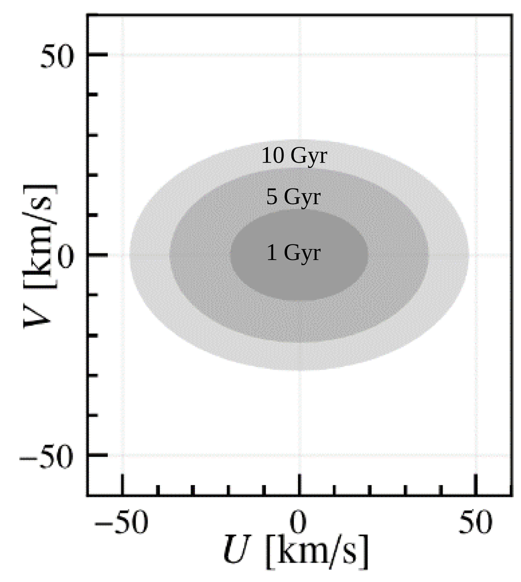
The robustness of short-period planets to tidal evolution as they age is one of the oldest unknowns in exoplanet astronomy. The detailed physics of tidal decay are highly non-linear and sensitively dependent on the details of stellar structure, so the problem is intractable from first principles. Only observational data can reveal the fates of these short-period planets. If short-period planets experience tidal decay, then they should only be found around relatively young stars. If they are robust to tides, then they can be found around stars of all ages. This simple idea has been impossible to test because of the difficulty of the stellar age inference problem. We have pioneered a new model-independent, non-parametric way to use the Galactic velocity dispersion of a stellar population to infer its average age. The application of our velocity dispersion technique has conclusively revealed that hot Jupiters are destroyed by tidal decay during their host stars' main sequence lifetimes. In contrast, we have found that ultra-short-period or USP planets are robust to tidal decay. This latter observation implies that the efficiency of tidal dissipation in exoplanet host stars often parameterized as Q*' must depend on a planet's period and/or mass and that USP planets experience eccentric migration.

Do hot Jupiters (HJ) and ultra-short-period (USP) planets tidally inspiral during their host's main sequence lifetime?



If tidal dissipation causes a population of exoplanets to inspiral before its hosts evolve off of the main sequence, then the hosts of that population should be on average younger than a similar population of non-host field stars

We use Galactic velocity dispersion as a relative age proxy

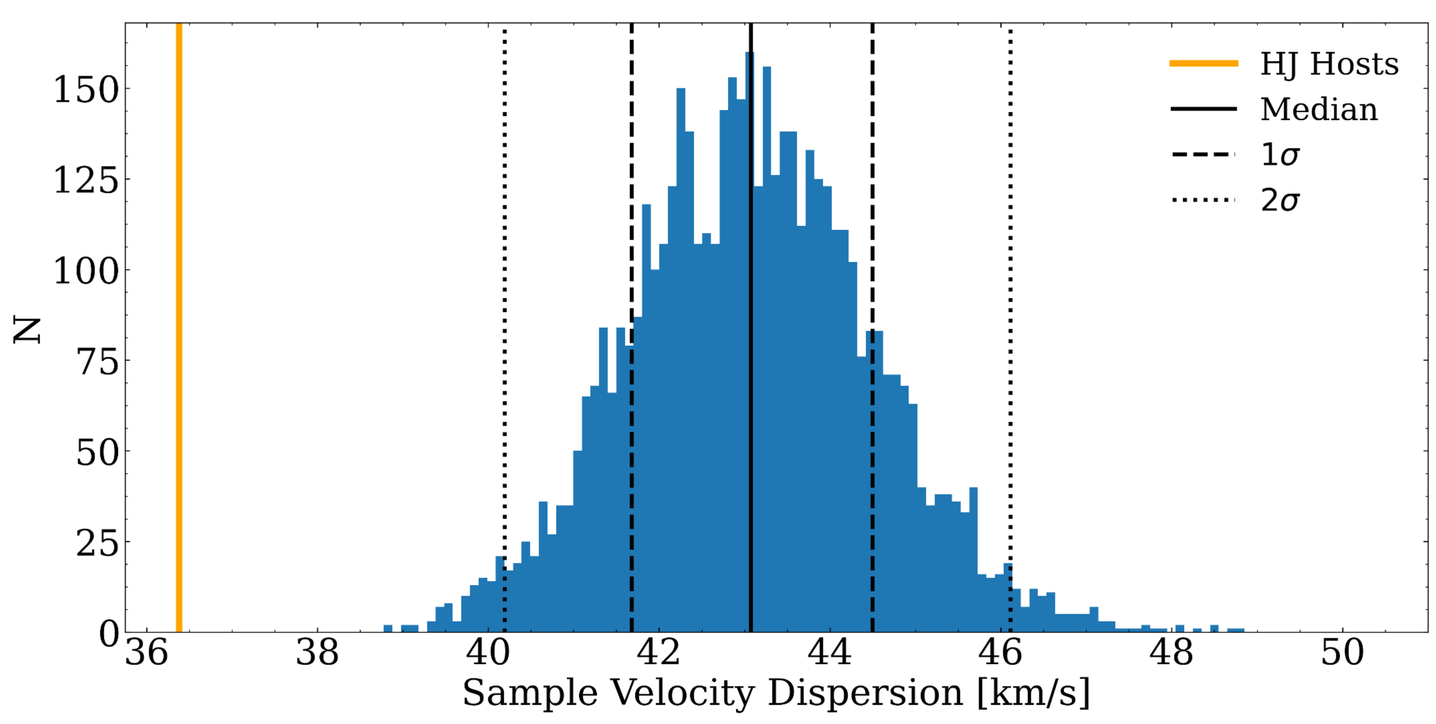


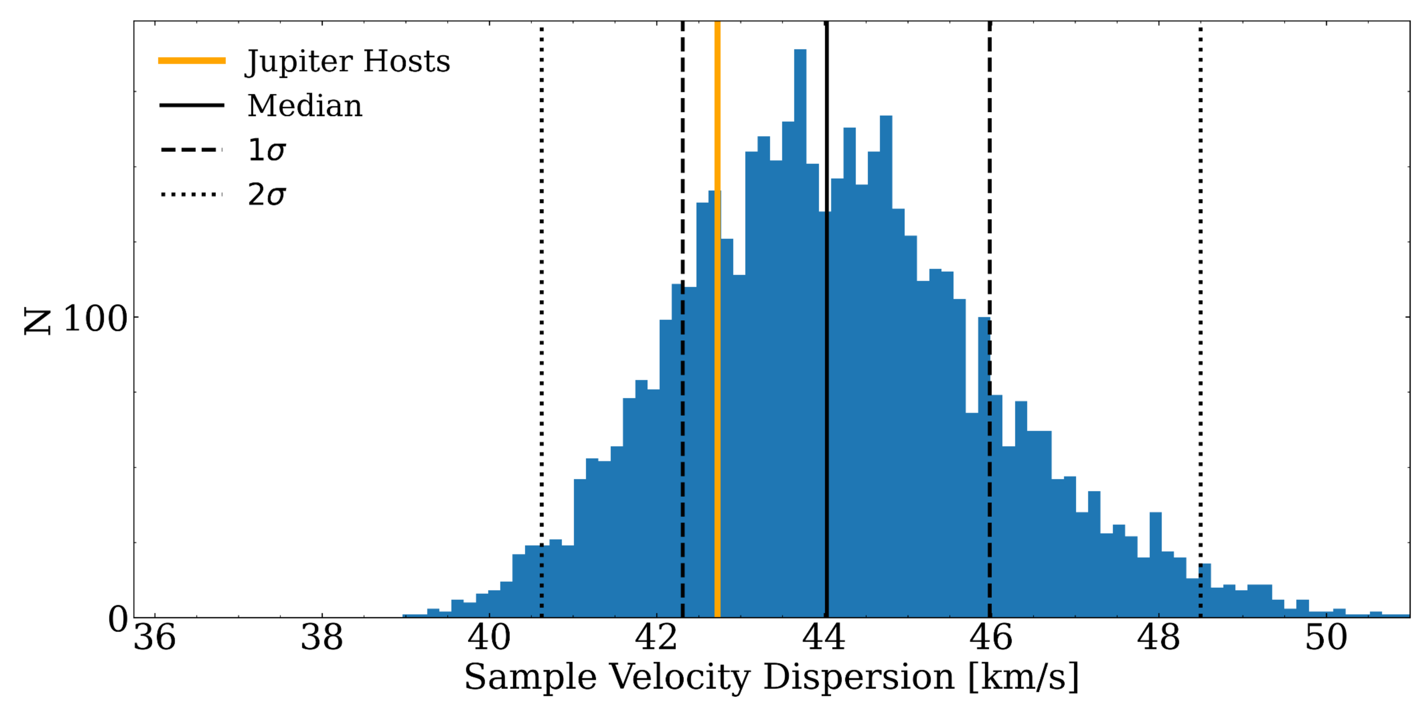
We use data from Gaia DR2 to derive UVW space velocities for hot Jupiter hosts and a large sample of field stars

We construct planet host and field star samples

313 Hot Jupiter hosts	68 USP planet hosts
335 Cooler Jupiter hosts	
~400,000 Field stars	~20,000 Kepler field stars

Hot Jupiter hosts have cooler kinematics than similar non-host stars, while longer-period giant planet hosts do not





Hot Jupiter hosts are a relatively young population while the hosts of longer-period giant planets, unaffected by tides, are not. Hot Jupiters are destroyed before the main sequence lifetimes of their hosts end.

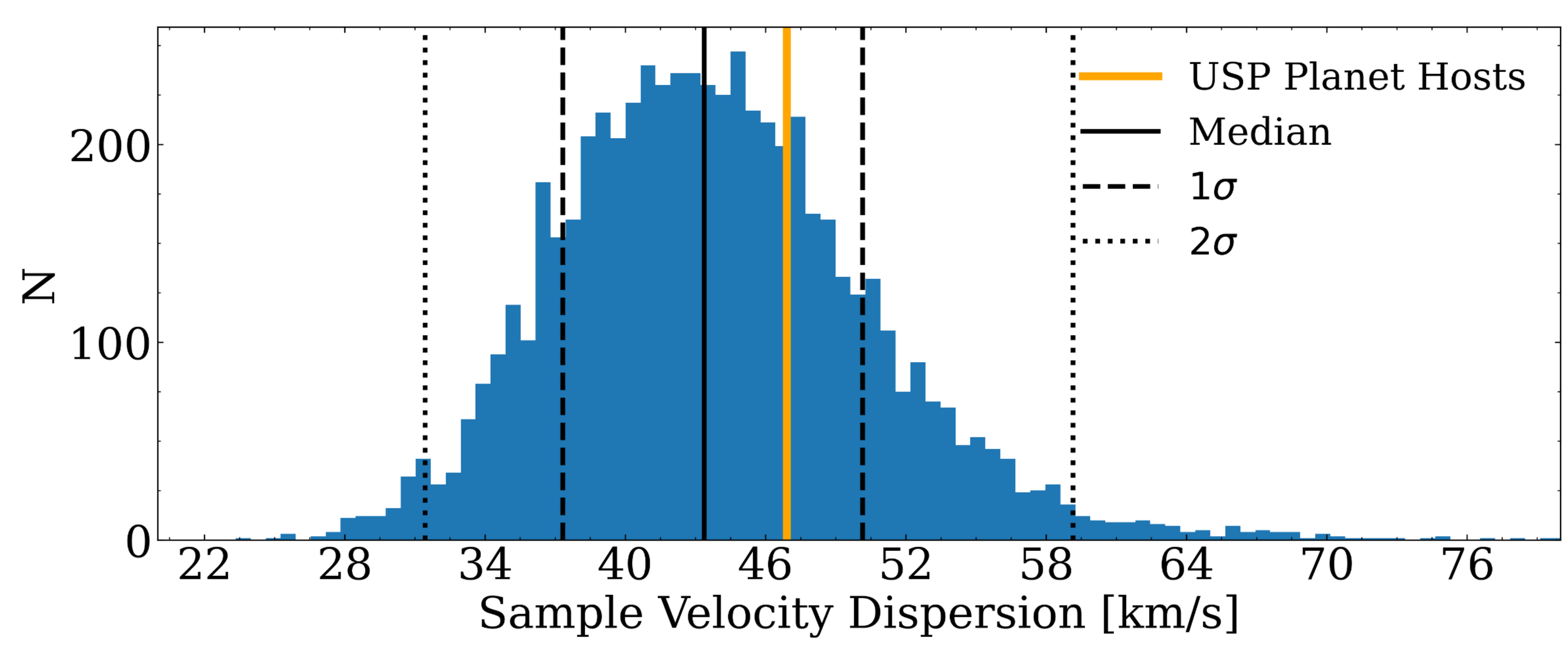
If Q'_* is the same as in HJ host stars, then USP planets should inspiral

$$t_{\rm in} = \frac{2}{13}\frac{2Q'_*}{9}\frac{M_*}{M_{\rm p}}\left(\frac{a}{R_*}\right)^5\frac{P}{2\pi}$$

$$\frac{t_{\rm in,USP}}{t_{\rm in,HJ}} = \frac{M_{\rm HJ}}{M_{\rm USP}}\left(\frac{P_{\rm USP}}{P_{\rm HJ}}\right)^{13/3}$$

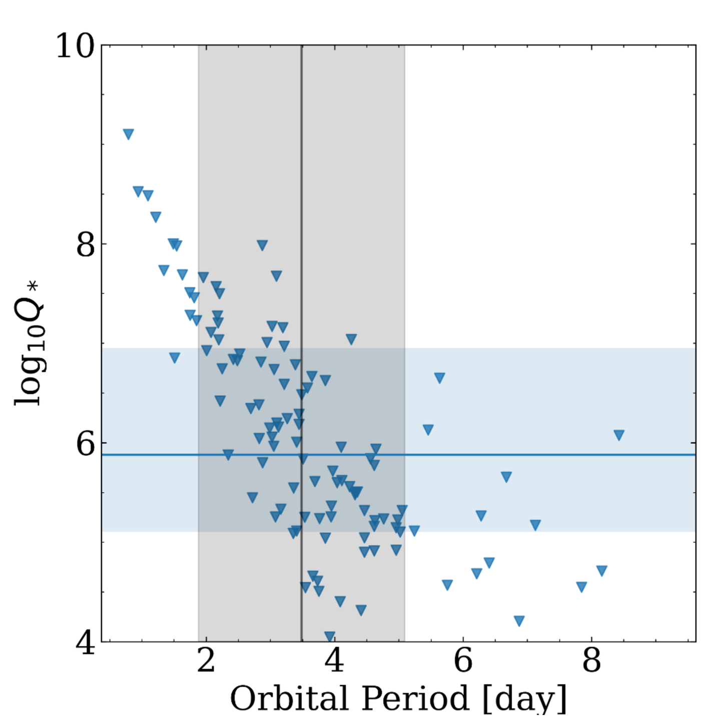
$$\frac{t_{\rm in,USP}}{t_{\rm in,HJ}} \sim 0.1$$

USP planet hosts have kinematics consistent with the field

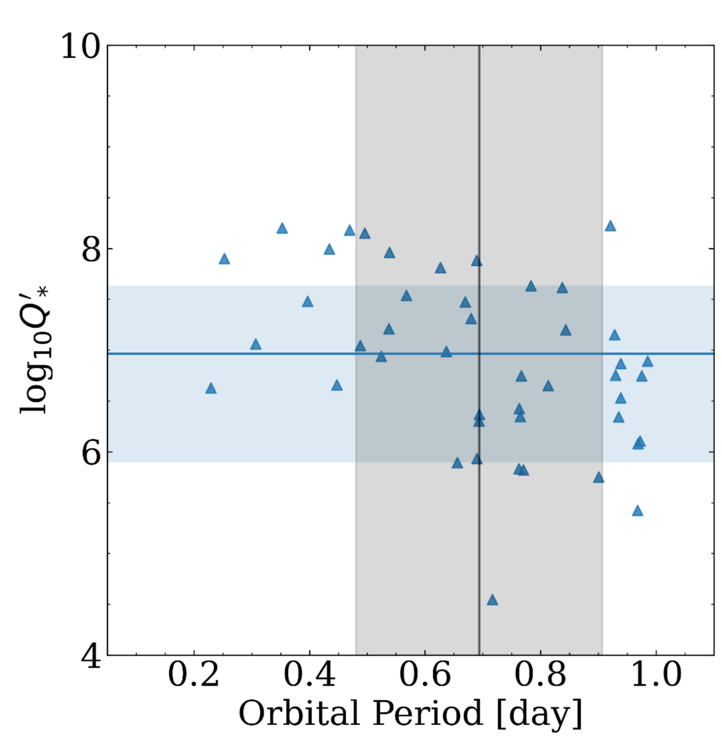


USP planet hosts are of consistent age with similar field stars, implying the robustness of USP planets against tidal decay. The dissipation triggered within USP hosts must differ from that triggered within hot Jupiter hosts.

These signals constrain the efficiency of tidal dissipation



$Q'_{*,HJ} < 10^7$



$Q'_{*,USP} > 10^7$

Summary

1) We developed a model independent method for comparing the relative ages of stellar populations, using data from Gaia DR2
2) We show that main sequence hot Jupiter hosts are preferentially young, implying hot Jupiters are destroyed by tides during their hosts's main sequence lifetimes
3) In contrast, USP planet hosts have an age consistent with the field, implying that USP planets are robust against tidal inspiral
4) The efficiency of tidal dissipation inside host stars triggered by USP planets must be lower than that triggered by HJs. The inefficient dissipation inside USP planet host stars is due to their shorter periods and/or lower masses
5) As tidal dissipation within the host star is inefficient, we favor models of USP planet formation which invoke eccentricity excitation and tidal circularization such as those put forward in Schlaufman et al. (2010) and Petrovich et al. (2019)