Ultra-Short-Period Planets Around Low Mass Stars

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Abstract

Planets with orbital periods less than a day, or ultra-short-period planets (USPs), are unique laboratories for observation and planet formation and evolution theories, but the planets' origins remain unclear. Competing origins theories make different, testable predictions: for instance, USPs may be the remnants of tidally disrupted hot Jupiters, or they may have been brought in from farther out by orbital decay driven by tides raised on their host stars. If USPs were brought in by tidal decay and interactions with other planets, that would mean USP systems would often (perhaps always) host additional planets. The characteristics of the ultra-short-period planet population can therefore be used to directly test the predictions of competing planet formation theories. Over 60 candidate or confirmed USPs have been identified around stars with radii smaller than 0.7 solar radii (about a quarter of all known USPs). M dwarfs are also a quarter of the stars with at least one identified companion planet, while K dwarfs are somewhat overrepresented. None of the 14 systems with 3 or more planets orbits a star more massive than the Sun. The Short Period Planet Group (SuPerPiG) is working to discover and confirm USPs and to explore the implications of USP population characteristics for planet formation theories.

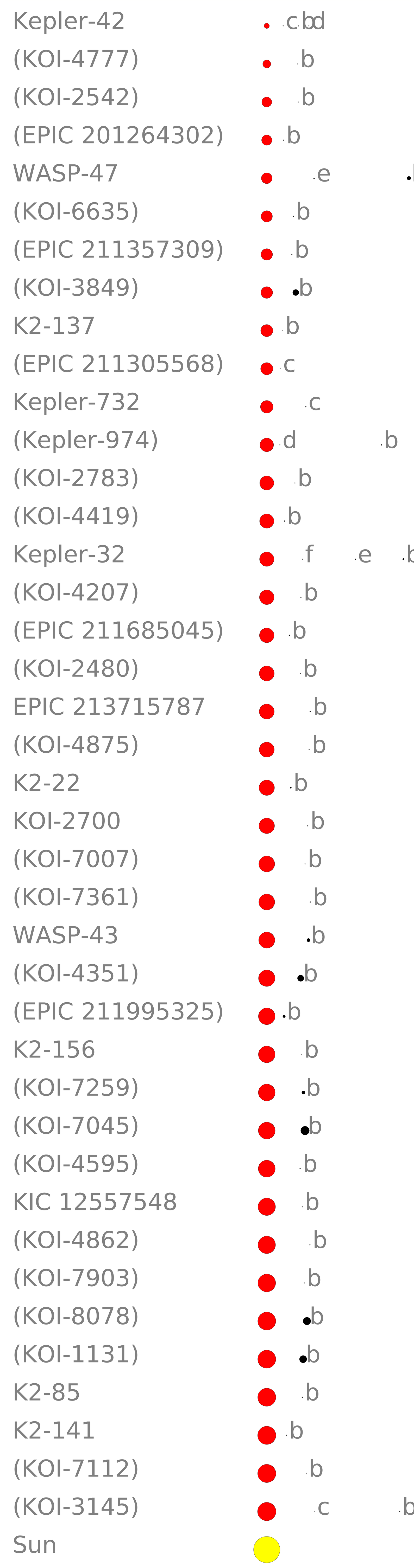


Figure 1. Entirely to scale (R_{Sun} = 1). All confirmed or (candidate) systems with at least one planet with P<1 day, around stars with $R_* < 0.7\ R_{Sun}$.

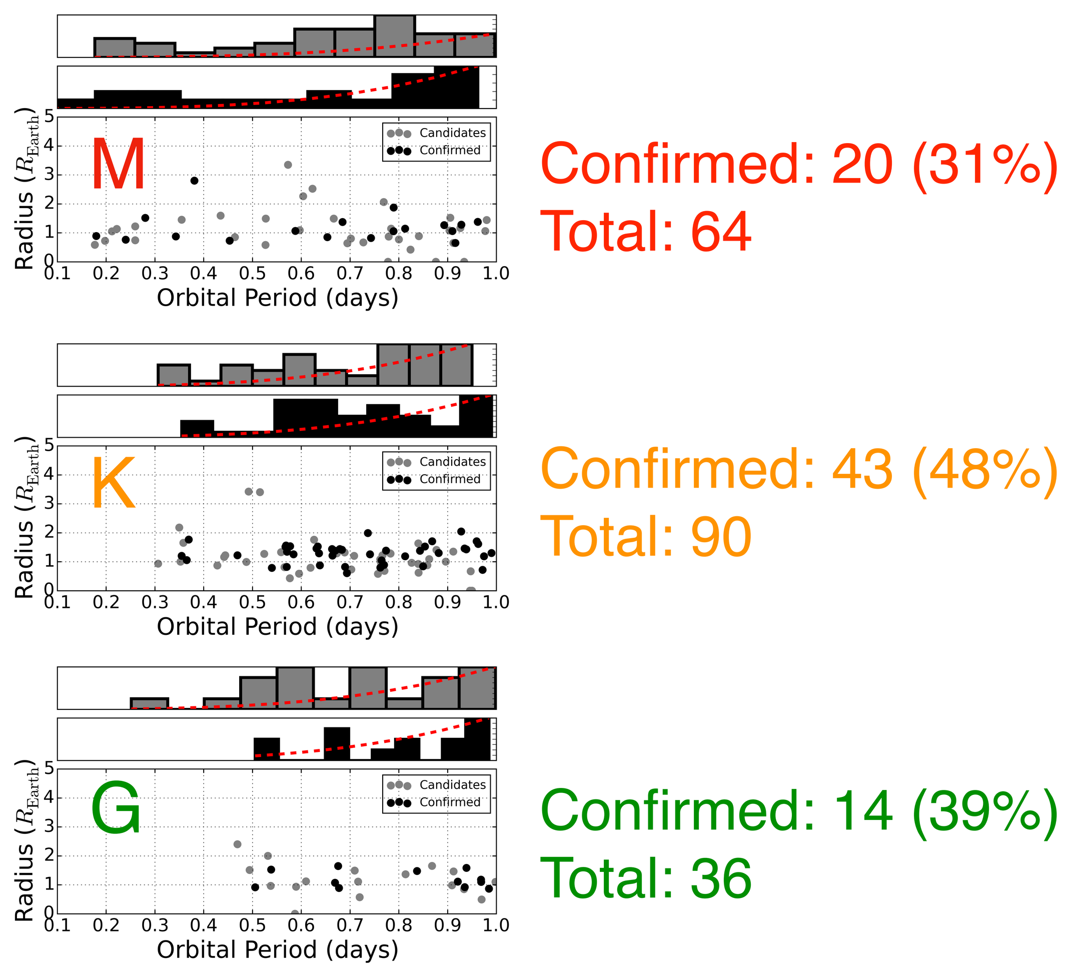
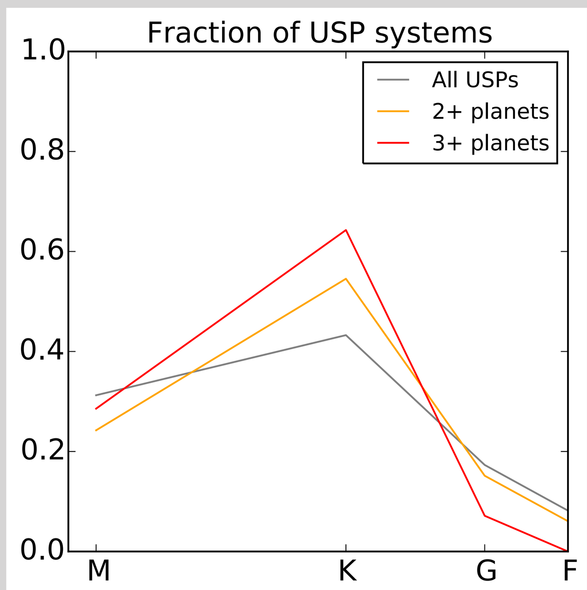
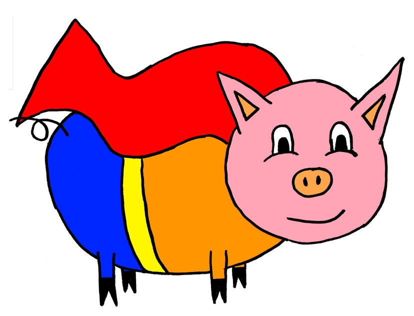


Figure 3. Cool stars have the closest planets. Planetary radius vs. orbital period, P, of confirmed (black) and candidate (grey) ultra-short-period planets (USPs), with period histograms above. The dashed red line is the expected fall-off (~$P^{10/3}$, Lee and Chiang, 2017) if orbital decay driven by stellar tides alone were responsible for producing USPs; note the difference in the confirmed and candidate distributions.

Figure 4. Most known multi-planet USP systems are around cool stars. The fraction of systems with USPs (grey) varies modestly with stellar type, with K stars most common among USP hosts. The preference toward smaller stars is more pronounced with multi-planet systems; among systems with 3+ known planets, only one is not around an M or K dwarf.



SuPerPiG



The Short Period Planet Group, or SuPerPig, has been working to discover and confirm ultra-short-period planets using Kepler and K2 data (Jackson et al. 2013, Adams et al. 2016, 2017), and eagerly anticipates TESS data. Over 240 candidates have been identified to date, with more candidates in the pipeline from additional K2 campaigns, reanalyzing previous work with EVEREST photometry (Luger et al. 2017), etc. But much work remains to be done on this sample to accurately test theories, especially in validating and de-biasing the USP sample:

1. More systems need observations for accurate stellar and planetary parameters. Status of follow-up observations of all USP candidates from Kepler or K2:
   a. have RV masses: 5% (10)
   b. have spectra: 52% (113 of 219)
   c. have high-resolution images: 63% (139 of 219)
2. We need to fully quantify the discovery biases for Kepler/K2 planets: how representative is this sample of the true population of USPs?
3. As a result, only ~40% of systems are confirmed or validated. In addition, up to 25% of candidates listed in databases are likely false positives.
4. SuPerPiG plans to validate every USP and produce de-biased distributions with planet orbital and physical parameters … stay tuned!

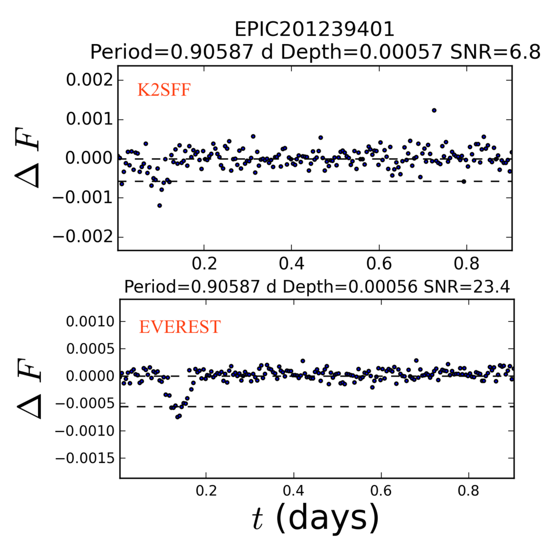


Figure 5. More candidates expected with improved photometry. The K2SFF pipeline (top) was used for our original searches, but the EVEREST pipeline (bottom) is expected to return up to twice as many candidates based on preliminary results. (Luger et al. 2017)

Spectra + imaging + photometry constraints = validated planets

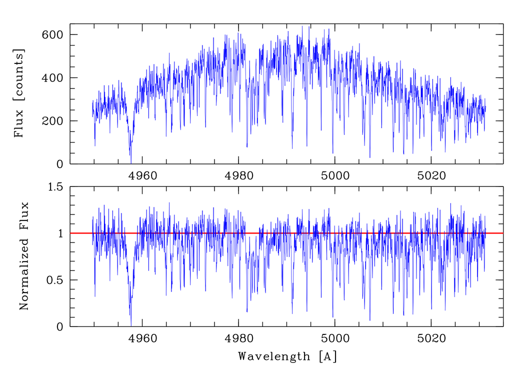


Figure 6. Example of a KOI reconnaissance spectrum before (top panel) blaze division and residual continuum flattening and after (bottom panel). The S/N of this spectrum at the top of the blaze of the order is S/N ≈ 17 : 1.

(From Endl 2017)

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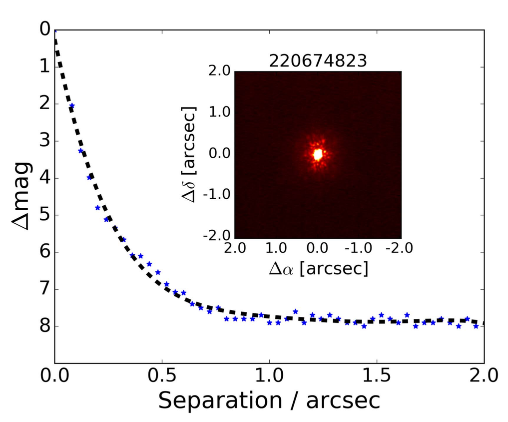

Figure 7. The AO image of EPIC 220674823 in *K* band with Keck/NIRC2 revealed no additional stars. Blue stars in the sensitivity curve are the measured minimal brightness of a possible companion consistent with a 5σ detection; the black dashed line is a fitting function.

(From Adams et al. 2017)

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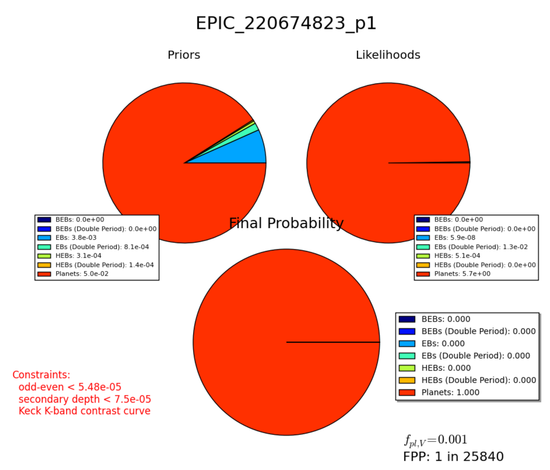

Figure 8. Validation results for K2-106 b, aka EPIC 220674823 (Adams et al. 2017) using the *vespa* software package (Morton 2015). In this case, all false positive scenarios were very definitively ruled out, validating the system as planetary.

References

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Mercury

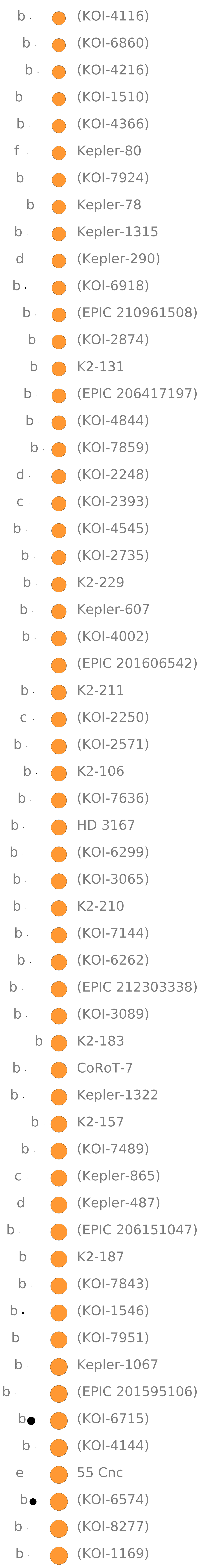

Figure 2. Same scale as Figure 1, but for $0.7 \le R_* < 0.96\ R_{Sun}$