Searching for Long-Period Giants within K2 Planetary Systems

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Abstract

Transit and RV surveys have given us insight into the current distribution of exoplanets. Kepler revealed that short- period small planets have an occurrence rate of <1 planet per solar-type star, while RV surveys revealed that long-period giant planets near the snow line are less common. A few formation models of planetary system architectures with both types of planets have been proposed. However, the correlation between them has yet to be determined due to these short and long-period planets being discovered from stellar samples with different stellar distances. To fix this gap, NASA repurposed the Kepler spacecraft for the K2 mission, whose primary goal was to survey thousands of nearby, bright stars hosting short-period planets. Our goal is to detect long-period companions within these systems by looking for long-term RV trends from their host stars. This study analyzes the current RV trends collected from 27 K2 systems using the High-Resolution Echelle Spectrograph (HIRES) at the W.M. Keck Observatory. We are conducting a homogeneous analysis of these RVs to reveal new giant companions within each system and measure their occurrence rate within the overall sample. The discovery of these planets and their frequency in the Solar neighborhood will help us determine the correlation between small and giant planet formation.

Introduction

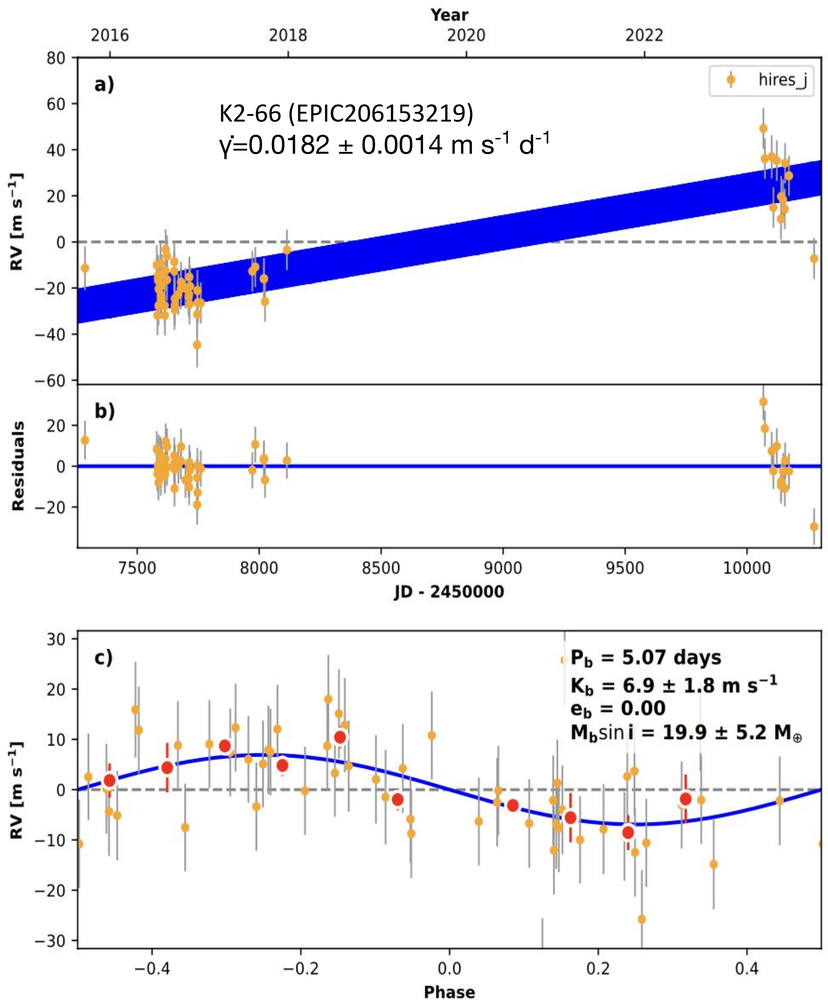
Massive companions on wide orbits serve as a signature for understanding planet formation. Kepler revealed that short-period small planets have an occurrence rate of <1 planet per solar-type star, while RV surveys revealed that long-period giant planets near the snow line are less common, with an occurrence rate of 5-10%. The rate of short-period planets with giant companions is believed to be 10-30%. Studies suggest a possible positive correlation between small and large planet formation, if protoplanetary disks rich in solid materials lead to the formation of each planet's core both within and beyond the snow line. On the other hand, the correlation could be negative if the long-period giants either prevent the cores of the smaller planets from migrating inward or allow them to form within the snow line before they migrate closer to the host star. This correlation and its implications remain unresolved.

We are working to close this gap in our understanding of small-giant planet formation. The K2 mission detected many short-period planets around bright stars, with some of these systems undergoing RV follow-up in 2015-2017 with the High-Resolution Echelle Spectrograph (HIRES). We are seeking to identify long-term RV trends from these K2 host stars; i.e., linear stellar accelerations induced by larger objects. We observed these systems further with HIRES to extend the baseline of these systems from ~1 year to ~6-7 years to reveal giant companions on much wider orbits. **The goal of this study is to complete a homogeneous analysis of all RVs collected over the extended baseline to reveal new giant companions and measure their occurrence rate within the overall sample.**

Method

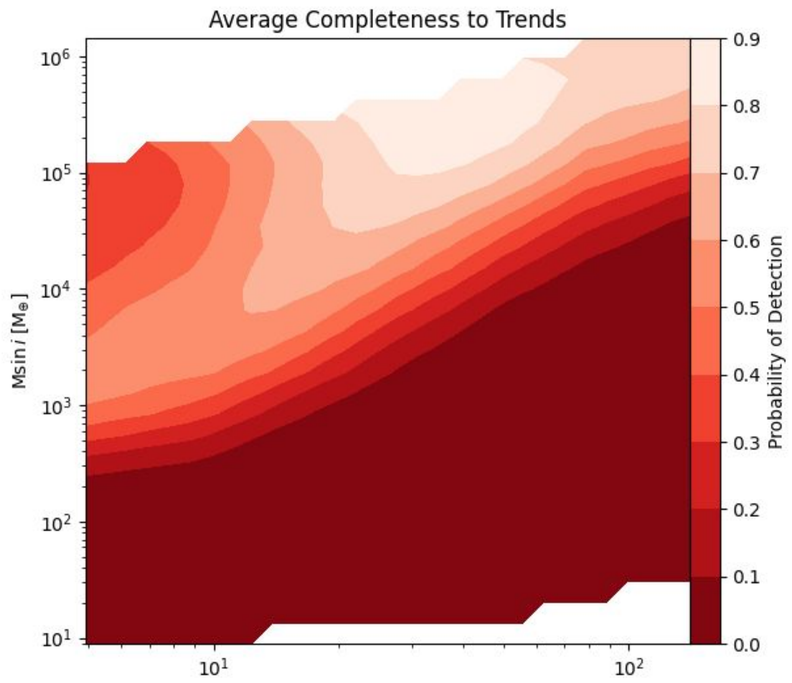
- We modeled and analyzed RV trends from 27 K2 targets using RadVel [2]. Our goal was to identify RV trends with a trend significance **≥ 3σ**.
- We used a modified version of RVSearch [3] by Dr. Judah Van Zandt to perform injection/recovery tests on each target to assess our survey's overall sensitivity to giant companions. We injected 3000 synthetic planetary RV signals/linear trends into each data set. Each injected planet's parameters include an RV semi-amplitude between 0.5 and 3600 m/s with a period between 4000 days and 612,000 days.
- We used the Python package "ethraid" [4] to determine the possible masses and semi-major axes of the companions inducing our significant trends.
- We also produced ratio maps between each target's ethraid posterior and their completeness map to identify the best M-a regions for detecting new companions.

Result 1: 4 New Long Period Companions Identified



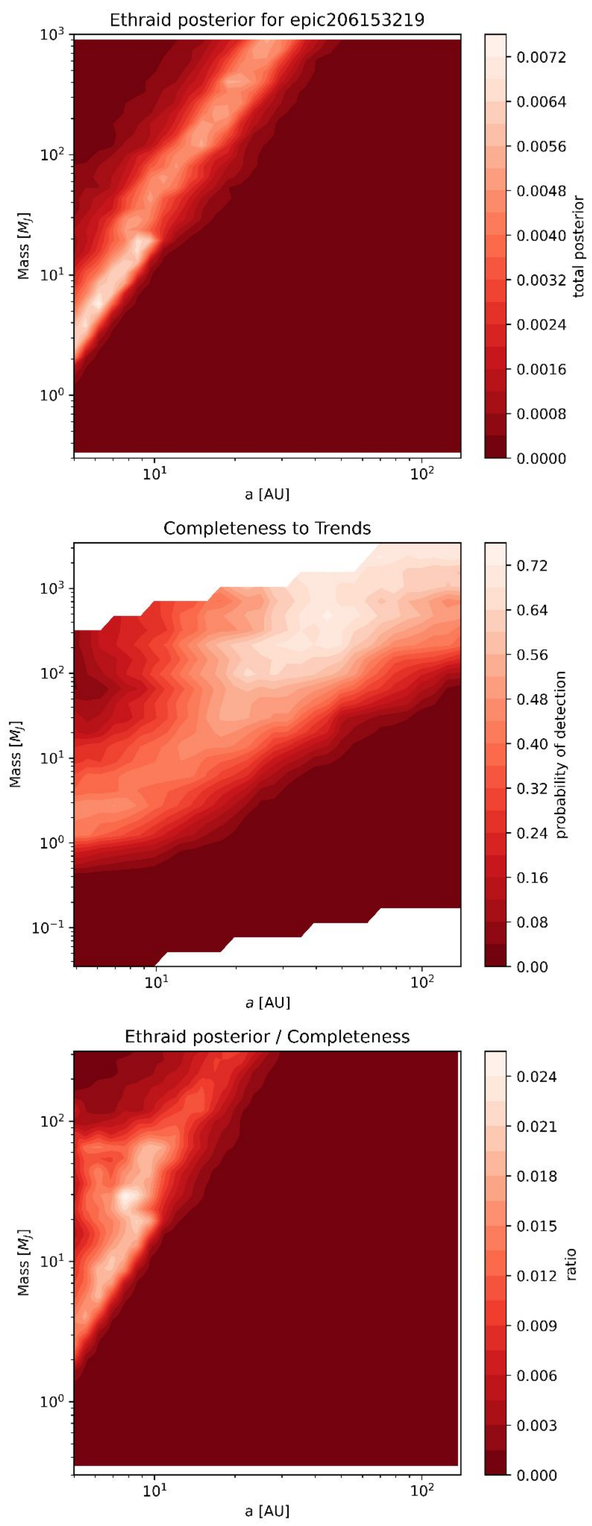
Our analysis of our HIRES RVs reveals at least **four new long-period companions, suggesting a >15% occurrence rate.** We recorded long-term linear accelerations **of γ̇ = -0.007 ± 0.001 for K2-108, γ̇ = 0.0182 ± 0.0014 for K2-66, γ̇ = 0.0092 ± 0.0025 for K2-234, and γ̇ = 0.0106 ± 0.0014** m s^{-1} d^{-1} **for EPIC245943455, all with a trend significance ≥ 3σ. (Above)** Best-fit RV model for K2-66, with a) the best-fit 1-planet model, b) the model's residuals, and c) the RVs phase-folded to the ephemeris of the short-period planet with its best-fit orbital parameters.

Result 2: K2-HIRES Survey Sensitivity to Giant Companions



Average completeness of all 27 targets. If the best-fit values for their orbital parameters match their original injected values to within 25%, the algorithm considers the planet as recovered and plots that planet in M sin i-a space. For planets with masses near 1000 $M_\oplus$ and semi-major axes close to 20 AU, **the probability of detection is 70%, showing a high recovery rate for companions out in the brown dwarf/stellar regime.**

Result 3: M-a Constraints for K2-66 and Ratio Map



M-a posterior for K2-66 from ethraid (top). Provided with each target's observed RV/astrometric trends and imaging data, ethraid draws 10^7 orbits from log-uniform priors of M = 0.1-1000 M_{Jup} and a = 3-256 AU. Each orbit is assigned a likelihood, based on how well its simulated RV/astrometric/imaging data match the observed data provided. The bright contour shows where the companion's M-a is most probable for this target's dataset. The injection/recovery plot for this target in M-a space (middle), and the ratio map between the two (bottom). The ratio map shows the best M-a regions for detecting companions is between 5 AU and 14 AU for separation, and between 10 and 30 M_{Jup}, with a higher ratio near 0.024.

Conclusions

- We revealed 4 giant companions with a linear trend significance ≥ 3σ, suggesting a >15% occurrence for giant companions within our sample
- More massive companions near 1000 $M_\oplus$ and at 20 AU have a higher completeness, nearing 70%, pushing our search for companions into the brown dwarf/stellar regime
- Our ethraid analysis and ratio map for K2-66 suggests that the best M-a region for probing secondary companions is [5, 14] AU for separation and [10, 30] M_{Jup} for companion mass.

References

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