Frequency of long-period Neptune and Saturn-mass planets in the Solar neighborhood

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Background

The orbital separation distribution of exoplanets gives important clues to the mechanisms of planet formation. Theories predict that the region within a protoplanetary disk where water can condense (ice line) is important to planet formation[1] and there should be an increase in planet occurrence beyond the ice line. The detection of an overabundance of Jovian planets near and beyond the ice line suggests that the additional protoplanetary solids in this region augment the formation of large planets. The region beyond the ice line corresponds to orbital periods of ~3-6 years (2-3.5 AU) for G stars (0.8-1.1 $M_{\odot}$) and ~1-2.4 years (1-1.8 AU) for K stars (0.6-0.8 $M_{\odot}$). This region of parameter space has not been previously explored by observations for planets $\lesssim 100 M_{\oplus}$.

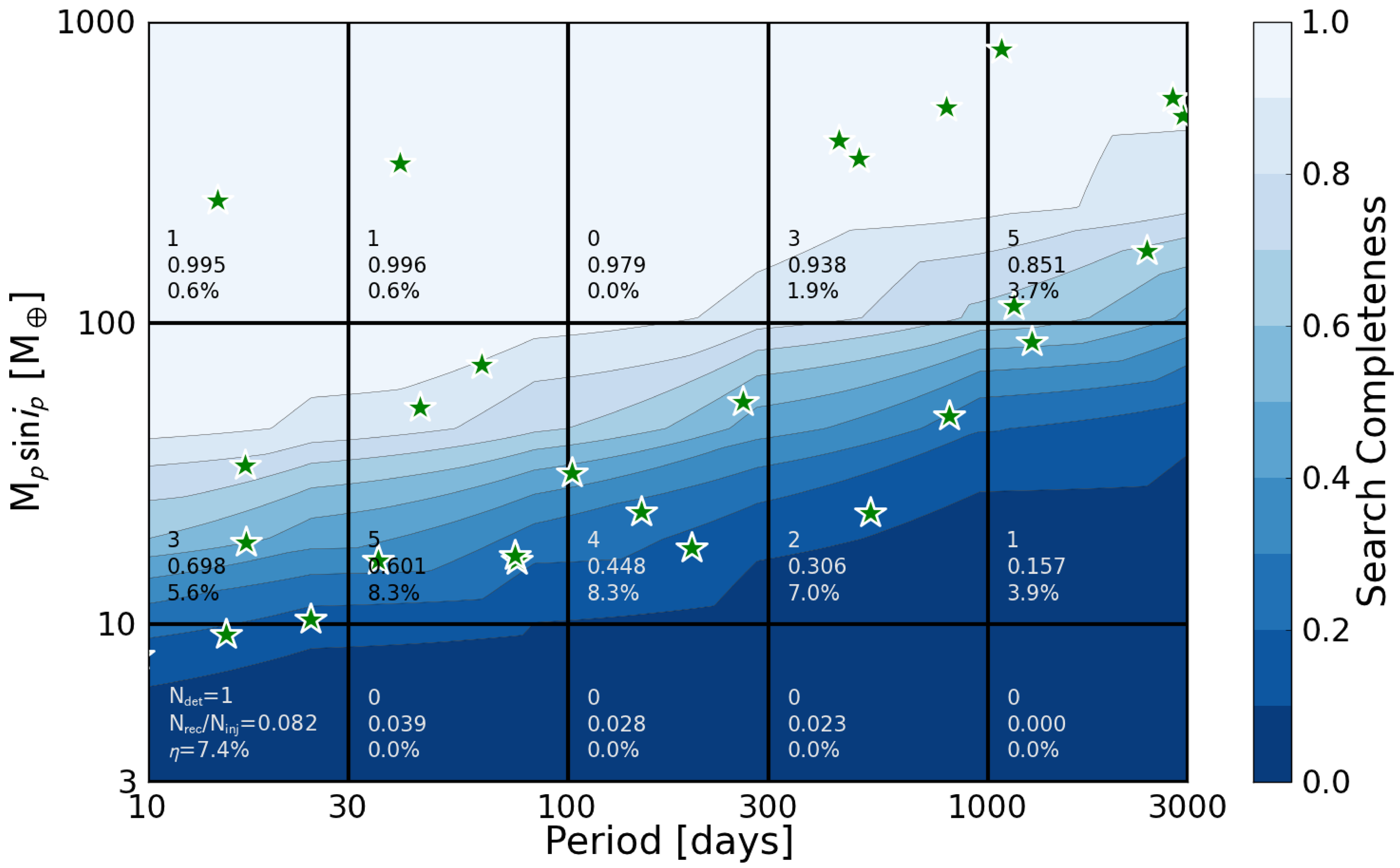
Method

- Developed an automated multi-planet detection pipeline utilizing the 2D Keplerian Lomb-Scargle periodogram (2DKLS)[3]
- Searched for planet candidates in the Keck-HIRES radial velocities from the Eta-Earth Survey[4]
- Empirically determined the significance of peaks in the periodogram by fitting the distribution of periodogram values.
- We search for multiple planets by adding an increasing number of Keplerian signals into the fit. The values for each periodogram represent $\Delta\chi^2$ of an N+1 vs. N planet fit.
- Determined survey completeness with injection and recovery tests

Summary

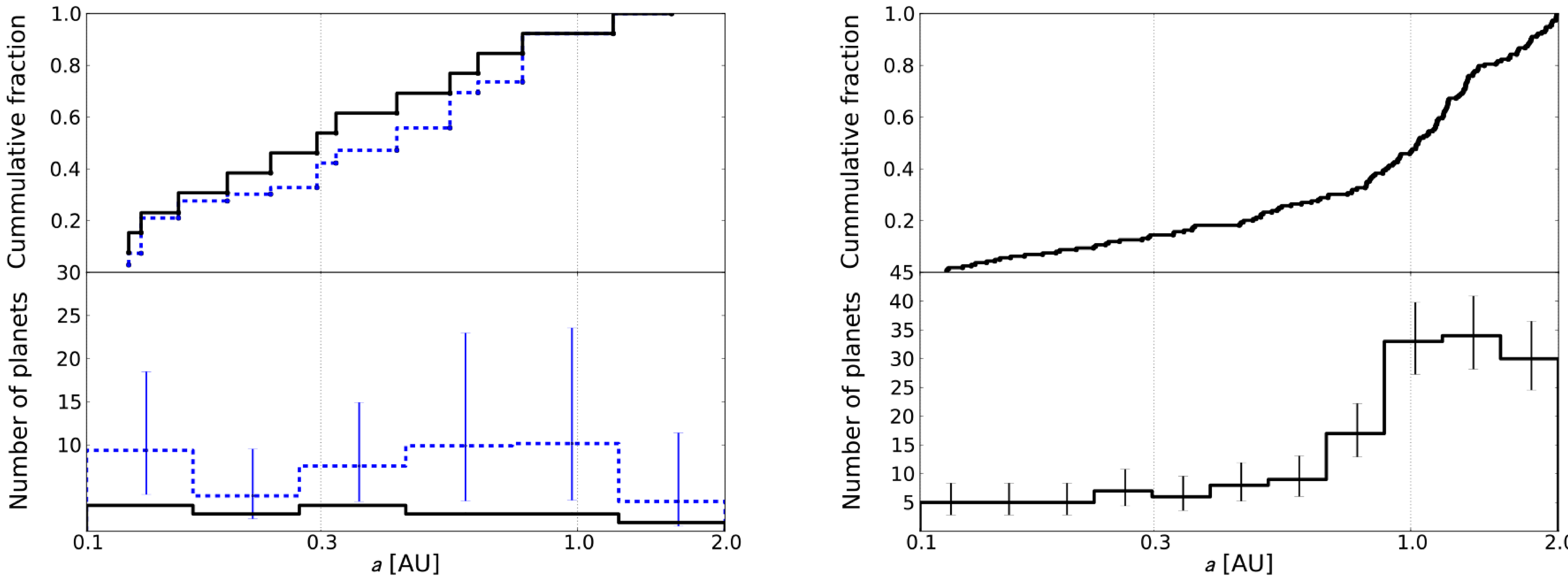
- We find 10 previously unpublished planet candidates.
- $27^{+10}_{-7}\%$ of solar-type stars host a Neptune to Saturn-mass planet with an orbital period between 10 and 1000 days.
- No "period valley" for planets with $M_p \sin i_p = 10 - 100\ M_{\oplus}$.

Occurrence rates and survey completeness



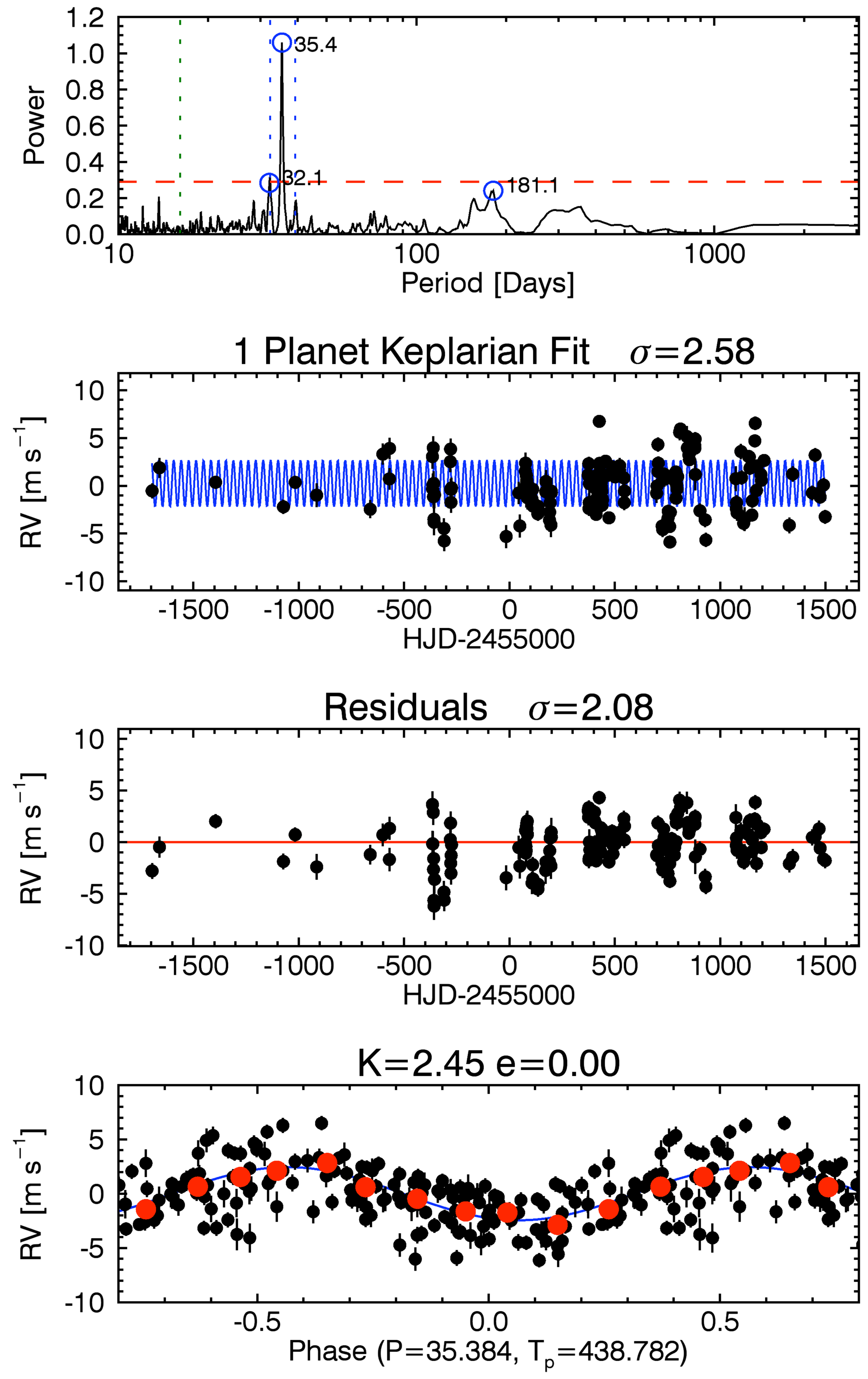
Sensitivity to injected planets (blue contours), detected planets (green stars), and derived occurrence rates. The numbers in each box from top to bottom are: the number of detected planets within the box, the fraction of injected planets that were recovered, and the mean occurrence rate for planets with parameters that fall within the box. **The occurrence rate is constant for planets with $M_p \sin i_p = 10 - 100\ M_{\oplus}$ and orbital periods between 10 and 1000 days.**

No period valley for Neptunes



Comparison between sub-Saturns (*left*) and Jovian-mass (*right*) semi-major axis distributions. The small number of Jupiters between 0.1 and ~1.0 AU is known as the "period valley"[2]. Jovian planets are much more common at both smaller and larger separations. **The period valley is not seen in the sub-Saturn semi-major axis distribution.**

Automated detection



Candidate vetting plots produced by the automated planet detection pipeline. *Top:* 2DKLS periodogram of the RV time-series. The dashed red line is our cutoff for a positive detection. The dotted vertical lines mark aliases of the highest period peak. *Upper-middle:* the RV time-series with the best-fitting single-planet model. *Lower-middle:* residuals to the single-planet fit. *Bottom:* RV data phase-folded to the period corresponding to the highest peak in the periodogram.

References

1. Ida, S. and Lin, D. N. C. Toward a Deterministic Model of Planetary Formation. IV. Effects of Type I Migration. *ApJ* **673**, 487–501, January (2008).
2. Wittenmyer, R. A., O'Toole, S. J., Jones, H. R. A., et al. The Frequency of Low-mass Exoplanets. II. The "Period Valley". *ApJ* **722**, 1854–1863, October (2010).
3. O'Toole, S. J., Tinney, C. G., Jones, H. R. A., et al. Selection functions in doppler planet searches. *MNRAS* **392**, 641–654, January (2009).
4. Howard, A. W., Johnson, J. A., Marcy, G. W., et al. The NASA-UC Eta-Earth Program. I. A Super-Earth Orbiting HD 7924. *ApJ* **696**, 75–83, May (2009).