Planet Hunters Update:

Many New Planet Candidates Identified by Citizen Scientists from *Kepler* Data, Including Several in the Habitable Zone

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Abstract

Since December, 2010, more than 250,000 public volunteers have searched through more than 19 million *Kepler* light curves hunting for transiting planets. The *Kepler* light curves are shown in 30 day sections, and with ~160,000 *Kepler* target stars, the users have contributed the equivalent of 180 years of work hours. This vetting process has resulted in over 40 new planet candidates and two new confirmed planets, including several not identified through the *Kepler* pipeline. Many of our candidate planets lie within their host star's habitable zone. We review the recent large release of new PH candidates in Wang et al. (2013), including one confirmed planet, and give preliminary results for our next PH candidate release.

The Planet Hunters Project

The Planet Hunters project (www.planethunters.org), launched in December, 2010 as a member of the Zooniverse network, has citizen scientists visually examine *Kepler* archival data for potential planetary transit signals. While the *Kepler*'s Transit Planet Search (TPS) algorithm (Jenkins et al. 2002, 2010) has clearly been very successful, Planet Hunters have found a number of signals missed by the TPS algorithm.

The process begins with Planet Hunters being shown a 30 day light curve. The user will mark the stellar variability and whether transit features are seen (see Figure 1). Planet Hunters are $\gtrsim$ 85% efficient at finding planets above 4 $R_\oplus$, but are still capable of finding weaker signals (Schwamb et al. 2012). In addition to marking transits, the Planet Hunters *Talk* discussion tool (talk.planethunters.org) allows users to publicly post and discuss interesting light curves with others, such as collections of potential eclipsing binaries, variable stars, microlensing, circumbinary planets, and "weird" light curves.

Volunteers who are first identifiers are co-authors on our published papers announcing new planet candidates (Fischer et al. 2012, Lintott et al. 2013, Schwamb et al. 2013, Wang et al. 2013). **Two planet candidates have been confirmed as planets: PH1 b is a circumbinary planet orbiting two stars in a quadruple star system (Schwamb et al. 2013), and PH2 b is a Jovian-sized planet orbiting in the habitable zone of its host star (Wang et al. 2013).**

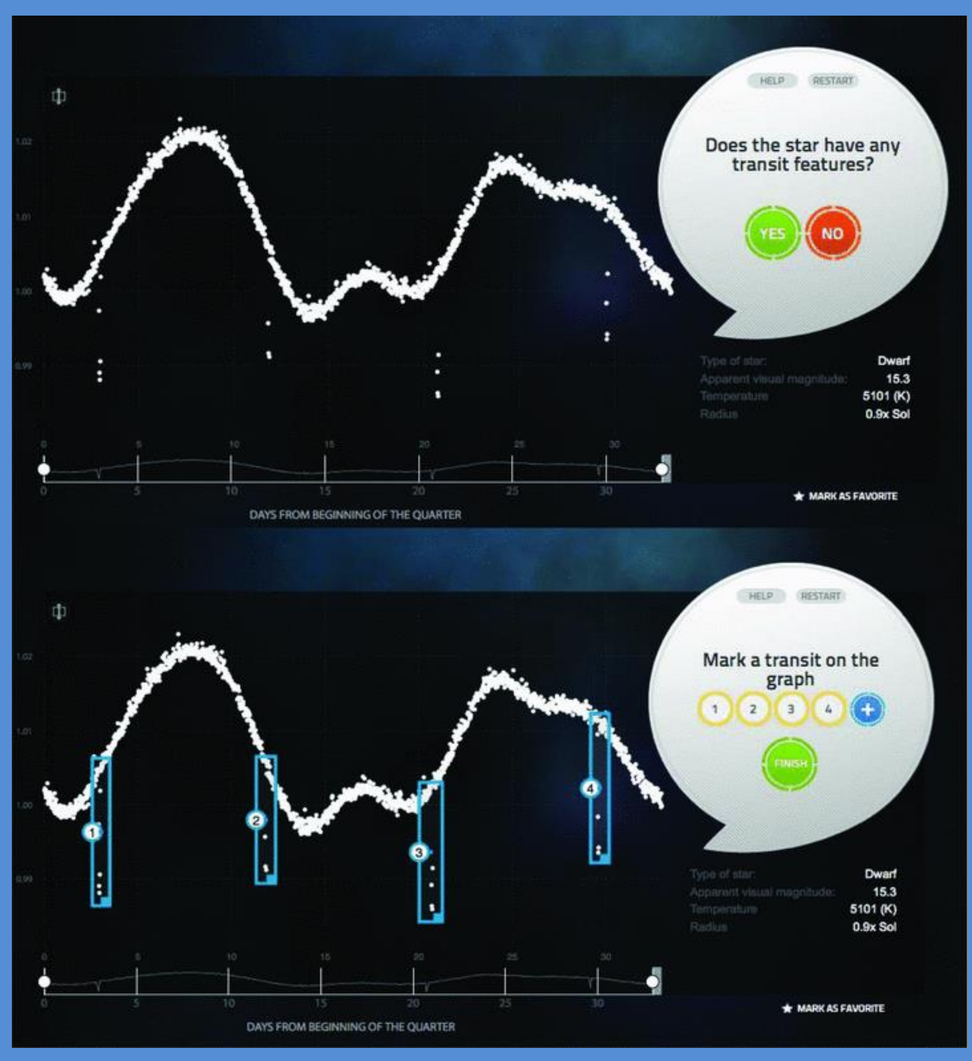

Figure 1: An example of what a Planet Hunter would see for Kepler-75 b (P = 8.9 days, R = 11.6 $R_\oplus$). From Fischer et al. (2012).

New Planet Hunters Candidates

The most recently released PH candidate list (Wang et al. 2013) was originally compiled by volunteers through their own vetting process via *Talk* discussions. All candidates were then analyzed with a custom transit analysis package by the science team. The final list of candidates passed all routine false positive tests, such as transit depth variations, secondary eclipse checks, and pixel centroid offsets.

For 9 of these candidates, we obtained follow-up Keck HIRES spectra, of which 4 also had Keck AO imaging. Combining these with galactic population models and planet priors can create tight constraints on false positives (Fressin et al. 2012; Barclay et al. 2013). **Using these methods, we achieved a planet confidence of 99.92% for KIC 12735740.** Doppler measurements of KIC 12735740 from Keck show low RMS scatter of 14 m/s over 25 days, ruling out spectroscopic binary transits on the primary source and confirming the planetary nature of this object, which we designate as PH2 b.

While no other candidates were confirmed, we found 42 planet candidates, including 3 missed by the *Kepler* TPS algorithm. Of these, 20 lie in the habitable zone, including PH2 b. These planets are shown as blue diamonds Figures 2 and 3.

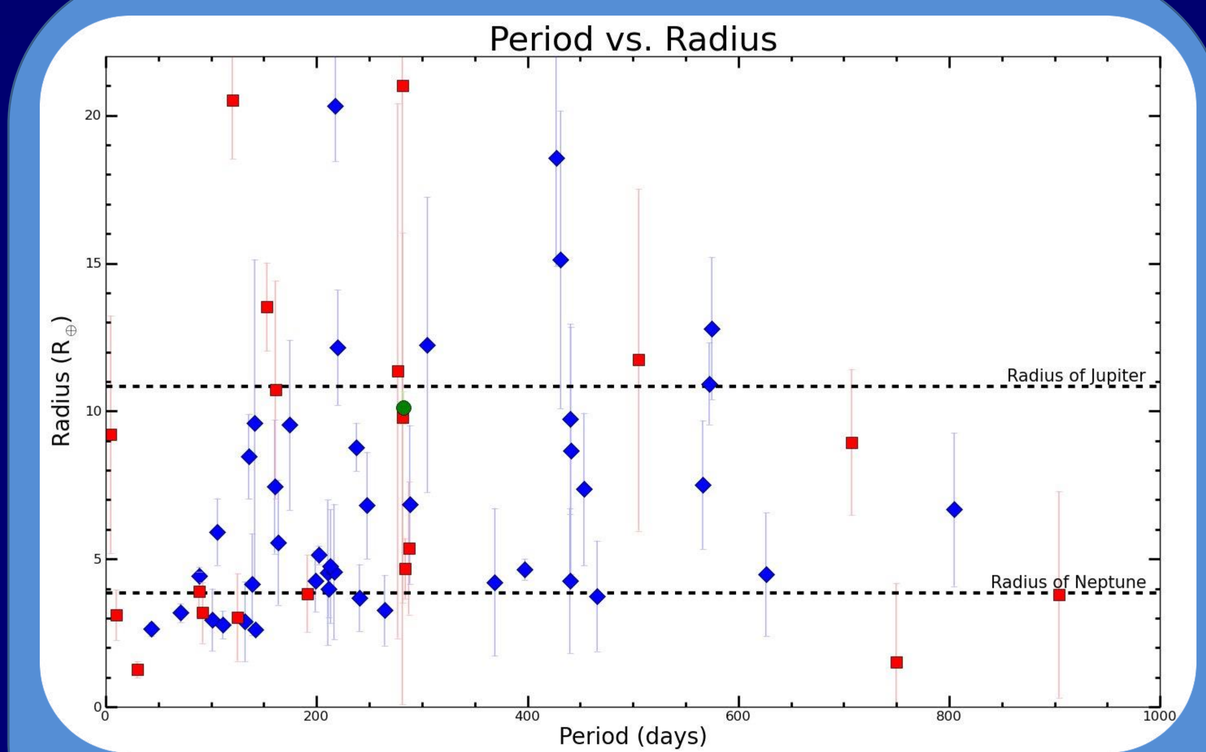

Figure 2: Period vs. planet radius. Blue diamonds are from Wang et al. (2013). The green circle is the newly discovered PH2 b. Red squares are in preparation for the next release. The radii of Neptune and Jupiter are plotted for reference.

Upcoming Release

A new Planet Hunters candidate list is being prepared for release (Schmitt et al., in preparation) using similar methods as Wang et al. (2013). Preliminary results are shown in red squares in Figures 2 and 3 and include 20 new candidates. The *Kepler* TPS algorithm has searched Quarters 1-12 for signals with at least 3 transits. **However, 5 new candidates, including 2 in multiplanet systems, meet these criteria without being discovered by TPS. Another candidate is a *Kepler* Object of Interest (KOI, Batalha et al. 2013) candidate with incorrect parameters which should have been properly detected.** Among the others are 3 candidates rated as "Not Dispositioned" on the KOI list (we exclude objects already flagged as candidates), 5 candidates on the TCE (Threshold Crossing Event, Tenenbaum et al. 2012) list, 3 candidates with a 3rd transit after Q12, and 3 candidates with just 2 transits.

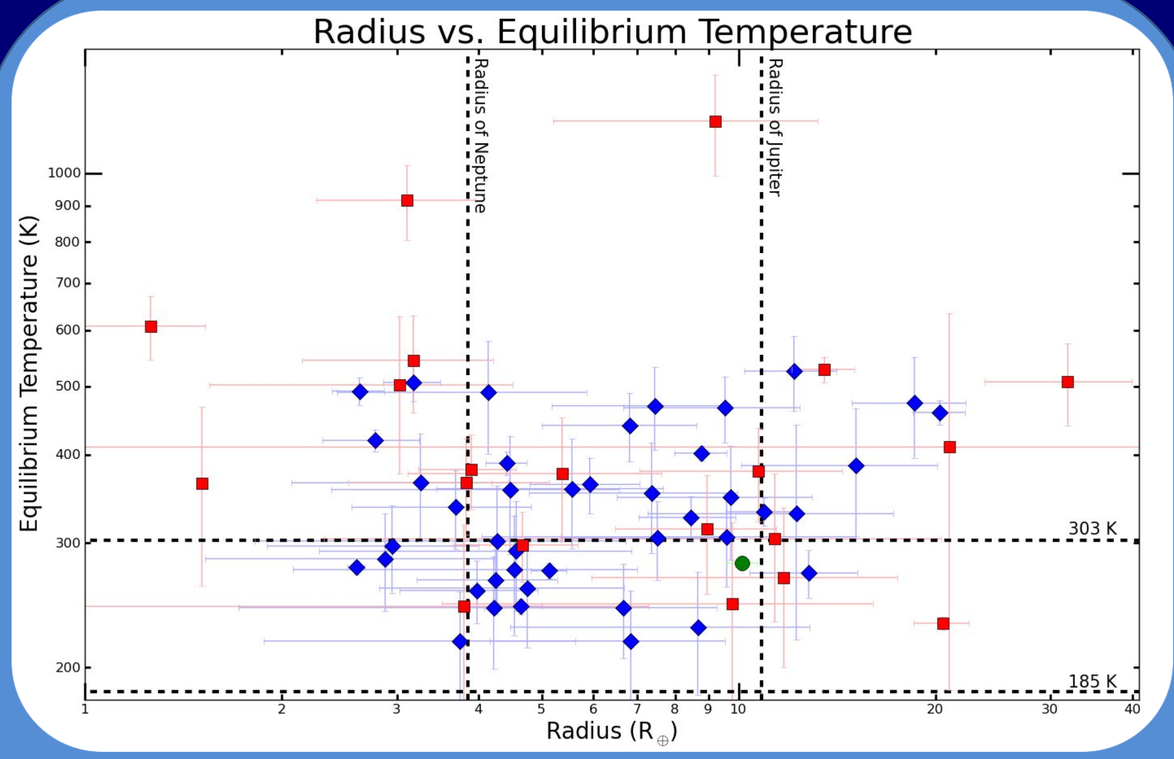

Figure 3: Radius vs. equilibrium temperature. Blue diamonds are from Wang et al. (2013). The green circle is the newly discovered PH2 b. Red squares are in preparation for the next candidate release. The radii of Neptune and Jupiter and the temperature limits for the habitable zone are plotted for reference.

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[1]The Planet Hunters team includes Debra Fischer (Yale University), Meg Schwamb (Yale University), Chris Lintott (Oxford University, Adler Planetarium), and 250,000 volunteers world-wide.