A Uniform Search for Nearby Planetary Companions to Hot Jupiters in TESS Data Reveals Hot Jupiters are Still Lonely

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Project Overview

- We performed a uniform search of 199 systems with known hot Jupiters in the TESS southern ecliptic hemisphere data
- No new planet candidates were identified after vetting and validation of candidate signals with DAVE and VESPA
- Results consistent with high-eccentricity migration as the dominant hot Jupiter formation mechanism

1. The Survey by the Numbers

The aim of this survey is to locate additional small planets closely orbiting near known hot Jupiters and search for system architecture similar to WASP-47[1], Kelper-730[2], and TOI-1130[3] to constrain the formation mechanisms of hot Jupiters.

- Hot Jupiter defined as a planet with P < 10 days and R > 4 $R_\oplus$
- Constrained search to TESS sectors 1-13 (southern ecliptic hemisphere)
- Target list created from NASA Exoplanet Archive on Jan 6, 2020 after all southern ecliptic hemisphere sectors had been observed
- Of 501 total confirmed hot Jupiters, 199 were observed by TESS in the southern ecliptic hemisphere
- Both 2-minute and 30-minute Full Frame Image (FFI) cadences were used when available
- 141 sources have 2-minute cadence, all 199 have 30-minute cadence
- Each cadence was searched independently

2. Transit Search Pipeline

Transit Least Squares

- Transit Least Squares (TLS)[4] fits a realistic planet transit shape.
- Optimized for smaller planets – exactly the type of planet this survey is expecting to find near hot Jupiters
- Signal Detection Efficiency (SDE) serves as built-in signal significance statistics
- SDE > 7.0 corresponds to false alarm probability < 1%

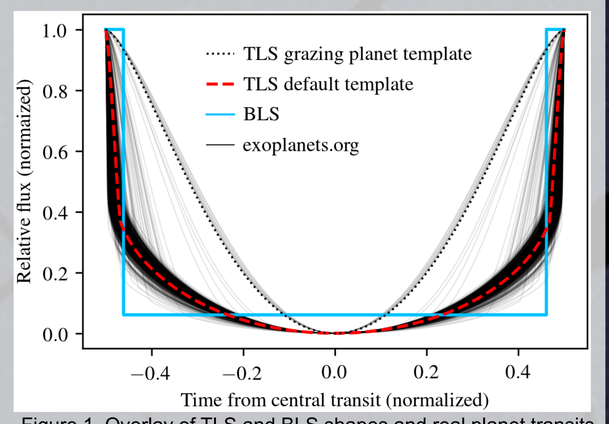

Figure 1. Overlay of TLS and BLS shapes and real planet transits

Search Pipeline

- Each source run through default and grazing TLS shapes until no further significant signals are recovered
- PDC light curves used for 2-minute cadence data, eleanor[5] package used to extract 30-minute light curves from FFIs
- TLS run information printed onto vetting sheet for quick manual review
- 2-minute cadence produced 242 new significant periodic signals, FFIs displayed only marginal signals

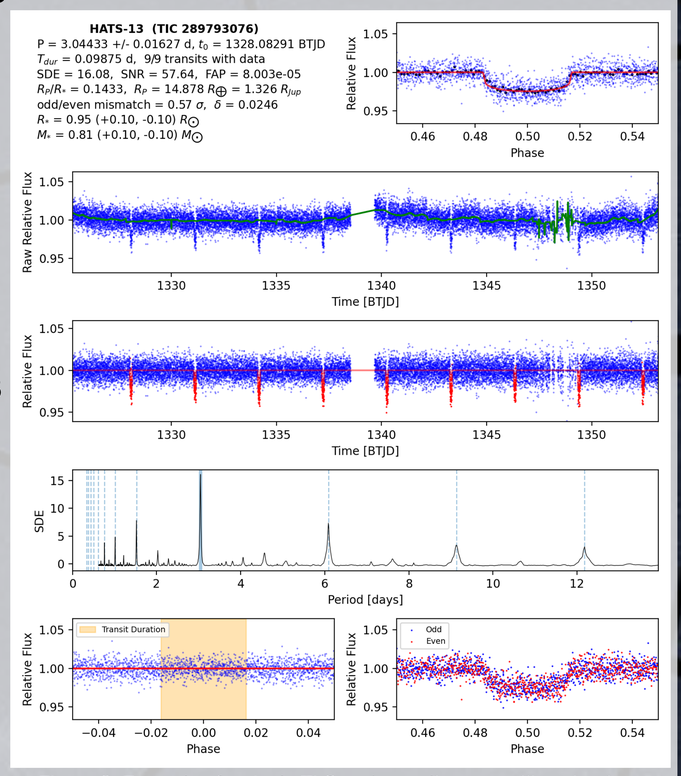

Figure 2. Example of a single TLS run's results on a vetting sheet.

3. Vetting and Validation of Transits

Discovery And Validation of Exoplanets (DAVE)

- Runs light curve-based and image-based vetting tests[6]
- Image-based tests most useful for this search since others require more human intervention

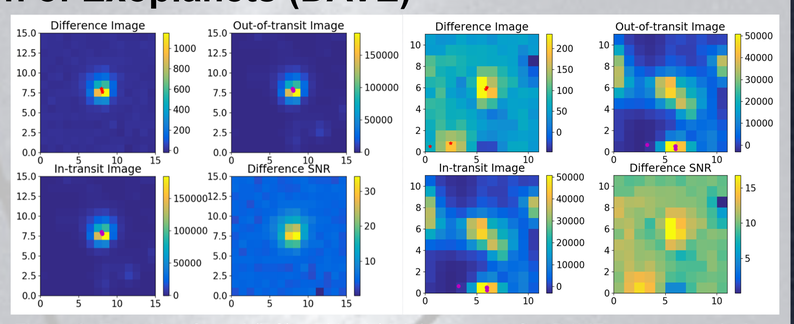

Figure 3. Example of good (left) and bad (right) sources after DAVE centroid analysis, part of the photocenter module.

- All sources that fail centroid analysis are investigated by hand
- 50 of the initial 242 signals passed DAVE vetting

Validation of Exoplanet Signals using a Probabilistic Algorithm (VESPA)

- Statistical validation package that calculates false positive probability after checking for six different astrophysical false positive scenarios[7]
- Simulates stellar characteristics, transit parameters, and background stellar population for blended sources
- False positive probability (FPP) < 1% is considered statistically validated

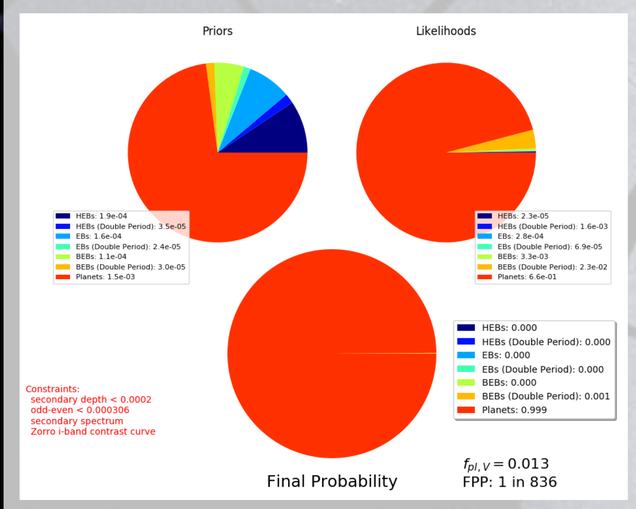

Figure 4. Example output summary plot from VESPA.

- Out of 50 new signals considered significant by TLS, 1 passed DAVE vetting and was validated by VESPA below the 1% threshold
- 13 others had FPP < 10% and were kept in case multiplicity boost lowered their FPPs
- Signals were then modeled for precise planet/orbital parameters using `exoplanet`[8]
- 0 signals kept after modeling showed they were noise

4. Recovery Rates

- Planet transits simulated using BATMAN[9] and injected into hot Jupiter light curves to probe sensitivity of our TLS implementation
- Radii between 0.3 $R_\oplus$ and 4 $R_\oplus$ simulated for orbital periods between 1 and 12 days
- 100% recovery for Rp>3 $R_\oplus$, host Tmag>9.5, and period<2 days with ~26% recovery when including small Rp, dim hosts, and long periods

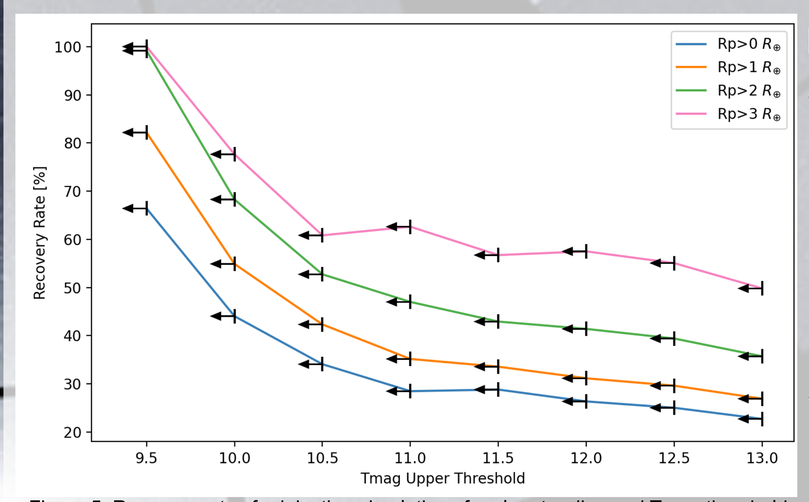

Figure 5. Recovery rates for injection simulations for planet radius and Tmag thresholds

Implications

- Lack of new nearby companions supports high-eccentricity migration formation mechanism for most HJs but does not definitively show this
- Findings are in agreement with results from other searches

References

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