One Man's TraSHDUMP is Another Man's Treasure:

An Exoplanet Candidate in the Kepler Bonus Light Curves

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1. What is a Bonus Object of Interest (BOI)?

Kepler Bonus Light Curves

The Kepler space telescope's [1] primary mission observed around 200,000 target stars [2]. However, hundreds of thousands of additional stars were serendipitously observed. Light curves for these bonus sources were extracted (see Martínez-Palomera, Hedges, & Dotson 2023 [3]) resulting in...

- ★ triple the number of planet-search stars
- ★ an increase in the number of M dwarfs by a factor of seven
- ★ an expected yield of several hundred new planet candidates

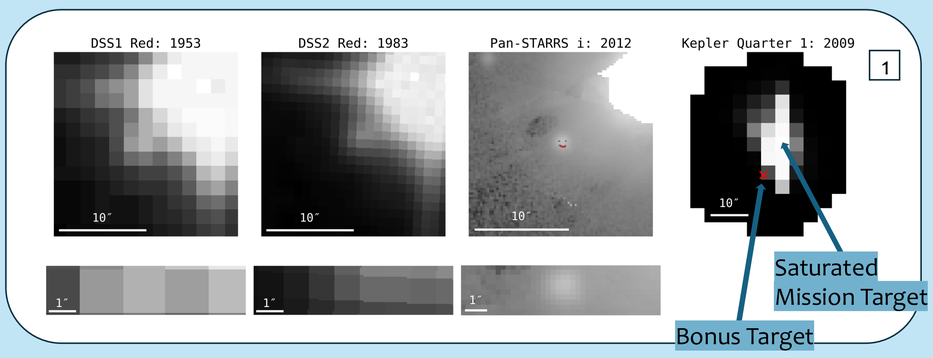


Fig 1. Archival imaging of BOI-1 from the Digitized Sky Survey 1 (1953) and the Digitized Sky Survey 2 (1983) in the Red photographic emulsion, Pan-STARRS in the i band (2012), and Kepler Quarter 1 Target Pixel File (TPF) (2009).

Stellar Parameters

We derive stellar parameters using grid-based isochrone fitting with `kiauhoku` [4,5] and the SPOTS model grid [6,7].

BOI-1 is a **17.8 G mag M-dwarf** with roughly **0.51 Solar radii** and **0.55 Solar masses** and is **less than 1 Gyr old.**

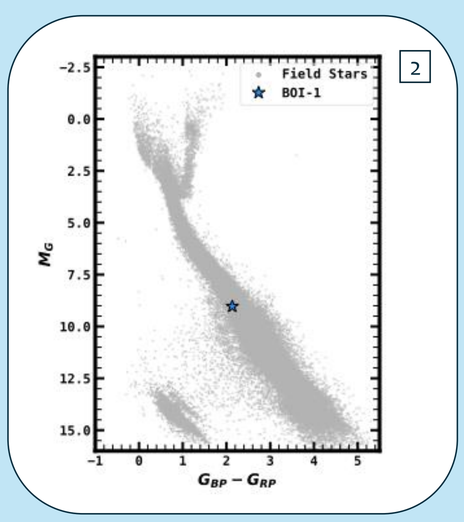


Fig 2. Color magnitude diagram for the Gaia Catalog of Nearby Stars [8] with BOI-1 highlighted as a blue star.

BOI = planet candidate found in `Kbonus` Light curves

2. Detecting BOI-1.01

Detrending the Light Curve

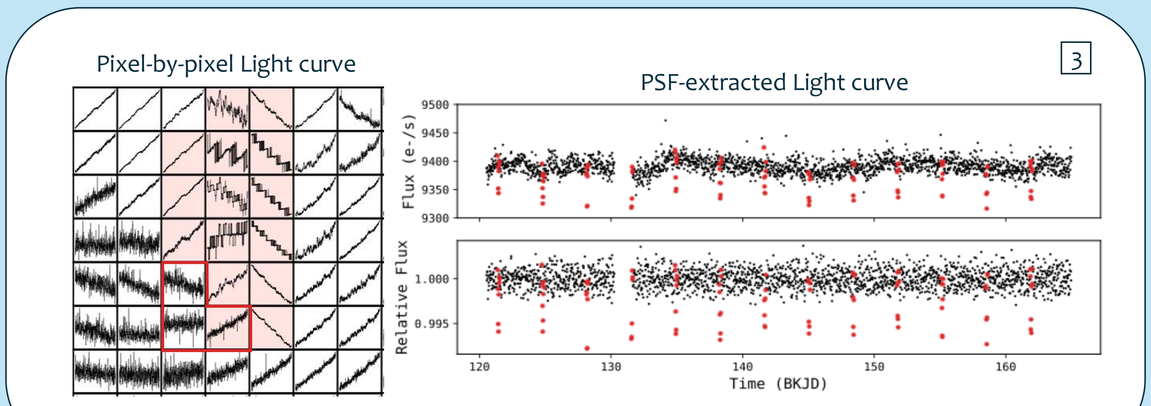


Fig 3. Left: Subset of the TPF, showing per-pixel light curves over a 10-day window; red outline mark pixels where the transit is visible. Right: The top panel shows the original light curve and the bottom panel shows the detrended light curve; in-transit points are in red.

TraSHDUMP: Threshold Crossing Event Detection

(**TRA**nsits with any **S**tellar **H**ost **D**etected with an **U**nbiased **M**atched-filter **P**ipeline)

`TraSHDUMP` is an unbiased matched-filter pipeline motivated by transit-search concepts developed for the Kepler pipeline [9,10]. It searches a range of period and transit duration combinations to find Threshold Crossing Events (TCEs).

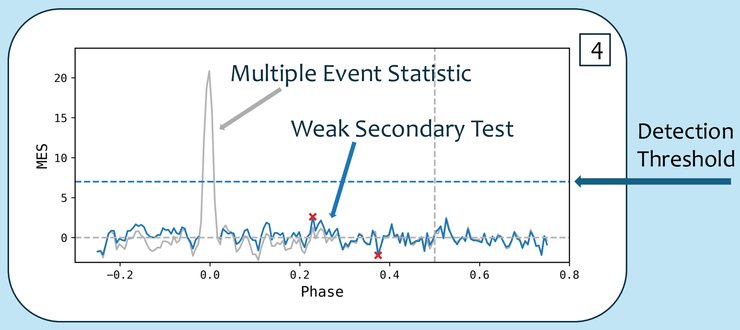


Fig 4. Multiple Event Statistic. Strong signal at phase 0 exceeds the 7.1σ threshold; no significant secondary near phase ≈ 0.5.

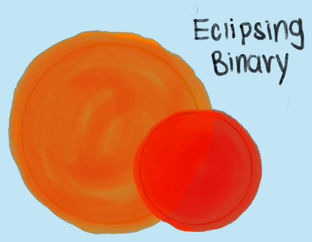
We detect a TCE for BOI-1 with a **period of 3.37 days** and a **duration of ~2 hours.**

3. IS BOI-1.01 A PLANET OR AN IMPOSTER?

RECYCLEBin: Flux-Level Vetting

(**R**emoval of **E**xoplanet **C**andidates **Y**earning to be **C**ondoned as **L**ookalikes and **E**clipsing **BIN**aries)

`RECYCLEBin` employs a suite of statistical tests, adapted from the Kepler Team's `Robovetter` [11], to determine whether the TCE is consistent with a planet candidate or false positive/alarm.



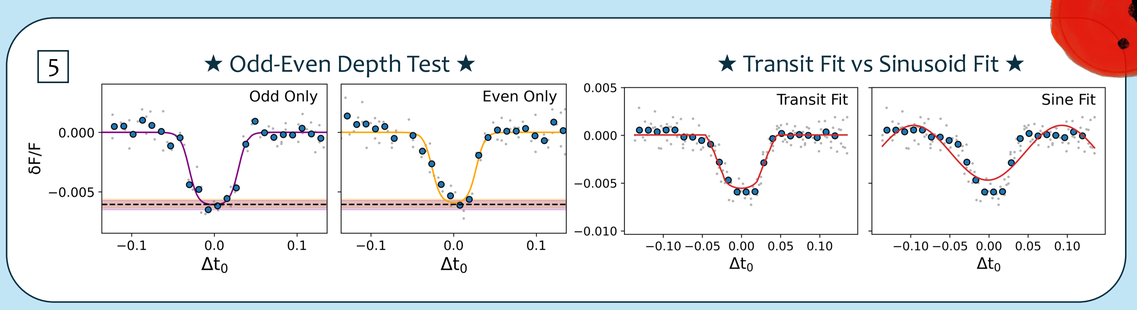


Fig 5a. We compare the depths of odd-numbered and even-numbered transits to check for near equal-mass EBs at half their true orbital period.

Fig 5b. We compare transit and sinusoidal fits to verify the TCE is not caused by stellar variability.

INCInERATOr: Pixel-Level Vetting

(**I**ndicator of **N**onaligned **C**entroids **IN** **E**xoplanet **R**eliability **A**nalysis of **T**ransit **O**bse**R**vations)

Scan me for `INCInERATOr`'s documentation!

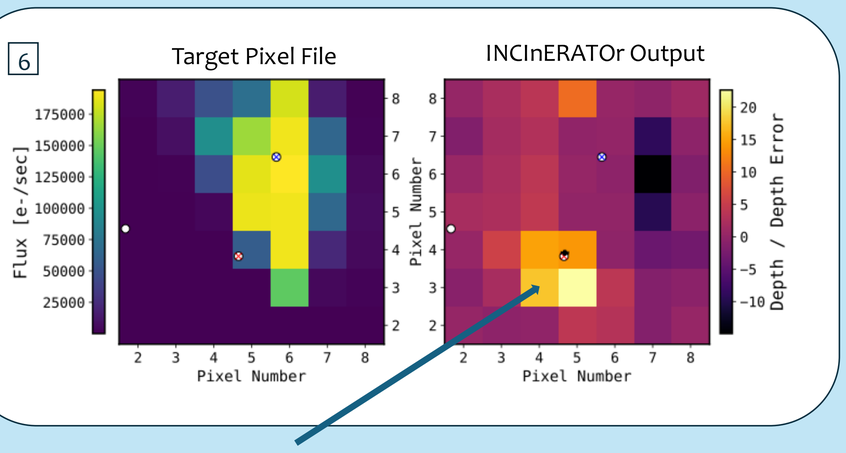


Fig 6. `INCInERATOr` output. Left: The Kepler TPF. The red cross marks BOI-1; the blue cross marks the mission target. Right: The depth heatmap indicating the most likely origin of the transit signal. The PRF-fitted location (black dot) lies on the same pixel as the Gaia DR3 position of BOI-1.

`INCInERATOr` **localizes transit signals at the pixel level** by mapping transit depth across the detector and fitting a PRF model to determine the signal's position.

Earning the b in BOI-1b

BOI-1.01 demonstrates the discovery power of `Kbonus` for exploring fainter target stars.

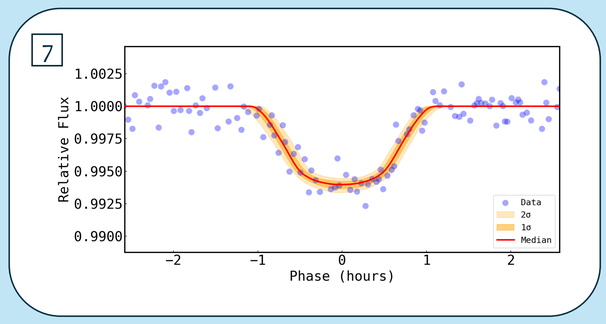


Fig 7. Phase-folded, detrended light curve of BOI-1 overlaid with the best-fit `pytfit5` transit model [12].

Our transit model indicates that BOI-1.01 is a **sub-Neptune** with a radius of around **2.94 +/- 0.15 Earth radii.**

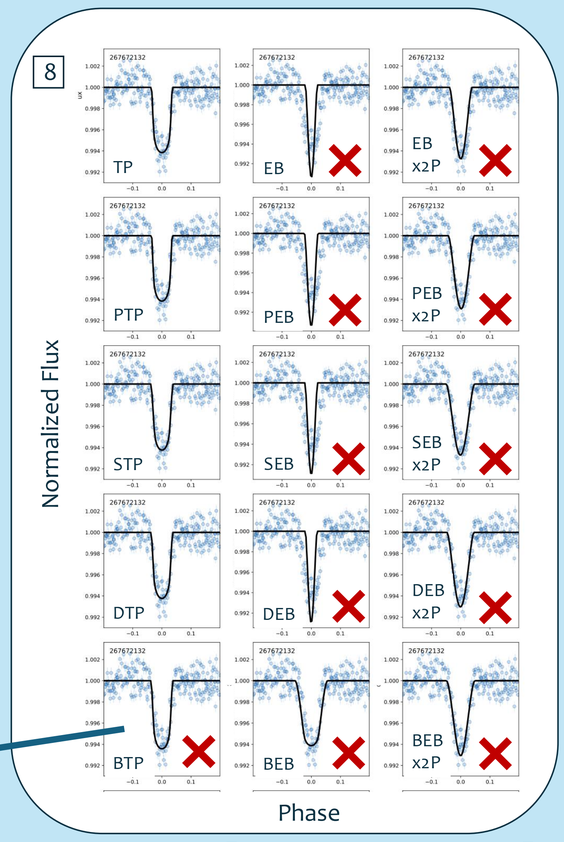


Fig 8. `TRICERATOPS-PLUS` [13, 14] outputs showing the best-fit model for each transit and false positive scenario.

We need smaller ephemeris uncertainties and higher-cadence data!

High resolution AO imaging rules out the Background Transiting Planet scenario.

The shape of the transit and the distribution of ultra-faint stars in our galaxy does not support EB hypotheses.

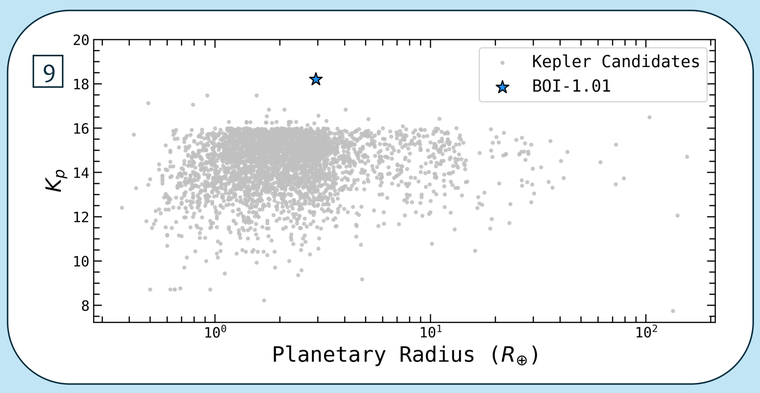


Fig 9. Kepler magnitude (Kp) versus planetary radius for the known Kepler planet candidate population (grey points), with our candidate BOI-1.01 highlighted as a blue star.

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