Recent Improvements in the Kepler Mission's Transiting Planet Detection Algorithm

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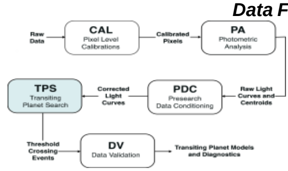
Abstract

We describe recent developments in the algorithm used by the Kepler Mission to detect the periodic reductions in stellar flux which are the characteristic signature of a transiting planet. The algorithm has been extended to allow searches in which the flux from a given star falls on different detectors within the focal plane at different times, which is necessary in order to accommodate the spacecraft's periodic axial rotations ("quarterly rolls"). A robust estimator of stellar noise characteristics allows the noise analysis process to function correctly in the presence of extremely deep transits such as those produced by an eclipsing binary or a Jovian or super-Jovian transit. Techniques for eliminating false detections due to step changes in pixel sensitivity or other non-transit phenomena have been incorporated into the algorithm. We also discuss future improvements to the detection algorithm, including a robust detection statistic which will permit far more effective filtering of false-positive detections.

Kepler SOC Science Processing Pipeline

Data Flow



Science data from over 160,000 long cadence (LC – 30 minute integrations) and 512 short cadence (SC – 1 minute integrations) stellar targets are processed in the SOC Science Processing Pipeline. Transiting Planet Search (TPS) runs on all LC targets but not on SC targets.

Components and Primary Functions

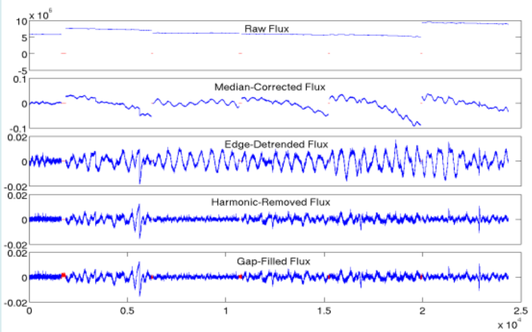
CAL	Calibrate science pixels (collateral, background and target) for each long or short cadence
PA	Extract raw flux and compute photocenter (centroid) for each target and cadence from associated target pixels
PDC	Correct systematic and other errors in raw light curves, remove excess flux due to aperture crowding, and condition light curves for the transiting planet search
TPS	Perform transiting planet search and return Threshold Crossing Events (TCEs) for detections
DV	Fit transiting planet model to light curves with TCEs, search for additional transiting planets, and perform statistical tests to validate candidate planets

What does Transiting Planet Search Do?

- Compute achievable photometric precision for each light curve at all times as a function of transit duration
  - Via wavelet-based time-frequency joint analysis of each light curve
- Compute single event statistics (SESs) for each light curve at all times as a function of transit duration
  - "How much does this point in the data look like a 3 hour transit?"
- Compute multiple event statistics (MESs) by folding single event statistics time series at all relevant periods and phases
  - Constrains detections to periodic signals
  - Improves SNR via statistical averaging
  - Different frequency-domain characteristics of transits and stellar noise allow detections of small planets against background of significant stellar variability

Multiple Quarter Operation

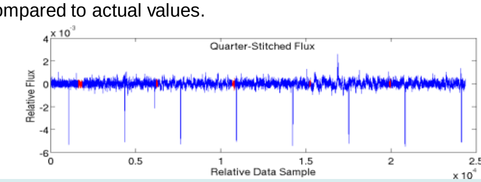
Kepler rotates by 90° about its axis every 93 days to keep its solar panels pointed at the sun. This causes light from each target to fall on different CCDs over the course of the mission, each of which unique performance characteristics. In order to search for long-period planets, TPS needs to combine the light from these sensors into a single flux time series.



In the figure above, a representative 6-quarter time series is shown in blue, with inter-quarter gaps in red. TPS performs median correction, edge detrending, removal of narrow-band harmonics, and filling of gaps in a manner which minimizes the disturbance of the overall power spectral density of the time series.

Robust Noise Estimation

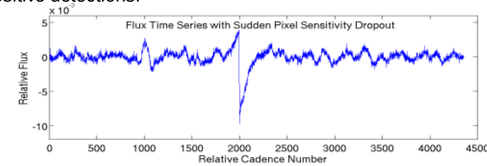
Extremely deep and/or frequent transits perturb the estimate of stellar noise, resulting in enhanced CDPP and reduced SNR compared to actual values.



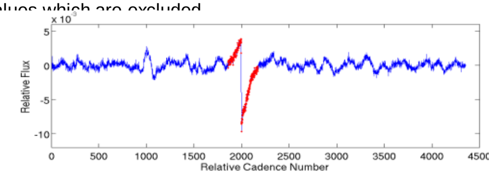
This perturbation is eliminated by replacing the standard RMS estimator of statistical fluctuations with a scaled Median Absolute Deviation (MAD) estimator, which computes the median absolute deviation from the median value, and scales by the RMS / MAD ratio for Gaussian noise. The small number of large excursions due to deep transits are ignored in this estimate.

Sudden Pixel Sensitivity Dropouts (SPSDs)

Sudden Pixel Sensitivity Dropouts (SPSDs) are step changes in individual pixel responses due to certain types of cosmic ray impacts. Many SPSDs are detected and corrected in PDC, but some are passed through to TPS, where they can cause false-positive detections.



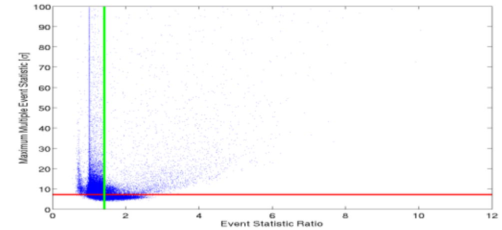
TPS now includes a detection-theory based technique for identifying SPSDs. The region around the SPSD is not used in computing the multiple event statistic, and therefore does not generate false-positive detections. The characteristic "up-down-up" shape of the SPSD is used to determine the range of data values which are excluded.



In the figure above, the excluded data values are shown in red, included data in blue.

Future Improvements

In order to limit the number of false-positive detections, TPS cuts all targets which have a multiple event statistic under 7.1 σ, and a ratio of multiple to single event statistics under √2. The latter cut eliminates some true-positive events, so a future robust multiple event statistic will allow this cut to be relaxed or eliminated outright.



Discovery Mission 10 - Launched 2009 - http://Kepler.NASA.gov

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