Validation & Verification of the *Kepler* planet-detection mission

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Abstract

To date, over 100 Jupiter-class and larger planets have been discovered around other stars using ground-based, radial-velocity (Doppler) techniques. The next leap forward, finding Earth-class exo-planets, will require the use of other techniques. The *Kepler Mission* will employ spaceborne differential photometry to detect and determine the frequency and characteristics of approximately 50 – 500 Earth-class planets in the extended solar neighborhood by monitoring 100,000 dwarf stars for transits by such planets. Recently selected as the tenth Discovery mission, *Kepler* is scheduled for launch in 2007 on a Delta-II with a nominal 4 year mission and a possible extension to 6 years. *Kepler* will be injected into an earth-trailing, heliocentric SIRTF-type orbit to minimize system instabilities. The flight segment consists of a 0.95m aperture, wide-field (100 deg^2) photometer supported by a robust spacecraft bus. The ground segment consists of a distributed and diverse set of facilities which cooperate to perform downlink data acquisition (5 Gbits/day), calibration, ensemble photometry, and transit detection, as well as complementary ground observations and mission direction (command, control, and health monitoring).

Given the relative change in stellar brightness associated with a Sun-Earth analog transit of 80 parts per million (ppm), *Kepler* must provide a system precision of 20 ppm for a 6.5 hour integration on a 12^{th} magnitude G2V star. At mv =12, the noise is composed of 10 ppm for the photometer, 14 ppm for shot-noise, and an assumed 10 ppm for stellar-variability. This level of photometric precision is unprecedented. A comprehensive set of ground testbed experiments have demonstrated the capability of the *Kepler* concept to meet this challenging requirement in the presence of all confounding factors. However, the tasks of validating and verifying the as-designed/built *Kepler Mission* still remain before us. We have created a preliminary project validation and verification plan for *Kepler*. Our near-term focus is validating the requirements to insure the project is designed and developed correctly. We have employed a "fault-tree-like" method of studying the decomposition of the driving requirements and their validation. A system end-to-end model, which includes representations of the major flight and ground segment elements (including data reduction algorithms), is key to validating the requirements and the combined differential photometric precision error budget. The model is in turn validated by the technology demonstration testbed. Verification that the as-built *Kepler Mission* meets the requirements will follow the standard approach used by most projects but with a particular challenge associated with confirming the end-to-end system performance. This performance verification is envisioned to include a test of the integrated flight photometer using a complex star-field and simulated stellar transits. The resulting data will be fed into an upgraded end-to-end simulation running the ground segment's data reduction algorithms to detect the transits and assess the as-built photometric performance. Subsequent pre-flight tests with the integrated photometer/spacecraft will confirm the photometric precision is robust and stable, thus insuring the ability to reliably detect Earth-class transits during the mission.