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 the radial-velocity (Doppler) method. The next step, finding Earth-class 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 up to 500 Earth-class planets in the extended solar neighborhood (a 100 deg^2 field to a distance of about 1 kpc) by monitoring 100,000 dwarf stars for transits by such planets. Recently selected as the ninth 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 one-meter aperture photometer with a wide field of view supported by a robust spacecraft bus. The ground segment consists of a distributed and diverse set of facilities which cooperate to perform high volume (5 Gbits/day) downlink data acquisition, calibration, and transit detection, as well as complimentary ground observations and mission direction (command, control, and health monitoring).

Given the stellar brightness change associated with a Sun-Earth analog transit (8×10^{-5}), *Kepler* must provide a system precision of 20 ppm for a 6.5 hour integration on a 12th magnitude G2V star, 10 ppm of which is allocated to photometer precision and the rest is due to stellar variability and shot noise. This level of precision is unprecedented. Although a comprehensive set of ground testbed experiments have demonstrated the capability of the *Kepler* concept to meet this challenging requirement in the presence of the expected confounding factors, 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 simulated transit source. The resulting data is used to feed the upgraded end-to-end model and other simulators in concert with the various ground segment elements to create an end-to-end data flow, including simulations of all error sources, in which transits are detected using the appropriate algorithms and system photometric precision is confirmed. Subsequent pre-flight tests with the integrated photometer/spacecraft will confirm the photometric precision remains constant, thus insuring the ability to detect transits during the mission.