A Decade of Extrasolar Planets around Normal Stars (ed. M. Livio), Cambridge: Cambridge University Press, 2005 in preparation

KEPLER MISSION: Design, Expected Science Results, Opportunities to Participate

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ABSTRACT

Kepler is a Discovery-class mission designed to determine the frequency of Earth-size and smaller planets in and near the habitable zone (HZ) of spectral type F through M dwarf stars. The instrument consists of a 0.95 m aperture photometer to do high precision photometry of 100,000 solar-like stars to search for patterns of transits. The depth and repetition time of transits provide the size of the planet relative to the star and its orbital period. Multi-band ground-based observation of these stars is currently underway to estimate the stellar parameters and to choose appropriate targets. With these parameters, the true planet radius and orbit scale, hence the relation to the HZ can be determined. These spectra are also used to discover the relationships between the characteristics of planets and the stars they orbit. In particular, the association of planet size and occurrence frequency with stellar mass and metallicity will be investigated. At the end of the four year mission, several hundred terrestrial planets should be discovered with periods between 1 day and 400 days if such planets are common. A null result would imply that terrestrial planets are rare. Based on the results of the recent Doppler-velocity discoveries, over a thousand giant planets will also be found. Information on the albedos and densities of those giants showing transits will be obtained. The mission is now in Phase C/D development and is scheduled for launch in 2008 into a 372-day heliocentric orbit.

1. INTRODUCTION

Since the first discoveries of planetary companions around normal stars in 1995, more than 150 such planets have been discovered. At least 5% and as many as 25% of solar-like stars show the presence of giant planets (Lineweaver and Grether, 2003). These planets are generally very massive, often exceeding that of Jupiter and Saturn. Further most have semi-major axes less than 1 AU and have high orbital eccentricities. The surprisingly small values for the semi-major axes imply that they form at several AU but then lose momentum to the accretion disk and spiral inward. It is unclear what processes terminate the inward motion and what fraction of planets fall into the star. However it is obvious that the inward motion of the giant planets will remove smaller planets by scattering them either into the star or out of the planetary system. It is also possible that the stars not showing the presence of giant planets are devoid of all planets because the giant planets merged with the star after their inward migration. Thus planetary systems with terrestrial planets might be very rare. However, a recent discovery (Rivera et all 2005) of a planet with a mass of 7.5 times that of the Earth and a 2.7 day orbital period indicates that at least some terrestrial planets survive.

Determination of the frequency of terrestrial planets and their distributions of size and orbital semi-major axes is needed to increase our understanding of the structure of planetary systems. The *Kepler Mission* is designed to discover hundreds of terrestrial planets in and near the habitable zone (HZ) around a wide variety of stars. For short period orbits, hundreds of transits will be observed during the four year mission so that planets as small as Mercury and Mars can be detected. *Kepler* is a PI-lead mission and was competitively selected as NASA Discovery Mission #10 in December 2001. It is scheduled to launch in June 2008 into an Earth-trailing orbit. A description of the mission and the expected science results are presented.

2. SCIENTIFIC GOALS

The general scientific goal of the *Kepler Mission* is to explore the structure and diversity of planetary systems with special emphasis on determining the frequency of Earth-size planets in the HZ of solar-like stars. This is achieved by surveying a large sample of stars to:

- Determine the frequency of terrestrial-size ($R_\oplus$) and larger planets in or near the habitable zone of a wide variety of spectral types of stars;
- Determine the distributions of sizes and orbital semi-major axes of these planets;
- Estimate the frequency of planets orbiting multiple-star systems;
- Determine the distributions of semi-major axis, eccentricity, albedo, size, mass, and density of short period giant planets;
- Identify additional members of each photometrically-discovered planetary system using complementary techniques; and
- Determine the properties of those stars that harbor planetary systems.

The *Kepler Mission* supports follow-on missions such as SIM, TPF, and the *Darwin Mission* by finding the association between the frequency and characteristics of terrestrial planets and stellar type and by determining the distributions of planetary size and orbital semi-major axis. Since the *Kepler* FOV is along a galactic arm at the same galactocentric distance as the Sun, the stellar population sampled with *Kepler* is indistinguishable from the immediate solar neighborhood. Thus the *Kepler* results should provide pertinent information for selecting the most promising targets for future missions.

3. PHOTOMETER AND SPACECRAFT DESCRIPTION

The instrument is a wide field-of-view (FOV) differential photometer with a 100 square degree FOV that continuously and simultaneously monitors the brightness of 100,000 main-sequence stars with sufficient precision to detect transits by Earth-size planets orbiting G2 dwarfs. The brightness range of target stars is from visual magnitude 9 through 15. The photometer is based on a modified Schmidt telescope design that includes field flattener lenses near the focal plane. Fig. 1 is an isometric view of the photometer. The corrector has a aperture of 0.95 m with a 1.4 m diameter F/1 primary. This aperture is sufficient to reduce the Poisson noise to the level required to obtain a 4σ detection for a single transit from an Earth-size planet transiting a 12th magnitude G2 dwarf with a 6.5 hour transit. The focal plane is composed of forty-two 1024x2200 backside-illuminated CCDs with 27 μm pixels

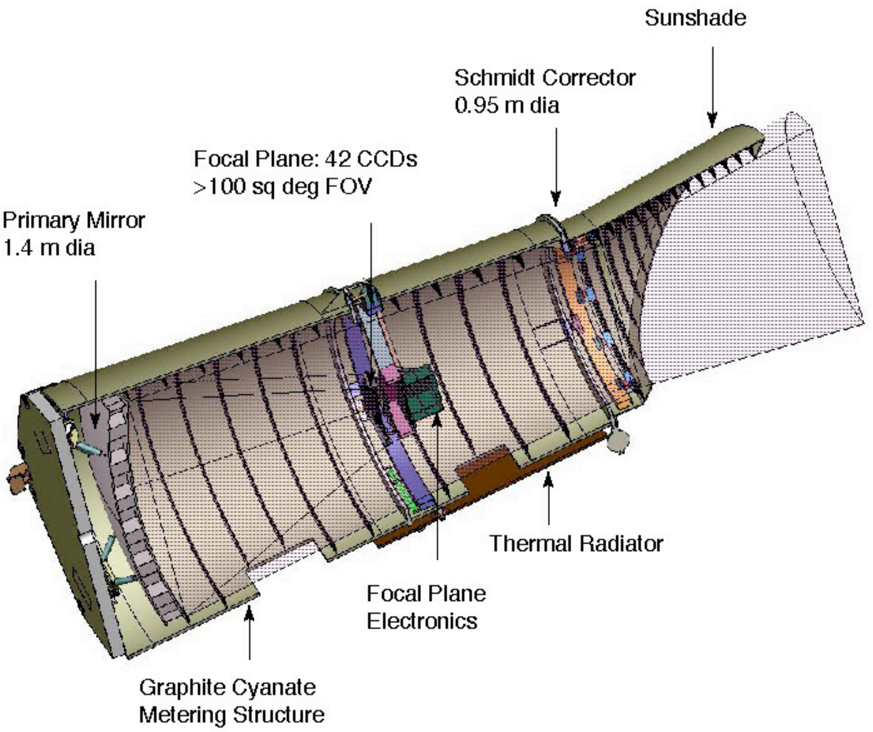

Fig. 1. Isometric view of the *Kepler* photometer.

The detector focal plane is at prime focus and is cooled by heat pipes that carry the heat out to a radiator in the shadow of the spacecraft. The low-level electronics are placed immediately behind the focal plane. A four-vane spider supports the focal plane and its electronics and contains the power- and signal-cables and the heat pipes.

The spacecraft bus encloses the base of the photometer and supports the arrays and the communication, navigation, and power equipment. Two antennas with different frequency coverage and gain patterns are available for uplink commanding and for data downlink. A steerable high-gain antenna operating at Ka band is used for high-speed data transfer to the Deep Space Network (DSN). It is the only articulated component other than the ejectable cover. Approximately 1 GByte/day of data are recorded and then transferred to the ground every few days when contact is made with the DSN. The spacecraft provides very stable pointing using four fine guidance sensors mounted in the photometer focal plane. Small thrusters are used to desaturate the momentum wheels. Sufficient expendables are carried to extend the mission to six years.

Both the photometer and the spacecraft are being built by the Ball Aerospace and Technology Corporation (BATC) in Boulder, Colorado. NASA Ames manages the photometer development, mission and operations, and scientific analysis. JPL manages spacecraft and mission development. A more comprehensive discussion of the mission design is given in Koch et al., this volume.

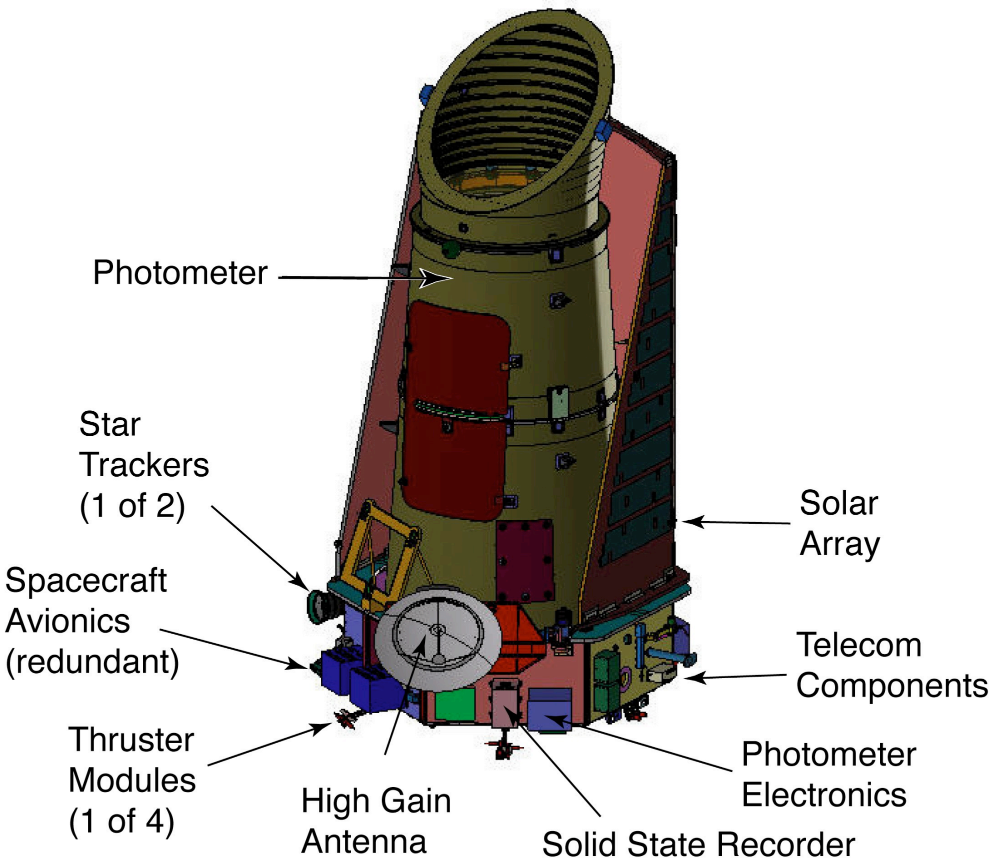

Fig. 2. Integrated spacecraft and photometer.

3. SCIENTIFIC APPROACH

To achieve the required photometric precision to find terrestrial-size planets, the photometer and the data analysis system must be designed to detect the very small changes (~1 part in 10^4)in stellar flux that are characteristic of transits by terrestrial planets. The *Kepler Mission* approach is best described as "differential relative photometry". In this approach;

- Target stars are always measured relative to the ensemble of similar stars on the same part of the same CCD and read out by the same amplifier.
- Only the time change of the ratio of the target star to the ensemble is of interest. Only decreases from a trend line based on a few times the transit duration are relevant (long-term stability of the trend is not required).
- Target star and ensemble stars are read out every five seconds to avoid drift and saturation
- Correction for systematic errors is critical.

Photometry is not done on the spacecraft. Instead, all of the pixels associated with each star image and the collateral, bias, and smear pixels are sent to the ground for analysis. This choice allows many different approaches to be used to reduce systematic errors.

The spacecraft is placed in an Earth-trailing heliocentric orbit by a Delta II 2925-10L launch vehicle. The heliocentric orbit provides a benign thermal environment to maintain photometric precision. It also allows continuous viewing of a single FOV for the entire mission without the Sun, Earth or Moon obtruding. Only a single FOV is monitored during the entire mission to avoid missing transits and to maintain a high duty cycle.

A pattern of at least three transits that shows that the orbital period repeats to a precision of at least 10 ppm and that shows at least a 7σ detection is required to validate any discovery. A detection threshold of 7σ is required to avoid false positives due to random noise. The mission is designed to provide a lifetime of four years to allow four transits in the HZ of a solar-like star to be observed so that a higher recognition rate can be obtained. Note that transit signatures with a mean detection statistics of $8\ \sigma$ will be recognized 84% of the time whereas those with a mean of 7σ will be recognized only 50% of the time.

Classical signal detection algorithms that whiten the stellar noise, fold the data to superimpose multiple transits, and apply matched filters are employed to search for the transit patterns down to the statistical noise limit [6]. From measurements of the period, change in brightness and known stellar type, the planetary size, the semi-major axis and the characteristic temperature of the planet can be determined. The latter gives some indication of whether liquid water could be present on the surface; i.e., whether the planet is in the habitable zone.

Because of limitations of the telemetry stream, only data from those pixels illuminated by the pre-selected target stars are saved for transmission to Earth. Data for each pixel are co-added onboard to produce one brightness measurement per pixel per 15-minute integration. Data for a subset of target stars can be measured at a cadence of once per minute. This option will be exercised to obtain detailed emersion-immersion profiles, for detecting changes in transit timing due to the presence of multiple planets, and for conducting observations for astroseismology.

4. SELECTION OF TARGET STARS AND FIELD OF VIEW

Continuously monitoring approximately 100,000 quiet, late-type target stars will provide a statistically meaningful estimate of the frequency of terrestrial planets in the HZ of solar-like stars. A FOV centered on a galactic longitude of 70 deg and latitude of + 6 deg satisfies both the constraint of a 55 degree sun-avoidance angle and provides a very rich star field. This FOV falls within the Cygnus-Lyra constellations and results in looking in a tangential direction from the galactic center. In the 100 sq degree *Kepler* FOV, there are approximately 450,000 stars brighter than 15th magnitude. A ground-based observation program led by David Latham (SAO) and Tim Brown (HAO) is underway to observe $2\text{x}10^6$ stars in the FOV brighter than 17th magnitude. A unique color-filter system based on the Sloan system augmented with special filters is used to identify both the luminosity class and spectral type of each star. Ancillary information from the 2 Mass catalog is also used. The resulting catalog allows the *Kepler Mission* to choose only F through M dwarfs and to exclude giants and early spectral types from the target list. By classifying stars down to K=14.5th magnitude for which we have complete photometry and all three 2 Mass bands available, several thousand M-dwarfs can be found and put on the target list. Because of their small diameter, these stars will provide sufficient SNR for detection of terrestrial-size planets even though they are dimmer than the majority of other targets. The Kepler results for the frequency of terrestrial planets orbiting M-dwarfs are important because most nearby stars are M-dwarfs.

Stellar variability sets the limit to the minimum size of planet that can be detected. It reduces the signal detectability in two important ways;

- The variability introduces noise into the detection passband and thereby reduces the signal to noise ratio (SNR) and thus the statistical significance of transits.
- Because the flux of every target star is ratioed to the fluxes of several surrounding stars to reject common-mode instrument noise, variability of the stars used in the normalization introduces noise into the target star signal.

The second concern can be alleviated by measuring the variability of each star relative to an ensemble of others and then iteratively removing the noisiest from the list of comparison standards. To mitigate the effects of the first concern, stars must be chosen that have low variability.

Power spectra for the Sun at solar maximum and minimum are shown in Fig. 3.

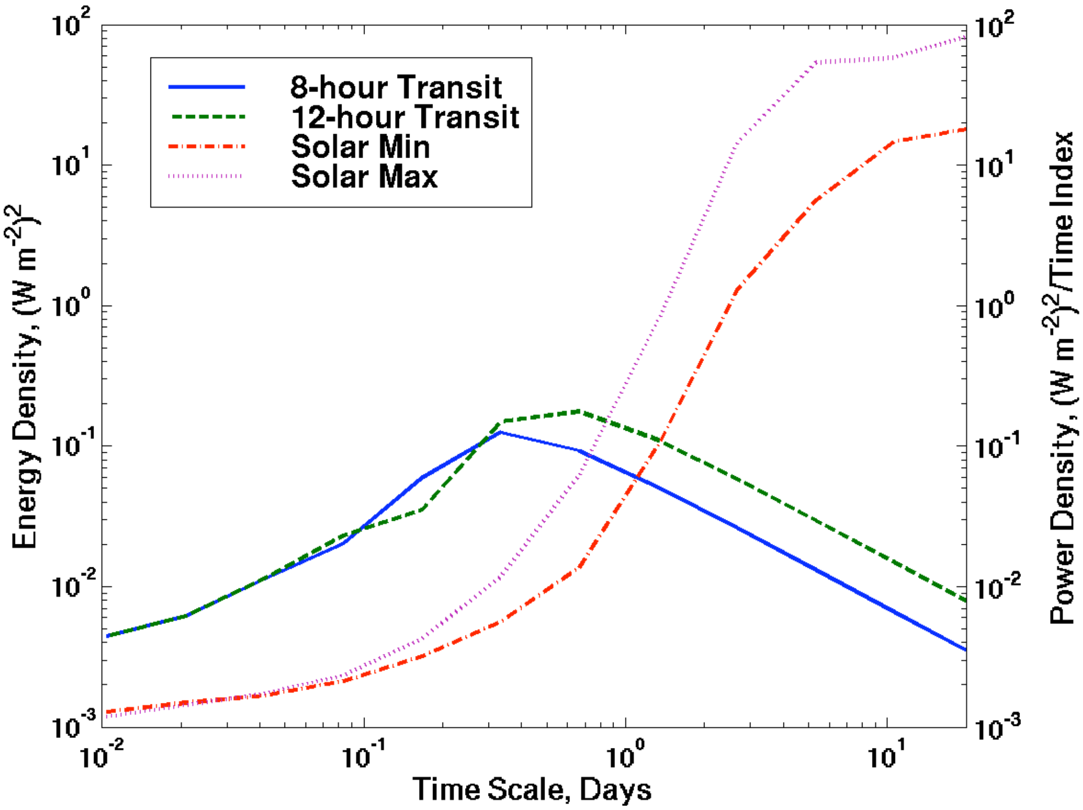

Fig. 3. Power spectra of solar variability at solar maximum and minimum. Also shown are energy spectra of 8-hr and 10-hr transits. (From Jenkins, 2002.)

Also shown are the energy spectra for transits with 8- and 10-hour durations. It's clear that most of the solar variability is at periods substantially longer than those associated with planetary transits. In particular, the Sun's variability for samples with duration similar to that for transits is about 10 ppm. For stars rotating more rapidly than the Sun, the power spectrum will increase in amplitude and move to shorter periods thus increasing the noise in the detection passband.

Stellar variability in late-type main sequence stars is usually associated with the interplay of the convective layer and the internal magnetic field. Because the depth of the convective layer is a function of the spectral type of the star and because the activity level is higher when the star is rotating rapidly, the variability of solar-like main sequence stars is related to both their spectral type and rotation rate. Further, because the rotation rate decreases with age, the age of a star is an important variable. Thus we expect that the factors that influence the variability of target stars are age and spectral type.

The age and rotation rate of the Sun are approximately 5 Gyr and 27 days, respectively. The age of the Galaxy is about 13.7 Gyr and about 2/3 of the stars are older than the Sun and are expected to be at least as quiet as the Sun. That extrapolation cannot be verified by examining the actual photometric variability of solar-like stars because no star other than the Sun has been measured to the requisite precision. However, the R'_{HK} index is believed to be well correlated to stellar variability. It is based on the spectral line profile of the Calcium II H and K lines and is readily measured with ground-based telescopes.

Fig. **4.** shows measurements of the R'_{HK} index for a variety of spectral types. As can be seen from this figure, about 70% of the stars are found to have the index at least as low as that of the Sun. Hence we plan to choose approximately 150,000 late type dwarfs to monitor during the first year of observations and then gradually eliminate those that are too variable to find Earth-size planets. This action will limit the time needed by the Deep Space Network to receive the telemetry from the spacecraft as it recedes from the Earth.

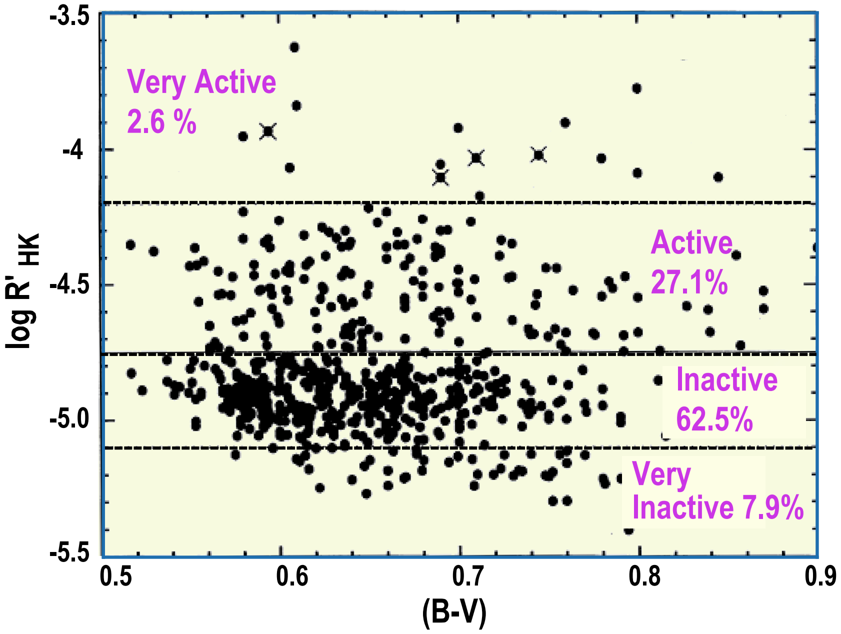

Figure 4. Activity indicator R'_{HK} versus stellar spectral type (Henry et al. 1966). The Sun lies in the middle of the inactive region. Its value of R'_{HK} varies throughout the bin during the solar activity cycle. Note that most stars are less active than the Sun.

Although most solar-like stars are expected to have stellar activity levels no higher than that of the Sun, planets can still be found around stars with higher activity levels if the size of the planets are somewhat larger than the Earth or if they are found around a later spectral types of if the stars are brighter (less shot noise) or if they are closer to the central star (more transits) or if the transit is closer to a central transit than assumed here (grazing transit). Planets in the HZ of K dwarfs have orbital periods of a few months and therefore would show about 16 transits during a four-year mission. Fig. 5. shows the minimum size planet required to produce an 8σ detection versus the amplitude of the stellar variability assuming that the frequency distribution of the stellar noise is the same as that of the Sun. The upper curve shows that the amplitude of the stellar noise would need to be at least eight times that of the Sun before it would prevent planets slightly larger than twice the radius of the Earth from being detected. For short period planets showing 16 transits, planets as small as 1.4 times the radius of the Earth would still be detectable for stars even if the star had eight times the amplitude variability of the Sun. See also Jenkins, 2002.

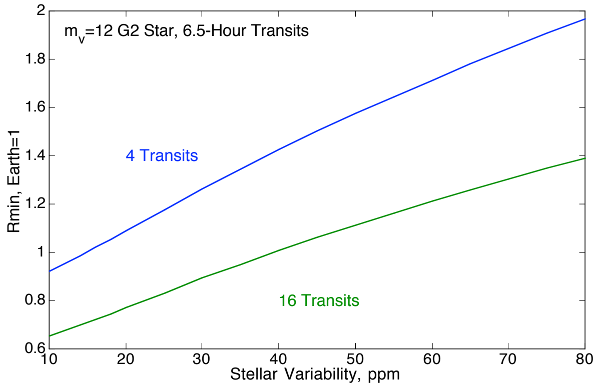

Figure 5. Effect of increased stellar variability on the minimum size planet that can be detected with 8σ.

6. INTERPLAY OF NOISE FROM STELLAR VARIABILITY, POISSON VARIATIONS, AND THE INSTRUMENT

As described earlier, it is important to find planets with a size sufficient to produce 8σ detections with three or more transits. Eq. 1. presents a simplified relationship of the signal to noise ratio (SNR) as a function of ratio of the area of the planet to area of the star (A_p/A_*), number of transits (N_{tran}), and the noise due to stellar variability (v), Poisson noise in the stellar flux (F), and instrument noise (i);

$$\mathrm{SNR}\ \alpha\ (N_{tran})^{1/2}\,(A_p/A_*)\ /\ [(i^2+v^2)+1/F]^{1/2}\ , \qquad (1)$$

where i, v, and F are in electrons counted over a sample period equal to the transit duration. It should be noted that “i” represents many separate noise sources (Koch, 2002) and that noise variance due to stellar variability is a function of the transit duration. (See Figure 3.) An examination of Eq. 1 shows that for very bright stars where the shot noise and instrument noise are small, the SNR is dominated by the stellar variability. The opposite is true for dim stars where 1/F is large and the SNR is dominated by the shot noise in the stellar flux. Table 1 presents calculated noise values for *Kepler*. For all entries in this table, a stellar variability of 10 ppm is assumed. Note that at 14th magnitude, the effect of stellar variability and instrument noise are negligible, the photometric precision is dominated by the shot noise. It is also clear that for stars 14th magnitude and dimmer, detectable planets must be somewhat larger than the diameter of the Earth if they are to be reliably detected orbiting G2 dwarfs. Planets much smaller than the Earth are readily found if they orbit smaller stars, are in short-period orbits, or orbit the 70% of stars that are expected to have lower variability than the Sun.

Table 1. Comparison of SNR and Minimum Size Planet that Produces an 8σ Detection for a Planet Transiting a G2 dwarf.

Visual magnitude	9	12	14
Stellar signal (photo electrons)	6.5×10^{10}	4.1×10^{9}	6.5×10^{8}
Stellar shot noise (ppm)	3.9	16	39
Instrument noise (ppm)	2.6	6.6	12
Solar variability (ppm)	10	10	10
Combined differential photometric precision (ppm)	12	20	42
Relative signal for Earth transit across the Sun (ppm)	84	84	84
SNR for 4 transits	14	8.4	4.0
Minimum detectable planet radius (Earth=1) at 8σ	0.75	0.98	1.4

7. EXPECTED RESULTS

As the mission duration lengthens from months to years, detection and follow up begin with the detection of three or more transits for larger planets in short period orbits and then expands outward to the detection of smaller planets and longer orbital periods. For terrestrial-size planets with orbital periods of a week or less and geometrical alignment probabilities of 10%, the number of discoveries during the first 30 days of observations should be of order; (100,000 stars * 10% alignment probability * fraction of stars with such planets). The predicted number of discoveries varies from 10,000 to 100 as the fraction of stars with planets in inner orbits varies from 1 to 0.01.

To estimate the number of planet discoveries expected as the mission progresses, a model of a planetary system was convolved with both the distributions of stars in the FOV and the system response. To assess the level of resources needed to examine the expected number of candidates, the planetary model makes the optimistic assumption that each star has a planetary system with two Earth-size planets positioned outside the HZ of the star and that there is one terrestrial-size planet in its HZ. It is assumed that planets found outside the HZ could be present with semi-major axes similar to those already found for the 150 giant planets already discovered. The model assumes that there is an equal probability of finding one of the two planets at 0.05, 0.1, 02, 0.4, 0.6, 0.8, 1.0, 1.2, or 1.5 AU. Whenever such a planet falls in or near the HZ of a star, it is removed to avoid conflict with the terrestrial-size planet already assumed to be in that position. The results shown in the figure are readily scaled to other assumptions and situations

It is clear from **Figure 6** that nearly 1300 Earth-size planets in short period orbits will be found during the first year of operation and that approximately 4,500 will be found after four years of operation. Most of this contribution occurs for inner planets because they have a high probability of geometric alignment and because the short period orbits produce large number of transits that greatly increases the SNR of the transit pattern. Although these values are probably high, they are useful for obtaining a conservative estimate the magnitude of the analysis and follow-up observation tasks. It should also be noted that if planets larger than Earth-size are common, they will produce higher SNR than assumed here, will be more easily detected around the many dim stars observed in the *Kepler* survey, and will thereby increase the values shown in Figure 6. Over the duration of a four year mission, the number of transits in a pattern will exceed 400 for the shortest period orbits. The resulting increase in the SNR of the folded data will exceed 8 even for planets as small as Mars or Mercury. Consequently, Kepler should produce an excellent estimate of the size distribution of terrestrial planets.

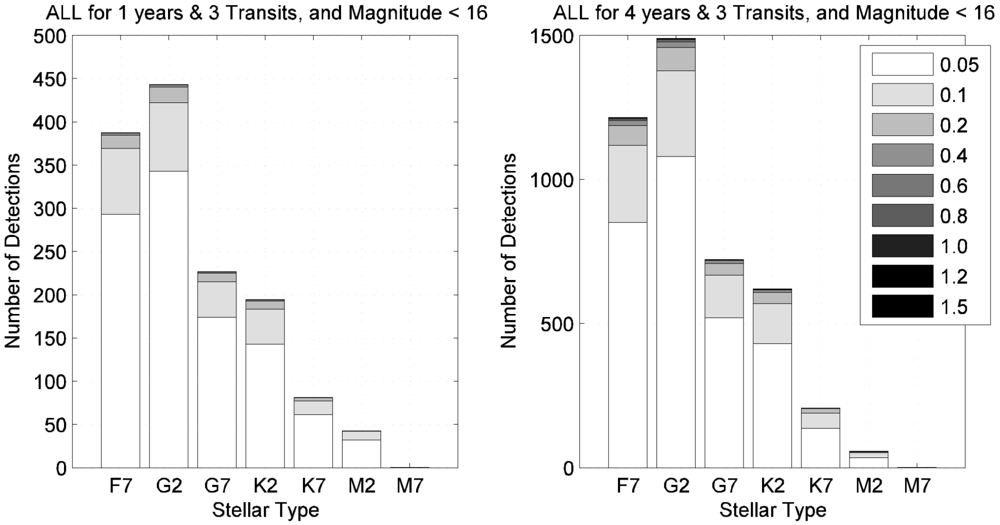

Figure 6. Number of Earth-size planets expected to be discovered as a function of stellar spectral type and semi-major axis and mission duration.

The model treats planets in the HZ differently than those placed outside the HZ. Here the objective is to determine the smallest possible planet that provides a SNR greater than the 7σ threshold value. The diameter of the terrestrial-size planet placed in the HZ of each star is systematically varied between values of Mars to 1.5 the radius of Earth (0.53, 1.0, 1.3, 2.0 $R_\oplus$) and the smallest detectable planet size is tabulated. The capability to detect small planets is valuable because a non detection rules out a larger range of planet sizes and because their detection provides information on the tail of the distribution of planet sizes. Figure 7 shows how many of each size can be detected for both four-year and six-year missions and for stellar types from F7 to M7. **Figure 7** shows that for a mission duration of 4 years, no terrestrial planets can be found for stars as early as F7. This result is dictated by the requirement to have at least three transits for a valid discovery and because planets in the HZ of early spectral types have orbital periods exceeding 1.5 years. However, when the mission duration is extended to six years, over 100 terrestrial-size planets can be discovered. A comparison of the results for a four-year versus six-year mission also shows that total number of expected discoveries increases and that the fraction of the total discoveries that are capable of detecting the smallest planets rises. Because of the small sizes of the M dwarfs and because planets in their HZ provide many transits per year, planets as small as Earth and Mars can be detected. Detection of a total 650 terrestrial-size planets including approximately100 Earth-size planets is expected.

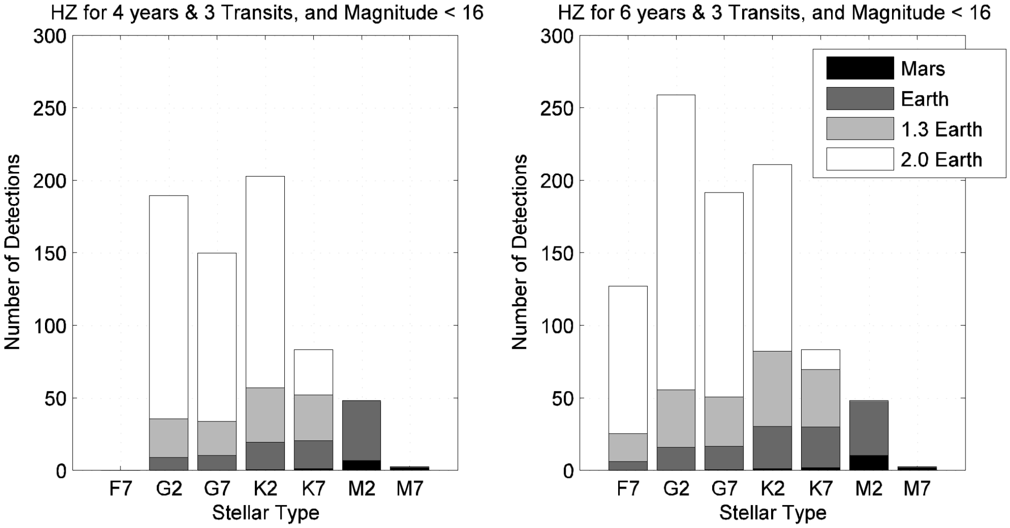

Figure 7. Number of terrestrial-size planets expected to be discovered as a function of stellar spectral type, semi-major axis, and planet size. It is assumed here that each target star has one terrestrial-size planet in its HZ.

With the ability to discover about 650 terrestrial planets in the habitable zone for a four year mission and about 900 for a six year mission, our knowledge of terrestrial planets in the HZ of a wide variety of stellar types may exceed that of extrasolar giant planets. Even if only 10% of the stars have such planets, correlations can be obtained for the frequency of planets with stellar type and metallicity. Given that several percent of solar-like stars have orbiting giant planets, it seems unlikely that as few as 1% of such stars have terrestrial planets. Nevertheless, if that should be the case, *Kepler* will find hundreds of Earth-size planets in inner orbits and at least a few terrestrial-size planets in the HZ. If no terrestrial-size planets are found, then they must be very rare and theories on terrestrial planet accretion and migration will need to be re-examined.

8. VALIDATION OF PLANET DETECTIONS

Before a candidate detection can be considered to be a validated planet, a rigorous validation process must be executed to ensure that it is not due to some other phenomenon (Borucki et al. 2003). Public release of false positives would ultimately discredit any mission results. Therefore to be considered a validated planet, the detection must meet several requirements:

1. The total statistical significance (SNR) of the superimposed transits must exceed 7σ. This requirement prevents false positives produced by statistical noise when $8\text{x}10^{11}$ statistical tests are carried out on 10^5 stars for orbital periods from 1 to 700 days.
2. At least three transits must be observed that demonstrate a period constant to 10 ppm. This test is independent of the previous test and demonstrates the presence of a highly periodic process. It essentially rules out mistaking stellar phenomenon for transits. (Exceptions must be made for planets showing timing variations caused by mutual perturbations.)
3. The duration, depth, and shape of the light curve must be consistent. The duration must be constant over all transits and consistent with Kepler's laws based on the orbital period. The depth must be consistent over all transits. A weaker requirement is that the shape must be consistent with a “U” shape of a planetary transit rather than a “V" shape of a grazing eclipse of a binary star. Low-amplitude transits are likely to be too noisy to make this distinction.

4. The position of the centroid of the target star determined outside of the transits must be the same as that of the differential transit signal. If there is a significant change in position, the cause of the signal is likely to be an eclipsing star in the background.
5. Radial velocity measurements must be conducted to demonstrate that the target star is not an eclipsing binary with the period of the transits.
6. High precision radial velocity measurements must be made to measure the mass of the companion or provide an upper limit that is consistent with that of a small planet.
7. High spatial resolution measurements must be made of the area immediately surrounding the target star to demonstrate that there is no background star in the aperture capable of producing a false positive signal.

Requirements #1 and #2 insure that statistical fluctuations in the data series will produce less than one false positive for the entire mission which is critical for the case of a null result. Requirements #3 through #7 greatly reduce the probability that unrelated physical phenomena could be mistaken for a pattern of planetary transits.

Other checks are also possible. For example, if future instrumentation on HST and JWST has sufficient precision to detect the color changes during the transit, a measured color change consistent with the differential limb darkening expected of the target star would strengthen the validation (Borucki and Summers, 1984). A shape or depth or color change substantially different than expected would point to the possibility of a very close background star that differed in spectral type or reddening.

Giant planets, like 51 Pegasi, with orbits of less than seven days are also detected by the periodic phase modulation of their reflected light without requiring a transit (Borucki et al. 1997). For the short-period giant planets that do transit, the planetary albedo can be calculated. Information on the scattering properties of the planet's atmosphere can also be derived (Marley et al. 1999, Seager et al. 2000, Sudarsky et al. 2000) from the phase curves.

Ground-based Doppler spectroscopy and/or space-based astrometry with SIM can be used to measure the larger planetary masses and can distinguish between a planet and a brown dwarf. These complementary methods can also detect additional massive companions in the systems to better define the structure of each planetary system. The density of any giant planet detected by both photometry and either radial velocity or astrometry can be calculated. Determination of the planet size, mass, semi-major axis, and stellar properties provides the properties critical for the validation and development of theoretical models of planetary structure.

White dwarf stars are about the size of the Earth and might be expected to produce a transit signal of similar magnitude. However, because of the gravitational lensing caused by their large-but-compact mass, the transits actually result in an increase in brightness (Sahu and Gilliland 2003) and are thereby readily distinguished from those of a planet.

9. DATA RELEASE POLICY

To avoid claims based on false positive detections, the series of data validation procedures and ground-based observations must be made and analyzed to validate the discovery before any announcements are made. It is expected that several months will be required to obtain telescope time on suitable ground-based telescopes and conduct the observations and analysis. The limited seasonal availability of the FOV and effects of poor weather will add to the delay. Hence the data can not be released until several months have passed from the time that the detection algorithm shows that at least three transits with a combined SNR $>7\sigma$ have been detected.

When data are released, both original calibrated data for each target and the light curves generated by ensemble photometry will be provided so that all interested members of the scientific community can independently assess the reliability of the results.

10. EDUCATION AND PUBLIC OUTREACH PROGRAMS

Bringing the science and the excitement of space missions to students and the general public is a major goal of all NASA efforts. To further this goal, the *Kepler Mission* includes two institutions that produce high quality educational materials and have high impact in education nationally: Lawrence Hall of Science (University of California) and SETI Institute. Formal education contributions will include *Great Explorations in Math and Science* (GEMS) teacher guides in math and science for grades K through 8, *Full Option Science System* (FOSS) teacher workshops for middle schools, and addition of a *Kepler*-science module in the *Hands-On Universe* high school curriculum. For informal science education, *Kepler* has developed an orrery demonstrating the detection-by-transit method. This "hands on" device is now a part of a traveling museum exhibit sponsored by the Space Science Institute (SSI). The informal education program is also developing programs explaining planet finding for small and medium-size planetariums serving both school and public audiences. *Kepler* will fund the creation of public radio broadcasts through *Stardate* and a video program suitable for public broadcast. To enhance participation by the public, predictions of the large-amplitude transits by giant planets will be distributed via the *Kepler* website (http://Kepler.NASA.gov) so that amateur astronomers and institutions with CCD-equipped facilities can observe planetary transits. To increase the use of CCD technology, several CCD cameras will be supplied to minority colleges that already have telescopes. Training and support will be provided to the college faculty in photometric observing techniques and data analysis methods required for high precision photometry in discovery and observation of planetary transits.

11. OPPPORTUNITIES TO PARTICIPATE

It is expected that several opportunities to participate in the *Kepler Mission* will be available. Current concepts envision a Participating Scientist Program (PSP) with a Guest Observer (GO) option and a Data Analysis Program (DAP).

PSP investigators will be encouraged to propose research topics that complement those of the Mission Team. It is expected that the PSP will have two options; the Participating Scientist (PS) option whereby the participating scientist proposes a research program directly concerned with detection, characterization, or understanding of extrasolar planets, and the GO option whereby the proposer specifies targets in the ***Kepler*** FOV that are to be observed for astrophysical interest, but would not otherwise be included on the target list.

For the PS option, the proposed programs can be analytical, observational, or theoretical in nature. Examples of appropriate analytic programs include: modeling eclipsing binary systems to determine the characteristics of the stars and planets, and measuring and modeling timing variations in the epoch of transits to detect non-transiting planets. The PS option can involve use of the existing target data or request observations of additional targets. Examples of ground-based observational programs include those designed to fully characterize those stars found to have planets, high-precision radial velocity measurements to determine the mass of the planets detected from transits or from reflected light, confirmation of transits or efforts to detect atmospheric absorption, and observations that verify that the transit signal is coming from the target star rather than a background star.

The GO option should accommodate those investigators who wish to make astrophysical measurements of the many different types of objects in the ***Kepler*** FOV. Generally, these targets will be different than those chosen for the transit search. Examples include variable stars of all types, distribution and time variation of zodiacal light, and extragalactic objects. It is expected that a total of about 3000 additional targets at any one time will be available and that these selections can be changed at intervals of 3 months. Most of the targets will be observed at a cadence of once per 15 minutes, but a small subset could be observed with a one minute cadence. All targets must be within the active area of the ***Kepler*** FOV. The FOV will not be moved to accommodate a GO request. For stars already on the Kepler target list, the GO will be referred to the DAP. The Kepler target list is expected to be available at launch to allow investigators to plan their requests.

Investigators desiring to analyze data from targets already on the ***Kepler*** target list will apply to the Data Analysis Program (DAP). DAP is an opportunity for the scientific community to perform data mining on the existing database. Examples of potential uses for the data are validation of planetary detections, exoplanet searches using alternative techniques, analysis of stellar activity cycles, white-light flaring, frequency of Maunder minimums, distribution of stellar rotation rates, etc.

A data release policy has been developed to release Mission data at the earliest time that allows for data calibration and validation and insures against false-positive planetary detections. The first three-month data set will be released approximately one year after commissioning and then supplements will be released annually. Publicly released ***Kepler*** observations will be freely available to all interested parties for data mining. The data will be archived In the Multimission Archive at Space Telescope (MAST) and supported for at least five years after the end of the mission.

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