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Kepler: NASA's First Mission Capable of Finding Earth-Size Planets



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Media Services Information

NASA Television

In the continental United States, NASA Television's Public, Education and Media channels are carried by MPEG-2 digital C-band signal on AMC-6, at 72 degrees west longitude, Transponder 17C, 4040 MHz, vertical polarization. They are available in Alaska and Hawaii on an MPEG-2 digital C-band signal accessed via satellite AMC-7, transponder 18C, 137 degrees west longitude, 4060 MHz, vertical polarization. A Digital Video Broadcast-compliant Integrated Receiver Decoder with modulation of QPSK/DBV, data rate of 36.86 and FEC 3/4 is required for reception. NASA TV Multichannel Broadcast includes: Public Services Channel (Channel 101); the Education Channel (Channel 102) and the Media Services Channel (Channel 103). Analog NASA TV is no longer available.

For digital downlink information for each NASA TV channel, schedule information for mission activities and access to NASA TV's public channel on the Web, visit <http://www.nasa.gov/ntv>.

Briefings

A mission and science overview news conference will be held at 1 p.m. EST (10 a.m. PST) on Thursday, Feb. 19 at NASA Headquarters approximately 14 days before launch (L-14). The news conference will be broadcast live on NASA Television. Pre-launch readiness and mission science briefings will be held at 1 p.m. and 1:45 p.m. EST (10 a.m. and 10:45 a.m. PST), respectively, on March 4, (launch minus one day) in the Kennedy News Center at NASA's Kennedy Space Center (KSC), Fla. These briefings will also be broadcast live on NASA Television. Media advisories will be issued in advance, outlining details of the news conferences.

L-14 Press Conference

Thursday, Feb. 19: A mission and science overview press conference will be held at NASA Headquarters, Washington at 1 p.m. EST (10 a.m. PST). On February 12, NASA HQ will issue a media advisory containing information about the press conference. Media advisories will be issued in advance, outlining details of the news conferences.

Accreditation and Media Access Badges for KSC and CCAFS

All news media, including those who are permanently badged, must complete the accreditation process for the activities associated with the Kepler launch. The press accreditation process may be done via the Web by going to: <https://media.ksc.nasa.gov/>.

Accreditation requests for the Kepler pre-launch, launch and post-launch activities at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS) must be received by Thursday, Feb. 5 for foreign national news media and by Friday, Feb. 27 for domestic news media. Foreign nationals must include full legal name, news organization, address, nationality/citizenship, passport number and date of birth. For information about media accreditation, contact Laurel Lichtenberger in the KSC news media accreditation office at 321-867-4036.

Pre-launch Press Conference (L-1)

Wednesday, March 4: Two pre-launch press conferences will be held at the NASA News Center at Kennedy Space Center to discuss the technical aspects of the mission, followed by a mission science briefing. KSC will issue a media advisory containing launch information and additional details about the pre-launch press conferences approximately 10 days before launch.

Post-launch Activities

No post-launch press conference is planned.

KSC News Center Hours for Launch

The NASA News Center at KSC will provide updates to the media advisories. Launch status reports will be recorded on the KSC news media codaphone that may be dialed at 321-867-2525 starting March 2.

Mission Science Updates/Major Announcements

Major science findings are usually presented via a Space Science Update briefing from NASA Headquarters broadcast live on NASA Television, or by a media telecon. These briefings will be accompanied by a news release issued by NASA Headquarters and NASA Ames Research Center, as well as supporting images and video products.

For science news of general interest but not of sufficient magnitude to warrant a Space Science Update, a news release will be issued jointly by NASA HQ and NASA Ames, or by NASA Ames Research Center only.

NASA Television Coverage

For information about NASA Television coverage of the launch, visit:

<http://www.nasa.gov/multimedia/nasatv/digital.html>

NASA Web Pre-launch and Launch Coverage

NASA's home on the Internet, <http://www.nasa.gov>, will provide extensive prelaunch and launch day coverage of the Kepler Mission.

To learn more specifically about the Kepler Mission, visit the Kepler sites at

<http://www.kepler.nasa.gov> and <http://www.nasa.gov/kepler>

Multi-Media Gallery

Images for Kepler can be found at:

http://www.nasa.gov/mission_pages/kepler/multimedia/images/index.html

Quick Facts

Mission

Launch period: March 5 to June 9, 2009 (two three-minute-long launch windows each day) Launch windows are 28 minutes apart.

First launch opportunity for March 5: 10:48 pm EST

Launch site: Cape Canaveral Air Force Station, Florida, Pad 17B

Launch vehicle: United Launch Alliance Delta II (7925-10L) with Star 48B upper stage

Fuel: Nine strap-on solid rocket motors; kerosene and liquid oxygen first stage, hydrazine and nitrogen tetroxide second stage; solid rocket third stage.

Orbit: Earth-trailing heliocentric

Orbital period: 371 days

Mission duration: 3.5 years with a possible extension to six years

Spacecraft

Dimensions: The overall size is about 2.7 meters (nine feet) in diameter and 4.7 meters (15.3 feet) high.

Mass: The total mass at launch is 1052.4 kilograms (2,320.1 pounds) consisting of 562.7-kilograms (1240.5-pounds) for the spacecraft, 478.0-kilograms (1043.9-pounds) for the photometer, and 11.7 kilograms (25.8 pounds) of hydrazine propellant.

Power: Power is provided by four non-coplanar panels with a total area of 10.2 square meters (109.8 square feet) of solar collecting surface area. Combined, the 2860 individual solar cells can produce over 1,100 Watts. Power storage is provided by a 20 Amp-hour rechargeable lithium-ion battery.

Fine Pointing: The spacecraft is three-axis stabilized to better than 9 milliarcseconds, three sigma over 15 minutes using fine-guidance sensors located on the instrument focal plane.

Telemetry: X-band is used for uplink commanding and realtime engineering data downlinking. Ka-band is used to downlink the stored science and engineering data.

Data storage capacity: About 60 days

Photometer

The sole Kepler instrument is a photometer. It has a 0.95-meter (37-inch) aperture Schmidt type telescope with a 1.4-meter (55-inch) primary mirror. Kepler's photometer has a very wide field of view for an astronomical telescope of about 15 degrees in diameter.

The photometer features a focal plane array with 95 million pixels. The focal plane array is the largest camera NASA has ever flown in space.

Project Cost

The project's life-cycle cost is approximately \$600 million. This includes funding for 3.5 years of operations.

NASA's Search for Habitable Planets

Is Earth unique? If not, how many Earth-size planets might there be in our galaxy, orbiting their parent stars at just the right distances to have liquid water on their surfaces? What are the distributions in planet size, in planet orbits and the types of stars hosting planets? These are the key questions that NASA's Kepler Mission team seeks to answer.

Kepler is NASA's tenth 'Discovery' mission, designed to survey our region of the Milky Way galaxy to detect potentially hundreds of Earth-size planets orbiting in or near the habitable zone. The habitable zone is the range in distance from a star where liquid water could exist on the surface of a planet orbiting that star. The first step in understanding our place in the universe is to determine the number of terrestrial planets (i.e., planets similar to Earth) in the habitable zone of solar-like stars.

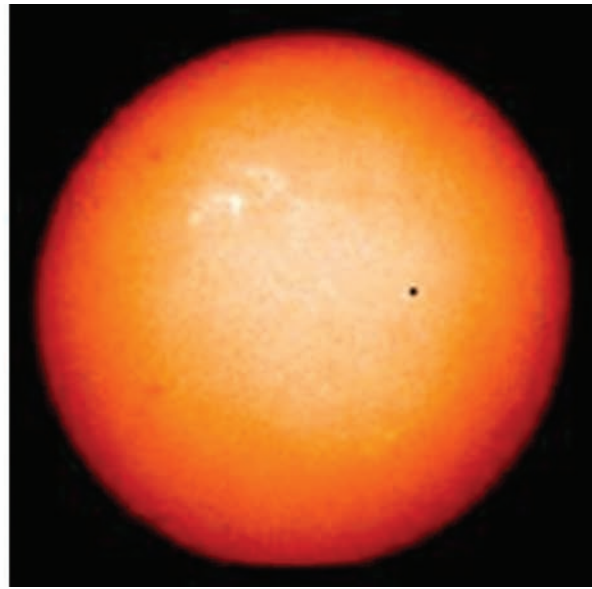
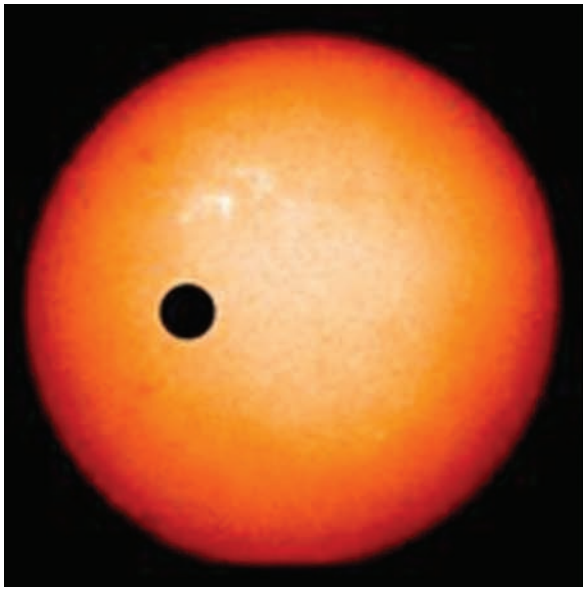
While more than 300 planets have been found using ground-based telescopes, most are large Jupiter-size planets. Many are in short-period orbits resulting in incredibly hot surface temperatures. None are as small as Earth. Small, rocky planets in the habitable zone of solar-like stars are considered to be more favorable for the development of life as we know it, than the giant gas planets previously discovered.

The Kepler Mission is a search for potentially habitable planets—it is not a search for life. However, the results of Kepler's planet search will directly impact future missions designed to measure signs of life in planetary atmospheres, by characterizing which types of stars in the solar neighborhood are likely to host Earth-size planets in the habitable zone. As one mission scientist described it, while not specifically searching for "ET," the Kepler Mission may potentially discover ET's home.

The results of Kepler's planetary census will allow scientists to develop a more complete understanding of planetary systems—the frequency of formation, structure of planetary systems and the generic characteristics of stars with terrestrial planets. A knowledge of other planetary systems that includes information about the number, size, mass and spacing of the planets around a variety of star types is needed to deepen our understanding of how planets form and the processes that produced final planetary configurations.

Searching for Earth-size planets orbiting other stars is nearly impossible with ground-based telescopes. The Earth's atmosphere is a turbulent mix of gases in constant motion, which contributes distortion to telescope images. Existing space-borne telescopes, such as NASA's Hubble Space Telescope (HST), overcome these problems by observing from above Earth's atmosphere. While incredibly powerful astronomical instruments, HST and other space telescopes are not optimized for planet hunting. They typically have very small fields of view, point at many different areas of the sky and rarely look continuously at just one star field, certainly not for years.

The Kepler Mission is specifically designed to maximize the likelihood of detecting planets as they pass in front of their stars. Kepler will look at just one large area of the sky in the constellations Cygnus and Lyra. Over the course of the mission, the spacecraft will simultaneously measure the variations in the brightness of more than 100,000 stars every 30 minutes, searching for the tiny "winks" in light output that happen when a planet passes in front of its star. The effect lasts from about an hour to about half a day, depending on the orbit and the type of star. The mission is designed to detect these changes in the brightness of a star when a planet crosses in front of it, or "transits the star." This is called the "transit method" of finding planets. These changes, or dips, in brightness are minuscule compared to the brightness of the star, and present a challenge to planet detection. Transits are only seen when a star's planetary system is nearly perfectly aligned with our line of sight. For a planet in an Earth-size orbit, the chance of it being aligned to produce a transit is less than 1%. For an Earth-size planet transiting a solar-like star the change in brightness is only 84 parts per million (ppm). That is less than 1/100th of 1%. The figure shows to scale both a Jupiter transit across an image of our sun on the left and an Earth-size transit to scale on the right. The size of the effect for an Earth is similar to the dimming one might see if a flea were to crawl across a car's headlight viewed from several miles away. Kepler's sophisticated instrument, called a photometer,



Actual H-alpha image of the sun on the left, with a Jupiter transit superimposed to scale, as if viewed from outside our solar system. The image of the sun on the right shows an Earth transit to scale.

is capable of detecting a change in a star's brightness equal to 20 ppm for stars that are more than 250 times fainter than can be seen with the naked eye. Three or more transits with a consistent period, brightness change and duration provide a rigorous method for detection of extra-solar planets. Stars spots and other variations in the brightness of a star do not repeat consistently, especially over many years.

Once Kepler's candidate planetary transit events are identified, a team of ground-based observers will perform follow-up observations to rule out false positive events that may mimic a sequence of transits. In some cases, for example, super-Earths in short-period orbits, the existence of the planet can be confirmed. The follow-up observations provide additional information about the characteristics of the parent stars, their size, mass, age, etc. and should detect other planets in the systems. These observations will take additional time to perform and analyze to the fullest confidence. The first planets discovered by Kepler will be gas giants, similar in size to Jupiter, in close orbits lasting only a few days around their parent stars. Planets in Mercury-like orbits with orbital periods of only a few months will be discovered using data from the first year of operations. Finding Earth-size planets in Earth-like orbits will require the entire length of the 3.5-year Kepler Mission. By the end of its mission, Kepler's planet census will tell us if Earth-size planets are common or rare in our neighborhood of the Milky Way galaxy.

Kepler is scheduled to launch in March 2009 on a Delta II rocket from NASA's Kennedy Space Center, Fla. Following launch, Kepler will soar away from the Earth. After just two days, the spacecraft will pass beyond the moon's orbit. Kepler's final orbit will be around the sun, trailing the Earth. The spacecraft will drift slowly away. In four years, it will be about 46.5 million miles (75 million kilometers) away from the Earth. The orbit is designed to provide the spacecraft with a stable view of the more than 100,000 stars being studied. The mission is planned to last 3.5 years, with the potential to extend it an additional 2.5 years.

Why Name the Mission After Kepler?

The science team chose to name the mission for Johannes Kepler (1571-1630) for his fundamental contributions to the fields of celestial mechanics and optics. It was Kepler who championed the Copernican idea of a heliocentric solar system, in which the planets all orbit the sun. Kepler discovered the laws of planetary motion—three basic mathematical expressions that describe the motions of planets.

To develop these laws, Kepler relied on precise data of planetary positions collected by Tycho Brahe, a Danish nobleman and astronomer who made all of his observations before the telescope was invented. The late planetary scientist Carl Sagan referred to Kepler as the first true astrophysicist, because he was the first to apply the universal concepts of physics to the cosmos. Kepler believed there was some form of central force that held the planets in their orbits. Kepler published his first two laws of planetary motion in his book *Astronomia Nova*, (New Astronomy) in 1609. These laws can be extended to other solar systems once the masses of the central stars are known. Kepler's third law will be used to determine the orbital size of planets discovered by the Kepler Mission using the measured period of the transits.

Kepler is also considered the founder of modern optics for the fundamental work he did in the field. Hans Lippershey, a German-Dutch lens maker, may have invented the telescope and Galileo may have been the first to point it to the heavens, but it was Kepler who explained how the telescope worked. In addition, he was the first to explain the process of vision by refraction in the eye, to formulate eyeglass design for near- and farsightedness, to explain the use of both eyes for depth perception, to investigate the formation of pictures with a pinhole camera, and to discover and describe the properties of total internal reflection. He coined the term diopter, which we still use today.

It is a fitting tribute to name this mission Kepler, after the founding father of celestial mechanics, modern optics and astrophysics, and that this mission to discover other Earths is being launched during the 400th anniversary year of his publication of the first two laws of planetary motion.

For more information about the Kepler Mission, visit:
<http://kepler.nasa.gov>

Scientific Goals and Objectives

The primary goal of the Kepler Mission is to survey our region of the Milky Way galaxy to discover hundreds of Earth-size or larger planets in or near the habitable zone of solar-like stars and determine how many of the billions of stars in our galaxy have such planets. Results from this mission will allow scientists to place our solar system within the continuum of planetary systems in the galaxy.

The scientific objective of the Kepler Mission is to explore the structure and diversity of extrasolar planetary systems. This is achieved by observing a large sample of stars to:

- Determine the frequency of terrestrial and larger planets in or near the habitable zone of a wide variety of stellar spectral types of stars. The frequency of planets is derived from the number and size of planets found versus the number and spectral type of stars monitored.
- Determine the distribution of the size of planets and the size of the planet's orbit. The planet's area is found from the fractional brightness decrease and the stellar area. The size of the planet's orbit is derived from the measured period and stellar mass, using Kepler's Third Law (a simple mathematical formula relating the size of the orbit of the planet and mass of the star to the amount of time it takes the planet to orbit its star).
- Estimate the frequency of planets in multiple star systems.
- Determine the distributions of orbital sizes, their light reflection properties (albedo), size, and density of short-period giant planets. Short-period giant planets are also detected from variations in their reflected light. As above, the semi-major axis is derived from the orbital period and the stellar mass.
- Identify additional members of each photometrically discovered planetary system using complementary techniques. Observations using ground-based Doppler spectroscopy, asteroseismology, and timing methods are used to search for additional massive companions that do not transit, thereby providing more information about each planetary system discovered.
- Determine the properties of those stars that harbor planetary systems. The spectral type, luminosity and composition for each star showing transits are obtained from ground-based observations. Additionally, rotation rate, amount of sun spots and stellar activity are obtained directly from the photometric data.
- Asteroseismology analysis of the data will be used to determine the mass, age, and size of the stars and astrometric analysis of the data will be used to calculate their distances, which also is used to calculate the size of the stars.

Mission Overview

Kepler will hunt for planets using a specialized instrument called a photometer. The photometer will continuously measure the variation in brightness of more than 100,000 stars, waiting for stars to “wink” when orbiting planets pass in front of them. These events, called “transits,” occur each time a planet crosses the line-of-sight between the planet’s parent star and the Kepler photometer. When this happens, the planet blocks some of the light from its star, resulting in a periodic dimming. This periodic signature is used to detect the planet and to determine its size and its orbit. The probability that a planetary orbit is aligned along our line-of-sight so that transits can be observed is equal to the diameter of the star divided by the diameter of the planetary orbit. This value is about one-half of a percent for a solar-like star and planets at the distance the Earth is from the sun. Consequently, to discover hundreds of planets, the instrument must monitor a large number of stars. In the case of Kepler, more than 100,000 stars will be monitored continuously and simultaneously.

By monitoring a large number of stars, Kepler will permit astronomers to estimate the total number of Earth-size planets orbiting in and near the habitable zone around stars in our galaxy. If Kepler does not discover any such planets, scientists may conclude that Earth-size planets are rare instead of common.

Kepler is scheduled to launch from the Cape Canaveral Air Force Station in Florida in March 2009 on a Delta II (7925-10L) launch vehicle. The mission begins with launch of the spacecraft and photometer payload into an Earth-trailing heliocentric orbit. Unlike most deep-space spacecraft, Kepler has no need for trajectory correction maneuver capability, as the launch vehicle places it directly into its desired orbit.

Following a 60-day commissioning phase, during which the photometer and spacecraft will be checked out and readied for the science mission, Kepler will spend three-and-a-half years conducting its search for planets that orbit other stars.

The vast majority of the approximately 300 planets known to orbit other stars are much larger than Earth, and none are believed to be habitable. The challenge now is to find Earth-size planets in the habitable zone—those which are potential abodes for life.

Mission Phases

Four mission phases have been defined to describe the different periods of activity during Kepler’s mission. These are: launch; commissioning; science operations; and post operations.

Launch Phase

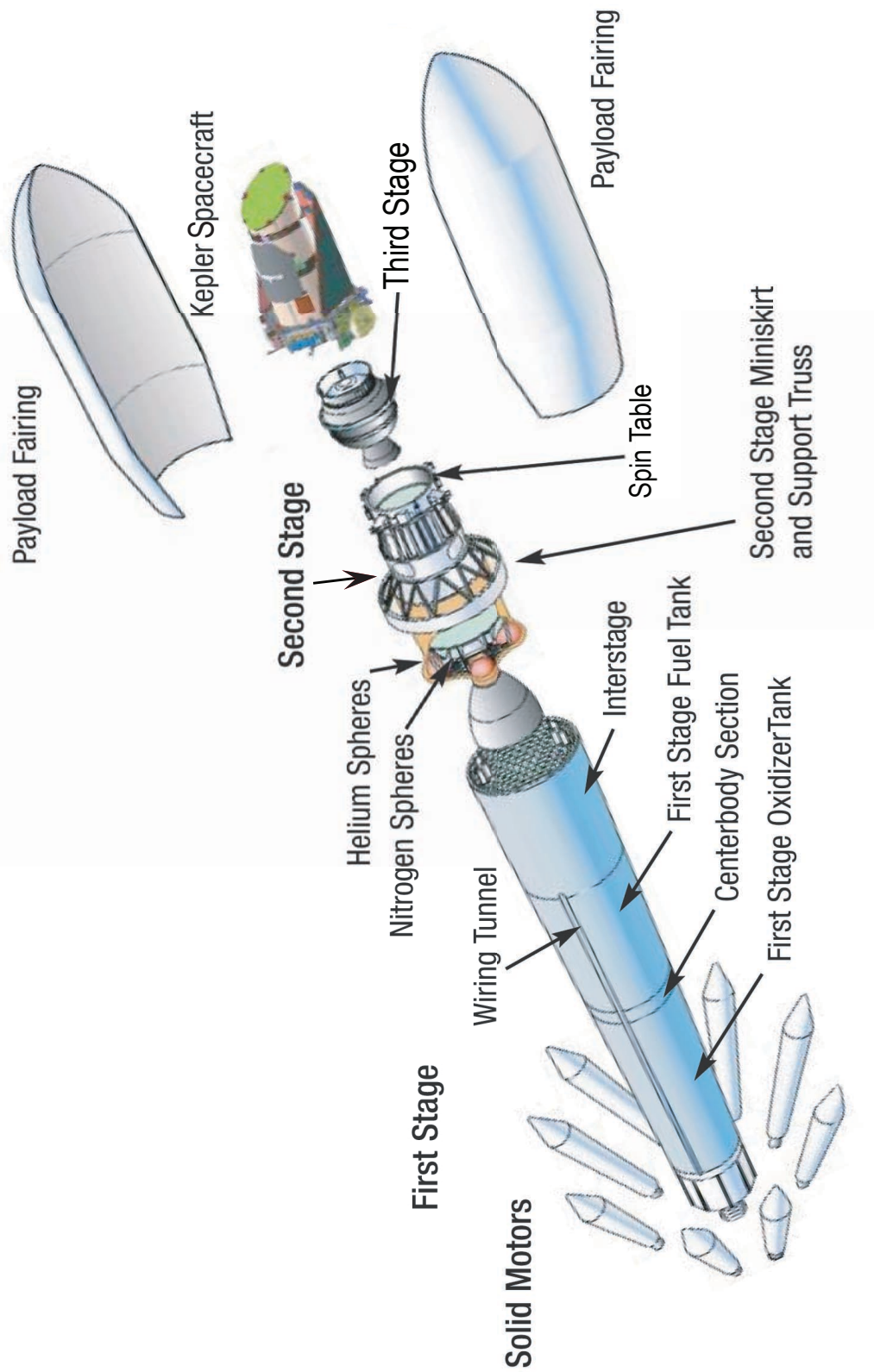
The launch phase is considered to begin three hours prior to launch and last until the Kepler spacecraft has separated from the rocket’s third stage.

Launch is scheduled from Space Launch Complex 17B at Cape Canaveral Air Force Station, Fla. Kepler’s launch period extends from March 5 through June 10, 2009. There are two three-minute launch windows each day. These two launch opportunities are just under 28 minutes apart and differ by their launch azimuths, which are 93° and 99°, respectively. The launch targets are similar for both launch windows.

The baseline launch vehicle for Kepler is a United Launch Alliance Delta II (7925-10L). This vehicle consists of a first-stage liquid-fuel booster augmented by nine solid-fuel booster motors, a bipropellant-fueled second stage, and a third stage using a Thiokol Star 48B solid rocket motor. A stretched 10-foot diameter (three meter) payload fairing encloses the second stage, third stage, and payload during first stage flight and the early portion of second stage flight.

Kepler Launch Profile

At the moment of liftoff, the Delta-II’s first stage’s main engine and six of the nine strap-on solid rocket motors are ignited. Following the burnout of the first six solids at 63.1 seconds, the remaining three solids



Delta Launch Vehicle with Kepler Spacecraft

are ignited at 65.5 seconds. The spent casings are then jettisoned in sets of three, once vehicle and range safety constraints have been met. The last set of three is jettisoned at 131.5 seconds after launch.

The first stage engine continues to burn for almost 4.5 minutes until Main Engine Cutoff. The first and second stages separate, and approximately 5 seconds later the second stage is ignited and burns for just over 5 minutes. The payload fairing is jettisoned at 4.7 minutes into the flight after the free molecular heating rate has fallen to within acceptable levels. The second stage continues to burn until it achieves a circular Earth orbit of 115 mile altitude (185 kilometers). The first shutdown of the second stage occurs at just under 10 minutes after launch.

The second stage is re-startable. The first burn of the second stage occurs during the final portion of the boost phase and is used to insert the vehicle into low Earth orbit. After parking orbit insertion, the launch vehicle and spacecraft will coast for approximately 43 minutes before reaching the proper position to begin the second, Earth-departure sequence. A little more than a third of the way through the parking orbit, the launch vehicle stack exits eclipse. For the rest of its mission, Kepler will remain in the sunlight. During the coast period, the Delta II second stage will roll in a barbecue-style along its longitudinal axis for thermal control of the launch vehicle to provide thermal stability.

After a coast phase, the second stage fires once again prior to the ignition of the third stage. Shortly after the second, second stage cutoff, the spin table rockets will fire, spinning the third stage up to about 70 revolutions per minute. The second and third stages will then separate.

The spin-stabilized third stage is powered by a Star-48B solid rocket motor burning ammonium perchlorate and aluminum. The third stage solid rocket motor will take almost 90-seconds to burn approximately 2,010 kilograms (4,431 pounds) of solid propellant, with an average thrust of 66,000 Newtons. Approximately 5 minutes after third stage burnout, a yo-yo device will deploy and de-spin the upper stage/spacecraft stack from about 55 rpm to 0 rpm, plus or minus 2.5 rpm. A few seconds later, southeast of New Guinea, Kepler will separate from the spent third stage motor at about 1.7 meters per second (3.8 mph). After injection by the launch vehicle third stage, Kepler will require no further trajectory corrections. Kepler will then be in an Earth-trailing, heliocentric orbit, similar to that of NASA's Spitzer Space Telescope (formerly SIRTf).

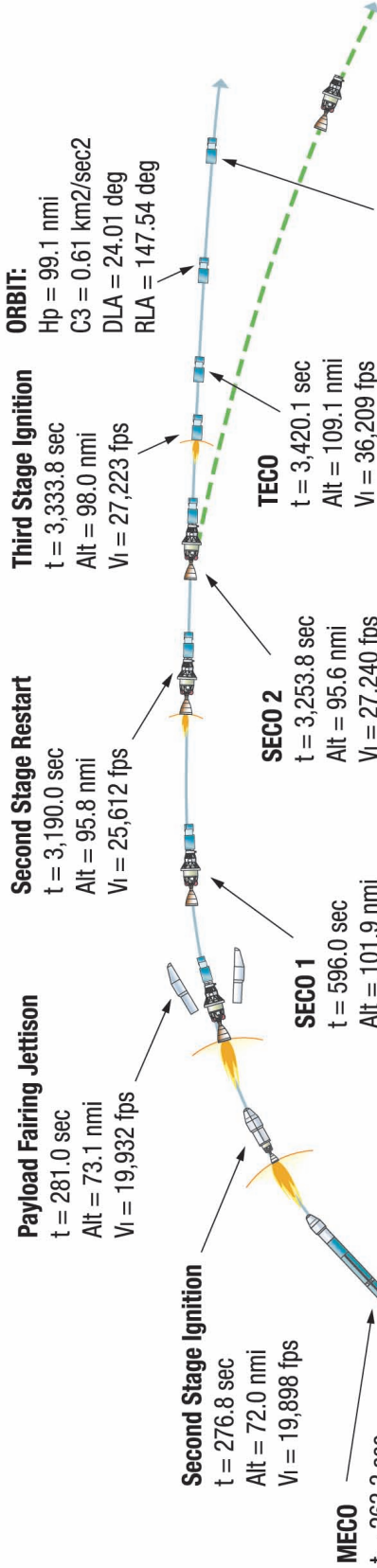
Spacecraft Orbit

The continuous viewing needed for a high-detection efficiency for planetary transits requires that the field of view of Kepler never be blocked. For a spacecraft in low-earth orbit, nearly half of the sky is blocked by the Earth and the obscured region is constantly moving. The most energy efficient orbit beyond Earth orbit is to launch into a helio-centric Earth-trailing orbit. Even then the sun, Earth and moon make it impossible to view some portions of the sky during an orbital year. Thus, Kepler looks above the ecliptic plane to avoid all these bright celestial objects. A star field has been selected in the Cygnus-Lyra constellations near the galactic plane that meets these viewing constraints and provides more than 100,000 stars to monitor for planetary transits.

An Earth-trailing heliocentric orbit with a period of 371 days provides the optimum approach to maintaining a stable trajectory that keeps the spacecraft within telecommunications capability. Telecommunications and navigation support for the mission are provided by NASA's Jet Propulsion Laboratory (JPL) and NASA's Deep Space Network (DSN).

Another advantage of this orbit is that it has a very-low disturbing torque on the spacecraft, which leads to a very stable pointing attitude. Not being in Earth orbit means that there are no torques due to gravity gradients, magnetic moments or atmospheric drag. The largest external torque then is that caused by light from the sun. This orbit also avoids the high-radiation dosage associated with an Earth orbit, but is subject to energetic particles from cosmic rays and solar flares.

Payload Separation
 t = 3,708.8 sec
 Alt = 389.6 nmi
 Vi = 34,861 fps



Third Stage Ignition
 t = 3,333.8 sec
 Alt = 98.0 nmi
 Vi = 27,223 fps

Second Stage Restart
 t = 3,190.0 sec
 Alt = 95.8 nmi
 Vi = 25,612 fps

Payload Fairing Jettison
 t = 281.0 sec
 Alt = 73.1 nmi
 Vi = 19,932 fps

Second Stage Ignition
 t = 276.8 sec
 Alt = 72.0 nmi
 Vi = 19,898 fps

MECO
 t = 263.3 sec
 Alt = 68.0 nmi
 Vi = 19,892 fps

TECO
 t = 3,420.1 sec
 Alt = 109.1 nmi
 Vi = 36,209 fps

SECO 2
 t = 3,253.8 sec
 Alt = 95.6 nmi
 Vi = 27,240 fps

SECO 1
 t = 596.0 sec
 Alt = 101.9 nmi
 Vi = 25,568 fps

Graphite Epoxy Motor (GEM) (3)
 t = 131.5 sec
 Alt = 30.8 nmi
 Vi = 7,962 fps

Graphite Epoxy Motor (GEM) (6)
 t = 66.0 / 67.0 sec
 Alt = 9.8 / 10.1 nmi
 Vi = 3,199 / 3,237 fps

Targeting Interface Point
 t = 3,933.8 sec
 Alt = 826.1 nmi
 Vi = 33,039 fps

ORBIT:
 94 nmi x 1,180 nmi
 28.55-deg inclination

ORBIT:
 100 nmi x 100 nmi
 28.5-deg inclination

ORBIT:
 Hp = 99.5 nmi
 C3 = 0.60 km²/sec²
 DLA = 23.99 deg
 RLA = 147.63 deg

t = Time after liftoff
 Alt = Altitude
 Vi = Inertial velocity

GEM Impact

Liftoff

Kepler Launch Profile

Commissioning Phase

This phase begins with the separation of the Kepler spacecraft from the launch vehicle and is planned to last for 60 days after launch, when the observatory is expected to be fully operational, but may be extended if required. It encompasses all activities necessary to prepare Kepler to conduct its scientific mission.

Major activities during this period include initial acquisition of the spacecraft's signal and confirmation of a valid radio link with the ground, confirmation that the spacecraft is generating its own electrical power via its solar panels and has returned telemetry recorded during launch. This phase also includes jettisoning of the photometer dust cover, checkout and calibration of the photometer, and fine-tuning of the spacecraft's guidance system.

Four antennas of the Deep Space Network will assist in the initial acquisition of spacecraft signal after separation. Two 34-meter (112-foot) antennas at Goldstone, Calif., and two 34-meter antennas in Canberra, Australia, will perform a sweep in both frequency and angle to acquire the one-way downlink signal from the spacecraft. Once two-way communication with the spacecraft is confirmed, ground controllers will begin the process of confirming that all spacecraft systems and instruments are operational.

One critical event during commissioning is the photometer dust cover jettison. The dust cover protects the photometer from contamination on the ground through launch, and from stray or direct sunlight during launch and early commissioning. While the dust cover is attached, all light is precluded from entering the photometer. This period will be used to characterize the performance of the detector electronics and to collect "dark" calibration data to be used throughout the mission. Given the high-precision measurements necessary to detect Earth-size planets, great care will be taken to ensure that all necessary dark calibration data are collected. Dust cover jettison is planned to occur about three weeks into commissioning, but the exact time will be adjusted to accommodate the calibration data activity. Once the dust cover is jettisoned, optical characterization will begin.

Commissioning phase will be considered complete when the spacecraft has demonstrated that it can generate sufficient power for science operations, point and maintain attitude to a fine degree, that its X-band and Ka-band communications systems are operating normally, that the mirror is focused and the geometry of the focal plane is measured, and that its photometer can collect science data from a full target set with sufficiently low noise to allow transit detections of Earth-size planets around solar-like stars.

Science Operations Phase

Kepler will survey three classes of main-sequence stars, also known as dwarf stars – stars bigger and hotter than Earth's sun (i.e., A and F main-sequence stars), stars similar to our sun in size and temperature (i.e., G main-sequence stars) and stars smaller and cooler than our sun (i.e., K and M main-sequence stars). Kepler will continuously monitor the brightness of more than 100,000 main-sequence stars in the Milky Way galaxy and must measure at least three transits to classify a signal as a valid planetary candidate.

During the science phase of the mission, Kepler will perform its data-gathering duties automatically. Twice a week, the operations team contacts the spacecraft to assess its health and status and upload any new command sequences. Once per month, the spacecraft stops taking data for one day, re-orientates the spacecraft to point the high-gain antenna at the Earth and downlinks the science data. Every three months, the spacecraft also must be rotated 90 degrees about the optical axis to maintain the maximum exposure on the solar array and to ensure the spacecraft's radiator is pointing towards deep space. After rotation, the instrument requires a new star pixel map for the 100,000 target stars and the 87 fine-guidance sensors stars. The photometer views the same star field for the entire duration of the mission.

The Kepler Mission begins to collect data immediately after commissioning and produces results in a progressive fashion shortly thereafter. The first results come in just a few months, when the giant inner planets with orbital periods of only a few days are detected. Objects that are in Mercury-like orbits of a few months, are detected using the data collected during the first year.

After several months of data processing and confirmation by ground-based telescopes, scientists hope to announce their first results approximately in December 2009 at NASA Headquarters during a NASA Science Update briefing about giant planets found in short-period orbits.

Approximately in December 2010, scientists expect to announce any discoveries they have made in the first year. This will be the first possible announcement of Earth-size planets in the habitable zones of M-type stars, which are stars smaller and cooler than the sun.

Discovery of Earth-size planets in Earth-like orbits requires nearly the full lifetime of the 3.5 year mission, although in some cases three transits are seen in just a little more than two years. Other results that require the full 3.5 years of data are: Planets as small as Mars in short period orbits, which utilizes the addition of dozens or more transits to be detectable; and the detection of giant-inner planets that do not transit the star, but do periodically modulate the apparent brightness due to reflected light from the planet.

Approximately in December 2011, scientists are expected to announce any discoveries made during the first two years of the mission. The announcement will be made at NASA Headquarters and later at the January 2012 American Astronomical Society (AAS) meeting held in Seattle, Wa., as well as at NASA's Ames Research Center. This will be the first possible announcement of Earth-size planets in the habitable zones of K-type stars.

Around December 2012, scientists are expected to announce any discoveries made during the first three years of the mission. The announcement will be made at NASA Headquarters and later at the AAS meeting held in Austin, Texas, as well as at NASA's Ames Research Center. This is the first possible announcement of Earth-size planets in the habitable zones of solar-like or G stars.

Post-Operations Phase

Following completion of the flight phase of the mission, which may be extended to six years, the entire data set will be reprocessed over the next year, incorporating what scientists learned throughout the mission. Results of that scientific analysis will provide valuable information needed to design future missions to further the quest for habitable planets and help answer the question: "Are we alone?"

Scientists are expected to issue the final report of the Kepler Mission discoveries in December 2013 at NASA Headquarters and later at the AAS meeting held in Long Beach, Calif., as well as at NASA's Ames Research Center. These results will summarize the discoveries, especially of the frequency of Earth-size planets and their distributions of size and orbital distances.

Mission Operations

Mission operations during both commissioning and science operations phases of the mission involve several organizations, including: NASA's Ames Research Center, Moffett Field, Calif., which will conduct Mission management and operate the Science Operations Center (SOC); The Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado in Boulder, Colo., which is the site of the Mission Operations Center (MOC); Ball Aerospace & Technologies Corp., also located in Boulder will use its Flight Planning Center (FPC) to provide engineering support; NASA's Jet Propulsion Laboratory, Pasadena, Calif. will use its Deep Space Network (DSN) for navigation and communication; Space Telescope Science Institute (STScI) in Baltimore, Md. will provide the data management services.

Commands will be sent from the MOC to the spacecraft via DSN. All commands will first be tested at the FPC. Scientific and engineering data will be transmitted by the spacecraft and received on the ground by

DSN. These data will then be transferred to the MOC, where they will be examined to monitor the health of the spacecraft. Scientific data will be sent to the DMC, where the raw data will be archived and initially calibrated. The data will then be sent to the SOC, for analysis. Scientists, engineers and programmers may request changes to the target list and operations based on these analyses. Scientists will search the data for the characteristic dimming caused by planetary transits.

Spacecraft

Like all spacecraft, Kepler's design is a delicate balance of form and function. The form is the spacecraft's dimensions and weight, dictated by the size and power of the launch vehicle lifting it into space. The function is the instrument observing capabilities of the scientific cargo onboard the spacecraft.

As the spacecraft instrument is tasked to survey many stars to determine the prevalence of Earth-size planets, the spacecraft exists to serve its one instrument – a photometer designed to measure the brightness variations of stellar targets as planets cross in front of them. The spacecraft provides the power, pointing, commanding, data storage and data transmission for the photometer. The photometer itself contains the largest camera NASA has launched into space. The spacecraft includes two command and control computers, a solid state data recorder, Ka-band and X-band communication systems, two star trackers, reaction wheels and a reaction control system.

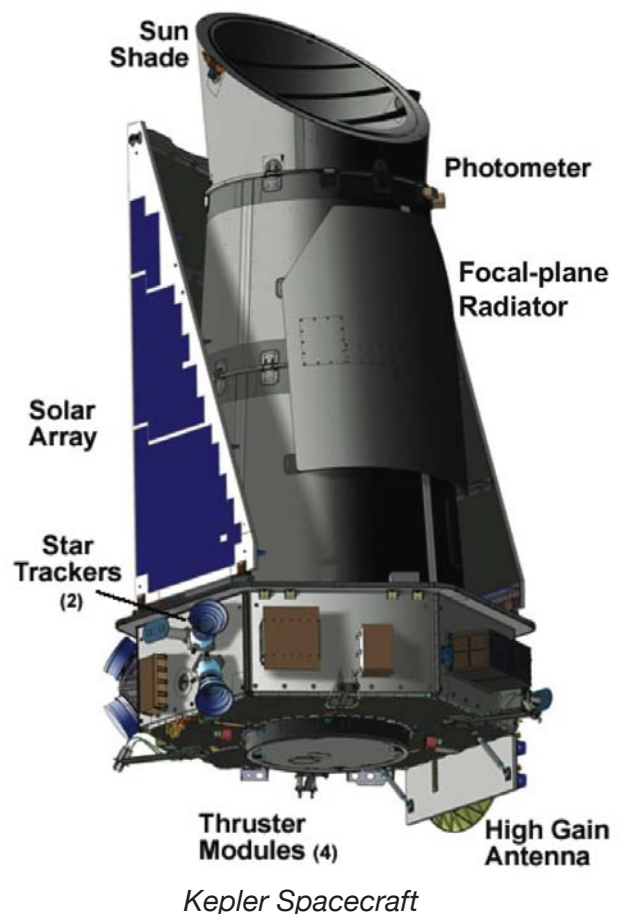
The spacecraft attitude is three-axis stabilized using a line-of-sight pointing control system. The electrical power distribution subsystem uses direct energy transfer, with a fixed solar array and a Li-Ion battery. A fixed solar array minimizes jitter disturbances and shades the photometer. The spacecraft bus structure is fabricated from aluminum honeycomb. A body-mounted high-gain antenna is used for high-rate data transmission. Two omni-directional low-gain antennas are used for low-rate data transmission and commanding.

Pointing at a single group of stars for the entire mission greatly increases the thermal and hence photometric stability and simplifies the spacecraft design. Other than the small reaction wheels used to maintain the pointing and an ejectable cover, there are no other moving or deployable parts onboard Kepler. The only liquid is a small amount of hydrazine for the thrusters, which is kept from sloshing by a pressurized membrane. This design enhances the pointing stability and the overall reliability of the spacecraft.

Spacecraft Structures and Mechanisms

The majority of Kepler's systems and subsystems are mounted on a low-profile hexagonal box which is wrapped around the base of the photometer. The hexagonal box structure consists of six shear panels, a top deck, bottom deck, reaction control system deck, and the launch vehicle adapter ring. Construction of the shear panels, decks, and solar array substrates, consists of sandwiched aluminum face-sheets on an aluminum honeycomb core. The six shear panels provide structure to accommodate mounting of the spacecraft electronics, portions of the photometer electronics, battery, star trackers, reaction wheels, inertial measurement units, radio equipment, and high- and low-gain antennas.

The top deck shear panel provides the mounting surface for the solar array panels. The bottom deck provides the interface to the photometer and also supports the thrusters, associated propellant lines, and launch



vehicle umbilical connectors. The reaction control system deck is attached to the inside of the launch vehicle adapter ring, and provides a mounting surface for the tank, pressure transducer, latch valves, and propellant lines. The base of the photometer is mounted to the lower deck.

Electrical Power

The electrical power system provides power for all onboard systems, including the photometer. Power is provided by the spacecraft's solar arrays and an onboard battery.

The solar array is rigidly mounted to the spacecraft's upper deck. As such, it pulls double-duty on this mission, providing power, as well as shielding the photometer from direct solar heating. The solar array is on four non-coplanar panels and totals 10.2 square meters (109.8 square feet) of triple-junction photovoltaic cells. It contains 130 strings each composed of 22 cells. The solar array is expected to generate up to 1,100 Watts of electrical power. Unlike most spacecraft solar arrays that are deployed or articulated, Kepler's solar array is fixed.

Powering the spacecraft during launch and providing voltage stability during the mission is a 20-Amp-hour lithium-ion battery.

Thermal Control

The thermal control subsystem is responsible for maintaining spacecraft component temperatures within operational limits. The solar array and thermal blankets shield the photometer from direct solar heating. The solar panels themselves are made out of a special material to minimize heat flow to the photometer, and their finishes also help regulate panel temperature.

Kepler is also protected by an "active" thermal control system that consists of heat pipes, thermally conductive adhesives, heaters and temperature sensors. Propane and ammonia flowing through pipes embedded in the spacecraft's exterior panels cool the focal plane. Various parts of the spacecraft that need to be heated in order to operate are equipped with controlled heaters but insulated to avoid heating the photometer.

Command and Data Handling

The command manager performs command processing of both stored-sequence and real-time commands. The command and data handling system is the spacecraft's brain. It can operate the spacecraft either with commands stored in computer memory or via real-time commands radioed from Earth for immediate execution. In addition, it handles engineering and science data destined to be sent to Earth.

At the heart of command and data handling is a RAD750 flight computer, a third-generation radiation-hardened version of the PowerPC chip used on some models of Macintosh computers. This flight computer was first used in space aboard NASA's Deep Impact mission. The RAD750 is also aboard NASA's Mars Reconnaissance Orbiter and the XSS-11 spacecraft.

Scientific and engineering data acquired by the Kepler Flight Segment will be stored in a 16 GigaByte synchronous dynamic random access memory solid-state recorder. The recorder has simultaneous read/write capability and can store 60 days of science and engineering data.

Attitude Determination and Control

The Kepler photometer uses a pointing control system to orient itself in deep space, or in engineering terms, to determine and control the spacecraft's attitude. The system is three-axis stabilized using a stellar reference for attitude. The hardware used to identify and change its attitude consists of fine guidance sensors, reaction wheels, coarse sun sensors, star trackers and inertial measurement units.

The four fine-guidance sensors are mounted on the outside corners of the photometer focal plane to ensure stable pointing. Fourteen coarse sun sensors are mounted on the flight structure and allow the spacecraft to locate the sun at all times. The two star trackers provide the spacecraft with inertial attitude data. The two inertial measurement units measure and control attitude rates, as well as provide short-term attitude estimates in the absence of sun sensor or star tracker data.

The reaction wheel assembly consists of four wheels mounted on non-orthogonal axes. The wheels are active redundant, meaning that all four are normally used, sharing the load. Reaction wheels will provide attitude control during almost the entire mission, except the initial tipoff from the launch vehicle. Eight 1-Newton reaction control system thrusters are mounted on the +Y and -Y axes. They are used to periodically remove momentum from the reaction wheels. They can also be commanded to maintain attitude control when the reaction wheels are unavailable.

As Kepler has no requirements to change orbits once it separates from the launch vehicle - there are no engines aboard capable of changing its orbit.

The attitude determination and control system performs the following functions:

- Stabilizes attitude after launch vehicle separation
- Points the photometer to the science attitude
- Holds science pointing to a very tight tolerance to enable high precision photometry
- Points the solar array to the sun and points high-gain Antenna to Earth when required
- Protects the photometer from imaging the sun
- Performs roll maneuvers when commanded
- Provides attitude control during safe and emergency modes

Telecommunications

The telecom subsystem will be used for receiving commands and for transmitting engineering, science and navigation data back to Earth. It is designed to operate out to a distance of 96 million kilometers (about 60 million miles). The system uses a parabolic dish high-gain antenna for transmitting, two receiving low-gain antennas and two transmitting low-gain antennas. The system can receive commands from Earth at speeds ranging from 7.8 to 2,000 bits per second, and can send data to Earth at speeds from 10 to 4.3 million bits per second. This transmission capability is the highest data rate of any NASA mission to date.

Kepler Photometer at a Glance

Spacebased Photometer: 0.95-meter (37.4 inch) aperture

Primary mirror: 1.4-meter (55 inch) diameter, 85 percent light weighted

Detectors: 95 mega pixels (42 charge-coupled devices – CCDs – with 2200x1024 pixels)

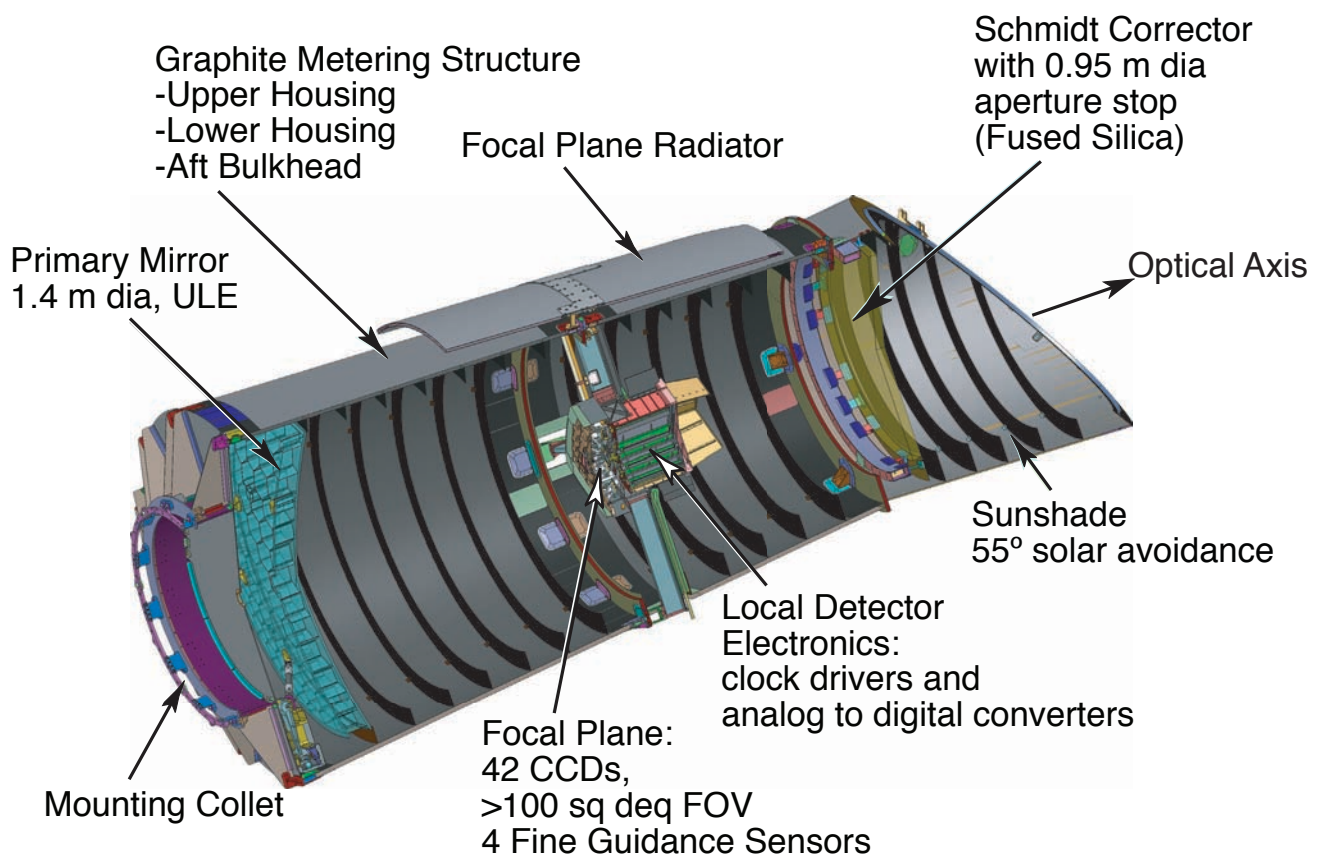
Bandpass: 430-890 nm FWHM (Full-Width Half-Maximum)

Dynamic range: 9th to 15th magnitude stars

Fine guidance sensors: 4 CCDs located on science focal plane

Attitude stability: better than 9 milli-arcsec, 3 sigma over 15 minutes.

Science data storage: about 2 months



Instrument - Photometer

The sole instrument aboard Kepler is a photometer (or light meter), an instrument that measures the brightness variations of stars. The photometer consists of the telescope, the focal plane array and the local detector electronics.

The Telescope

Kepler has a very large field of view — approximately 100 square degrees — for an astronomical telescope. The photometer optics are a modification of the classic Schmidt telescope design. They include a 0.95-meter (37-inch) aperture fused-silica Schmidt corrector plate and a 1.4-meter (55-inch) diameter 85 percent light weighted ultra-low expansion-glass primary mirror. The mirror has an enhanced silver coating. The optical design results in 95 percent of the energy from a star being distributed over an area at the focal plane of approximately seven pixels in diameter. The primary mirror is mounted onto three focus mechanisms, which may be used in flight to make fine focus adjustments. The focus mechanisms can adjust the mirror's piston, tip and tilt. While electrical power is required to move the focus mechanisms, they are designed to hold the position of the primary mirror without continuous power. A sunshade is mounted at the front of the telescope to prevent sunlight from entering the photometer. Kepler is the ninth largest Schmidt telescope ever built and the largest telescope ever to be launched beyond Earth orbit.



Inspection of the 1.4 meter primary mirror honeycomb structure. The mirror has been 86% light weighted, and only weighs 14% of a solid mirror of the same dimensions.

Focal Plane Array

At the heart of the photometer is the Focal Plane Array. This consists of a set of charged coupled devices (CCDs), sapphire field flattening lenses, an invar substrate, heat pipes and radiator.

The CCDs are the silicon light-sensitive chips that are used in today's TV cameras, camcorders and digital cameras. The CCDs aboard Kepler are not used to take pictures in the conventional sense. Kepler's wide-field optics reflect light from the star field onto the array of 42 CCDs. Each of the 42 CCDs are 59 by 28 millimeters (2.32 by 1.10 inches) in size and contain 2,200 by 1024 pixels, that is, individual picture elements, for a total of 95 megapixels. The CCDs are four-phase, thinned, back-illuminated and anti-

reflection coated devices. Each device has two outputs, resulting in a total of 84 data channels. The CCDs are mounted in pairs and have a single sapphire field-flattening lens over each pair. The optics spread the light of the stars over several pixels within an individual CCD to improve differential photometry thus making the system less sensitive to inter-pixel response variations and pointing jitter.

The focal plane is cooled to about minus 85 degrees Celsius (minus 121 degrees Fahrenheit) by heat pipes that carry the heat to an external radiator. Data from the CCDs are extracted every six seconds to limit saturation and added on board to form a 30-minute sum for each pixel. The array is supported midway between the Schmidt corrector and the primary mirror.



Completed flight focal plane array with the 42 science CCDs and four fine guidance CCDs in the corners.

Local Detector Electronics

A local detector electronics box communicates with the 84 data channels and converts the CCD output analog signals into digital data. The electronics box is located directly behind the focal-plane array in the center of the photometer structure. It has more than 22,000 electronic components tightly packed into a volume measuring slightly more than one cubic foot. Careful thermal engineering was required in order to isolate the cold detectors from the heat of the detector electronics. The data are stored in the spacecraft's solid-state recorder and transmitted to the ground approximately once a month.

Data Handling

Since the entire 95 megapixels of data cannot be stored continuously for 30 days, the science team has pre-selected the pixels of interest associated with each star of interest. This amounts to about 5 percent of the pixels. These data are then requantized, compressed and stored. The on-board photometer flight software gathers the science and ancillary pixel data and stores them in a 16 GigaByte solid-state recorder. Data are required to be stored and downlinked for science stars, p-mode stars, smear, black level, background and full field-of-view images.

Selecting the Kepler Star Field

The star field for the Kepler Mission was selected based on the following constraints:

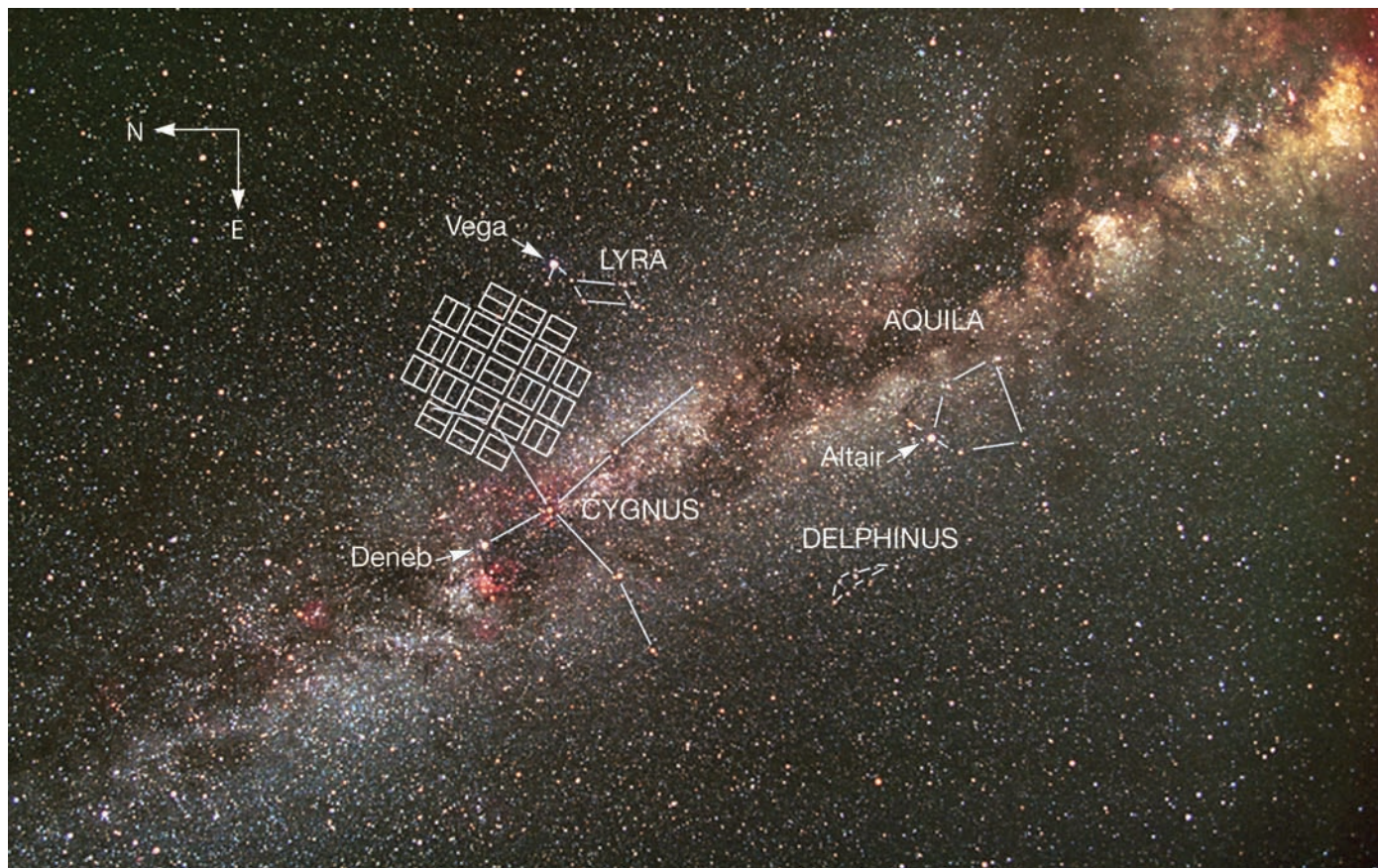
1. The field must be continuously viewable throughout the mission.
2. The field needs to be rich in stars similar to our sun because Kepler needs to observe more than 100,000 stars simultaneously.
3. The spacecraft and photometer, with its sunshade, must fit inside a standard Delta II launch vehicle.

The size of the optics and the space available for the sunshade require the center of the star field to be more than 55-degrees above or below the path of the sun as the spacecraft orbits the sun each year trailing behind the Earth.

This left two portions of the sky to view, one each in the northern and southern sky. The Cygnus-Lyra region in the northern sky was chosen for its rich field of stars somewhat richer than a southern field. Consistent with this decision, all of the ground-based telescopes that support the Kepler team's follow-up observation work are located at northern latitudes.

Distances to the Kepler Stars

Kepler will be looking along the Orion spiral arm of our galaxy. The distance to most of the stars for which Earth-size planets can be detected by Kepler is from 600 to 3,000 light years. Less than 1% of the stars that Kepler will be looking at are closer than 600 light years. Stars farther than 3,000 light years are too faint for Kepler to observe the transits needed to detect Earth-size planets.



The Kepler Field of View

Education and Public Outreach

The Kepler Mission Education and Public Outreach (EPO) program capitalizes on the excitement of discovering Earth-size planets in the habitable zone of other stars to stimulate student learning in math and science, as well as the public's interest in their space program. The EPO program is led by educators at the Lawrence Hall of Science and the SETI Institute in partnership with NASA. The Kepler EPO program leverages existing collaborations, networks, relationships and experience to maximize the impact of EPO products and activities. The program addresses three areas: formal education, informal education and public outreach.

Formal Education deals directly with school curriculum. Kepler has contributed to the development for *Great Explorations in Math and Science Space Science Sequence*, *Full Option Science Sequence*, and *Hands On Universe*. All three of these are nationally distributed curriculum. Kepler has provided many teacher workshops around the country and recently published a mission poster with activities in the journals *Science Scope* and *Science Teacher*, which reaches every member of the National Science Teachers Association in the country. In the area of informal education, Kepler has contributed to the development of the traveling exhibit "Alien Earths," which has already appeared at many tech museums and planetariums throughout the country. Kepler is in the process of developing a planetarium program "Strange Earths" which is currently in national field testing.

The Public Outreach area includes programs like "Name In Space," "Uncle Al's Star Wheel" (a planisphere), "Shadows and Silhouettes" as part of the "Night Sky Network" for amateur astronomers, StarDate programs and various other activities.

Other Exoplanet Activities

Kepler is the trailblazer mission for the emerging field of exoplanet exploration. Kepler's results will significantly influence the direction of future exoplanet space missions. Kepler planetary candidates will be followed up by a suite of facilities, both ground-based and in space, to help scientists fully investigate the discovered planets as well as the properties of stars hosting Earth-size planets.

Ground-Based Facilities

A number of different ground-based facilities will be utilized for various purposes to rule out several situations that could lead to a false positive, such as a grazing eclipse by a large companion, or a transit due to a white dwarf companion or to confirm the planetary nature of Kepler exoplanet candidates. Moderate-precision Doppler shift measurements will be able to rule out transits due to large mass companions. The Keck observatory — a 10-meter telescope on Mauna Kea, Hawaii, and by far the most prolific facility for exoplanet hunting — will play a key role in Kepler's exoplanet inventory using higher precision measurements to obtain mass estimates for intermediate-sized Kepler exoplanet candidates. This work capitalizes on NASA's partnership with the Keck observatory. Equipped with the upgraded HIRES echelle spectrometer, Keck is optimized for measuring precise Doppler shifts as small as 1 m/s in the spectral lines of stars due to the gravitational pull of their planetary companions. During the Kepler Mission lifetime, numerous nights of Keck observing time will be set aside for follow-up on promising exoplanet candidates. At present, the highest Doppler shift precision is available with the High Accuracy Radial velocity Planet Searcher (HARPS) instrument at La Silla in the southern hemisphere. HARPS-North, which is under construction, will improve on this and play a key role in the follow-up observing for Kepler.

NASA/European Space Agency (ESA) Hubble Space Telescope (HST)

HST has made several complementary contributions in our understanding of extrasolar planets. Shortly after ground-based observations detected the first transiting planet, HD 209458b, HST used the Space Telescope Imaging Spectrograph (STIS) to observe the planet while transiting its host star to detect Sodium in its atmosphere. Similar observations have now been extended into the infrared using Near Infrared Camera Multi-Object Spectrograph with resulting detections of water, carbon dioxide and methane in the exoplanet atmospheres. With observations in the ultraviolet using STIS and Advance Camera for Surveys, detections have been made of extended atmospheres around a few planets, suggesting that the atmospheres of these planets, all of which are located close to their host stars, are being slowly evaporated. The Advanced Camera for Surveys recently captured the first visible-light images of a planet outside our solar system, a giant planet orbiting the relatively nearby star Fomalhaut. Currently, scientists are using the Fine Guidance Sensors as a high-speed photometer on a bright transiting system for which both stellar seismology and detailed transit observations are expected to provide information about both the host star and orbiting planet. HST remains a unique resource that has significantly advanced, and will continue to do so, the field of exoplanet research. HST may be expected to operate throughout the prime Kepler Mission and is expected to be used for several follow-up science applications of Kepler discoveries.

NASA's Spitzer Space Telescope

The Spitzer Space Telescope is another complementary mission to Kepler. The Spitzer mission was designed to study comets, stars and galaxies in infrared light. It has also turned out to be a very powerful tool for characterizing exoplanets. The telescope is particularly adept at studying transiting hot, gas exoplanets. It can make unprecedented, precise measurements over time scales of hours, thanks to its Earth-trailing orbit — the same orbit as Kepler's, which provides a high degree of stability and long continuous viewing periods.

Since 2005, Spitzer has made several ground-breaking discoveries, including: the first direct detection of light from exoplanets; the temperatures and constraints on the chemical composition of many exoplanets; the first two-dimensional "weather map" of an exoplanet; and the first observation in real-time of an exoplanet "heat-storm," in which a gas planet heats up to red-hot temperatures in a matter of hours before quickly cooling back down. So far, Spitzer has characterized more than 15 exoplanets.

Spitzer's contributions to exoplanet studies will continue when it runs out of coolant and enters its "warm mission" phase, expected to begin in spring 2009. During this phase, the mission will continue to observe exoplanets, and will confirm and characterize the atmospheres, compositions and orbital parameters of gas exoplanets found by Kepler. It will also help confirm the presence of Earth-size rocky planets identified by Kepler by ruling out other explanations for the data.

NASA/ESA/Canadian Space Agency James Webb Space Telescope (JWST)

The James Webb Space Telescope (JWST), scheduled for launch in 2013, will bring a qualitative advance in scientists' ability to probe planetary atmospheres. While HST has been able to detect a few atmospheric constituents around a handful of the most optimal cases, JWST will provide much greater sensitivity. JWST will be able to return atmospheric diagnostics not only for transiting planets the size of Jupiter, but will also have sufficient sensitivity to easily probe Uranus- Neptune-size planets during transit of their host stars, and in extremely favorable cases, could provide first results on super-Earth-size planets. The broad wavelength coverage from 1 to 25 microns available with JWST will also vastly increase the number of atmospheric species that can be studied in planetary atmospheres. JWST will continue to expand on discoveries from both HST and Spitzer in recent years, and will initiate a new era of quantitative, comparative exoplanet studies. Launched following Kepler, and with much improved diagnostic capability, JWST will provide important follow-up observations of many Kepler discoveries.

The Convection Rotation and Planetary Transits Mission (CoRoT)

The CoRoT space mission launched December 27, 2006, by the Centre National d'Etudes Spatiales (CNES) the French space agency, is a mission led by CNES in association with French laboratories and with several international partners that will also search for extrasolar planets.

The CoRoT mission is dual purpose. It uses a method called stellar seismology to probe the inner structure of the stars, and it looks for transits by extrasolar planets.

Kepler and CoRoT are similar in their observation of transits in search of terrestrial planets, but there are significant differences in the design and operations of the two missions. The CoRoT spacecraft is equipped with a 27-cm diameter telescope while Kepler has a 95-cm aperture telescope. This difference gives Kepler 12 times the light-gathering power as CoRoT. CoRoT uses two CCDs for transit detection with a total field of view of four square degrees as compared to Kepler using 42 CCDs with approximately 100 square degree field of view.

CoRoT views a portion of the sky for five months, then turns to a new area. In two years, it will cover a total of about 20 square degrees. CoRoT is capable of finding planets close in to their stars. Kepler views a single portion of the sky, about five times larger than CoRoT views, for several years. This longer viewing period will enable Kepler to find Earth-size planets in the habitable zones around their stars.

CoRoT launched two years earlier than Kepler and will contribute significantly to scientists' understanding of terrestrial planets with short orbital periods.

Science Team

Hundreds of people across the country are involved in the Kepler Mission. NASA's Jet Propulsion Laboratory (JPL), Pasadena, Calif., managed the development of the project for NASA's Ames Research Center (NASA Ames), Moffett Field, Calif., and is responsible for ensuring that Kepler's flight system performs successfully on orbit. NASA Ames managed the development of the ground system and will conduct scientific analysis for the mission. Ball Aerospace and Technologies Corp. (BATC), developed Kepler's flight system, including the spacecraft and the photometer, and is participating in mission operations. NASA Ames will manage flight operations after commissioning is completed.

The Science Principal Investigator is William Borucki¹ and the Deputy Principal Investigator is David Koch, both of NASA's Ames Research Center. Other members of Kepler's science team include Co-Investigators, a science working group and participating scientists.

The Co-Investigators include Gibor Basri, University of California at Berkeley, Berkeley, Calif.; Natalie Batalha, San Jose State University, San Jose, Calif.; Timothy Brown, Las Cumbres Observatory Global Telescope (LCOGT), Goleta, Calif.; Doug Caldwell, SETI Institute, Mountain View, Calif.; Jørgen Christensen-Dalsgaard, University of Aarhus, Denmark; William Cochran, McDonald Observatory, University of Texas at Austin; Edna DeVore, SETI Institute; Edward Dunham, Lowell Observatory, Flagstaff Ariz.; Nick Gautier, JPL, Pasadena, Calif.; John Geary, Smithsonian Astrophysical Observatory (SAO), Cambridge, Mass.; Ronald Gilliland, Space Telescope Science Institute (STScI), Baltimore, Md.; Alan Gould, Lawrence Hall of Science (LHS), Berkeley, Calif.; Jon Jenkins, SETI Institute; Yoji Kondo, NASA's Goddard Space Flight Center, Greenbelt, Md.; David Latham, SAO; Jack Lissauer, NASA Ames; Geoff Marcy, University of California at Berkeley; David Monet, US Naval Observatory-Flagstaff Station (USNO), Flagstaff, Ariz. and Dimitar Sasselov, Harvard University, Cambridge, Mass.

The Science Working Group is comprised of Alan Boss, Carnegie Institution of Washington, Washington D.C.; John J. Caldwell, York University, Canada; Andrea Dupree, SAO; Steve Howell, National Optical Astronomy Observatory (NOAO), Tucson, Ariz.; Hans Kjeldsen, University of Aarhus, Denmark; Soren Meibom, SAO; David Morrison, NASA Ames and Jill Tarter, SETI Institute.

Participating Scientists are Derek Buzasi, Eureka Scientific, Oakland, Calif.; Matt Holman, Harvard-Smithsonian Center for Astrophysics (CfA), Cambridge, Mass.; David Charbonneau, CfA; Sara Seager, Massachusetts Institute of Technology, Cambridge, Mass.; Laurance Doyle, SETI Institute; Jason Steffen, Fermi National Accelerator Laboratory, Batavia, Ill.; Eric Ford, University of Florida, Gainesville; William Welsh, San Diego State University, San Diego, Calif. and Jonathan Fortney, University of California at Santa Cruz, Santa Cruz, Calif.

The team members collaborate on various tasks within the project. For example:

- Scientists at SAO, USNO and LCOGT made the observations and interpreted the data used to build the Kepler Input Catalog,
- Scientists at SAO, Harvard, University of California at Berkeley, University of Texas at Austin, NOAO, Lowell Observatory and JPL will conduct the follow-up observing work to confirm discoveries, detect other planets in the systems and improve our understanding of the stellar properties,
- Educators at LHS and SETI Institute conduct the Education and Public Outreach program,
- Scientists at the University of Aarhus lead the Kepler Asteroseismic Science Consortium that determines stellar masses, sizes and ages from the Kepler data.

¹William Borucki published the concept for detecting Earth-size planets by using photometry in a paper in 1984. W.J.Borucki and A.L., Summers, *Icarus*, **58**, 121 (1984)

Project Management

Kepler is a NASA Discovery mission. At NASA Headquarters, Ed Weiler is associate administrator for the Science Mission Directorate. Jon Morse is the director of the Astrophysics Division. Lia LaPiana is the Kepler program executive. Patricia Boyd is the Kepler program scientist.

NASA's Marshall Space Flight Center, Huntsville, Ala., manages NASA's Discovery program. Dennon Clardy is Discovery program manager. Steve McClard is mission manager for the Kepler Mission.

NASA's Ames Research Center was responsible for the ground system development and is responsible for mission operations and science data analysis. Roger Hunter will manage the Science Operations Phase.

Kepler mission development was managed by NASA's Jet Propulsion Laboratory (JPL), Pasadena, Calif. James Fanson is the Kepler project manager. Peg Frerking is deputy project manager. JPL is a division of the California Institute of Technology in Pasadena.

Ball Aerospace & Technologies Corp., Boulder, Colo., developed the Kepler flight system and supports mission operations. John Troeltzsch is the Kepler program manager.

