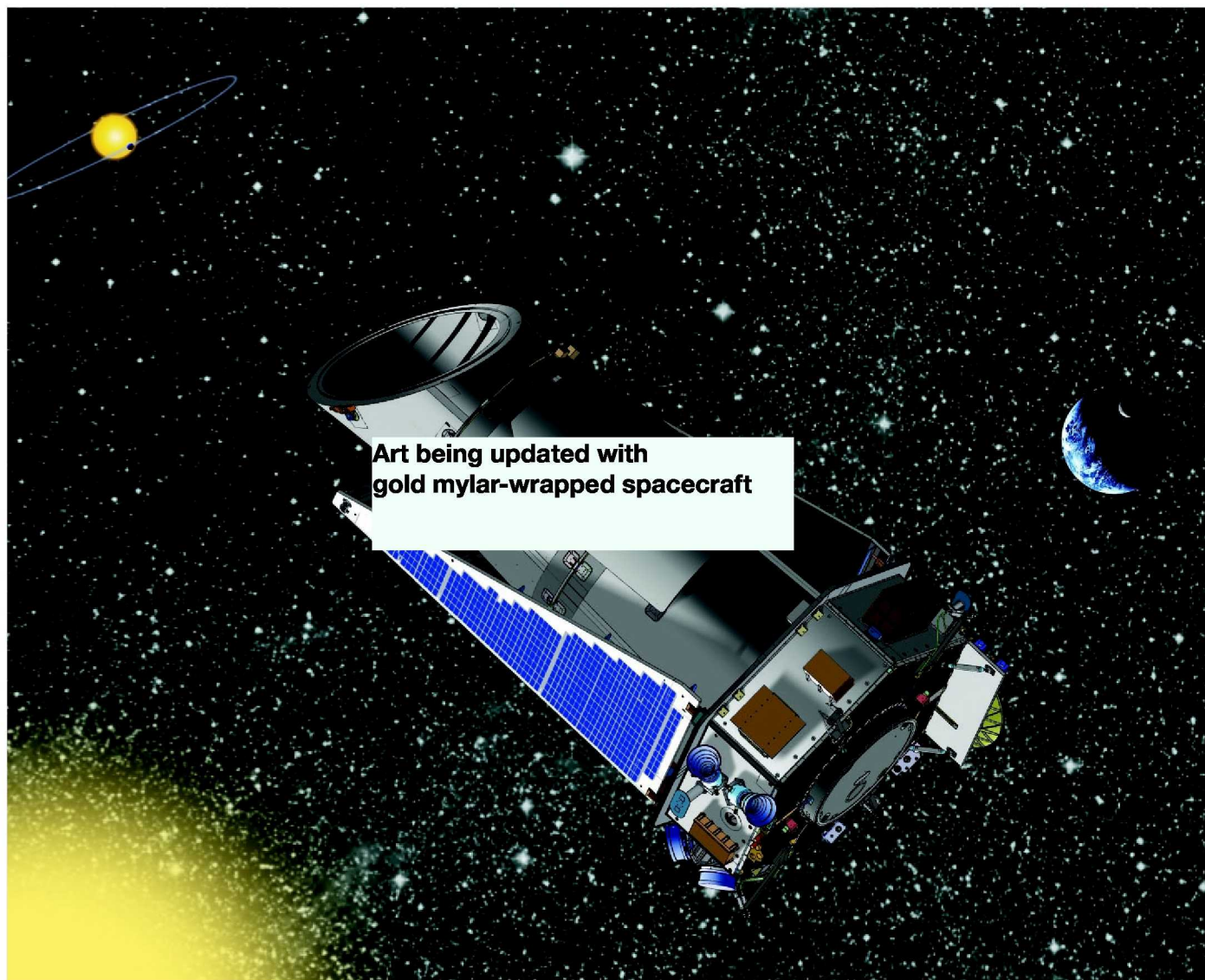




PRESS KIT/FEBRUARY 2009

## *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're 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 (4 p.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 (4 p.m. and 4:45 p.m. PST), respectively, on March 4, (launch minus one day) in the Kennedy News Center at NASA's Kennedy Space Center, Fla. These briefings will also be carried live on NASA Television. Media advisories will be issued in advance, outlining details of these broadcasts.

## 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. Scheduled briefing participants include:

Dr. Jon Morse, Director, Astrophysics Division  
NASA Headquarters, Washington

Dr. William Borucki, Science Principal Investigator  
NASA Ames Research Center, Moffett Field, Calif.

Dr. James Fanson, Kepler Project Manager  
Jet Propulsion Laboratory, Pasadena, Calif.

Debbie Fischer, Astrobiologist  
University of Washington, Seattle

## 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 media accreditation, contact Laurel Lichtenberger in the 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. The scheduled briefing participants are:

Ed Weiler, Associate Administrator, Science Mission Directorate  
NASA Headquarters, Washington

Omar Baez, NASA Launch Director/Launch Manager  
Kennedy Space Center, Fla.

Rick Navarro, Delta II Program Director  
United Launch Alliance, Cape Canaveral, Fla

William Borucki, Science Principal Investigator  
NASA Ames Research Center, Moffett Field, Calif.

Natalie Batalha, Co-Investigator  
San Jose State University, San Jose, Calif.

John Troeltzsch, Program Manager  
Ball Aerospace & Technologies Corp., Boulder, Colo

Gibor Basri, Co-Investigator  
University of California at Berkeley, Berkeley, Calif.

Joel Tumbiolo, U.S. Air Force Delta II Launch Weather Officer  
45th Weather Squadron, Cape Canaveral Air Force Station

## **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.

## **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 about the Kepler Mission, visit the Kepler main page at  
<http://www.kepler.nasa.gov>

# Quick Facts

## Spacecraft

### Dimensions

2.7 meters (9 feet) diameter, and 4.7 meters (15.3 feet) high.

### Weight

1052.4 kilograms (2,320.1 pounds) at launch, consisting of a 562.7-kilogram (1240.5-pound) spacecraft, a 478.0-kilogram (1043.9-pound) photometer, and 11.7 kilograms (25.8 pounds) of hydrazine propellant.

### Power

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 of electrical current. Power storage is provided by a 20 amp-hour rechargeable lithium-ion battery.

### Mission

Launch period: March 5 to June 10, 2009 (two three-minute-long launch windows each day) Launch windows are about 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 48 upper stage

Fuel: 9 strap-on solid rocket motors; kerosene and liquid oxygen first stage, hydrazine and nitrogen tetroxide second stage

Orbit: Earth-trailing heliocentric

Orbital period: 371 days

Mission duration: 3.5 years

### Photometer

The sole Kepler instrument is a photometer – it has a wide field of view 0.95-meter (37-inch) aperture Schmidt type telescope with a 1.4-meter (55-inch) primary mirror. Kepler's photometer has a field of view 33,000 times greater than the Hubble Space Telescope.

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

### Program Cost

Program cost is \$508 million total (not including launch vehicle), consisting of \$449 million development and \$59 million mission operations.

# Mission Overview

Kepler, a NASA Discovery mission, is a spaceborne telescope designed to search a nearby region of our galaxy for Earth-size planets orbiting in the habitable zone of stars like our sun. The habitable zone is that region around a star where the temperature permits water to be liquid on the surface of a planet. Liquid water is considered essential for the existence of life.

Kepler will hunt for planets using a specialized one-meter-diameter telescope (about 3.3 feet) called a photometer. The photometer will continuously measure the precise 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 telescope. 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.

By monitoring a large number of stars, Kepler will permit astronomers to estimate the total number of Earth-size planets orbiting in the habitable zone around stars in our galaxy. If Kepler does not discover any such planets, scientists will be able to conclude that we are likely alone in the galaxy.

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 orbiting 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

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

### ***Launch Phase***

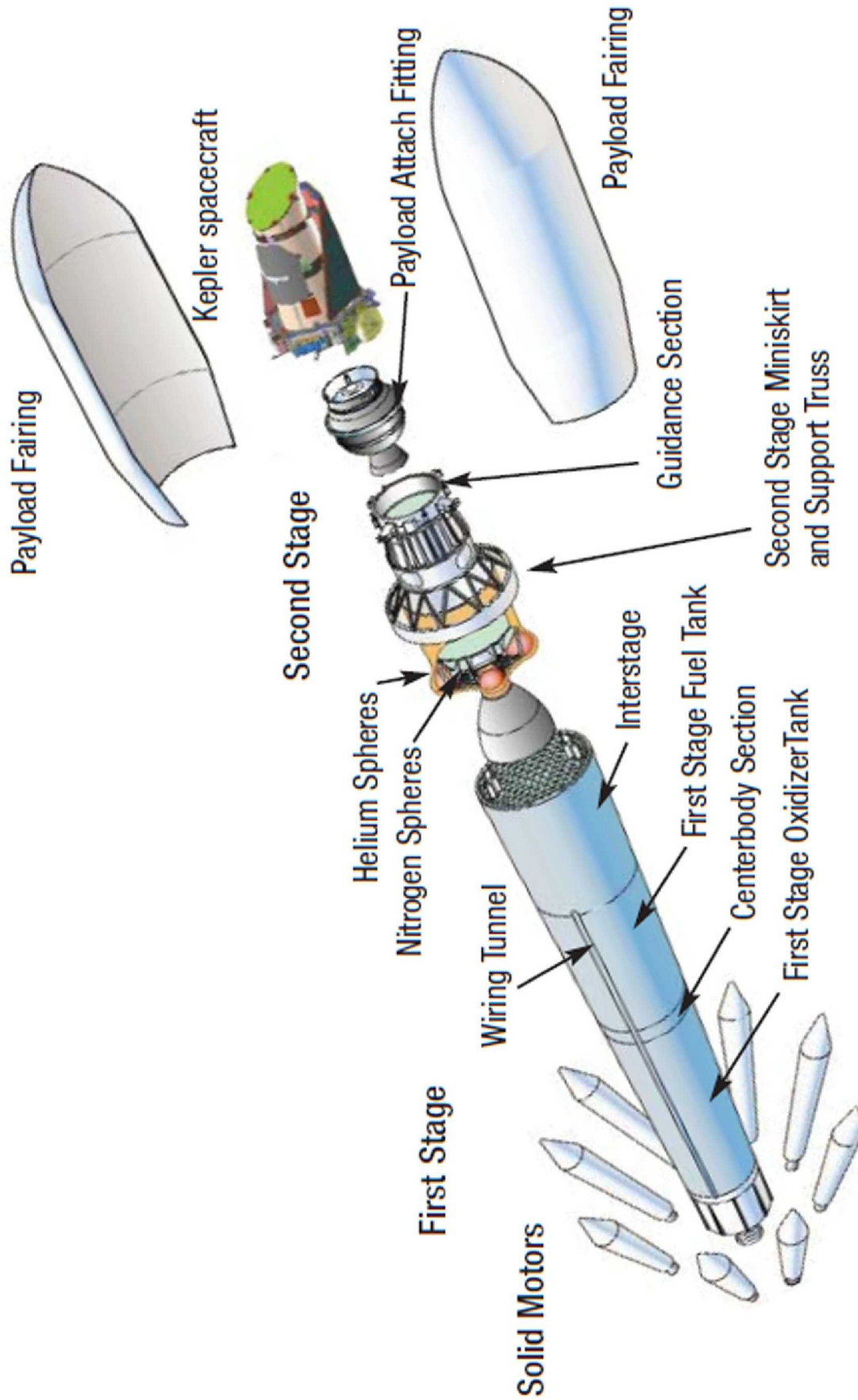
For planning purposes, the launch phase is considered to begin three hours prior to launch and last until the Kepler spacecraft has separated from the rocket’s third stage.

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 (3 meter) payload fairing encloses the second stage, third stage, and payload during first stage flight and the early portion of second stage flight.

(A graphic of the Delta Launch Vehicle with Kepler Spacecraft is on the next page, followed by a graphic of Delta launch milestones.)





*Delta Launch Vehicle with Kepler Spacecraft*

*Kepler Launch Profile*

*(full-page graphic: ULA's graphic of Delta launch milestones -- file may be available Mon. Jan 26?)*

## **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. The remaining three solids are ignited following the burnout of the first six solids. 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 a few seconds after they burn out.

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 two-burn, 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. 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).

Kepler will be launched into an Earth-trailing, heliocentric orbit similar to that of NASA's Spitzer Space Telescope. After orbital injection by the launch vehicle third stage, Kepler will require no further trajectory corrections.

## **Spacecraft Orbit**

(See graphic on following page: Kepler Orbit)

The continuous viewing needed for a high detection efficiency for planetary transits requires that the field-of-view of the photometer be out of the ecliptic plane so as not to be blocked periodically by the sun or moon. A star field near the galactic plane that meets these viewing constraints and has a sufficiently high star density has been selected.

An Earth-trailing heliocentric orbit with a period of 372.5 days provides the optimum approach to meeting of the combined sun-Earth-moon avoidance criteria within the launch vehicle's capability. Telecommunications and navigation for the mission are provided by NASA's Deep Space Network.

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 solar pressure. This orbit also avoids the high radiation dosage associated with an Earth orbit, but from time to time is subject to solar flares.



## ***Commissioning Phase***

This phase begins with the separation of the Kepler spacecraft from the launch vehicle and nominally ends 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 science mission.

Major activities during this period include - initial acquisition of spacecraft signal and confirmation of a valid radio link with the ground and confirmation spacecraft is generating its own electrical power via its solar panels and has returned telemetry recorded during launch. The phase also includes the 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 (112-foot) 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 communications 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 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/early commissioning. While the dust cover is attached, all light is precluded from entering the telescope. 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 critically sensitive measurements necessary to detect Earth-size planets, great care will be taken to assure that all necessary dark calibration data is 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 nominally, and that its photometer can collect science data from a full target set with sufficiently low noise to allow transit detections of Earth-like planets around a sun-like star.

## ***Early Science Operations Phase***

Kepler will survey three classes of stars – bigger and brighter than Earth's sun (A and F stars), similar to our sun in brightness and size (G stars) and those less bright than our sun (K and M stars). Kepler will continuously monitor the brightness of more than 100,000 stars in the Milky Way galaxy and must measure at least three transits to classify a signal as a valid Earth-size planetary candidate.

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

Scientists expect to announce their first results in May 2009 at NASA Headquarters during a Space Science Update briefing about short-period planet detections.

In January 2010, scientists expect to announce any discoveries they have made in the first year of the four-year mission. This will be the first possible announcement of Earth-size planets in the habitable zones of M-type stars, which are stars less bright than the sun.

Earth-size planets in Earth-like orbits require nearly the full lifetime of the four year mission, although in some cases three transits are seen in just a little more than two years. Other results that require the full

four years of data are: Planets as small as Mercury in short period orbits, which utilizes the addition of a 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.

## ***Science Operations Part 2***

In January 2011, scientists are expected to announce any discoveries made during the first two years of the mission. The announcement will be made at the at the American Astronomical Society (AAS) meeting, as well as at NASA Ames Research Center. This is the first possible announcement of Earth-size planets in the habitable zones of K-type stars.

In January 2012, scientists are expected to announce any discoveries made during the first three years of the mission. The announcement will be made at the at the American Astronomical Society (AAS) meeting, as well as at NASA Ames Research Center. This is the first possible announcement of Earth- size planets in the habitable zones of solar-like or G stars.

By 2013, the Kepler Mission is expected to accomplish several objectives, including:

- Detect the frequency of Earth-size planets;
- Determine the distribution of sizes and semi-major axes of terrestrial planets;
- Determine the densities, albedos, and distributions of giant planets;
- Determine the correlations of planetary and stellar characteristics;
- Determine whether Earths in the habitable zone of other stars are common or rare.

The science results will provide critical information needed to design successor missions in the continuing search for habitable planets.

## ***Post-Operations Phase***

Following completion of the mission, scientific analysis of the data obtained during the course of the mission will continue to be analyzed to learn more about habitable planets. 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 January 2013 at the American Astronomical Society (AAS) meeting, as well as at NASA Ames Research Center. These results will summarize the discoveries, especially of the frequency of Earth-size planets in the habitable zone of other stars. The science results will provide critical information needed to design successor missions in the continuing search for habitable planets.

## ***Decommissioning (graphic artist's note)***

(to be inserted by NASA Ames PAO?) First paragraph under "Mission Phases" refers to "decommissioning," not "Post-Operatios Phase." They should be consistent

## **Mission Operations**

Mission operations during both launch and commissioning phases of the mission will be conducted from the Laboratory for Atmospheric and Space Physics in Boulder, Colo. Spacecraft engineering support will be provided by Ball Aerospace & Technologies Corp., also located in Boulder. Navigation and Deep Space Network communication will be provided by NASA's Jet Propulsion Laboratory, Pasadena, Calif. Science operations will be conducted by the NASA Ames Research Center, Mountain View, California, and data management services will be provided by the Space Telescope Science Institute in Baltimore, Md.

# Science Goals and Objectives

The Kepler Mission is a photometric space mission that will continuously observe a single 100-square-degree field of view (FOV) of the sky of more than 100,000 stars in the Cygnus-Lyra region for four or more years. The primary goal of the mission is to survey our region of the Milky Way galaxy to discover hundreds of Earth-size and smaller 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 us 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 and from the number and spectral type of stars monitored.
- Determine the distribution of sizes and orbital semi-major axes of these planets. The planet's area is found from the fractional brightness decrease and the stellar area. The planet's semi-major axis is derived from the measured period and stellar mass, using Kepler's Third Law (a simple mathematical formula relating the average distance a planet is from the sun to the amount of time it takes to orbit the sun).
- Estimate the frequency of planets orbiting multiple star systems.
- Determine the distributions of semi-major axis, its light reflection properties (albedo), size, and density of short-period 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 both the Space Interferometry Mission (SIM) and ground-based Doppler spectroscopy are used to search for additional massive companions that do not transit, thereby providing greater details of 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.

# Spacecraft

Like all spacecraft, the design of the Kepler observatory 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 observing capabilities of the scientific cargo onboard the spacecraft.

As the spacecraft is tasked to survey distant stars to determine the prevalence of Earthlike planets, it exists to serve its one instrument – a photometer designed to measure the brightness of distant stellar targets. The spacecraft provides the power, pointing and telemetry 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, and reaction wheels.

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 high-gain antenna is used for high-rate data transmission. Body-mounted low-gain antennas are used for low-rate data transmission and commanding.

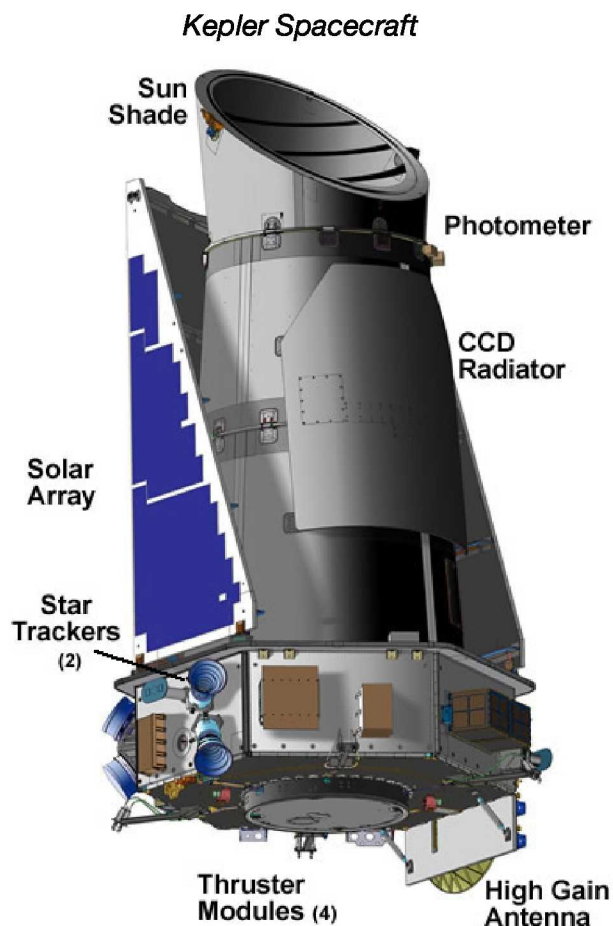
## Overview

The spacecraft provides the power, pointing and telemetry collection for the photometer. Pointing at a single group of stars for the entire mission greatly increases the 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 for the thrusters, which is kept from slosh by a pressurized membrane. This design enhances the pointing stability and the overall reliability of the spacecraft.

## Spacecraft Structures and Mechanisms

Perhaps appropriate for a spacecraft that exists solely for one instrument, 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 low-profile 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 shortly after entering space, 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 telescope, 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 conduct heat away from the observatory. 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 telescope.

## **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 128 Gigabit synchronous dynamic random access memory (SDRAM) solid-state recorder. The recorder has simultaneous read/write capability and can store more than 60 days of science and engineering data.

## **Attitude Determination and Control**

The Kepler telescope uses a pointing control system to orient itself in deep space (or, in engineering language, 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 angular rates, and are used to control attitude rates as well providing 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 nearly the entirety of the 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 energy 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 telescope to the science attitude
- Holds science pointing to a very tight tolerance to enable differential 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, two receiving low-gain antennas and two transmitting low-gain antennas. The system can receive commands from Earth at speeds ranging from 7.8125 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.

During the science phase of the mission, Kepler will perform its data-gathering duties automatically. About every thirty days, the spacecraft will change its attitude to point its high-gain antenna at Earth so the collected stellar information can be downloaded.

## Payload - Photometer

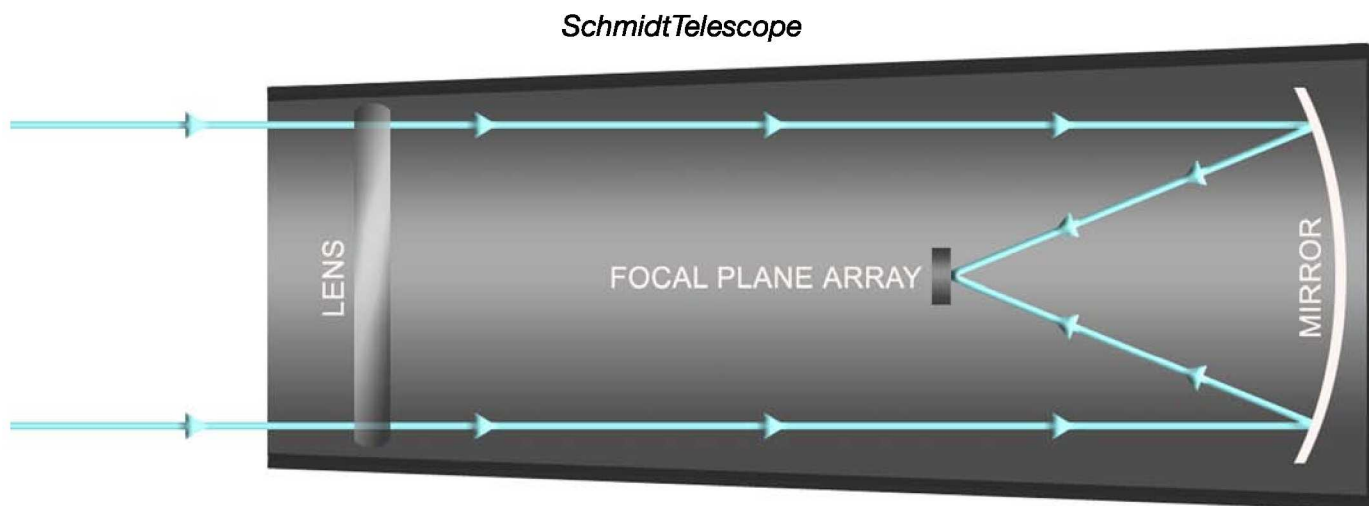
The sole instrument aboard Kepler is a photometer (or light meter), an instrument that measures the brightness of stellar targets. The photometer is a wide field of view 0.95-meter (37-inch) aperture Schmidt type telescope with a 1.4-meter (55-inch) primary mirror and an array of 42 charged couple devices.

For an astronomical telescope, Kepler has a very large field of view — 105 square degrees, which is comparable to the area of your hand held at arm's length. This wide field of view is required as the

photometer aboard Kepler is tasked to continuously measure the brightness of a star field of 100,000 stars. The telescope stares at these same stars for the entirety of the mission, monitoring their brightness. The mission's photometer will be sensitive enough to see changes in brightness caused by planets passing in front of, or transiting, stars whose diameters are 100 times larger than any planets orbiting them.

## Schmidt Telescope

Invented by Estonian optician Bernhard Schmidt in 1930, the Schmidt telescope is known for its wide field of view. The optical components of a Schmidt include a concave spherical corrector lens near the opening of the telescope, a spherical primary mirror, and a data-gathering device located at the primary focus midway between lens and mirror (in Kepler's case, this is the CCD array).



As Schmidt telescopes use a spherical collecting mirror instead of a paraboloidal mirror (as conventional reflecting telescopes do), they are free from astigmatism and so have a wide field of view. This allows for a more accurate gathering of light from a wider swath of sky, providing a sharper image of a larger area of the celestial sphere than ordinary reflectors. Astronomical observations where Schmidt telescopes excel include sky surveys, comet and asteroid searches, and artificial satellite tracking.

Notable Schmidt telescopes include the Alfred Jensch Telescope at the Karl Scharzschild Observatory in Tautenburg, Germany (at 2 meters in diameter (6.6 feet) the world's largest Schmidt telescope) and the Oschin Schmidt Telescope at Palomar Observatory near San Diego, which hunts the night's skies for near-Earth objects.

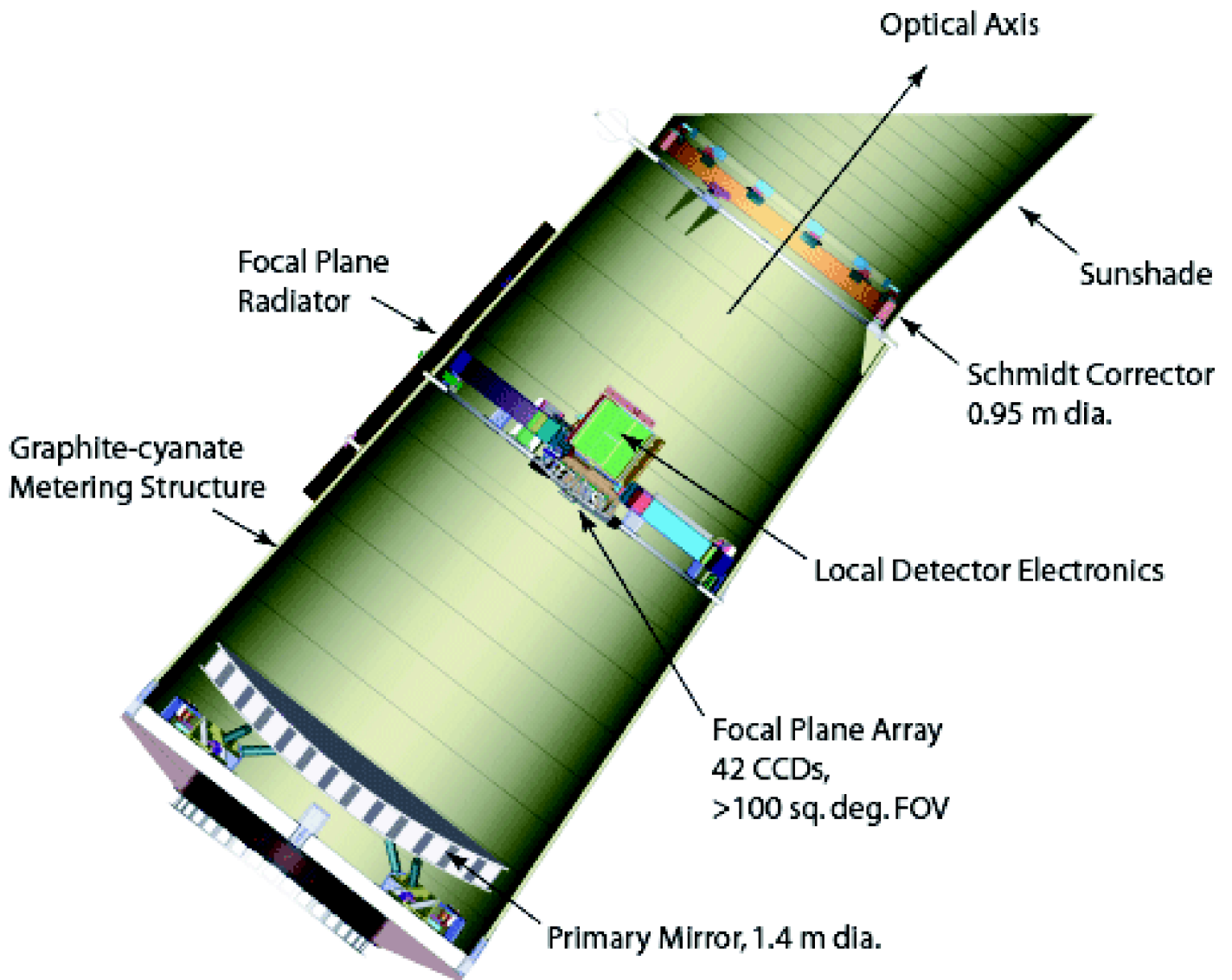
(See graphic of photometer on following page.)

## Optics

The photometer optics are a modification of the classical Schmidt design. They include a 0.95-meter (37-inch) aperture fused-silica Schmidt corrector plate (lens), and a 1.4-meter (55-inch) diameter ultra-low expansion-glass primary mirror. The scaling factor of the optical design results in 95 percent of the energy from a star being distributed over an area at the focal plane of approximately 7 detector pixels in diameter.

The photometer's primary, 1.4-meter (about 4.6 feet) 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.

*Kepler Photometer*



## Detector Electronics

The key technology at the heart of the photometer is a set of charged coupled devices (CCDs) that can measure the brightness of hundreds of thousands of stars at the same time. CCDs are the silicon light-sensitive chips that are used in today's TV cameras, camcorders and digital cameras. Note that the CCDs aboard Kepler are not used to take pictures in the conventional sense. The images are intentionally defocused to 10 arc seconds to improve their photometric precision.

Kepler's wide field primary mirror will reflect light from its target star field onto an array of 42 CCDs. Each of the 42 CCDs are 50 by 25 millimeters (1.97 by 0.98 inches) in size and contain 2,200 by 1024 pixels. The photometer spreads the light of these stars over several pixels within an individual CCD to improve differential photometry by making the system less sensitive to inter-pixel response variations and pointing jitter. With a grand total of more than 94 million individual pixels, Kepler's focal plane array of CCDs makes up the largest camera NASA has ever flown in space

The CCDs are read out every six seconds to prevent saturation. Only stars with an absolute magnitude greater than  $M_v = 14$  have their information recorded. The focal plane is designed to operate at about minus 85 degrees Celsius (minus 121 degrees Fahrenheit) to minimize the noise coming from the detectors.

A local detector electronics box operates the photometer's 21 science CCD modules and converts the CCD output analog signals into digital data. It is located with the focal plane array in the center of the telescope structure. Careful thermal engineering was required in order to shield 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 about once every 30 days.

A sunshade is mounted at the front of the photometer to protect it from stray light.

# Instrument

The heart of the Kepler spacecraft is its single scientific instrument, a photometer, built by Ball Aerospace and Technologies of Boulder, Colo. Ball Aerospace also built the spacecraft, which provides power, pointing, and telemetry for the photometer and telescope.

During its four-year space mission, Kepler will record data from a set of approximately 100,000 stars in the Cygnus-Lyra region of the Milky Way Galaxy. When a planet passes in front of its parent star, as seen from our solar system, it blocks a small fraction of light from that star – which is known as a transit. A transit of a Sun-sized star by an Earth-sized planet reduces the star’s brightness by a miniscule amount, only 84 parts per million (ppm), for an interval of a few hours to half a day. Kepler’s photometer is so sensitive it can detect a variation as small as 20 ppm.

Kepler will collect light from its target star field using a compound telescope (Schmidt-type design), which sits atop the spacecraft. The telescope has a 0.95-meter (3.12-foot) diameter aperture and a 105-square-degree (12-degree diameter) field of view.

Collected light is reflected off the 1.4-meter (4.6-foot) diameter primary mirror at the far end of the telescope. Light from the primary mirror is then focused into the photometer, or focal plane array, which is positioned in the middle of the compound telescope.

The photometer looks like a 20-inch-square television tube and is composed of 42 charged-coupled devices (CCDs – each measuring 50 x 25mm) that when combined make an image that is 2200x1024 pixels. The CCDs are paired to form square modules, each covering 5-square degrees of the sky that only record light from stars brighter than 14th magnitude (that is 1600 times fainter than the faintest star that can be seen by the naked eye). When the data from all 42 CCDs are combined, it forms an image that is approximately 95 megapixels (compared to today’s most advanced consumer digital cameras that have eight to 10 megapixel capabilities).

(See graphic of Photometer cross section on following page.)

## Data Retrieval

Once Kepler’s photometer records its data, the on-board Photometer Flight Software gathers science and ancillary pixel data and stores them in a 64-Gbit solid-state recorder for downlink, approximately once a week. Data are required to be stored and downlinked for science stars, p-mode stars, smear, black level, background and full field of view images. Downloading speeds vary depending upon which bandwidth is used (Downlink X-band: 10 bps to 16 kbps; Downlink Ka-band: Up to 4.33125 Mbps).

## Periodic Maintenance

On a quarterly basis, the spacecraft is rotated to maintain the maximum exposure on the solar array and to ensure the spacecraft’s radiator is pointing away from the sun. After rotation, the instrument requires a new star pixel map for the 100,000 target stars and the 87 fine guidance sensors (FGS) stars. The upload bandwidth (Uplink X-band: 7.8125 bps to 2 kbps) and Deep Space Network (DSN) contact time limit the data that can be transmitted. A new, more efficient pixel addressing technique has been developed, which allows pixel selection with 95 percent less data than when a full map upload is used, allowing star selection and pixel pattern definition in one 32-bit word per star. This method exceeds the pattern requirement and provides a greater than 100 percent uplink margin.

## Kepler Photometer at a Glance

**Spacebased Photometer:** 0.95-meter (3.12-foot) aperture

**Primary mirror:** 1.4-meter (4.6-foot) diameter, 85 percent light weighted

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

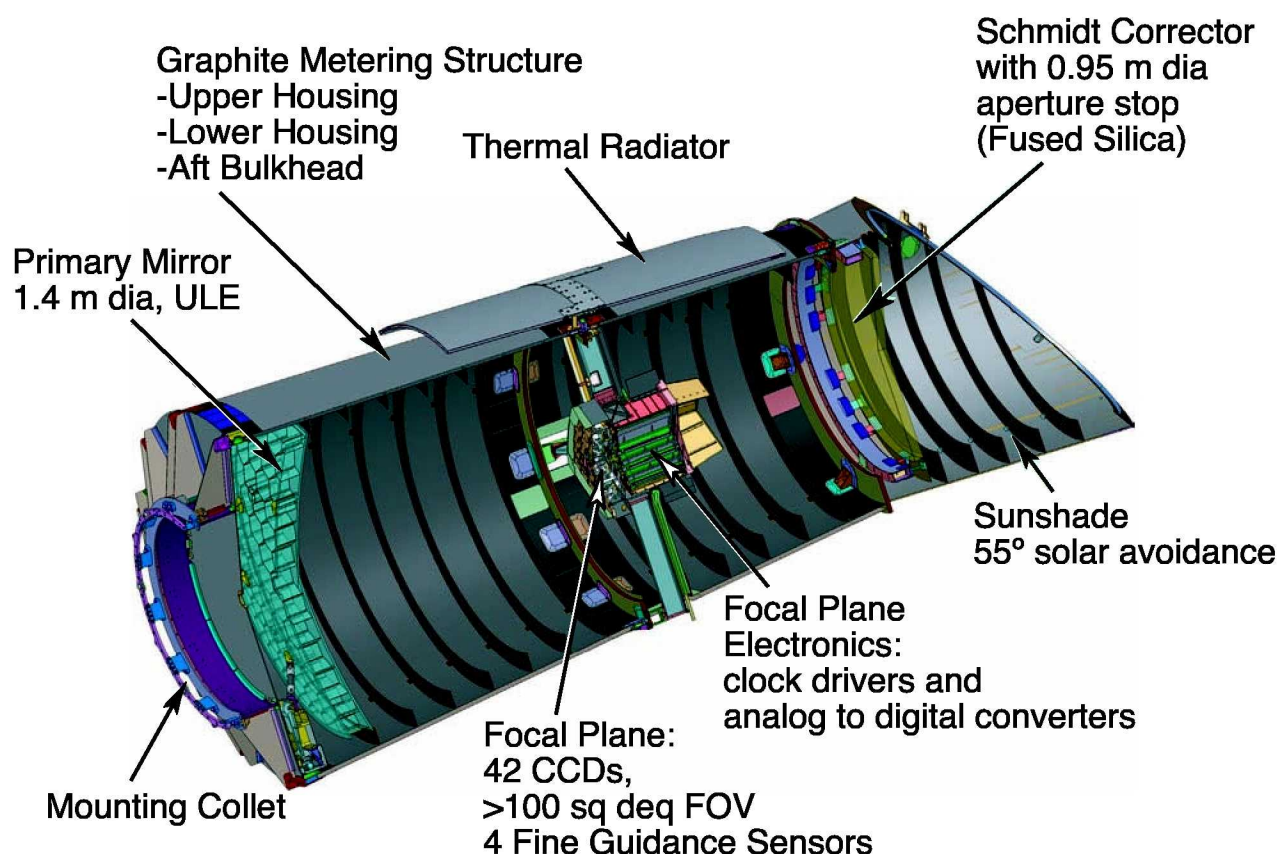
**Bandpass:** 430-890 nm FWHM (Full-Width Half-Maximum)

**Dynamic range:** 9th to 16th magnitude stars

**Fine guidance sensors:** 4 CCDs located on science focal plane

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

**Science data storage:** less than 60 days



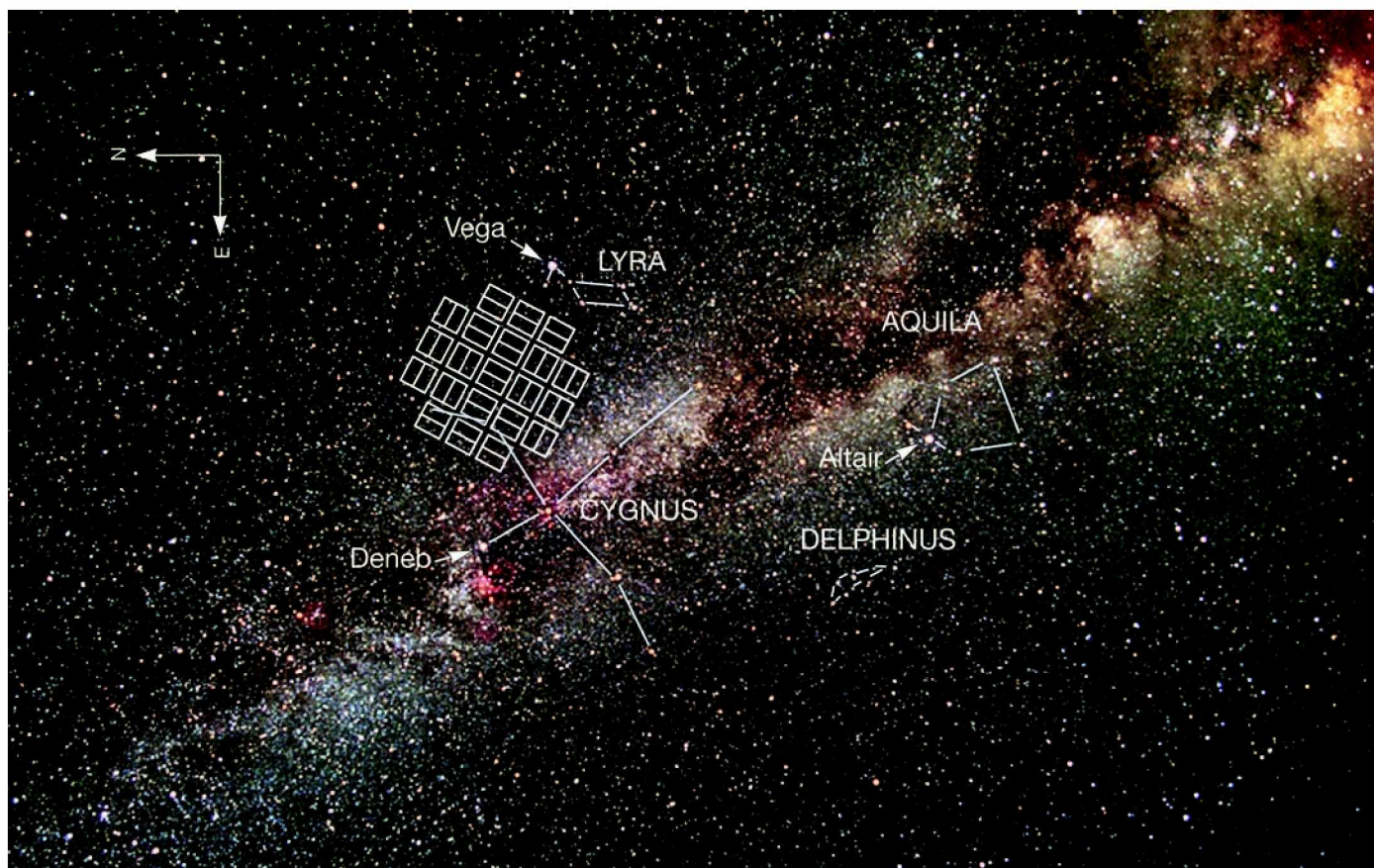
## Selecting the Kepler Star Field

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

1. The field must be continuously viewable throughout the four-year mission.
2. The field needs to be rich in stars similar to our Sun, and Kepler needs to observe 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 sunshield 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. 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.



*The Kepler Field of View*



# NASA's Search for Habitable Planets

What are the chances that Earth is unique to supporting life? If our planet is not unique, how many Earth-size planets are there? These are key questions that NASA's Kepler Mission team seeks to answer.

NASA's Kepler spacecraft will greatly expand the quest for planets orbiting stars – not only the giant, Jupiter-size planets, but also smaller, Earth-size planets that might contain liquid water – and thus support life.

Kepler is a NASA 'Discovery' mission scientists have designed to survey our region of the Milky Way galaxy to detect potentially hundreds of Earth-size and smaller planets in or near habitable zones. A habitable zone is the distance from a star where liquid water could exist on the surface of planet orbiting that star. The first step in discovering the extent of life in our galaxy is to determine the number of terrestrial planets in the habitable zone of solar-like stars.

While more than 300 planets have been found using Earth-based telescopes, all are very large and none are as small as Earth. Small, rocky planets in the habitable zone of solar-like stars are more likely to harbor life than the giant gas planets previously discovered.

Kepler is the first space telescope specifically designed to find Earth-size planets in the habitable zones around distant stars. As one mission scientist described it, while not specifically searching for 'ET,' the Kepler Mission is looking for ET's home.

Selected in 2001 for NASA's Discovery Program, the Kepler Mission will explore the structure and diversity of planetary systems to determine the frequency of terrestrial planets in our galaxy. The results will provide scientists with a broad understanding of planetary formation, 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 planets orbiting other stars is difficult with Earth-based telescopes that have to peer through Earth's atmosphere, obscured by the nocturnal lights of cities, and the smoke and smog emanating from civilization. Even NASA's Hubble Space Telescope, which orbits Earth, has its limitations, as it was not designed to observe one small section of the Milky Way for years.

The Kepler spacecraft will focus at one large area of the sky in the constellation Cygnus about equal in size to two human hands held at arm's length. Over the course of the next four years, the spacecraft will measure the brightness of more than 100,000 stars every 15 minutes. Kepler includes a lens, a primary mirror and a charge-coupled device (CCD) array that is similar, but larger, than the CCDs found in digital cameras. The Kepler focal plane is made up of 95 pixels, considerably larger than a typical consumer digital camera that only may have five pixels. The word 'pixel' is derived from two words: 'picture element' the smallest unit or piece of a computer, television or similar image. Similar to a photographer's light meter, the CCD array will not take actual images of planets, but instead will seek starlight that dims and then brightens on a regular schedule.

The Kepler Mission uses the CCD photometer to detect 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 and similar to detecting a mosquito crossing in front of a car's headlight. Kepler uses a sophisticated photometer capable of detecting a change in a star's brightness equal to 20 parts per million.

Scientists will transmit engineering and science data from the Kepler spacecraft every 30 days over NASA's Deep Space Network for analysis. Engineering data will be sent to the missions operations center at the University of Colorado in Boulder, where it will be studied to monitor the health of the spacecraft.

Science data will be sent to the Space Telescope Science Institute, Baltimore, Md., where researchers will archive the raw science information received from the Kepler Mission. The researchers in Baltimore will relay the raw science data to the science operations center at NASA Ames Research Center, Moffett Field, Calif., for analysis. Scientists will study the data to determine if there is any potential dimming caused by planetary transits.

Hundreds of people across the country are involved in the Kepler Mission. NASA's Jet Propulsion Laboratory, Pasadena, Calif., manages the project for NASA's Ames Research Center, Moffett Field, Calif., and is responsible for ensuring that Kepler's flight system performs successfully in orbit. NASA's Ames Research Center managed the development of the ground system and will conduct scientific analysis for the mission. Ball Aerospace and Technologies Corp., developed Kepler's flight system, including the spacecraft and the photometer, and is participating in mission operations. NASA's Ames will manage flight operations after commissioning is completed. Commission is the period following launch when the spacecraft's systems and the photometer are checked to ensure they are operating normally and are ready to begin conducting science operations.

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, and in a few days, the spacecraft will be beyond the moon's orbit. Kepler's final orbit will be around the sun, trailing Earth. Scientists expect the spacecraft to drift slowly until it is about 46.5 million miles (75 million kilometers) behind the Earth in four years. 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 four years, with potential to extend it an additional two years.

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

# Recent, Current and Upcoming Missions

Competitively selected in December 2001 as NASA's 10th Discovery mission, the Kepler Mission supports NASA's Origins Program theme missions, particularly the Space Interferometry Mission (SIM) and the Terrestrial Planet Finder (TPF) mission by finding the association between the frequency and characteristics of terrestrial planets and stellar type planets.

Terrestrial Planet Finder is a mission concept currently under study by NASA for a potential future mission suite. TPF would study all aspects of exoplanets: from their formation and development in disks of dust and gas around newly forming stars to their suitability as abodes for life.

TPF mission planners will need to design an instrument with enough range to search the appropriate number and types of stars to successfully measure the composition of the atmospheres of terrestrial planets in the habitable zone.

If Kepler finds that many stars have terrestrial-size planets, then TPF mission planners will design and build a TPF coronagraph for the mission. If few planets are found, then TPF planners will have to design and build a much more complicated and expensive TPF-based interferometer.

SIM is expected to launch several years after the Kepler Mission and therefore will be able to target those stars known to have planets. SIM will have the sensitivity to find giant planets in outer orbits for all orientations of their orbital plane. If SIM finds that such planets exist outside the orbits of the terrestrial planets, then scientists will know that the inner planets have some protection from impacts of comets and asteroids that could sterilize life on these terrestrial planets.

Another extrasolar planet mission, the CONvection ROTation and Planetary Transits (CoRoT) space telescope launched Dec. 27, 2006, by the Centre National d'Etudes Spatiales (CNES) the French space agency, is a mission of astronomy led by CNES in association with French laboratories and with several international partners.

The spacecraft is equipped with a 27-cm diameter focal telescope and a 4-CCD camera sensitive to tiny variations of the light intensity from stars. Compared to Kepler, CoRoT has a 27 cm aperture while Kepler has a 95 cm aperture telescope. The difference means that Kepler has 12 times the light-gathering power compared to CoRoT.

The CoRoT instrument uses a method called stellar seismology to probe the inner structure of the stars, as well as to detect many extrasolar planets, by observing what occurs when these bodies transit in front of their parent star.

CoRoT can view a portion of the sky for only five months before it must turn away. Kepler views a single portion of the sky for several years. Therefore, Kepler can search for planets in the habitable zone of sun-like stars while CoRoT mostly will find planets too hot for life.

CoRoT has a field of view that allows it to monitor 12,000 stars simultaneously while Kepler monitors over 100,000 stars simultaneously. CoRoT's major advantage over Kepler is that it launched 1.5 years earlier than Kepler and may make important discoveries of terrestrial planets before Kepler does.

# Program/Project Management

Kepler is a NASA Discovery mission. The NASA Ames Research Center, Moffett Field, Calif., is the home organization of the Science Principal Investigator and is responsible for the ground system development, mission operations and science data analysis. Kepler mission development is managed by NASA's Jet Propulsion Laboratory, Pasadena, Calif. Ball Aerospace & Technologies Corp., Boulder, Colo., developed the Kepler flight system and supports mission operations.

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 Kepler program scientist. NASA's Marshall Space Flight Center, Huntsville, Ala., is manager of the Discovery program.

At NASA's Jet Propulsion Laboratory, 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.

Data collected from the Kepler mission will be stored at the Data Management Center at the Space Telescope Institute in Baltimore, Md.

John Troeltzsch is the Kepler program manager at Ball Aerospace & Technologies, Corp.