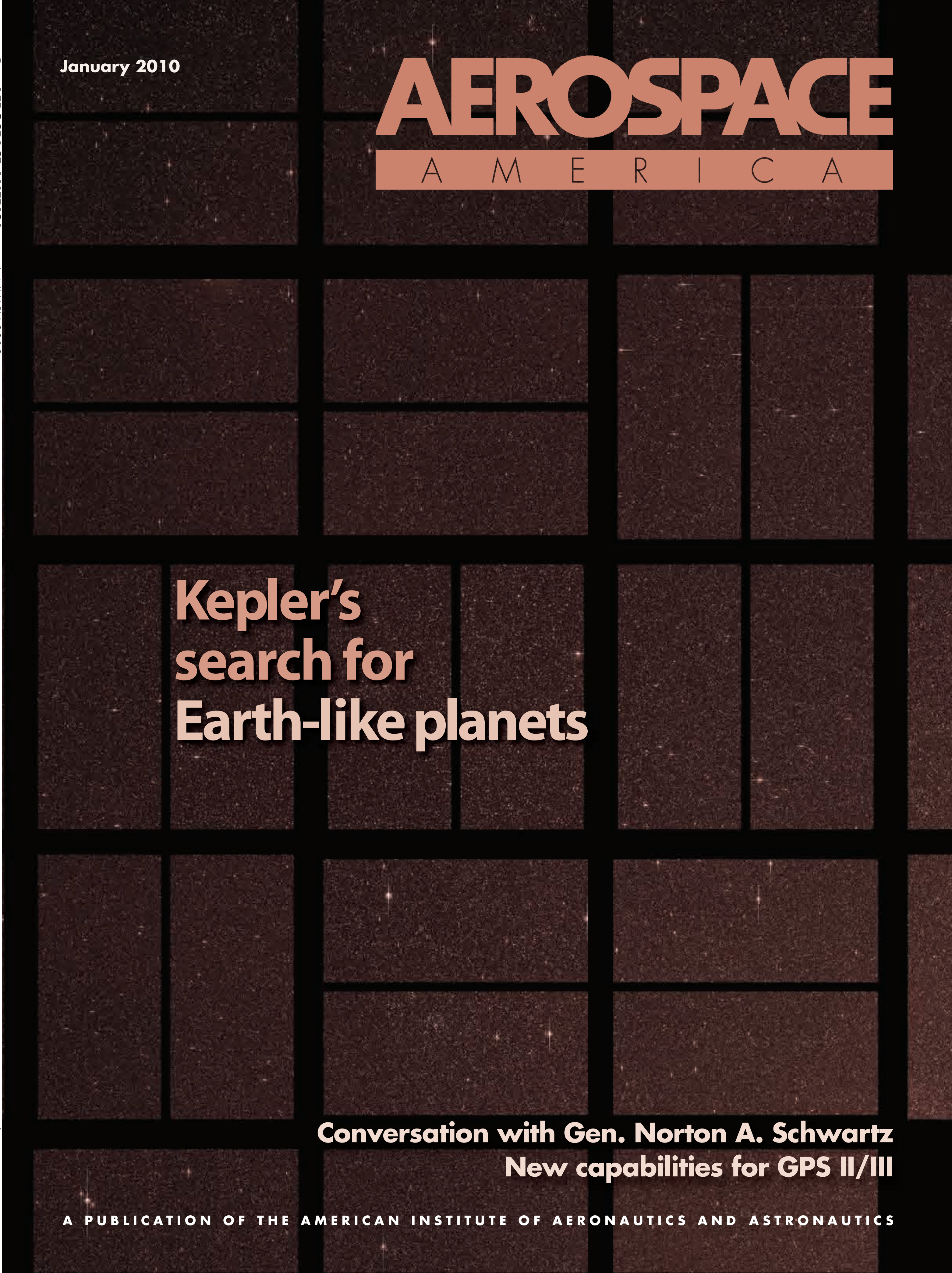
1 AEROSPACE AMERICA JANUARY 2010

January 2010

AEROSPACE AMERICA



Kepler's search for Earth-like planets

Conversation with Gen. Norton A. Schwartz

New capabilities for GPS II/III

A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

Seeking other Earths

NASA's Kepler spacecraft will search for worlds that could host life. It is the first mission with the ability to find planets similar to Earth—rocky planets that orbit Sun-like stars in a warm zone where liquid water could be maintained on the surface. Liquid water is believed to be essential for the formation of life.

"Kepler is a critical component in NASA's broader efforts to ultimately find and study planets where Earth-like conditions may be present," says Jon Morse, the Astrophysics Division director at NASA Headquarters in Washington, D.C. "The planetary census Kepler takes will be very important for understanding the frequency of Earth-size planets in our galaxy and planning future missions that directly detect and characterize such worlds around nearby stars."

Kepler was launched from Cape Canaveral AFS, Fla., aboard a Delta II rocket on March 6, 2009. The mission will spend three-and-a-half years surveying more than 100,000 Sun-like stars in the Cygnus-Lyra region of our Milky Way galaxy. It is expected to find hundreds of planets the size of Earth or larger at various distances from their stars. If Earth-size planets are common in the habitable zone, Kepler could find dozens. If they are rare, it might find none.

In the end, the mission will be our first step toward answering a question: Are there other worlds like ours, or are we alone?

"Finding that most stars have Earths implies that the conditions that support the development of life could be common throughout our galaxy," says William Borucki, Kepler's science principal investigator at NASA Ames. "Finding few or no Earths indicates that we might be alone."

Designed for detection

The Kepler telescope is specially designed to detect the periodic dimming of stars, caused by planets as they pass by. Some star systems are oriented in such a way that their planets cross in front of their stars, from our earthly point of view. As the planets pass, their stars' light appears to dim slightly, or wink.

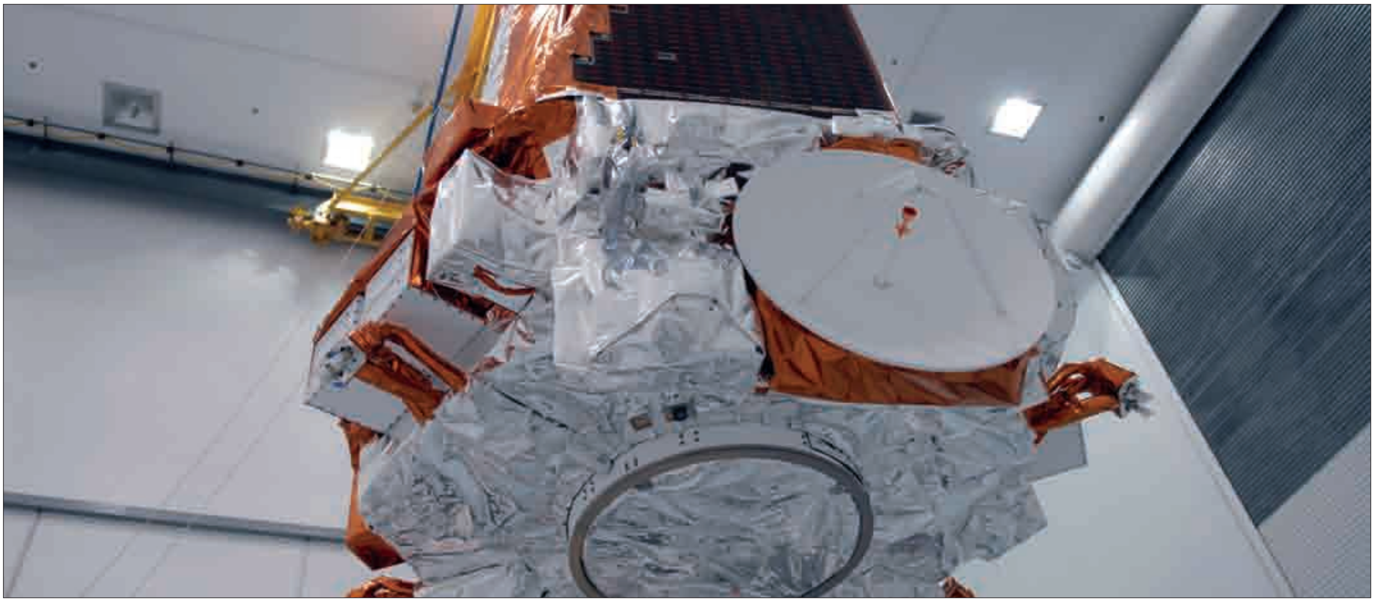
The telescope can detect even the faintest of these winks, registering changes in brightness of only 20 parts per million. To achieve this resolution, Kepler will use the largest camera ever launched into space, a 95-megapixel array of charge coupled devices.

"If Kepler were to look down at a small town on Earth at night from space, it would be able to detect the dimming of a porch light as somebody passed in front," says James Fanson, Kepler project manager at JPL in Pasadena, Calif.

By staring at one large patch of sky for the duration of its lifetime, Kepler will be able to watch planets periodically transit their stars, over multiple cycles. This will allow astronomers to confirm the presence of planets. Earth-size planets in habitable zones would theoretically take about a year to complete one orbit.

To confirm the presence or absence of such planets, Kepler will monitor those stars for at least three years. Ground-based telescopes and NASA's Hubble and Spitzer space telescopes will

The Kepler spacecraft, shown during its preparation for launch, is now searching for planets. Credit: NASA and Ball Aerospace.



perform follow-up studies on the larger planets.

"Kepler is a critical cornerstone in understanding what types of planets are formed around other stars," says exoplanet hunter Debra Fischer of San Francisco State University. "The discoveries that emerge will be used immediately to study the atmospheres of large gas exoplanets with Spitzer. And the statistics that are compiled will help us chart a course toward one day imaging a pale blue dot like our planet, orbiting another star in our galaxy."

Early payoff

In August 2009, a few months after its launch, the Kepler space telescope detected the atmosphere of a known giant gas planet, demonstrating the telescope's extraordinary scientific capabilities. The discovery was published in the journal *Science*.

The find is based on a relatively short 10 days of test data collected before the official start of science operations. The observation demonstrates the extremely high precision of the measurements made by the telescope, even before its calibration and data analysis software were finished.

"As NASA's first exoplanets mission, Kepler has made a dramatic entrance on the planet-hunting scene," says Morse. "Detecting this planet's atmosphere in just the first 10 days of data is only a taste of things to come. The planet hunt is on!"

Kepler team members say these new data indicate the mission is indeed capable of finding Earth-like planets, if they exist.

"When the light curves from tens of thousands of stars were shown to the Kepler science team, everyone was awed. No one had ever seen such exquisitely detailed measurements of the light variations of so many different types of stars," says Borucki, the paper's lead author.

The observations were collected from a planet called HAT-P-7, known to transit a star located about 1,000 light-years from Earth. The planet orbits the star in just 2.2 days and is 26 times closer to it than Earth is to the Sun. Its orbit, combined with a mass somewhat larger than that of the planet Jupiter, classifies this planet as a "hot Jupiter." It is so close to its star that the planet is as hot as the glowing red heating element on a stove.

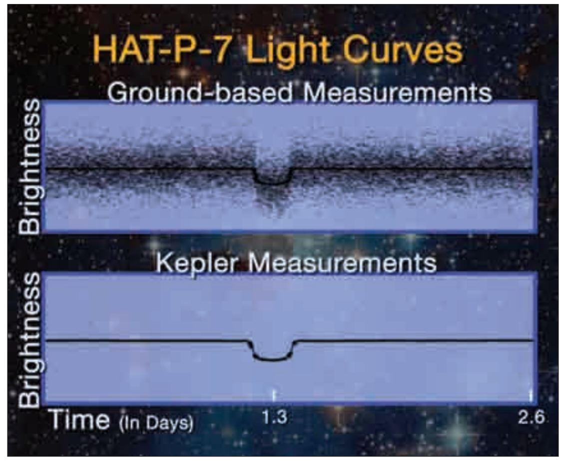


Chart compares the ground- and space-based light curves for exoplanet HAT-P-7b. The small drop in light called an occultation occurs when the planet passes behind its star. Image credit: NASA.

The Kepler measurements show the transit from the previously detected HAT-P-7. However, these new measurements are so precise that they also show a smooth rise and fall of the light between transits caused by the changing phases of the planet, similar to those of our Moon. This is a combination of the light emitted from and reflected off the planet. The smooth rise and fall of light is also punctuated by a small drop in light, called an occultation, exactly halfway through each transit. An occultation happens when a planet passes behind a star.

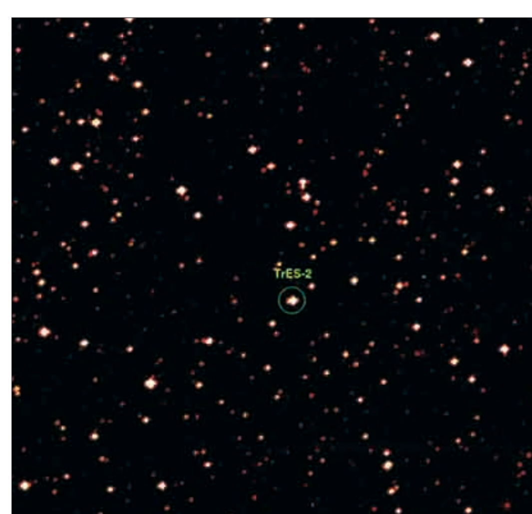
The new Kepler data can be used to study this hot Jupiter in unprecedented detail. The depth of the occultation and the shape and amplitude of the light curve show the planet has an atmosphere with a day-side temperature of about 4,310 F.

Little of this heat is carried to the cool night side. The occultation time compared to the main transit time shows the planet has a circular orbit. The discovery of light from this planet confirms the predictions by researchers and theoretical models that the emission would be detectable by Kepler.

This new discovery also demonstrates that Kepler has the precision to find Earth-size planets. The observed brightness variation is just one-and-a-half times what is expected for a transit caused by an Earth-sized planet. Although this is already the highest precision ever obtained for an observation of this star, Kepler will be even more precise after analysis software being developed for the mission is completed.

"This early result shows the Kepler detection system is performing right on the mark," says David Koch, deputy principal investigator at NASA Ames. "It bodes well for Kepler's prospects to be able to detect Earth-size planets."

Kepler is a NASA Discovery mission. Ames is the home organization of the science principal investigator, and is re-



As you zoom into a small portion of Kepler's full field of view, at the center is a star with a known hot Jupiter planet, TrES-2, zipping closely around it every 2.5 days. The area is one-thousandth of Kepler's full field of view, and shows hundreds of stars at the very edge of the constellation Cygnus. The image is color-coded so that brighter stars appear white, fainter stars, red. Image credit: NASA/Ames/JPL-Caltech.

sponsible for the ground system development, mission operations, and science data analysis. JPL manages the Kepler mission development. Ball Aerospace & Technologies in Boulder, Colo., is responsible for developing the Kepler flight system and also for supporting mission operations.

For more information about the Kepler mission, visit: http://www.nasa.gov/kepler

The bigger picture

Providing additional perspective on the search for living planets, Alan Boss, affiliated with the Carnegie Institution for Science, Washington, D.C., says that we entered a new era of human understanding of our universe following a major advance that occurred in 1995: the discovery of planetary systems around stars other than the Sun.

Speaking at the February 2009 meeting of the American Association for the Advancement of Science in Chicago, he pointed out that roughly 300 planets have been found outside our solar system to date, ranging from the fairly familiar to the weirdly unexpected. Nearly all the planets discovered so far appear to be gas giants similar to our Jupiter and Saturn.

The star COROT-7 is located at a distance of about 500 light-years. Slightly smaller and cooler than our Sun, CoRoT-7 (in the center of the image) is also thought to be younger, with an age of about 1.5 billion years. It is now known to have two planets, one of them (COROT-7b) being the first to be found with a density similar to that of Earth. (Copyright: ESO/Digitized Sky Survey.)

However, Boss adds that the past few years have witnessed the discovery of over a dozen planets with much lower masses, in the range of 5-20 times that of the Earth—masses comparable to those of our ice giant planets, Uranus and Neptune. It is not yet clear if these smaller mass planets are ice giants or perhaps rocky planets similar in composition to the Earth, but with much more mass—that is, super-Earths. The latter possibility would be tantalizing evidence that Earths are common.

European space agencies and NASA have launched and planned an array of space-based telescopes that will carry out this search in the next several decades.

COROT's results

The French-led COROT Mission and NASA's Kepler are searching for evidence of Earth-mass planets by relying on the transit technique, whereby the presence of a planet is inferred from the tiny dimming of starlight it causes as it passes in front of its star. COROT and Kepler are likely to provide our first firm estimates of the frequency with which habitable Earth-like planets are distributed in our neighborhood of the galaxy.

Once that frequency is known, Boss adds, scientists can design specialized space telescopes that can image these new worlds and tell us whether their atmospheres show evidence of the molecules necessary for life (such as water and oxygen), and possibly even evidence of those created by life (methane).

He points out that we will then know if any of the nearby stars harbor planets that are habitable and perhaps even inhabited. We will know just how crowded the universe really is.

Some early results of the COROT space mission are remarkable. The COROT (convection, rotation, and planetary transits) satellite is a 30-cm space telescope launched on December 27, 2006, from Baikonur, Russia. Since then it has been orbiting at about 900 km from the Earth, monitoring the changes in brightness of a huge number of stars with unprecedented accuracy. This aims at both detecting exoplanets by the transit method and studying the seismology of a wide variety of stars.

In October 2009 *Astronomy & Astrophysics* published a special issue dedicated to the early results from COROT. The mission was developed and is operated by the French space agency CNES, with the participation of ESA's RSSD and science programs, Austria, Belgium, Brazil, Germany, and Spain.

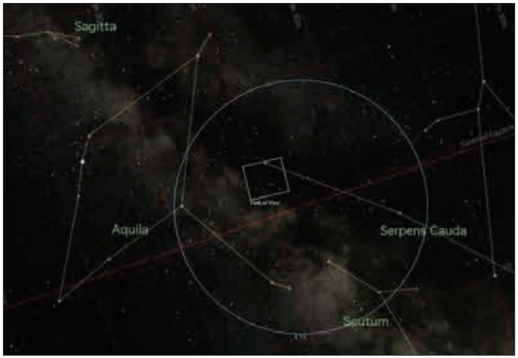
So far, seven exoplanets have been discovered in the COROT data and confirmed by ground-based follow-up campaigns. The difficulty with this exoplanet hunting is that it requires a long process of deciphering the candidates and finally characterizing a few stars hosting planets among tens of thousands.

The most exciting, and now famous, planet-hosting star is named COROT-7. The discovery of COROT-7b, the smallest exoplanet ever found, was announced in February 2009 during the first COROT international symposium. Scientists measured the mass of the planet—five Earth masses—using additional ground-based measurements. They calculated its density (about 5.6 g/cm^3), showing that COROT-7b, like Earth, is rocky. This is the first rocky exoplanet confirmed to date. Scientists also discovered a second planet in the COROT-7 system. Now known as COROT-7c, it is another super-Earth exoplanet of about 8 Earth masses.

Detection of the secondary transit of COROT-1b provides an example of the accuracy of COROT's data when the planet passes behind its star. This is a real challenge, because the amplitude of such an event is about 100 parts per million. Comparing the depths of both transits provides information on the albedo of the planet, hence on the nature of its atmosphere.

Seismology of stars

COROT's primary goal is not only to hunt exoplanets, but also to study the seismology of stars. This part of the mission is also a major step forward. Several scientists are working to detect and measure solar-like oscillations in distant stars. COROT shows that the oscillations are generally more complicated than those of the Sun, which poses new problems of interpretation. Such oscillations have also been detected and quantified for the first time in many red giants, us-



The field of view is seen at the frontier between Aquila and Serpens Cauda. Alya is an appropriate seamark to precisely locate the sky surveyed by COROT.

ing data from the exoplanet search program. The physical processes responsible for these complex oscillations are now understood.

COROT's observations of hot stars also gave astonishing results. The satellite observed a Be star during an outburst phase and measured the change in the oscillation spectrum during this rare event. A Be star is a B-type star that shows hydrogen emission lines. The B spectral type includes luminous, white-blue stars, with surface temperatures of 10,000-30,000 C. Typical Be stars are rapidly rotating, variable bodies. Achernar (a Eridani), the ninth brightest star in the sky, is a famous Be star. These observations gave insight into the nature of the explosion. It will help in solving a question that has been pending for years: Are oscillations the cause of the outburst?

Stellar physics

Although primarily devoted to asteroseismology and exoplanet search, COROT also addresses many important topics in stellar physics. Several scientists who deal with stellar activity have detected spots in the stars' photospheres, giving access to their rotation rate. In some cases, it is even possible to detect the latitude dependence of the rotation rate. Significant progress in the modeling of fast-rotating stars will help in understanding the new data.

The COROT satellite has been orbiting the Earth for nearly three years and will be operated until 2013. Already it has been a pioneering mission that has led to major insights in both exoplanetary and asteroseismic domains.

An even more ambitious mission, the ESA project PLATO, is still under assessment as part of the ESA Cosmic Vision program for 2015-2025. PLATO will be able to combine the detailed study of the stellar interior and of the planetary environment of tens of thousands of bright stars.

Edward D. Flinn
edflinn@pipeline.com