

# Space-Based Detection of Extrasolar Planets

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**In the last decade, the study of extrasolar planets has developed into a major observational field. Over 130 extrasolar planets are now known, mostly from ground-based radial-velocity measurements. This very rich field of research includes the formation of planets from circumstellar disks and the dynamics and evolution of planetary systems. A major goal in this field is the detection and characterization of Earth-like planets. Detection of low-mass planets requires space-based techniques. In this paper, we summarize the goals of the next generation of space missions which will study planetary systems around nearby stars.**

## I. Introduction

One of the most important areas of research in modern astronomy is the study of extrasolar planets. Planets are believed to form during the late stages of the formation of stars from protostellar clouds. With the discovery of Jupiter-like planets around a significant fraction of Sun-like stars, the study of star formation now extends to encompass the smallest mass and size scales – those of the formation of planetary systems. The long-term objective of this field is therefore to understand the formation and evolution of both stars and planets.

With the discovery in 1995 of the first extrasolar planet orbiting another star, the quest to understand the planetary makeup of nearby stars received new impetus. Ground and space based instruments are actively studying the formation of planets, through observations of the circumstellar disks out of which planets form, and through searches for planets in systems which have completed the formation process. Detecting planets from the ground is done almost entirely through the detection of the gravitational ‘wobble’ induced in the parent star by an orbiting planet. This wobble is seen as a Doppler shift in a high-resolution spectrum of the star. The technique favors massive planets orbiting close to the star, and is ultimately limited by variability in the star itself resulting from processing in the stellar photosphere. Masses for the over 130 extrasolar planets now known, mostly range from several Jupiter-mass, down to Saturn mass. The limit, even for planets in short-period orbits, is around 10 times the mass of the Earth. Detecting Earth-mass planets from the ground is probably beyond the reach even of future large telescope and improved techniques, so astronomers are looking to a new generation for space-based instruments to perform comprehensive studies of extrasolar planets. Of course, one of the big questions to be answered is whether planets like our own Earth, in a ‘habitable zone’ around their parent stars where liquid water can exist on the surface, exist around the nearest stars. Beyond that, we will study the properties of the planet itself – mass, radius, orbit parameters, temperature, and the chemical characteristics of its atmosphere. Ultimately, we would like to know ‘Are we alone?’ These questions are among the many to be answered in this rich and growing field of research.

In this paper, we will briefly outline some of the future space missions that will detect and characterize extrasolar planets. These missions complement each other, with each delivering important data that will allow astronomers to explore comparative planetology in extrasolar planetary systems. This will allow us to set in context any Earth-like planets that we discover, as well as bringing important results from other missions. Many ground based telescopes and several space missions are already active in this area, primarily to help understand the processes of star and planet formation. The Hubble Space Telescope and the Spitzer Space Telescope are powerful instruments for studying debris disks (dust disks left over after planet formation is mostly complete), and protoplanetary disks of gas and dust around young stars. Future missions such as the James Webb Space Telescope (JWST) and Herschel will continue these studies and greatly extend the number of systems that can be imaged. In particular, JWST will have

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the combination of angular resolution and sensitivity in the infrared to make direct detections of young Jupiter-like planets.

The most current source of information on each of these missions may be found on their respective websites. WWW links to each are listed in Section V below.

## **II. Corot and Kepler**

COROT (CONvection, Rotation & planetary Transits) is a mission of the French National Space Agency CNES, due for launch in 2006. Its dual objectives are stellar seismology – the study of the structure of stars through their oscillations – and photometric monitoring of thousands of stars for the signatures of transiting planets. A transit is detected by precisely measuring the dimming of a star due to passage of a planet across the face of the star. The mission expects to continuously survey roughly 12000 stars with a magnitude < 15.5, and detect up to a few dozen low-mass planets.

The Kepler Mission, planned for launch in 2007, is designed to continuously monitor the brightness of approximately 100,000 stars. It will be sensitive to planets with sizes smaller than the Earth, may detect Earth-size planets if they are common around solar-like stars. Kepler will detect planets with a range of sizes, and because it observes a very large number of stars, it will establish the statistical properties of planets occurrence and greatly add to our understanding of the formation of planets. Knowledge of the frequency of occurrence of planets will be helpful in planning the observing strategy for missions like TPF-C and TPF-I that will study a smaller number of planets in much more detail to measure their physical characteristics.

## **III. SIM PlanetQuest**

Space Interferometry Mission PlanetQuest (SIM PlanetQuest) will be a powerful tool for discovering planets around nearby stars, through detection of the stellar reflex motion. SIM PlanetQuest, due for launch in 2011, will search for terrestrial planets around 250 solar-type stars in our solar neighborhood. Because SIM detects planets through the gravitational interaction with the parent star, it will use dynamics (Kepler's laws) to directly measure the mass of planets it detects. Mass is the single most important physical parameter of a planet. It is critical for determining the ability of a planet to retain an atmosphere, which is essential if we are to eventually search for life on any discovered Earth-like planets. SIM will measure the orbital parameters of the planets it detects allowing detailed studies of the dynamics of each system. For instance, it will measure the mutual inclinations in multiple planet systems – a measurement that is not possible using the radial-velocity method.

SIM Planetquest will be the first long-baseline interferometer in space dedicated to precision astrometry. It will build on the scientific legacy of the very successful ESA Hipparcos mission, but will return accuracies over 200 times more precise. In addition to planet-searching, SIM PlanetQuest will use its unique capability for micro-arcsecond accuracy astrometry to perform important research in stellar and galactic astrophysics. Topics in astrophysics range from stellar astrophysics, to Galactic structure and formation, dark matter in our local universe, to the structures within distant AGN (active galactic nuclei). The SIM PlanetQuest website lists the investigations already approved for observation with SIM; additional projects will be competitively selected.

## **IV. Terrestrial Planet Finder (TPF)**

NASA is planning two Terrestrial Planet Finder (TPF) missions to directly detect planets and characterize their surfaces and atmospheres through spectroscopy. The first of these will be an optical coronagraph, capable of returning spectra of dozens of Earth-like planets, if they turn out to be common. This will be followed by a mid-infrared TPF (TPF-I) which will operate as small constellation of telescopes in a formation-flying interferometer.

### **A. TPF Coronagraph (TPF-C)**

The first space-based instrument designed specifically to detect light from an extrasolar planet will be the Terrestrial Planet Finder Coronagraph (TPF-C). It is planned as a large telescope with a roughly 25 sq-m aperture, operating in the visible waveband from 0.4 – 0.9  $\mu\text{m}$ . It will work in conjunction with a coronagraphic instrument capable of detecting a planet less than 0.1" from the parent star and up to  $10^{10}$  times fainter. This requires stability over many several hours and control of the stellar wavefront to about 20 pm.

The scientific objectives of TPF-C are now being developed in detail. Its principal goal is to observe a large number of nearby stars for planets, with the ability to detect Earth-like planets in the 'habitable zone'. The Habitable Zone is the region around a star where liquid water can exist on the surface of a planet. In our solar system, this corresponds roughly to the region between the orbits of Venus and Mars; water is considered essential to all forms of life that we understand. Habitability also depends on many other factors, including the nature of its atmosphere. Knowing the mass of a planet is important because that helps constrain the physical characteristics of the planet, including the ability to retain a dense atmosphere. SIM PlanetQuest will help TPF-C by helping prioritize targets, and by providing masses for its detected planets (SIM will be most sensitive to planets exceeding about 3 Earth masses).

TPF-C will perform spectroscopy on the planets that it discovers. A visible-light spectrum of an extrasolar planet will provide direct information on the composition of its atmosphere, allowing a search for molecules indicative of life, including oxygen, water vapor, and ozone.

### **B. TPF Interferometer (TPF-I)**

The coronagraph mission will be followed by a large space-based mid-infrared interferometer (TPF-I) to search for planets through their thermal signatures, and to perform spectroscopy of molecules with absorption lines in the mid-infrared. The spectral signatures of common atmospheric molecules are very different in the optical and in the mid-infrared, so the combination of spectra in both wavebands will form a powerful diagnostic of extrasolar planetary atmospheres, as noted above under TPF-C. In particular, ozone is detectable in very small concentrations through its very deep band at 9 $\mu\text{m}$ ; similarly carbon dioxide has a very strong band at 15 $\mu\text{m}$ . Water vapor has strong absorption bands toward the long and short-wavelength ends of the likely TPF-I observing band. Other molecules of interest include nitrous oxide and methane.

TPF-I is being designed as a formation-flying mid-infrared interferometer, with up to four spacecraft with collecting apertures, and a combiner spacecraft which brings the light beams together. The heart of the instrument is the 'nulling' beam combiner; the stellar flux is nulled out at a zero of the interference fringe pattern, allowing off-axis light from a planet to be detected. The mission will be capable of adjusting its angular resolution by changing the separation of the individual spacecraft, all of which must fly in precision formation. Increasing the telescope separation improves the angular resolution, which permits TPF-I to observe a larger sample of more-distant stars for planets. Both TPF-C and TPF-I will be very capable instruments for other astrophysical research programs besides finding and characterizing Earth-like planets. However, for both instruments, the design and its operating mode are governed by the very demanding requirements on starlight suppression and angular resolution needed for the primary task of separating planet from star.

The TPF-I instrument may be developed as a collaboration with the European Space Agency, which is studying the Darwin mid-infrared interferometer mission, with similar science goals.

## **V. Planet Search Missions**

Comprehensive websites contain detailed information on each of these planet-finding missions, and may be found via the URLs below.

Corot – <http://smc.cnes.fr/COROT/>

Kepler – <http://www.kepler.arc.nasa.gov/>

SIM PlanetQuest – <http://planetquest.jpl.nasa.gov/SIM>

Terrestrial Planet Finder (TPF-C and TPF-I) – <http://planetquest.jpl.nasa.gov/TPF>

Darwin Mission – <http://sci.esa.int/science-e/www/area/index.cfm?fareaid=28>

Hubble Space Telescope (HST) – <http://hubble.nasa.gov/>

James Webb Space Telescope (JWST) – <http://www.jwst.nasa.gov/>

Herschel– <http://sci.esa.int/science-e/www/area/index.cfm?fareaid=16>

Spitzer Space Telescope – <http://www.spitzer.caltech.edu/>

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