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The Darwin mission: Search for extra-solar planets

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Abstract

The direct detection of an Earth-like planet close to its parent star is challenging because the signal detected from the parent star is between 10^9 and 10^6 times brighter than the signal of a planet in the visual and IR respectively. Future space based missions like Darwin and TPF-I concentrate on the mid-IR region between 6 and 20 μm, a region that contains the CO_2, H_2O, O_3 spectral features of biomarkers in Earth's atmosphere.

The InfraRed Space Interferometer Darwin is an integral part of ESAs Cosmic Vision 2020 plan, intended for a launch towards the middle of the next decade. It has been the subject of a feasibility study and is now undergoing technological development. It is focused on the search for, and characterization of Earth-like planets orbiting other stars. A secondary objective is to carry out imaging of astrophysical objects with unprecedented spatial resolution. The implementation is based on the new technique of 'nulling interferometry'. New designs have been developed that will be implemented on four spacecrafts and search for planets around a minimum of 165 stars within the mission lifetime.

Keywords: Darwin; Extrasolar planet search; Biomarkers; Nulling interferometry; Darwin targets stars; TPF-I

1. Introduction

The InfraRed Space Interferometer Darwin is a major element in the Cosmic Vision 2020 program of the European Space Agency. Darwin has the explicit purpose of detecting other Earth-like worlds, analyze their characteristics, determine the composition of their atmospheres and investigate their capability to sustain life as we know it.

The closing years of the 20th century have allowed us, for the first time, to seriously discuss interferometric instruments deployed in space achieving unprecedented spatial resolution. These missions will lead to new astrophysics. Especially – and this is the greatest challenge – we expect to be able to carry out the first detailed study of terrestrial exoplanets (defined as planets similar to our own Earth as what concerns size and mass, and orbiting other stars than our Sun) as well as comparative planetology based on the diversity of planets detected. The detection and study of the latter promises to open a new era in science and will affect a broad spectrum of science and technology. We can now confidently expect the first results from space based interferometers within 10 years. Sophisticated instruments will follow in short order.

Analysis of the planetary light requires that the stellar light is suppressed to a high degree. This is done by a technique called nulling interferometry, in essence this means that achromatic phase shifts are applied to the beams collected by individual telescopes before recombination such that the on-axis light, i.e., stellar light, is cancelled by destructive interference, while the much weaker planetary light emitted at a certain off axis angle interferes constructively.

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The Darwin mission is implemented on four free flying spacecraft including one beam-combining spacecraft. The beam combiner and the telescope spacecraft fly in one plane with each telescope spacecraft at the same distance from the beam combiner. The resolution of the interferometer is adjusted by changing the distance between the telescope spacecrafts. A similar activity has been taking place in the United States within the context of NASAs Origins program. A science collaboration has already been established.

2. Extrasolar planets

The last years have seen the detection of planets beyond our solar system finally becoming a fait accompli. The techniques utilized so far have been indirect. Radial velocity relies on measuring the reflex motion of the parent star, with respect to the common center of mass of the star–planet system. The transit method measures the reduction in flux when a planet crosses the line of sight between earth and its host star. The first detection of a planet outside the Solar System using radial velocity method was reported by Mayor and Queloz (1995) for the Solar type star 51 Peg. This was quickly followed by the Lick group who reported planets around 70 Vir and 47 Uma (Marcy and Butler, 1996; Butler and Marcy, 1996). It appears unlikely, however, that this method could be used to infer the presence of Earth-type planets. The current precision in radial velocity is $\sim$3 m s^{-1}, while the Earth at 1 AU from the Sun would require 0.1 m s^{-1}. Acoustic pressure-mode oscillations in solar-type stars have amplitudes of 0.5–1 m s^{-1}, and will thus make it essentially impossible to detect a deflection of an Earth simile.

The planets so far found with the radial velocity method are objects more akin to the planet Jupiter than something like our own Earth. Radial velocity searches for planets are strongly biased toward planets with large mass and short orbital period because of their easy detectability. As time passes longer and longer periods are being picked up, and there are now a number of confirmed planets in orbits with periods of several years. A few of the objects are likely Brown Dwarfs. The radial velocity method provides us with a lower limit to the mass and the orbital radius. If the inclination of the planetary orbit is not known, there is no way to determine the planets absolute mass, actual size or composition – without other data.

One trend that has been seen in radial velocity star surveys is that a plot of the number of detected objects vs. $M\sin(i)$ increases strongly towards $M\sin(i) < 1\,M_{\mathrm{jup}}$. An unknown process would have to bias our detection towards only picking up systems seen face on (Fischer and Valenti, 2003; Marcy et al., 2003).

In the case of the first observed occultation, the planet orbits the star HD 209458 every 3.52 days at a distance of about 0.05 AU. The occultation lasts about 2.5 h and from this observation, the inclination is found to be 87.1°. Charbonneau et al. (2000) derive a planetary mass of 0.63 M_{Jup} and a planetary radius of 1.27 R_{Jup}. This can be done since the orbital radius is well known from the radial velocity measurements, and the stellar radius is known to good accuracy from stellar evolution theory. The actual shape of the light curve during the occultation (Mazeh et al., 2000), constrains the planetary radius and orbital inclination to a very high degree. The average density of the planet turns out to be only half that of the major gaseous giant planets in our own Solar System immediately ruling out that the planet is a rocky, terrestrial body (super-Earth) that could have formed close to its current location since such a planet would be significantly smaller than 1.27 R_{Jup}. The planet is thus a gas giant. Being physically larger than Jupiter but with a lower mass is caused by its proximity to its primary which heats it to a surface temperature of 1200 K. Such temperatures would, however, only affect the outer 1% of the planet, and the large diameter immediately says something about its evolution. As pointed out by Lunine (2001), what is happening is that the flux from the star retards the cooling of the planetary interior. A giant planet formed in isolation would cool in a brief time ($\sim 10^6$ years), and thus it also shrinks rapidly from its original distended state. For a planet in very close proximity to a star such as is the case for HD 209458b, the atmospheric temperature profile is flattened and the rate by which heat can be transported outwards from the interior is reduced and the contraction will be retarded. Detailed models (Burrows et al., 2000) show excellent agreement with the planetary radius at its current age of 4–7 billion years (the age being determined from stellar evolution theory). It can also be shown in these models, that the planet must have arrived at an orbital radius of $\sim$0.05 AU within at most a few tens of millions of years after formation. Otherwise it would take longer than the present age of the Universe for the external heat to diffuse inwards far enough to expand the radius to the observed value. The observation of a single occultation thus shows that the so called 'hot Jupiters' either form in place or migrate inwards within at most $\sim$a few $\times 10^7$ years (Lunine, 2001; Burrows et al., 2000).

Another indirect method is to obtain astrometric data and thus track a star's path across the sky, measuring the wobble introduced by the rotation around the common center of mass of the star–planet system. The European Space Agency's GAIA mission promises large statistical surveys of massive planets (Perryman, 2000).

2.1. Direct detection of terrestrial planets

All of the above mentioned methods will continue to refine our knowledge about planetary systems. Unfortunately they are restricted towards the indirect detection