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Details on DARWIN and the Search for Extrasolar 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 infrared (IR), respectively. Future space based missions like DARWIN and TPF concentrate on the region between 6 μm and 18 μm, a region that contains the CO_2, H_2O, O_3 spectral features of the atmosphere.

Using several small collecting telescopes and a beam combiner allows us to build an instrument with an angular resolution normally associated with monolithic telescopes of much larger diameters. The relative positions of the telescopes, forming the interferometer, are selected such that when the optical signals, collected by the individual telescopes, are coherently combined, the small angular distance between the planet and the star can be resolved. Different configurations of the free flying interferometer array influence the performance of the nulling array. The concepts for space nulling interferometers and the influence of different schemes of beam combination on the detected signal are investigated. The contribution of background noise to the detected signal is examined.

1. Introduction

Using blackbody radiation laws, the lowest ratio of the light received from a star to that detected from a planet is found in the IR, where the thermal emission of the planet is at its maximum. In the thermal part of the spectrum, the shape gives a measure of the temperature of the object examined. The mid-IR spectra can determine the planet's albedo, the temperature of the observable emitting regions and thus the planet's size. Visible to near-IR spectra offer higher spatial resolution for the same collecting area, are minimally affected by temperature and therefore able to determine the abundance of atmospheric species. However the visible/near-IR continuum does not give direct indication of the planet size because of the possible albedo range (Des Marais et el. 2001).

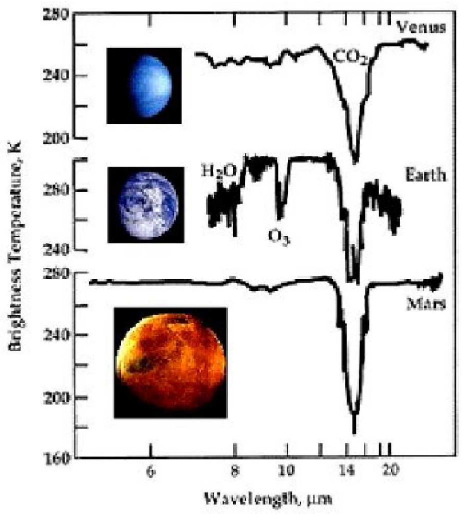

Figure 1. Thermal infrared spectra of Venus, Earth and Mars. The 15 μm CO_2 band is seen in all three planets. Earth also shows evidence of O_3 and H_2O (http://sci.esa.int/home/darwin/index.cfm).

The detection of O_2 or its product O_3 is our most reliable biomarker so far. The existence of H_2O in liquid state on the surface of a planet is considered essential for the development of life; even so, it is not a biomarker.

In a nulling interferometer light from an on-axis source can be destructively interfered. The star can be centred on the deep central null. The intensity signal of a companion can be modulated by a known periodic function using different techniques. Mariotti & Mennesson (1997) proposed internal modulation, a technique using fast signal multiplexing to isolate the planetary signal from the noise sources. The outputs of two sub-interferometers are recombined on a beam combiner, which induces a $\pi/2$ phase shift between the input beams in the first output and a -$\pi/2$ phase shift in the second output. That adds an additional level of signal modulation to the expected planetary signal in the face of varying backgrounds and detector drifts, see Figure 2. Furthermore the transmission maps associated with the two outputs S_{ij}, S_{ji} are asymmetric, although symmetric to each other with respect to their centre, see Figure 3.

Asymmetry of a transmission map is important because it allows distinguishing the planetary signal from the signal of a symmetric dust disk around the star by rotation or modification of the transmission map. Extended sources with central symmetry have the same contribution on both outputs while point sources have a modulated signal as it alternatively lies on a bright or dark fringe in the transmission map of the two outputs.

The rejection ratio r of a nulling interferometer array is defined as the inverse of the stellar transmission, calculated as the integral over the stellar disk divided by the interferometer's response integrated over the stellar disk. Figure

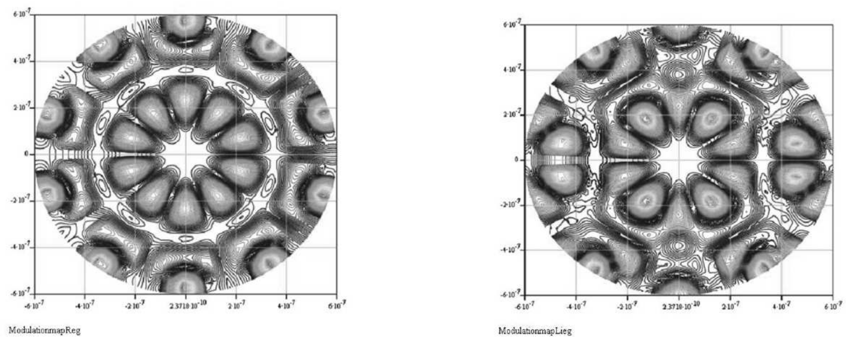

Figure 2. Modulation efficiency map for an array of 5 telescopes, regularly spaced on a circle and an optimized configuration(left side), the Ligeoise configuration by Absil (2000)(right side), both using a 25m radius. Graphs based on (Absil 2000).

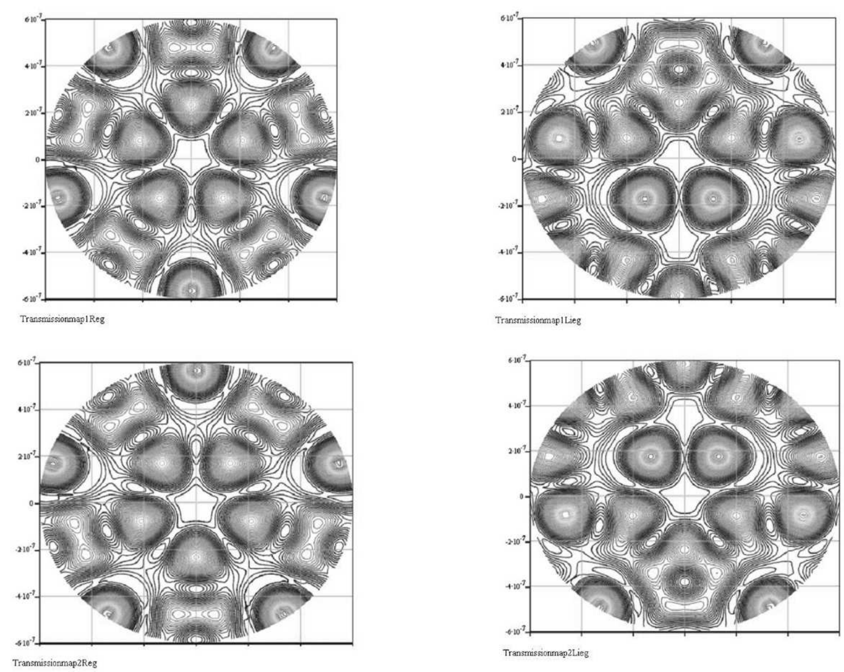

Figure 3. Transmission map of the two nulled outputs of an array of 5 telescopes, regularly spaced on a circle of 25m radius (left side) and the optimized Ligeoise configuration by Absil (2000) (right side). Work based on (Absil 2000).

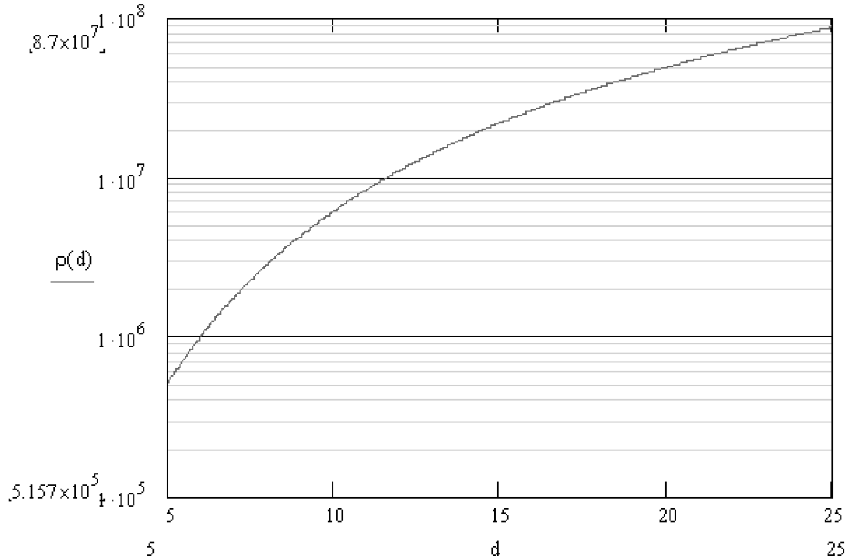

Figure 4. Rejection ratio of the Ligeoise configuration versus distance of the system in parsec (pc).

4 shows the rejection value of the Ligeoise configuration for a solar type star at distances between 5 pc and 25 pc using a baseline radius of 15 m as used by Absil (2000) for easy comparison.

2. Background Flux

For observations of a system similar to our own, thermal emission of the zodical dust is the strongest source of background photons at wavelengths beyond 8 μm. It varies somewhat with sun angle and elevation with respect to the ecliptic plane (Landgraf et al. 2001). The stellar leakage is relevant for smaller wavelengths, assuming a rejection of at least 10^5. The thermal background level due to the emission of the optics can approach that of the zodical dust for temperatures above 40K (Karlsson & Mennesson 2000). If the exozodical dust around the observed system is larger than in our solar system, it can become the strongest source of noise. The amount of dust around main sequence stars is a poorly known factor in the context of the DARWIN or TPF mission. Were it ten times larger then in our solar system, the integration time needed to detect extrasolar planets would greatly increase.

3. Free Flyer Configuration

DARWIN could be implemented in a wide variety of configurations, constrained by the number of telescopes and the necessary background and starlight suppression. There is a performance trade-off between the ability to provide a deep and wide null to suppress starlight combining all telescopes into one single array, and the ability to suppress large-scale diffuse emissions form a zodiacal cloud by observing alternately the signals of different sub-array interferometers with narrower nulls. The later method was proposed by Mariotti & Mennesson (1997) and is called "chopping".

Using several small collecting telescopes and a beam combiner allows us to build an instrument with an angular resolution normally associated with monolithic telescopes of much larger diameters. The relative positions of the telescopes, forming the interferometer, are selected such that when the optical signals, collected by the individual telescopes, are coherently combined, the small angular distance between the planet and the star can be resolved.

Information on the spatial distribution of the source can be found by temporal encoding, e.g., by characteristic modulation of the signal emitted by an off-axis source through rotation of the array. A planet can then be detected through the intensity, the characteristic shape and wavelength dependence of its modulated signal. The transmission map of an interferometer array is a function of the coordinates of the source in the sky (ϕ, θ) in reference to the telescope plane. It can be used as a criterion to select the geometry of the array configuration. Modulation at high frequency reduces different noise sources like thermal and local zodiacal light background slow drifts. Using fast modulation, one can distinguish a planetary signal from systematic errors and $1/f$ type noise sources.

Different concepts are investigated for the Darwin mission: one is a concept for space interferometers employing delay lines of fixed length to obtain achromatic nulling of an on-axis object over a fixed bandwidth, using N apertures was originally proposed by Mieremet & Braat (2002). We confirm that different transmission maps can be generated by switching sign of the fixed path length delays. Thus an expected planetary signal could be modulated and the spatial information extracted without rotating the array.

4. Integrated Optics Beamcombiner

Since the 80's, integrated optics (IO) components on planar substrates have become available for telecommunication applications. The principle of IO is similar to that of fiber optics since the light propagates in optical waveguides, except that the former propagates inside a planar substrate. IO can provide an interferometric combination unit on a single optical chip. The compactness of the optical layout of an integrated optics device provides stability, low sensitivity to external constrains like temperature, pressure or mechanical stresses, no necessity for optical alignment except for coupling, simplicity and intrinsic polarization control (Malbet et al. 1999). It has been demonstrated that spatial filtering before the interferometric combination significantly improves the quality of visibility measurements (Kern et al. 1996) as single mode propagation performs spatial filtering. In addition to simplicity and compactness, using IO

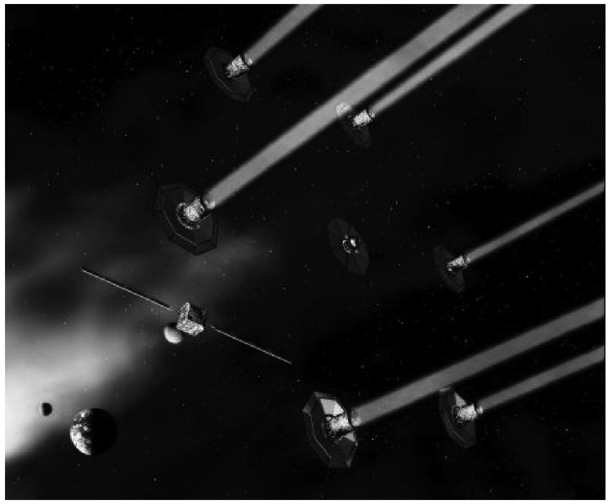

Figure 5. Artistic view of the DARWIN mission (DARWIN 2000).

beam combiners would also increase the output signal of the interferometer. In the current DARWIN design, the collected beams are combined pairwise. Using standard beam combiners like semi-transparent mirrors, at least 50% of the signal is lost at each combination. Alternative designs, like a beam combination scheme using IO components, should provide much higher transmission. Currently tests are underway to classify the properties of these components. Especially in the wavelength range interesting for DARWIN, IO components have to be tested to specify their behaviour.

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