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Study of the polarization effects in a Nulling interferometer: Design consequences

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Abstract. Nulling interferometry is one of the promising techniques for the study of extra terrestrial planets. This technique will be applied in the future space missions Darwin and TPF-I, and from the ground with GENIE. The nulling interferometry techniques require high symmetry of the interfering beams, to obtain the required contrast (typically 10^6 to detect terrestrial exoplanets in the thermal infrared). In this paper we consider the polarization symmetry issue, such as polarization rotation and polarization phase shifts occurring on slightly misaligned optics. We study the consequences of these symmetry requirements on a nulling interferometer design. We find the relation between the misalignment tolerances and the achievable nulling, and we show that this tolerance is highly dependent on the interferometer configuration (the way beams turn right, left, up or down in the interferometer arms). It is typically of the order of the arcminute (not the arcsecond) for a 10^6 contrast. We present a analytical and numerical analyses.

Keywords. Interferometers, Nulling, Darwin.

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1. Introduction

Nulling interferometry, is a technique aiming at interferometric coronography. The challenge is to reach the highest and most stable interferometric contrast. The application of such a technique is the search for extra-solar planet: space mission Darwin/TPF-I and Pegase instruments, and ground based instruments such as GENIE. The required contrast to detect extra-solar earths, is 10^6. (baseline requirement for the Darwin mission). This will be the contrast level targeted by this study. The performances of such an interferometer are called nulling ratio N: normalized value of the light leakage of the instrument. Nulling interferometry require a high symmetry in the beam properties of the different interferometer arms. The requirements for polarization symmetry have been described M. Ollivier 1999. The polarization ϵ_θ rotation should be

$$\epsilon_\theta \leqslant 3.10^{-2} rad \tag{1.1}$$

The phase shift difference $\Delta\varphi_{sp}$ between s and p component should be less than:

$$\Delta\varphi_{sp} \leqslant 2.10^{-3} rad \tag{1.2}$$

The mean phase difference between the two beam $\Delta\varphi$ should be:

$$\Delta\varphi \leqslant 2.10^{-3} rad \tag{1.3}$$

These requirement are well established, but it is necessary to study the source of the polarization mismatch in an interferometer. If we ignore the observed object properties

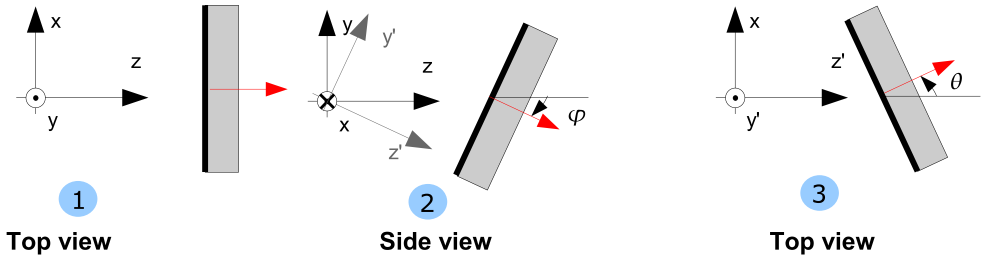

Figure 1. Convention describing the successive rotations to obtain the 3D orientation of a surface.

see]Elias2004, Polarization mismatches come from the reflection and transmission effects in the arms of the interferometer. Traub, 1988 studied some design rules for standard stellar interferometer. Elias *et al.* 2004 also studied the instrumental polarization effects, in particular the misalignment consequences, but the study was independent from the interferometer design (Monte-Carlo simulation on arbitrary optical trains). We will show that polarization mismatches are very dependent from the interferometer design. We have built a numerical model predicting the alignment requirement for a given optical assembly and a nulling requirement.

For the whole study we used Jones formalism see. The electrical field is represented by a 2 component complex vector. It is to be noted that for the whole paper the sign convention for electrical field and the Fresnel equations are the one by Gay, Rabbia 1994.

$$E = \begin{bmatrix} E_x \\ E_y \end{bmatrix} \tag{1.4}$$

In a two beam interferometer the nulling achieved is then:

$$N = \left| \frac{E_1 + E_2}{2E_1} \right|^2 \tag{1.5}$$

2. Polarization effects

The aim of the present work is to determine the alignment requirement of a nulling interferometer, as a function of the nulling requirement and the optical setup design. To describe the misalignment of optics we use the conventions represented in figure 1. We suppose in the whole paper that the *entrance* beam of the interferometer is horizontal, and propagates along the $z > 0$ direction.

2.1. *Effect of the θ rotation*

A rotation around the vertical (y) axis has a quite simple effect (provided the impinging beam is horizontal): It changes the incidence angle. Therefore the reflection or transmission complex coefficients vary. The Fresnel coefficient are function of the incidence angle. Thus the nulling contribution of such a rotation is linked to the Fresnel coefficient variation. It is proportional the square of the alignment error $d\theta^2$.

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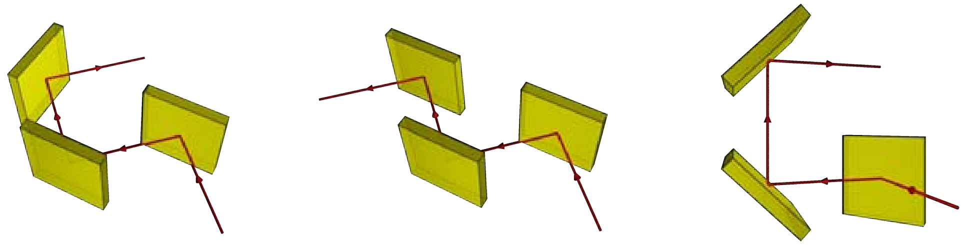

Figure 2. Alignment tolerance for 3 mirrors hypothetic interferometers. We have supposed that both arms of the interferometer are composed of mirrors arranged as shown. The tolerance are calculated for gold coating or bare znse mirrors, at $6\mu m$ Palik, 1985, Tropf, 1995.

2.2. *Effect of the φ rotation*

The φ rotation is more difficult to express. It combines a variation of incidence and a polarization rotation. Around 45 of incidence the incidence variation induced by the φ rotation is of the second order. The major effect is then polarization rotation. For one mirror the polarization rotation is proportional to the φ rotation angle.

3. optical trains modeling

We want to study the effects of misalignment on polarization nulling contribution. Therefore we will suppose that at the output beams of the interferometer are perfectly aligned. That way we separate polarization nulling contribution and tilt nulling contribution.

To perform computations, we build polarization analysis numerical model based on a 3D extension of the Jones Formalism. This program was checked with the commercial simulation software ZEMAX. In simple cases it has been checked with analytical calculations.

4. Results

Most of the numerical result presented here were obtained with Monte-Carlo simulation. Thus the tolerances given are expressing a probability to obtain a certain nulling contribution. The here we give tolerances that ensure to have a 80% of a nulling contribution smaller than 10^{-6}

4.1. *Tolerance variations with configurations*

We have found that the misalignment tolerances are greatly dependent of the mirror configuration in the interferometer. We give the tolerances for 3 interferometer configurations figure 2, with the same total number of mirrors. The tolerance variation can be explained by the geometry. In the configuration 1 the polarization rotation introduced by the 2 first mirrors are compensated by the last mirror. In the two other configurations the last mirror worsen the polarization rotation.

We find that there are two kinds of setup: auto-compensating setups, and setups that add polarization rotations. The rule proposed by Traub, 1988 is good to find out if the setup is auto-compensating or not, at least in plane interferometer setups. In one arm the beam turns should go always in the same direction.

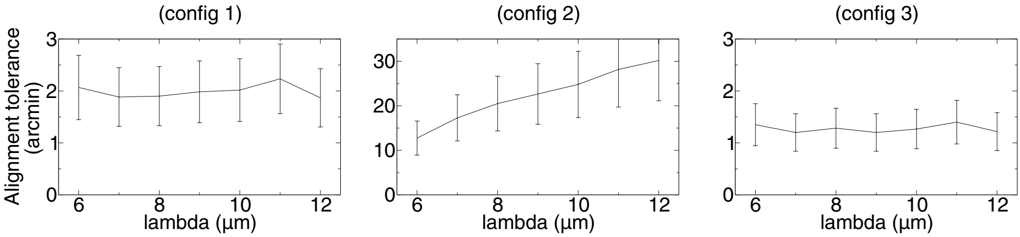

Figure 3. Alignment tolerance versus λ for gold coated mirrors and ZnSe dielectric plates Palik, 1985, Tropf, 1995 for the configuration of figure 2.

4.2. *Materials*

The material on which transmission or reflection occurs have an influence on the alignment tolerances see figure 2. The effect is more sensitive with auto-compensating designs.

4.3. *Wavelength dependence*

The Fresnel coefficients are function of the wavelength. Thus the polarization affect are partly wavelength dependant (see figure 3). This is however untrue for geometrical polarization effects. Only auto-compensating setups have tolerances that vary with wavelength.

5. Conclusion

In this poster we have shown the basic effects of misalignment on the polarization of the beams in a nulling interferometer and the variation of these effects with several parameters. The typical tolerance is around the arcminute for a nulling of 10^{-6}. For the rare autocompensating setups this tolerance can be relaxed of a factor 10.

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