Simple and homothetic interferometric apodization using a Mach-Zehnder interferometer

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Introduction

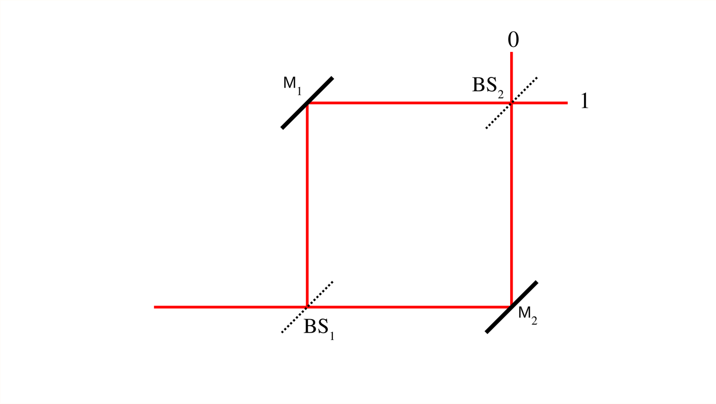
Currently, several scientific projects are attempting to develop methods for the direct detection and characterization of extrasolar planets. Two major difficulties :

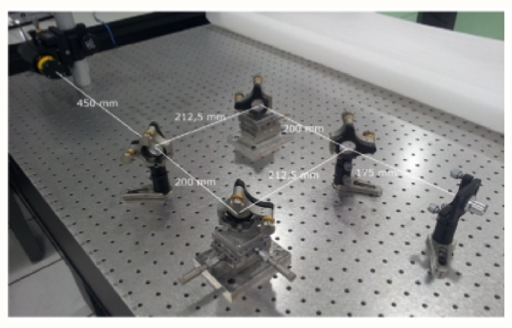
- the important contrast due to the difference in luminosity between the planet and its parent star (10^9 in the visible, 10^6 in the infrared) ;
- the small angular distance between the two objects which requires a high angular resolution.

To achieve this, one solution is to equip telescopes with a coronagraph and apodize its entrance pupil to focus a large part of the flux at the center. The apodization can be obtained using interferometric assemblies. We present laboratory results obtained with a MZI (1D) and homothetic (2D) interferometer.

Mach-Zehnder interferometer

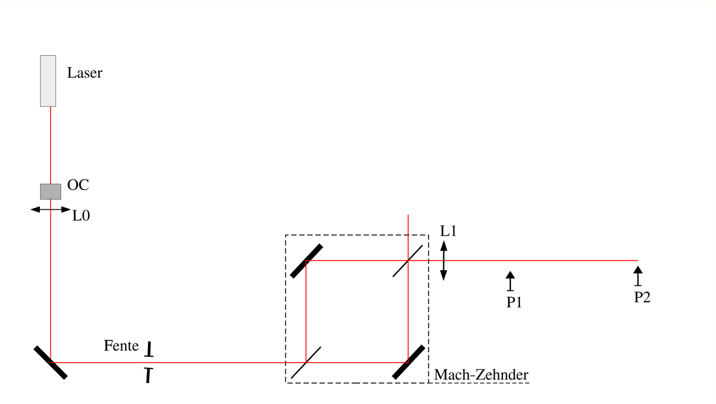
Mach-Zehnder interferometer is a two-wave interferometer composed essentially of two mirrors and two semi-reflecting blades. It has the advantage of having two outputs, it allows to benefit from the totality of the incoming light. Moreover, these arms are traversed only once, which avoids the folding of the light on itself.



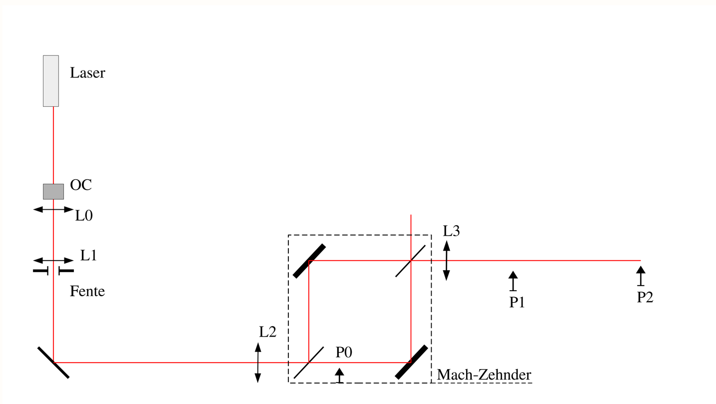


Simple Apodization 1D

Two montages used

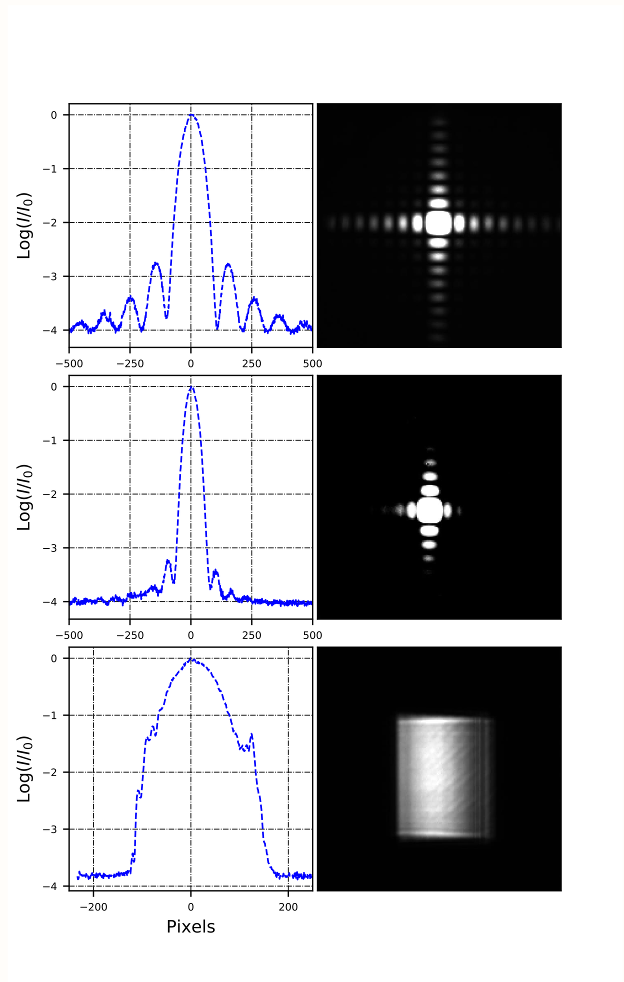


(c) Montage I

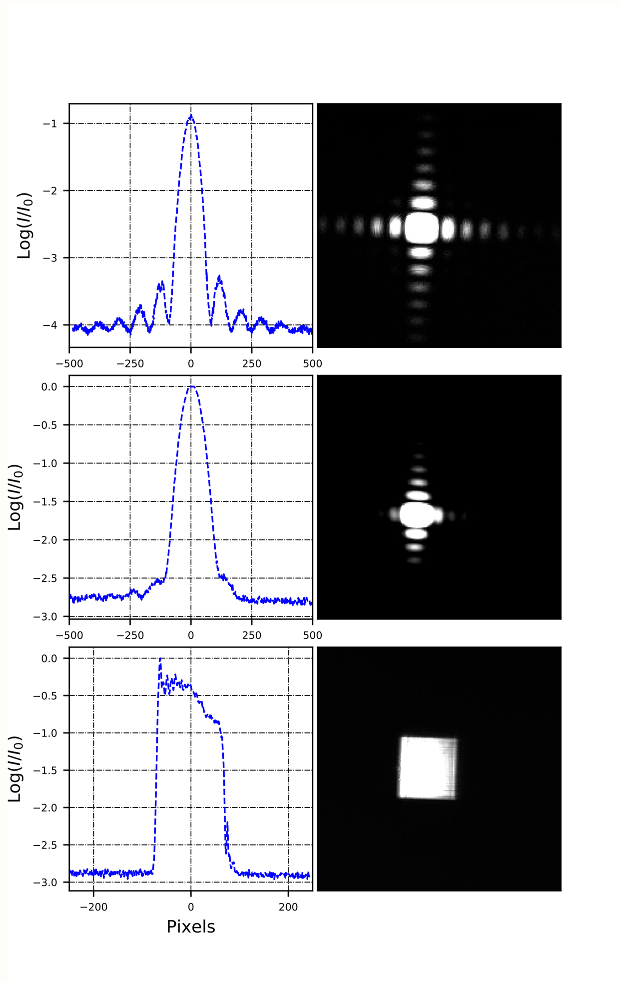


(d) Montage II

Experimental results



(e) Result of the Montage I



(f) Result of the Montage II

Apodization by homothety

Principe

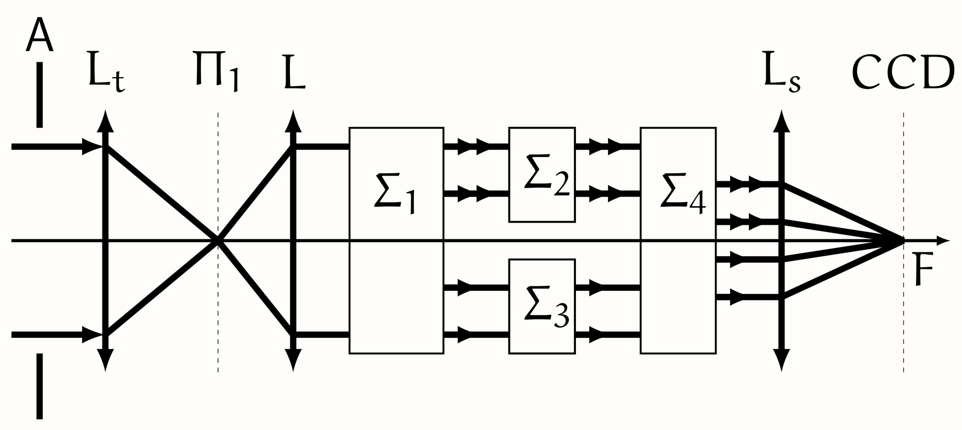


Figure 1: Principle of interferometric apodization

Optimization

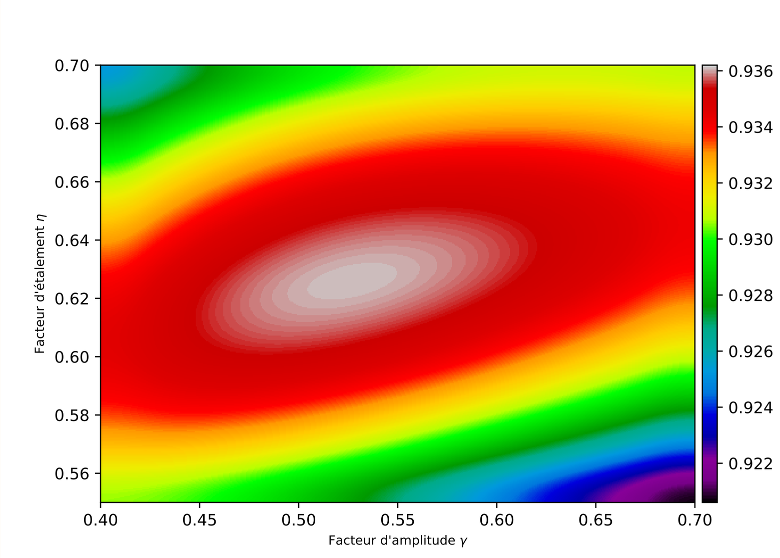
The resulting amplitude of the recombination of the beams in the focal plane of the system is written as the sum of two PSFs :

$$\Phi(u) = \Psi(u) + \gamma\Psi(\eta u) = 2\frac{J_1(\pi u)}{\pi u} + 2\gamma\frac{J_1(\pi u \eta)}{\pi u \eta} \quad (1)$$

Where γ is the ratio of the amplitudes and η of spread.

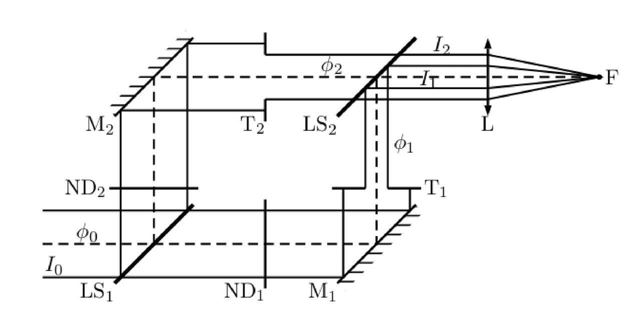
We introduce the function $epsilon(\gamma, \eta)$ which represents the percentage of the energy outside the central spot compared to the total energy in the focal plane, defined by :

$$\epsilon(\gamma, \eta) = \frac{\int_0^{u_m(\gamma,\eta)} I(u, \gamma, \eta)\, 2\pi r\, dr}{\int_0^{+\infty} I(u, \gamma, \eta)\, 2\pi r\, dr} \quad (2)$$



$\epsilon_{max} = 93,6\%$, $\gamma_{max} = 0,525$ et $\eta_{max} = 0.625$

Diffraction hole assembly



Dimensioning

The dimensioning relations are written:

$$\phi_2 = \eta\phi_1 \qquad \text{et} \qquad D_2 = TD_1 \qquad \text{avec} \qquad T = \frac{\gamma^2}{\eta^2} \quad (3)$$

Diffraction holes

Table 1: The values of ϕ_1, ϕ_2, γ, η and Transmission (T)

	$\phi_1(\mu m)$	$\phi_2(\mu m)$	η	γ	Transmission (T)
Optimum	1000	625	0.625	0.525	0.704
Standard	1000	600	0.6	0.503	0.704

Transmission

Table 2: The values of ϕ_1, ϕ_2, γ, η, Transmission (T) and ND

	$\phi_1(\mu m)$	$\phi_2(\mu m)$	η	γ	T	ND
Optimum	1000	625	0.625	0.525	0.704	
Standard	1000	600	0.6	0.498	0.69	$ND_1 = 0.2$ et $ND_2 = 0.04$

Results of simulations

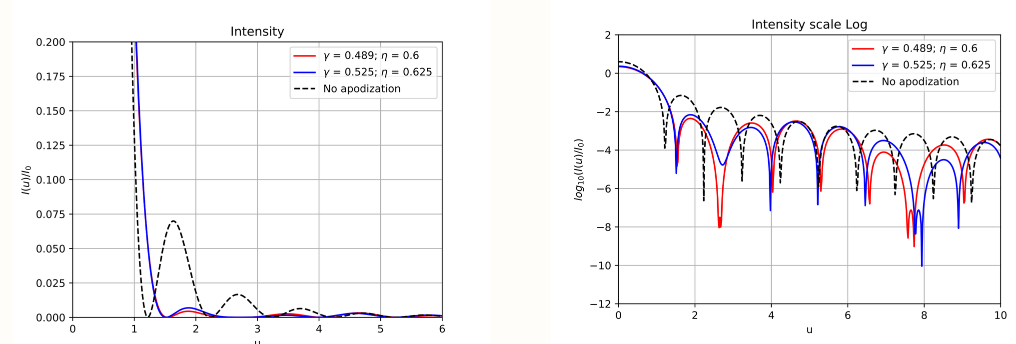
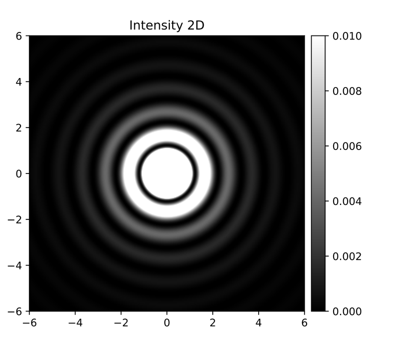
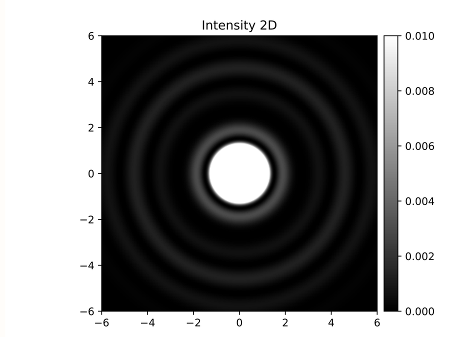


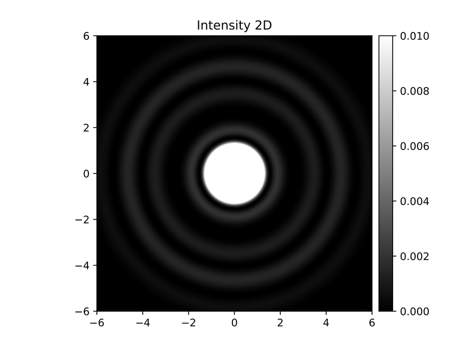
Figure 2: Left: Radial sections of the normalized PSF intensities. Right: in Log.



(a) No apodization



(b) With optimum apodization



(c) With standard apodization

Conclusion

- Realization of simple (1D) interferometric apodization using MZI.
- Optimization of apodization by homothety (simulation and dimensioning).

Reference

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[4] Habib A., Azagrouze O., El Azhari Y., Benkhaldoun Z. and Lazrek M. et al.Monthly Notices of the Royal Astronomical Society, Volume 406, Issue 4, pp. 2743-2748. 2010.

[5] Azagrouze, O. ; Habib, A. El Azhari, Y. ; Benkhaldoun, Z. Lazrek, M. Homothetic apodization of circular aperture HACA: simulation results Proceedings of the SPIE, Volume 7734, id. 77343I (2010).

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