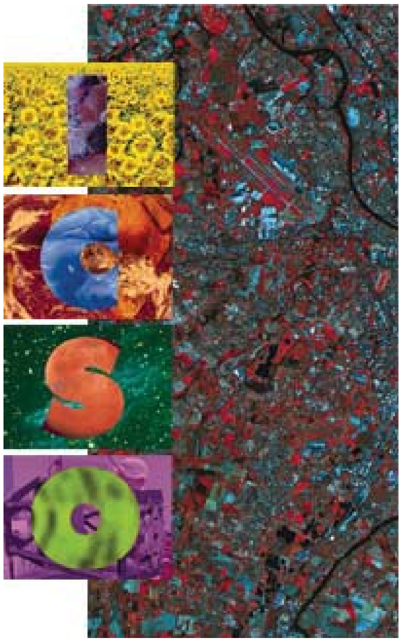
International Conference on Space Optics—ICSO 2000

Toulouse Labège, France

5–7 December 2000

Edited by George Otrio



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International Conference on Space Optics — ICSO 2000, edited by George Otrio, Proc. of SPIE Vol. 10569
105692G · © 2000 ESA and CNES · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2307866

HIGH RESOLUTION SOLAR PHYSICS BY APERTURE SYNTHESIS: THE SOLARNET PROGRAM

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ABSTRACT

We present the 3 telescopes breadboards used to demonstrate the cophasing and imaging capabilities of the Solar Imaging Interferometer (SOLARNET).

1. INTRODUCTION

Following several years of design studies of UV imaging interferometers for Solar Physics Space Missions (from SUN/SIMURIS to SOLARNET) (Ref. 1), we decided, in 1995, for demonstration purpose, to realize a complete test of the cophasing feasibility and performance directly on the Sun. Accordingly, our laboratory breadboard of a 2 telescopes cophased interferometer (on which demonstration of the cophasing method were performed from 1992 to May 1995) was moved to the "Grand Sidérostat de Foucault" at Meudon Observatory. During summer 1995, and up to March 1997, the feasibility and performances of the cophasing of two telescopes on extended objects like the Sun, the Moon and planets (Mars, Saturn, Jupiter) were demonstrated. These results really opened the possibility to use and discover from Solar Interferometers, not only in Space but also on ground. With a 1 meter baseline or so, a Space imaging interferometer will reach a permanent spatial resolution of 0.01" in the UV on a coherent field-of-view of 40", and yet 0.1" in the visible. We present progress on our current laboratory realization of a 3 telescopes cophased (fine phasing by active delay lines) and pointed (fine pointing by active mirrors) demonstration breadboard of the SOLARNET Space Interferometer. The 3 telescopes interferometric imaging breadboard has been installed at Meudon Observatory for extensive tests (on the Sun, stars and planets) since June 2000, after a successful laboratory integration and testing.

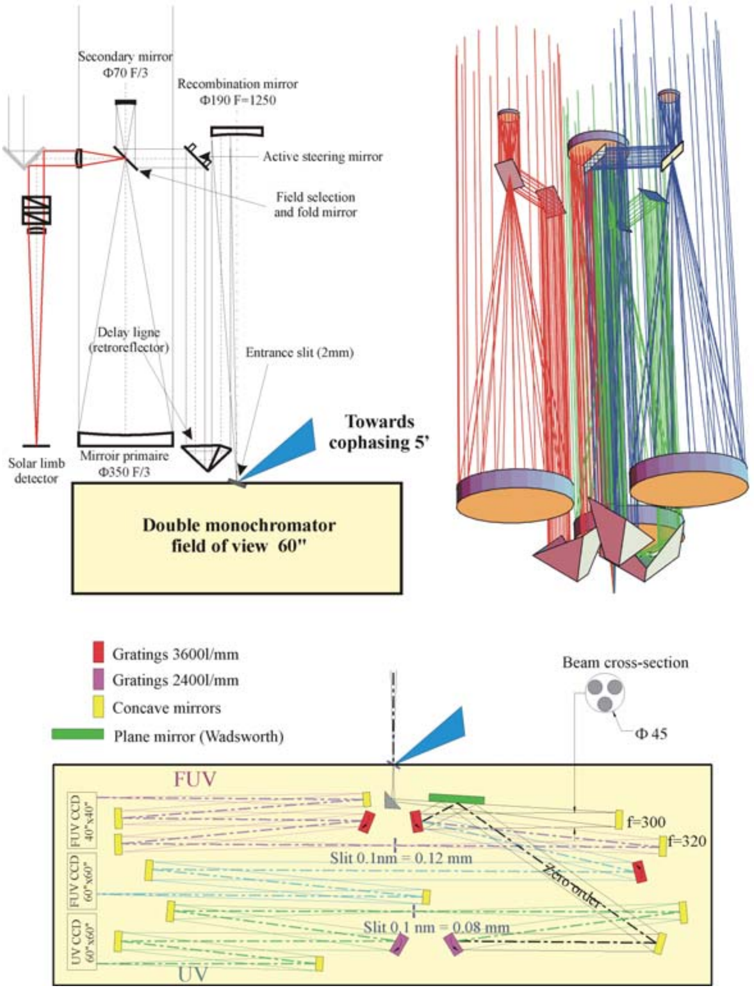


Figure 1 SOLARNET Design.

2. THE DEMONSTRATION BREADBOARD

The optical set-up used (see Figure 2) for the test and demonstration of the feasibility of Optical Synthetic Aperture (OSA) for solar and planets observation is composed of four parts:

- The white light source and the three telescopes positioned on the vertex of an equilateral triangle. There are also three active mirrors for fine pointing.
- Three delay lines (a retro-reflector and a right angle prism) for the OPD (Optical Path delay) corrections.
- The recombination of the three beams (the entrance and the exit pupils are homothetic) for the large field imaging.
- The cophasing interferometers that allow to correct the phase errors between the beams ❶ and ❷, and between the beams ❶ and ❸.

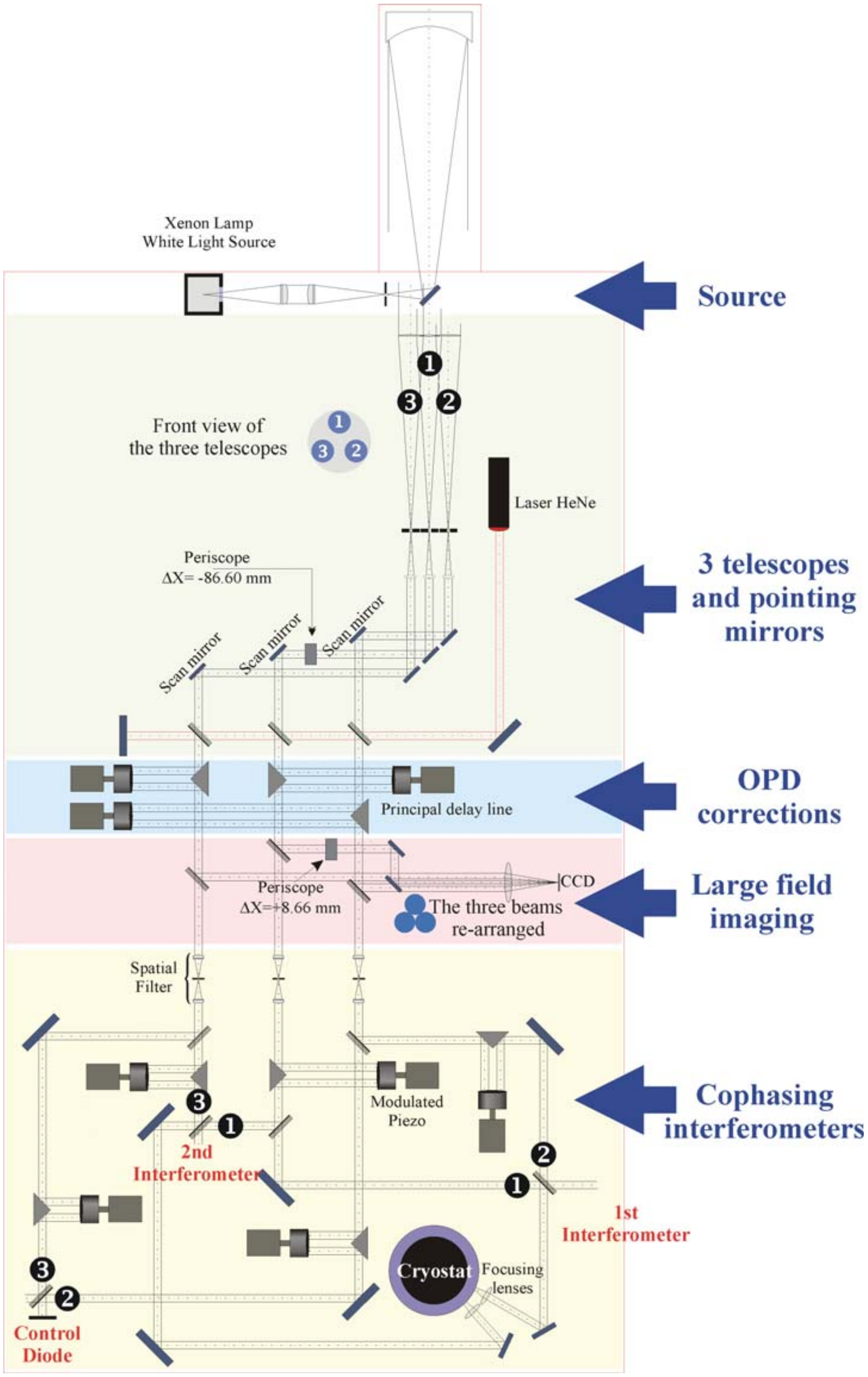
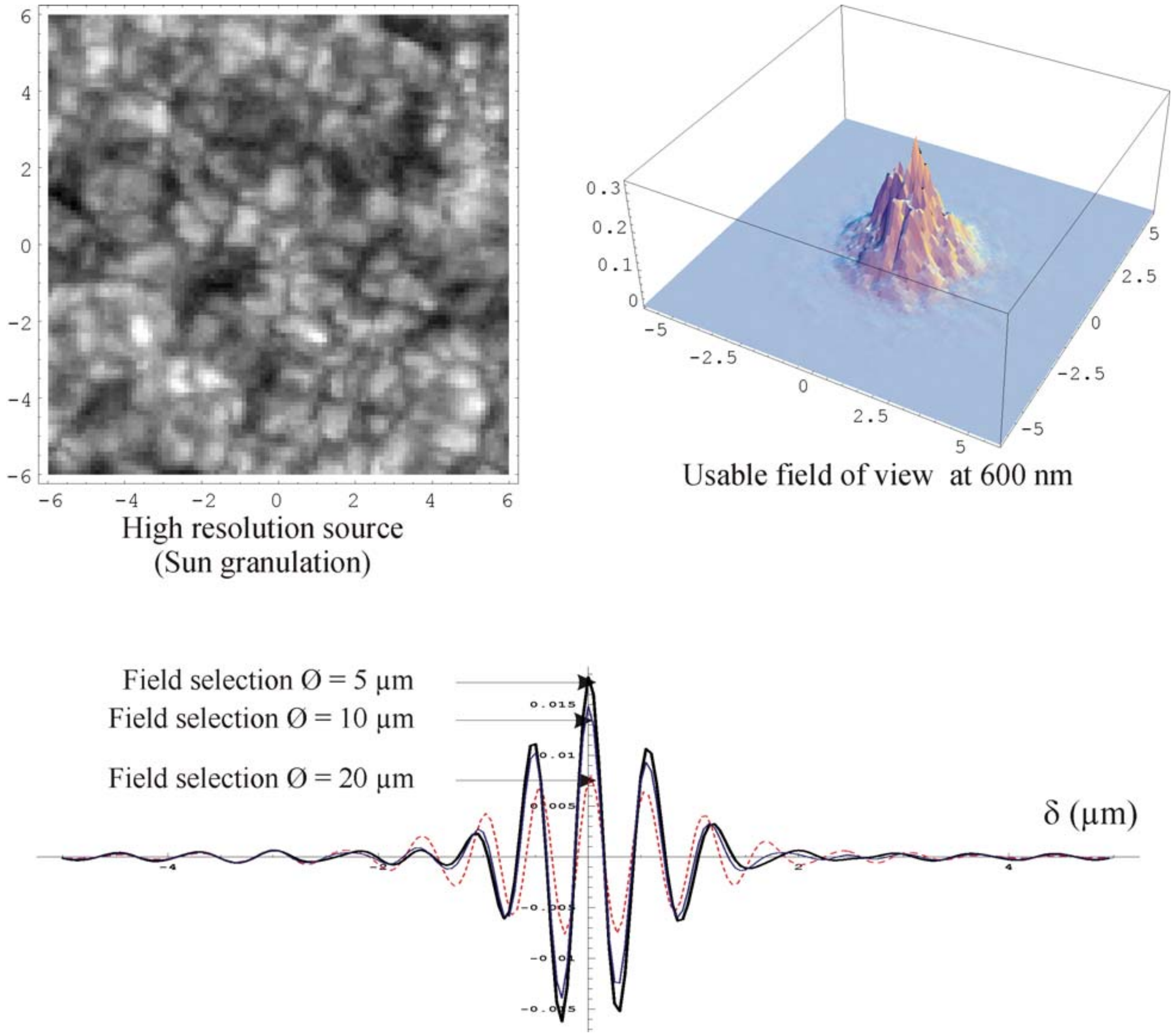


Figure 2 The 3 telescopes laboratory breadboard.

3. COHERENCE AND PHASE CONTROL

The extended light source has a large spectral bandwidth, therefore the coherence length is short and there are only a few fringes on the interferogram (see Figure 3). In the best case, the fringe pattern has the best contrast for the null OPD, so it is easy to find it. Yet, the interferences are always symmetric around the zero OPD (if the glass crossings are identical for the different beams), and we can achieve it by the study of the extrema of the different signals.



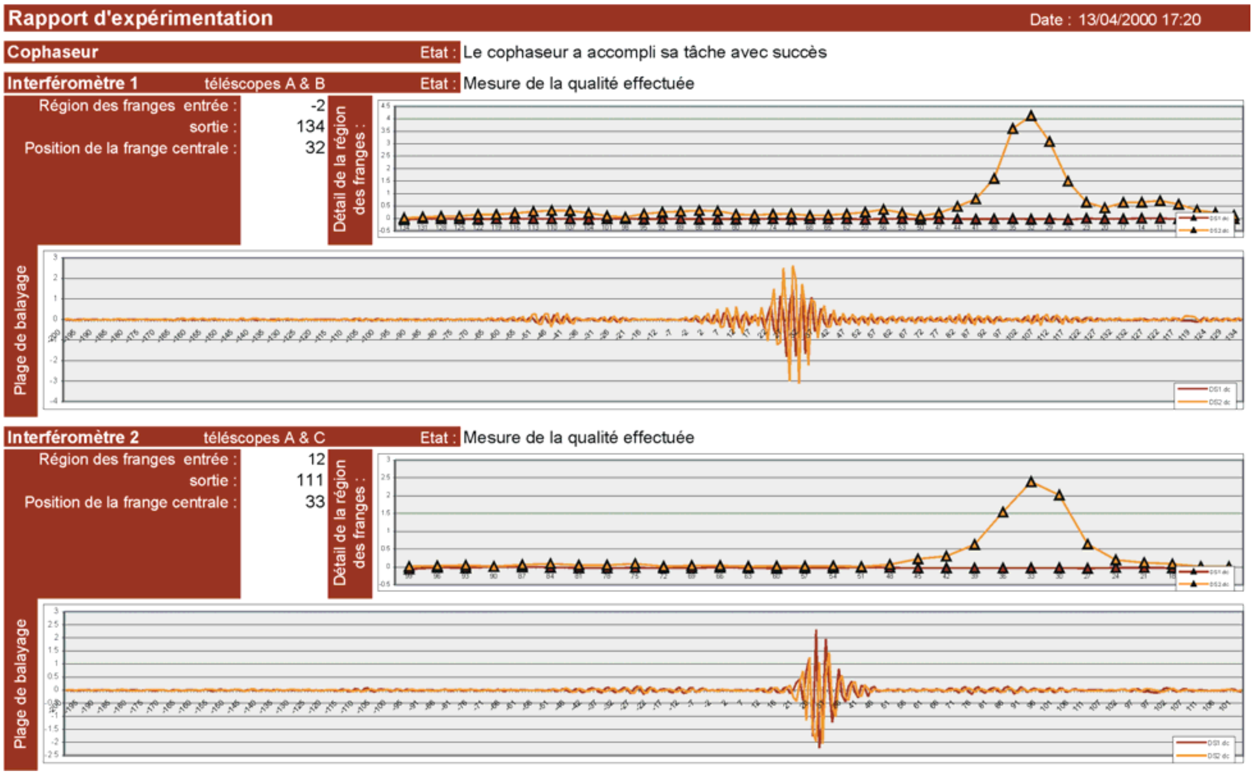
High resolution source
(Sun granulation)

Usable field of view at 600 nm

Figure 3 Fringes pattern for an high resolution white source and a spatial filter.

The interference's signal is modulated by a longitudinal oscillation of one delay line. Two lock-in amplifiers use this modulated signal to obtain, at first order, the first and second derivative of the fringes' interference. Thus, the zeros in the first derivative, that correspond to extrema in fringes signal, allow an active real-time control of the phase errors between the three telescopes. The second derivative, because of its similarity with the interferogram, permits to select the correct fringe to achieve the best image in the focal plane of the camera.

Figure 4 shows an example of the research of the central fringe: for the two interferometers that control the 3-telescope imaging interferometer we have two curves. The lower ones shows the signal issued of the synchronous detection at simple frequency (dark curve) and the synchronous detection at double frequency (ligth curve), and this during the Principal Delay Line move. The phase between these two signals is well equal to $\pi/4$ as the mathematical simulation showed it. The signals' form is not perfect, because of the average of multiple measures and the elementary move of the delay line (0.1 µm) which is not infinitely small. The upper curve shows this same signal during the search of the central fringe (null OPD) with a phase control. Then the signal of the synchronous detection at simple frequency is null while the signal of the synchronous detection at double frequency grows until the null OPD is reached.



Rapport d'expérimentation Date : 13/04/2000 17:20

Cophaseur Etat : Le cophaseur a accompli sa tâche avec succès

Interféromètre 1 téléscopes A & B Etat : Mesure de la qualité effectuée

Région des franges entrée : -2
sortie : 134
Position de la frange centrale : 32

Interféromètre 2 téléscopes A & C Etat : Mesure de la qualité effectuée

Région des franges entrée : 12
sortie : 111
Position de la frange centrale : 33

Figure 4 Control interface of the 3-telescope breadboard of SOLARNET.

4. RESULTS

Although the fringe signal was not perfect (low contrast, about 12%, due to spatial coherence), we were able to perform measures at low flux by using different density. The major results obtained are shown in Figure 5.

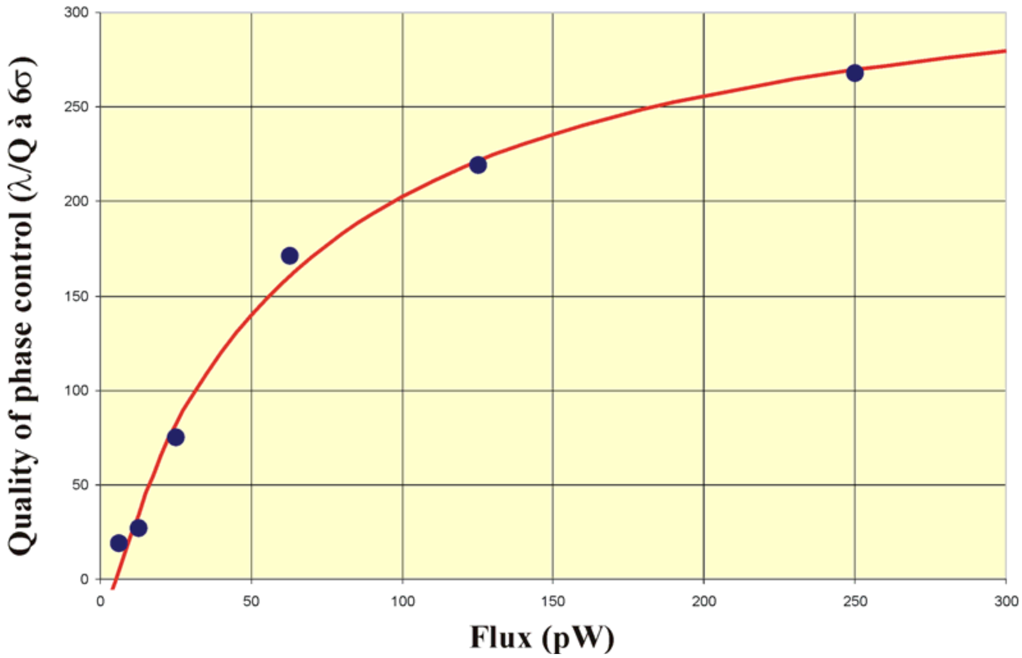


Figure 5 Stability of the phase control (at 6σ) as measured with low fluxes.

The experimental values (black dots) are coherent with the curve drawn on this figure. This curve depend of two noise source:

- Electronic noise for the very low flux measures
- The noise of the white source for the high flux measures that limits the apparent quality of the phase control, which is necessarily better.

Thus, we will be able to reach very good quality even though the optical quality of the interfering beams was not perfect (astigmatism, residue of differential glass crosse...). Furthermore, a phase quality of $\lambda/6$ is fully sufficient to allow a numerical reconstruction of the resulting pictures.

5. THE 3 TELESCOPES BREADBOARD AT MEUDON OBSERVATORY

Although the laboratory results were excellent, there were still doubts that laboratory conditions could reproduce the exact solar conditions. Therefore the experiment was moved to the "Grand Sidérostat de Foucault" at Meudon Observatory during summer 1995 and during the period from June 1996 to March 1997 (Ref. 3). The cophasing was realized, for two telescopes, on stars (Altair, Arcturus) but also on extended objects like planets (Mars, Jupiter) or the Sun, yet with much difficulty due to a lack of fine pointing. In the latest case the contrast was very low (about 4%) but we nevertheless cophased two telescopes with a stability of $\lambda/140$ (at λ_{ref}=550nm). At this point the essential demonstration was made: we observed and cophased fringes on extended objects.

During summer 2000 we reinstalled the optical set-up at Meudon Observatory, but there is now 3 telescopes (with active scan mirrors for fine pointing) instead of the 2 telescopes previous experimentation. Imaging capabilities and performances will be investigated in the next months.

Figure 6 "Grand Sidérostat de Foucault" and the 3 telescopes breadboard demonstrator at Meudon Observatory.

6. EVOLUTION OF THE SOLARNET OPTICAL SET UP

We have also studied, with the help of a CNES R & D program, the miniaturization/spatialization of the three reference interferometers with the use of optics in molecular adherence. Indeed, the actual reference interferometers take a large place (1.1 x 1.5 m^2) while the dimensions of the miniaturized block is less than 20 x 30 cm^2 (cf. Figure 7), suitable for a space mission like SOLARNET. The fabrication file of the block of interferometers is underway and we can expect to test it in 2001.

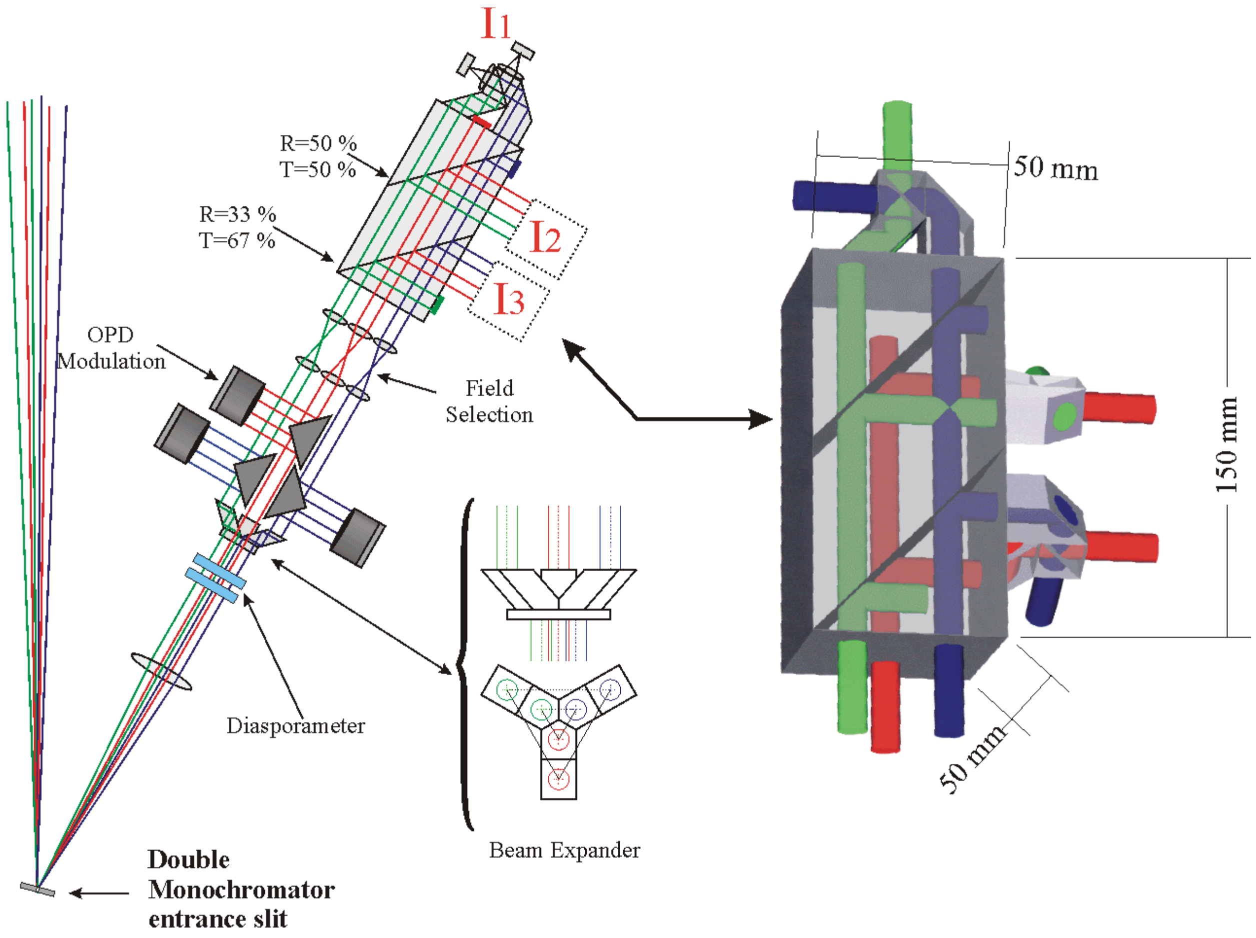


Figure 7 Miniaturization of the reference interferometers.

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