LABORATORY AND SKY DEMONSTRATIONS OF SOLAR INTERFEROMETRY POSSIBILITIES

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ABSTRACT

We present the 2 and 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 and THEMIS Multi-Aperture Cophased System (MACS). The 3 telescopes interferometric imaging breadboard will be installed at Meudon Observatory for extensive tests (on the Sun, Stars and Planets) in July 1998 after laboratory integration and testing.

2. THE DEMONSTRATION BREADBOARD

The optical set-up used (see Figures 1 & 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 .

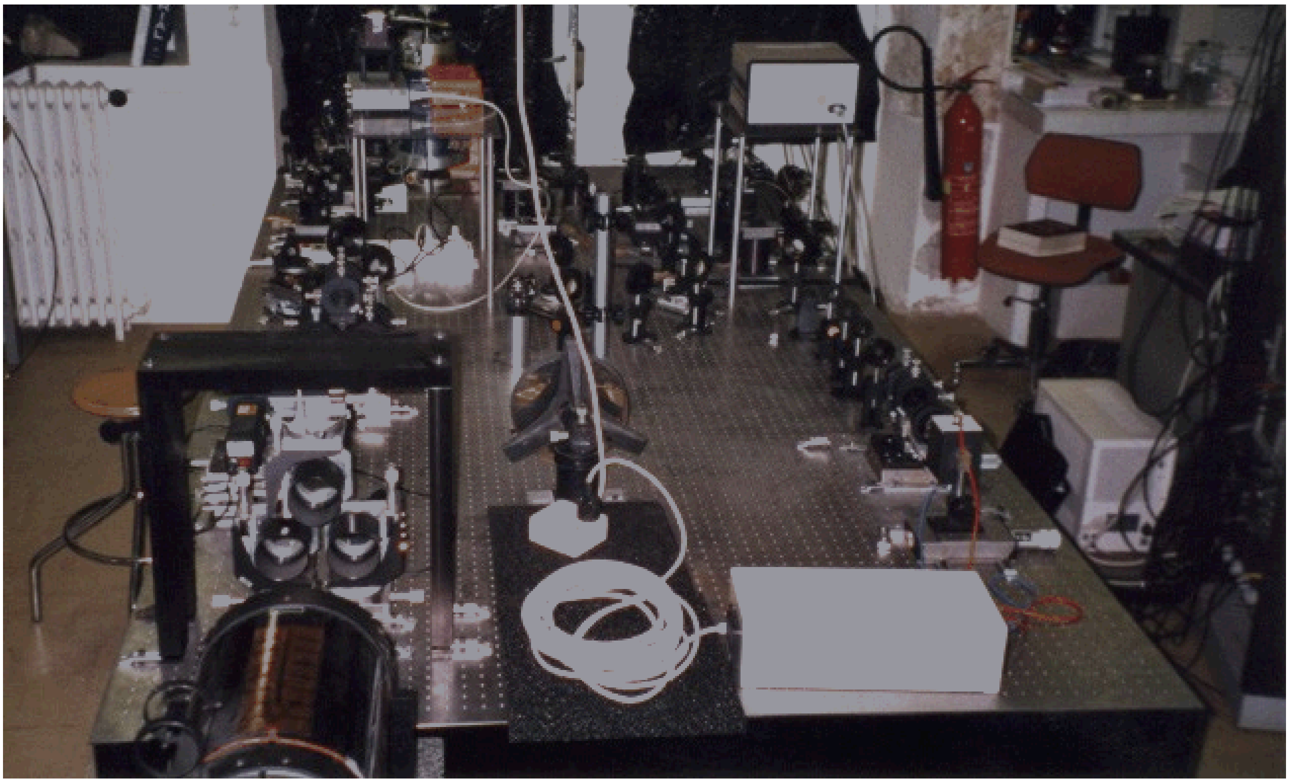

Figure 1. The 3 telescopes laboratory breadboard installed on a 3x1.5m optical bench

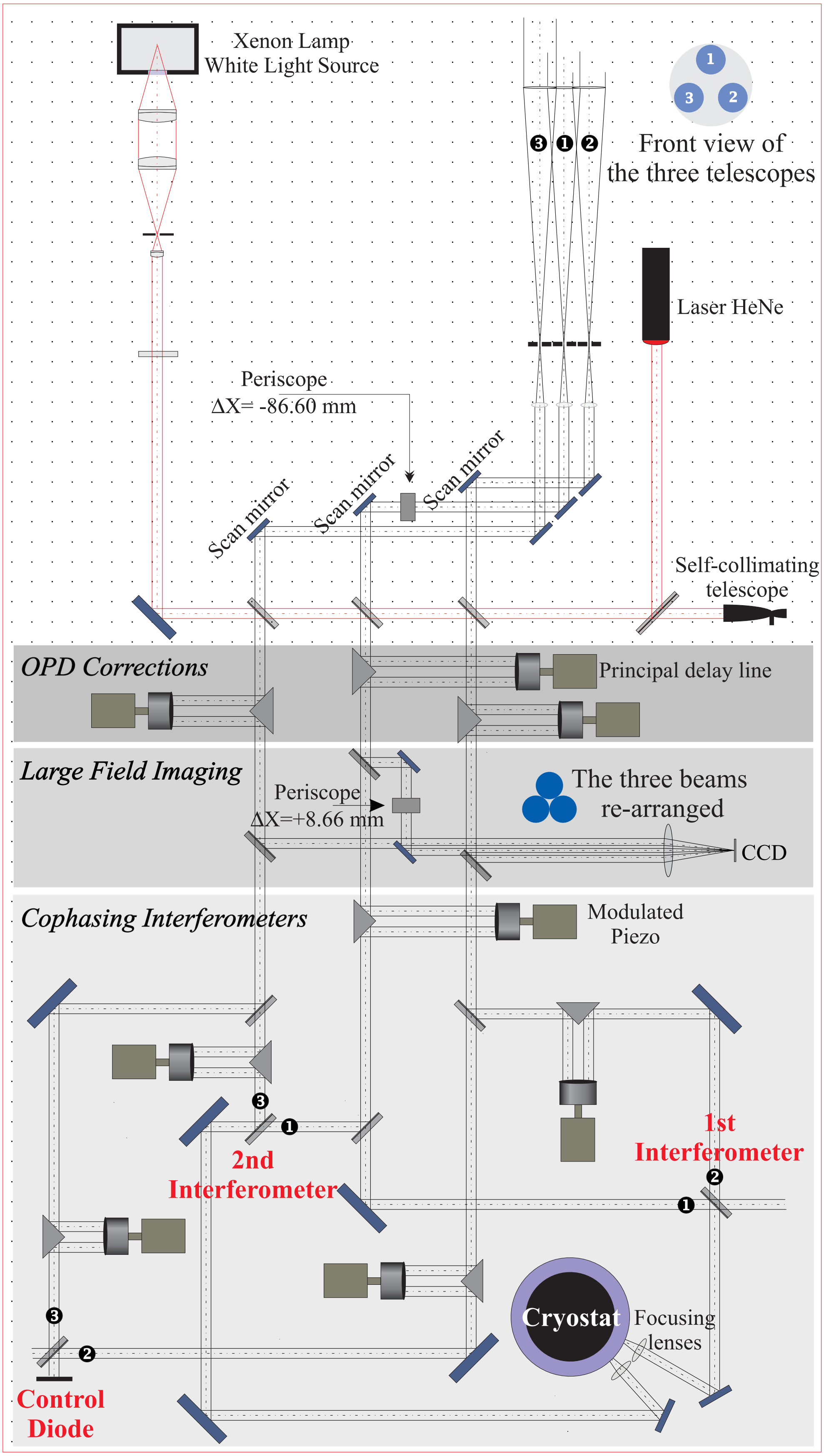

Figure 2. Demonstration breadboard of the SOLARNET Space Interferometer

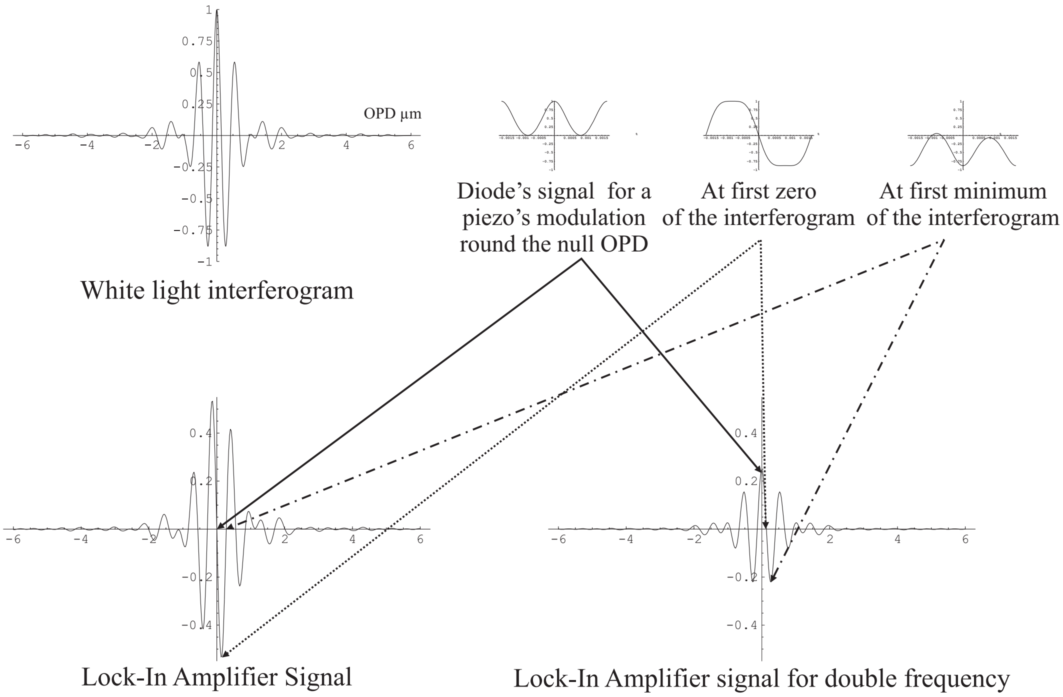

Figure 3. Fringes' signal and signals from the two lock-in amplifiers

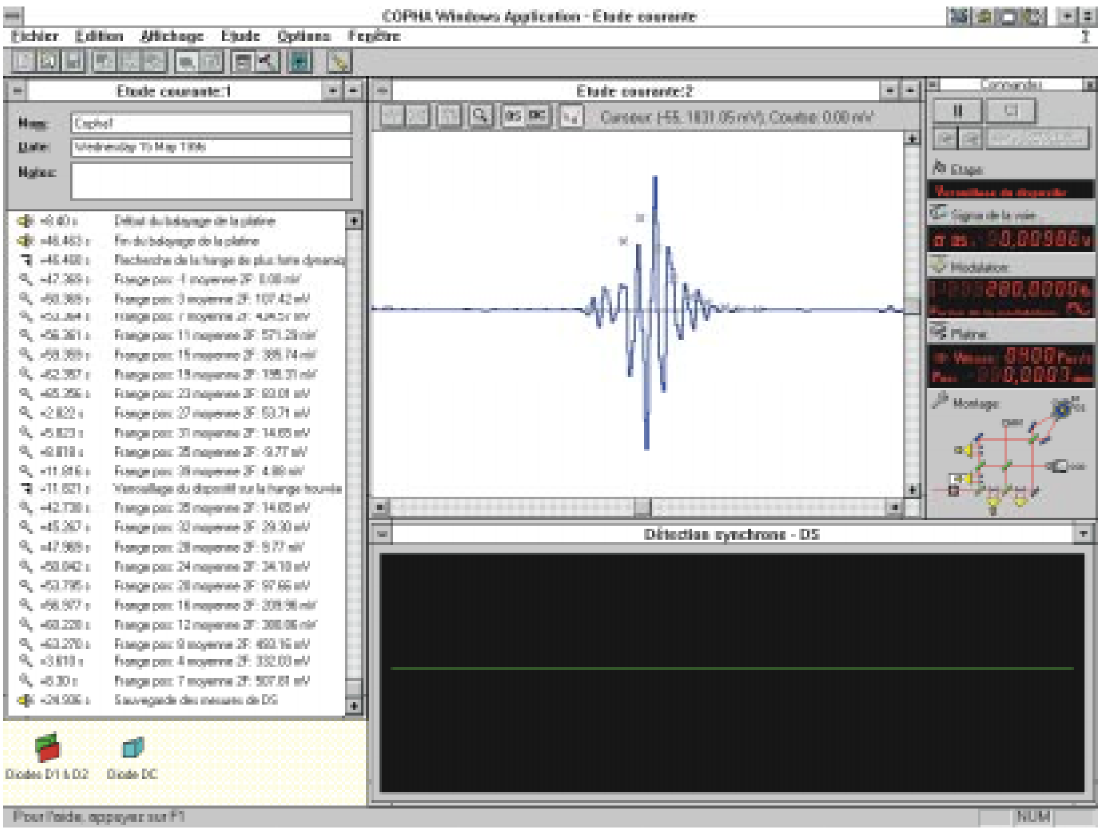

Figure 4. Synchronous detection signature of the fringes as observed during an acquisition

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.
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 (Fig. 3). 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: the acquisition curve is the Lock-in Amplifier's signal and the crosses give the value at twice the modulation frequency of the synchronous detection (2F). In this case, the active control is made when the value of 2F is the highest.

4. RESULTS

Although the fringe signal was not perfect (low contrast, about 30%, due to differential glass crosses), we were able to perform measures at low flux for an ESA study (Ref. 2). The global transmission of our optic setup was about 3 ‰ and we still cophased the system up to a magnitude of 7, assuming a 1m equivalent monolithic telescope. The major results obtained are shown in Table 1.
VppSD gives the correspondence between a value in mV and an OPD in λ. It is obtained by the measurement of the maximum minus the minimum of the synchronous detection that corresponds to the distance between two consecutive zeros in the interferogram. Future improvements of the set-up (correction of the glasses' dispersion and reduction of the electronic noise) will allow us to reach even better contrasts and better stability values.

Optical density	Flux (nW)	Visual Magnitude	Vpp SD (V)	σ fluctuations (mV)	Stability λ/ (pp@6σ)
None	0.48	2.2	2.6	1.2	361
0.3	0.24	3.0	3.4	2.6	207
0.6	0.12	3.7	3.4	3.8	149
1.0	0.048	4.8	1.3	6.6	50.5
1.3	0.024	5.5	3.5	38.5	15.2
1.6	0.012	6.3	1.6	26.1	10.2
2.0	0.005	7.3	0.8	23.1	5.8

Table 1. Stability of the phase control (at 6σ) as measured with fluxes from 0.48 to 0.005nW

5. THE 2 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 1998 we will reinstall the optical set-up at Meudon Observatory, but there will be 3 telescopes (with active scan mirrors for fine pointing) instead of the 2 telescopes previous experimentation. Imaging capabilities and performances will be investigated.

Figure 5. The tesbed of SOLARNET at the "Grand SidÈrostat de Foucault" at Meudon Observatory

6. REFERENCES

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