The Navy Precision Optical Interferometer for SSA applications: an update

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ABSTRACT

The Navy Precision Optical Interferometer (NPOI) has been at the forefront of developing Interferometric tools for both Space Situational Awareness and astrophysical imaging. In 2009 we were the first group to attain fringes on a GEO satellite. Since then we have developed more sophisticated modelling tools and at the same time we have started to commission more and more stations. NPOI is now a 12 telescopes array with two more stations coming on line by the end of the year. We are commissioning both shorter and longer baselines, and new beam recombination systems. In this paper we present an update of these efforts and our future prospects for the NPOI.

1. INTRODUCTION

The necessity of being able to collect spatially resolved images of GEO satellites implies the use of very large telescopes. At visible wavelengths a telescope of 40-50 meters in diameter would be required. While the astronomical community is planning and envisioning such large telescopes, see the Thirty Meter Telescope (TMT) program for example, the cost and time to bring to fruition render such an approach quite difficult for Space Situational Awareness (SSA) applications. Another solution is to employ Long Baseline Interferometry (LBI). Interferometry at radio wavelengths is not only a routine technique but is virtually the most commonly used technique to obtain high angular resolution images of astronomical objects. At visible wavelengths in the past decade several instruments have demonstrated not only the capability of phasing widely separated telescopes but also that their routine use is indeed possible and effective. Currently three optical interferometers are operating on a routine basis, the Georgia State Center for High Angular Resolution Astronomy (CHARA) located on Mt. Wilson CA, the Navy Precision Optical Interferometer (NPOI) located in Flagstaff AZ and finally the European Southern Observatory Very Large Telescope Interferometer (VLTI) located in Chile. These instruments have their differences in terms of range off wavelengths covered, baselines, number of elements etc. In what follows we describe the NPOI and its use for SSA and most of all the improvements and commissioning of new stations in the last two years. For a basic description of the NPOI layout and "classic" beam recombination scheme Armstrong [1] will be the basic reference, for basic long baseline interferometry see Monnier [2].

2. NEW STATIONS AND BASELINES

The basic design of the NPOI consists of a Y shaped array with 6 siderostats, as shown in Fig.1. The siderostat are 50 cm in diameter and the beam is sent to a tip-tilt mirror that sends the beam in the vacuum system. The final beam is 12 cm in diameter and this is the limiting factor for the current sensitivity of the system, roughly at m_V~6. However, the array was built with 30 stations that can be populated with further siderostats. In order to increase the *u,v,* coverage of the array in the past two years we have commissioned 8 new stations bringing the total available stations to 14. The furthermost stations on the West and East arms respectively, form also the longest baseline for an optical interferometer in the world at 432 meters. The current status of the NPOI is shown in Fig. 2 where the green circles indicate the stations as of 2012 and the yellow circles indicate the new stations. The solid yellow circles are stations that have been already commissioned and used, while the lighter yellow circles indicate the two stations in the process of being commissioned. In 2009 we were the first optical baseline interferometer to phase and record a fringe on GEO satellite, Hindsley [3]. However during those observation our shortest baseline, where the fringes were recorded, was of 19 meters. The necessity of having shorter baselines was at the basis of the new stations commissioning. The shortest baseline now will be of 14 meter. Also with the new back-ends we will be able to both perform a baseline bootstrapping technique and coherent integration. The bootstrapping technique is absolutely essential for tracking on complex object with very low visibilities in the longer baseline, like GEO satellites, this is because the signal is too weak there for direct phasing, thus it is necessary to lock and phase the array on shorter baselines, where the signal is stronger, and then integrate on the longer baselines, where the signal is much weaker.

Figure 1: Aerial view of the NPOI

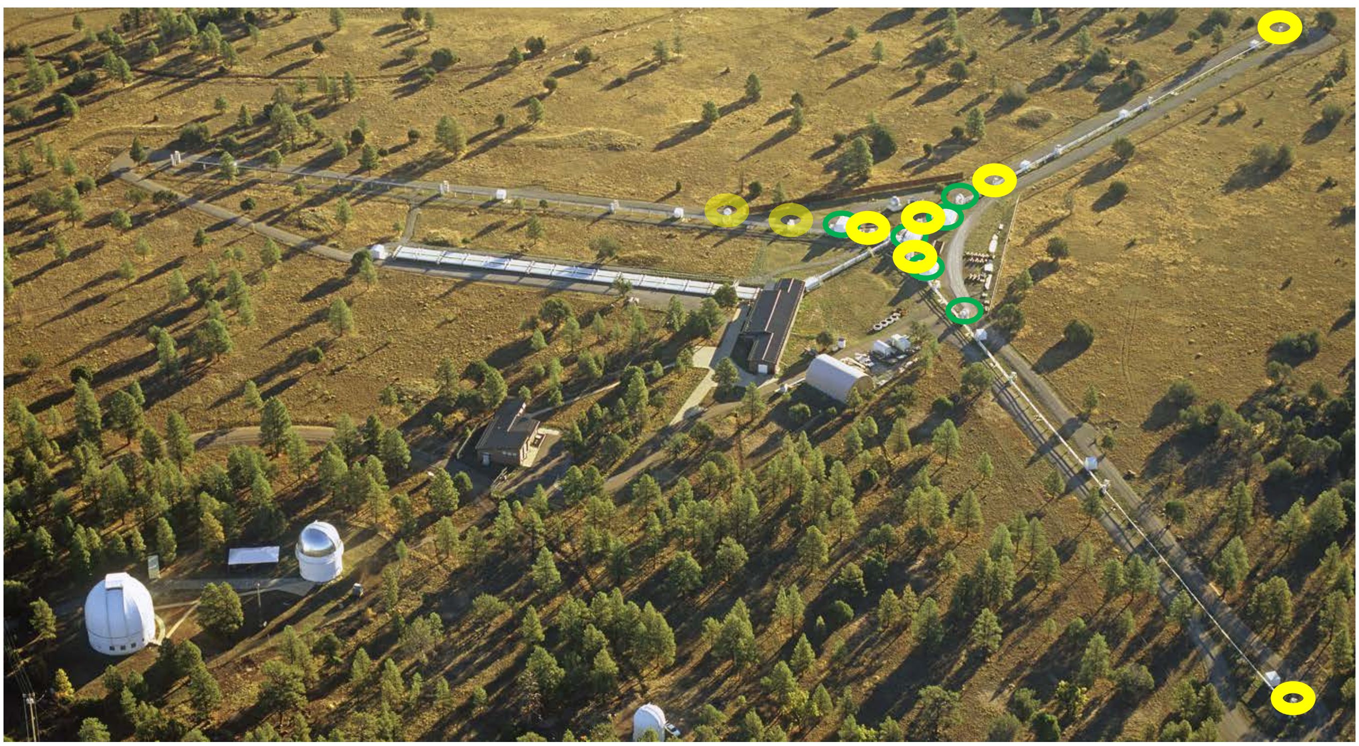

Figure 2: The new stations at NPOI. The green circles indicate the existing stations and the solid yellow the new, already commissioned stations. The light yellow circles indicate the two stations in the process of being commissioned.

This technique is called baseline bootstrapping and the NPOI array was designed specifically to implement such technique. The technique is illustrated in Fig. 3, where the fringes on the longest baseline, the red line, are obtained by the phasing of the shorter baselines, the green lines. The correspondent signal is shown in the right end side of the figure.

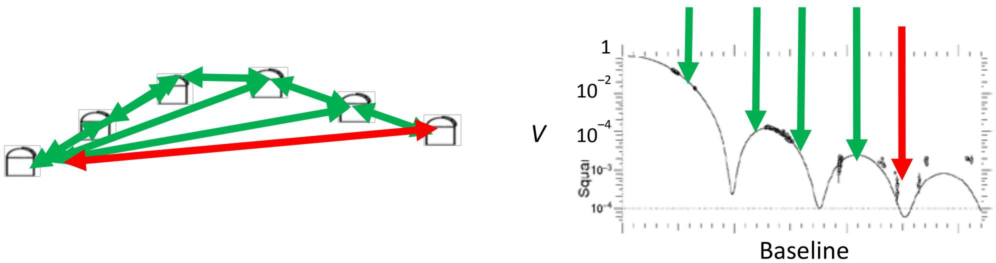

Figure 3: Notional diagram for the baseline bootstrapping approach.

Lastly, we also mention that our current program, jointly with our partners at USNO and Lowell Observatory, for the installation of 1.8 m telescopes is on track and will start in FY15. This will greatly increase the sensitivity of the array.

3. COHERENT INTEGRATION AND NEW BACK-END

In order to keep the random phase fluctuations of the Earth's atmosphere small, the integration time of each fringe packet at the NPOI is set at 2 msec. This rapid sequence generates data that intrinsically has a low Signal-to-Noise-Ratio (SNR). In order to increase the SNR one needs to add many frames together. However, it has been demonstrated that since all these frames have residual random phase errors, after adding a certain number of frames one reaches a point where adding more frames does not improve the SNR. In order to overcome this limitation we have developed and use the technique of coherent integration, Anders [4]. In this technique a model of the fringes and the instrumental errors is used to model-fit the observations and remove as much as possible the residual phase errors. After this model fitting the individual frames are co-added producing a much higher SNR because less random phase fluctuations are introduced in the average. The difference between incoherent integration and coherent integration can be seen in Fig. 4.

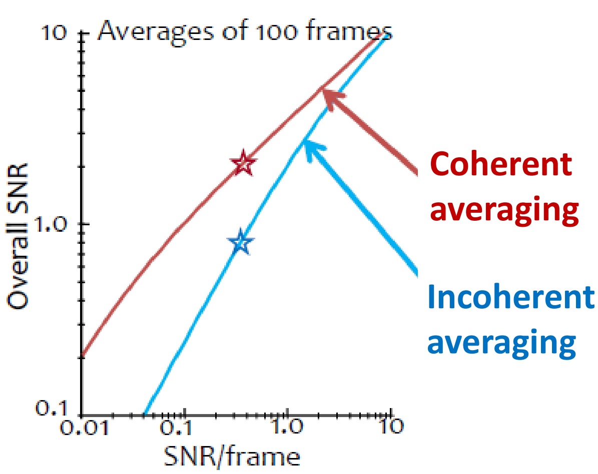

Figure 4: Difference in SNR between coherent and incoherent integration.

4. CONCLUSIONS

We have reported in this paper the ongoing expansion and modernization of the NPOI with some of these aspects directly linked to addressing SSA problems for GEO satellites. Our current and future plans make the NPOI a unique instrument with unique capabilities to explore long baseline optical interferometry for SSA related applications. Furthermore, the long-term investment of the US Navy in this facility, and the support of its scientific staff makes the NPOI a national asset with few rivals in terms of capabilities and infrastructures. Our future plans, besides the continuing commissioning of stations, back-ends etc., involves a new series of observing campaigns, starting this coming middle of October, during the glinting season. We expect to be able to observe glints on multiple baselines and this will allow us to constrain better our models. It will also enable the field test of several of techniques that we have discussed here, specifically on GEO satellites that represent a particularly formidable problem from the imaging point of view.

5. REFERENCES

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[2] Monnier J., *Rep. Prog. Phys.* **66** 789-857 (2003)
[3] Hindsley R., et al., *App. Opt.,* **50(17)** 2692-2698 (2011)
[4] Anders J., et al., *A.J.,* **134** 1544-1550 (2007)