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Simulations and Preliminary Experimental Investigation of the Received Field and Back-reflection from an On-axis Telescope

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Abstract. SGO will use a reflecting telescope to transmit and receive light between spacecraft. One design involves axially aligned secondary and primary mirrors in a Cassegrain configuration. There are several concerns for this type of telescope. One possible issue is that some of the light reflected from the secondary will travel back to the optical bench and can introduce phase noise into the LISA measurement signal. Other issues have to do with the intensity distribution and wavefront of the field received from the far spacecraft. Shadows from secondary support structure will create an irregular distribution in this field. This distribution will have an effect on wavefront sensing as well as the efficiency of the optical train and therefore must be studied.

SGO will use a reflecting telescope to exchange laser fields between spacecraft. The initial LISA telescope design used two axially aligned mirrors (Cassegrain) to expand and collimate the beams (McNamara 1998). In this configuration some of the light incident on the secondary will be back-reflected to the optical bench and this light can introduce phase noise to the science interferometer. Additionally, the secondary supporting structure will cast a shadow in the intensity distribution from the far spacecraft. The shape of this distribution will have an impact on wavefront sensing, the back-reflection induced phase noise, and the efficiency of the optical train.

Quadrant photodetectors (QPD) will be used as differential wavefront sensors to measure angular misalignments between the wavefronts of the local oscillator and the field received from the far spacecraft. The angular alignment requirements depend on the slope of the captured wavefront which in turn depends on the wavefront quality and point ahead angle. LISA used requirements of 8 nrad/rtHz and rms misalignments of the same magnitude (Maghami et al. 2005). The QPDs compare the received wavefront with a wavefront of a local reference field. While the local field is well approximated by a Gaussian distribution, the wavefront and intensity distribution of the received field is corrupted by the support structure of the secondary. Our goal is to study how the beam distortions affect the length and alignment sensing system of LISA.

We started modeling the visibility of the beat signal between these different field distributions; the visibility determines the amplitude of the signal which directly competes with shot noise. The received field was simulated with an FFT light propagation script described in Yamamoto et al. (2006). The simulation starts with a 40 cm diameter top hat intensity distribution expressed on a grid. A cross hair shadow from the four supporting struts and secondary mount is then removed. This distribution is then propagated with the FFT script over the 60 cm length of the telescope. Next the distribution is multiplied by a wavefront curvature term to simulate reflection from the curved primary mirror. The distribution is then propagated over the length of the telescope again and expressed on a smaller grid, due to the beams convergence, at the location of the secondary mirror. Another wavefront curvature term is multiplied by the distribution to simulate reflection from the secondary. At this point the distribution is collimated if the wavefront curvature terms at the primary and secondary mirrors are correctly tuned. It is then propagated 1 m to complete the simulation. The result can be seen on the left in figure 1. Despite the obvious deviations from a Gaussian, the simulated distribution has a spatial overlap of 0.85 with the 2.1 mm radius gaussian beam that would be used as the local oscillator.

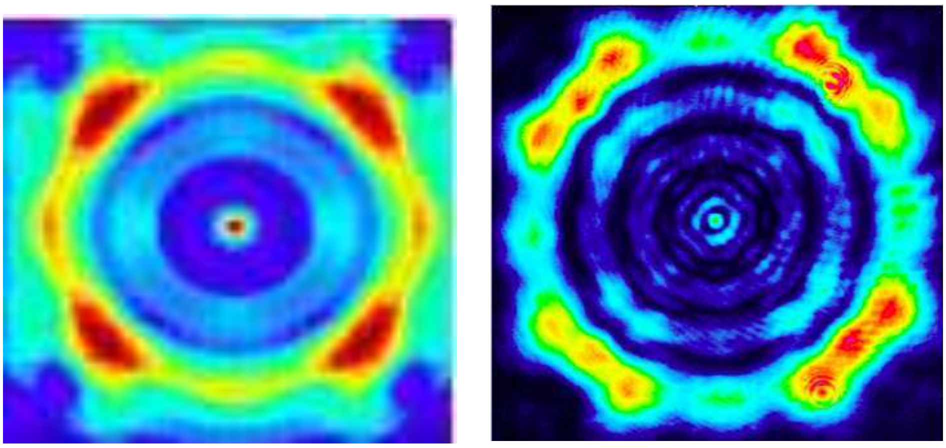

Figure 1. Left: Simulated far field distribution at the science interferometer. Right: Experimental result of trying to recreate the simulated distribution.

We also set up a laser and a cross hair representing the struts of the secondary support structure to generate a similar beam profile. This profile is shown in figure 1. The four-fold symmetry is clearly visible although the generated field shows more structure or higher spatial frequencies than the simulated field. Nevertheless, the measured visibility of a beat signal between this mode and a Gaussian reference field was around 80%, similar to the predicted value. Additional spatial frequency filters may further improve the generated field and increase the similarity with the field expected in LISA.

We also simulated ways to reduce the back reflection from the center of the secondary by either drilling a hole in it of by covering it with a non-reflective coating. It is well known that a circular symmetric hole will create an on axis beam due to the high coherence of the light scattered back from the edge. We tested various shapes to reduce the spatial coherence (Spector & Mueller 2012) and are now in the process of studying this experimentally. Future work will also include simulations and experimental measurements of the impact of the shadow from the secondary support structure on the alignment sensing system.

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