Multiple-baseline detection of a geostationary satellite with the Navy Precision Optical Interferometer

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ABSTRACT

Using the Navy Precision Optical Interferometer (NPOI), we have made the first multiple-baseline interferometric detection of a glinting geostationary satellite. The observations, carried out during the March 2015 glint season, succeeded in detecting the satellite DirecTV-7S with an interferometer baseline with 8.8 m of length, observing at wavelengths from 850 nm to 700 nm, which corresponds to a resolution of 0.02 arcsec, or 4 m at geostationary altitude. We have also achieve brief simultaneous detection of fringes with a baseline with 9.8 m of length.

Keywords: geostationary satellites, optical interferometry, imaging, telescope arrays

1. INTRODUCTION

Resolving the structure of geosats from the ground is a Space Situational Awareness tool that is currently not available. Given their sizes and distances, these satellites cannot be resolved using single telescopes, and require the use of other techniques, such as optical interferometry. Our group has successfully detected single baseline interferometric fringes from the glinting geosat DTV9S using a single baseline in 2009,[4] which allowed us to determine the sizes and relative fluxes of two glinting structures.

Based on the success of this experiment, undertaken at the NPOI,[1,2] we devised a new experiment to observe glinting geosats with multiple baselines. The simultaneous observation of a target with three or more baselines allows us to obtain closure phases. These closure phases are a key piece of information that can be used to better determine the relative location of the glinting structures and the structure of these satellites.

2. NPOI IMPROVEMENTS AND OBSERVATIONS

In order to achieve the goal of observing a glinting geosat with multiple baselines we commissioned three new stations at the NPOI.[2,6] In Fig. 1 we show the inner array layout, where one can see the astrometric stations and the newly commissioned stations (W04, E03 and N03). We chose to commission these stations because they are located in the inner part of the array and can be combined with the current astrometric stations to create short baselines. The shortest baseline currently available, between stations W04 and AC, has a length of 8.8 m.

A lesson learned from our previous detection of fringes on a glinting geosat[4] is the need for short baselines. A target with a dimension of 2 m at an altitude of 37,000 km has an angular size of 11 mas. A target with this dimension is resolved (i.e. the fringe visibility drops to zero) at 550 nm on a 12.6 m baseline. Since one needs to detect the interference fringes on a few ms time scale in order to track and correct atmospheric changes, the availability of short baselines is essential for the success of this project.

Our observations of DTV7S (NORAD ID 28238) were done with the NPOI on the nights of 2015-03-05 and 2015-03-06. This satellite is at longitude 119°W, which puts it at $\sim$ 7°W of the local meridian. Based on astrometric observations obtained with the USNO Flagstaff Station 40” telescope we determined a drift rate of 0.02” s^{-1} in elevation and 0.126” s^{-1} in azimuth. These observations were used to determine the satellite position with a precision better than 1 arcsec, which is essential for the accurate positioning of the delay lines and the detection of the interferometric fringes while the satellite is glinting. The NPOI observations were done

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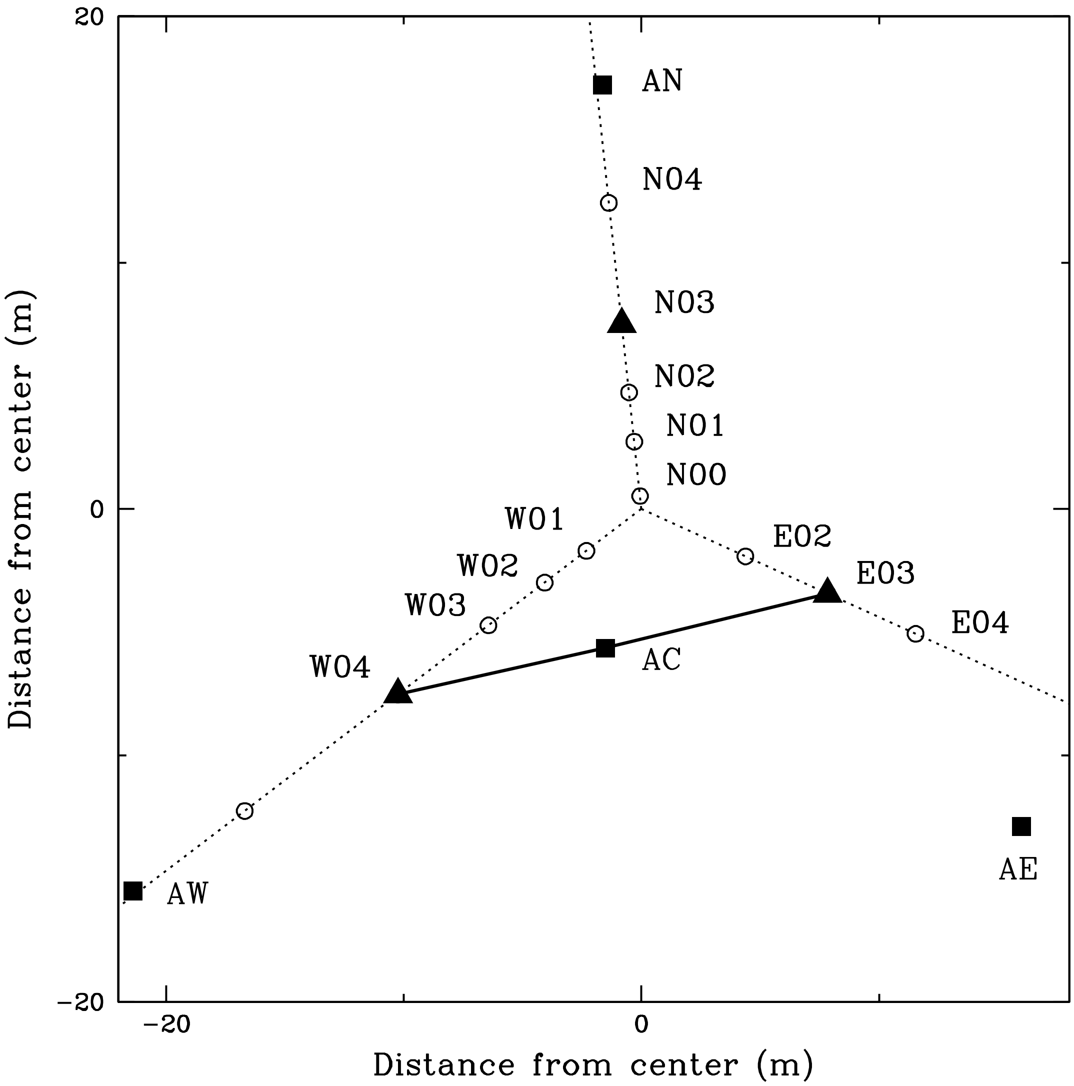

Figure 1. Layout of the inner stations of the NPOI. The black squares show the astrometric stations AW, AC, AE and AN. The black triangles show the new stations, W04, E03 and N03, commissioned for the observation of geosat glints. The black lines show the baselines W04-AC and AC-E03, used to observe DTV7S.

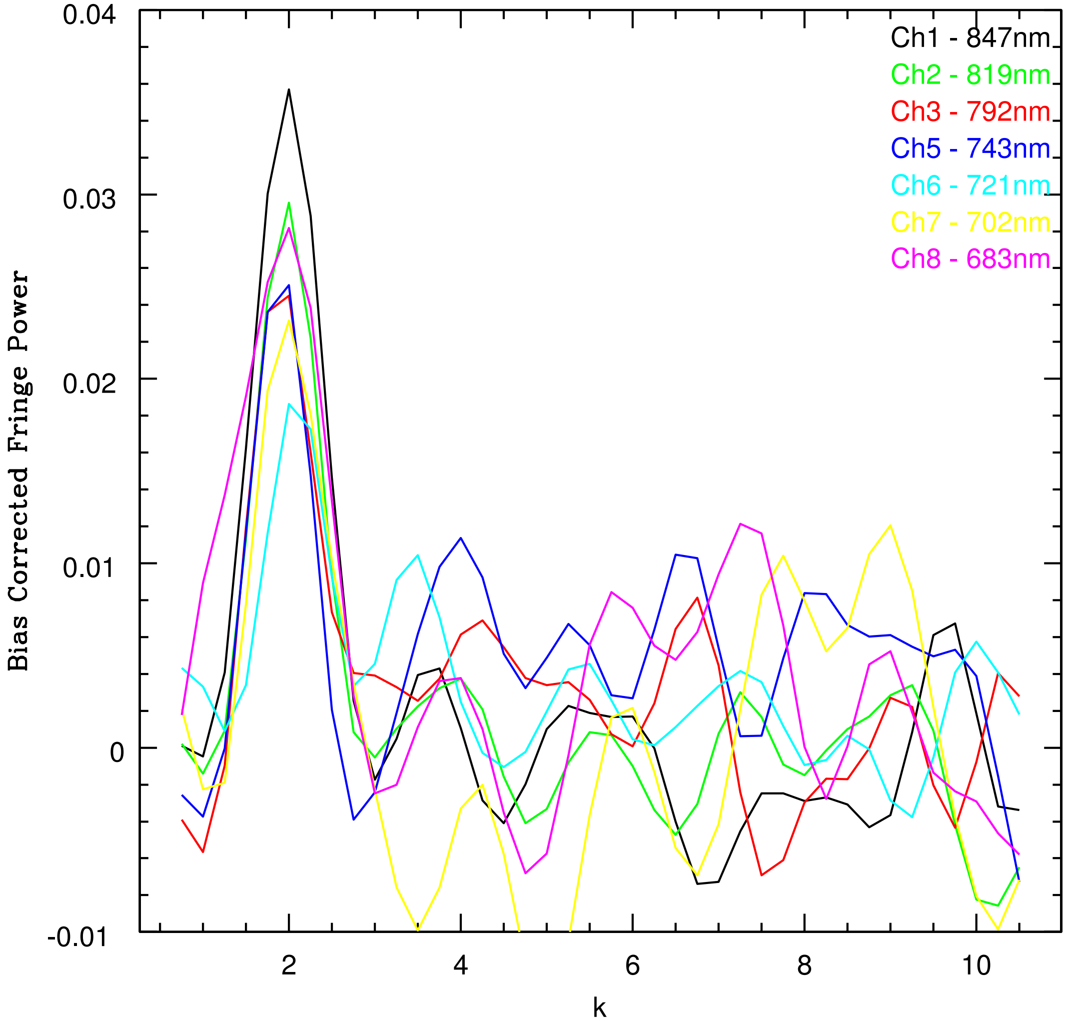

Figure 2. Bias corrected power spectrum of the DTV7S observations recorded in Spectrograph 2, which recorded only the baseline W04-AC. Each line correspods to a different channel, as indicated by the legend on the top right. We show only channels for which there is enough signal. Baseline W04-AC has fringe frequency $k = 2$.

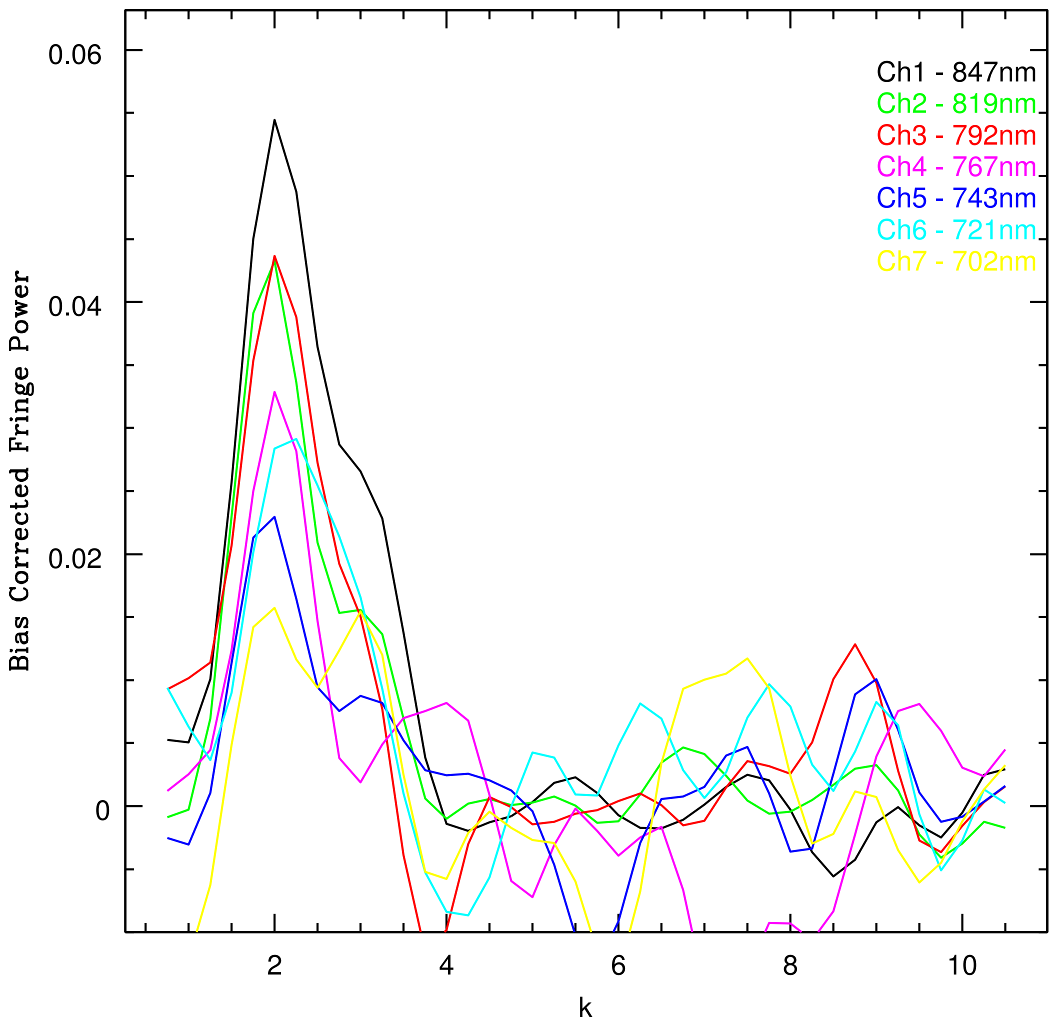

Figure 3. Same as Fig. 2 for Spectrograph 2. Baselines W04-E03, W04-AC and AC-E03 have fringe frequencies $k = 1$, 2 and 3, respectively.

using stations W04, AC, E03 and N03, but no fringes were detected on a baseline involving station N03. The maximum baseline lengths projected toward the target achievable with station W04, AC and E03 is 8.8 m for W04-AC, 9.8 m for AC-E03 and 18.6 m for W04-E03. The observations were done using the NPOI classic beam combiner,[2] which simultaneously records 16 spectral channels in the wavelength range 550-850 nm, in two different spectrographs. The configuration of stations and delay lines selected for these observations allowed us to record the baselines W04-AC alone in spectrograph 2, while spectrograph 1 recorded all the baselines. In order to be able to detect and separate the interference fringes from the different baselines, triangle wave modulations are imposed on the different delay lines. Our choice of modulation amplitudes resulted in fringe frequencies $k = 1$, 2 and 3 fringes per modulation period for the baselines W04-E03, W04-AC and AC-E03, respectively.

3. RESULTS

The NPOI observations of DTV7S allowed us to determine the magnitude and colors of this satellite during glint. Comparing the spectrum of the satellite to that of the G9 giant star ζ Hyadrae ($V = 3.1$ mag, $I = 1.9$ mag), we calculated that DTV7S had $I = 2.6$ mag and $V = 4.5$ mag during the period when fringes were detected. An important conclusion drawn from these numbers is the fact that this satellite is significantly redder than the Sun, the source of light it reflects. We found that DTV7S has $V - I = 1.9$ mag, while the Sun has $V - I = 0.75$ mag. This result is consistent with other observations of geostationary satellites.[3,7,8]

Single baseline fringes of DTV7S were obtained on the night of 2015-03-05, at UT=6:20, with baseline W04-AC. On the night of 2015-03-06, at UT=6:23, we were able to detect fringes with baseline W04-AC for approximately 4 s, over a period of 27 s, while baseline AC-E3 was detected for smaller periods. Due to the poor weather conditions and less than optimal tip-tilt correction, the fringe detection was intermittent. The observations were further complicated by the fact that they were done during the last days of the glinting season, which means that the glints were shorter in duration and less extreme in brightness than they would have been at the peak of the season.

In Figs. 2 and 3 we present the bias subtracted power spectra of DTV7S in different spectral channels. In Fig. 2, which corresponds to the spectrograph that recorded only the fringe W04-AC, we detect a strong signal at a fringe frequency $k = 2$, which is the expected fringe frequency for the baseline W04-AC. In Fig. 3 we detect a strong signal at $k = 2$ and a weaker one at $k = 3$, corresponding to baselines W04-AC and AC-E03. The fringe signal from W04-AC can be detected all the way to channel 8 (Fig. 2). In the case of the baseline AC-E03, the fringe signal can be detected up to channel 3. Considering the lengths of these baselines and the wavelength at which the visibilities approach zero, we can estimate that the size of the glinting region is $\sim$0.02 arcsec, which corresponds to a glinting region of $\sim$4 m at the distance of the satellite.

Even though the two shortest baselines were tracking fringes, we do not detect any significant signal at fringe frequency $k = 1$, which corresponds to the baseline W04-E03. Under normal conditions we should have been able to detect fringes on the longest baseline by bootstrapping from the shorter baselines. In this case we were not able to do this due to the bad atmospheric conditions, the short amount of time during which we detected fringes, and the size of the target.

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