National Aeronautics and Space Administration

NEAR-IR VLBI FOR HIGH ANGULAR RESOLUTION ASTRONOMY

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Program: Spontaneous Concepts

Background:

VLBI is a powerful interferometry technique that connects global networks of telescopes to achieve exquisite spatial resolution, as recently demonstrated by the direct imaging of the M87 blackhole at 1.3 mm wavelength. The technique has so far been limited to the radio/microwave wavebands due to the lack of coherent detector technology for shorter wavelengths, such as the optical and near IR. High spatial resolution imaging in the optical/near-IR are critically needed for future studies of exoplanets and for the understanding of the physics of planetary formation, and realizing such technology is the subject of intense research and development.

Project Objective:

We propose to demonstrate the feasibility of a near-IR VLBI network similar to the mid-IR heterodyne stellar interferometer pioneered by Townes et al. (1984). Heterodyne downconversion preserves the phase of the incoming light, and the down conversion by mixing with a local oscillator makes it possible to record the instantaneous electric field and synthesize an image by combining the electric field measurements from distant images. The sensitivity of such heterodyne system scales as $\sqrt{\Delta\nu}$ where $\Delta\nu$ is the bandwidth of the detector. The key factor that makes our concept feasible, we believe, is the large bandwidth of the superconducting nano-wire single photon detector (SNSPD) recently achieved by Matt Shaw's group. More importantly, because the SNSPD can resolve individual photon events, only time tags of photons need to be recorded to disk. Depending on the collecting area of the telescope and the brightness of the star, this can allow the data rate to be reduced orders of magnitude with respect to that required for a photodiode, and into the range of reason for the 100 GHz bandwidths needed for optical VLBI.

Approach & Results: We assemble a laboratory prototype for optical heterodyne interferometry at a wavelength of 1550 nm. We choose 1550 nm for our initial study because of the availability of lasers with good stability at this wavelength, and for interest in exoplanet studies in the near IR waveband. We characterize the system using photodiodes. We complete the optical setup shown in Figure 1 with existing hardware from our lab, and with additional components supported by this funding, including a pair of photodiodes and 1550 nm laser. The plots below demonstrate an initial milestone of eliminating laser intensity fluctuations by the use of a balanced mixer.

We will follow-up by exchanging the photodiodes with JPL's SNSPD, and testing whether correlation can be maintained at the low LO power limit necessary to achieve a realistic data rate.

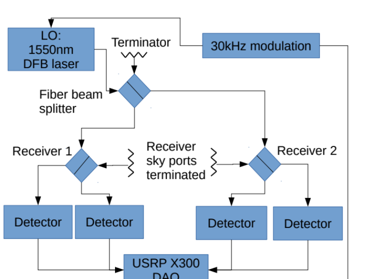

Fig 1.
Experimental configuration for characterizing laser noise for an optical heterodyne interferometer. Two identical balanced heterodyne receivers have their sky inputs terminated. A 1550nm laser is used as a local oscillator which is split and sent to both receivers. Both output ports of the receiver beam splitter are recorded so that correlated fluctuations in the laser intensity can be separated from the laser shot noise and ultimately the heterodyne downconverted sky signal. The detector outputs are recorded with a 32MHz bandwidth and digitized at 100Msps. The laser intensity is modulated at 30kHz. The modulation is detected by software lock-in to calibrate the laser to DAQ transfer function for each detector.

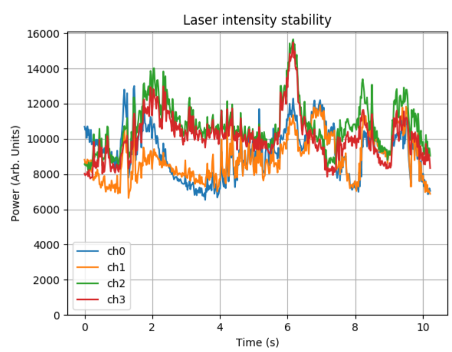

Fig 2. Timestream of detected laser intensity vs. time in each of the four detectors. The laser intensity is measured by locking in to a 30kHz modulation. The laser intensity fluctuates due to fringing from small reflections between the fiber optic components, and drifts slowly in time due to temperature changes lengthening fibers at the micron level.

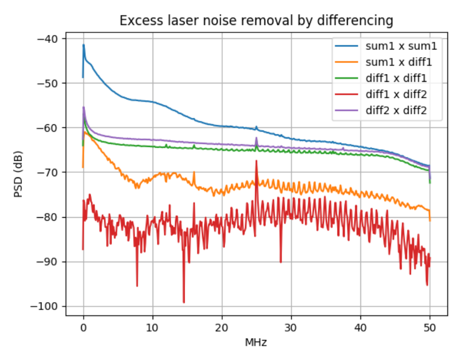

Fig 3. Power spectrum of receiver timestreams. The receiver detector gain is calibrated by the laser intensity from Fig 2. Then the balanced mixer product, which is free of laser noise, is formed by differencing the two detector timestreams from one receiver (diff1 and diff2). The power spectrum of laser intensity fluctuations is shown in the sum1 x sum1 auto spectrum. The laser intensity fluctuations are removed to less than the receiver noise floor. The residual laser intensity fluctuations in the difference timestream is extracted by inspecting the cross spectrum sum1 x diff1, which is 8dB below the receiver noise floor diff1 x diff1.

Benefits to NASA and JPL (or significance of results):

If successful, this development will pave the way to demonstrate direct imaging of exoplanets with unprecedented spatial resolution in the near IR.

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