TITLE
ASP Conference Series, Vol. **VOLUME***, **YEAR OF PUBLICATION**
NAMES OF EDITORS

Direct detection of exoplanets using long-baseline interferometry and visibility phase

Jeffrey Meisner

Sterrewacht Leiden, Postbus 9513, 2300 RA Leiden, The Netherlands

1. Introduction

Long-baseline interferometry at optical (including infrared) wavelengths is a rapidly advancing technology which enables extremely high-resolution observations. The best known application of optical interferometry involves the direct measurement of stellar diameters. Other notable applications include resolving closely separated (i.e. spectroscopic) binaries, and narrow-angle astrometry at the sub-milli-arcsecond level. Precision astrometry using interferometry from space (NASA's future "Space Interferometry Mission", or SIM) is expected to detect near-terrestrial sized planets from stellar reflex motion.

Here, however, we wish to discuss *direct detection* of planetary companions at separations that are otherwise unresolvable due to atmospheric turbulence. Light emanating both from the star and the planet are hopelessly mixed together, until such waves received from two (or more) widely separated telescopes are recombined interferometrically. The correlation between the electric fields of two such single-spatial-mode waves, contains a signature dependent on the underlying (but unresolved, using single telescopes) image of the two objects.

This application of interferometry is, in principle, no different from the previous use of interferometry in detecting and characterizing closely-separated binaries. In this case however, the major issue becomes one of *dynamic range.* Even in the most favorable cases, the ratio of planet to star brightness, a, is no larger than about .001. The consequent variations in interferometric visibility amplitude produced is at most $\pm a$, while the precision yet attained by interferometers is no better than about 1%, limited by calibration uncertainties.

However it is proposed that the *phase* of the interferometric visibility,which is (again assuming $a = .001$) perturbed by no more than .001 radians due to the planet, can nevertheless be observed. That expectation is based on the fact that unlike calibration fluctuations, phase fluctuations (when properly referenced, as discussed below) will be zero-mean. Long observations can then sufficiently reduce the measurement noise to permit detection.

However the instantaneous phase of interferometric visibility (at a single wavelength) is never directly observable. Not only is the phase continually corrupted by relatively huge random atmospheric optical path delays (OPD), but it is intertwined with the object's exact position on the sky and the precise baseline geometry. There are two proposed techniques which can nevertheless recover a phase signature due to a faint companion, which we shall briefly present.

2. Closure Phase Method

While most interferometric observations obtain the fringe visibilities corresponding to individual baselines (separation vector between two telescopes), there is a useful statistic obtainable whenever interference is simultaneously measured over three baselines using radiation collected by three telescopes. The so-called *triple product*, formed as the product of the measured complex visibilities over the three baselines, has the special property that it is totally insensitive to external phase variations introduced in any of the three beams. Thus we obtain a unique measurement incorporating the three underlying visibility phases.

This so-called *closure phase* has the property that it is uniquely zero for any symmetric object, but will be perturbed by asymmetries in the underlying image (such as the presence of a planet) which are at least slightly resolved by the interferometer baseline. In the most favorable case a closure phase (in radians) can be generated which is 8/3 times the brightness ratio a. Using a fixed physical baseline trio, and measurements of closure phase over an extended period employing earth rotation synthesis, one can solve both for the separation vector and for the brightness ratio $a(\lambda)$ (and hence the planet's emission spectrum) at all wavelengths where such a signal can be measured. This promising technique will be used to observe "hot Jupiters" in the near infrared, using the forthcoming AMBER instrument of the VLT interferometer (VLTI).

3. "Differential Phase" Method

There is another method by which tiny phase perturbations due to the presence of the light from a planet mixed with the light of a bright star, can be detected. That involves long-baseline interferometry with simultaneous detection (using a single beam-combiner) over a wide wavelength range. One detects differences in the phase delay between interference at different wavelengths, which occur either because of the gradual change in "resolvability" due to the separation vector as a function of wavelength, or due to wavelength-dependent spectral features in the contrast ratio $a(\lambda)$. Commonly known as the "differential phase" method (a slight misnomer, as only the phase delay, not the phase itself, has a uniquely defined offset between wavelengths), this involves measurement of induced phases which are of maximum amplitude $\pm a(\lambda)$ radians, from wideband interference using a single beam-combiner whose output is spectrally dispersed.

An important factor that interferes with such measurements, is random longitudinal dispersion in the atmosphere (mainly due to water vapor fluctuations), which can be largely degenerate with the phase shift over wavelength induced by a dim planetary companion. But with a sufficient *difference* in the resolvability over bandwidth, or with sharp spectral features in $a(\lambda)$, this degeneracy can be broken, and a unique phase delay signature of the planet observed.

4. Further Details

For an additional explanation of the mathematical basis and complexities of these two methods, the reader may wish to view the following presentation.

`http://www.strw.leidenuniv.nl/~meisner/planetdetection.pdf`