Multiple anamorphic beam combination

Erez N Ribak\textsuperscript{1}, Mario Gaia\textsuperscript{2}, Daniele Gardiol\textsuperscript{2}, Davide Loreggia\textsuperscript{2}, and S G Lipson\textsuperscript{1}

\textsuperscript{1} Physics Dept., Technion - Israel Institute of Technology, Haifa 32000, Israel 
eribak@physics.technion.ac.il
\textsuperscript{2} Osservatorio Astronomico di Torino, Via Osservatorio 20, 10025 Pino Torinese, Italy

Summary. We suggest a new approach to the problem of simultaneous combination of many beams in an optical or infra-red stellar pupil-plane interferometer. All the beams are combined with all other beams. First all beams are stretched anamorphically to create a comb of light, then this comb is interfered with itself rotated at right angle. The diagonal, with self-interfering beams, provides also the individual intensity calibration.

1 Various combination schemes

In multiple-beam stellar interferometry, one has to combine and interfere many beams. Several configurations may arise. The first is when the beams arrive from different telescopes with the same size (e.g. Keck I and II, COAST), or or different sizes (VLT, OHANA). In another case the beams arrive from openings inside the telescope aperture, in what is called aperture masking.

The approaches taken to create interference are classified as the Fizeau and the Michelson realisations. In the Fizeau approach, real images of the stellar object with identical magnifications are superimposed and interfere on an imaging detector. Because of the large number of pixels over which the image falls, this scheme is not so efficient in star light. The modified Fizeau approach, or the densified pupil, maintains only the positions of the original telescopes on the secondary plane. At the same time, the sizes of the beams are made relatively larger by a constant factor. This allows plugging more photons into the central lobe of the image and improves its signal to noise ratio.

The Michelson combination approach requires far fewer detector pixels, and is thus more light efficient. Here each beam is split many ways by a cascade of beam splitters, and these beams are combined by a similar arrangement of beam combiners. In addition, intensity fluctuations in the beams need to be measured simultaneously with the interference of the same beams for calibration purposes. For $n$ beams, the number of splitters and combiners is of order $n^2$, and the number of detector pixels is also of the same order. When the number of beams is large, the arrangement of all beams splitters and mirrors becomes very cumbersome. Because of the large number of reflections and divisions, which may be lossy and also change polarizations,
3 Optical design and realisation

In a fully engineered design, two processes must be applied to obtain the main body of optical elements. The first is the anamorphic projection, which was designed to optimise the optical system for the given requirements. The second is the final correction of the focus, which was done in the laboratory. For the final design, a second-order optical element was used, which was designed to optimise the focus for the given requirements. For the final correction, a second-order element was used, which was designed to optimise the focus for the given requirements. For the final correction, a second-order element was used, which was designed to optimise the focus for the given requirements.
modest stretching of ten we obtained a maximum phase error of 250 nm, and all of this error was in the margins of the ellipse. When these are excluded, the error drops to 3 nm. In another design two anamorphic achromatic lenses served as telescope in one axis, using cylindrical doublets. The performance was slightly worse, and the band width was limited by the lenses, as opposed to the mirror solution.

The idea was tested in a simple experiment, using a square Sagnac interferometer. A dove prism, rotated at 22.5° turned the beams about their axes by 45° in opposite directions, and the two images interfered with 90° rotation between them. Two independent lasers, combined by a beam splitter, served as a source, the angle between them being such that they were barely resolvable by a lens a few metres away. Light was collimated again by a second lens, and fed into the interferometer. We punched a number of holes in an opaque card to simulate the beams just behind the collecting lens, and placed a cylindrical lens at its focus to stretch them anamorphically by a factor of about twenty (Fig. 2).

The results are shown in Fig. 3 for one laser and two. Since the first is unresolved, all fringes have high contrast. This changes when the coherence function drops to zero at some base lines by the addition of a second laser,
making the system resolved. Notice the high contrast along the diagonal, where each beam interferes with itself. This also provides intensity calibration for each beam, especially important for unequal telescopes and for fibre beam transport.

4 A few comparisons and perspectives

Naturally we start with the advantages of the tested scheme. In the first place, the simplicity of measurement: the two output patterns need only use a single camera each. The number of pixels may also be limited, to essentially twice to four times the number of fringes. In addition, every two beams give four fringe patterns for calculation of both the contrast and the phase between them. If more than a single fringe is measured in such a matrix element, it also allows fringe phase tracking. In cases where the intensity in each beam is not constant, there is no need for a calibration bleeder, namely a separate light pick up channel. This is easily achieved by the matrix diagonal which allows the intensity calibration of each beam with itself.
Fig. 3. A single unresolved laser (left) producing a matrix of interfering beams. When another laser is added, some of the off-diagonal beams lose their contrast (right). Artificial fringes are created by misalignment of the telescope and interferometer.

Other optical advantages will be the use of mirrors in a final design (excluding the beam splitter), reducing significantly the dispersion and permitting measurement at most wavelengths, and reducing polarisation losses. The losses are minimal, since there is only one beam-splitter (used twice), independent of the number of beams, with a further five mirrors (three being in a reflective equivalent of a dove prism). The volume is also much more compact.

On the negative side, we mention that some light is lost between the stripes. If we choose to have many fringes, we need many pixels, considerably more than the number of single pixel detectors in the Michelson approach. Also, the readout noise and time are worse than the single detectors. In some shearing interferometers the symmetric output is difficult to access. The anamorphic stretch is limited to about twenty beams, and it limits the spectral capability.

Currently we have the optical design performed in Turin, and the initial results obtained in Haifa. We are testing a new shear interferometer which is both stable, has fewer reflections, and has two accessible outputs. We need to finalise the optical design, and perform a light budget study and a full comparison as mentioned above.

References