The COAST Interferometer

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Abstract. The Cambridge Optical Aperture Synthesis Telescope (COAST) [1] will be the first instrument of its kind to exploit the techniques of aperture synthesis and closure phase to produce very high resolution (one milliarcsecond) optical images. The instrument will consist of four identical independent mobile 40 cm telescopes, and an optical building incorporating the path compensators and the fringe and acquisition and auto-guider detector systems. The present status is; there are three operational telescopes on site with two fully functional path compensator trolleys, an acquisition and auto-guider system capable of controlling up to four telescopes, correlator and a fringe detector system.

Key words: Optical Interferometry

1. Introduction

COAST will be the world's first imaging interferometer for astronomy. It is planned as a coherent array of four 40 cm telescopes operating in the visible and near infra-red over interferometer baselines up to 100 m. It will produce images with milliarcsecond resolution for a wide range of astronomical programmes.

The astronomical objectives of COAST are to provide milliarcsecond images of a wide variety of stellar systems down to a red magnitude of 10. These will include pictures of stellar surfaces, the envelopes of pre-main sequence stars, pulsating variables, circumstellar shells, compact planetary nebulae and close binary and multiple systems. With the improvement in sensitivity available under conditions of modestly improved seeing a very exciting aim of future observations will be the imaging of active galactic nuclei and gravitationally lensed objects.

The first observation was made of fringes simultaneously on all three baselines from star light on 16th December 1992. The star was the unresolved α *Tau* (Aldebaran) type K5, though closure-phase could not be verified.

2. The Instrument

2.1. Telescope

The telescope design [2] comprises a 50cm siderostat feeding a fixed horizontal 40cm f/5.5 Cassegrain telescope with a magnification of 16 times. The overall design results in a very rigid structure. The telescope is mounted kinematically on three feet. This arrangement ensures easy and repeatable positioning. Due to possible differential expansion between the foundations and the telescope, the feet must have some compliance whilst still maintaining accurate location.

The 50cm diameter flat mirror is mounted on two commercially available precision rotary tables. One table is mounted on to the telescope frame and rotates the mirror about the vertical axis. The second rotary table which is mounted on top of the first, rotates the mirror about an axis at 45^o to the vertical. The mirror it self

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is mounted at 45^o to the second axis. By rotation about these two axes the mirror can be made to point in any direction in the upper hemisphere.

2.2. Acquisition and Auto–guider System

An acquisition and auto-guider system has been developed for COAST [3]. Two separate functions are managed by the system. Firstly the four individual telescopes of COAST have to be pointed so that each acquires the field of interest. Facilities have to be provided to coalign the four images at the beginning of each exposure so that they overlap well enough to allow interference. Then the auto-guider must operate to maintain coalignment to within a fraction of a second of arc for the duration of the exposure. The telescopes have 40cm apertures corresponding to $\leq 3r_o$ at the operational wavelengths, therefore simple tilt correction with the auto-guider leads to good superposition of single speckle images from each telescope.

A single cryogenically cooled CCD detector system is used for both the acquisition and auto-guiding for all four telescopes. The detector is operated in two independent modes (i.e. two readout formats) depending on whether it is being used to acquire or guide on an object. The initial acquisition is achieved using the CCD in the normal astronomical manner (i.e. a shutter exposure to integrate the image followed by a slow readout). After the system has acquired all the objects it switched to guiding. This invokes a change in the CCD readout format to generate quadrature cells for the auto-guiding. The images are stablised by driving piezo-driven mirrors mounted on the back of the telescopes.

The CCD can be readout while controlling four telescopes in auto-guider mode, in < 5 ms. Including a typical integration time of 5 ms we get a loop bandwidth of $\sim$100Hz. The acquisition and guiding system is fully operational.

2.3. Correlator

The optical correlator (figure 1) lies at the heart of the COAST interferometer. It takes as its input the (suitably path compensated) beams from the M telescopes and produces as its output estimates of the complex visibilities on the $M(M\text{-}1)/2$ possible baselines. The requirements for COAST is that the system has to be able to combine the beams from at least 3 telescopes simultaneously so that the closure phase can be determined.

The decision to use discrete APD detectors means that to adopt a spatially sampled fringe pattern scheme for four telescopes would require at least 60 detectors [4] compared with only four for a temporally sampled scheme, per spectral channel. A temporally sampled, pupil plane beam combining optical system (correlator) has been designed and is shown below. The wavefronts of the parallel beams from the telescopes are superposed using beamsplitters and the total intensity of each of the emerging beams is measured. In this arrangement the use of small angle of incidence (10^o) on the beamsplitters overcomes the polarisation inequalities usually associated with them and the combination of all four beams in each detector output removes any requirement for extreme thermal stability in the dimensions of the correlator.

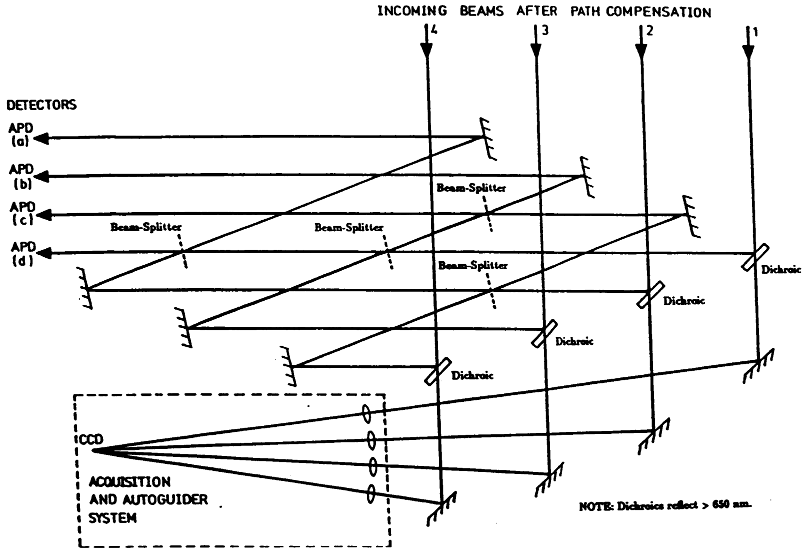

Fig. 1. Beam Combining Optics (Correlator)

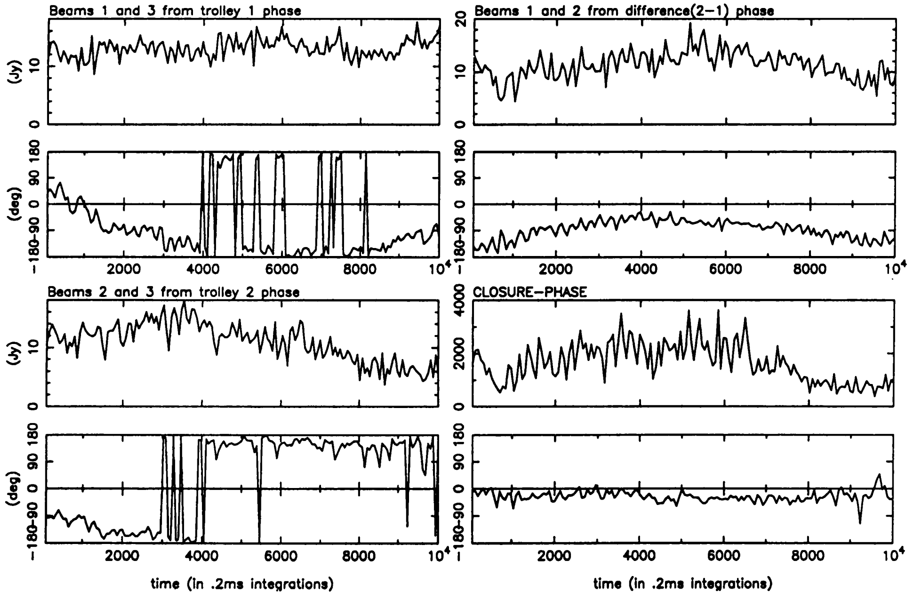

Fig. 2. Calibration amplitude and phase and triple product (closure phase) with three baselines

An observation using an artificial source was made on all three baselines with the paths scanned by a sawtooth at a common frequency of ~80 Hz but with amplitudes of 0, 1 and 3 respectively. Figure 2 shows the calibration amplitudes and phases from the two APDs, their difference and the triple product.

2.4. Path Compensation Trolley

Equalisation of the light paths from a star through the telescope to the detectors is carried out by a movable trolley carrying a roof mirror reflector running on precisely aligned steel rail tracks. The roof mirror is supported by a pair of flexible struts which allow frictionless translation of the mirror unit relative to the trolley without tilting. The mirror unit is driven electromagnetically by a loudspeaker voice coil and its position measured continuously by reflection of a beam of a Hewlett-Packard 5527A laser interferometer system (at a resolution of $\lambda/16$) from a corner cube attached to the mirror unit. A 68020 microprocessor determines an error signal, at a rate of 5 KHz, and the servo loop is closed by an output to the voice coil. A position sensor between the mirror unit and the carriage then permits the carriage to be driven to follow the mean position of the mirrors. Since early summer 1992 stellar fringes have been regularly tracked by the first servo-controlled pc trolley.

2.5. APD Detectors

The short atmospheric coherence time (~ 10 ms) and length (~ 10 cm) forces the use of small collecting apertures and short integration times and therefore limited photon rates. COAST therefore requires a detector with exceptionally good quantum efficiency and large dynamic range to gain adequate signal to noise. Several existing detectors were considered but none satisfied all the requirement of COAST and it was decided to develop a new detector system optimized for our needs using Avalanche Photodiodes (APD's) [5].

Silicon APD's have internal gain, a detection efficiency of 45 % and a spectral range 400 – 1000 nm. Due to thermal noise of the APD it was chosen to use them in 'Geiger' mode. In this mode an incident photon causes catastrophic electron multiplication which is sensed and actively 'quenched' in < 150 ns. A system has been developed which utilises RCA Electro Optics SiAPD's in so-called 'actively-quenched' configuration, giving a maximum counting rate of around 3,000,000 cts/sec. The detector is contained in a small module containing all the electronics to control and thermo-electrically cool the APD.

References

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