A new Infra-Red Camera for COAST

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The Cambridge Optical Aperture-Synthesis Telescope:

- COAST is a long-baseline interferometer with ability to measure closure phases. It can measure spatial frequencies and can also obtain images via aperture-synthesis.

- It operatates in the **Red** and near **Infra-Red** between 600 nm – 1.3 μm.

- COAST is currently configured with baselines upto 48 m long. It can use 100 m baselines which would give an angular resolution of 1 milli-arcsecond. This is equivalent to resolving a man on the moon!

- The sensitivity is (theoretically) as high as 10^{th} Magnitude stars in the red.

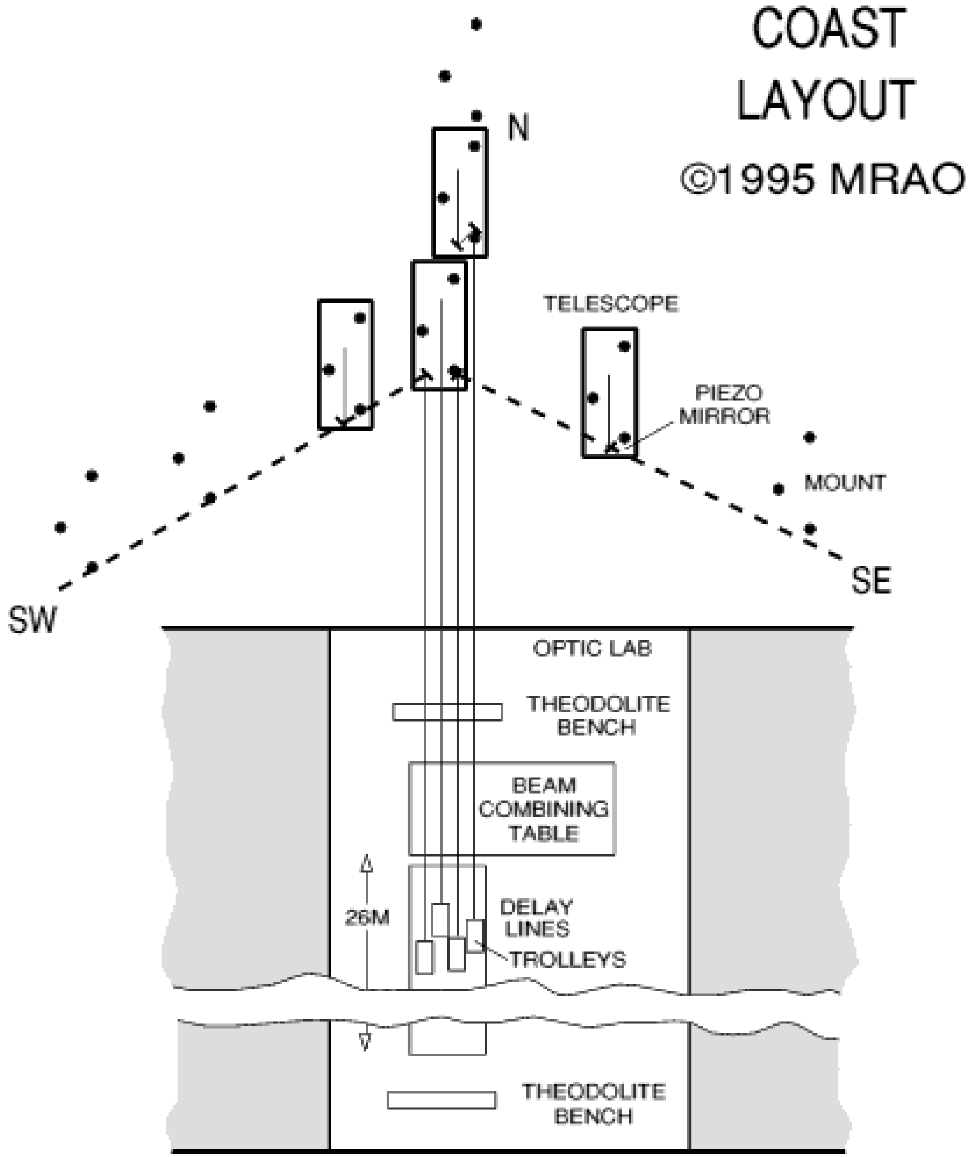
- COAST was designed in 1986 and built at a cost of a mere £850,000. This compares favourably with the Hubble Space Telescope (£1.5 billion for an angular resolution ~ 100 milli arcsec.)

- COAST is still world-beating and in active use for observing as well as being a test-bed for the planned Magdalena Ridge Observatory (MRO).

COAST Overview (1):

COAST has 5 siderostats, of which up to 4 are used simultaneously. Each contains a movable flat mirror which tracks the star and a Cassegrain telescope to focus the light down into a beam tube. The aluminium tubes transport the light into the optical lab in the bunker.

The bunker is a corrugated steel half-cylinder, covered in soil and grass: it has very small thermal fluctuations.



COAST Overview (2):

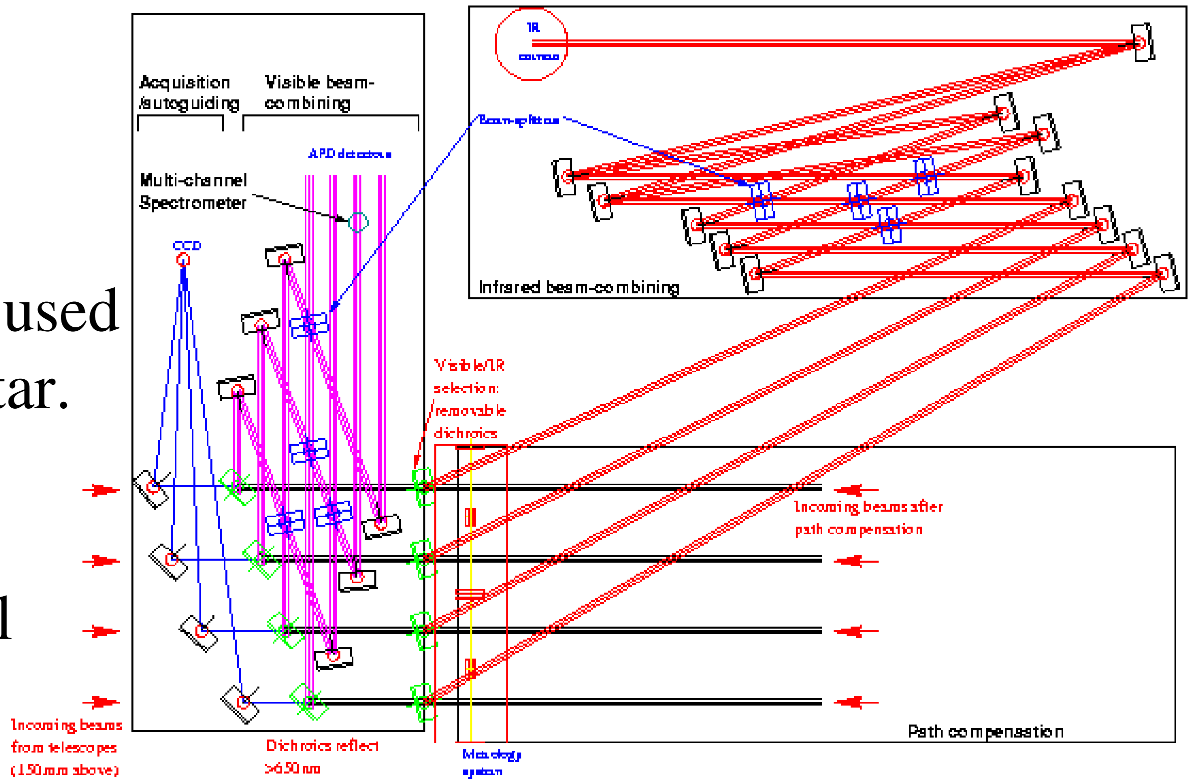
In the bunker, the optical path lengths are first equalised by moveable mirrors mounted on trolleys. The 4 beams are combined and interfered. The resulting fringes, are tracked.

• Red light is detected by Avalanche Photo Diodes (APDs).

• IR is detected by 4 pixels of the NICMOS camera.

• The remaining visible light is used by the autoguider to track the star.

The trolleys have their own highly-accurate position control using a laser interferometer.



Magdalena Ridge Observatory

The MRO project in New Mexico is a collaboration between America (New Mexico Tech, New Mexico State University, the University of Puerto Rico, Los Alamos, US Naval Research) and Cambridge.

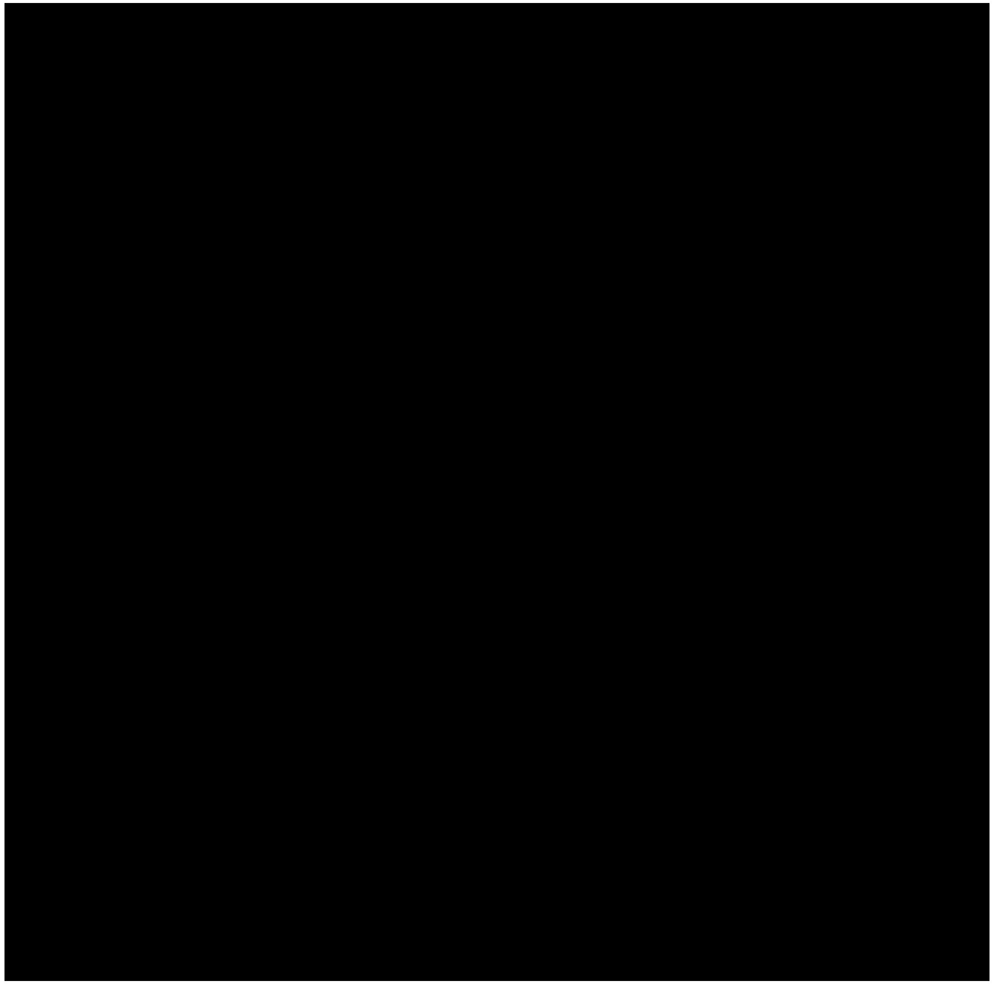
It will have 10 interferometer elements, each with 1.4 m diameter mirrors, on baselines up to 400m. This will provide extremely high angular-resolution and sensitivity. At 3.2 km above sea-level, it will also avoid much atmospheric distortion. It should be completed in 2008.

It will be the successor to COAST, and will (hopefully!) use my IR camera design...

The Current Infra-Red Camera

The current camera uses a NICMOS sensor which was state-of-the-art at the time COAST was designed.

It was used to obtain this, the first infrared image from an aperture synthesis array. This shows the binary star Capella and was observed with COAST using the infrared correlator at a wavelength of 1.3 microns on 25 October 1997.



The Current Infra-Red Camera

The current camera can read out pixels in the following ways:

- 4 pixels, read @1 kHz
- 2 pixels, read @ 2.5 kHz
- 1 pixel, read 16 times @ 1 kHz

Pixels are normally reset after each read, but I have implemented a new readout scheme where 1 pixel is read multiple times. It is only reset once per sweep, and allowed to integrate during that sweep. Omitting the reset saves sufficient time to permit multiple reads - and this improves the Signal/Noise ratio by $\sqrt{n}$.

This gives an improvement of ~ 2 (albeit at a cost of lowering the dynamic range).

Limitations of the Current Camera

• The NICMOS sensor was advanced at the time; it is now over 15 years and 2 generations behind the state of the art. The AstroMed CCD controller is obsolete.

• Readout is too slow (4 pixels @ 1kHz or 2 pixels, 2.5 kHz max). This means that we cannot use all the light captured (on 4 beams) while working quickly enough to obtain closure-phases.

• There is no ability for spectral resolution.

• It is too noisy: the read noise is ~16 electrons.

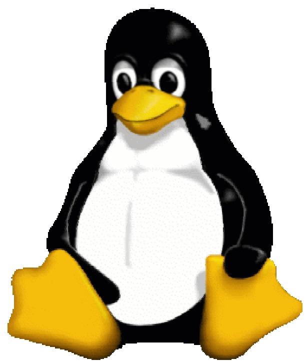
• Anomalous non-linearities can occur if reads are omitted.

• It is an MS-DOS based system - poor networking, not remotely controllable, non-user friendly, hard to develop for and debug.

The **New** Infra-Red Camera

This will take advantage of a current-generation HAWAII sensor. It will have:

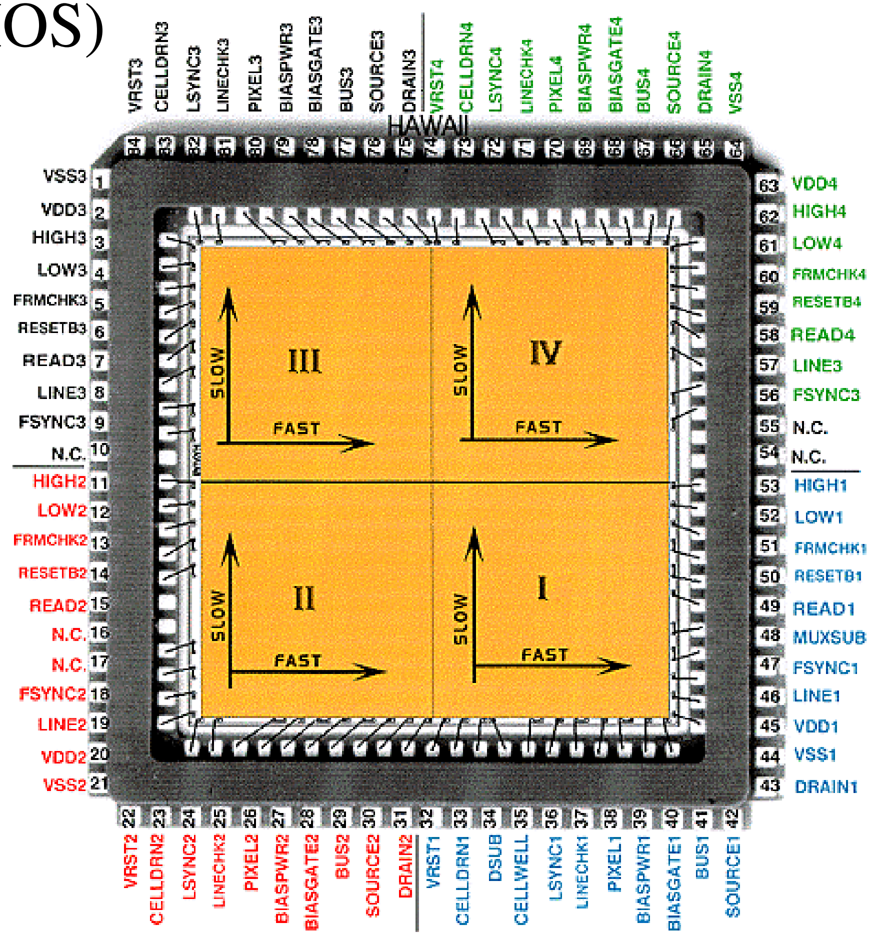
- Faster readout. We can read more pixels, at a higher sample rate, or with multiple reads.
- Better Signal/Noise ratio (3 electron read-noise, reduced from 16)
- More modes, including spectroscopic and imaging.
- Better system, learning from usability problems with the current camera.
- Bells and whistles...control and monitoring.
- Linux, so capable of remote (network) operation, rather then personally sitting over a reluctant MS-DOG !



The HAWAII Chip

- HgCdTe Focal Plane Array with low dark current at 78 K.
- 512 x 512 pixels arranged in 4 independent quadrants - the engineering grade probably has 3 of these working.
- Pixel size 18.5 μm (c.f. 27 μm for NICMOS)
- < 3 electron read noise is attainable (using multiple reads).
- Sensitive from 0.85 μm - 2.5 μm

These sensors cost $150,000 from Rockwell. Fortunately, UKIRT have one spare, which they are lending us. Since we cannot afford $27,500 for Rockwell's “SIDECAR” control system, we must design our own...



New camera – at COAST

We are aiming to achieve:

- Fast readout: 4 pixels @ 5-10 kHz, with averaging over multiple reads.
- Low read noise.
- No non-linearities (hopefully!) (1% should be attainable; we can calibrate this.)
- Perhaps up to 10 spectral channels.
- Aim for ease of use, and reconfigurability within 10 (ideally 1) seconds.
- Must operate locally or remotely over the network.
- Must "talk" to COAST DataManager in the right format.
- Instrument design must allow for calibration, and have "hooks" for upgrading.
- It must be completed well within the timeframe of a PhD!
- Adequate documentation - for my successor...

New camera – at MRO

The COAST camera will be a prototype for MRO. So, it should be possible to make simple upgrades, rather than fundamental design changes:

MRO will have 10 elements, and probably 8-way beam combiners. This may mean reading more pixels, or it may require separate sensors.

There will be much more light available - hence spectroscopy will be desirable. Using a grating, we might have ~ 128 pixels to read in different channels.

Imaging will not be needed in the normal sense, but will be important for calibration and alignment.

So, the readout modes must be flexible, and the data-rate could be very high.

New camera – Design Overview

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                                       16-bit to 8-bit multiplexer
                                       Insert headers. Optional FIFO                       Hard Drive - log the data.
                                            |  .                                          /
         __________       ___________       |  .                   __________________    |
~~~~~>  |CCD       |    |"Home-made"|      V  .  Parallel Port(s)     | Real-time         |--/     --->--Screen - displays status
~~~~~>  |in dewar |=>==|ADC [x4]   |=====>======== EPP ~ 2MByte/s  ==>==| Linux PC          |        /      and analysed data
~~~~~>  |_________|    |           |          .  (or Digital I/O card)| Does:             |-------/
           ^           |___________|          .                       |*Processing,       |
        ___|____             ^                .                       |*Storage,          |----<--->----Network - to other systems.
       | CLOCK  |       _______|_____________ .                       |*Data Transport,   |
       | (RAM)  |--<--|PIC microcontroller  |==<==>== Serial ===<==>====|*Analysis,         |
       |________|     |for control and      |  .      Port for slow   |*Display,          |
           ^          |monitoring functions |  .      control signals |*Control and       |-----<-------Keyboard - local user interaction
  _________|_____     |Probably a 16F877    |  .      RS232 over USB. | Monitoring        |
| External        |   |_____________________|  .                      |___________________|
| Master Clock.   |    ____________________    .                                             ______________________
|(Trolley-sweep   |   | Stable (toroidal,  |   .                                            | Bells and Whistles:  |
| and             |   | linear) PSU        |   .                                            |  - Measure temp.     |
| pixel clock     |   |____________________|   .                                            |  - Check LN2 level   |
| from main       |                            .                                            |  - Control shutter   |
| control system) |   (low noise, sensitive)   .  (may be electrically, sonically  )        |  - Run filter wheel  |
| 10MHz,5kHz,1Hz  |   (on this side of line)   .  (and thermally noisy on this side)        |______________________|
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The aim is to keep this as general as possible, avoiding the introduction of arbitrary limits we may later regret. It should also be *simple* !

Any Questions ?

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-- The End