VLTI: current facility and prospects

EuroSummer School

Observation and data reduction with the Very Large Telescope Interferometer

Goutelas, France
June 4-16, 2006

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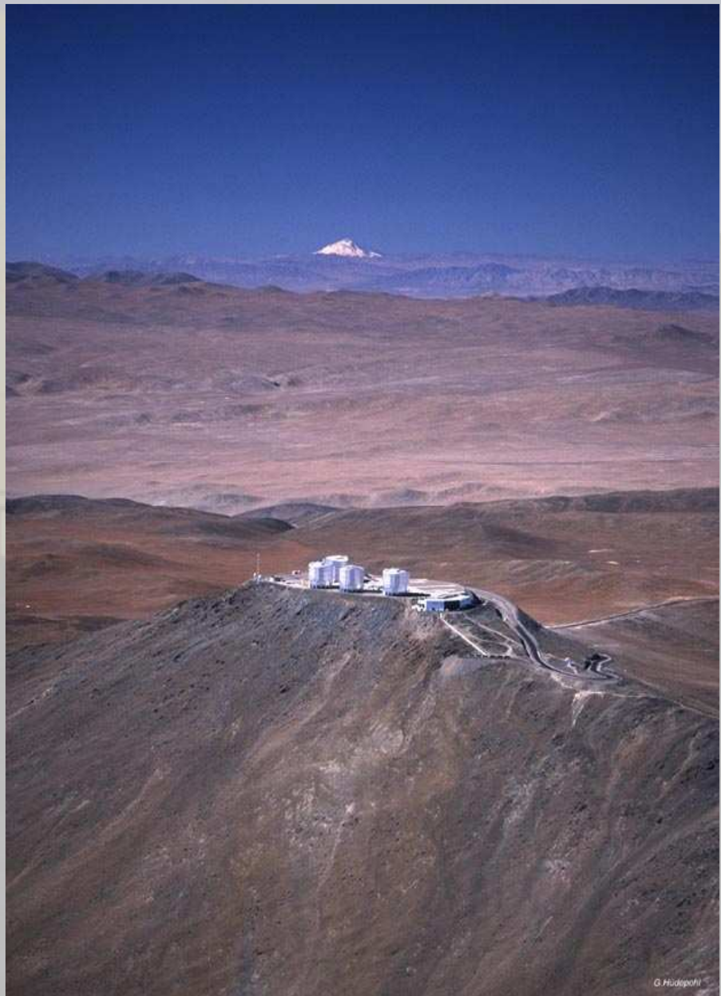
(with input from Jason Spyromilio
and Francoise Delplancke, among others at ESO)
European Southern Observatory
June 09, 2006

A brief history of VLTI

- 1980s - Interferometry integral part of the VLT project, early linear array design for UTs goes to trapezium structure
- Early 1990s - engineering of the general layout
- 1993 - council stalls the VLTI, infrastructure implementation (light ducts, tunnel, lab) continues
- 1996 - MPG/CNRS/ESO tri-partite agreement for third AT
- 1997 - MIDI and AMBER proposed by community
- 1998 - contracts for ATs and Delay Lines awarded, MIDI and AMBER instruments started
- 2000 - start of implementation on Paranal (siderostats and delay lines)
- March 2001 - first fringes with VINCI on siderostats

VLTI

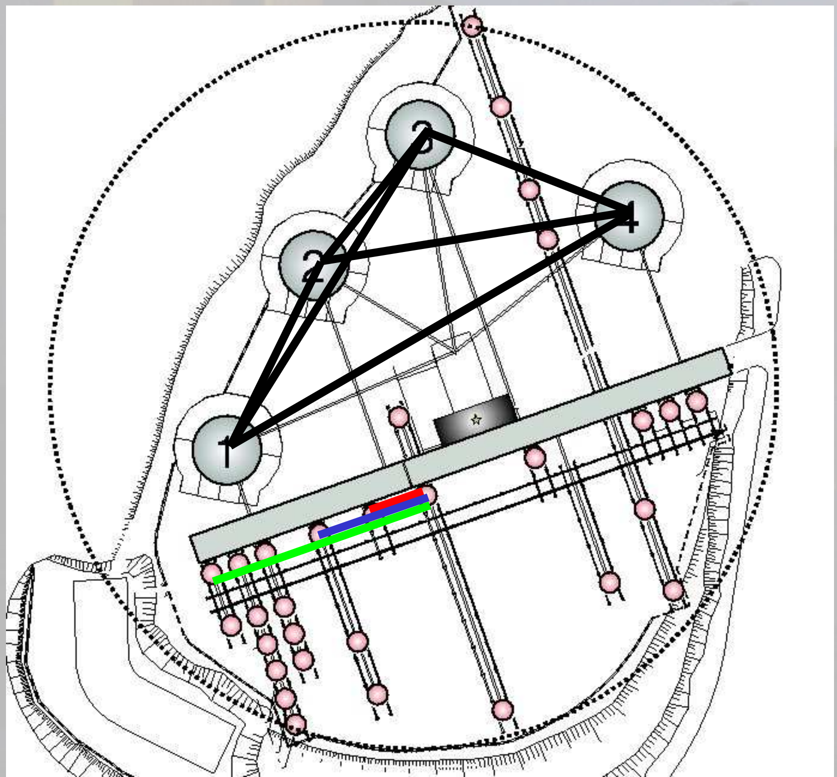


Four 8.2m telescopes (UTs)
All equipped with AO (MACAO)
Six Baselines 47m-130m

Four 1.8m telescopes (ATs)
Movable to 30 stations
Baselines 8m-202m

Six delay lines
PRIMA dual feed facility
FINITO fringe tracker
IRIS lab tip/tilt tracker
MIDI/AMBER/VINCI

Status

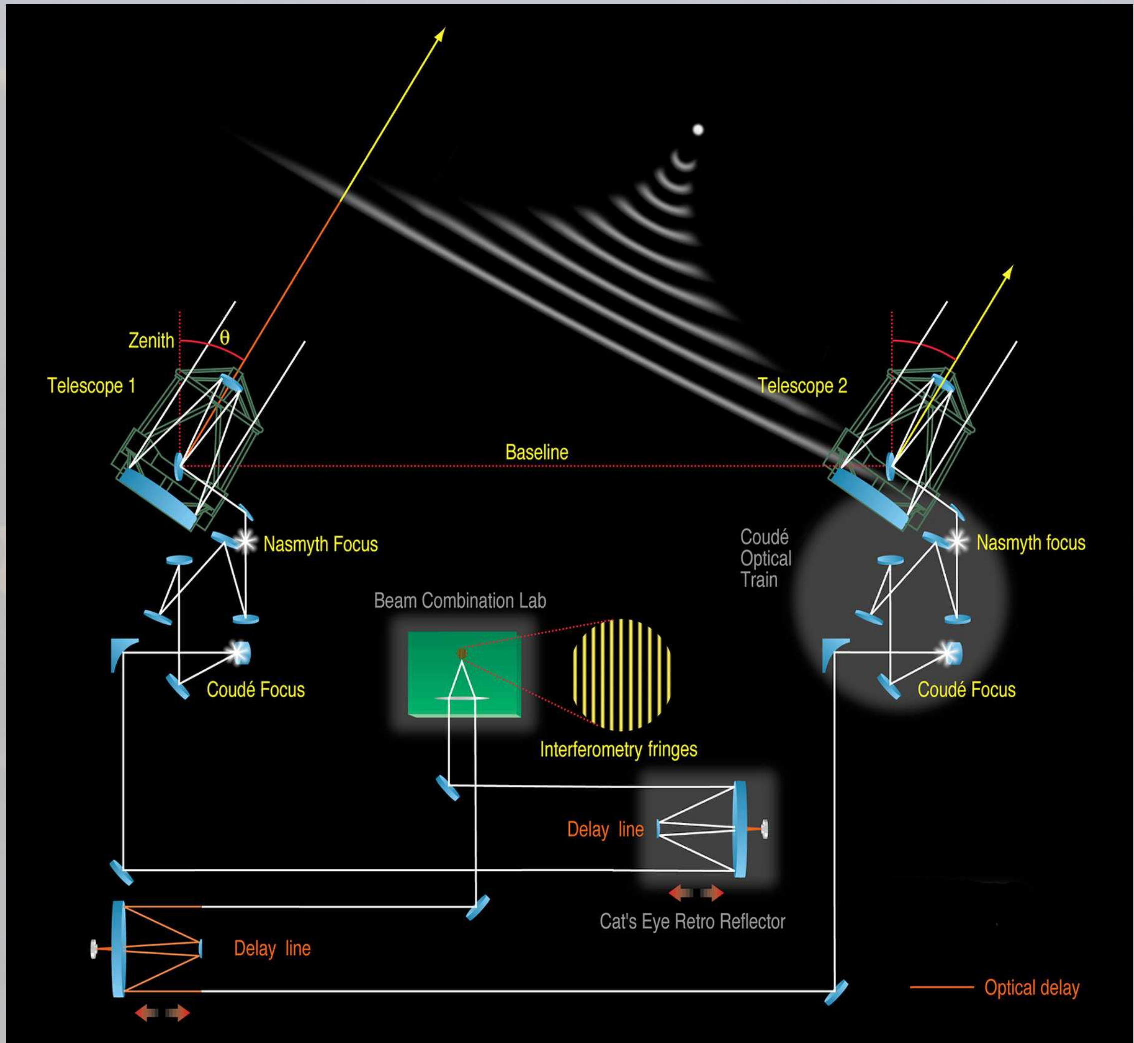


- All UTs operational with full AO, all six baselines and all four baseline closures used for science
- AT1/2/3 in operations on three baselines
- AT4 will arrive in Aug 2006
- 4 Delay Lines in operations for UTs, 2 Delay Lines for ATs
- MIDI offered since April 2004 on UTs and October 2005 on ATs
- AMBER offered on UTs since October 2005
- 38+40 nights of VLTI science operations in P76 (Oct 05-Mar 06)
- Six operations astronomers, three fellows, several TIOs to run VLTI
- 40+ refereed papers

Some acronyms

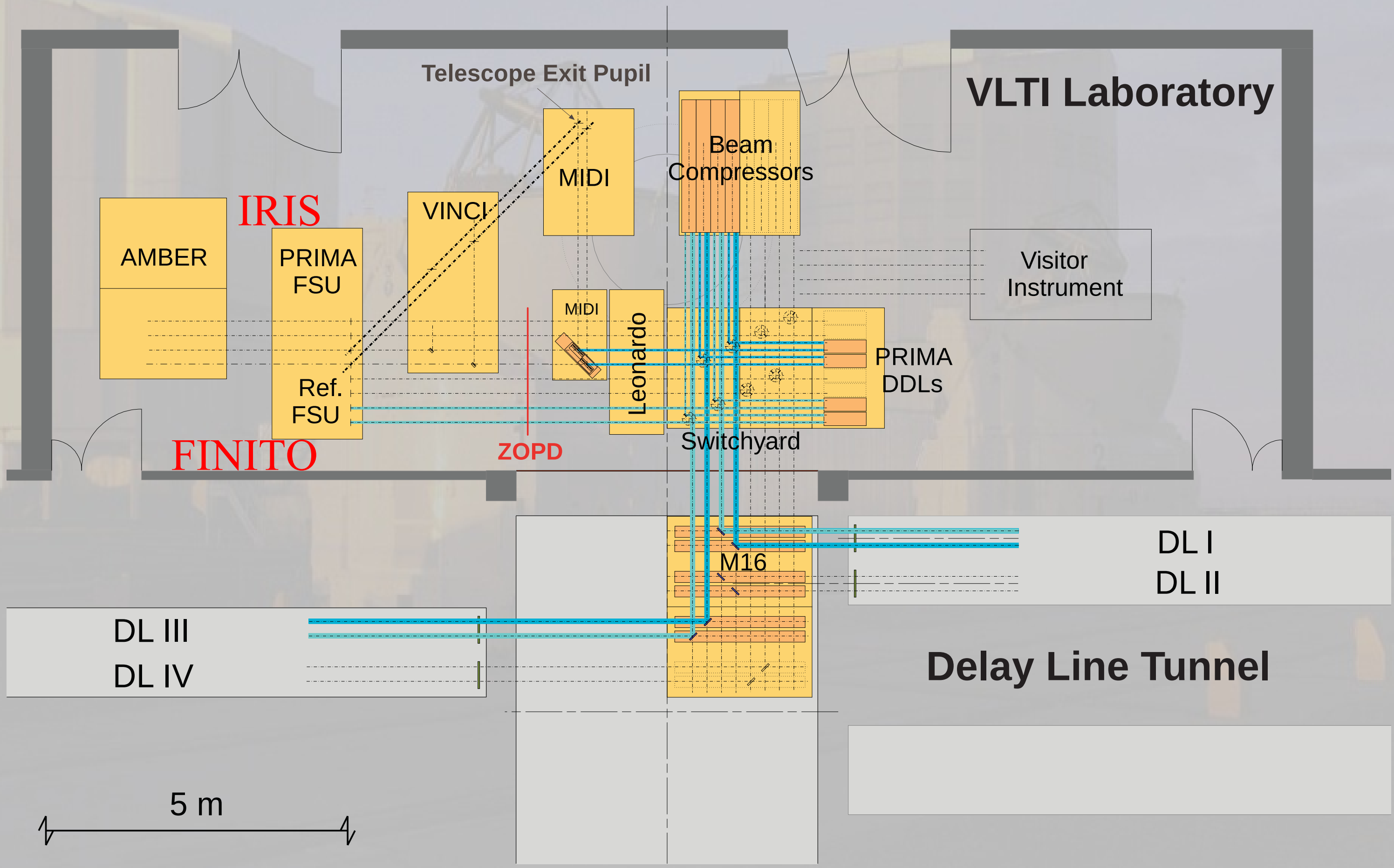
- OPL - optical path length
- OPD - optical path difference
- ZOPD - zero optical path difference
- UT - Unit Telescope (8.2m)
- AT - Auxiliary Telescope (1.8m)
- MACAO - Multi Application Curvature Adaptive Optics
- STRAP - System for Tip-tilt Removal with Avalanche Photo diodes
- VINCI - VLT INterferometer Commissioning Instrument
- AMBER - Astronomical Multiple BEam Recombiner
- MIDI - MID Infrared interferometric instrument
- FINITO - Fringe sensing Instrument NIce TOrino
- IRIS - InfraRed Image Sensor
- ISS - Interferometer Supervisor Software

VLTI Scheme



Zenith
θ
Telescope 1
Telescope 2
Baseline
Nasmyth Focus
Nasmyth focus
Coudé
Optical
Train
Beam Combination Lab
Coudé Focus
Coudé Focus
Interferometry fringes
Delay line
Cat's Eye Retro Reflector
Delay line
Optical delay

The interferometric laboratory



What does the VLTI infrastructure do?

Put the light in the one place at the one time.

- Inject the image plane in the lab
- Make the pupils coincide
- OPD variations should only be atmospheric

How does VLTI do it?

Each UT has a MACAO system that concentrates the bulk of the photons within the Airy ring.

The beam is propagated via the relay optics to the delay lines

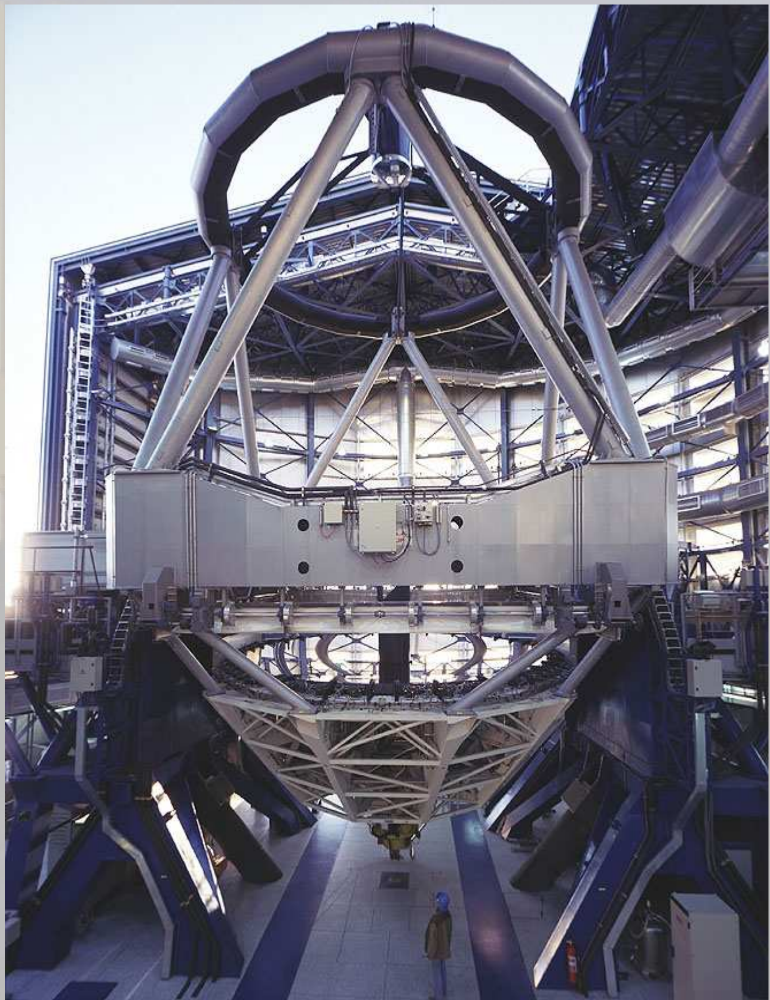
The delay lines correct in ‘open loop’ geometric OPD (telescope and star locations)

The VCMs on the delay lines move the pupil in the ‘axial’ direction.

IRIS corrects for drifts in the conjugation between the MACAO reference and the lab reference

FINITO corrects for atmospheric OPD variations through the delay lines

The VLTI Telescopes



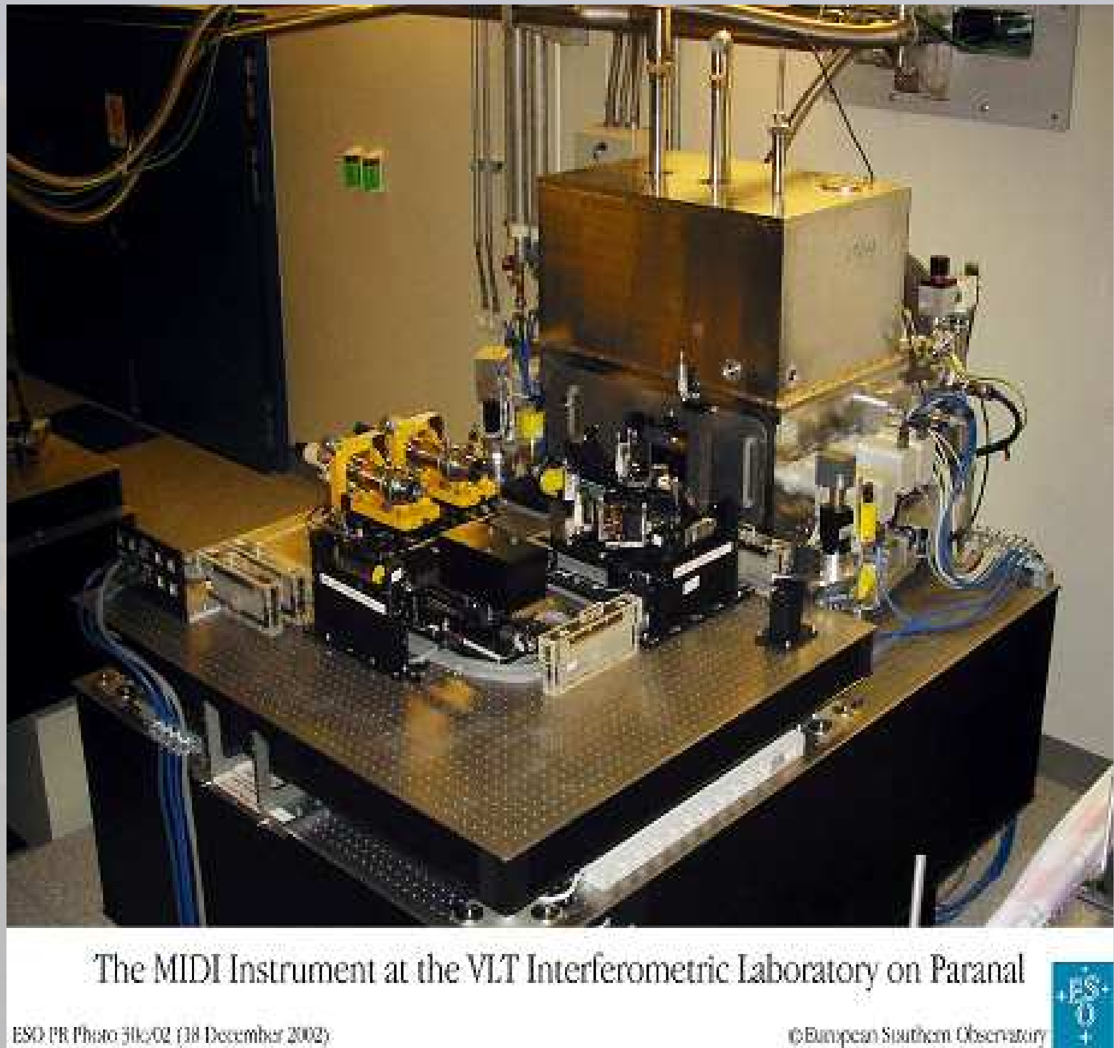
Delay Lines


VLTI Delay Line Retroreflector Carriage
ESO PR Photo 26c/00 (11 October 2000)
© European Southern Observatory

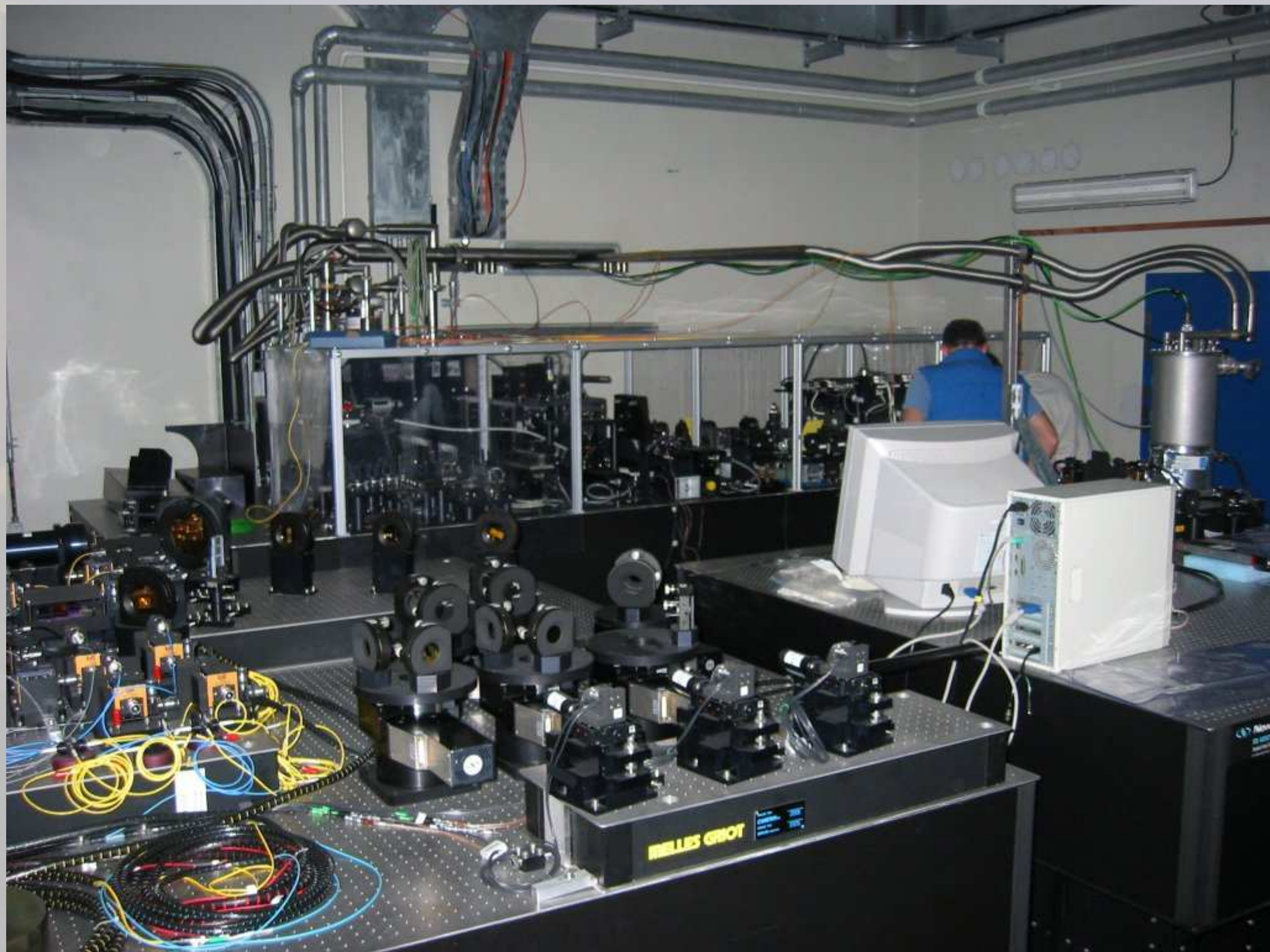
VLTI 1st gen Science Instrumentation

	Bands	# telescopes	spectral resolution	limiting magnitude (UTs)
AMBER	J,H,K	3	35, 1500, 12,000	7
MIDI	N	2	30, 230	4 (1Jy)

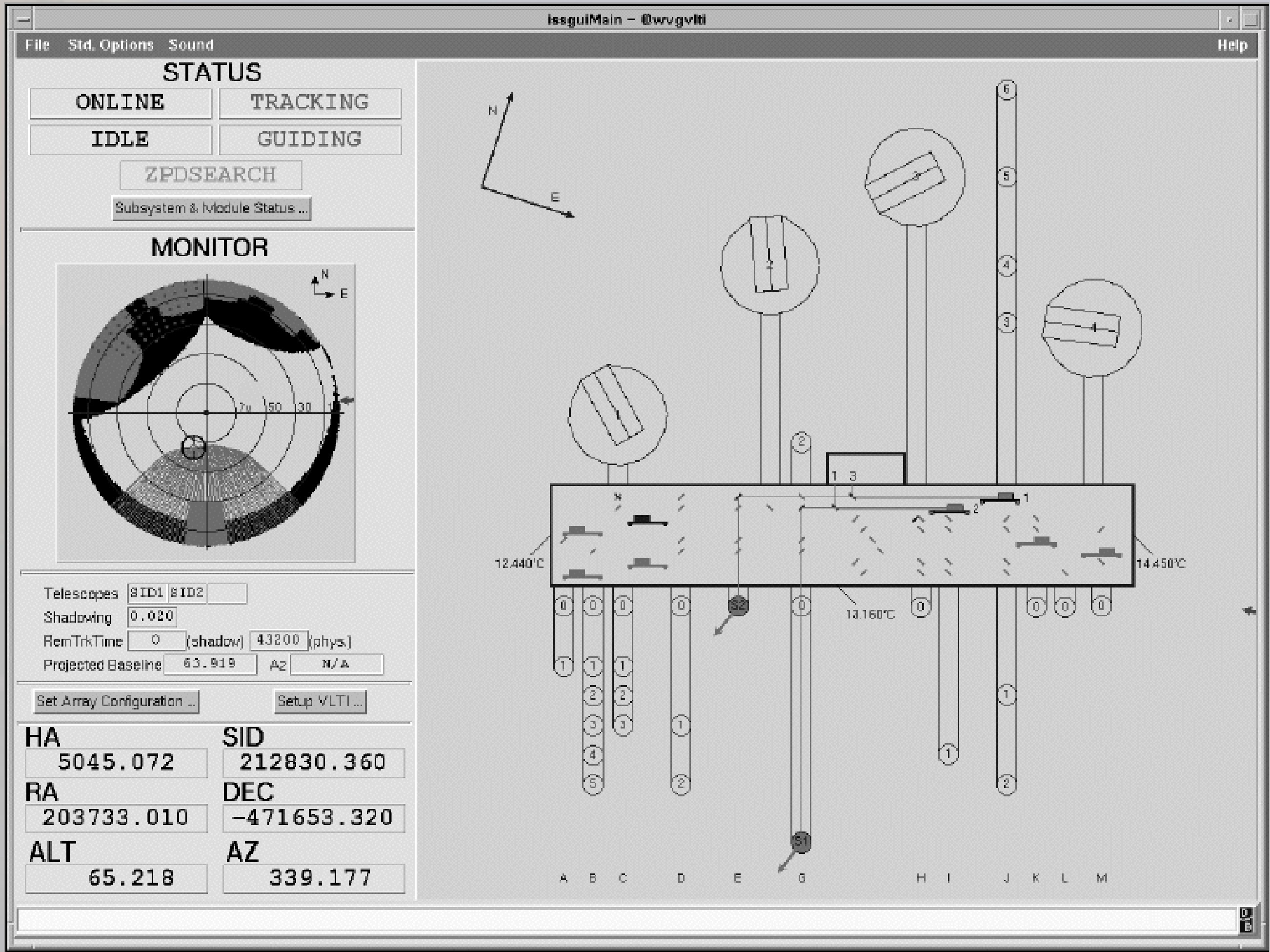
MIDI in the VLTI lab



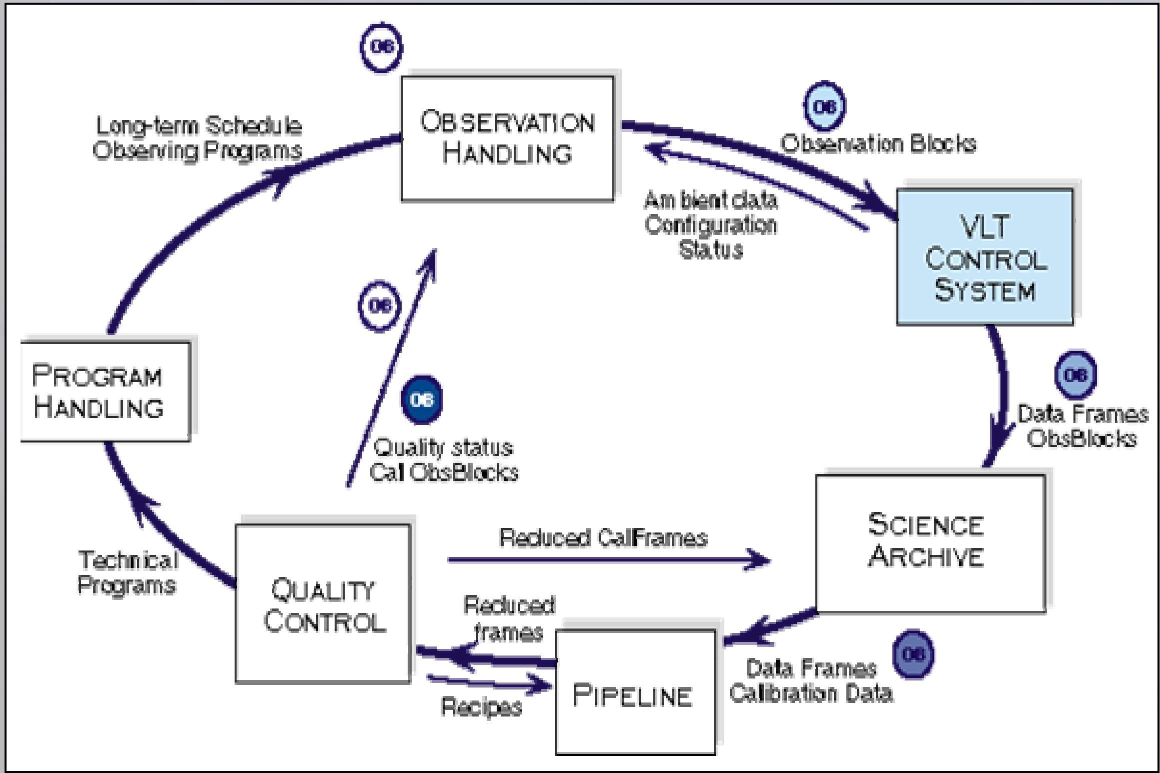
AMBER in the VLTI Lab



Interferometer Supervisor Software



VLTI Operations



VLTI follows the VLT data flow: proposal form, OB preparation and execution, FITS data, archive

Observations performed in Visitor and Service Mode

VLTI offered modes

P70 (Oct 2002) - VINCI on siderostats

P72 - nothing offered

P73 - MIDI on two UT baselines, prism only, 5Jy

P74 - MIDI on three UT baselines, grism, 1Jy

P75 - MIDI on all UT baselines

P76 - MIDI on three AT baselines

- science photometry mode
- slightly better limiting fluxes
- AMBER offered on all four UT triples
- LR-HK, MR-K (low/medium resolution)

P78 (Oct 2006) - AMBER also offered in HR-K

- reduced overheads on AMBER

P79 - AMBER on AT baselines (?)

Operating the VLT

- One shift leader (24h on call)
- Two day time astronomers (DA) for all UTs plus one for VLTI
- One engineer per UT and VLTI for coordination of daytime access (UT and VLTI managers)
- One night astronomer (NA) per UT single telescope use and one for VLTI
- One telescope instrument operator (TIO) per UT and one for VLTI
- Typically at least one DA or NA in training (e.g. 13 new fellows in 2006, each with at least three weeks of initial training)

- VLT is based on line replacable units (LRU) !!!

VLTI staff

- Six VLTI support astronomers: Stephane Brillant, Christian Hummel, Sebastien Morel, Fredrik Rantakyrö, Thomas Rivinius, Stan Stefl
- Three + two fellows: Carla Gil, Daniel Kubas, Jean-Baptiste LeBouquin; Emmanuel Galliano, Martin Vannier
- Instrument scientists:
  - AMBER - Fredrik and Stan
  - MIDI - Sebastien and Thomas

La Silla/Paranal schedule P77 (now)

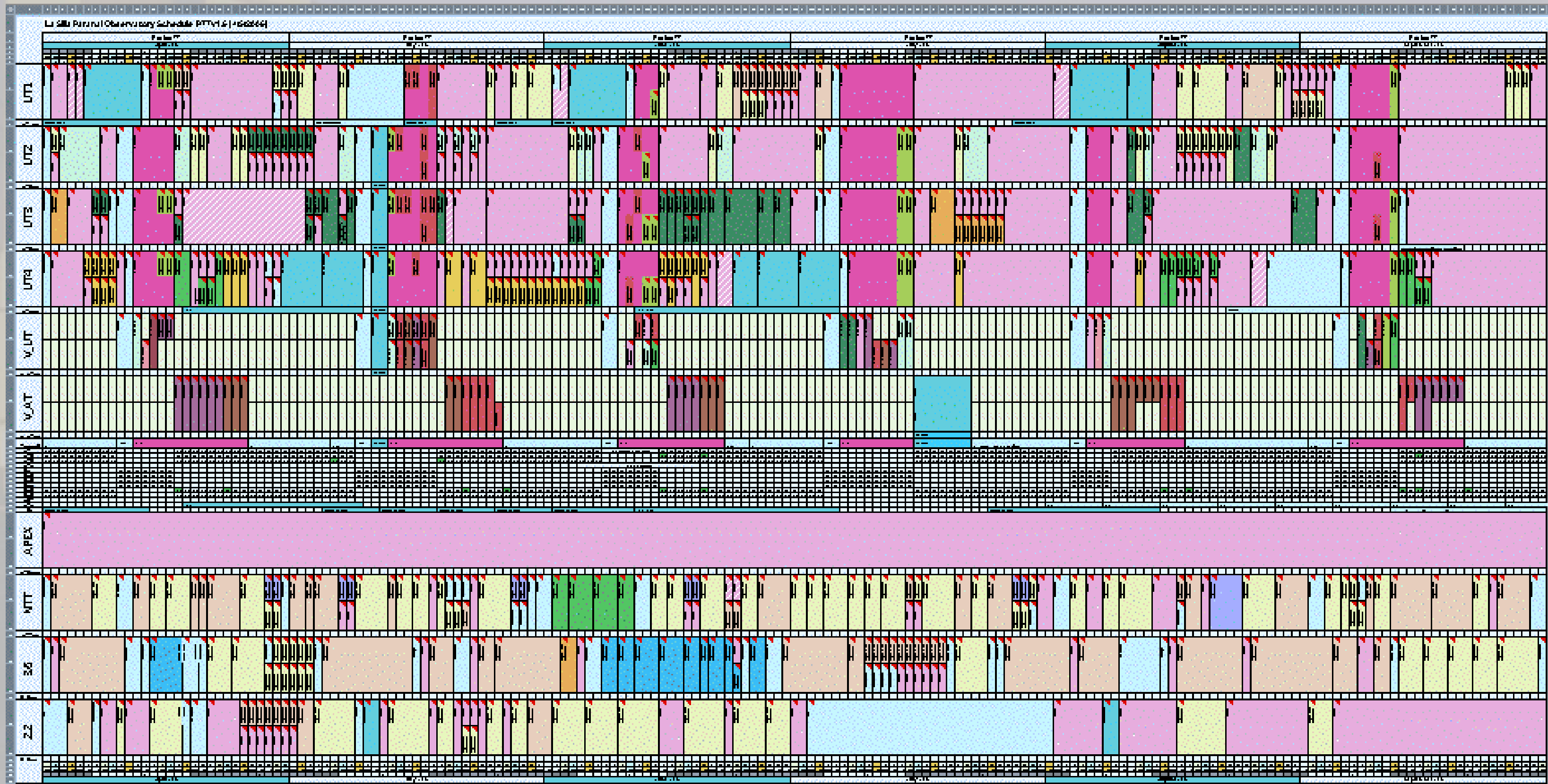


Image Planes

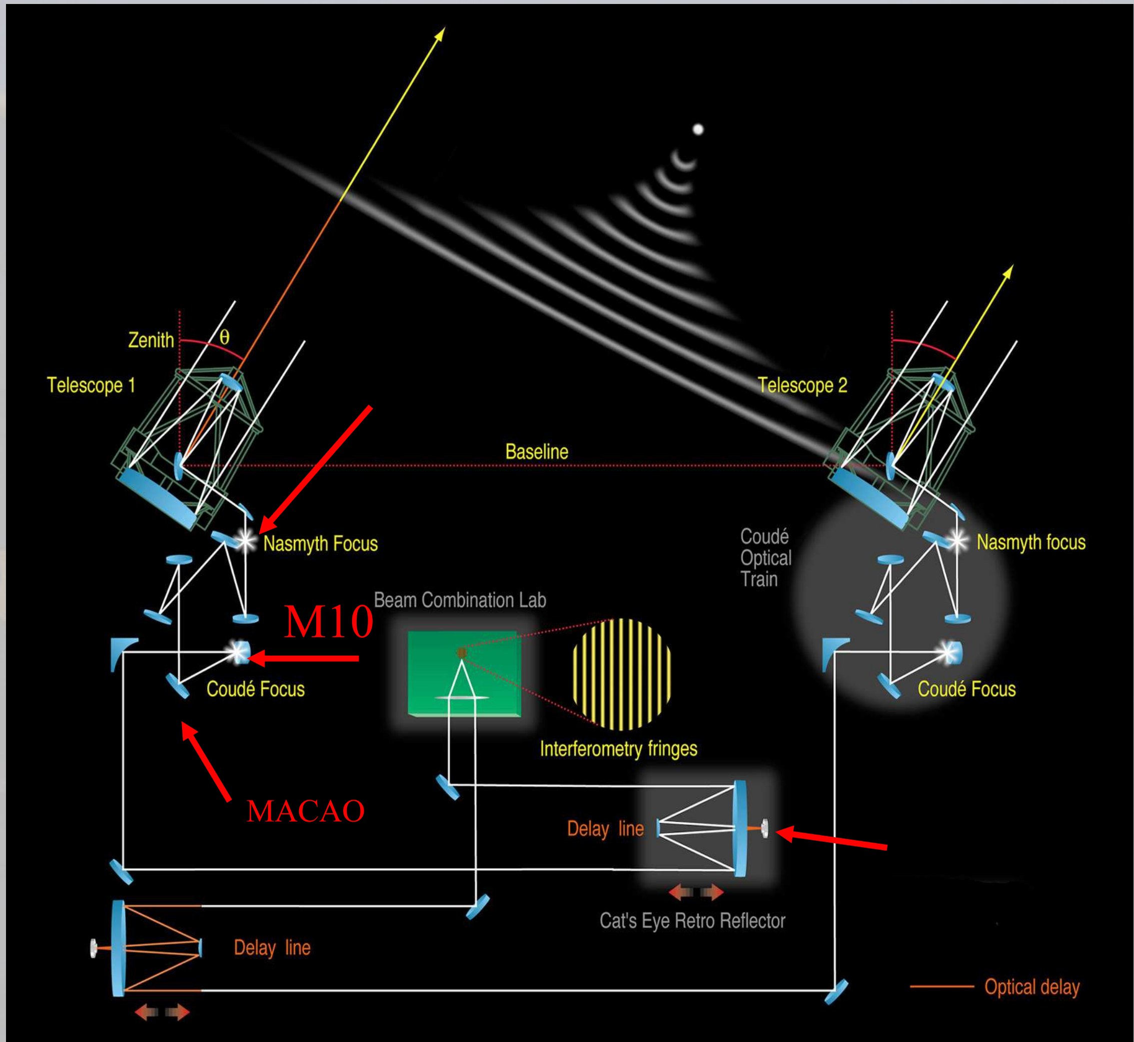
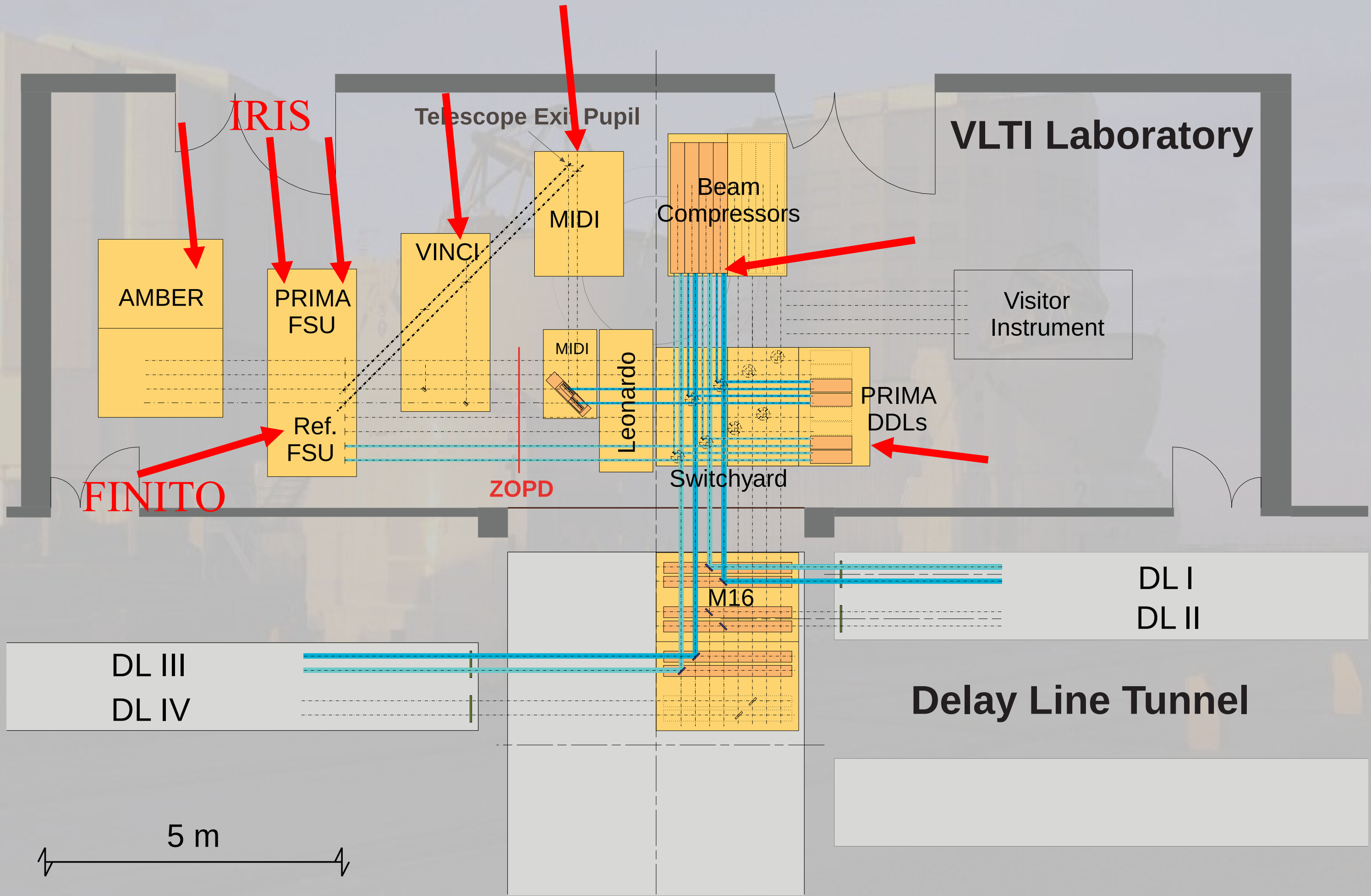
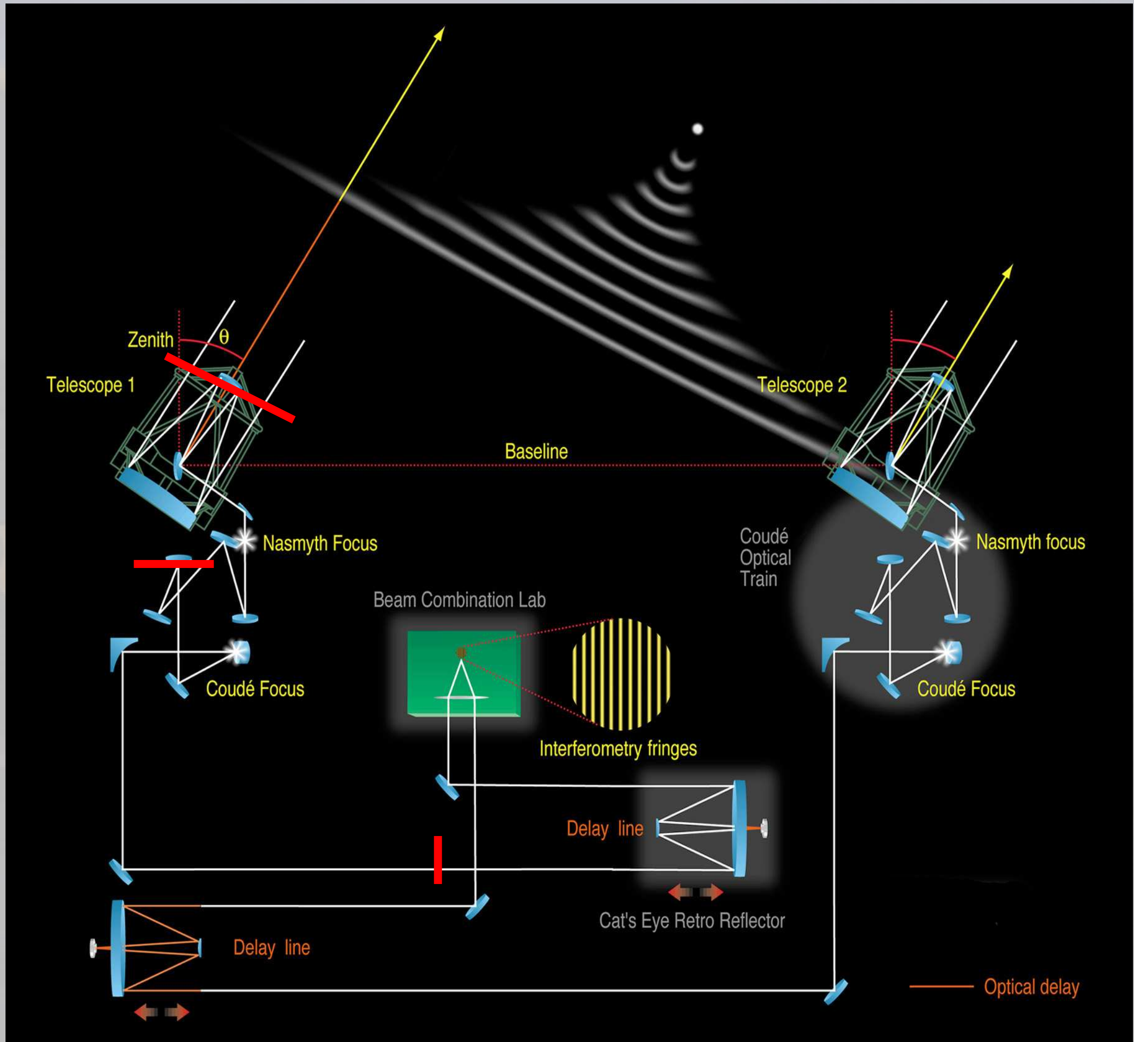


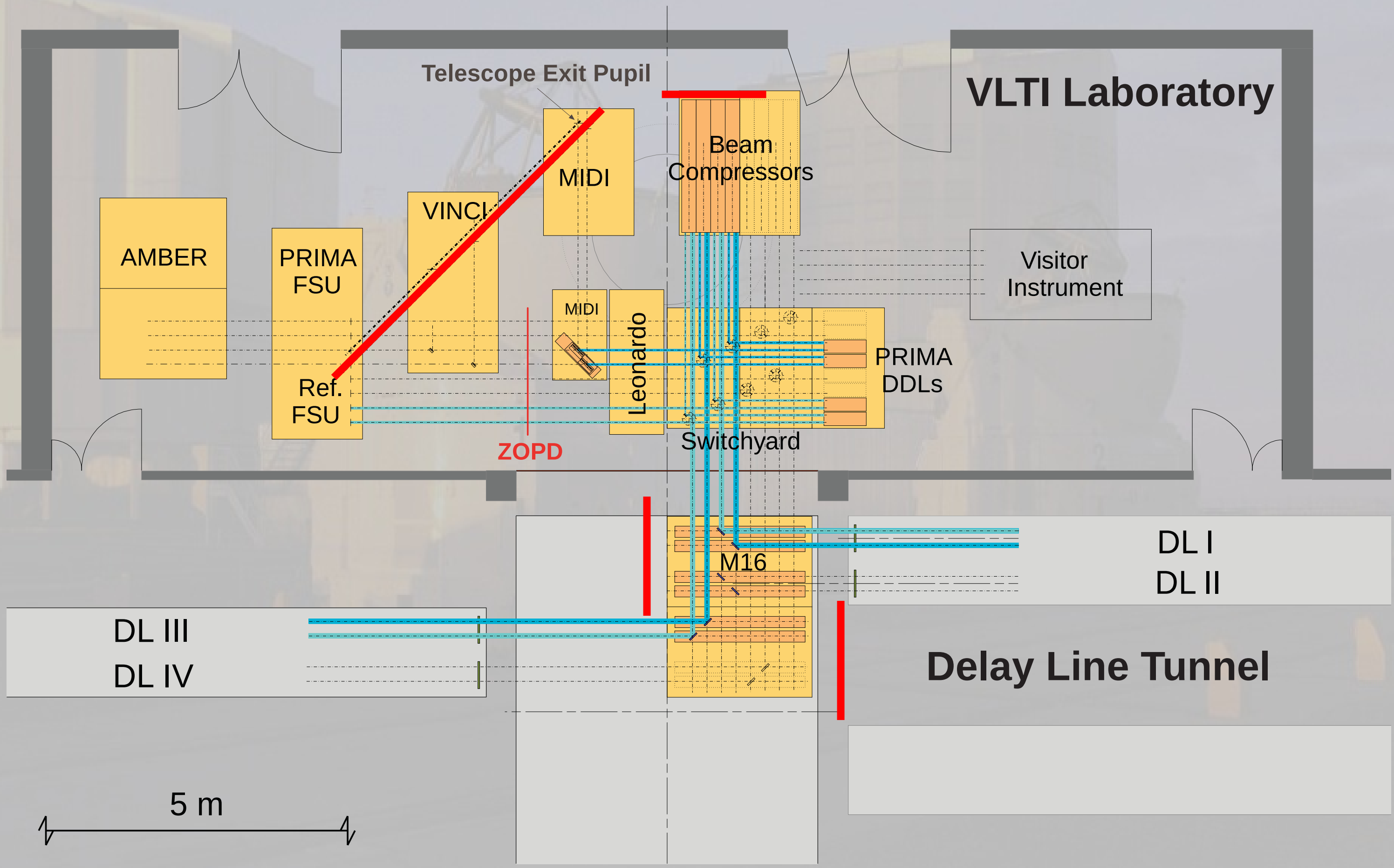
Image planes in the lab



Pupil Planes



Pupil planes in the lab



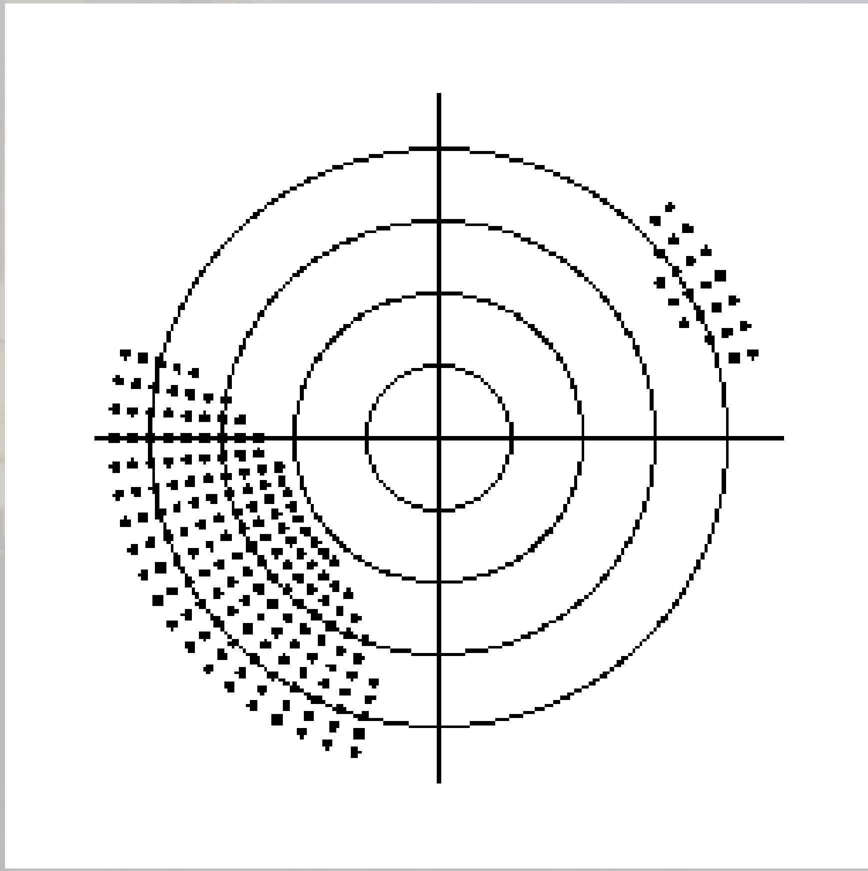
Fringe acquisition

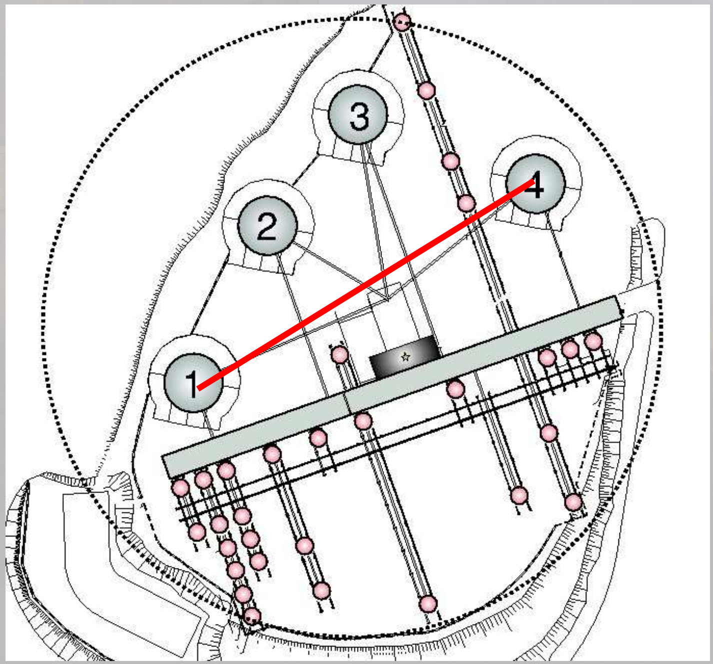
- Preset telescopes and delay lines to the positions given by the object coordinates (including proper motions), taking the pointing models of the telescopes and the OPD model of the interferometer into account
- UTs: acquire the Nasmyth focus guide star - 30’
- Acquire the Coude guide star on MACAO (UTs) or STRAP (ATs) - 2’
- Acquire the science object on IRIS - 2”
- Acquire the science object on AMBER or MIDI (includes chopping)
- Search for the fringe by modulating the OPD in small steps around the ZOPD

Sending image offsets

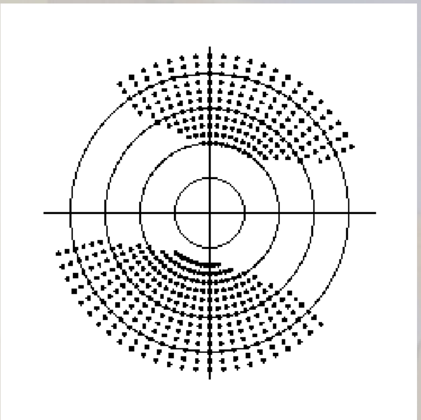
- AMBER sends an OFFSGUV (offset guide probe in UV (ie ground) coordinates) to ISS
- ISS forwards this command to IRIS, IRIS modifies its reference pixel
- IRIS sees that the guide star is not at the new reference pixel and sends an offset to the telescope main guider, eg on a UT the MACAO system
- This offset is applied to the xy-table which holds on top the MACAO curvature sensor
- The MACAO sensor sees that the star is moving away from its central reference point and will counteract by sending a command to the M8 tip/tilt stage,
- If the M8 tip/tilt stage is getting into its operational limit, it will offload the tip/tilt to the M2 mirror

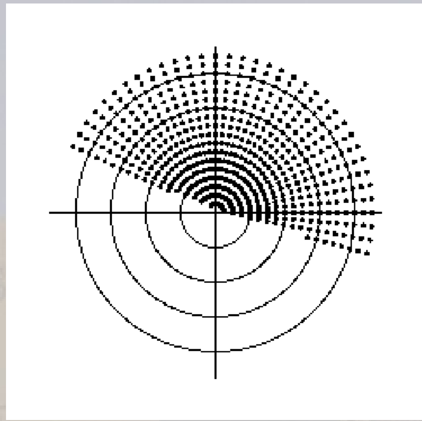
DL restrictions on UT1/4

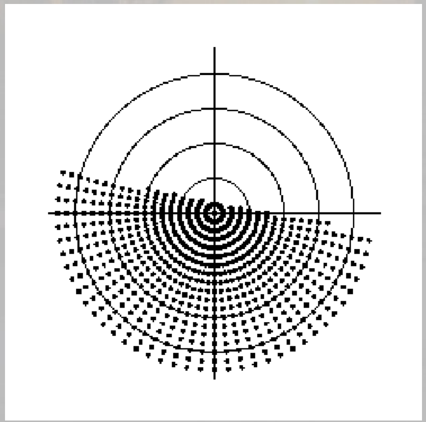


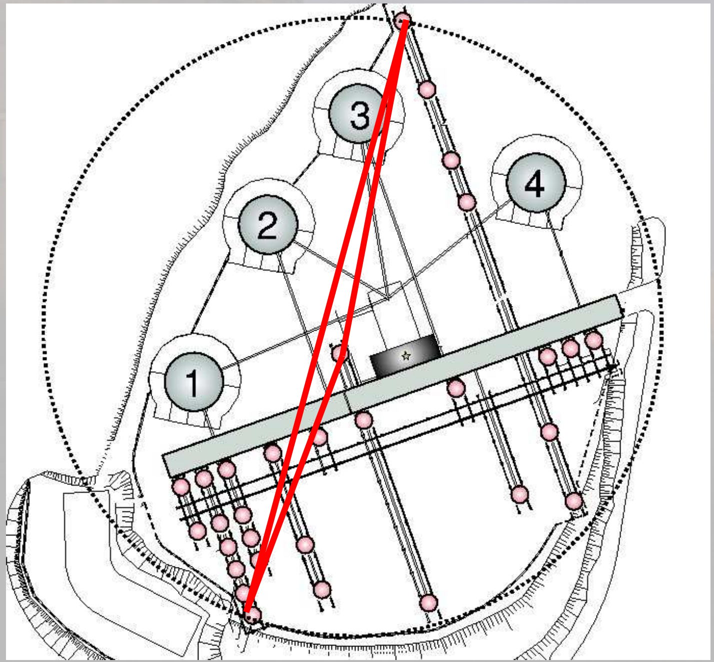


DL restriction on ATs









Dec 2004 VLTI Review results and actions

In late 2004 ESO held a review of the existing VLTI infrastructure to establish its performance, operability, maintainability, and capability to host PRIMA.

Although scientifically successful the VLTI infrastructure required certain subsystems to be brought to robust operation and some others to be fully commissioned to streamline the operations and allow further deployments.

In particular, before PRIMA deployment and second generation instrumentation we would need to know that we can fringe track.

Paranal accepted the infrastructure and launched the Interferometry Task Force (ITF) in Apr 2005 to seek the understanding necessary to make improvements to the system.

Focus: BFQ - the Big FINITO Question, i.e. fringe tracking on the UTs.

Delay Lines

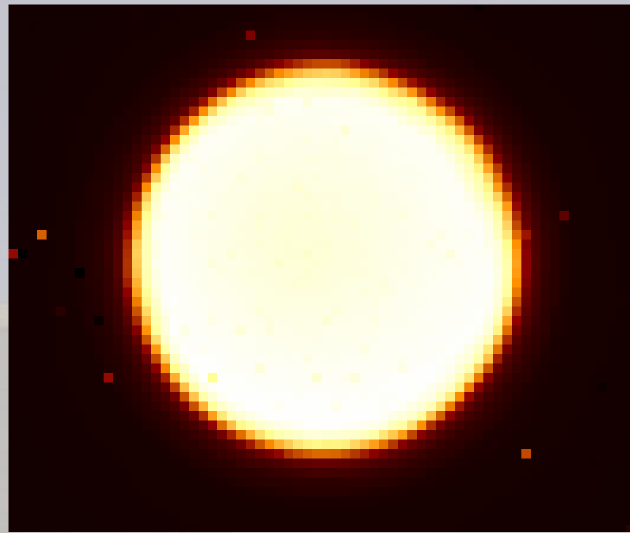
Align the Delay Line rails to better than 20µm and develop a maintenance plan for the alignment.

Install and control the Variable Curvature Mirror in the Delay Lines to allow control of longitudinal pupil position.

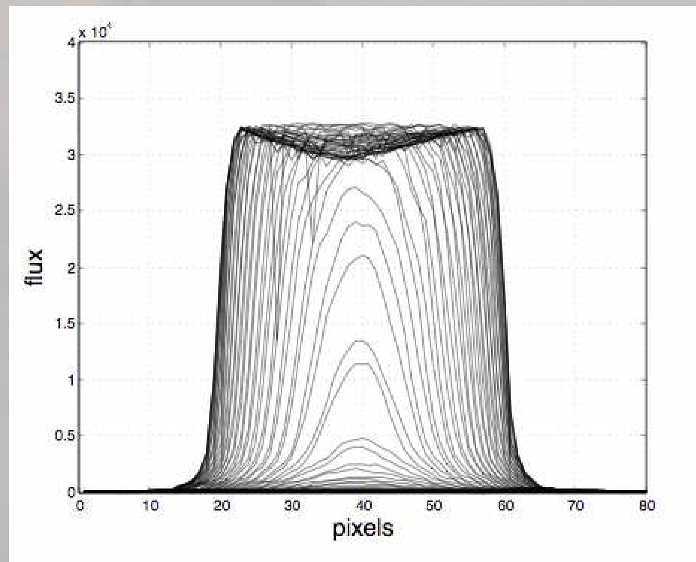
Ensure glitchless operations.

VCMs

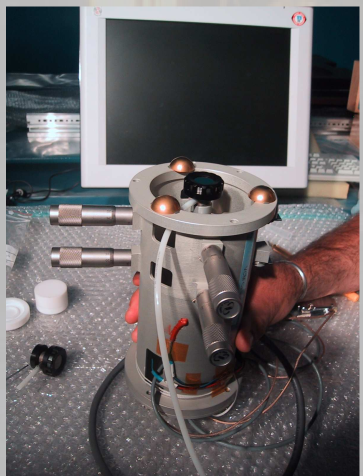
Without the VCMs functioning the field of view of the ATs is limited to an arcsecond or so (approx the diffraction limit of a 1.8-m telescope at 10 microns).

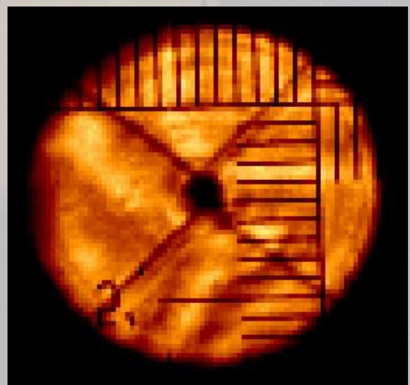


J moon in IRIS



Fwhm = 7.6 arcsec





AT2 pupil on ARAL through DL6

Delay Lines : DELIRIUM

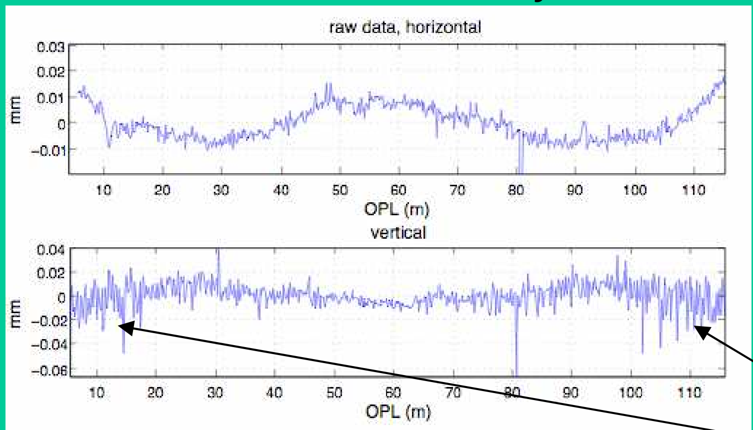
two 2D capacitive sensors *(+water pots for earth horizon referencing)*

One inclinometer for roll measurement

Metrology (laser or coarse)

Complete trajectory reconstruction

DELIRIUM linearity



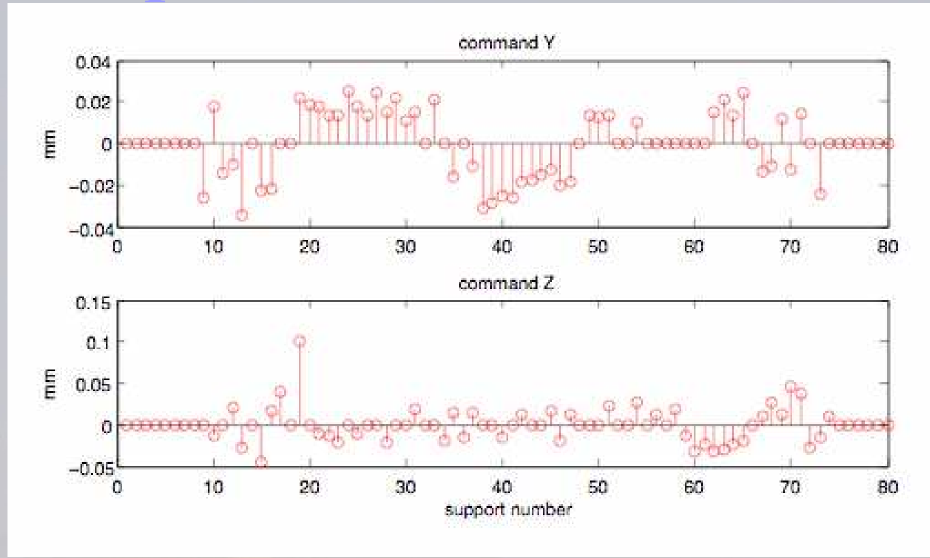
DELIRIUM raw data (DL5).
Diff between 2 scans with wire sags of resp. 9 and 6 mm

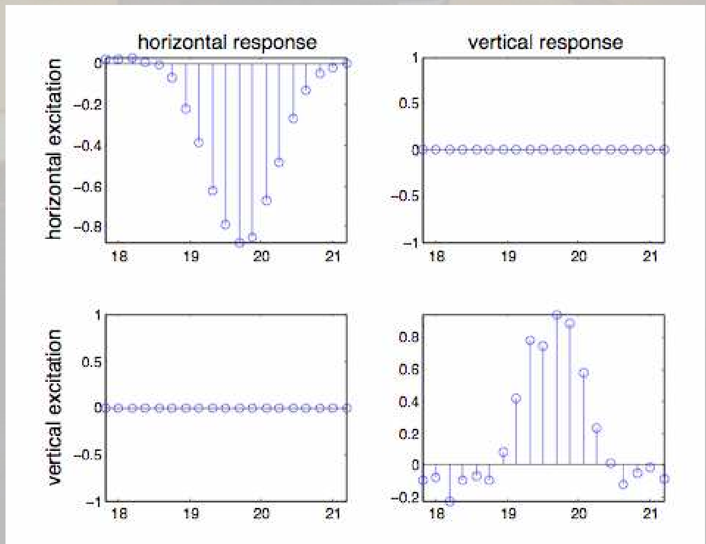
Weird, but goes away with laser metrology (TBC)

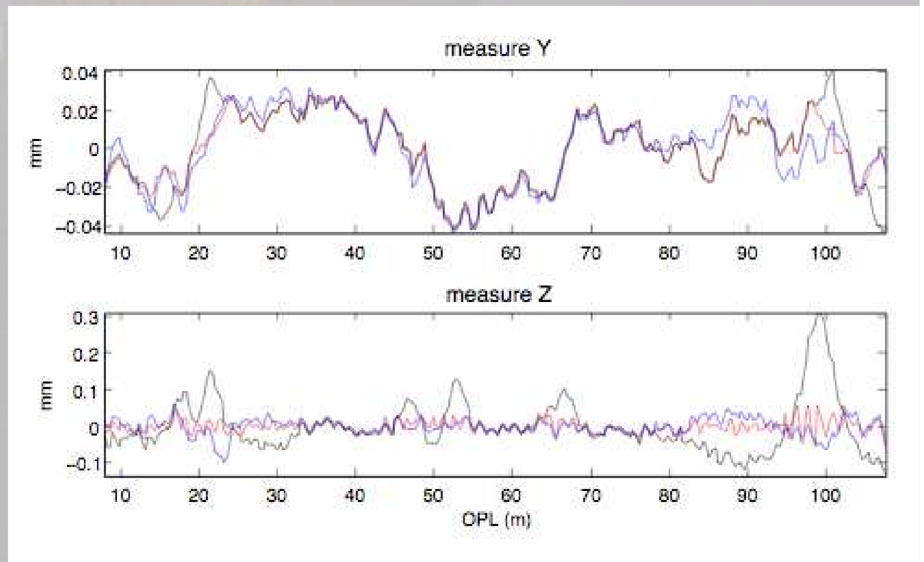
DL rail shape control

Closed loop control based on global reconstruction

- Influence function measurements (on one support)
- Construction of IM / CM (assuming same response on all supports)
- Scan results multiplied by CM to produce correction sequence (control gain = 1)
- Corrections clipped to 10% of max error (or 5 microns ~ limiting accuracy)

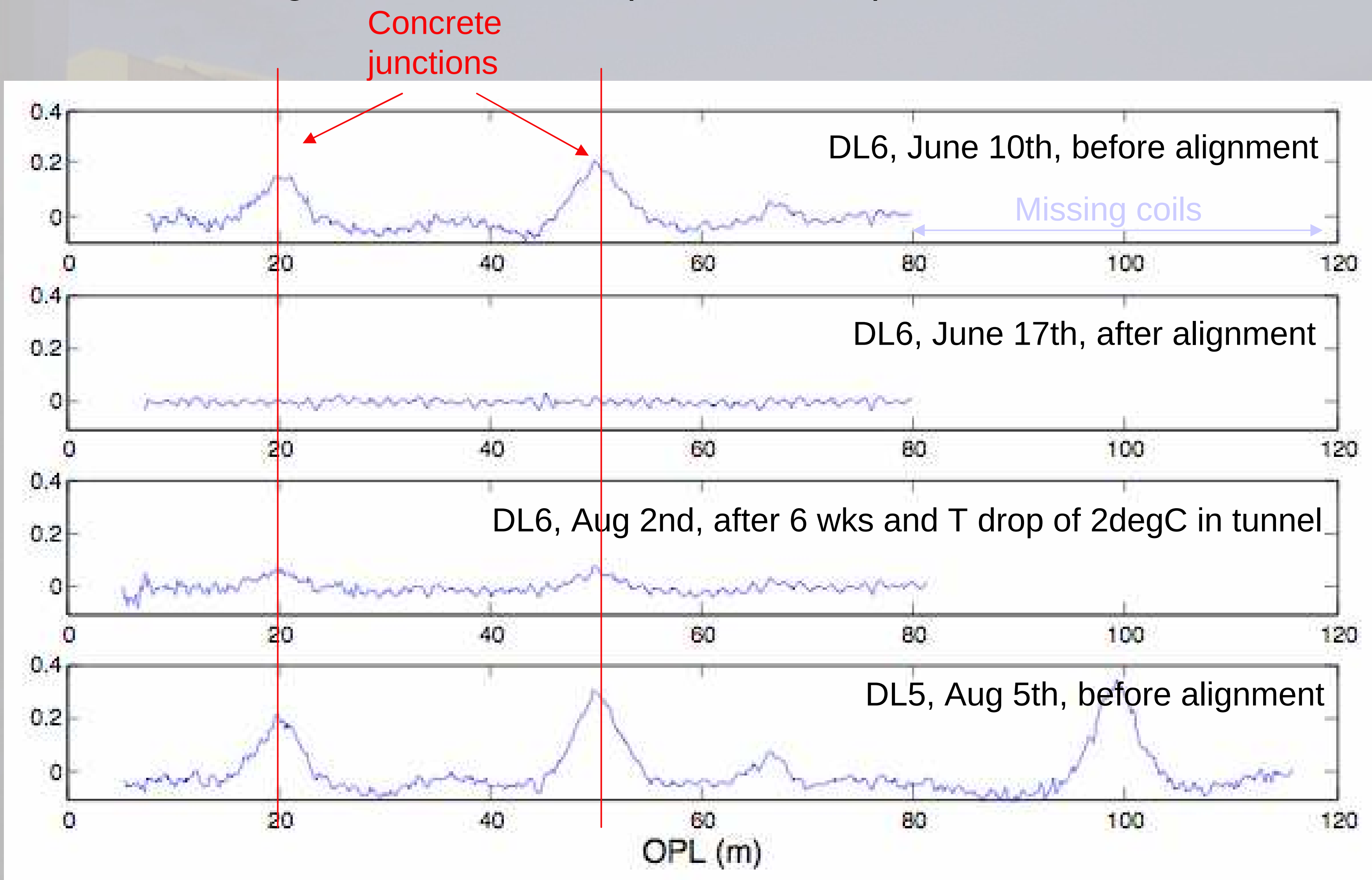






DL rail drift

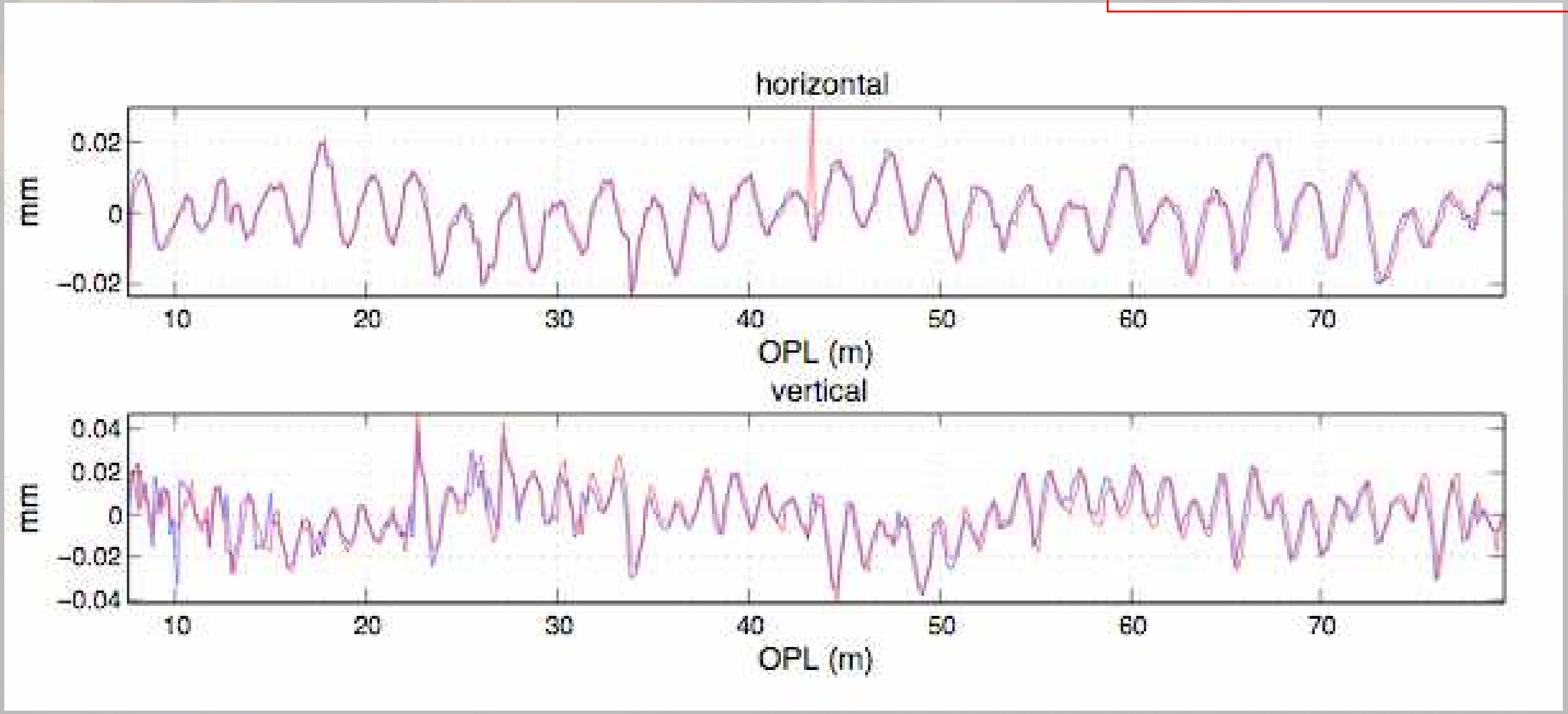
DL6 was aligned in Dec 2004 (summer time)



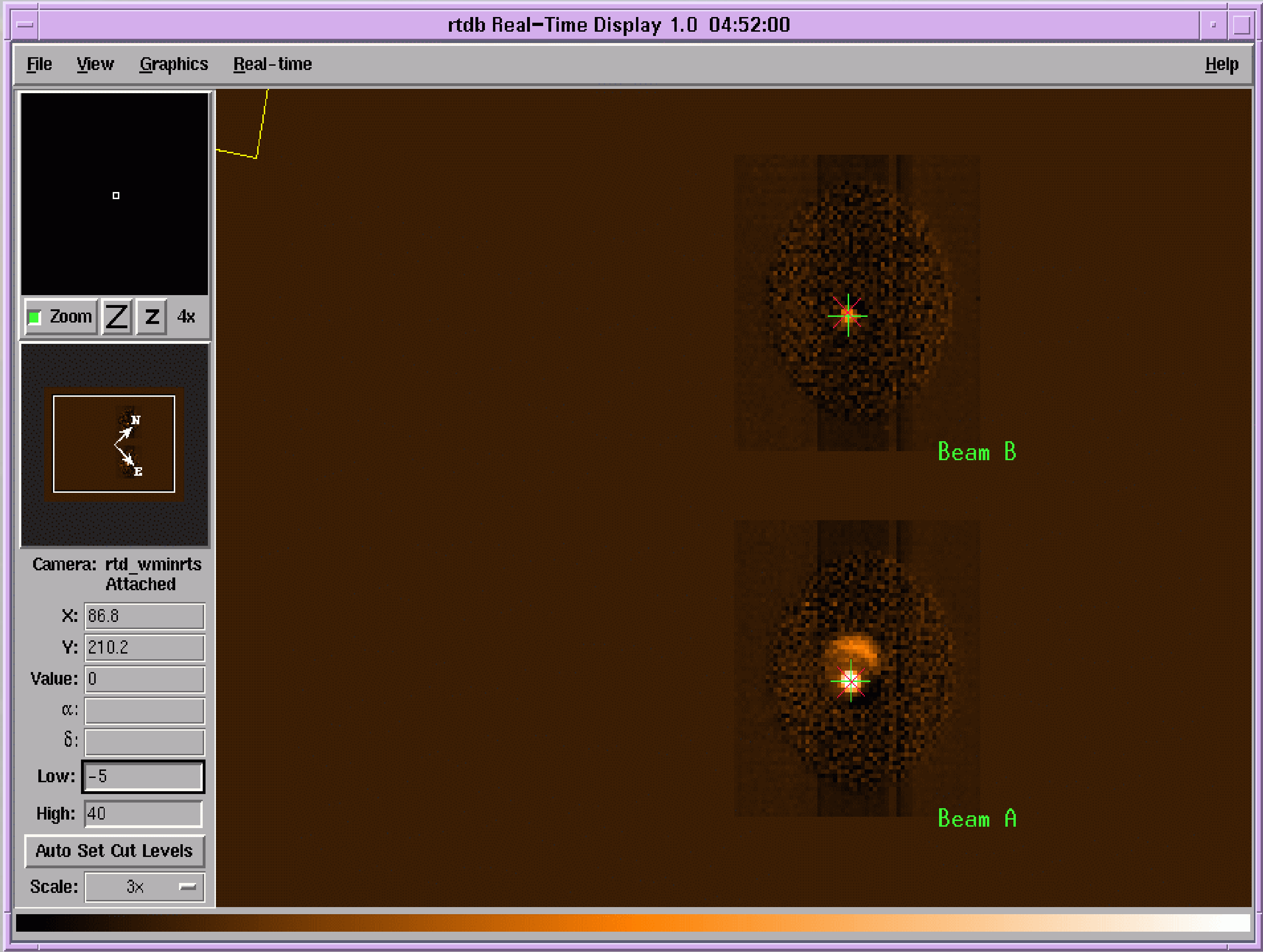
Iquique Earthquake

June 13th, 22:44 UT (during rail alignment campaign)
Richter 7.9
Distance 500 km north (i.e. wf // to rail)
The rail did not deform at all

Blue: DL6 at 08:38 UT
Red: DL6 at 23:23 UT

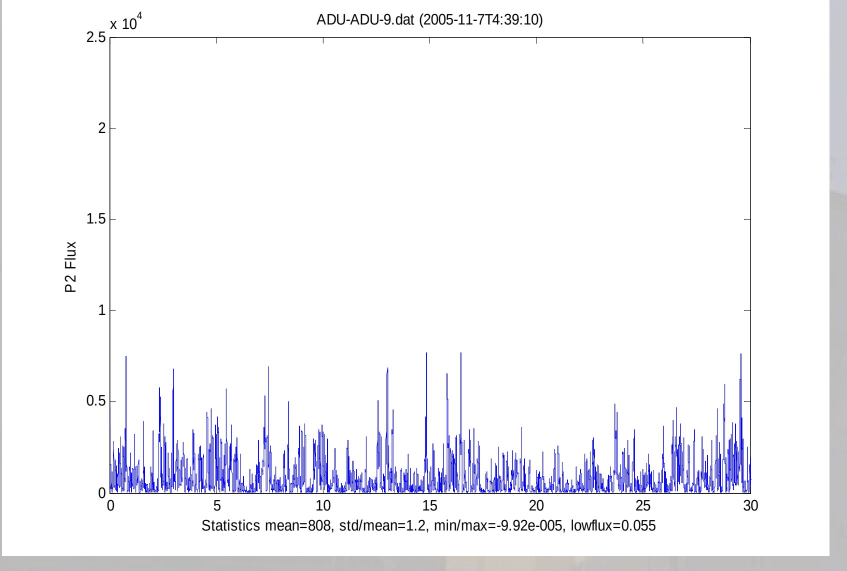


AT field of view

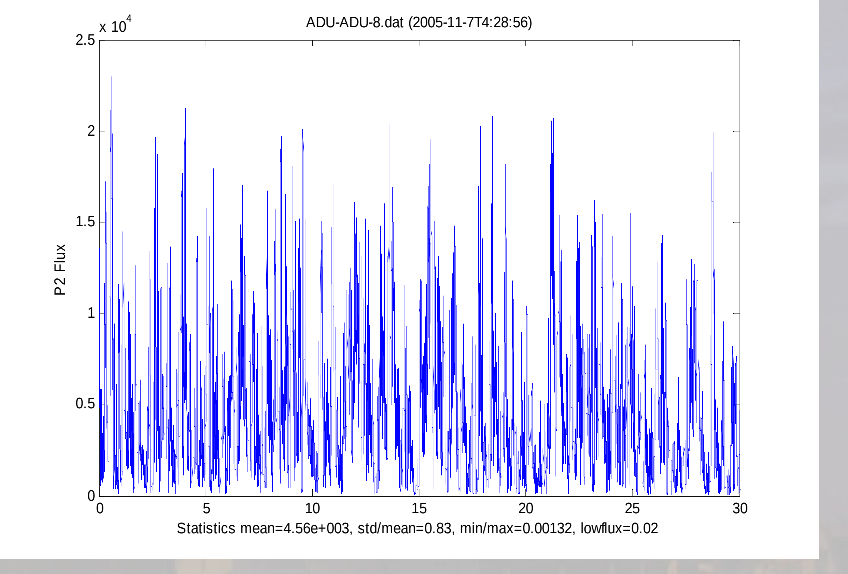


AT Injection

No VCM



VCM



- **Correcting the longitudinal pupil position with the VCM significantly increases the mean injected flux (factor 5 in this case).**
- **As expected the pupil longitudinal position has no impact on the injection fluctuations.**

Beam injection

Beacon from Nasmyth A to IRIS

QuickTime™ and a
decompressor
are needed to see this picture.

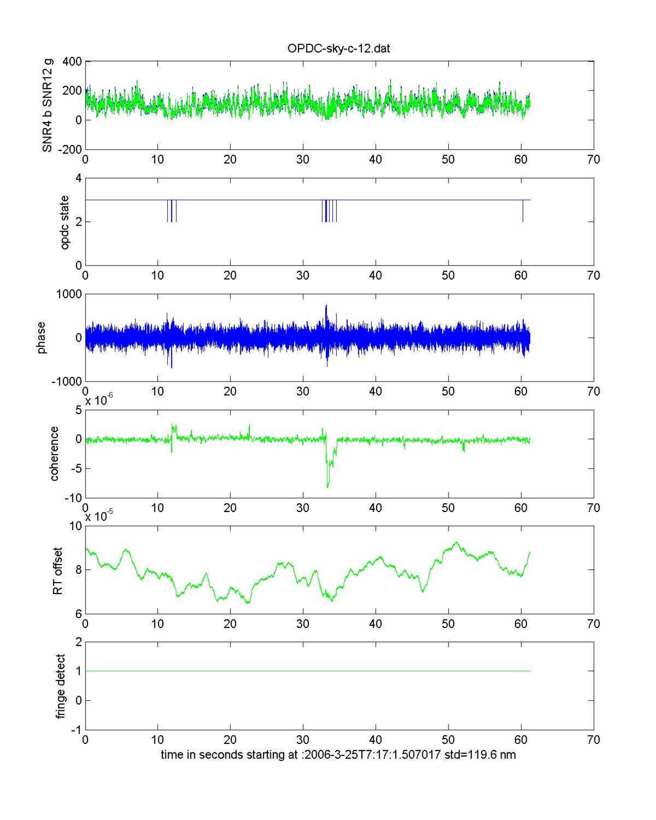
Beam injection

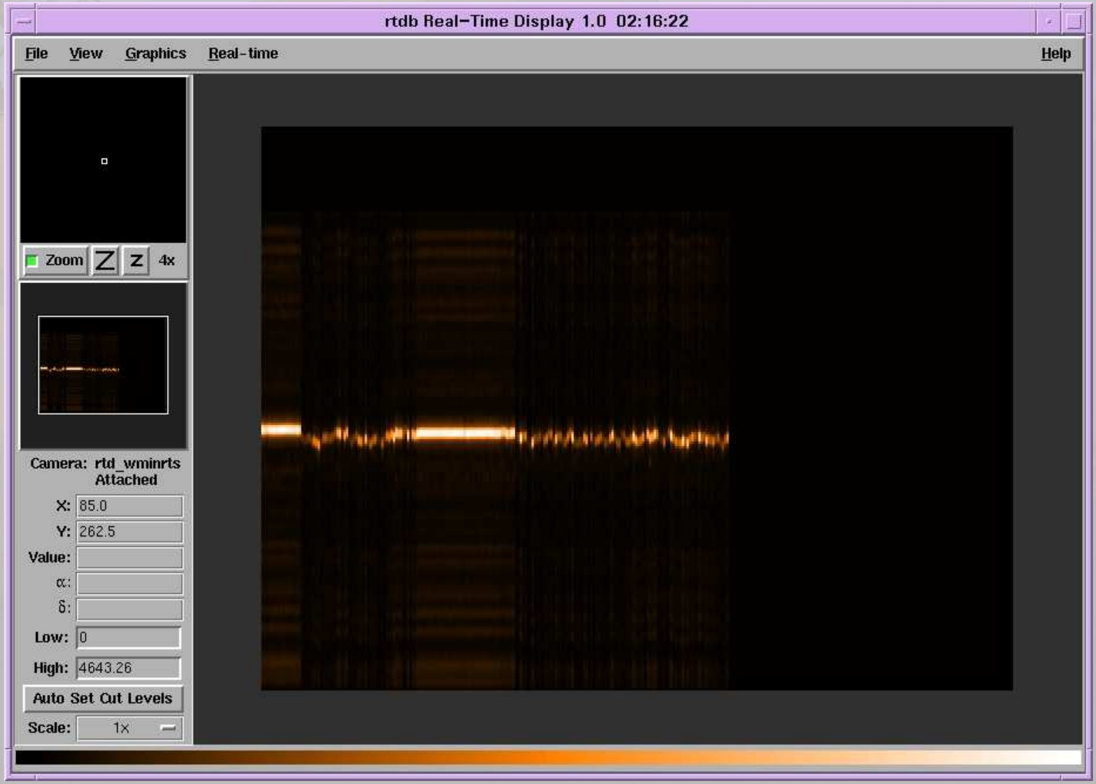
Star to IRIS

Where should the IRIS signal be sent?

The ACU actuators directly in front of the fiber, normally used only to align the fiber, were retuned from a few Hz bandwidth to a few 100 Hz bandwidth and IRIS now drives them open loop (signal from IRIS feeds ACU but there is no feedback)

24th March on the ATs





The stable beam challenge on the UTs

MACAO although meeting specs for long term Strehl performance did suffer from saturation of the mirror creating PSF explosions and flux dropouts.

Long and frequent flux Dropouts are FINITO killers.

The ITF developed the SMA (saturation management) and AW (anti-windup) algorithms and deployed them in the RTC of MACAO

- SMA manages the expensive aberrations without loss of Strehl.

OPD variations

Vibrations coming from:

- MACAO cabinets (50Hz)
- acoustic waves from pumps through cooling circuits (96Hz)
- M1 cell Eigenmodes
- M3 tower Eigenmodes
- …

Possible solutions:

- damp vibrations
- determine vibrations with accelerometers
- determine vibrations with other sensors, ie MACAO

And the answer is:

We can fringe track on the ATs, night after night after night (24, 26, 27, 28, 29 of March all successful) in decent but not exceptional atmospheric conditions and for as long as tens of minutes (it glitches but recovers)

On the UTs we need to do more about the “vibrations”. We have the injection part under reasonable control. By early June 2006 we can fringe track on the UTs, yet with poor performance (~450nm rms)

Current step

Focus the core ITF on the BFQ residuals (UT vibrations).

Deploy VCMs, SMAs, IFGs, DELIRIUMs and put them into operations.

Immediate improvement installation - ATs

- Installation of the variable curvature mirror (VCM) in all six Delay Lines
- Get FINITO operational on the ATs for three beams
- Allow AMBER fringe tracking on three ATs: dichroics, injection stabilization

Further prospects

- **Installation of PRIMA starting in 2007**
- **Start of 2nd gen instrumentation phase A studies**

PRIMA motivation and principle

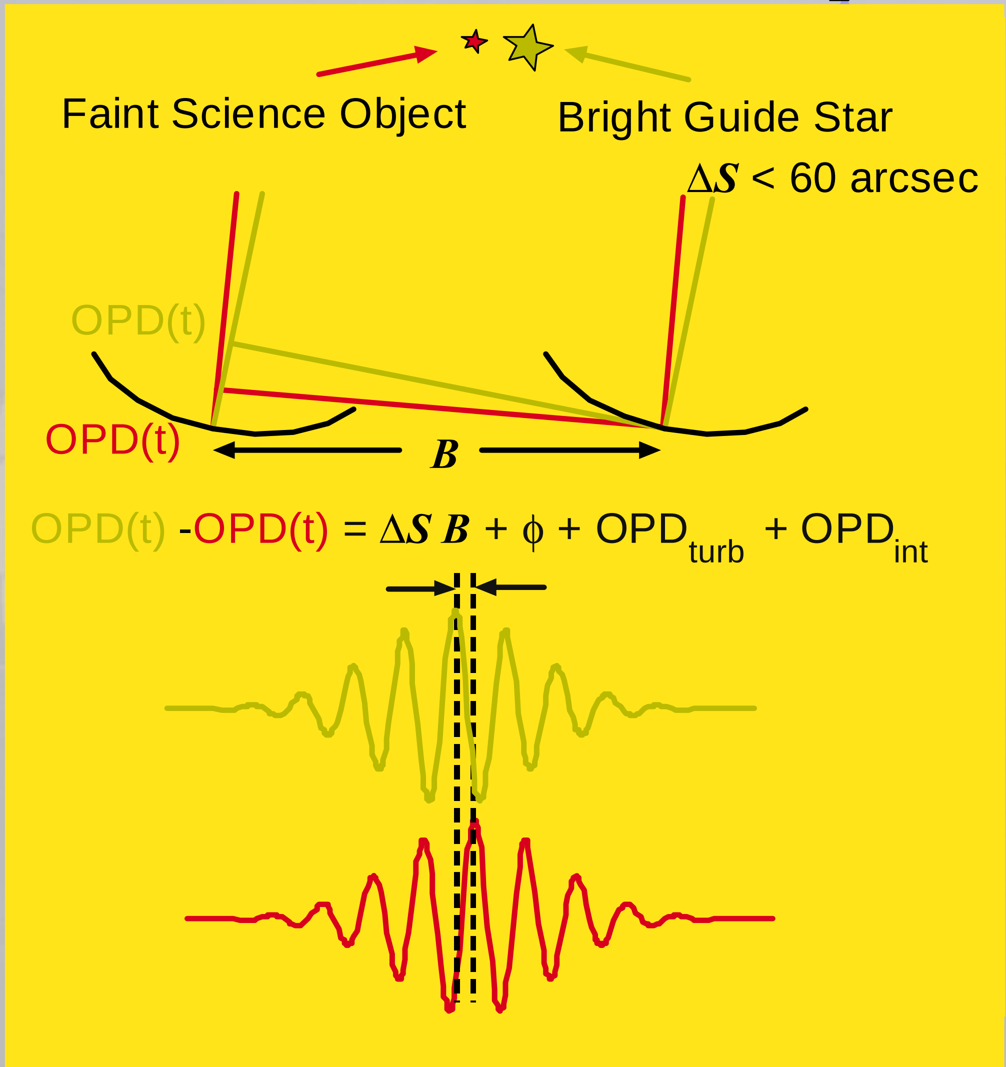
Main limitation of ground interferometers = atmospheric turbulence =>

- Fast scrambling of the fringes =>
  - need of snapshots to measure them =>
  - limitation of the integration time =>
  - low limiting magnitude (VINCI => ~K=8 on UT)
- Impossibility to measure the absolute position / phase of the fringes accurately
  - Fringe position (introduced OPD) <=> astrometry
  - Fringe phase <=> imaging

Solutions:

- "Adaptive optics for the piston term" => increase the limiting magnitude
- Find a phase reference (as quasars in radio astronomy) => phase-referenced imaging and differential astrometry

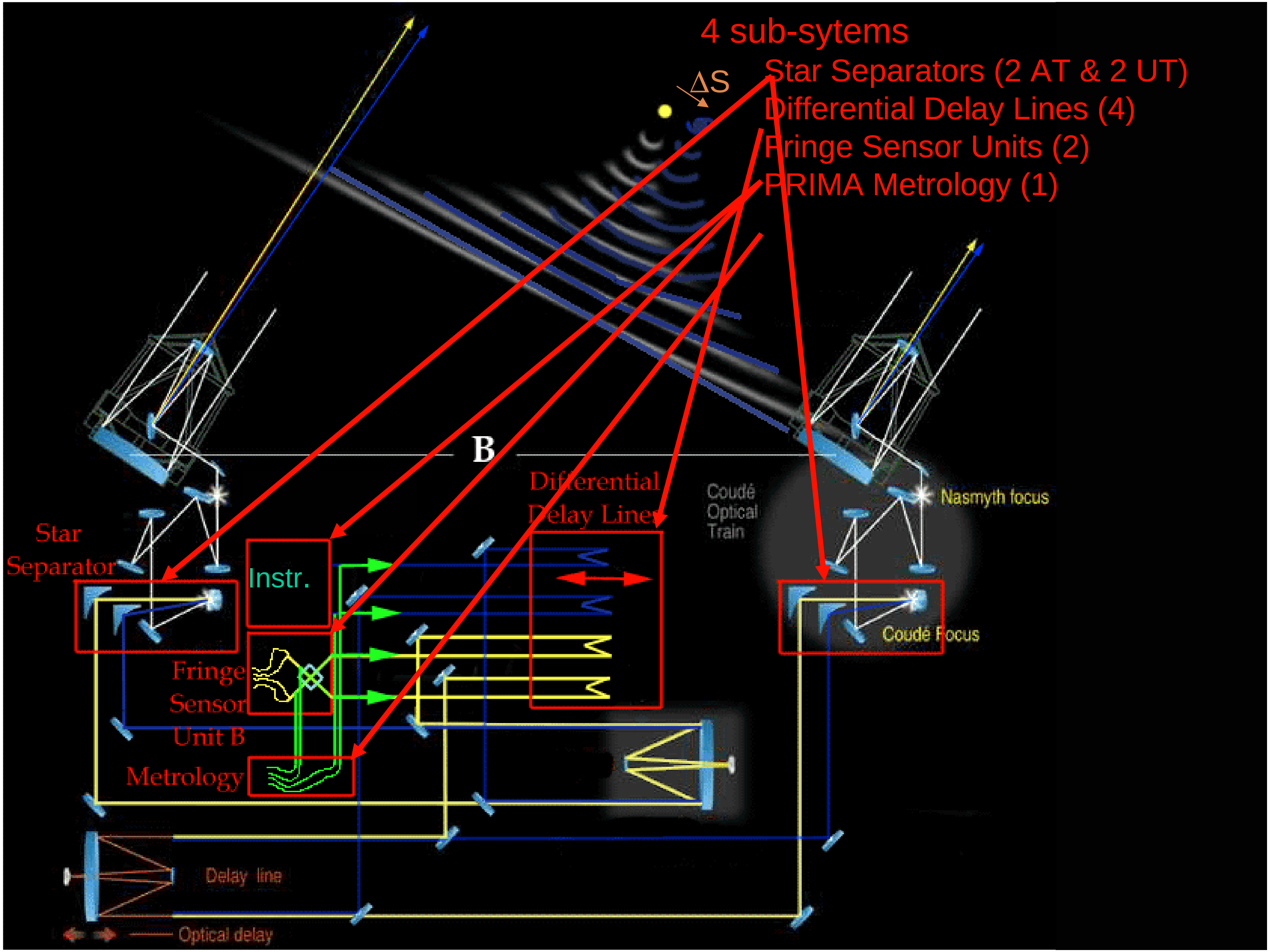
PRIMA principle



Δs = astrometry => goal of 10µas (planets...)

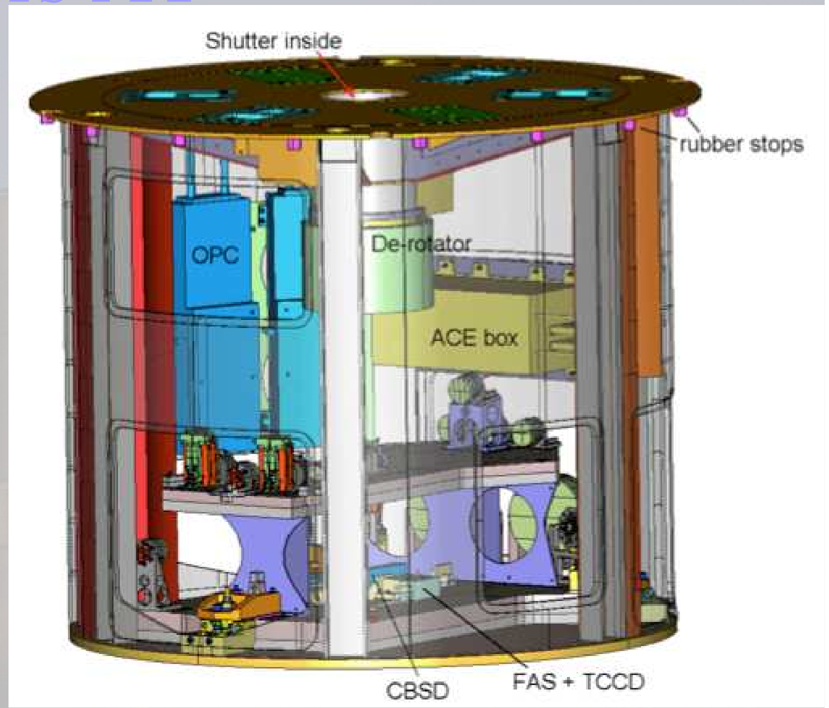
ϕ = imaging with high dynamic range (AGNs, star environment...)

=> needs to know the dOPD with nanometric accuracy

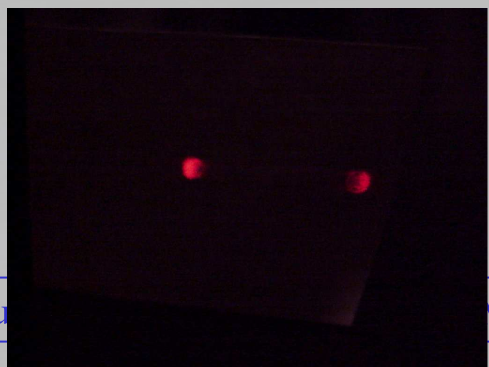


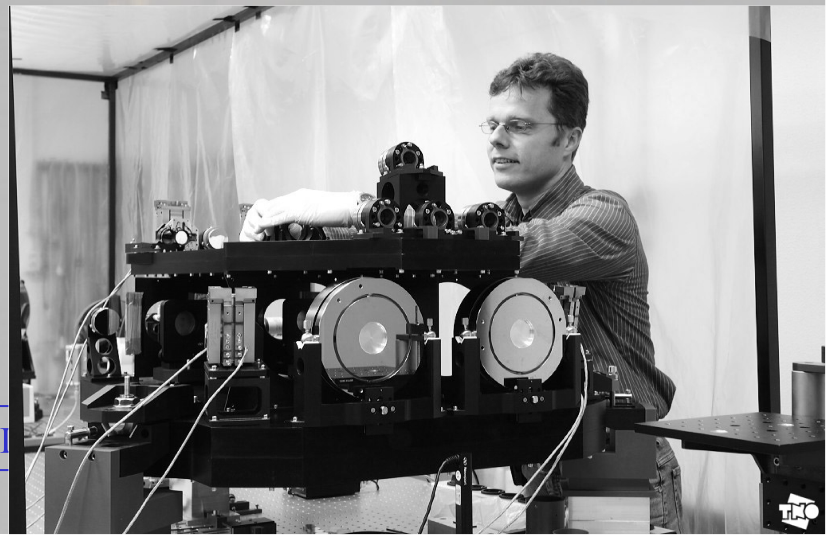
4 sub-sytems
Star Separators (2 AT & 2 UT)
Differential Delay Lines (4)
Fringe Sensor Units (2)
PRIMA Metrology (1)
ΔS
B
Star Separator
Instr.
Fringe Sensor Unit B
Metrology
Differential Delay Lines
Coudé Optical Train
Nasmyth focus
Coudé Focus
Delay line
Optical delay

Star Separators AT

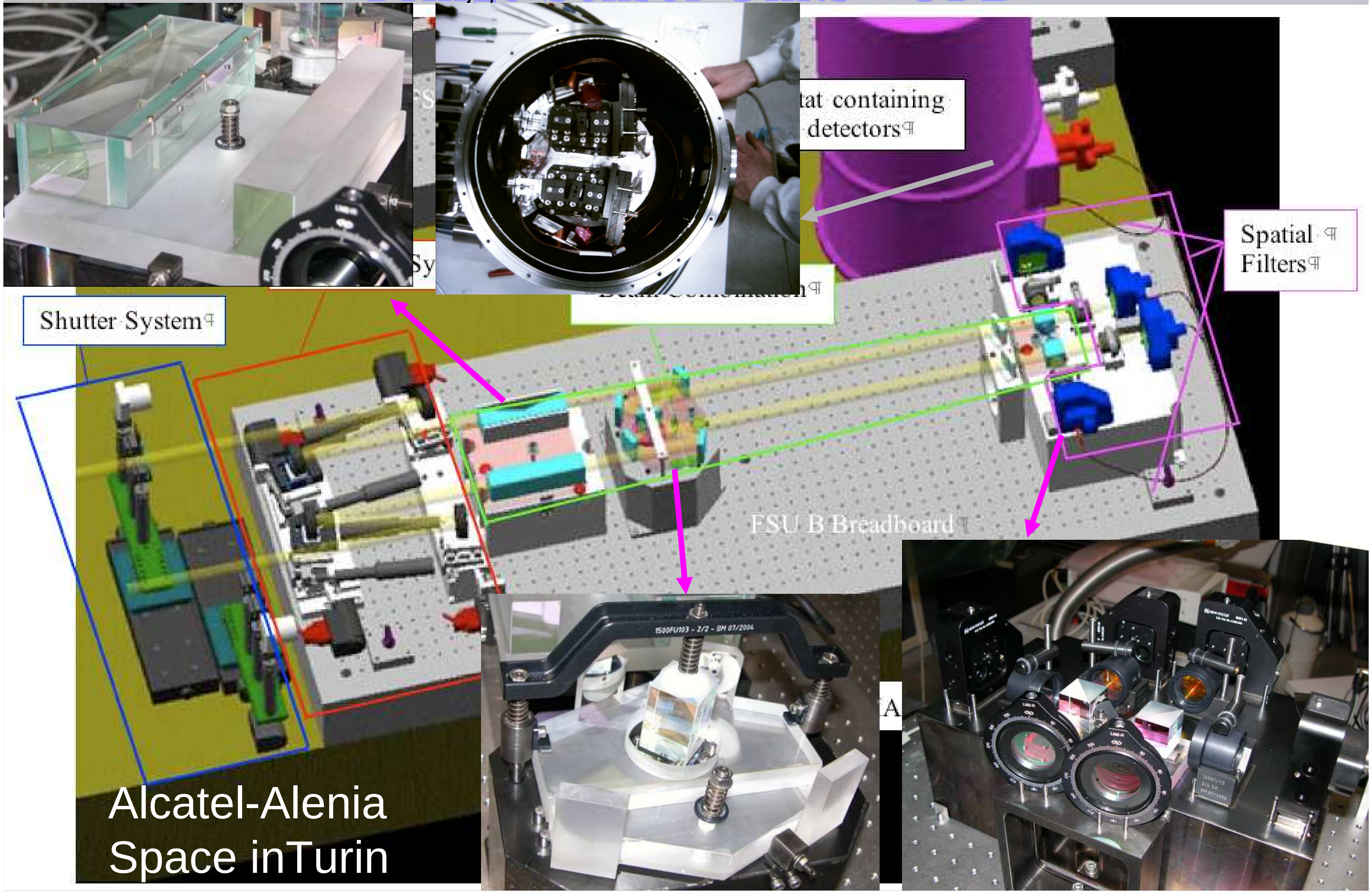


- In cylinder below the ground: ø 1.25m x 1.5 m
- global FoV = 2’
- sub-fields diameters = 2”
- completely symmetrical
- sharp roof mirror to split the PSF of the star in 2
- fast tip-tilt and pupil actuators
- stiff, thermally insensitive structure
- done by TNO (Delft, Holland)

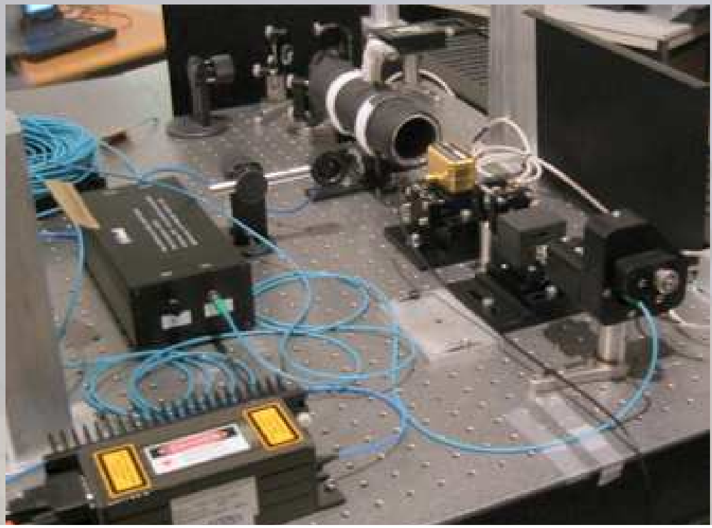


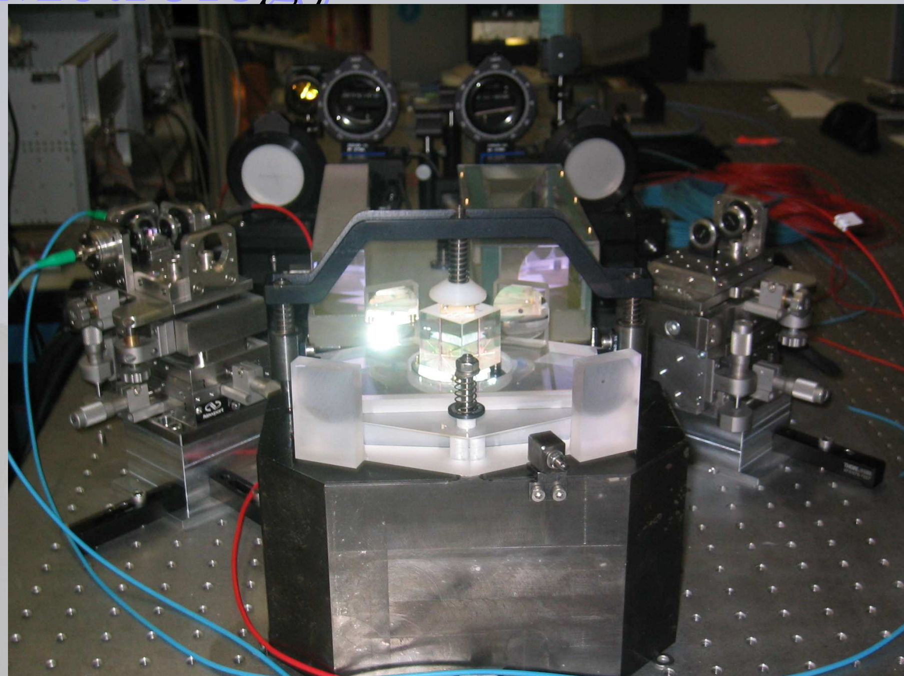


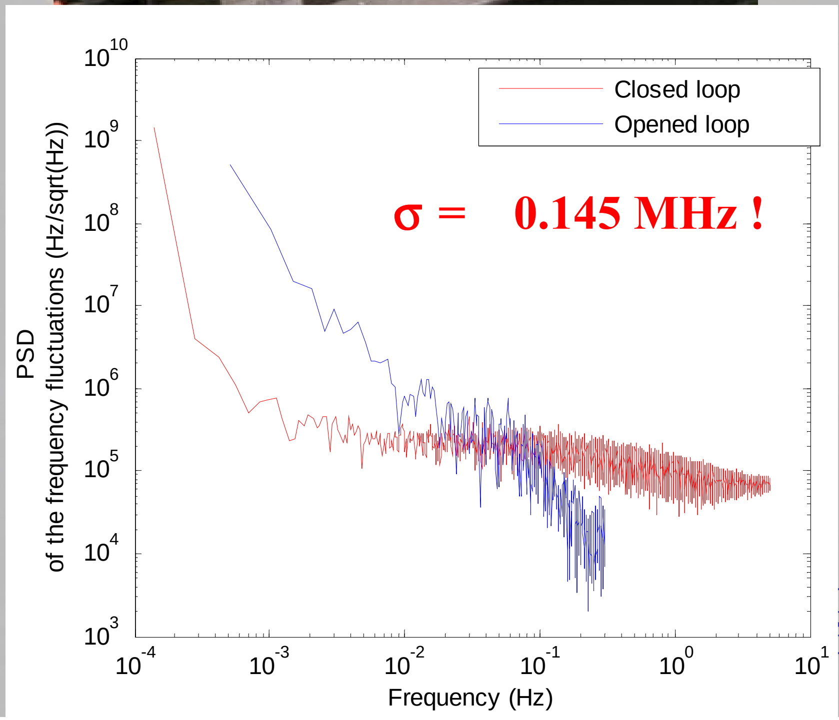
Fringe Sensor Units - OPD

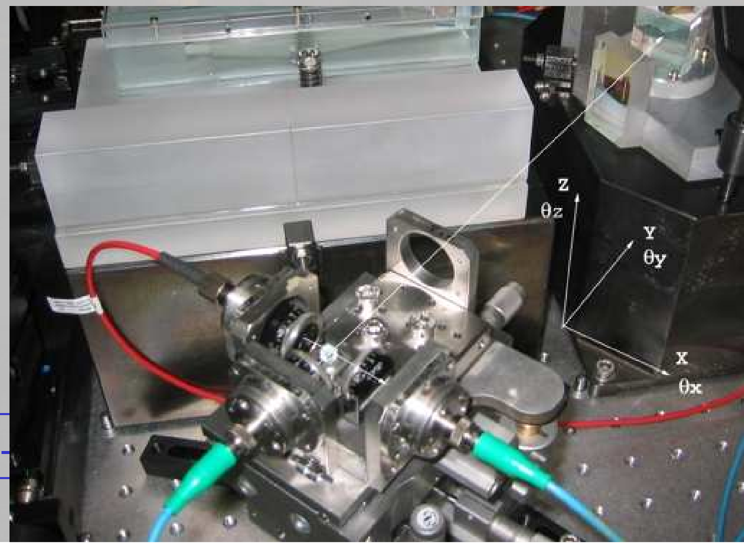


PRIMA Metrology

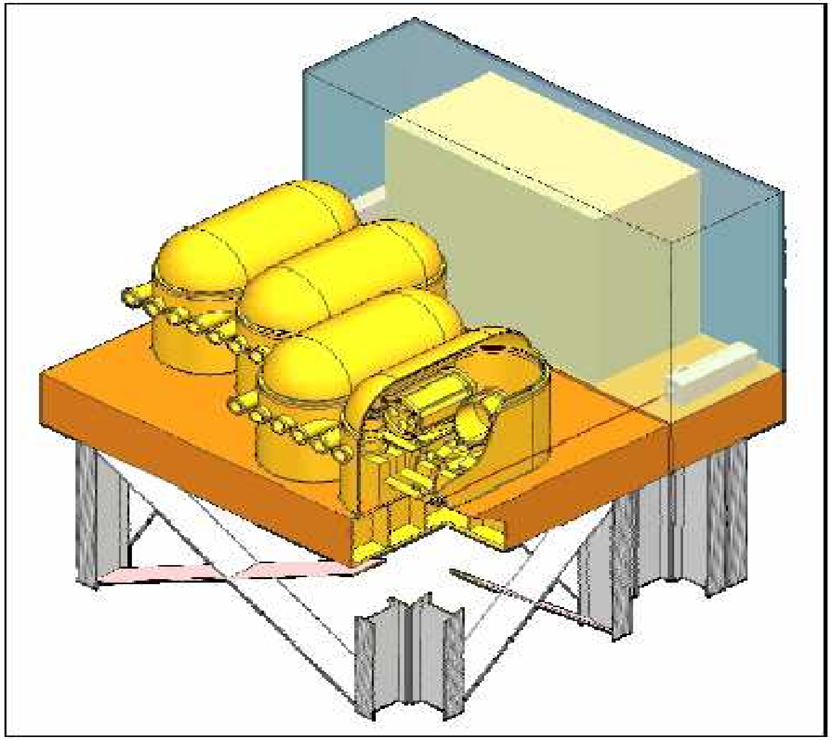








Differential Delay Lines



- under vacuum
- bandwidth 200 Hz - actuation at 8 kHz
- pupil shift when moving < 25 µm PTV
- nanometric resolution

Consortium: MPIA, Obs. Geneva & Heidelberg

Francesco Pepe's talk 6268-73