Adverse effects in optical interferometry

EuroSummer School

Observation and data reduction with the Very Large Telescope Interferometer

Goutelas, France
June 4-16, 2006

F. Malbet
LAOG, CNRS and university Joseph Fourier
8 June 2006

What do we mean by « adverse effects »?

Phenomena that prevent the user to measure what he/she wants!

→ what do we want to measure?

→ how do we want to measure it?

→ analyse the different steps where things can happen !

In the framework of the VLT interferometer with AMBER and MIDI

OUTLINE

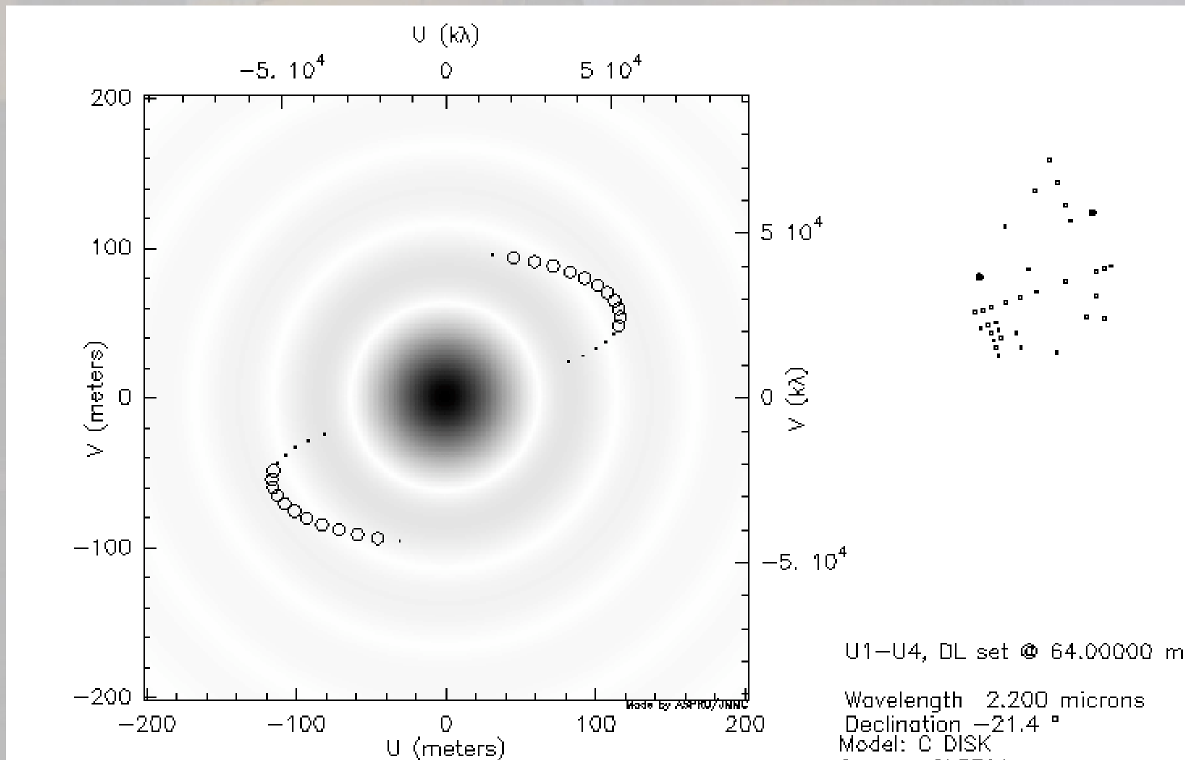
- Reminder on formation of the interference signal
- Atmosphere is a main contributor to adverse effects
- Infrastructure and instruments
- Calibration

Some reminders

REMINDER

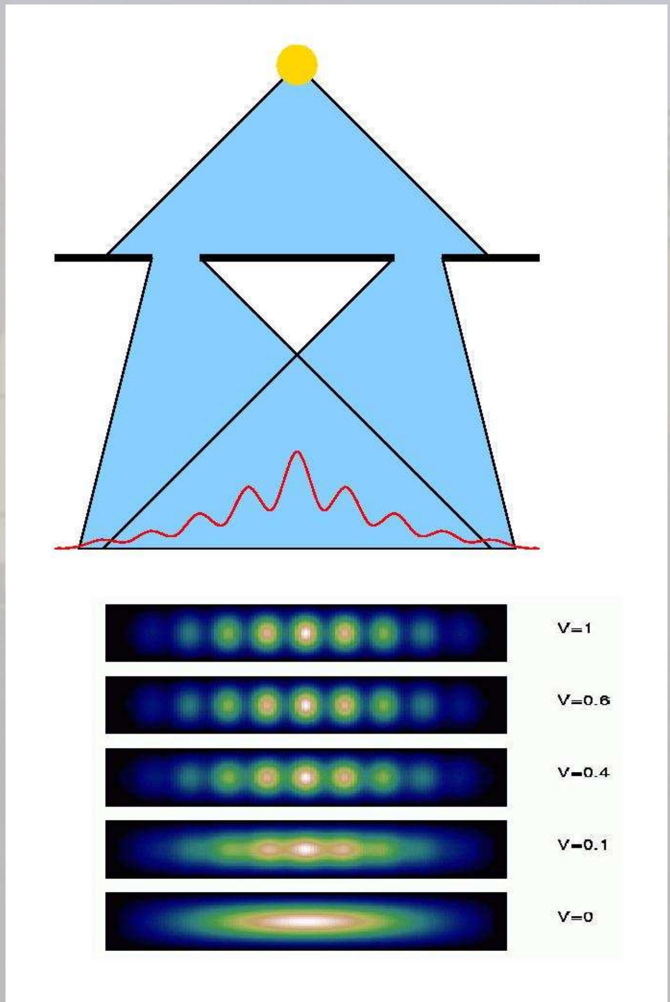
Objectives of interferometry observations

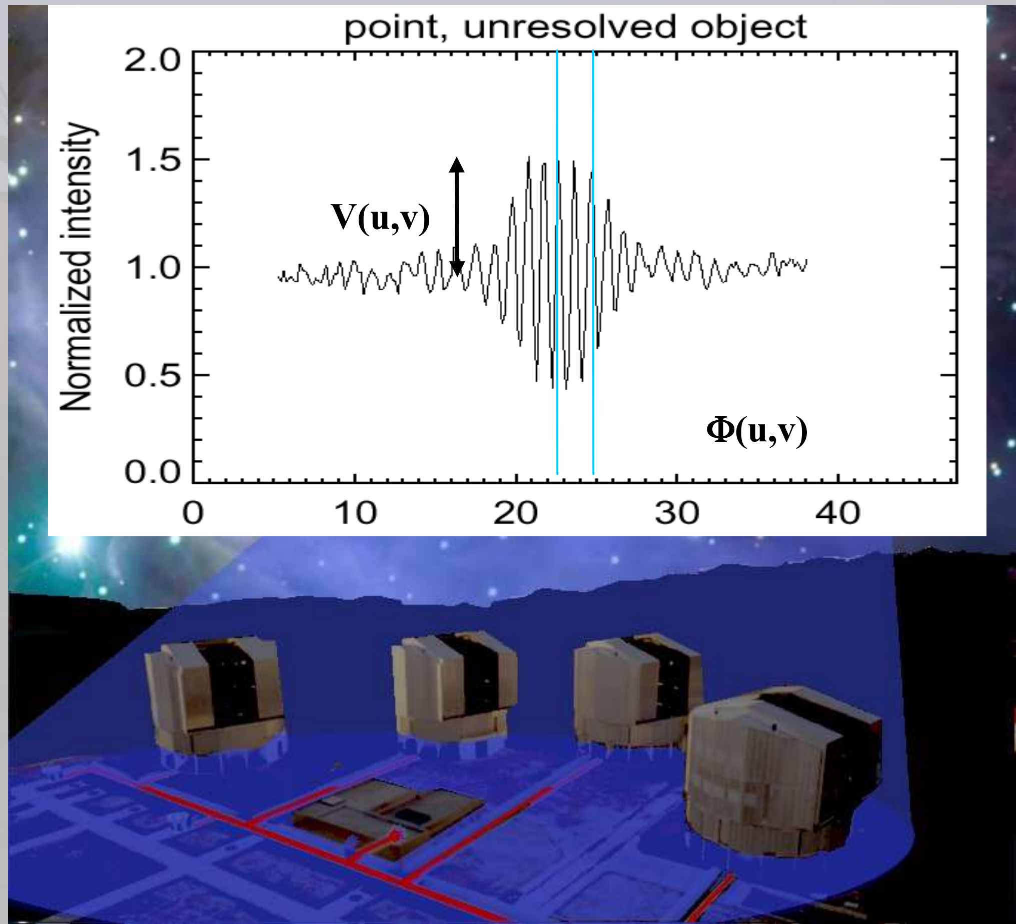
To get spatial information on the object by measuring several components of its Fourier transform (theorem of Zernike-van Cittert).



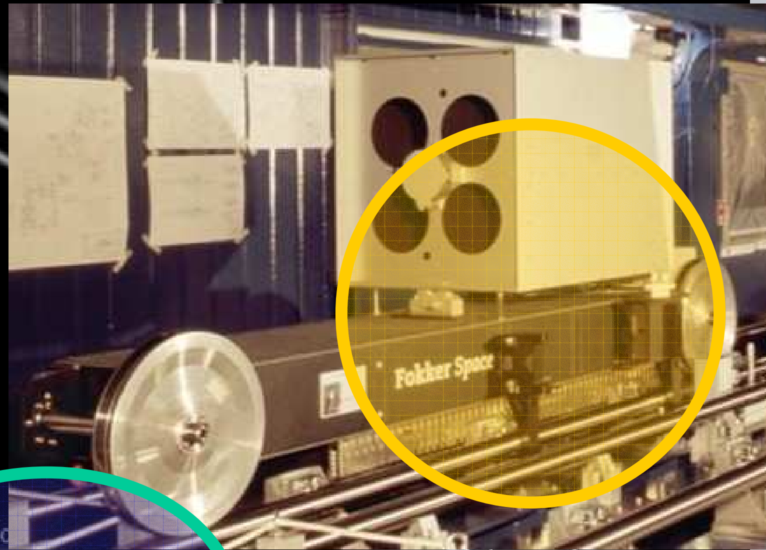
Apparatus to measure the Fourier components of a source with spatial resolution

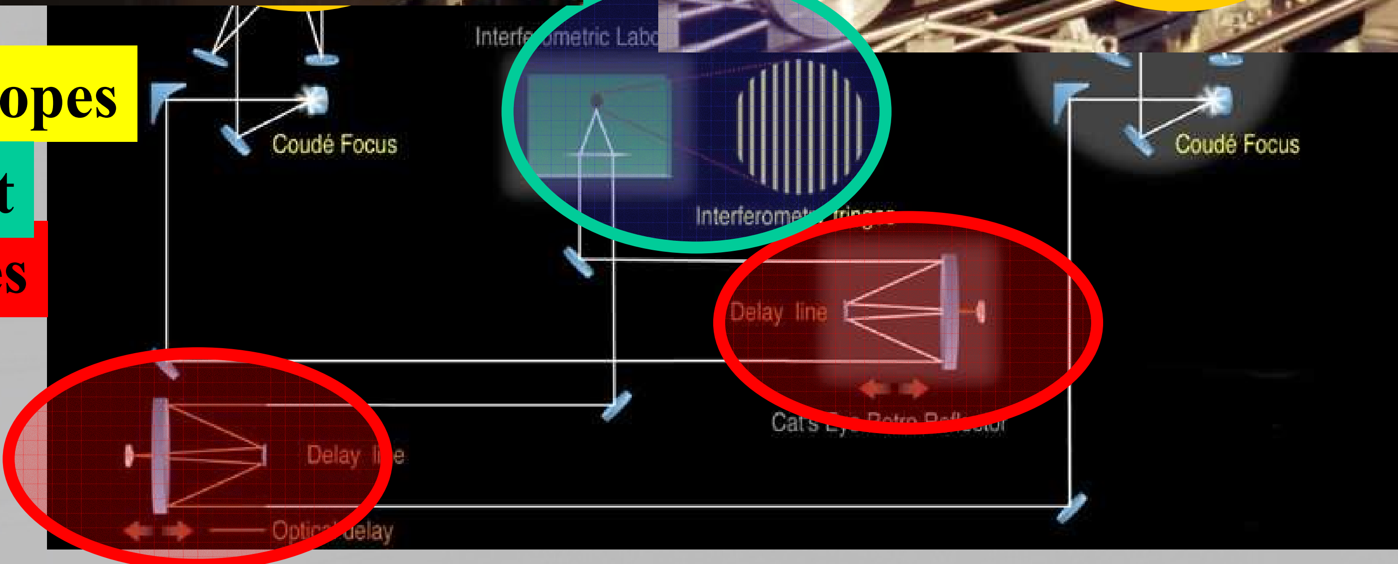
REMINDER





The infrastructure





The telescopes

The instrument

The delay lines

Interferometric basic equation

REMINDER

$$I_{12}(x_k) = I_1 + I_2 + 2\sqrt{I_1 I_2}\, V_{12}^{\mathrm{inst}} V_{12}^{\mathrm{obj}} \cos(2\pi\sigma[s.B_{12} + d_1 - d_2])$$

Where the variables x_k are:

- I_k : input photometry
- V_{12}^{inst} : contrast including system and atmosphere
- σ : wavenumber ($1/\lambda$)
- s : input beam direction
- B : baseline
- d_k : delay

Realistic interferometric equation

REMINDER

The measurement are integrated over a number of variables:

$$P = \int_{x_1}^{x_2} I(x)\,dx$$

$$P = \frac{1}{x_2 - x_1} \int_{x_1}^{x_2} \left[I_1 + I_2 + 2\sqrt{I_1 I_2}\, V_{12} \cos\left(2\pi\sigma[s.B + d_1 - d_2]\right)\right] dx$$

Where x_k can be:

- I_k : input photometry
- V_{12}^{inst} : contrast including system and atmosphere
- σ : wavenumber ($1/\lambda$)
- s : input beam direction
- B : baseline
- d_k : delay

Main sources of perturbations

REMINDER

- **Atmosphere:** spatial and temporal fluctuations of wavefront
- **Individual elements of infrastructure:** displacements (tip-tilts, optical path, piston), vibrations, drifts
- **Photon detection:** photon noise, read-out noise, dark current, cosmetics
- **Polarization**: light is naturally polarized
- **Human action**

The Atmosphere

Atmosphere

ATMOSPHERE

Key parameter: refraction index

***n*(λ,t,r)**

– Wavelength dependence

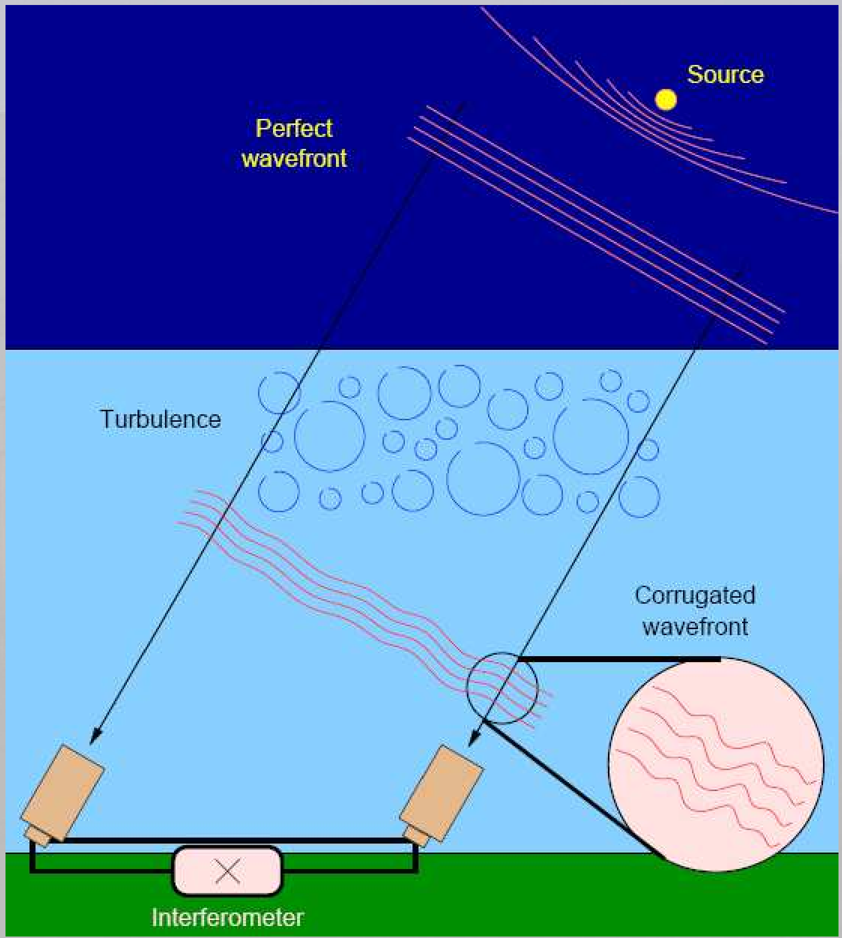
Eddies due to turbulence induce temperature fluctuations

– Spatial dependence

– Temporal dependence

→ corrugated wavefronts

→ OPD fluctuations

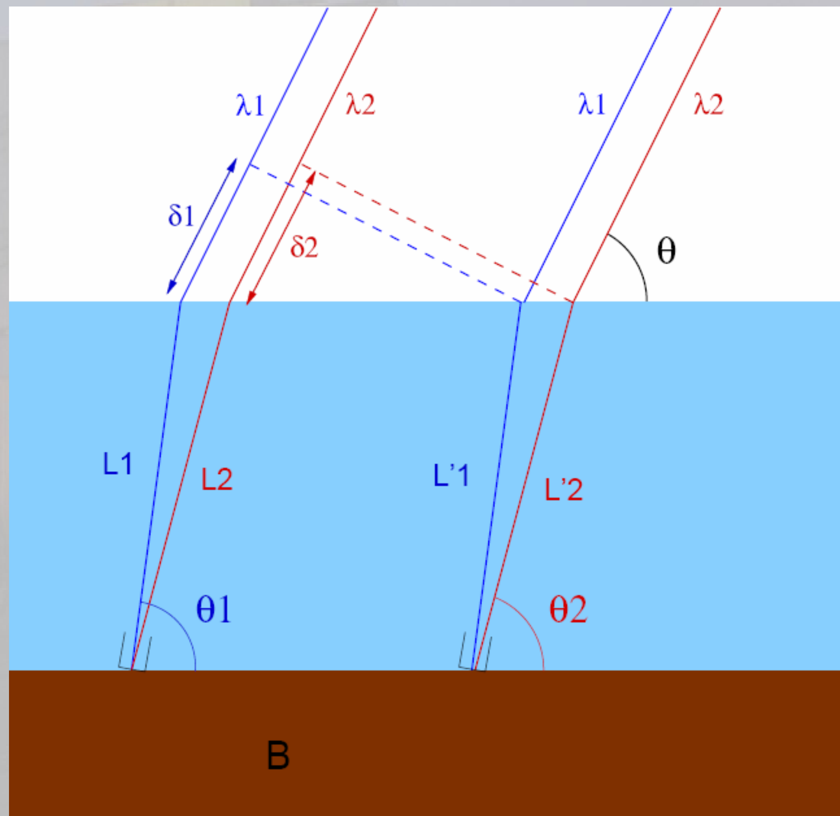


Transverse atmospheric refraction

Dispersion of the light for each incoming beam: the focal image is replaced by a small spectrum

BUT no delay problems

Main limitation is loss of optical throughput especially if light is injected in hole or fiber.



ATMOSPHERE

Longitudinal atmospheric dispersion

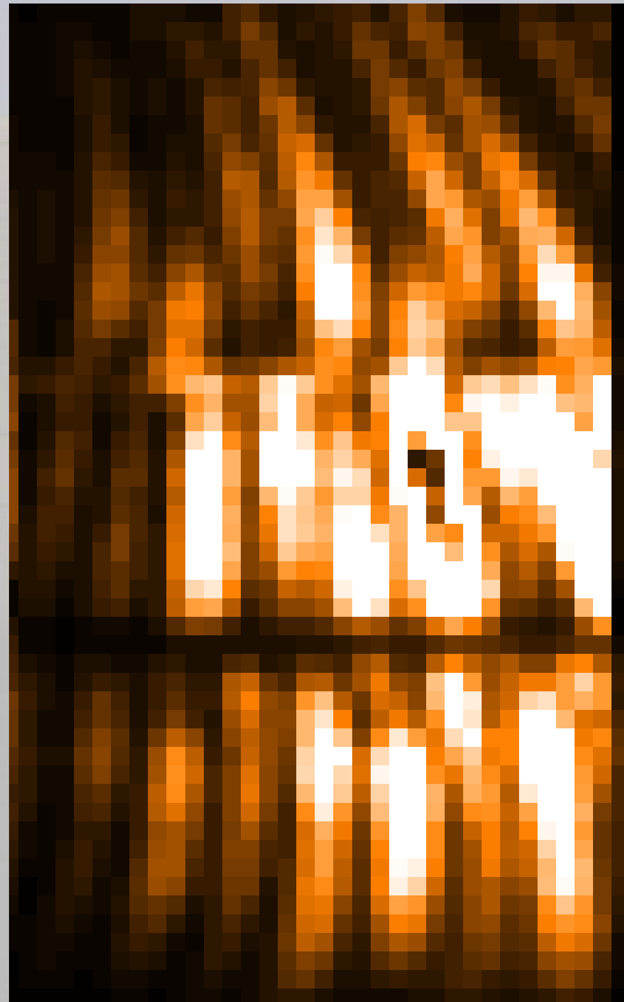
Unevacuated delay lines means that the delay corrected by the delay lines is valid only for a wavelength:

$$\mathrm{OPD}(\lambda) = \left(\frac{n(\lambda)}{n(\lambda_0)} - 1 \right) \delta$$

→ Curved fringes if spectral resolution

→ Loss of contrast if broad band observations

λ



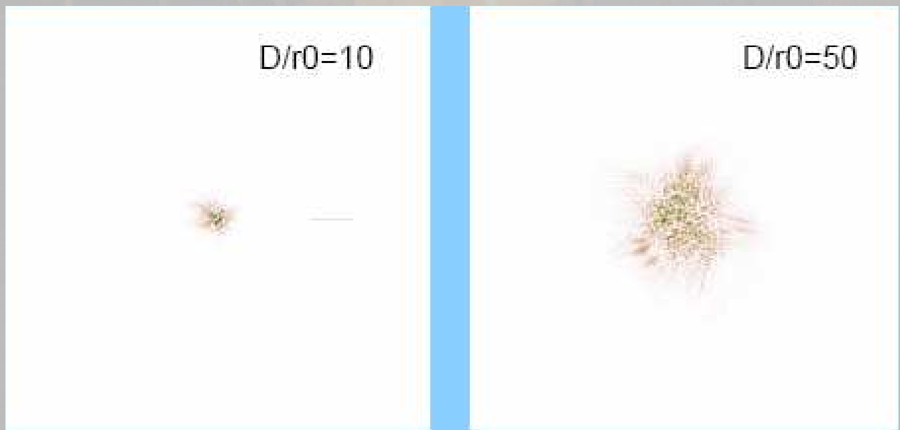
ATMOSPHERE

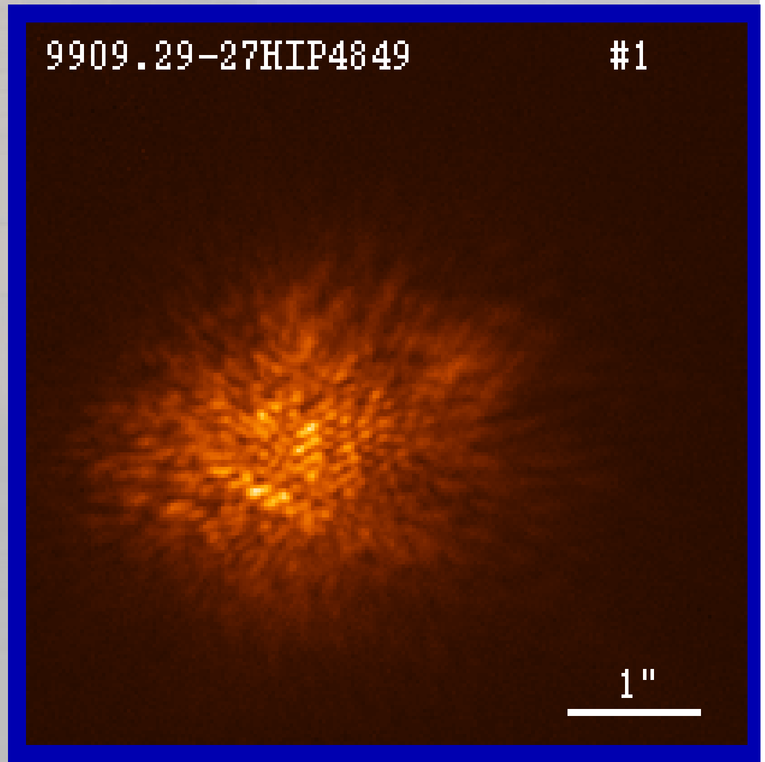
Wavefront corrugation

Speckles due to wavefront corrugation.

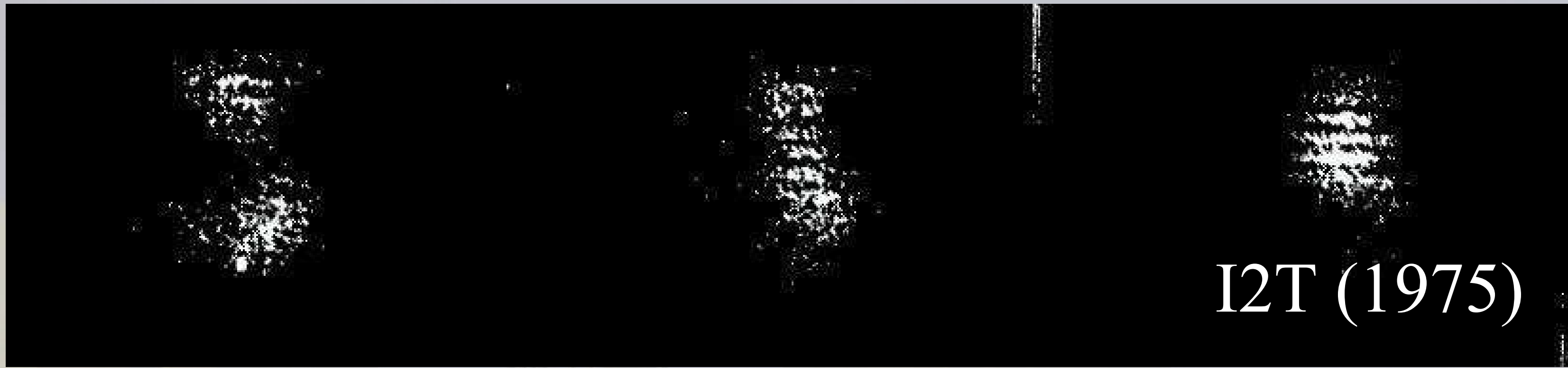
The key parameter is the **Fried parameter:**

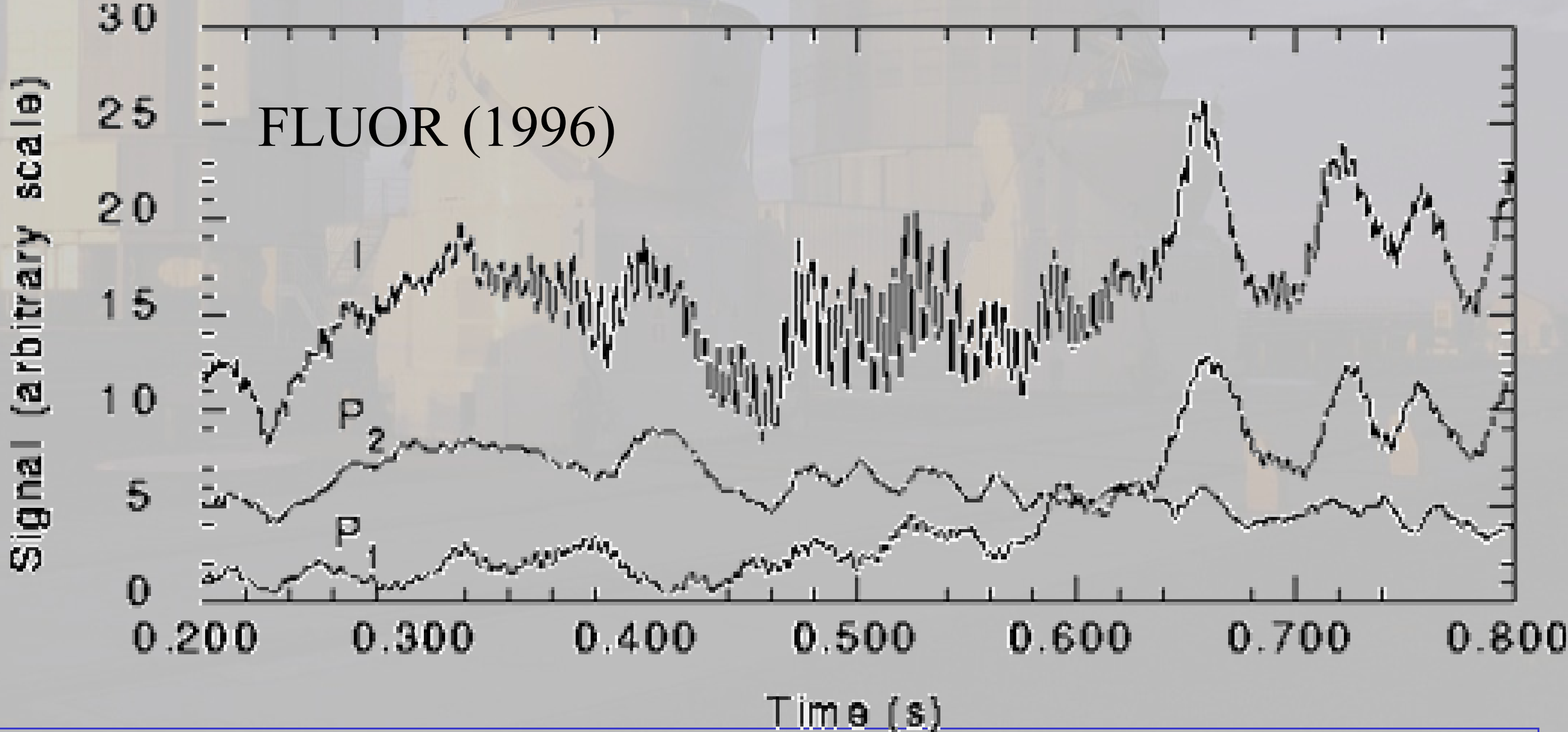
- Size of coherence cell
  $r_{0:}$~60cm@2.2µm
- Coherence time τ_0~50ms
- Outer scale L~10-100m?





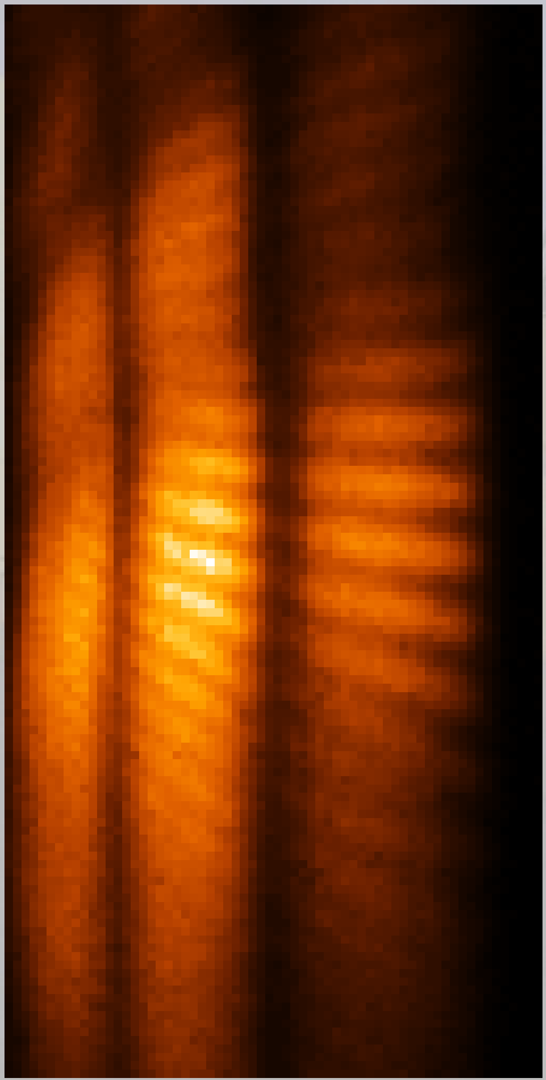
ATMOSPHERE


I2T (1975)

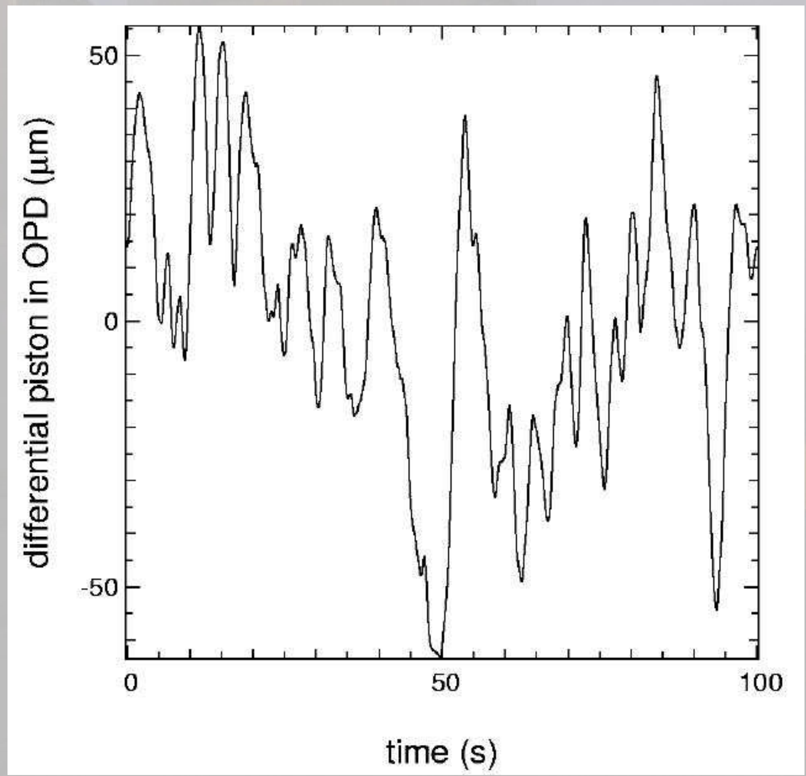

FLUOR (1996)
Signal (arbitrary scale)
Time (s)
I
P_2
P_1
0
5
10
15
20
25
30
0.200
0.300
0.400
0.500
0.600
0.700
0.800

Atmospheric piston

ATMOSPHERE

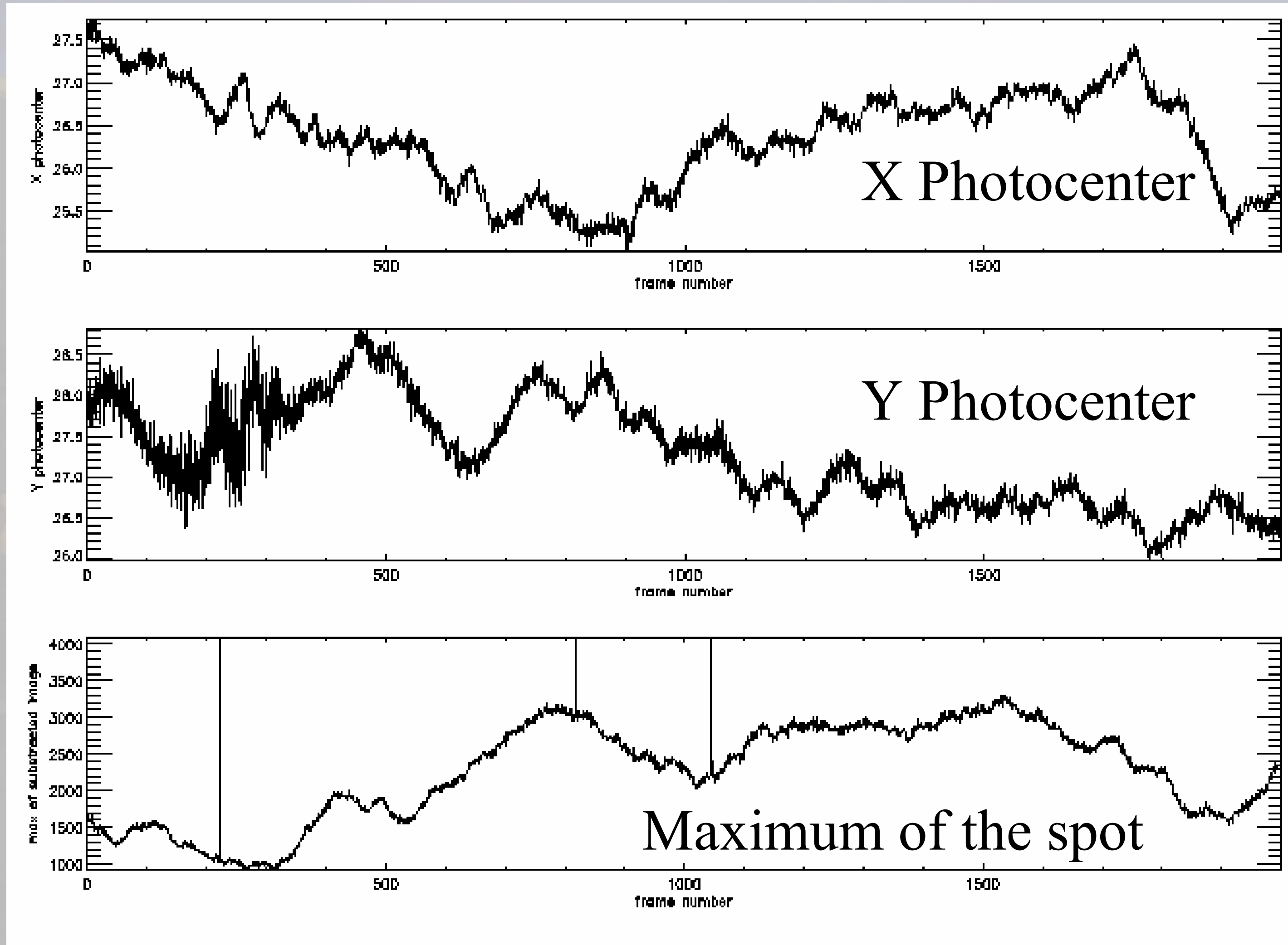


Piston corresponds to the phase difference of the wavefront between the telescopes.



ATMOSPHERE

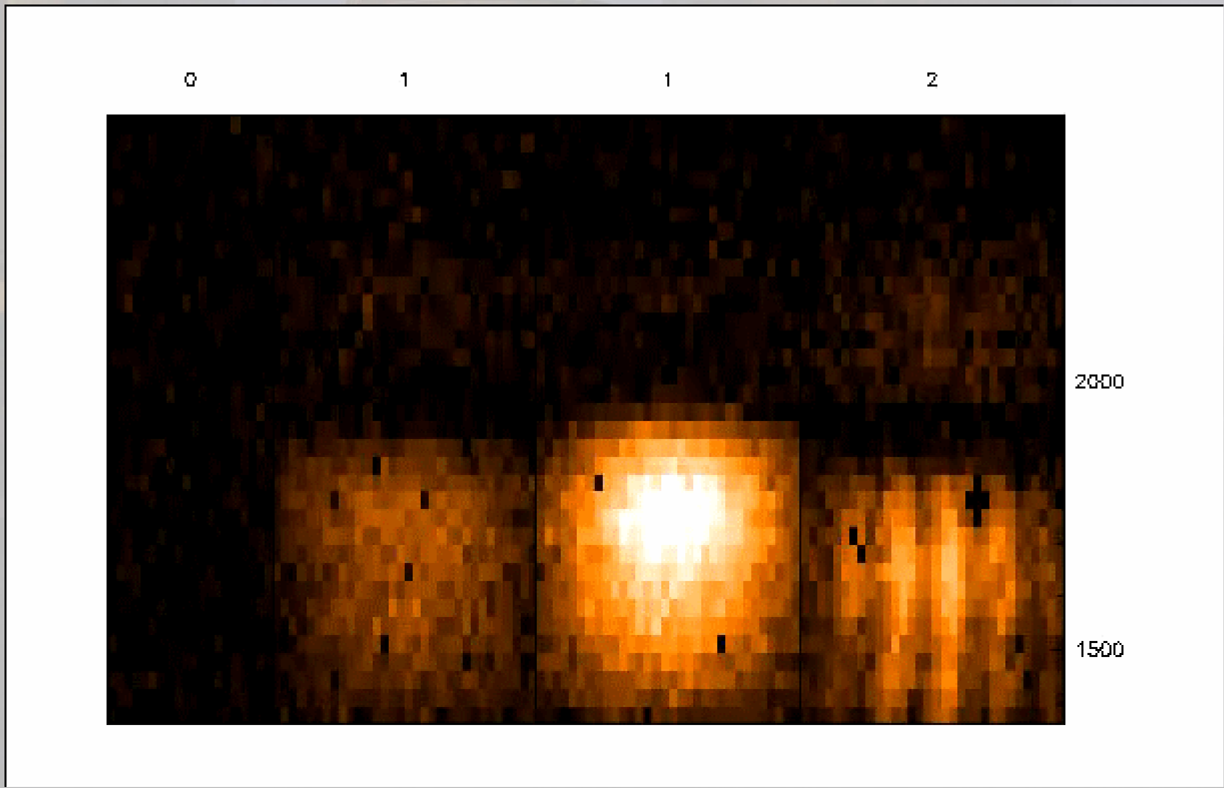
Image jitter as seen by MIDI



'Bad' seeing conditions: 1.4", stddev~170 mas (~1 PSF)

AMBER data

- Injection fluctuation
- Piston



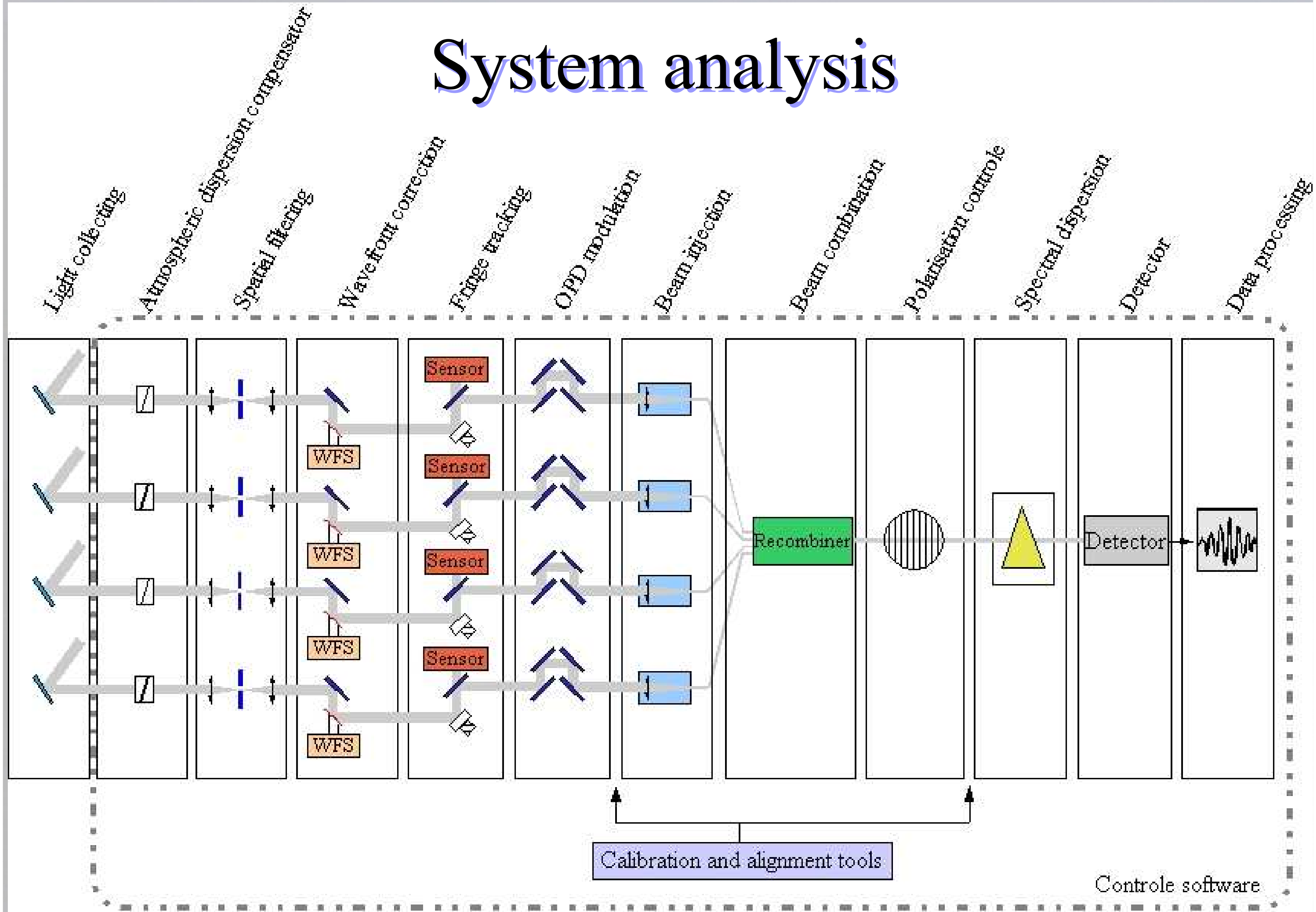
Infrastructure and Instruments

How to overcome atmospheric perturbations?

INFRASTRUCTURE
INSTRUMENTS

- **Atmospheric dispersion compensator** (ADC):
  Made of pair of prisms to control the spectral dispersion
- **Beam stabilization** (wavefront sensor + actuator):
  - Tip-tilt correction → angle tracker
  - Adaptive optics: requires a deformable mirror
- **Fringe tracking** (fringe sensor to act on delay line actuator)
- **Spatial filtering**: pinhole or single mode fiber + photometric calibration

System analysis



But subsystems can introduce new perturbations

- When complexity increases, number of sources of perturbations too!
- Reliability becomes also an issue when the number of subsystems increases

Collectors: guiding, active optics

Beam routing: 32 motors

Adaptive optics: wavefront sensors, deformable mirrors, real-time control, configuration

Delay lines: carriage trajectory, 3 translation stages, metrology, switches,

Beam stabilisation: variable curvature mirrors, image and pupil sensors (ARAL/IRIS), sources (LEONARDO)

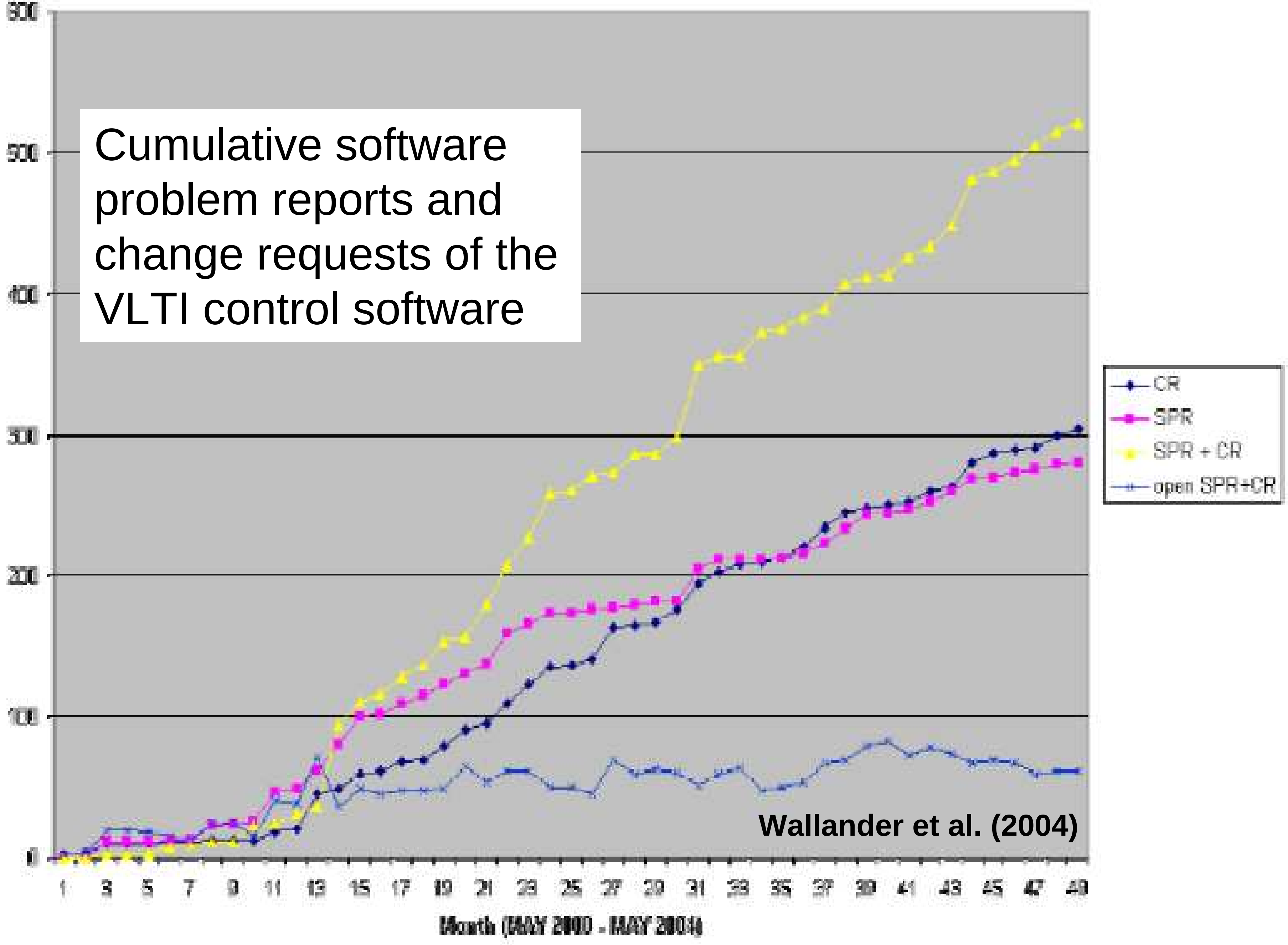
Fringe tracking: fringe search, group delay, phase tracking, locks

Beam combination: spectral resolution, spatial filtering, atmospheric dispersion, polarization, detection

Control software (cf. Wallander, SPIE April 2004):

60 computers, 750000 lines of code

INFRASTRUCTURE
INSTRUMENTS

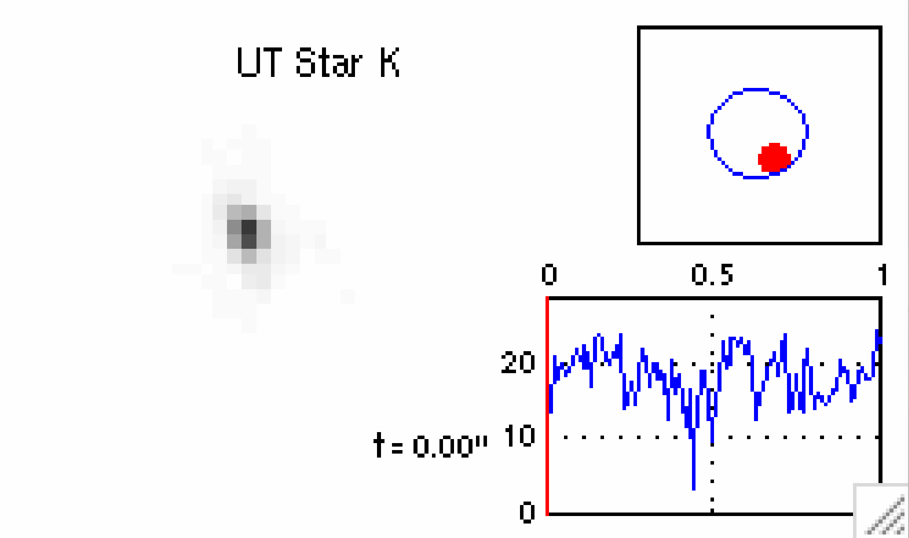


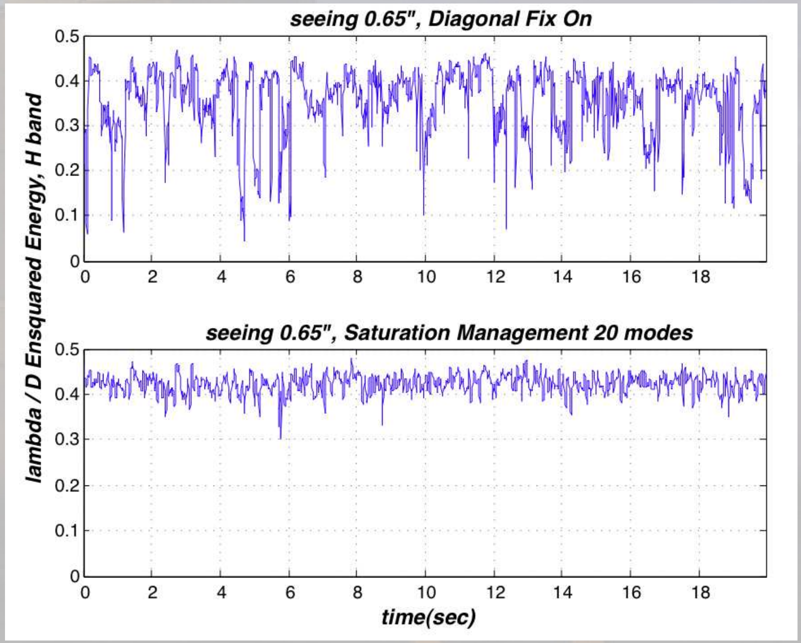
Cumulative software problem reports and change requests of the VLTI control software
Wallander et al. (2004)
CR
SPR
SPR + CR
open SPR+CR
Month (MAY 2000 - MAY 2004)

Wavefront correction can mess things up!

INFRASTRUCTURE
INSTRUMENTS

Observations made on a UT with IRIS (IR image sensor) in front of AMBER



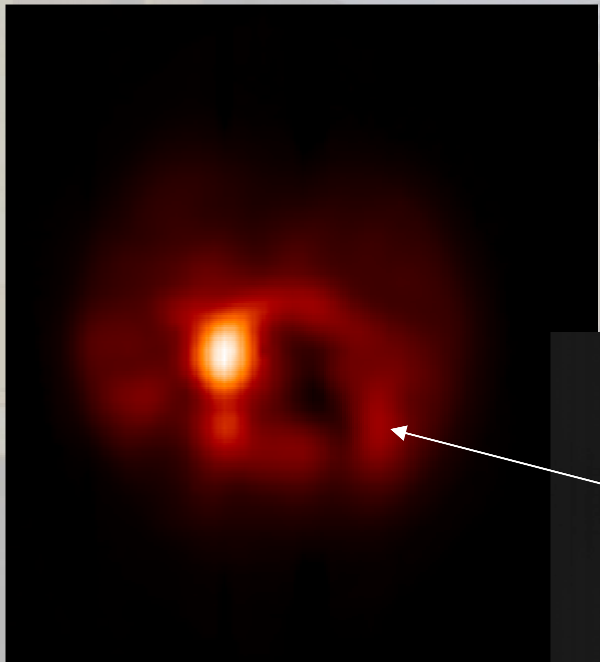


Classical AO algorithms are not necessarily the best ones for interferometry!

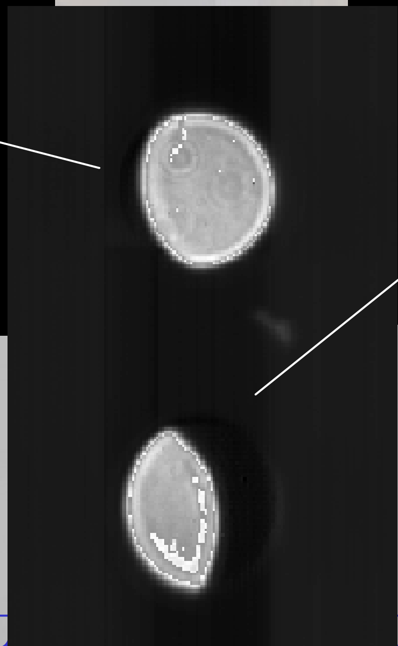
→ **saturation management** in MACAO on the VLTI

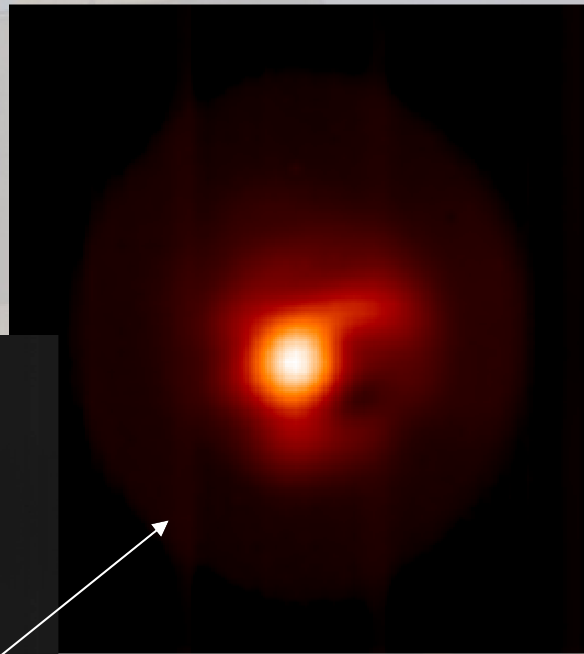
INFRASTRUCTURE
INSTRUMENTS

Alignment problems crucial for MIDI



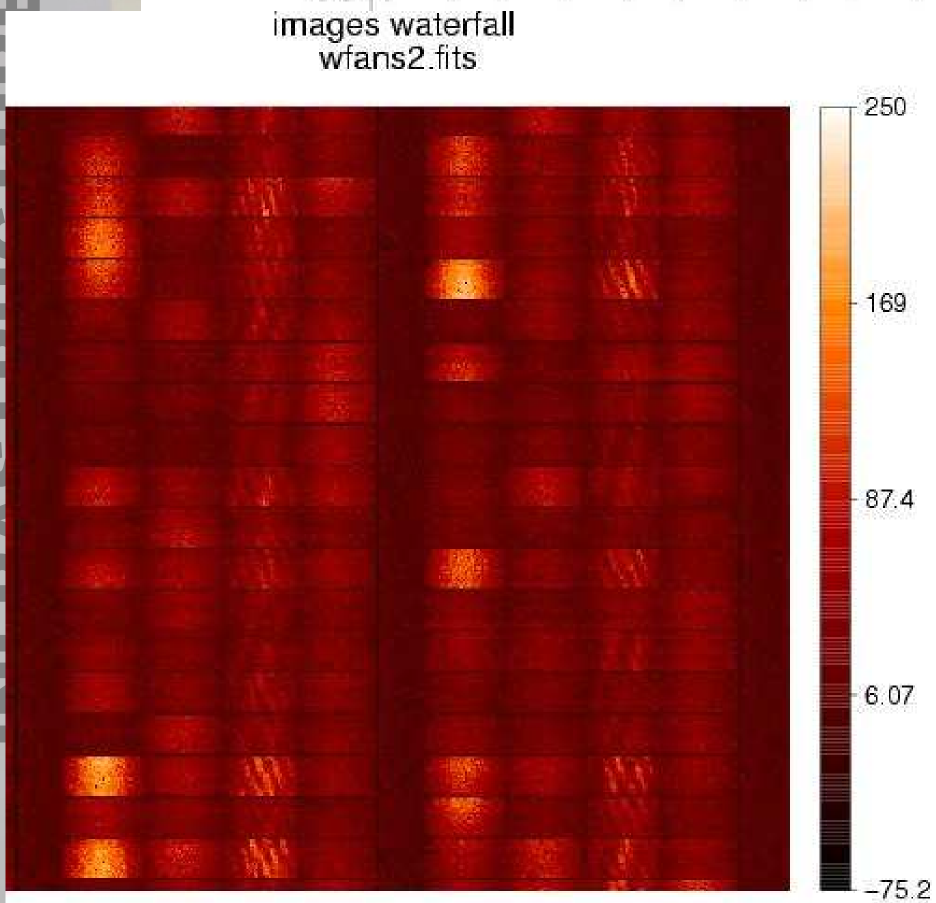
UT3 Beam B

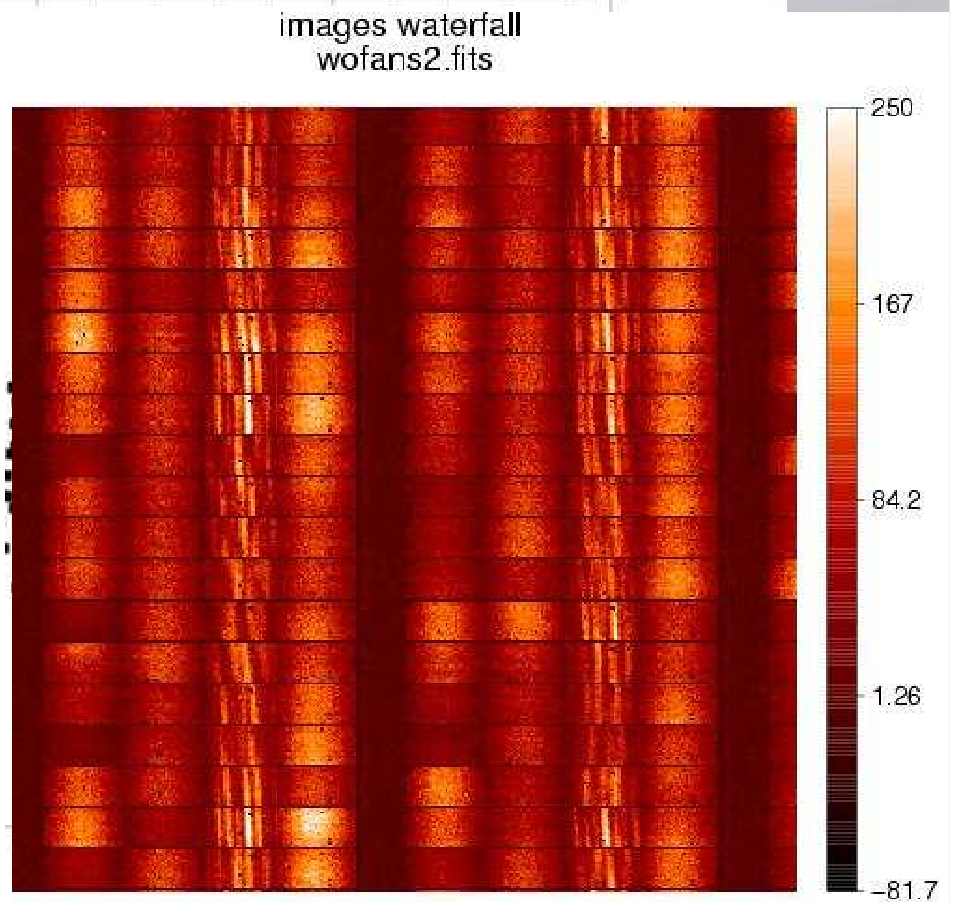




UT1 Beam A

Major vibrations seen by AMBER





MACAO electronic rack: vibrating fans

INFRASTRUCTURE
INSTRUMENTS

Acoustic propagation?

Accelerometer measured the position of a mirror of the VLTI train and this is what one get when there is …

… MACAO fans on

… outside music on

Wrong OPD models leads to drifts

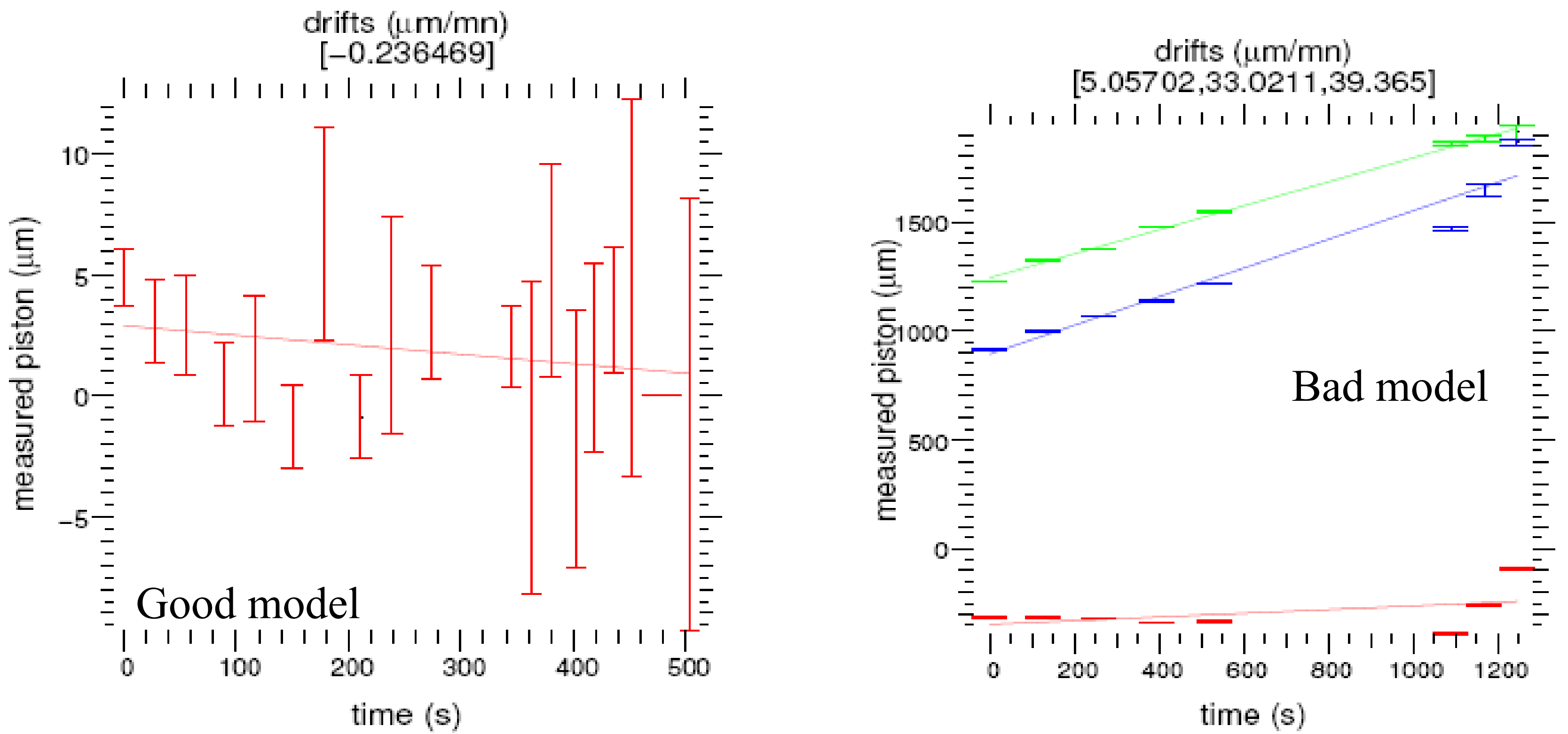
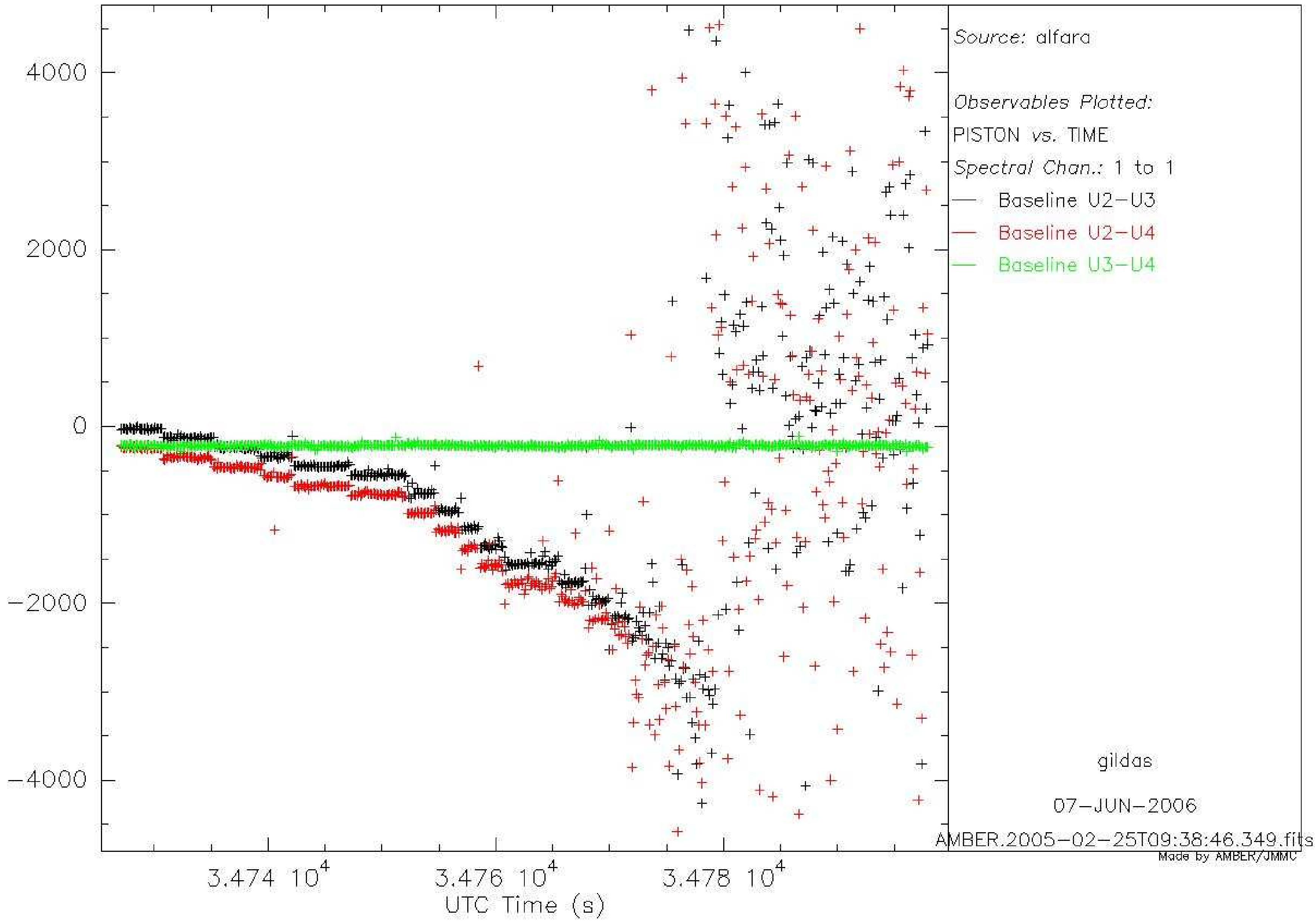


Figure 5: OPD measured during an observation without actuating the delay lines for an offset. Left pannel: the siderostat baseline (D0-H0) has a drift of -0.24 microns/minute; right panel: the 3 UT baselines have a more rapid drift. UT2-UT3: 5.06 microns/minute (red), UT3-UT4: 33.0 microns/minute (green), UT2-UT4: 39.4 microns/minute (blue).

AMBER Commissioning #2 report

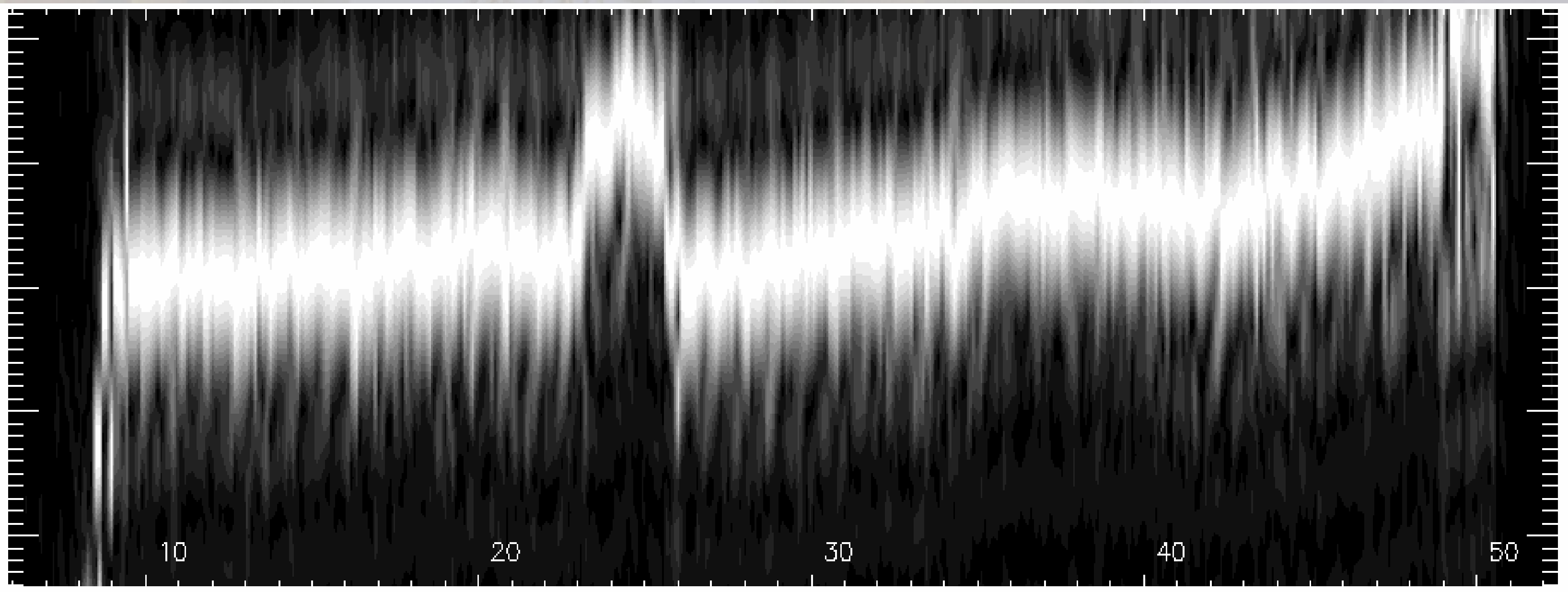
INFRASTRUCTURE



Source: alfara
Observables Plotted:
PISTON vs. TIME
Spectral Chan.: 1 to 1
Baseline U2-U3
Baseline U2-U4
Baseline U3-U4
Piston (microns)
4000
2000
0
−2000
−4000
3.474 10^4
3.476 10^4
3.478 10^4
UTC Time (s)
gildas
07-JUN-2006
AMBER.2005-02-25T09:38:46.349.fits
Made by AMBER/JMMC

OPD stability measured by MIDI

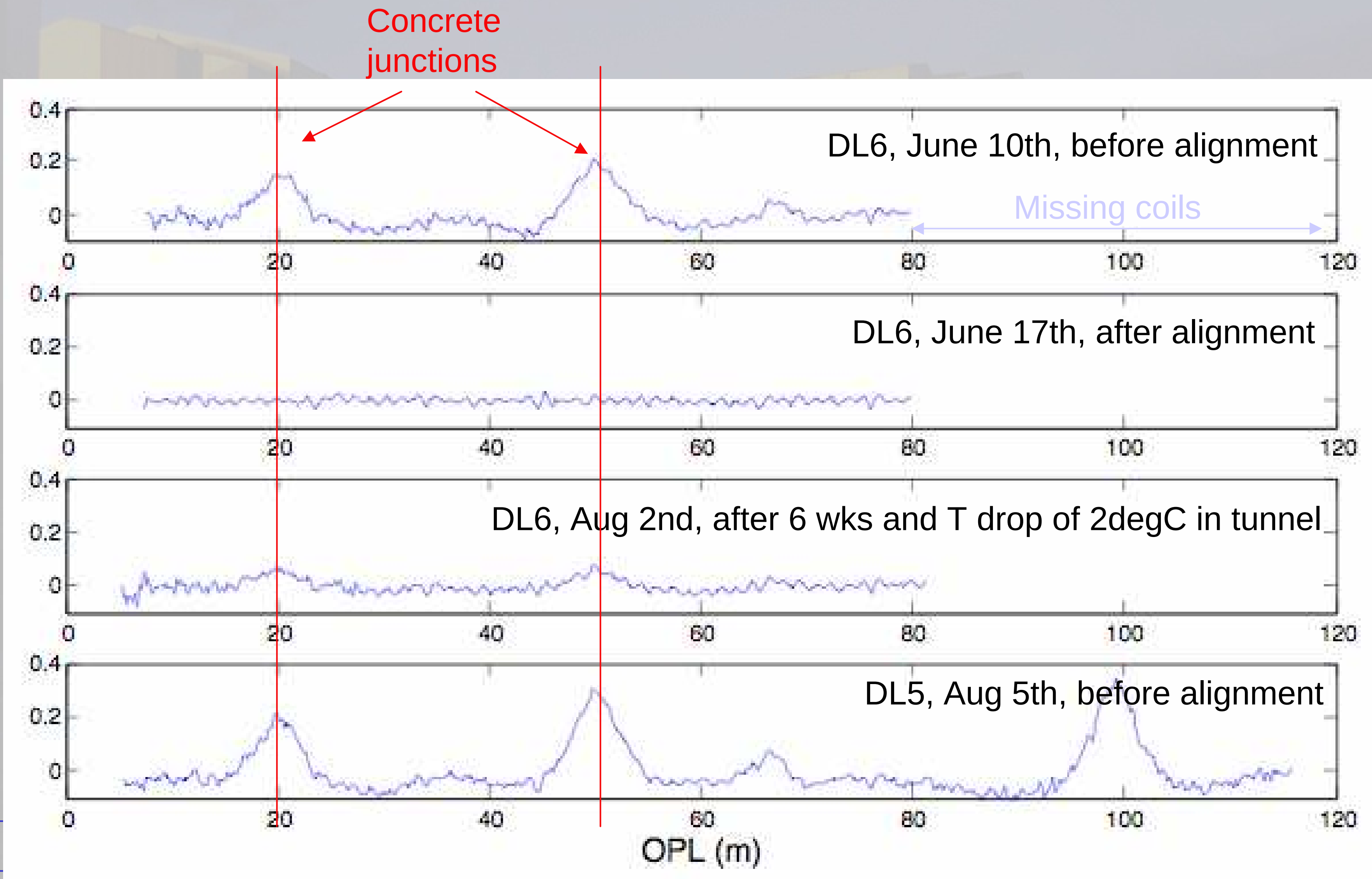
Fringe position as recorded by the MIDI instrument



INFRASTRUCTURE
INSTRUMENTS

Delay line rail drift

DL6 was aligned in Dec 2004 (summer time)



INFRASTRUCTURE

Iquique Earthquake

INFRASTRUCTURE
INSTRUMENTS

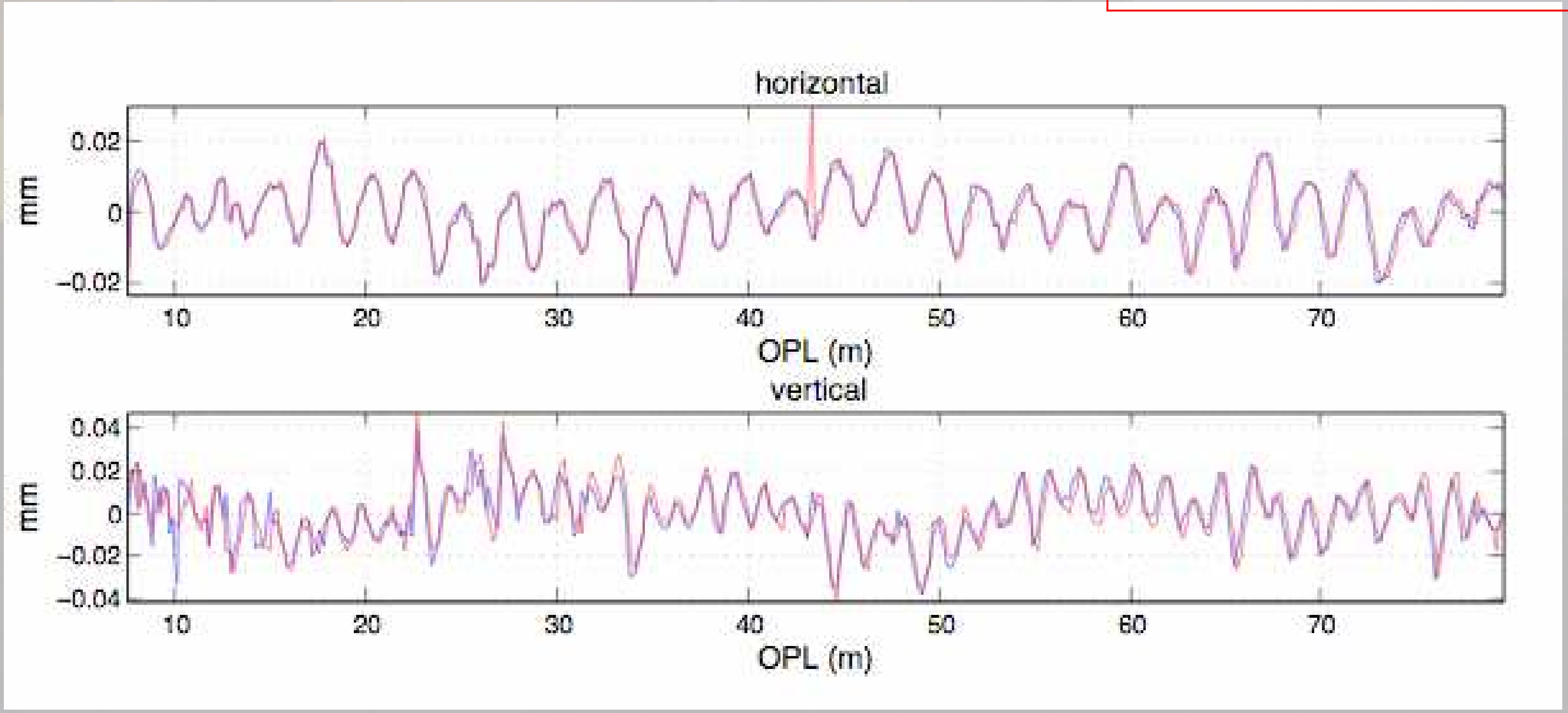
June 13th, 22:44 UT (during rail alignment campaign)

Richter 7.9

Distance 500 km north (i.e. wf // to rail)

The rail did not deform at all

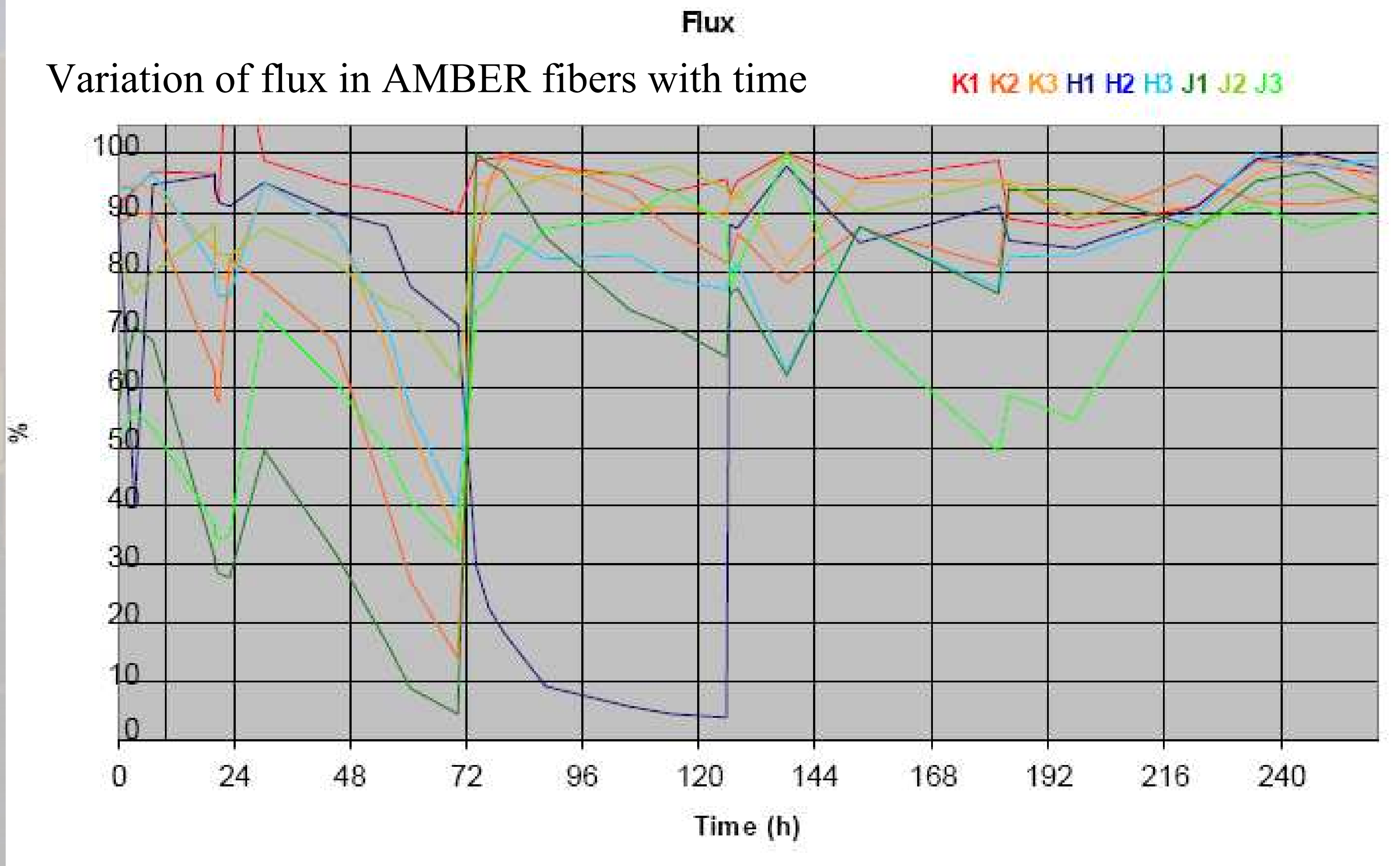
Blue: DL6 at 08:38 UT
Red: DL6 at 23:23 UT



Maintaining optical alignment

INFRASTRUCTURE
INSTRUMENTS

Variation of flux in AMBER fibers with time

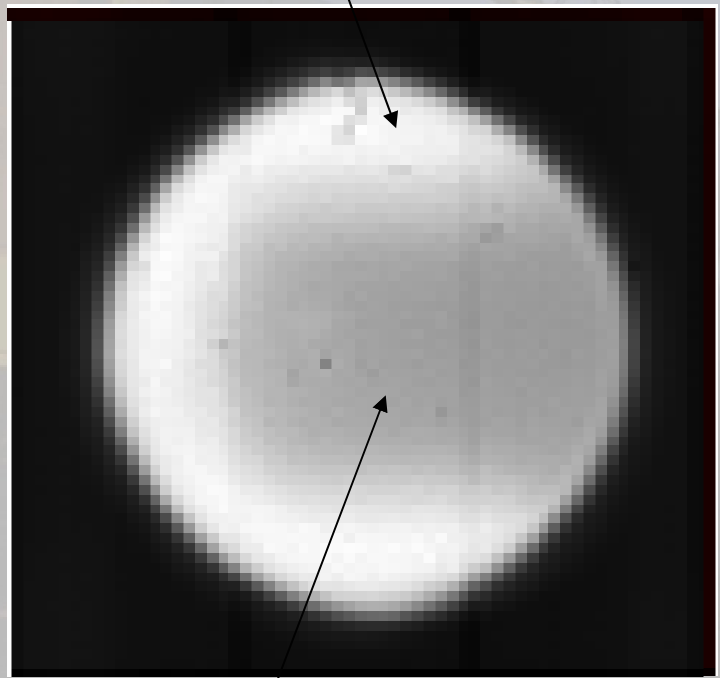


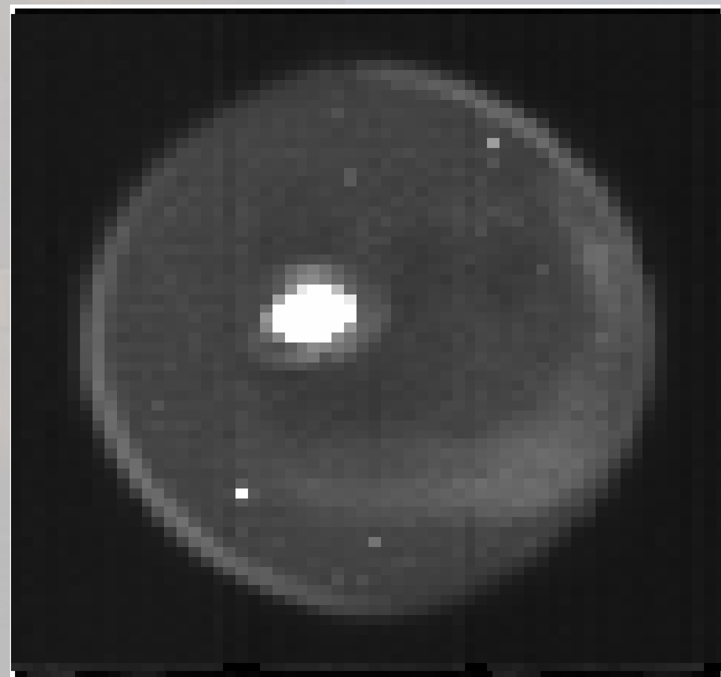
AMBER Commissioning #1 report

Thermal background as seen by MIDI

INFRASTRUCTURE
INSTRUMENTS

Tunnel background
~17 °C



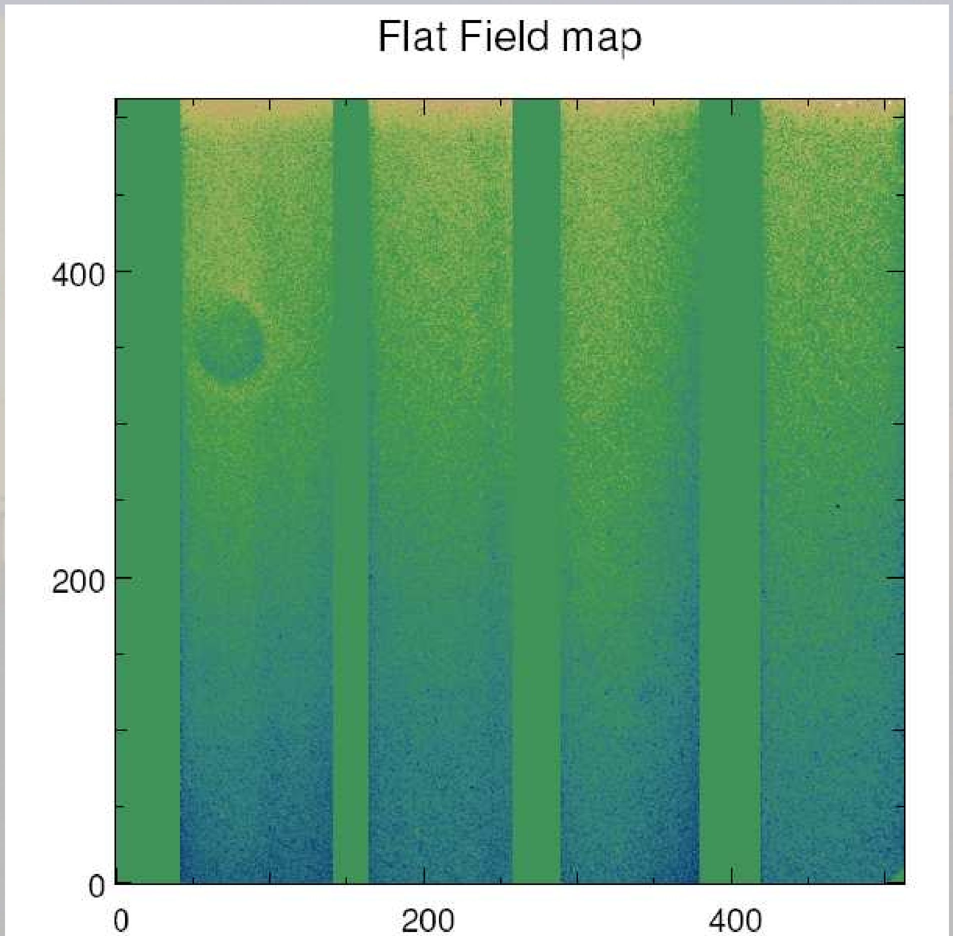


UT1 Beam A
UT3 Beam B

Sky background: Observing Field Of View (FOV)
~5-10 °C

INFRASTRUCTURE
INSTRUMENTS

Signal detection



Many issues related to signal detection:

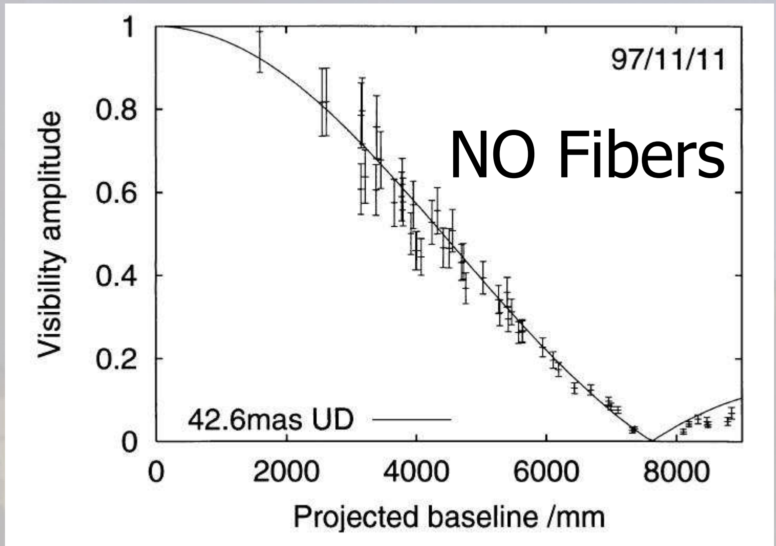
- photon noise
- read-out noise
- dark current
- falt field
- …

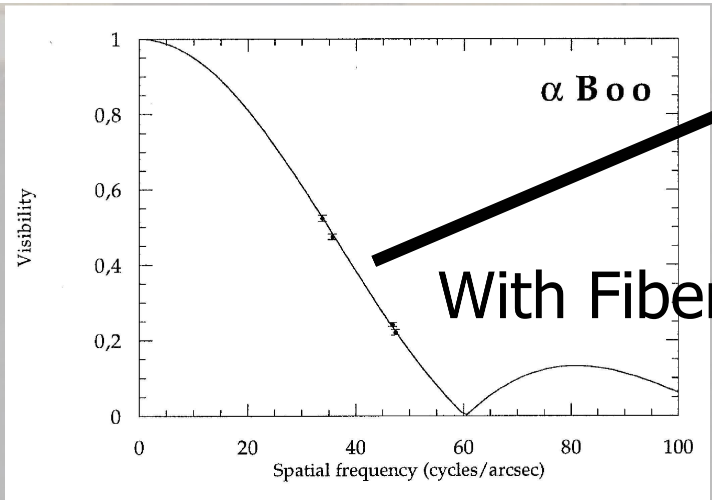
See specific presentations on data reduction next week.

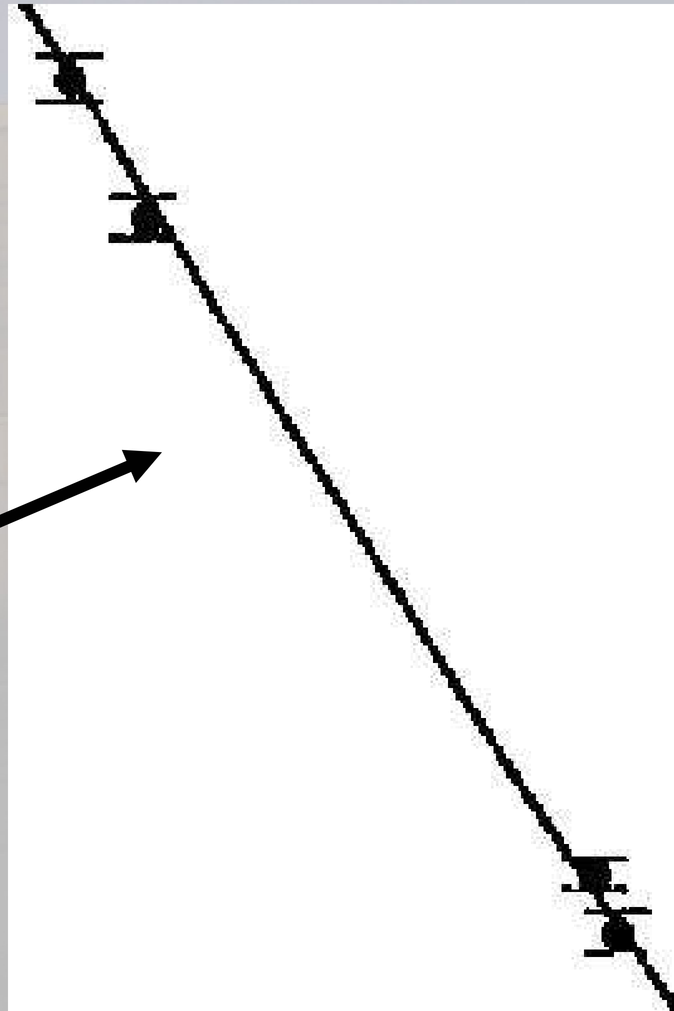
Fighting adverse effects

Spatial filtering with single mode fibers

CALIBRATION

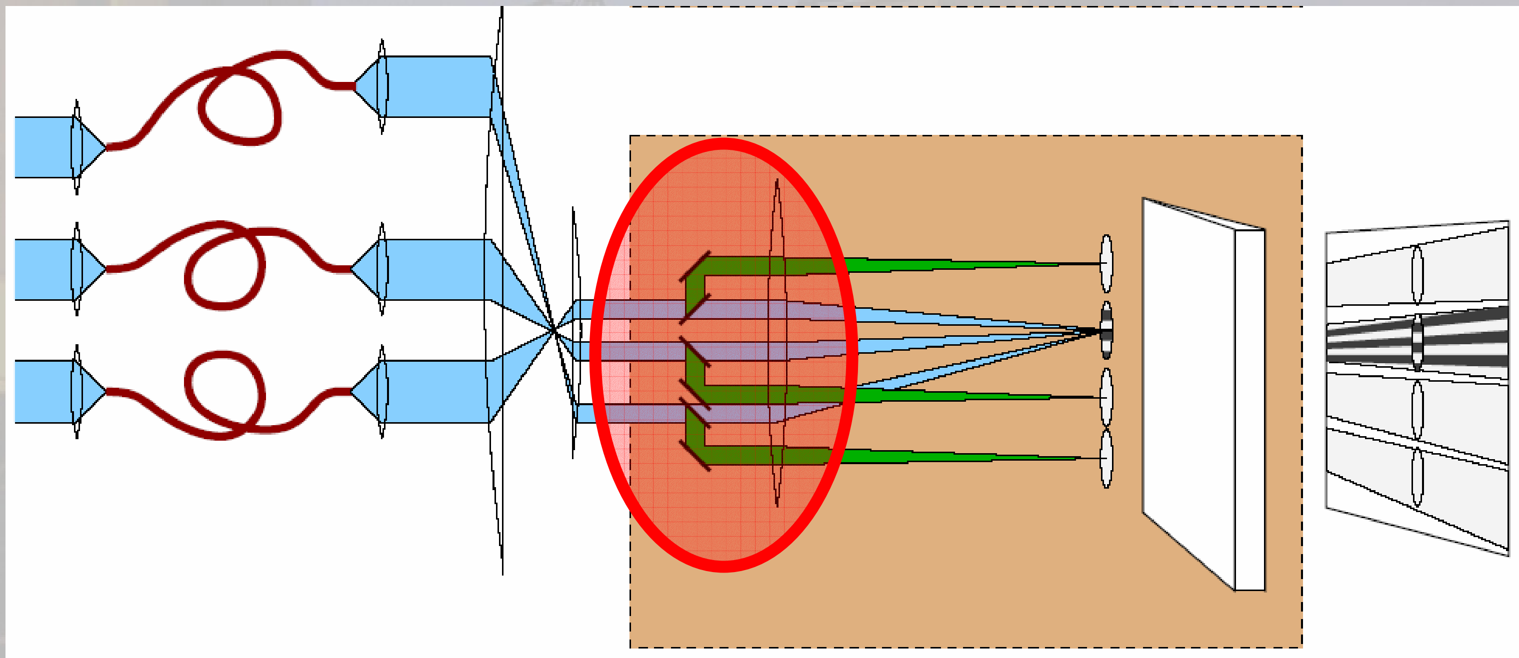






Monitoring photometric fluctuations

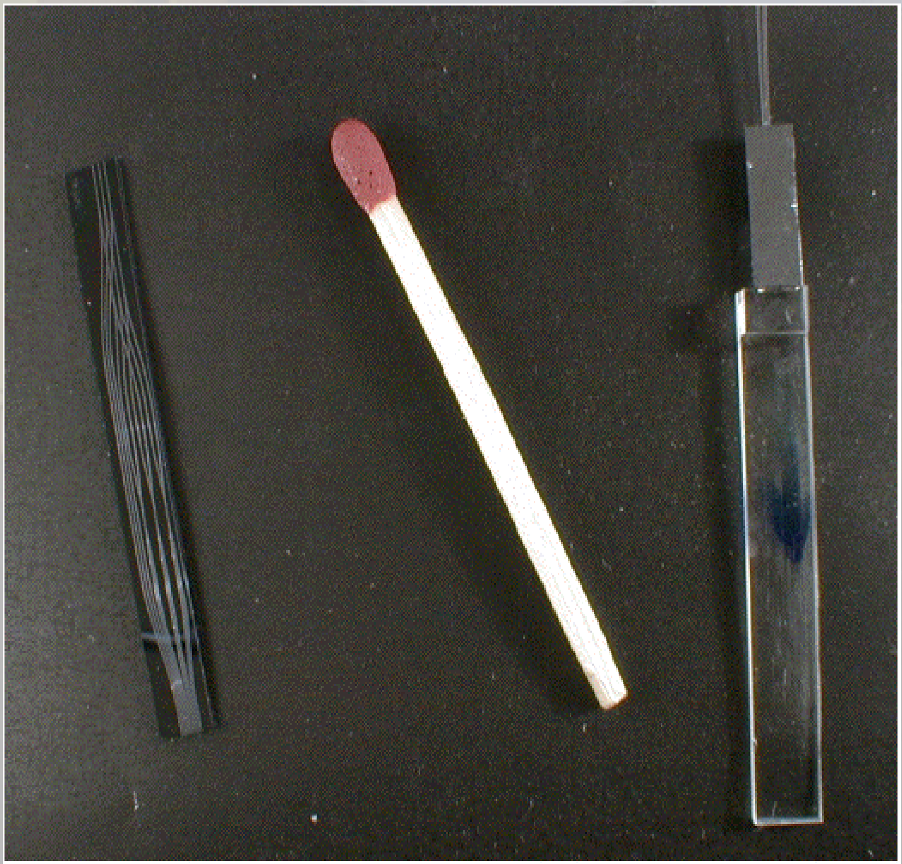
CALIBRATION

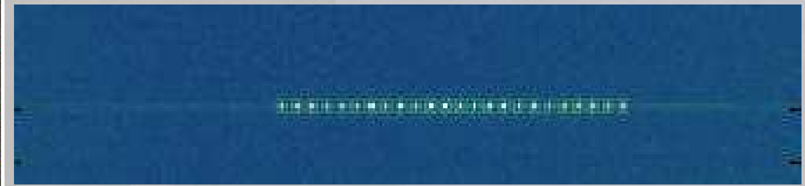


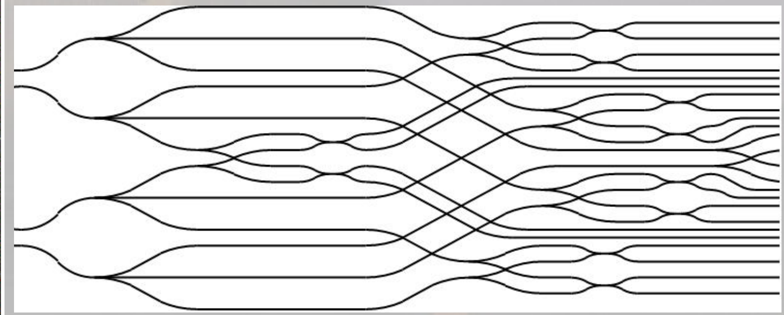
Photometric channels monitor the flux in each beam

Instrument stable by construction

CALIBRATION



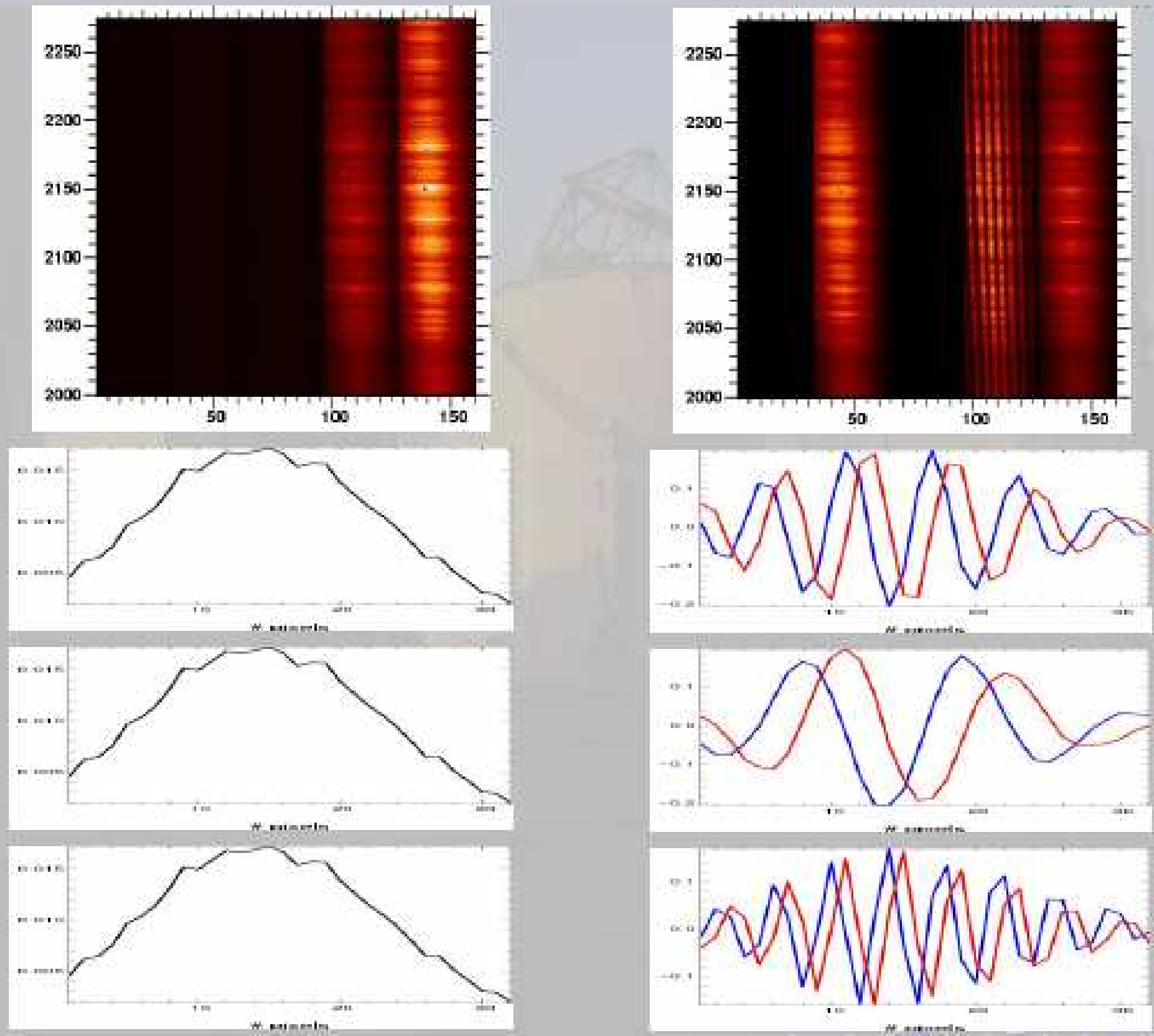




IONIC integrated optics used for the IOTA beam combiner

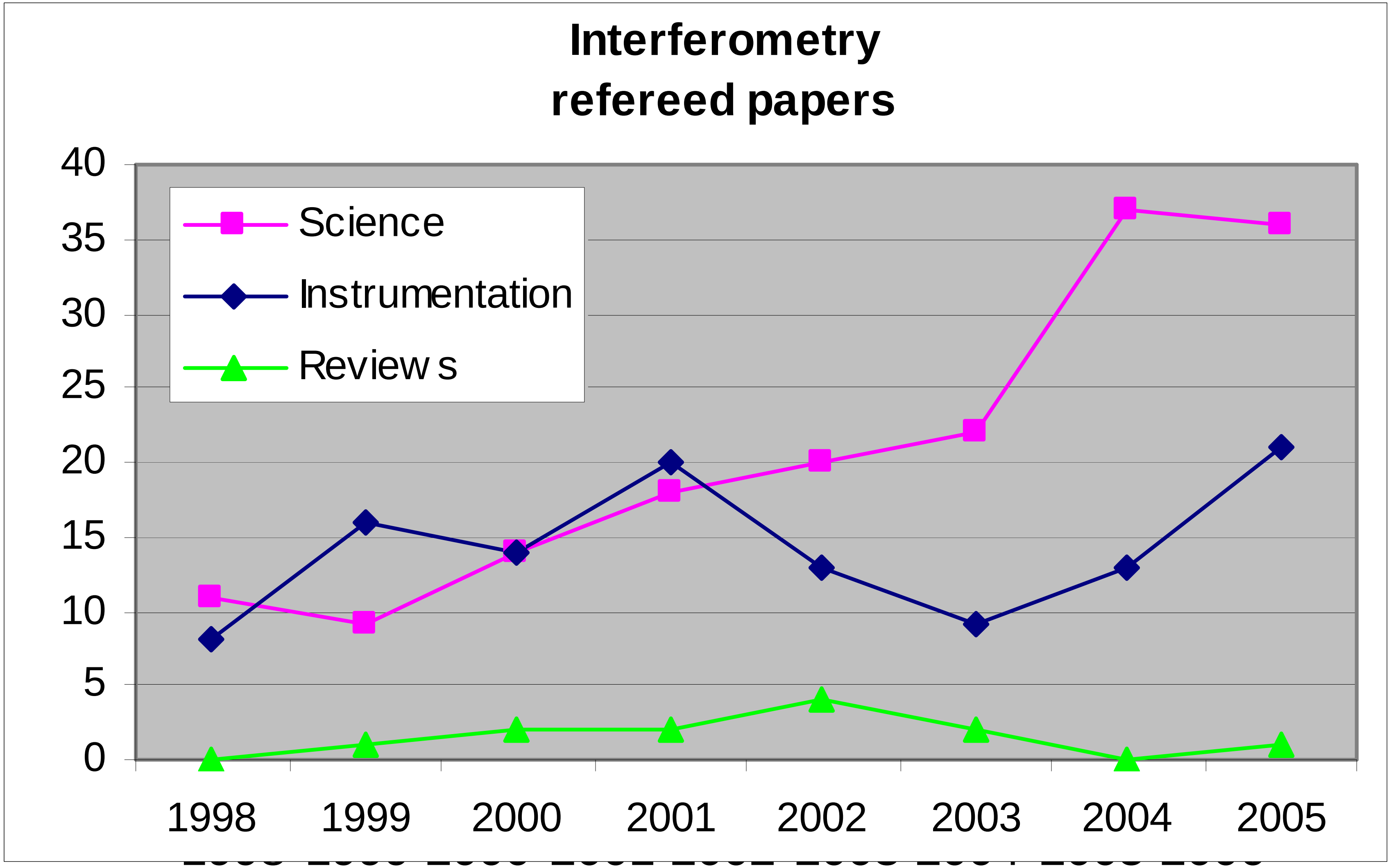
CALIBRATION

Appropriate internal calibration and data reduction



Should we be pessimistic?

CONCLUSION



Interferometry
refereed papers
40
35
30
25
20
15
10
5
0
Science
Instrumentation
Review s
1998
1999
2000
2001
2002
2003
2004
2005

CONCLUSION

There is always a solution when we understand the origin of adverse effects!

We must be patient and keep on working…

CONCLUSION

- Best if most elements do not move during observations
- Atmosphere is a main contributor
- When increasing complexity, we also increase the potential source of perturbations
- We have many solutions to overcome adverse effects
- It is a daily, or rather a nightly, struggle

One must be aware of these effects and always ready to critize its own measurements