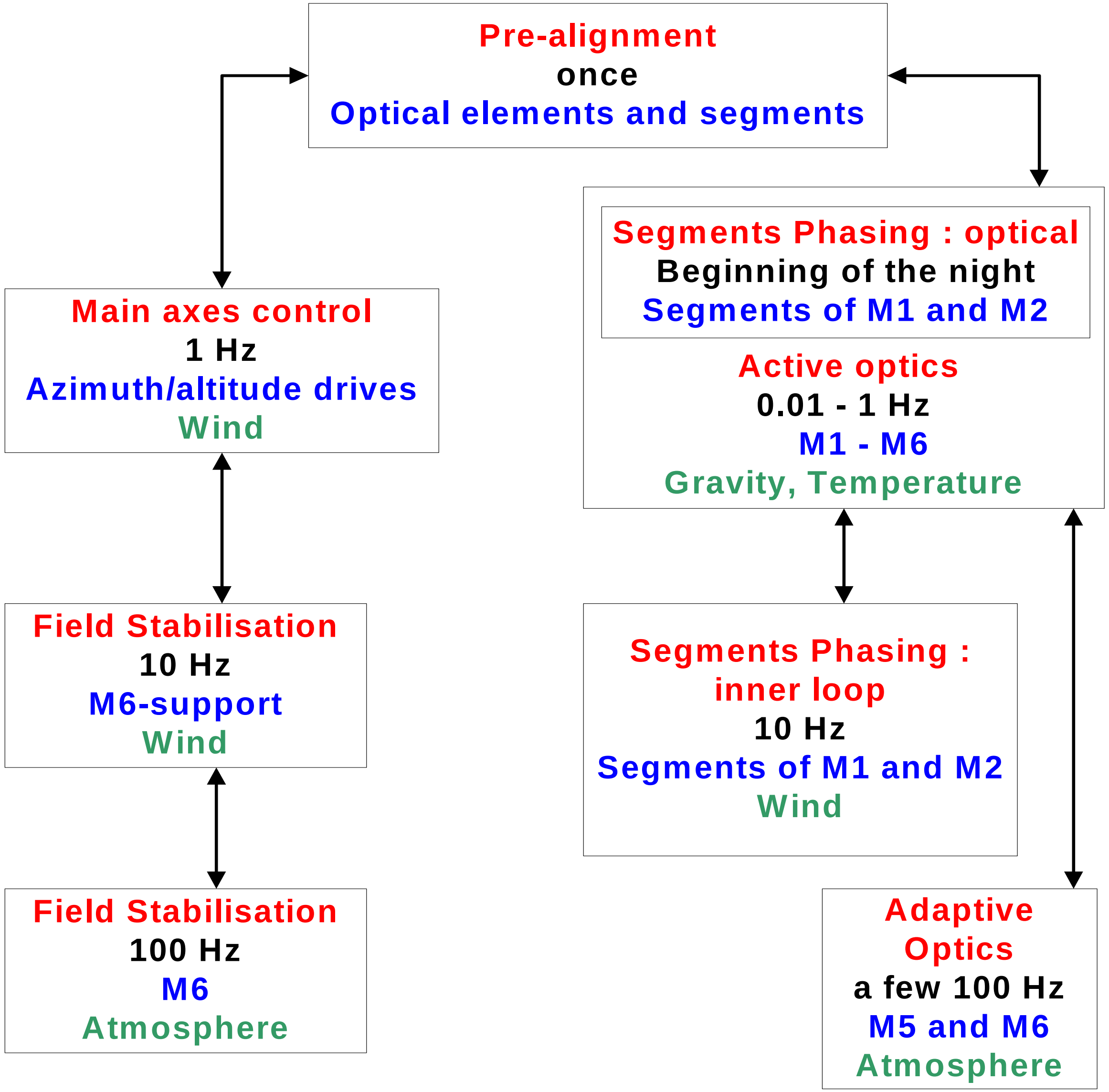
Non-adaptive Wavefront Control

(Presented by L. Noethe)

Specific problems in ELTs and OWL

- Concentrate on problems which are specific for ELTs and, in particular, for OWL
- Alignment and shape correction of optical surfaces
    - Large number of segments in segmented mirrors
    - Six optical surfaces
    - Two segmented mirrors
    - Requires mainly further development of already existing active optics techniques
- Operation in open air
    - Advantages: thermal equilibrium and predictable wind loads
    - Disadvantage: larger wind loads
    - Feasible with extensive use of fast control loops

Overview : Wavefront Control



Pre-alignment
once
Optical elements and segments

Main axes control
1 Hz
Azimuth/altitude drives
Wind

Segments Phasing : optical
Beginning of the night
Segments of M1 and M2

Active optics
0.01 - 1 Hz
M1 - M6
Gravity, Temperature

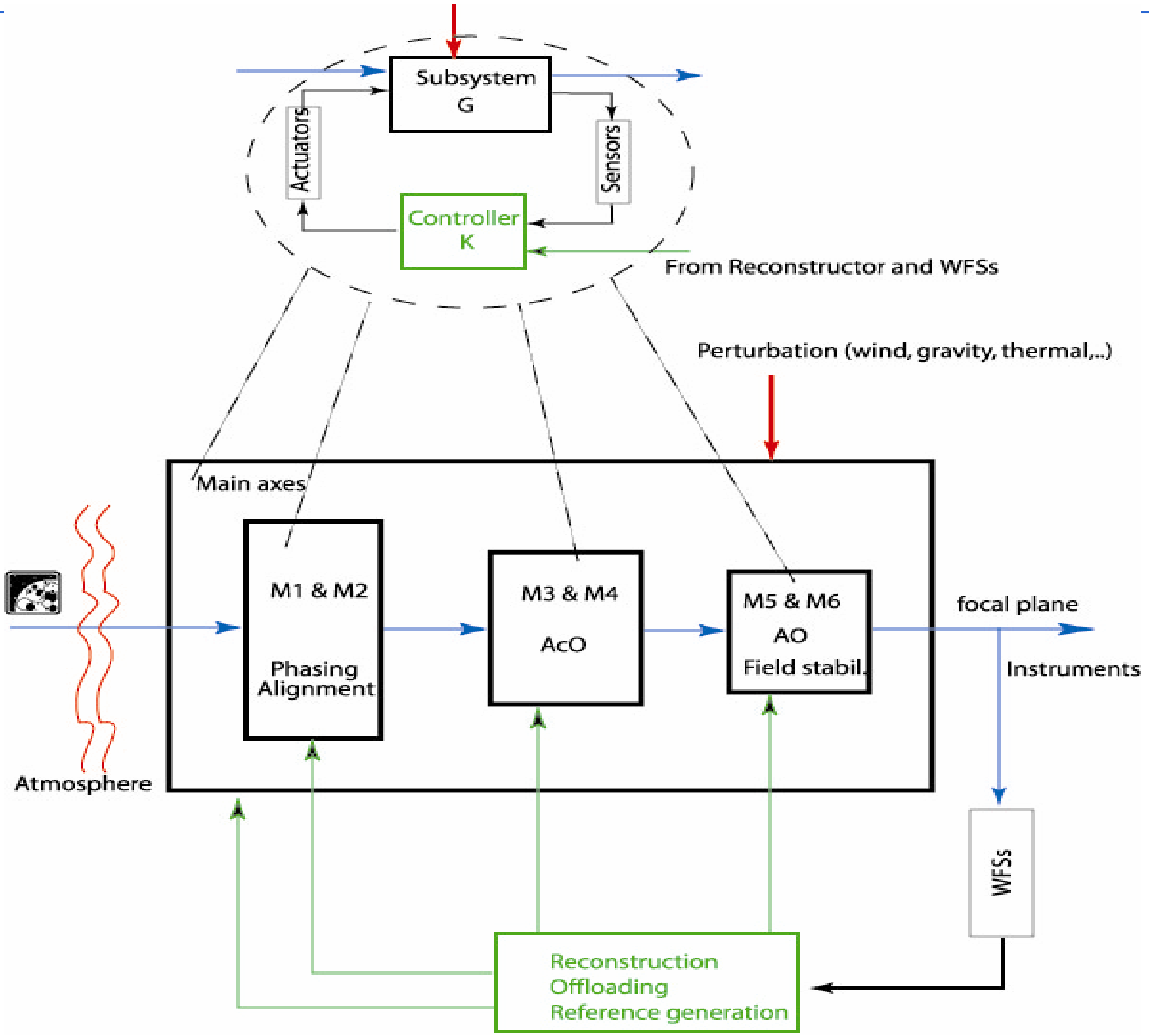
Field Stabilisation
10 Hz
M6-support
Wind

Segments Phasing : inner loop
10 Hz
Segments of M1 and M2
Wind

Field Stabilisation
100 Hz
M6
Atmosphere

Adaptive Optics
a few 100 Hz
M5 and M6
Atmosphere

Control Architecture



Subsystem G

Actuators

Sensors

Controller K

From Reconstructor and WFSs

Perturbation (wind, gravity, thermal,..)

Main axes

M1 & M2

Phasing Alignment

M3 & M4

AcO

M5 & M6

AO

Field stabil.

focal plane

Instruments

Atmosphere

WFSs

Reconstruction

Offloading

Reference generation

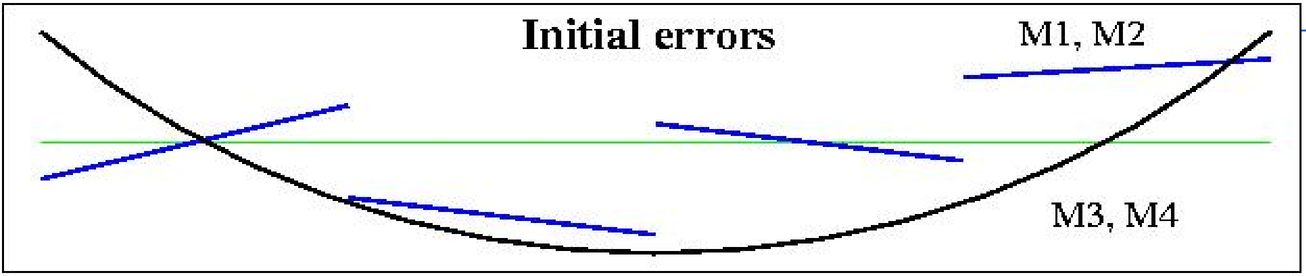
Pre-alignment

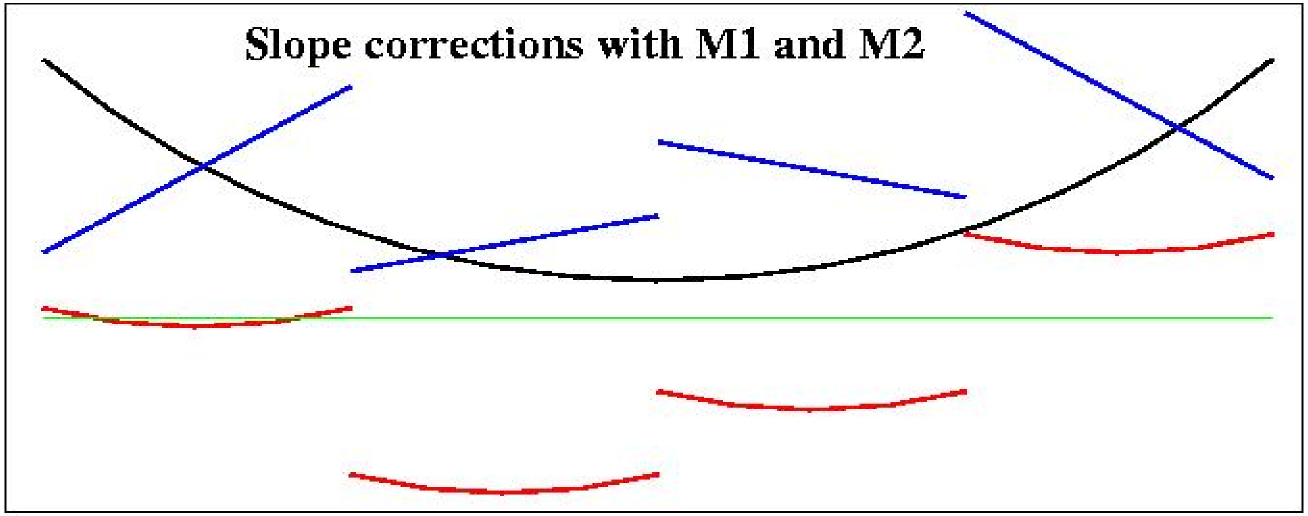
- Alignment of segments
  - Use of a spherometer to align a new segment relative to its neighbours
  - Stacking of the images produced by individual segments
- Alignment of optical elements
  - Use of a fibre extensiometer to be developed within the FP6 ELT study
- Residual errors after pre-alignment
  - Positions M1 – M6 : ~1 mm
  - Tilts M1 - M6 : ~ 1 arcsec
  - Piston errors of segments : ~ 2 µm
  - Deformations M3 and M4 : ~ 30 µm

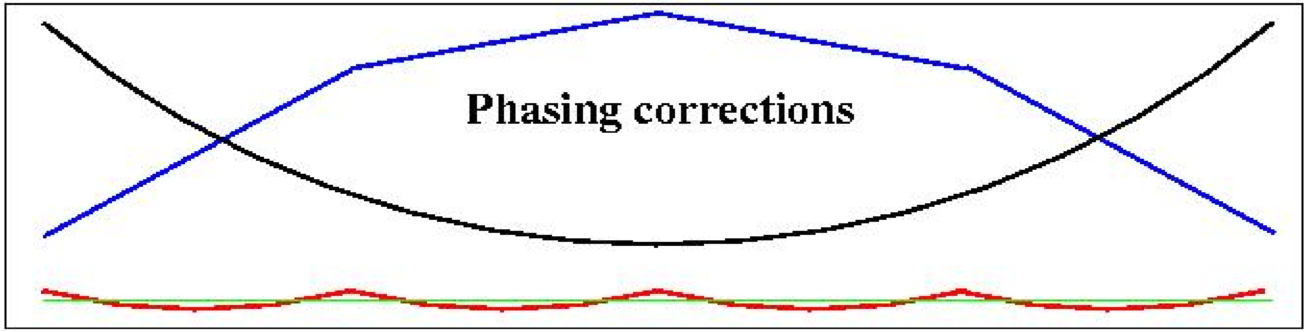
Correction strategy

- Complete correction in one step
  - Measurements from several Shack-Hartmann sensors and one phasing sensor
  - Inversion of the matrix relating the actuator degrees of freedom to the measured parameters by singular value decomposition
  - Calculation of the actuator commands from the measured signals with the inverted matrix
  - Disadvantage : requires a very large matrix
- Alternative approach : split the correction into several steps
  - More than one possible strategy
- One sequence of correction steps
  - Correction of slope errors with the segments
  - Phasing of the segments
  - Correction of misalignments and deformations of M1 to M6

Active optics corrections with one Shack-Hartmann and one phasing wavefront sensors

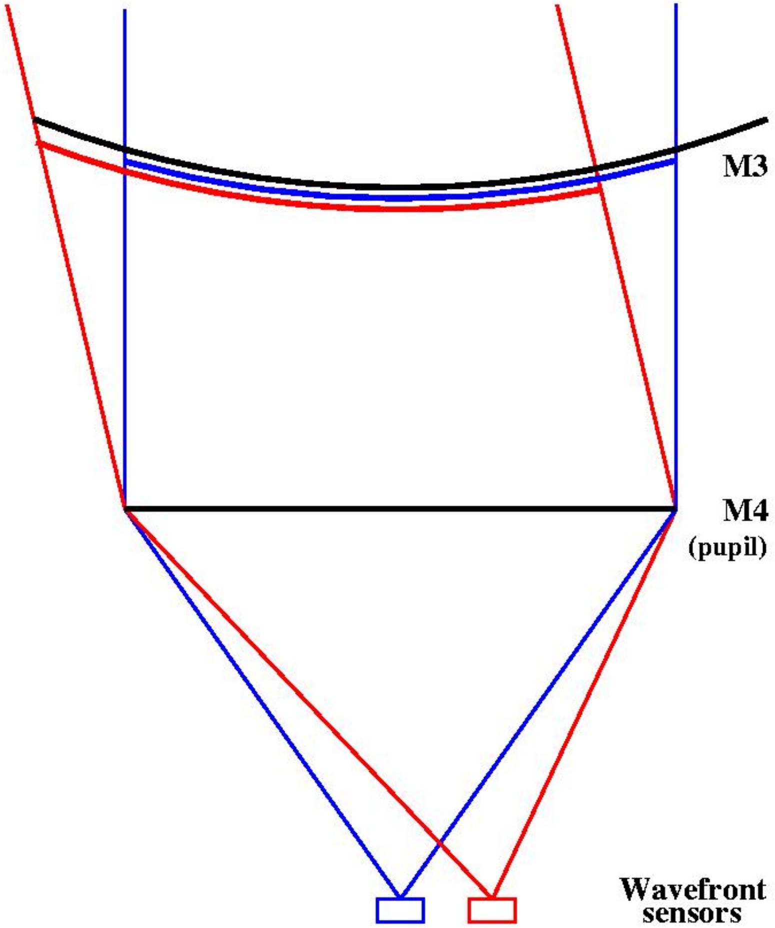






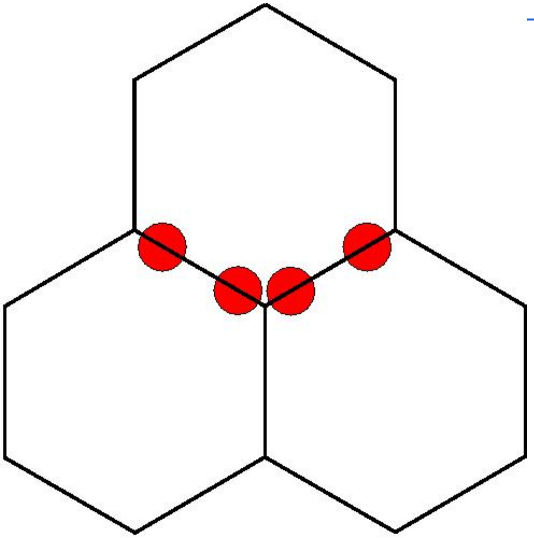
Full correction with wavefront sensors in several field positions

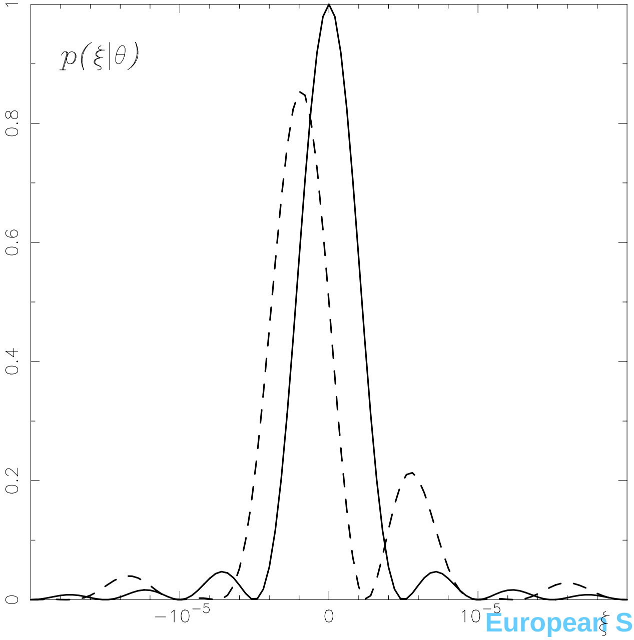
- Aberrations generated by
  - Misalignments of the mirrors
  - Deformations of the meniscus mirrors
  - Characteristic patterns of additional field aberrations
  - Correction with an in-pupil mirror only possible for one field angle
- Required wavefront sensors
  - 1 Shack-Hartmann sensor with 19 lensets per M1 segment
  - At most 6 Shack-Hartmann sensors with 20 by 20 subapertures covering M1
  - 1 (baseline) or 2 (optional) phasing sensors



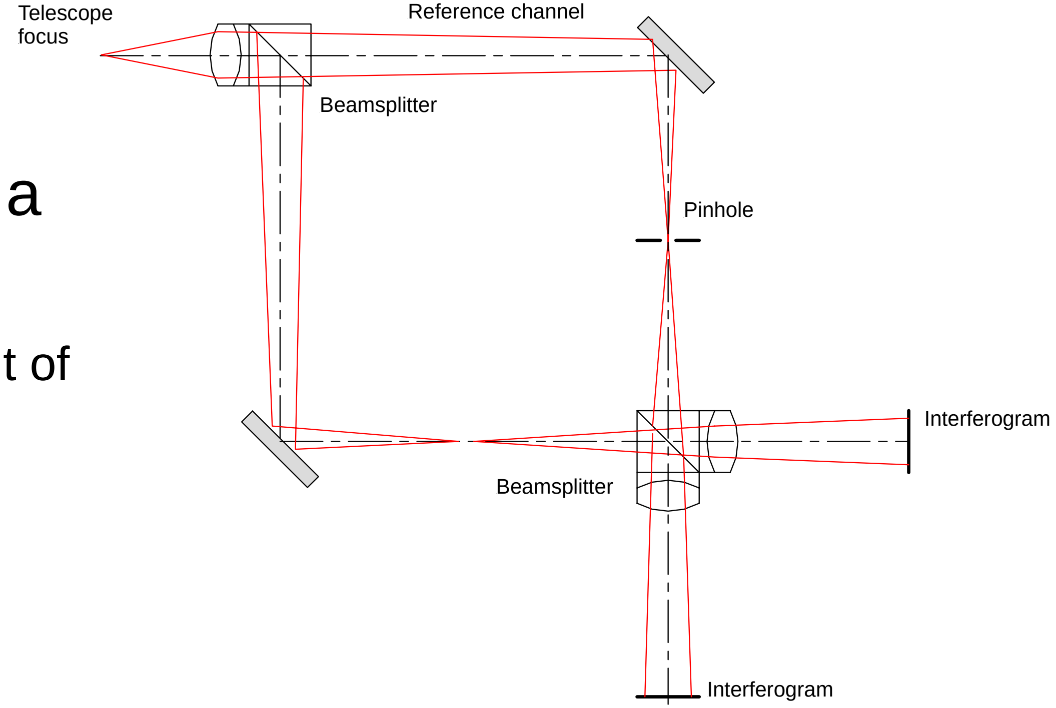
Phasing wavefront sensors

- Multi-wavelengths techniques
  - Reduce the wavefront piston steps of 2 µm to less than 100 nm
- Narrowband techniques
  - Shack-Hartmann: lenslets covering subapertures centered on segment borders
  - Information contained in the position of the maximum and in the shape of the diffraction pattern
  - Applied in the Keck Telescope extracting the shape information
  - Problem : exact positioning of a large lenslet array in the re-imaged pupil

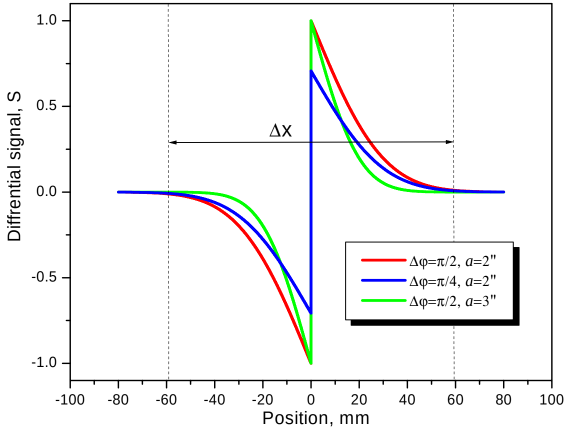


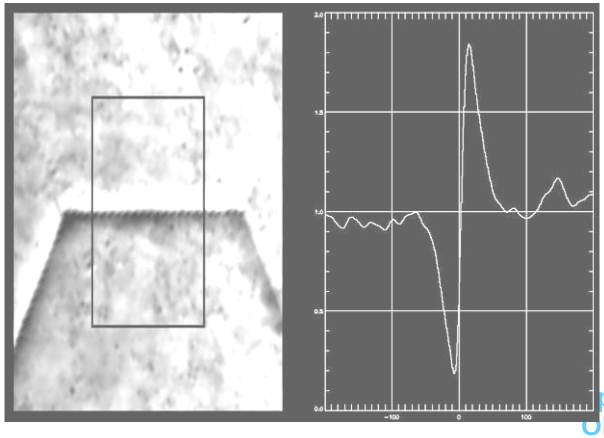


Phasing wavefront sensors: Mach-Zehnder



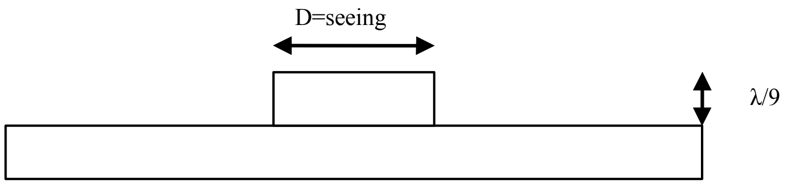
- Spatial filtering in a focal plane
  - Problem : Alignment of the optics

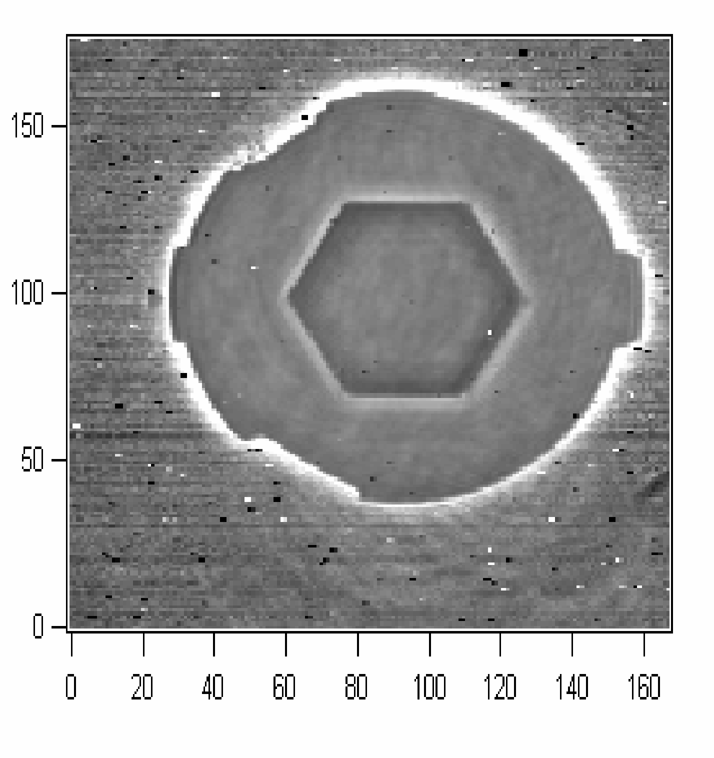


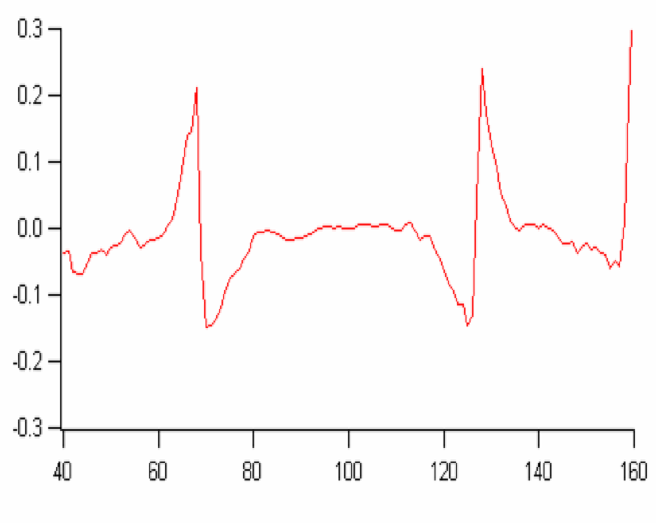


Phasing wavefront sensors – phase filtering (LAM/IAC)

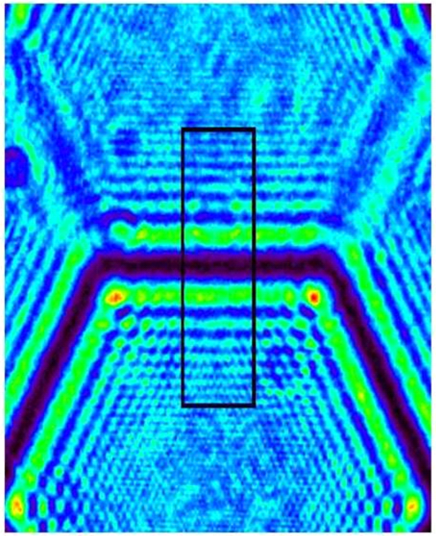
- Adding of a phase delay in the center of the image
  - Easier to align than the Mach-Zehnder sensor

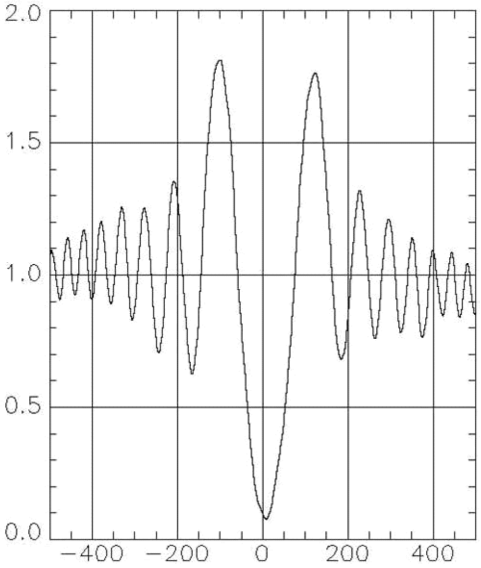


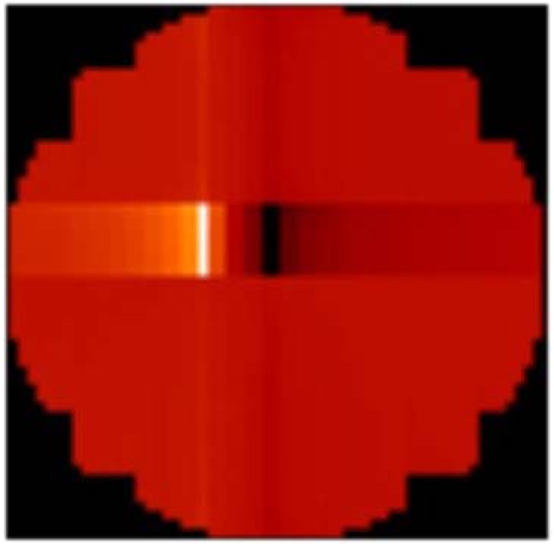


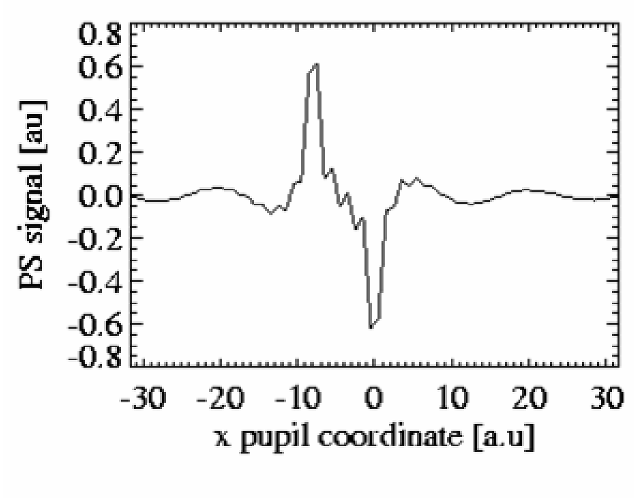


Phasing wavefront sensors – defocusing (IAC) and pyramid sensor (Arcetri)



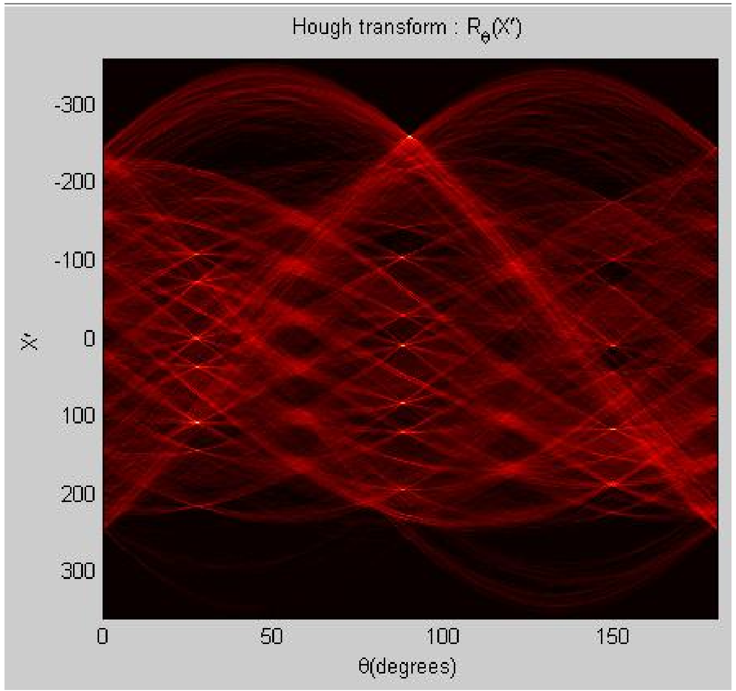


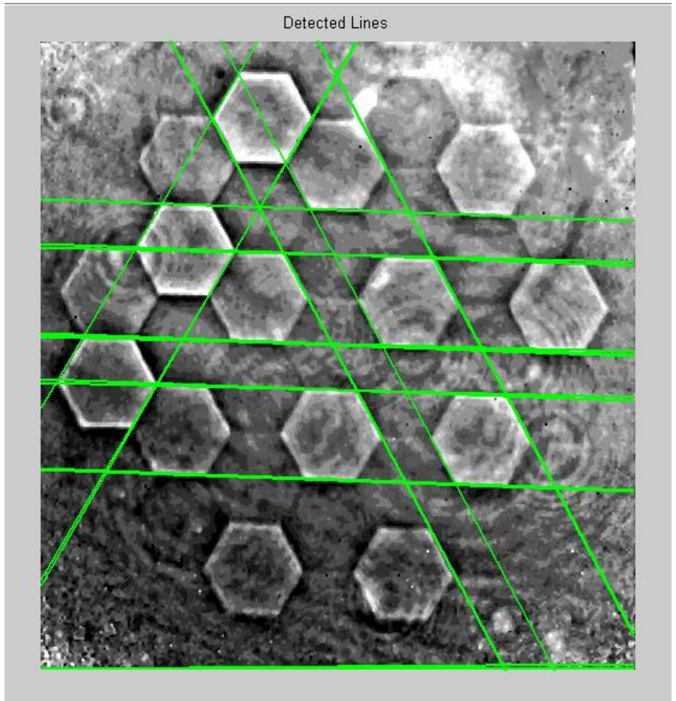




Phasing wavefront sensors – identification of borders

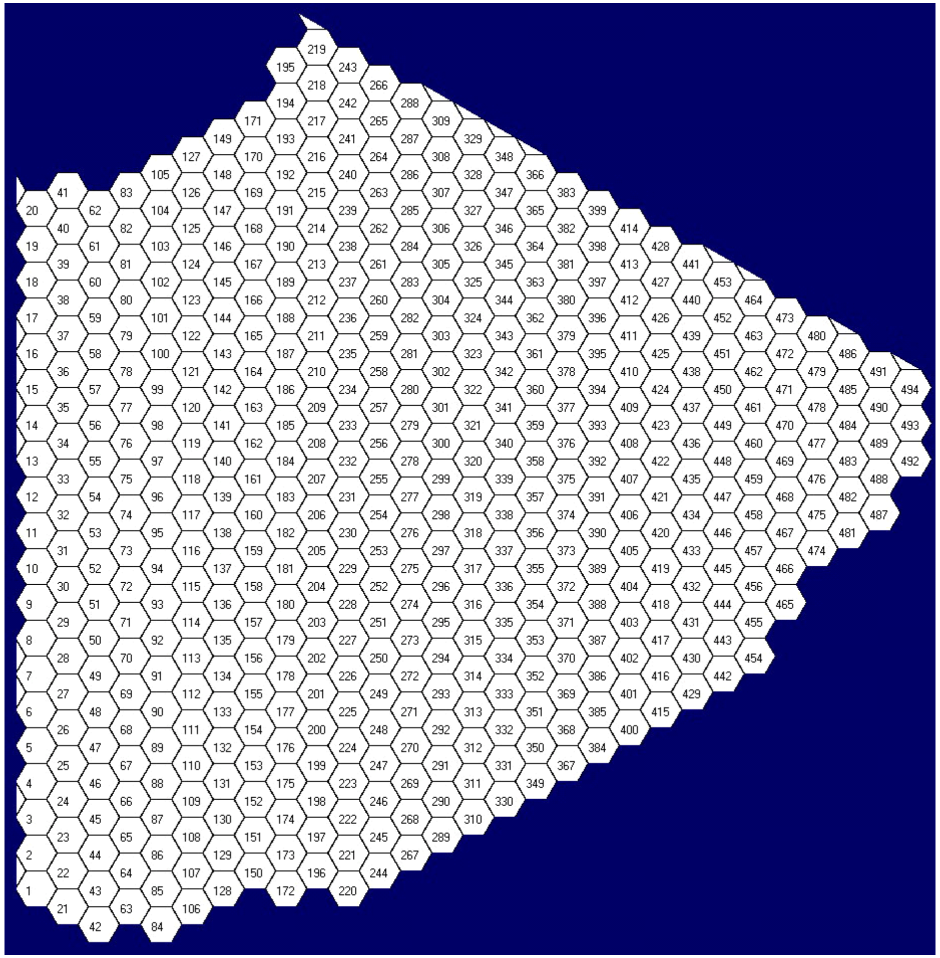
- Possible algorithm : contrast enhancement and Hough transform
  - Promising for large piston steps
  - To be validated for small piston steps
- Imaging of the gaps
  - 10% reduction of the intensity for pixels covering gaps





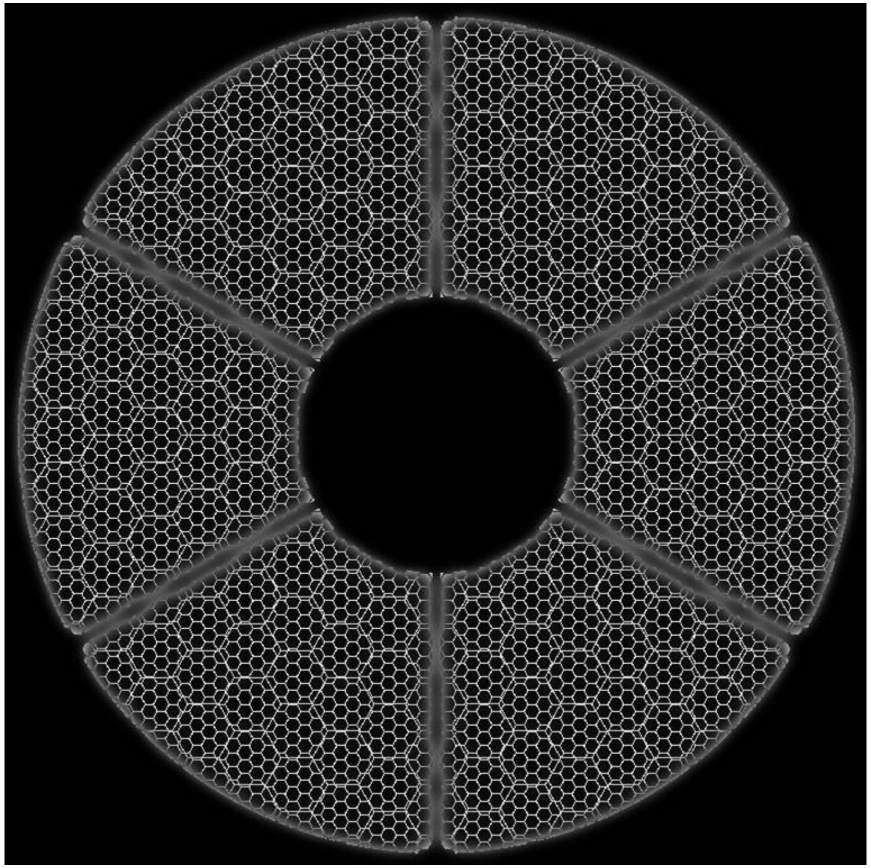
Phasing of petals

- The M2/corrector support structure may optically divide M1 into six petals.
- Struts thin enough to allow optical phasing of the full segmented mirror
- Backup solution : additional special wavefront sensor for the phasing of the petals relative to each other



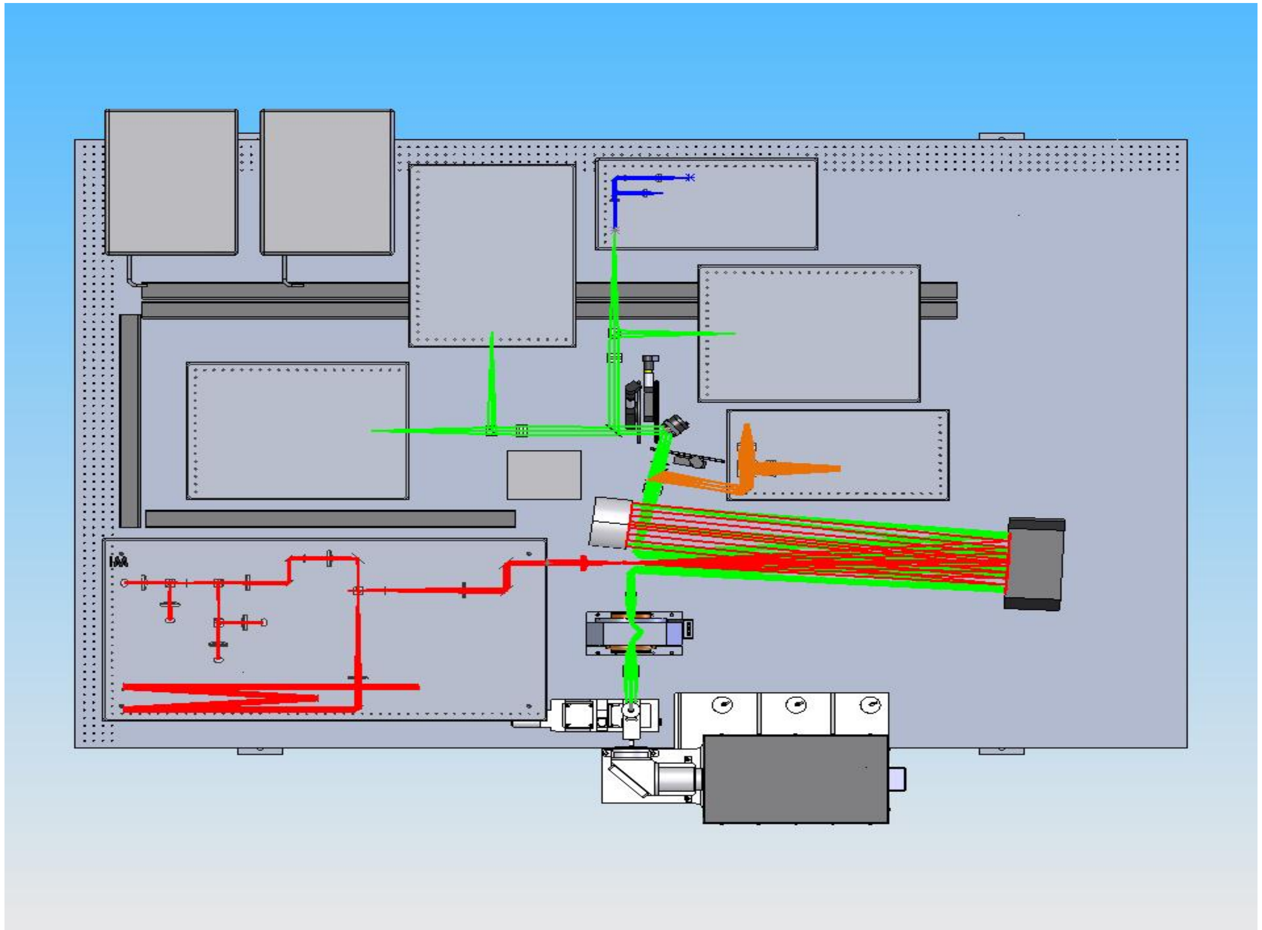
Phasing – disentangling M1/M2 segmentation

- Segmentation patterns originating from M1 and M2 are superimposed in the detection planes of the wavefront sensors
- Disentangling could be done by
  - Spatial filtering in the Fourier space
  - Use of two or three phasing wavefront sensors in the field



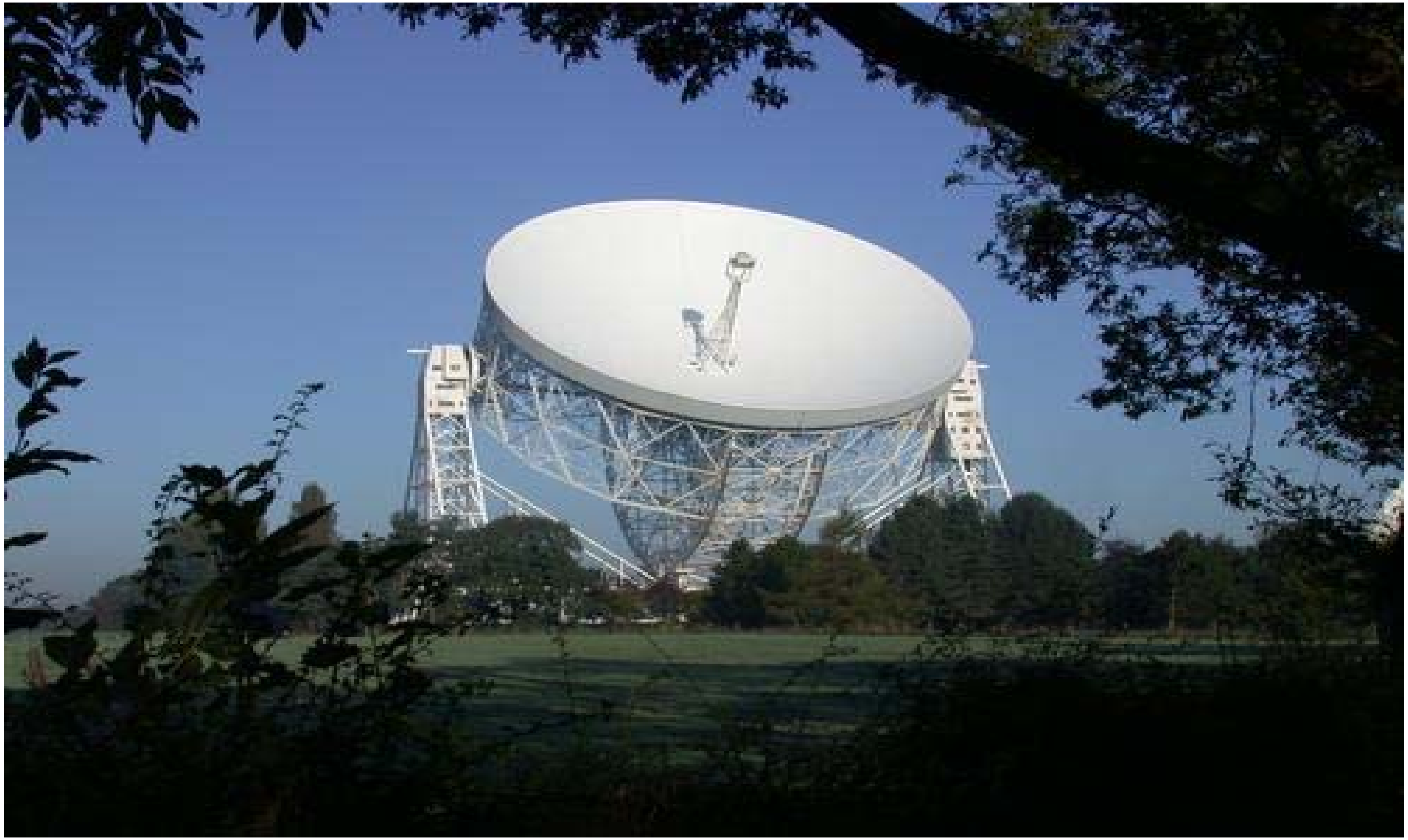
Active Phasing Experiment

- Comparison of different phasing wavefront sensors
- Test of simultaneous correction of wavefront errors generated by segmented and flexible meniscus mirrors

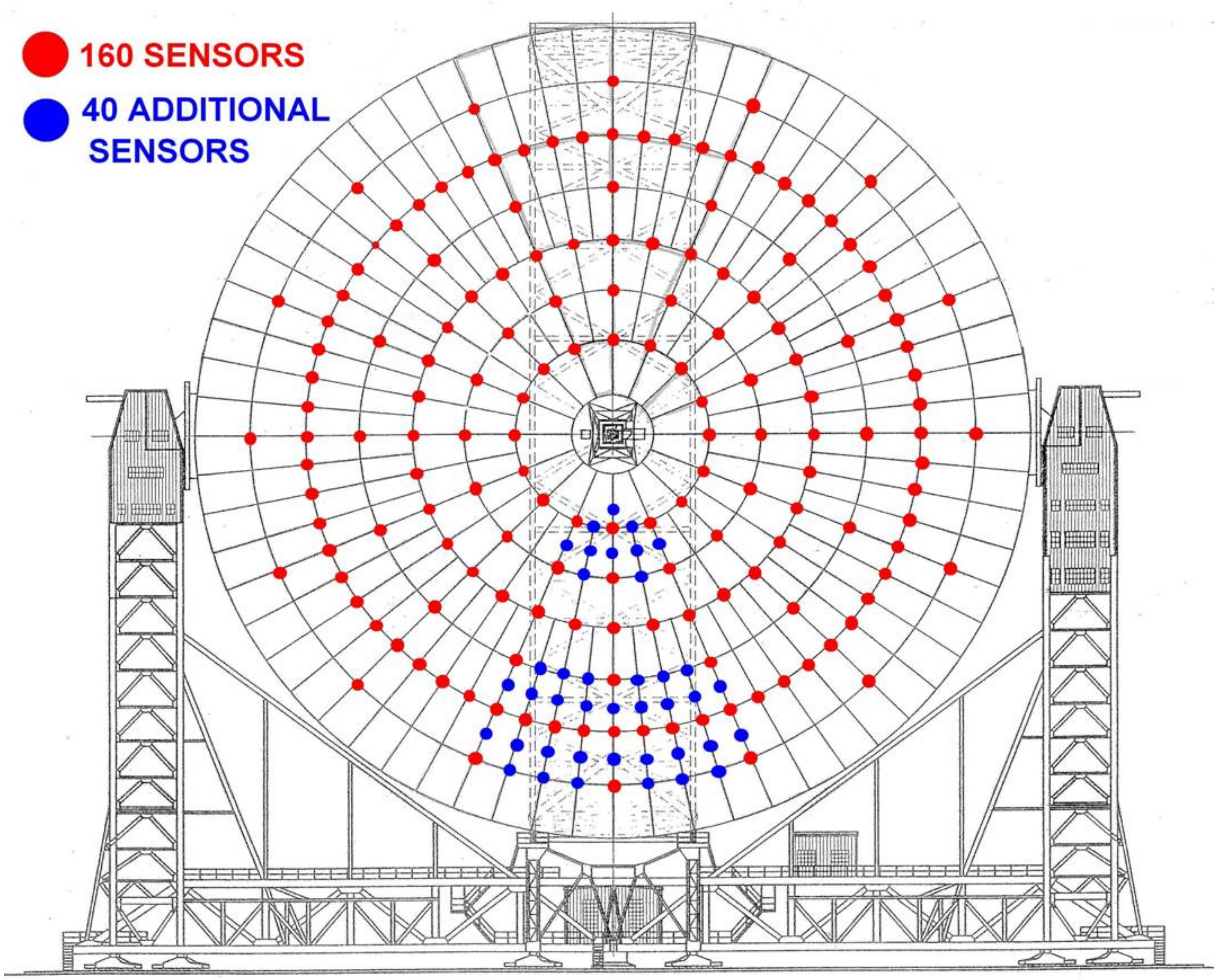


Full scale pressure measurements

Jodrell Bank Radio Telescope
Diameter : 76 m

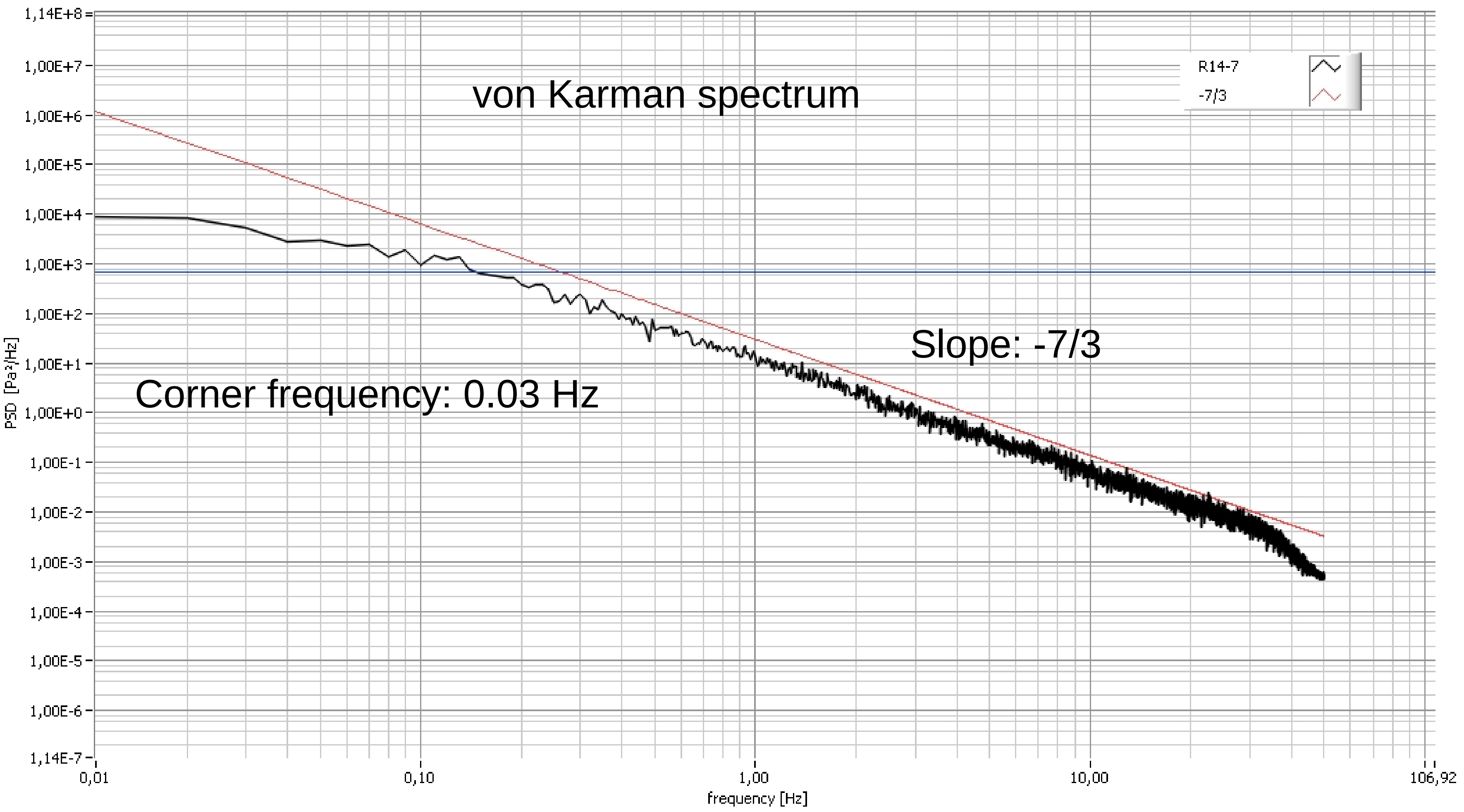


Jodrell Bank – Location of pressure sensors



Jodrell Bank – Power spectrum

Wind speed: 10 m/sec, Sampling rate : 8 kHz, Integration time : 78 min



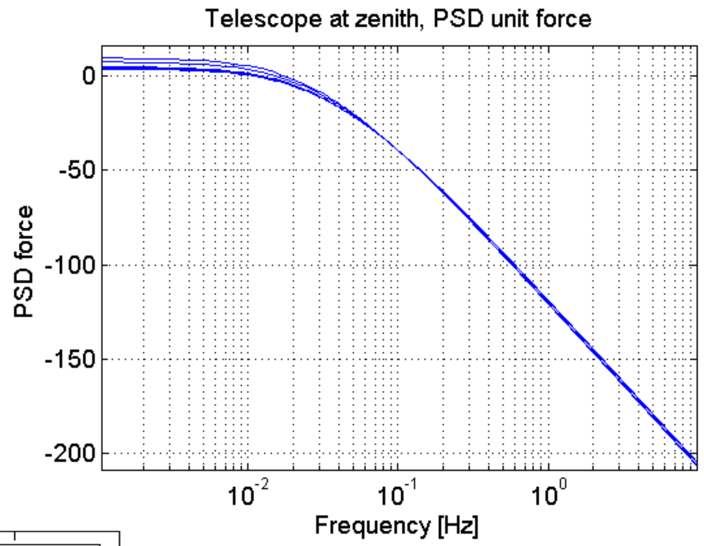
von Karman spectrum

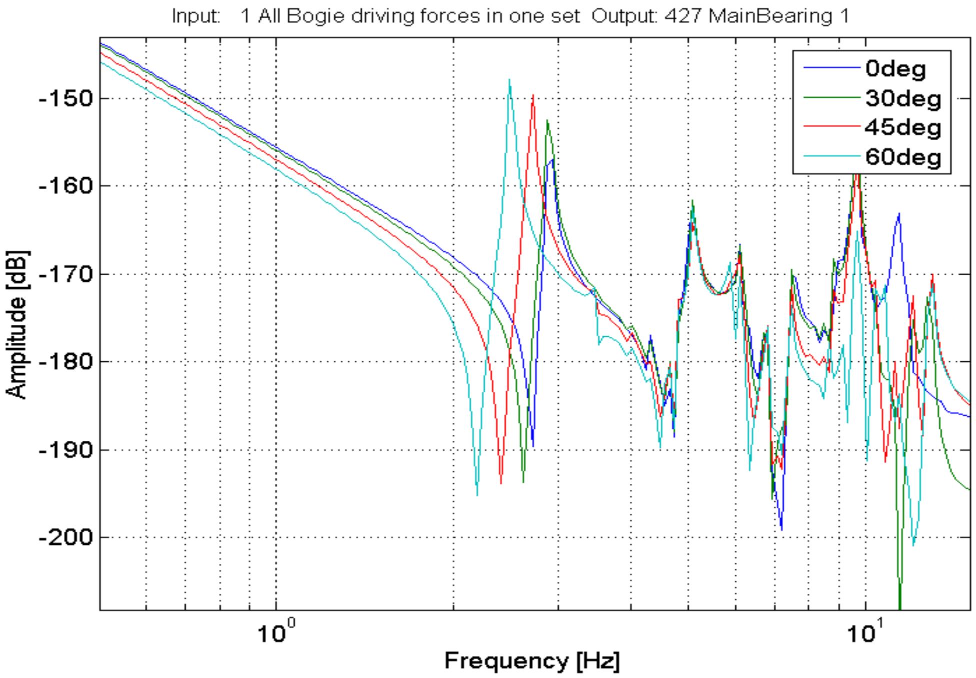
Slope: -7/3

Corner frequency: 0.03 Hz

Main axes control - wind spectra and altitude transfer function

- Von Karman wind spectra
  - Wind speed 10 – 14 m/sec
  - Turbulence intensity 0.15
  - Corner frequency 0.02 Hz

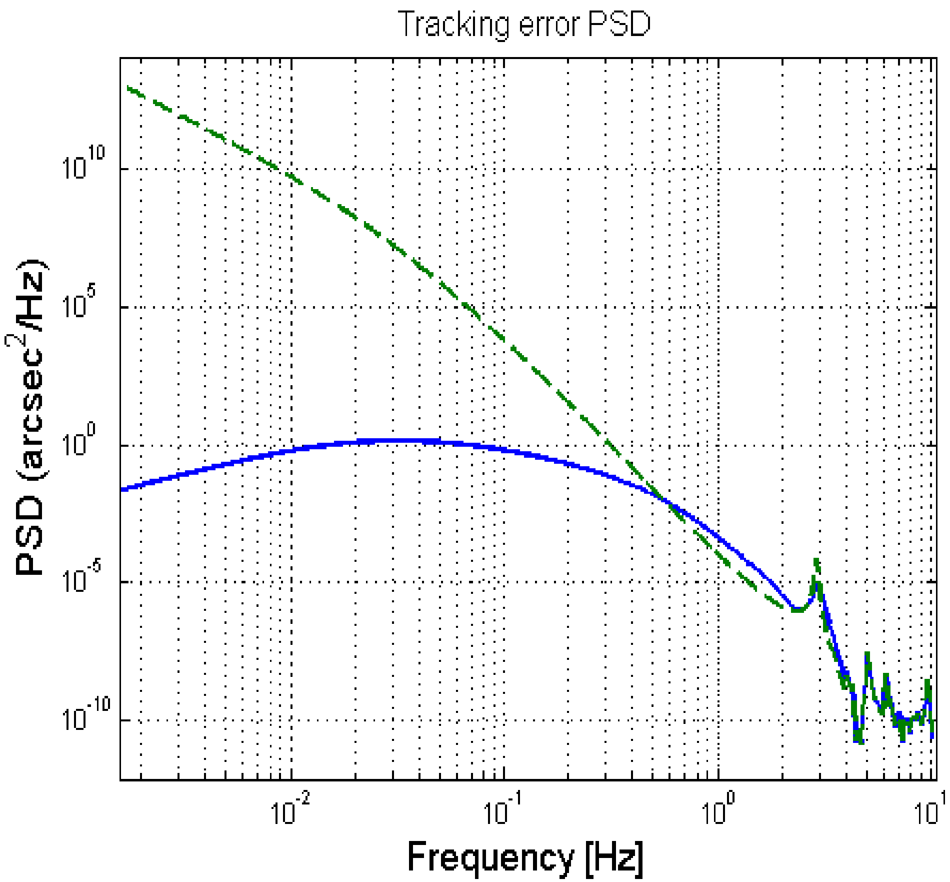




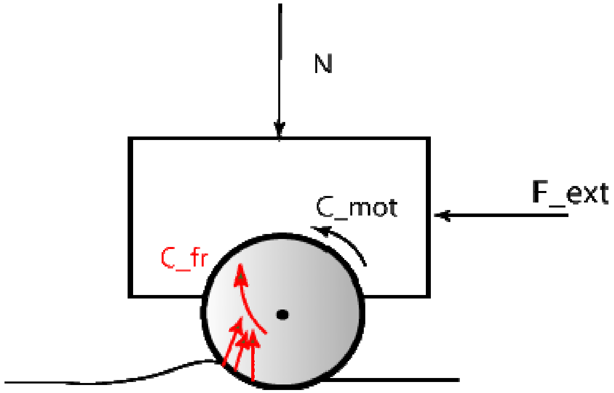
- Altitude axis transfer functions

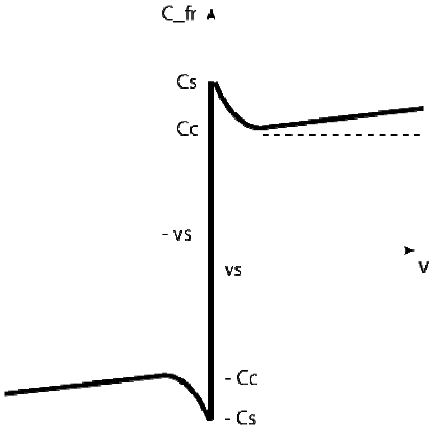
Main axes control - Residual tracking errors

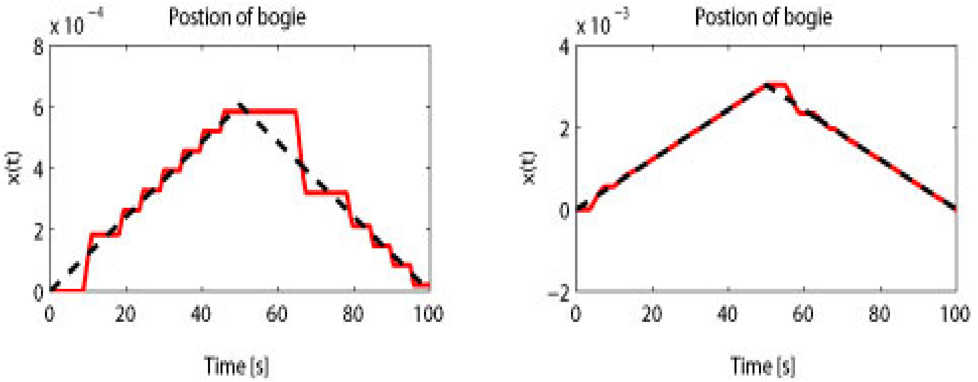
- Goal: Residual tracking errors be within the correction range of the fast tip-tilt corrections with the M6-support
- Closed-loop bandwidth: 1 Hz
- Robust design with sufficient modulus margins
- Residual RMS errors: 0.19 arcsec for 0 deg 0.32 arcsec for 60 deg

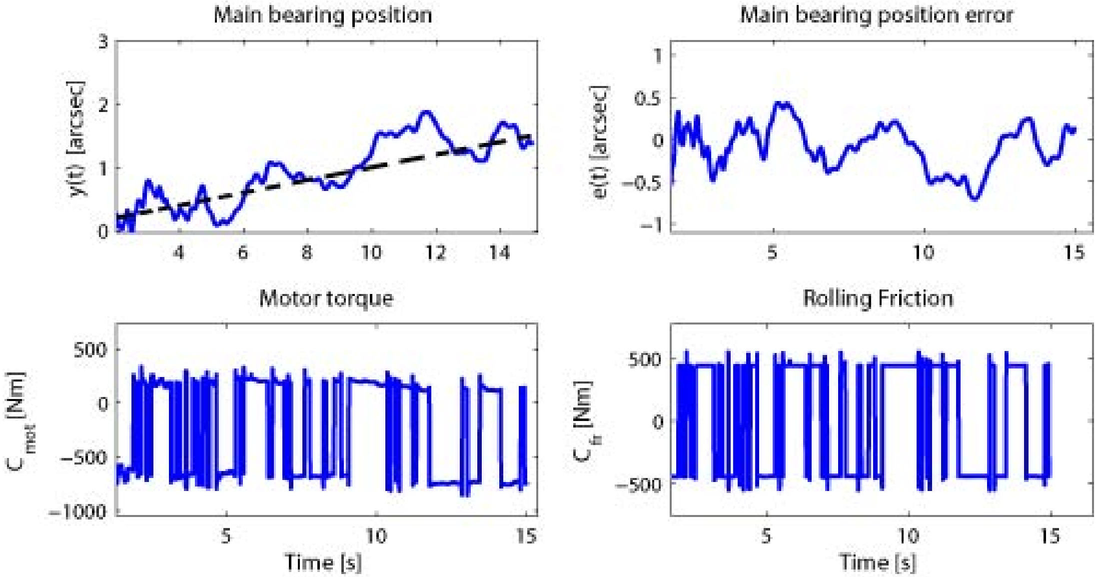


Rolling friction effects of Bogies



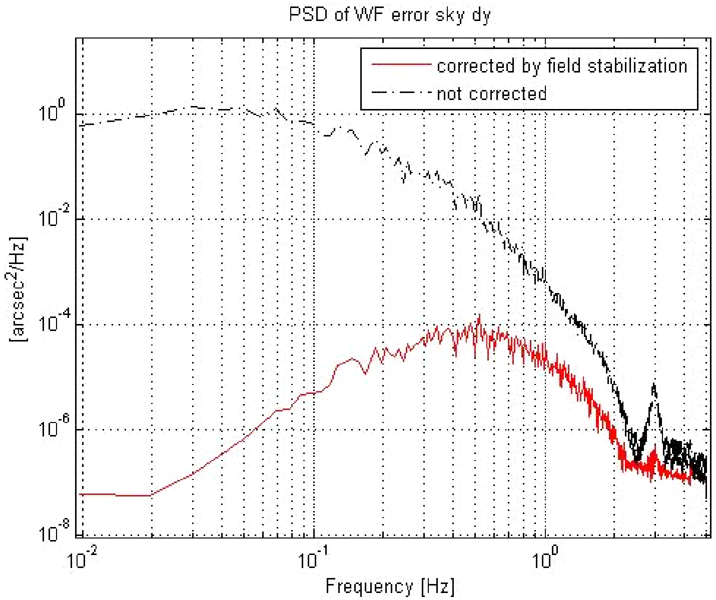


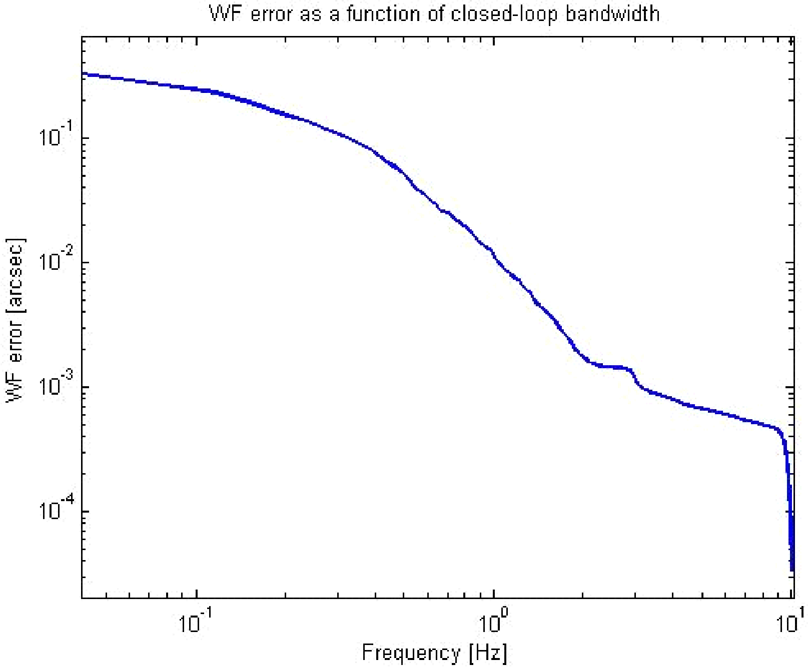




Correction of tracking errors by M6-support

- Power spectral density of the tilt error with and without closed-loop corrections by the M6-support (closed-loop bandwidth: 3.5 Hz)

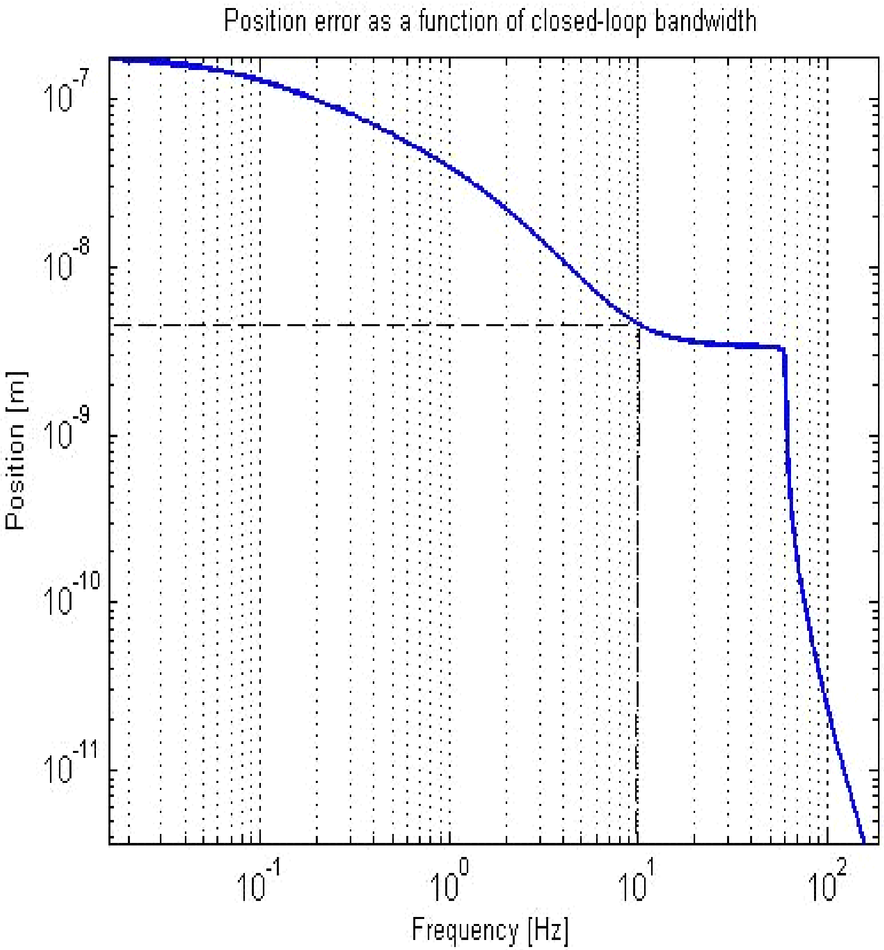




- Residual tilt error as a function of the closed-loop bandwidth
- Will be corrected by adaptive M6

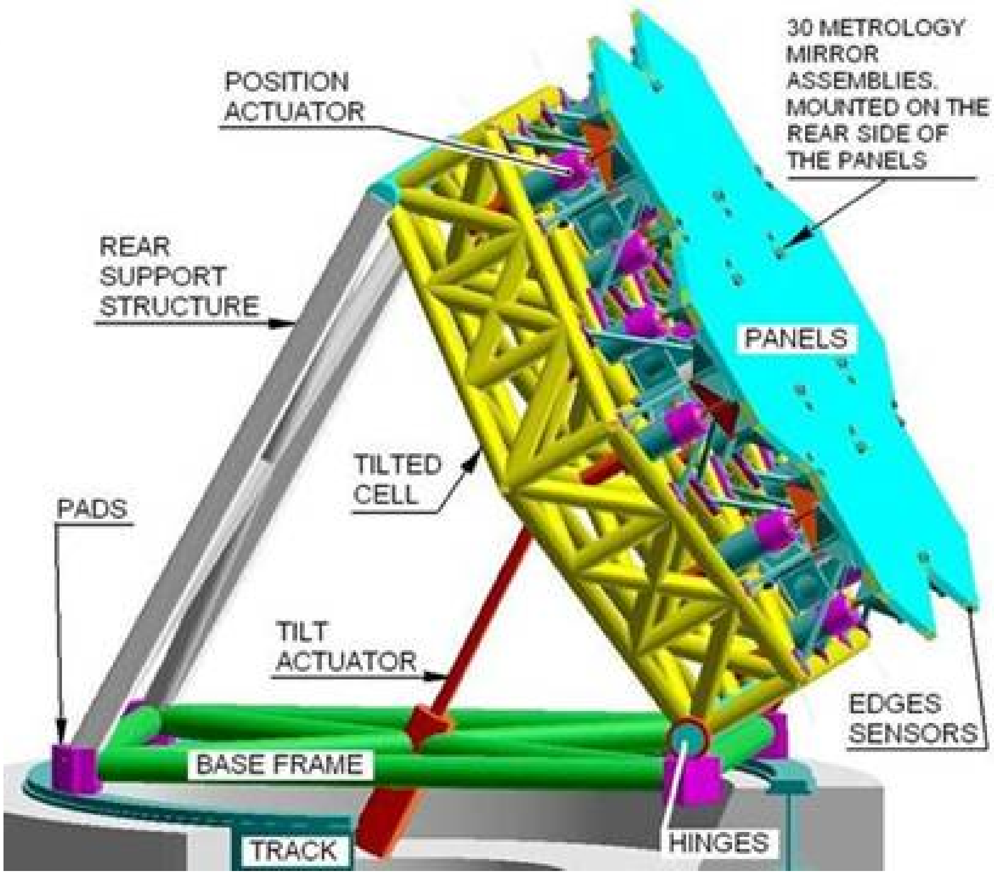
Control of segment position

- Control of the segment position based on signals from the edge sensors
- Wind speed : 10 m/sec, corner frequency: 0.07 Hz, turbulence intensity: 0.15
- Lowest segment piston frequency : 60 Hz
- Residual closed-loop error with a 10 Hz bandwidth : ~ 7 nm
- Further reduction may be possible with acceleration feedback control



Wind Evaluation Breadboard

- Test edge sensors, position actuators and control algorithms under observatory conditions



Conclusions

- Further development required for phasing wavefront sensors
  - Disentangling of overlapping segmentation patterns
  - Detection of the segmentation pattern
  - Optionally continuous wavefront sensing
  - Questions are addressed by the APE experiment
- Operation of the telescope seems feasible in open air
  - Segmented mirrors controlled by fast feedback loops
  - Large meniscus mirrors shielded from the wind
- No fundamental problems with the non-adaptive wavefront control