The PRIMA facility: Phase-Referenced Imaging and Micro-arcsecond Astrometry

Plan

- PRIMA Principle
- Scientific objectives
  - in particular circumstellar disks and planet search
- Physical limitations
  - Off-axis angle
  - Limiting magnitude
- Requirements
  - Group delay measurement accuracy
  - Fringe stabilisation
- Problems
- PRIMA system & sub-systems
- Observation / calibration / operation strategy
- Data reduction

PRIMA motivation

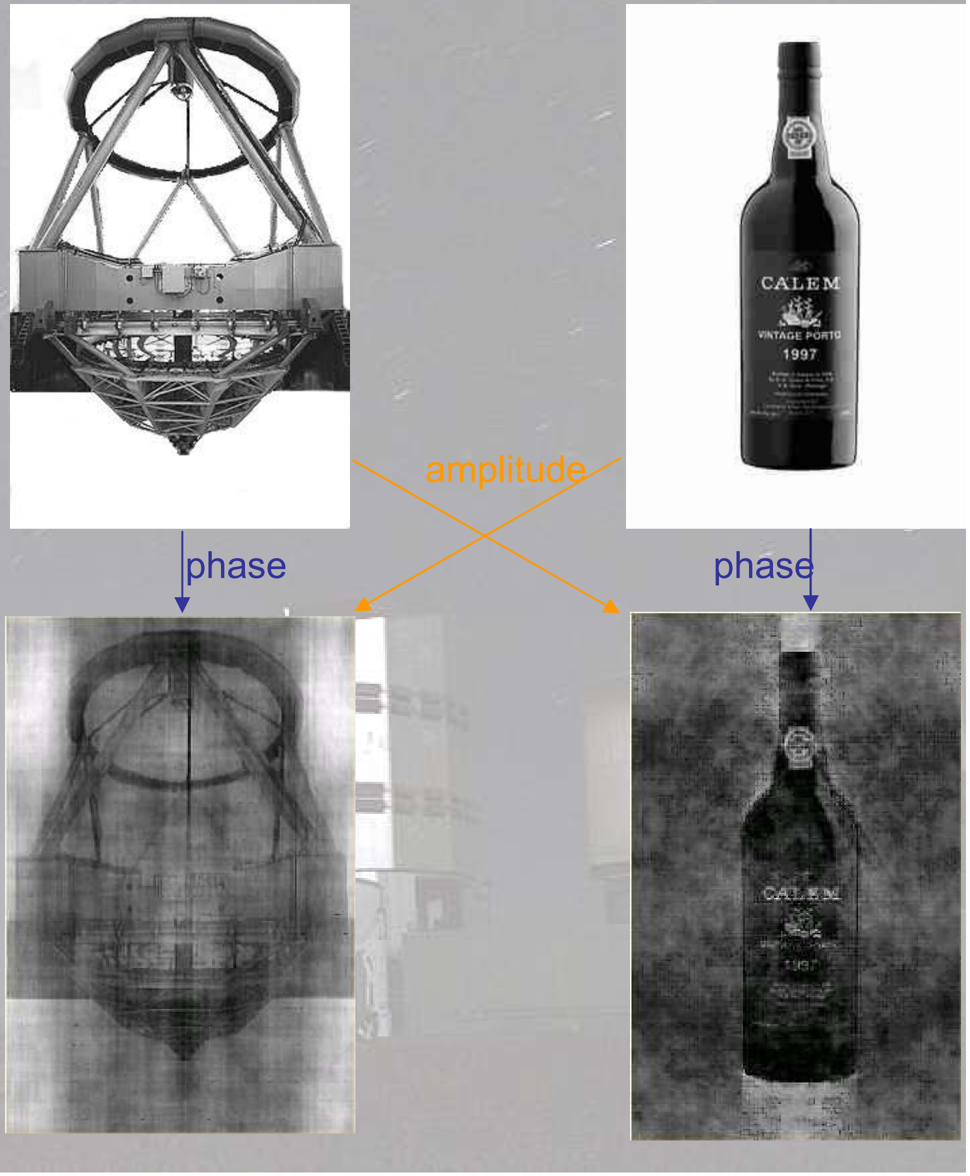
- Main limitation of ground interferometers = atmospheric turbulence =>
  - Fast scrambling of the fringes => snapshots
    => short integration time (~ 50 ms in K)
    => low limiting magnitude (VINCI => K~8 on UT)
  - Impossibility to measure the absolute position / phase of the fringes accurately
    - 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

The importance of the phase

- Original images =>
- take their Fourier Transform
  => amplitude part (squared visibility) and
  phase part
- cross the phase of one image with the amplitude of the other
- reconstructed images =>

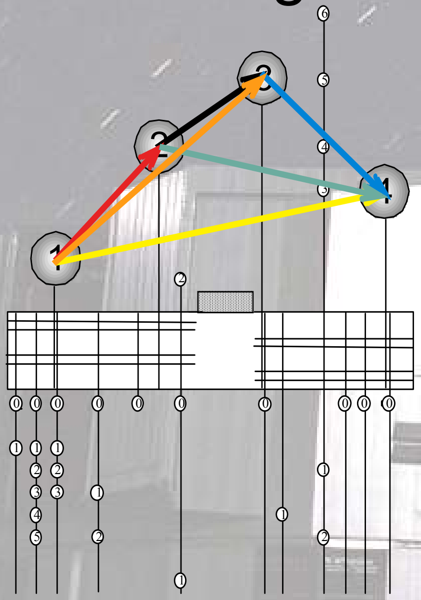
Conclusion: the phase of the image contains the most important part of the information on its shape !

Quizz: what do you get when you set all visibility moduli to 1 ?

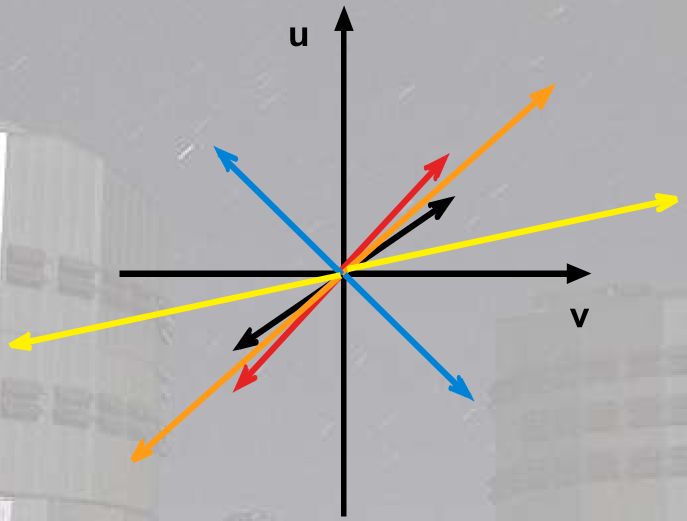


u-v plane and reconstructed PSF

- Image intensity: $I_{im}(\alpha)$ = IFT $(\Gamma(u_1 - u_2))$ (inverse the Fourier transform)
  with $u_1 - u_2$ = baseline vector and Γ = complex visibility
- Good “synthetic aperture reconstruction” if good u-v coverage

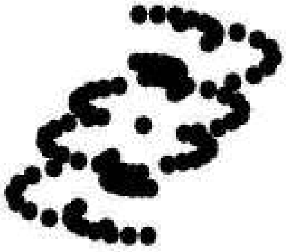


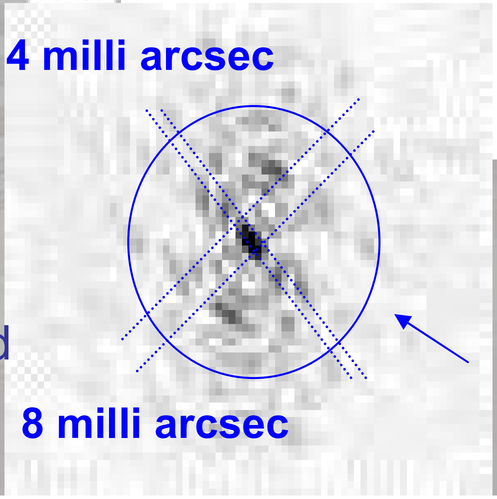
This is NOT the u-v plane



This IS the u-v plane

u-v coverage
(UT 8 hours δ=-15º)



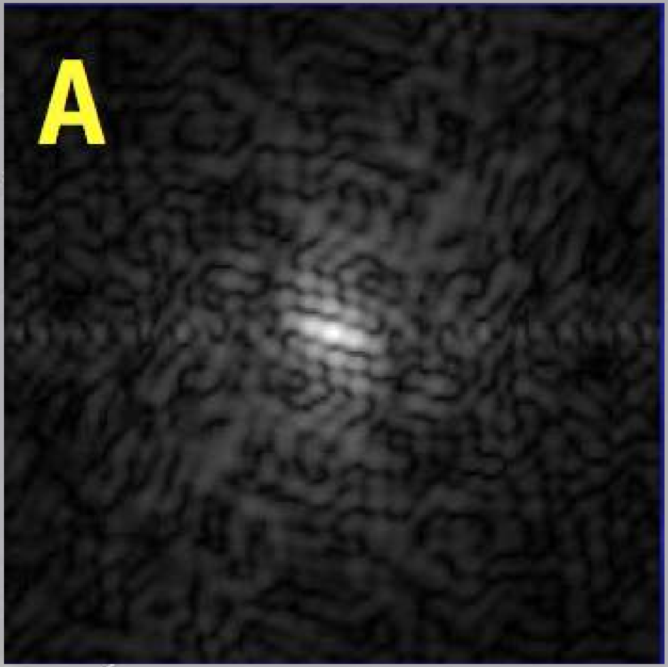


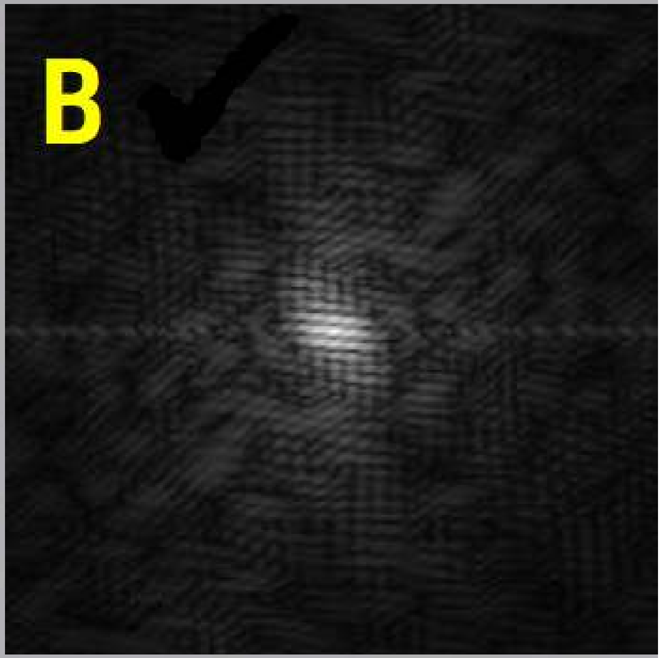
Reconstructed
PSF
K-band

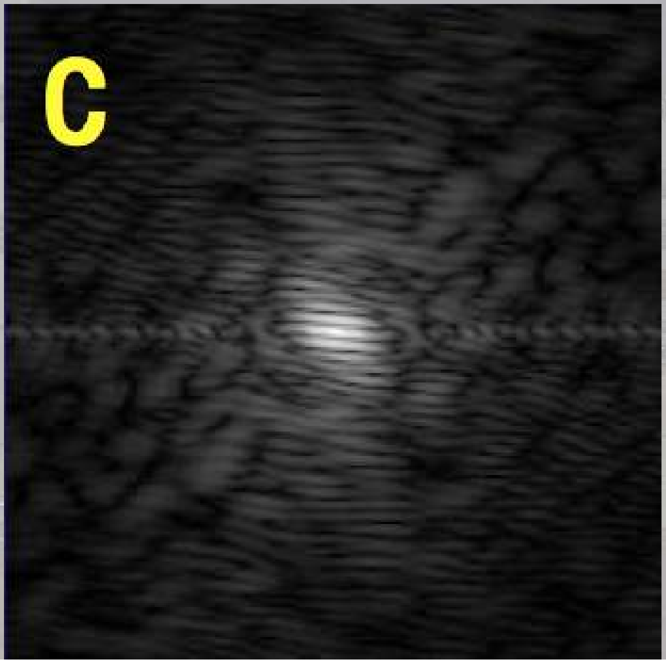
Airy disk
UT

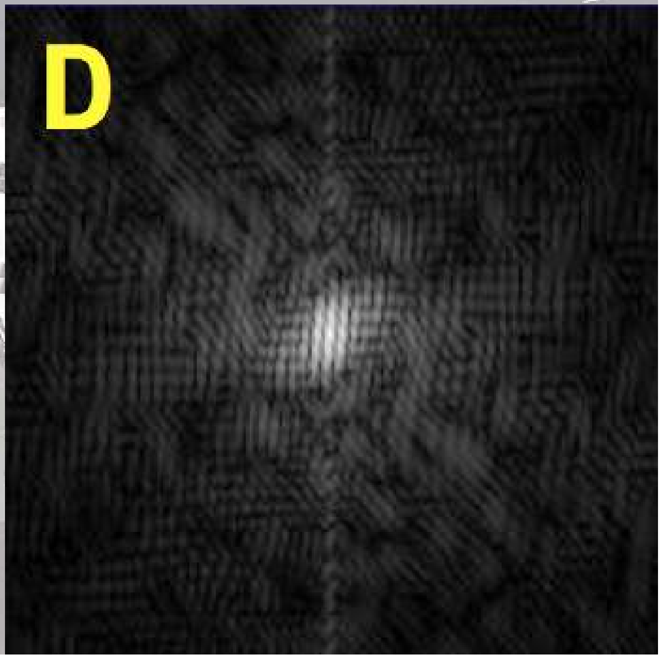
Quizz

What’s the Fourier transform (so in u-v plane) of Michelson’s picture?









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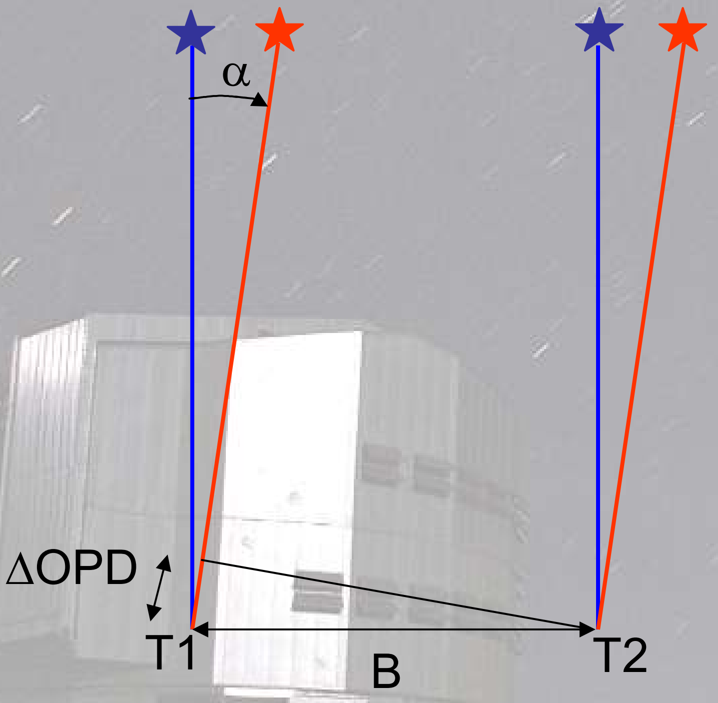
P. Tuthill

Narrow-angle differential astrometry



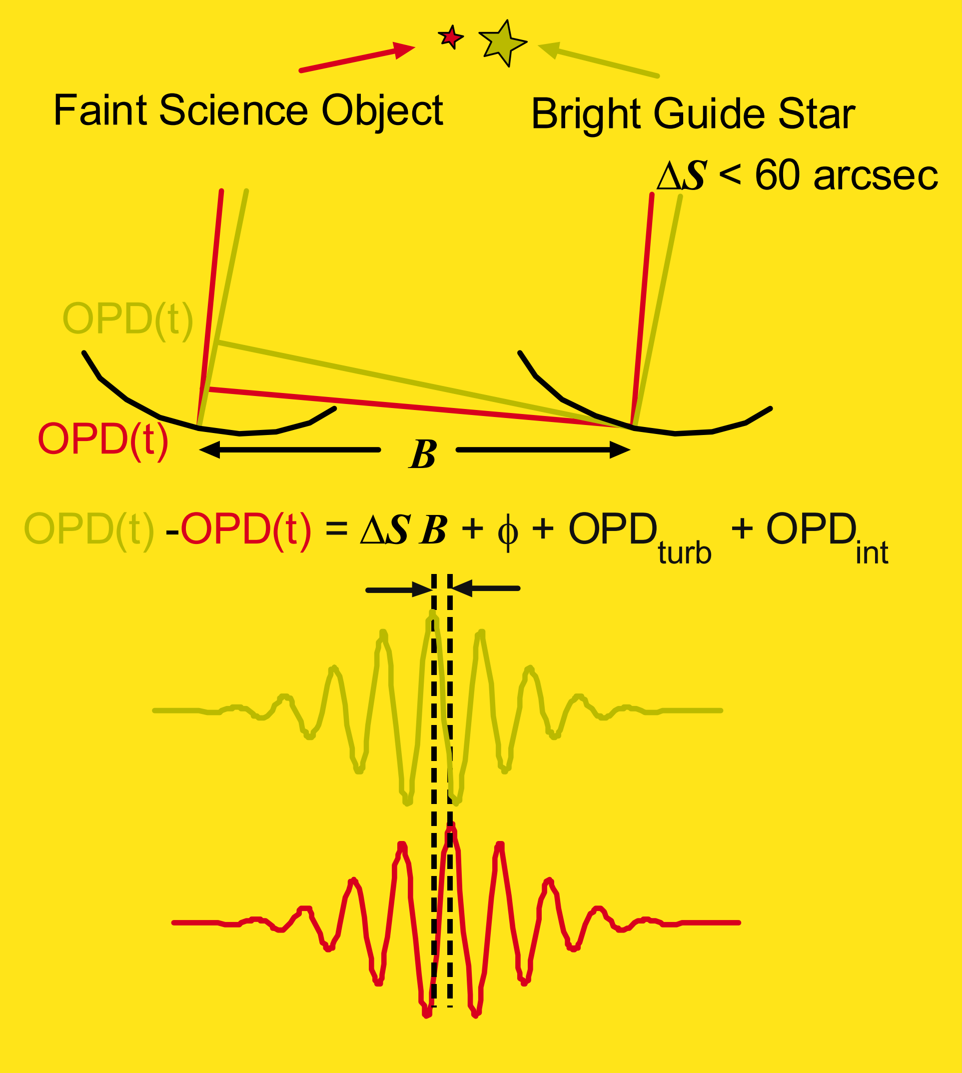
- Observe two stars simultaneously
- Slightly different pointing directions => ΔOPD to be introduced in the interferometer, between the two beams to get the fringes

$$\Delta OPD = B \, . \, \sin \alpha$$

- Moreover, the differential astrometric piston introduced by the atmosphere is several order of magnitude lower than the full piston => these perturbation (of the measured angle) average to zero rapidly

  ~ 30 min for 10” separation and 200 m baseline

Phase-referencing + astrometry



- Pick up 2 stars in a 2 arcmin field
  - bright star for fringe tracking
  - faint object / star
- $\Delta\mathrm{OPD} = \mathbf{\Delta S.B} + \phi + \mathrm{OPD}_{turb} + \mathrm{OPD}_{int}$
  - OPD_{int} measured by laser metrology
  - OPD_{turb} mean tends to 0
  - ΔOPD measured by VINCI / AMBER / MIDI / FSU
  - $\mathbf{\Delta S}$ => object position => astrometry
  - ϕ => object phase => imaging
- complex method but very powerfull
  - many baselines => many nights
- synthetic aperture imaging @ 2mas resolution
- astrometry @ 10 μas precision

The scientific objectives

- General
- Circumstellar disks =>
  - imaging
- Planets =>
  - differential astrometry
  - gravitational microlensing

PRIMA goals

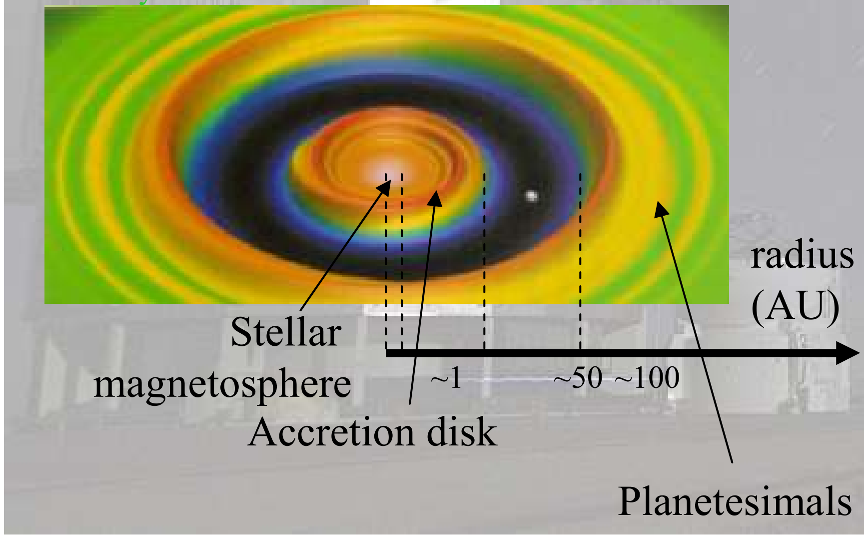
- 3 Aims:
  - faint object observation (by stabilizing the fringes)
    - dual-feed / dual-field : 2’ total FoV (2” FoV for each field)
    - K= 11? (guide star) - K=18? (object) on UTs
    - K= 8? (guide star) - K=15? (object) on ATs
  - phase-referenced imaging
    - accurate (1%) measurement of the visibility modulus and phase
    - observation on many baselines
    - synthetic aperture reconstruction at 2 mas resolution at 2.2 μm and 10 mas resolution at 10 μm
  - micro-arcsecond differential astrometry
    - very accurate extraction of the astrometric phase: 10 μas rms
    - 2 perpendicular baselines (2D trajectory)

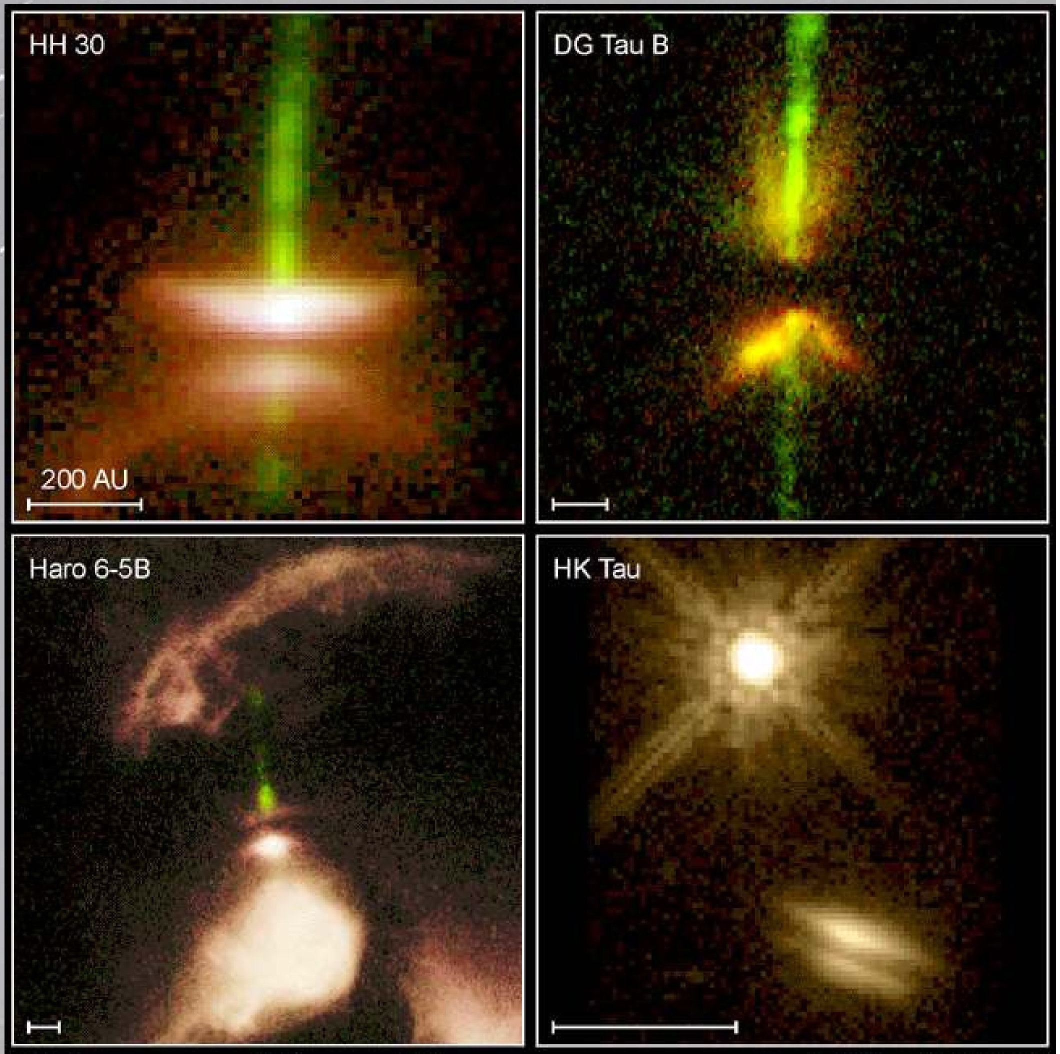
Scientific objectives - imaging

Accretion disks

Structures of 1AU scale can be observed:
- up to 1kpc at 2.2 µm and
- up to 100 pc at 10 µm

Lynne Allen and Javier Alonso

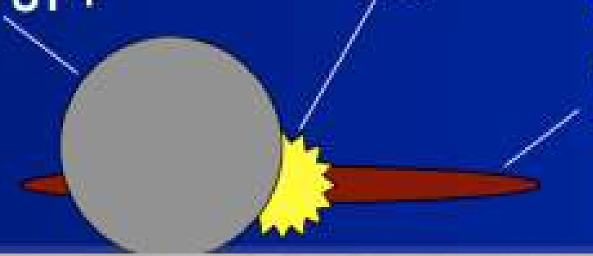




Disks around Young Stars **HST • WFPC2**
PRC99-05b • STScI OPO
C. Burrows and J. Krist (STScI), K. Stapelfeldt (JPL) and NASA

Scientific objectives - imaging

Distance to system [pc]	Angular size of internal disk (1 AU)	External angular size of the dust torus (100 AU)	Angular distance to planets (5 AU)
10	0.1" = resolution limit of 2-m class telescopes with tip-tilt correction	10"	0.5" = (good) seeing limited telescopes
100	0.01" = resolution of 10µm long baseline interferometry (VLTI-MIDI)	1" = (bad) seeing limited telescopes	0.05" = diffraction limited 8-m class telescopes with adaptive optics
1000	0.001" = resolution of 1µm long baseline interferometry (VLTI-AMBER)	0.1" = resolution limit of 2-m class telescopes with tip-tilt correction	0.005" = resolution of 2µm long baseline interferometry (VLTI-AMBER)

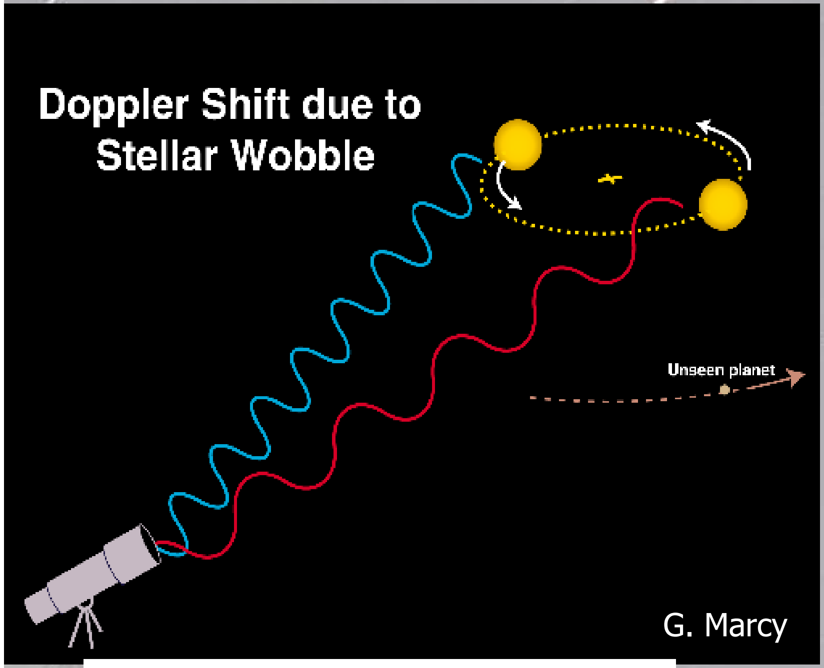


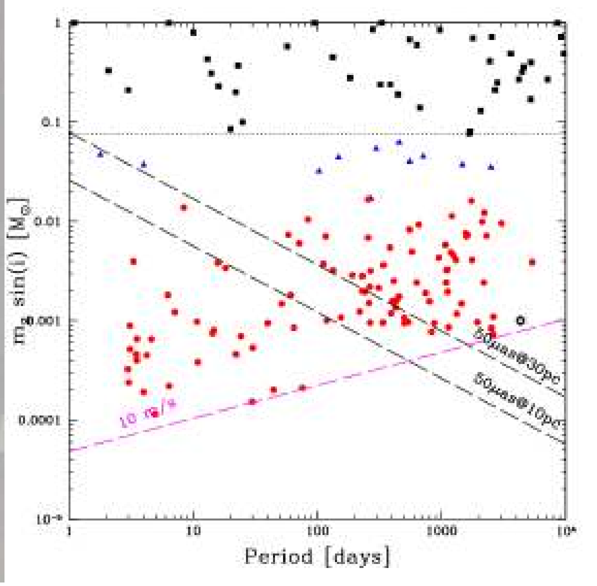
Instrument field of view (interferometric beam UT + Adaptive Optics)

Star

Circumstellar disk (typical contrast of about 10^-5)

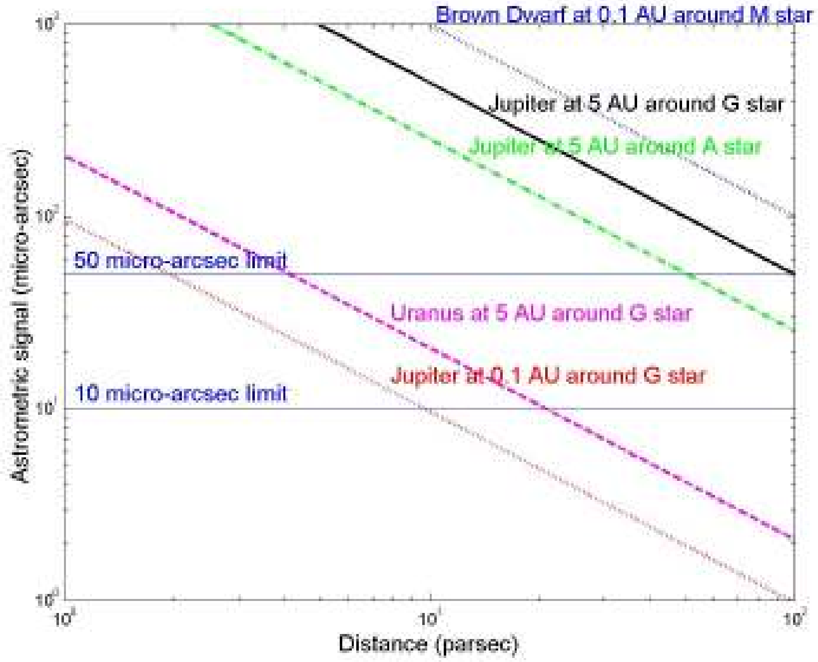
Scientific objectives: planets

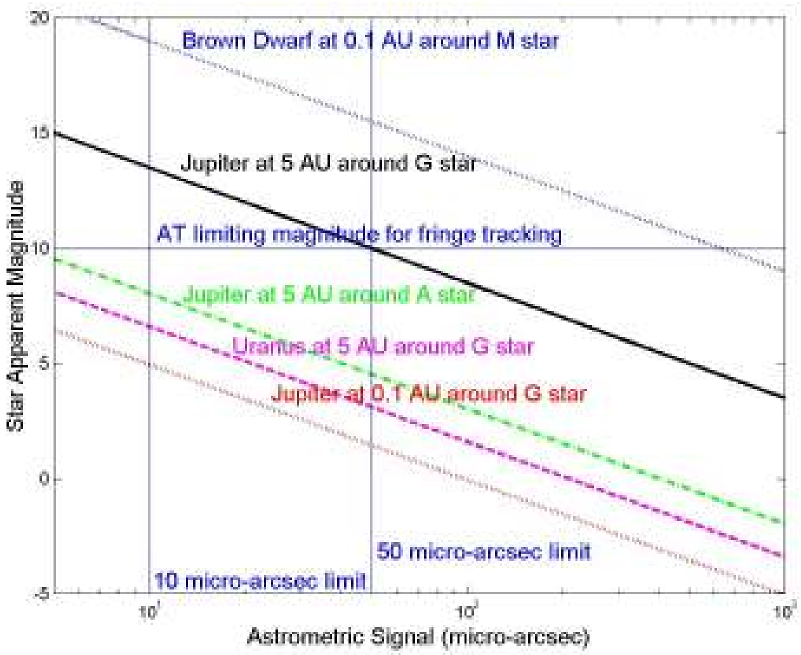




- Reflex motion of the star due to planet presence
- Wobble amplitude proportional to:
  - planet Mass
  - (star mass)$^{-2/3}$
  - (planet period)$^{2/3}$
  - 1 / distance to the star
  - amplitude does **not** depend on orbit inclination
- Complementarity with radial velocities:
  - better for large planets at large distances
  - not sensitive to sin(i)
  - applicable to (almost) all star types
- Need of long-duration survey programmes to characterise planets far from the star
- Need to maintain the accuracy on such long periods !

Astrometric signature of planets

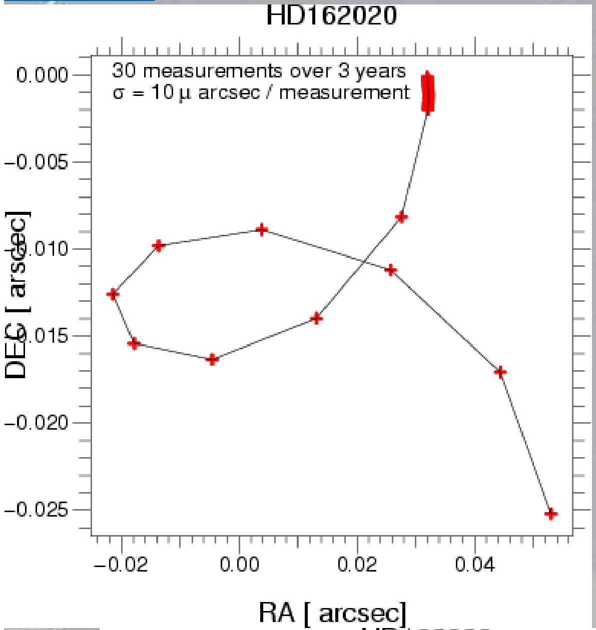


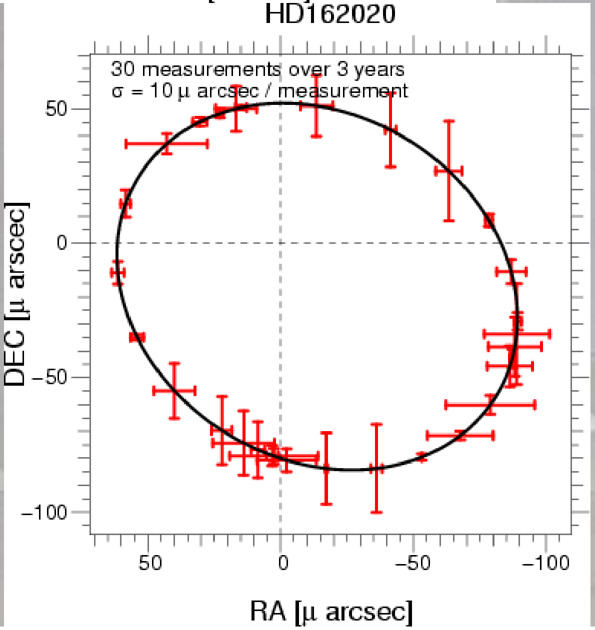


- •Jupiter-like planet around sun-like star => 50 µas reflex motion

- •If the astrometric signal is large enough to be detected at 50 µas level, the star is almost always bright enough to be PRIMA guide star (if K=10 is reached !)

Astrometry & planets: errors

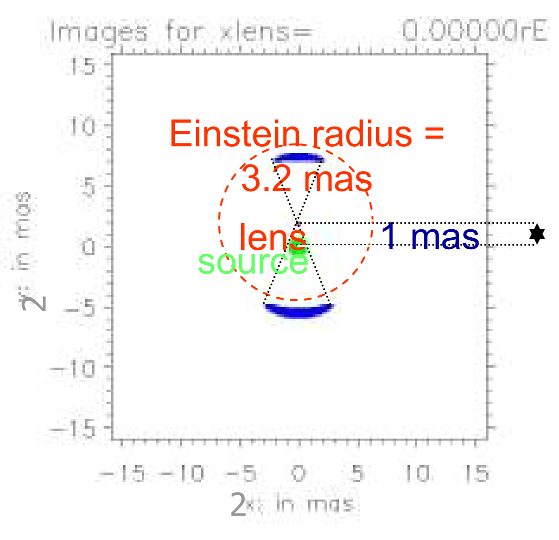


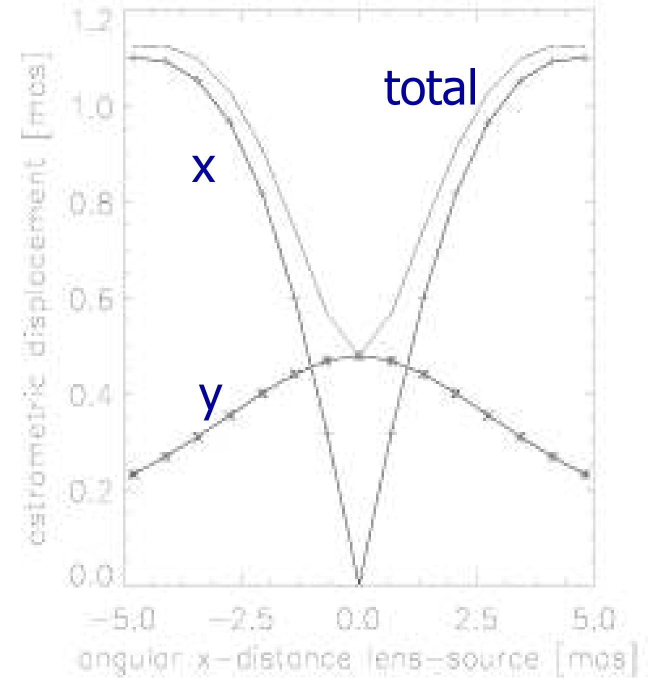


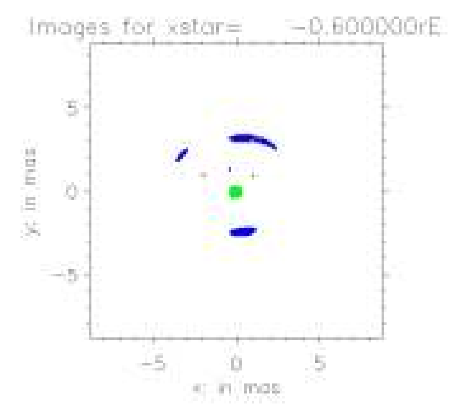
- The astrometric signal is dominated by parallax and proper motion =>
- Measurements have to be done very carefully
- Astrophysical effects have to be taken into account in the data reduction:
  - – Observer’s velocity aberration:
    - 10 µas (= 50 pico-rad) global astrometry requires 50 pico-c for the knowledge of the observer's velocity (= 15 mm/sec), but:
    - Narrow angle (<1' = 0.3 m-rad) relaxes that to 50 m/sec
  - – Angular perspective acceleration:
    - Important in a few years for velocities around 10 km/sec and distances of a few pc
- Phases of both stars are assumed to be null (centro-symmetric) or known

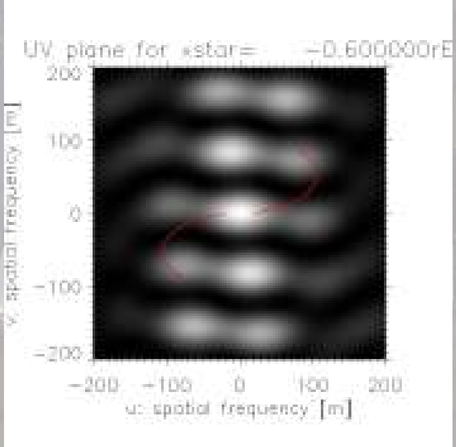
Scientific objectives: micro-lensing

- Difference in amplification on both images =>
  - displacement of total photocenter
- Example: M = 10 M_{sun}, impact parameter = 1mas, r_E = 3.2 mas
  - maximum photocenter displacement = 1.2 mas
  - NOT maximum at closest approach
- In case of planet around the lens:
  - secondary photometric peak and
  - more complex shape (3 to 5 images) => imaging and astrometry
- But has to work on alerts & needs high limiting magnitude (K~15-16 on secondary object)





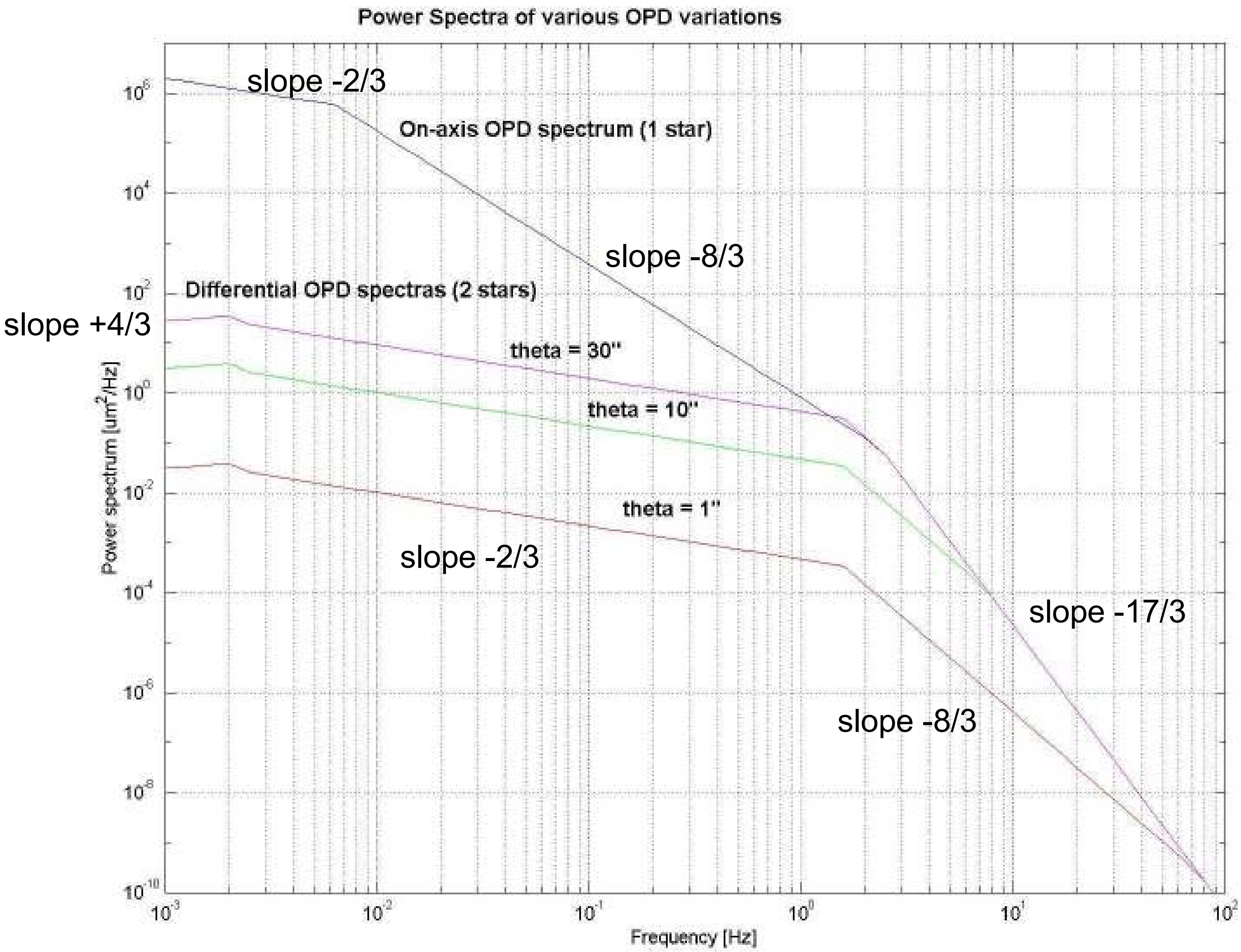




The physical limitations and The scientific requirements

- Physical limitations
  - – Atmospheric anisoplanatism
  - – Sky coverage
- Scientific requirements
  - – OPD accuracy for imaging / astrometry
  - – OPD stabilization for fringe tracking

Atmospheric anisoplanatism 1



Kolmogorov spectrum

Balloon measurements at Paranal

Seeing = 0.66” at 0.5 µm

τ_0 = 10 ms at 0.6 µm

Atmospheric anisoplanatism 2

- Off-axis fringe tracking <=> anisoplanatic differential OPD

$$\sigma_{OPDmeasurement} \cong 370.B^{-2/3}.\frac{\theta}{\sqrt{T_{obs}}}$$

for narrow angles (θ < 180” UT or 40” AT) and long total observation time T_{obs} >> ~100s

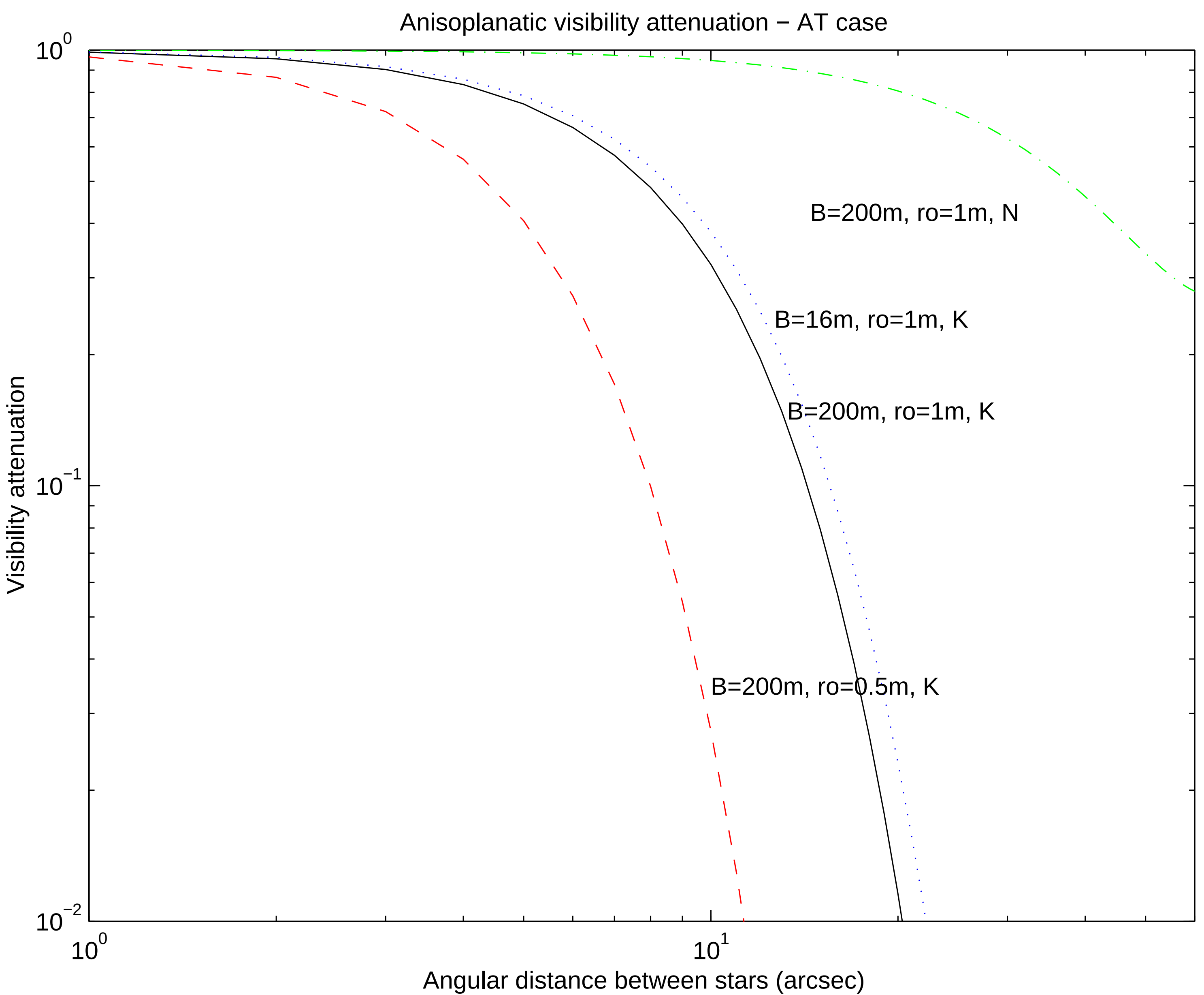
for Paranal seeing = 0.66” at 0.5µm, τ_0 = 10 ms at 0.6µm (L. d’Arcio)

Factor = 300 for Mauna Kea (Shao & Colavita, 1992 A&A 262)

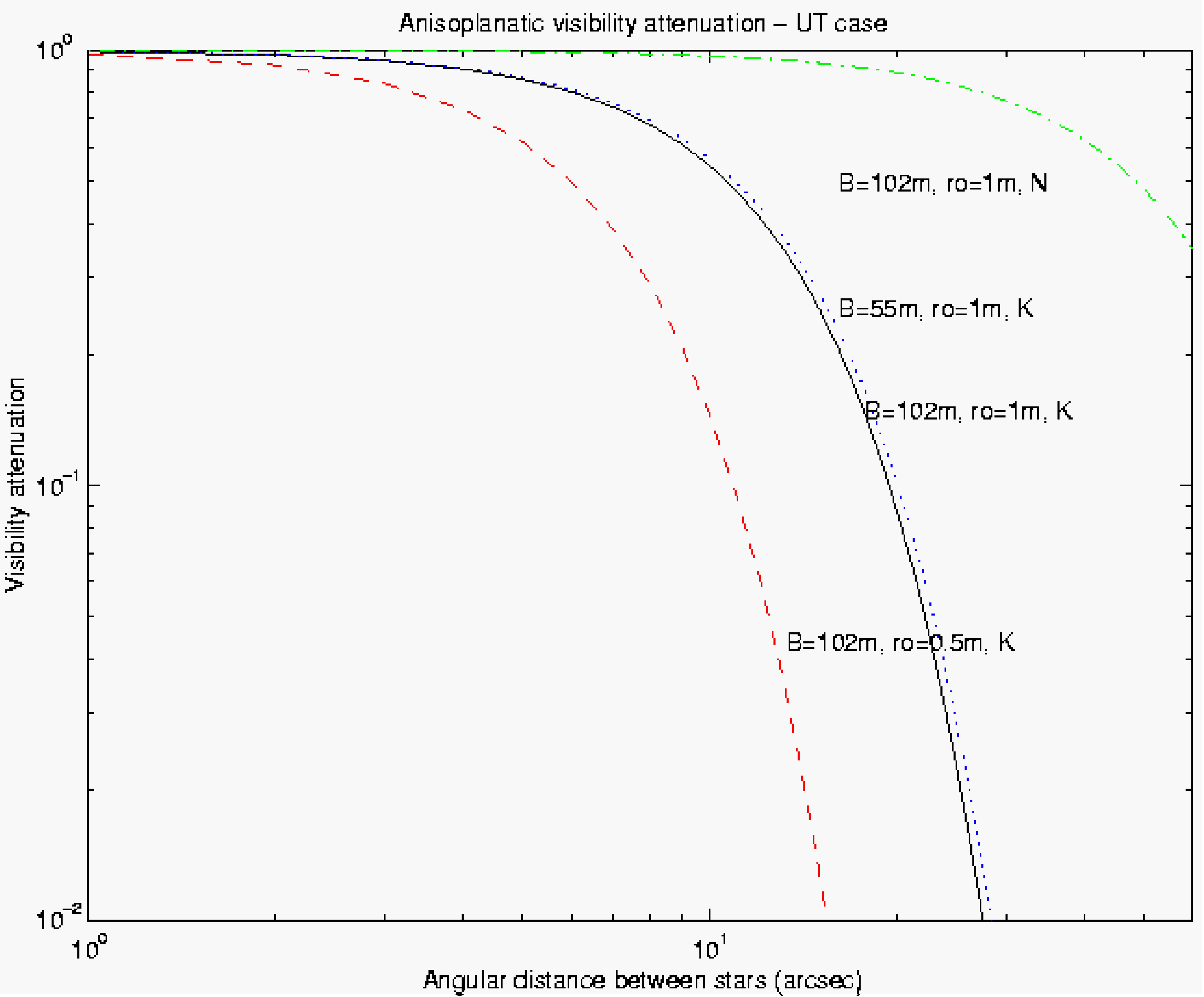
  - Increases with star separation
  - Decreases with telescope aperture (averaging)
  - High impact of seeing quality
- Translates into off-axis maximum angles to limit visibility losses (< 50 to 90%):
  - K-band imaging (2 µm)
    - Bright fringe guiding star within 10-20”
  - N-band imaging (10 µm)
    - Bright fringe guiding star within 2’

$$V = V_0.\exp\left[-2.\left(\frac{\pi}{\lambda}.\sigma_{residual\_OPD}\right)^2\right]$$

Anisoplanatism AT

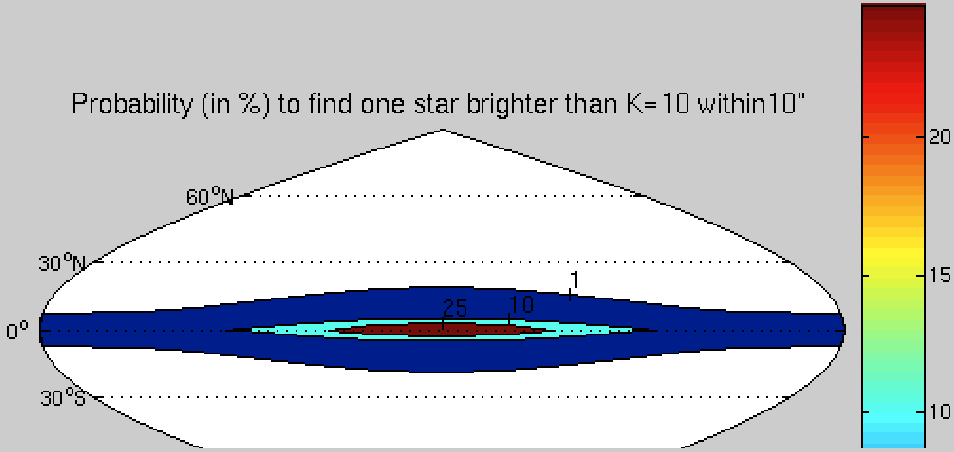


Anisoplanatism UT

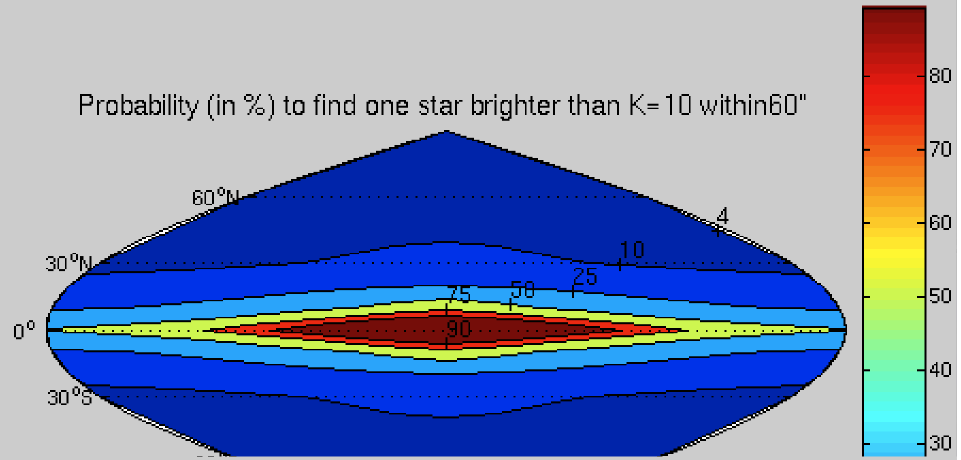


Sky coverage

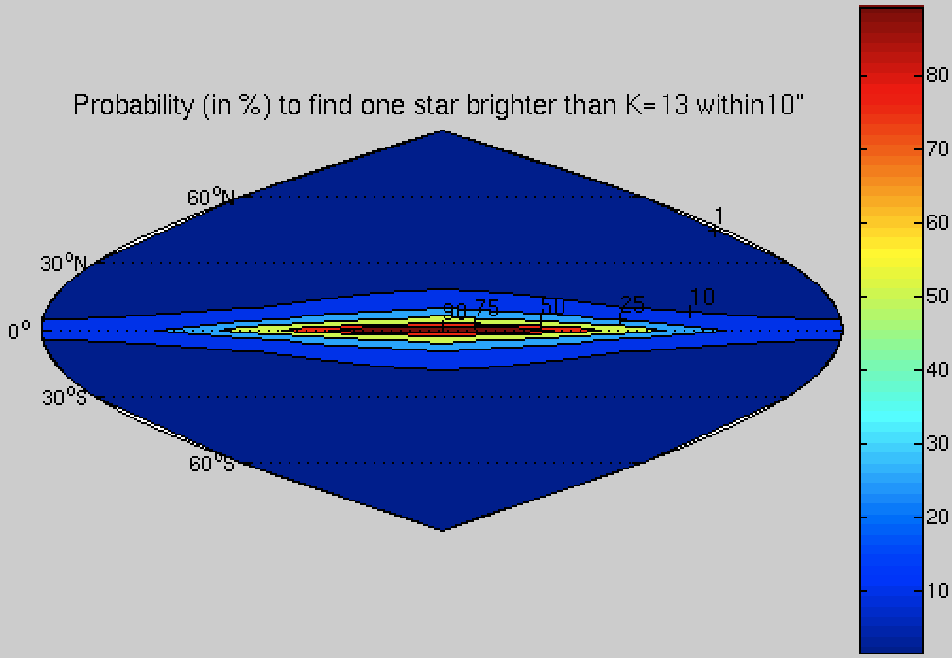
- Sky coverage <=> limiting magnitude



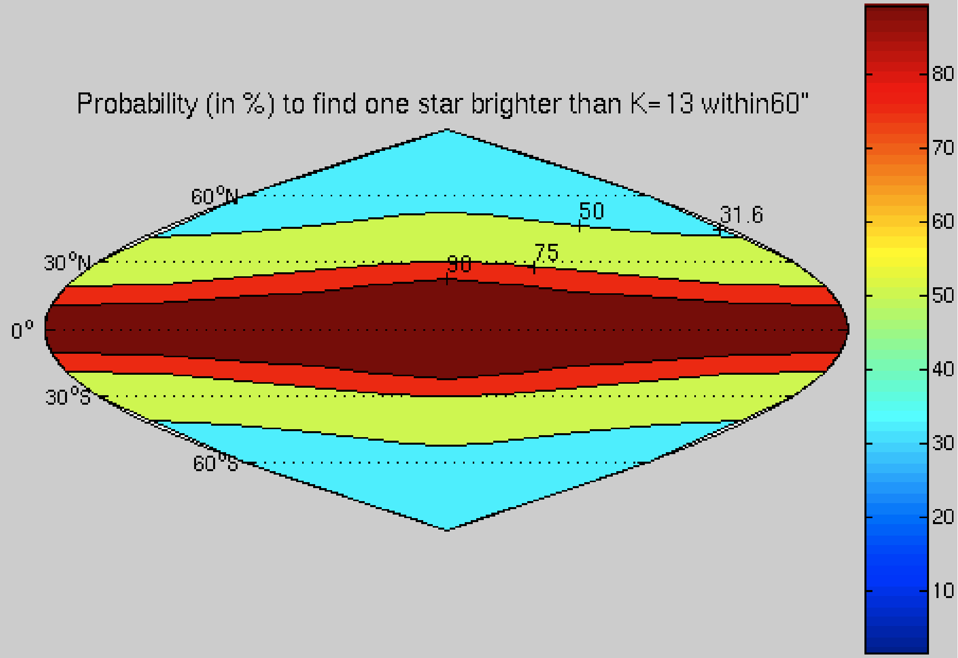
Probability (in %) to find one star brighter than K=10 within10"



Probability (in %) to find one star brighter than K=10 within60"



Probability (in %) to find one star brighter than K=13 within10"



Probability (in %) to find one star brighter than K=13 within60"

Accuracy requirements

- Phase-referencing measurable: difference of group delay

$$\underset{\text{Fringe sensor}}{\underset{\uparrow}{\Delta OPD}} = \underset{\text{astrometry}}{\underset{\uparrow}{\Delta \mathbf{S.B}}} + \underset{\text{imaging}}{\underset{\uparrow}{\phi}} + \underset{\text{atmosphere}}{\underset{\uparrow}{OPD_{turb}}} + \underset{\text{Internal metrology}}{\underset{\uparrow}{OPD_{int}}}$$

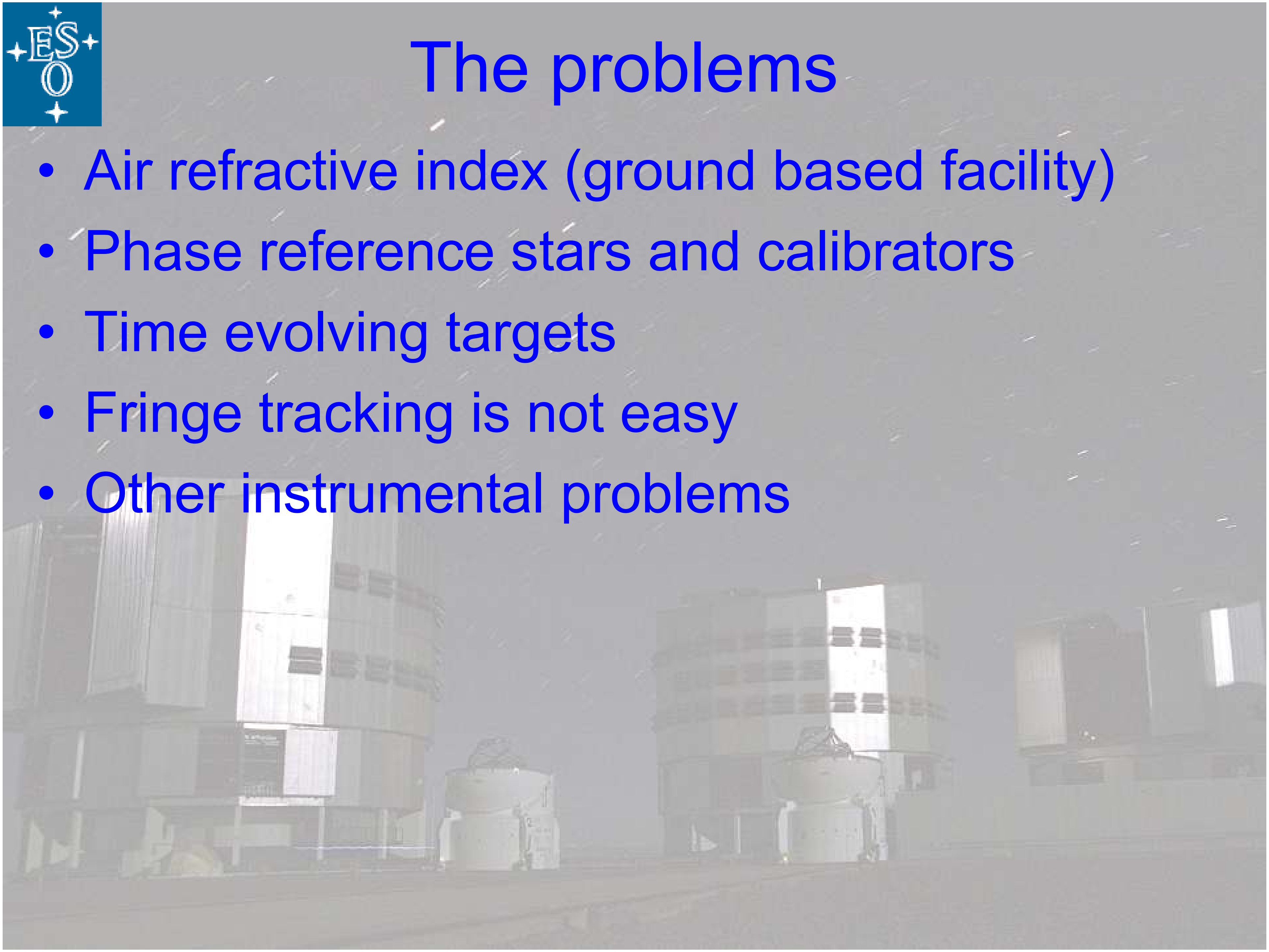
- Astrometric requirement
  - For 2 stars separated by 10" - 0.8"seeing - B=200m => Atmosphere averages to 10µas rms accuracy in 30 min
  - <=> 5nm rms measurement accuracy
- Imaging requirement =>
  - dynamic range is important (ratio between typical peak power of a star in the reconstructed image and the reconstruction noise level)
  - DR ~ M . $\phi / \Delta\phi$ where M = number of independent observations
  - DR > 100 and M=100 <=> $\Delta\phi / \phi < 0.1$ <=> 60nm rms in K
- Ability to do off-axis fringe tracking

Fringe tracking requirements

- Fringe tracking performance if limited by atmosphere:
  - Total closed loop residuals should not introduce more fringe visibility loss (5-10%) than typical anisoplanatism => < 100 nm rms total OPD residuals
  - $$\sigma_{residual\_OPD} \cong 2.54.10^{-6}.\frac{1}{D}.T^{11/6}$$
  - Fringe tracking residuals depend on control loop transfer function:
    - low bandwidth (45 Hz) => 100 nm - improved bandwidth (100 Hz) => 70 nm
- In practice, it is very difficult to reach => what is needed ?
  - K-band:
    - Residual OPD < 300 nm rms =>
      - 0.1% probability of fringe jumps in K-band
      - loss of visibility on instrument < 30% but can be calibrated
    - Larger residuals => fringe jumps to be recovered by group delay tracking => loss of SNR accelerates =>
      - larger observation time to get the fringes out of the noise: T ~ noise^2
      - difficulty to calibrate the visibilities
  - N-band:
    - Relaxed coherencing requirements: residual closed-loop OPD <~ 10µm rms
    - Accurate fringe position measurement for post-processing: OPD noise < 1µm rms

The problems

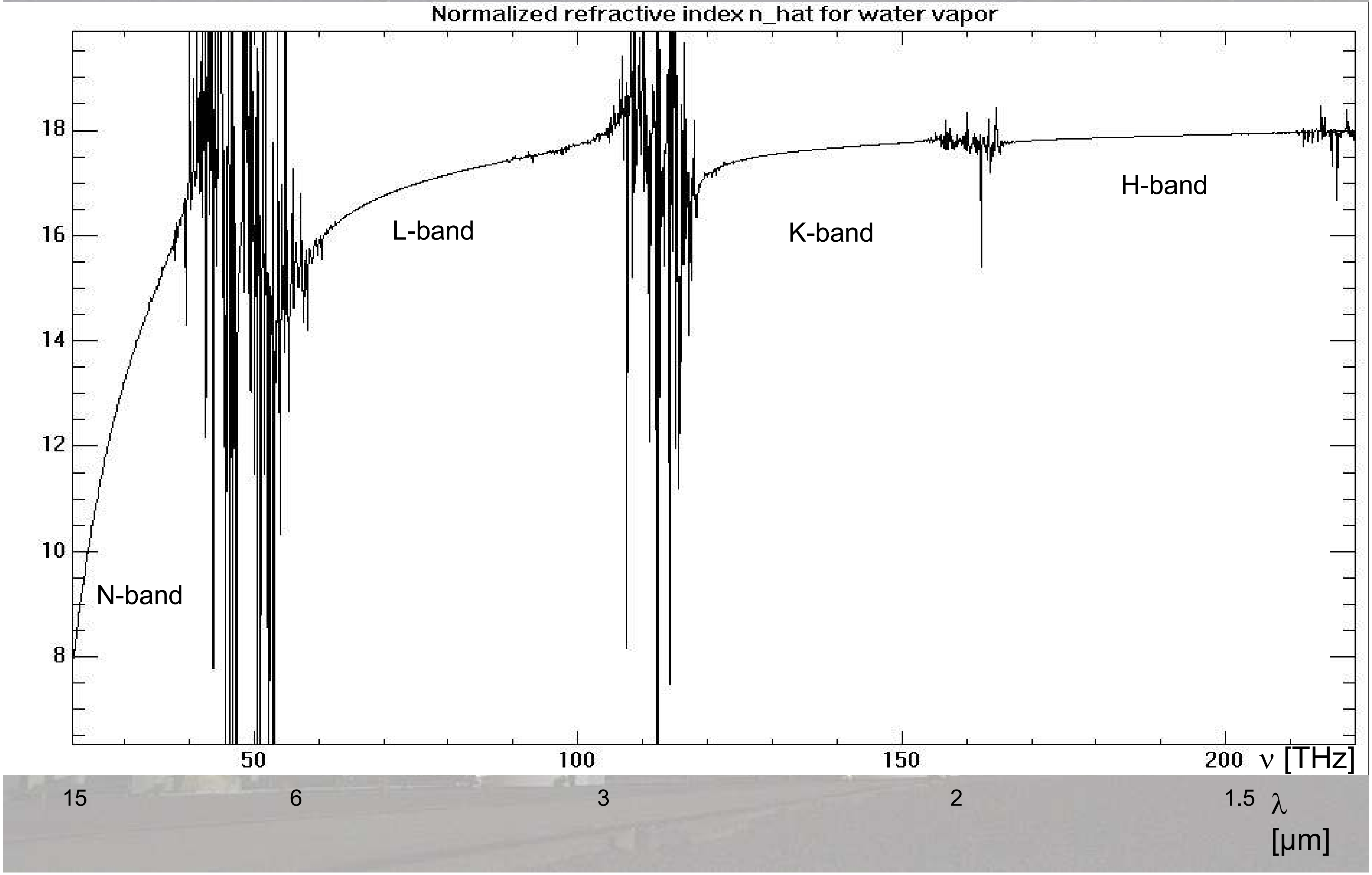
- Air refractive index (ground based facility)
- Phase reference stars and calibrators
- Time evolving targets
- Fringe tracking is not easy
- Other instrumental problems



Dispersion and H_2O seeing

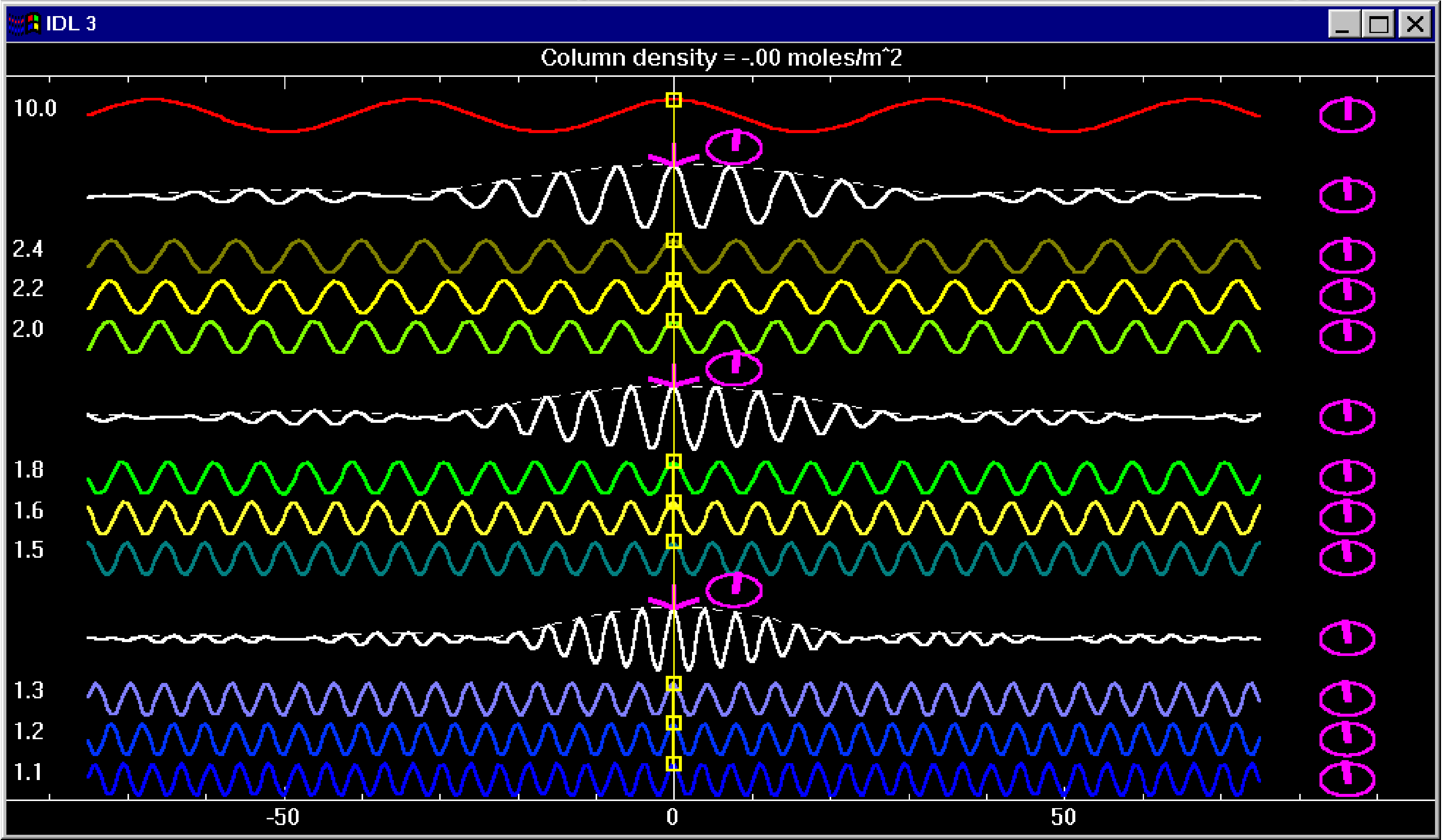
- Transversal & longitudinal dispersion
- Fringe tracking and observation at different λ
- Air index of refraction depends on wavelength =>
  - phase delay   group delay
  - group delay depends on the observation band
  - fringe tracking in K does not maintain the fringes stable in J / H / N bands
- Air index varies as well with air temperature, pressure & humidity
  - overall air index dominated by dry air
  - H_2O density varies somewhat independently
  - H_2O effect is very dispersive in IR (between K and N)
- Remedy: spectral resolution

Refractive index of water vapor (©R. Mathar)



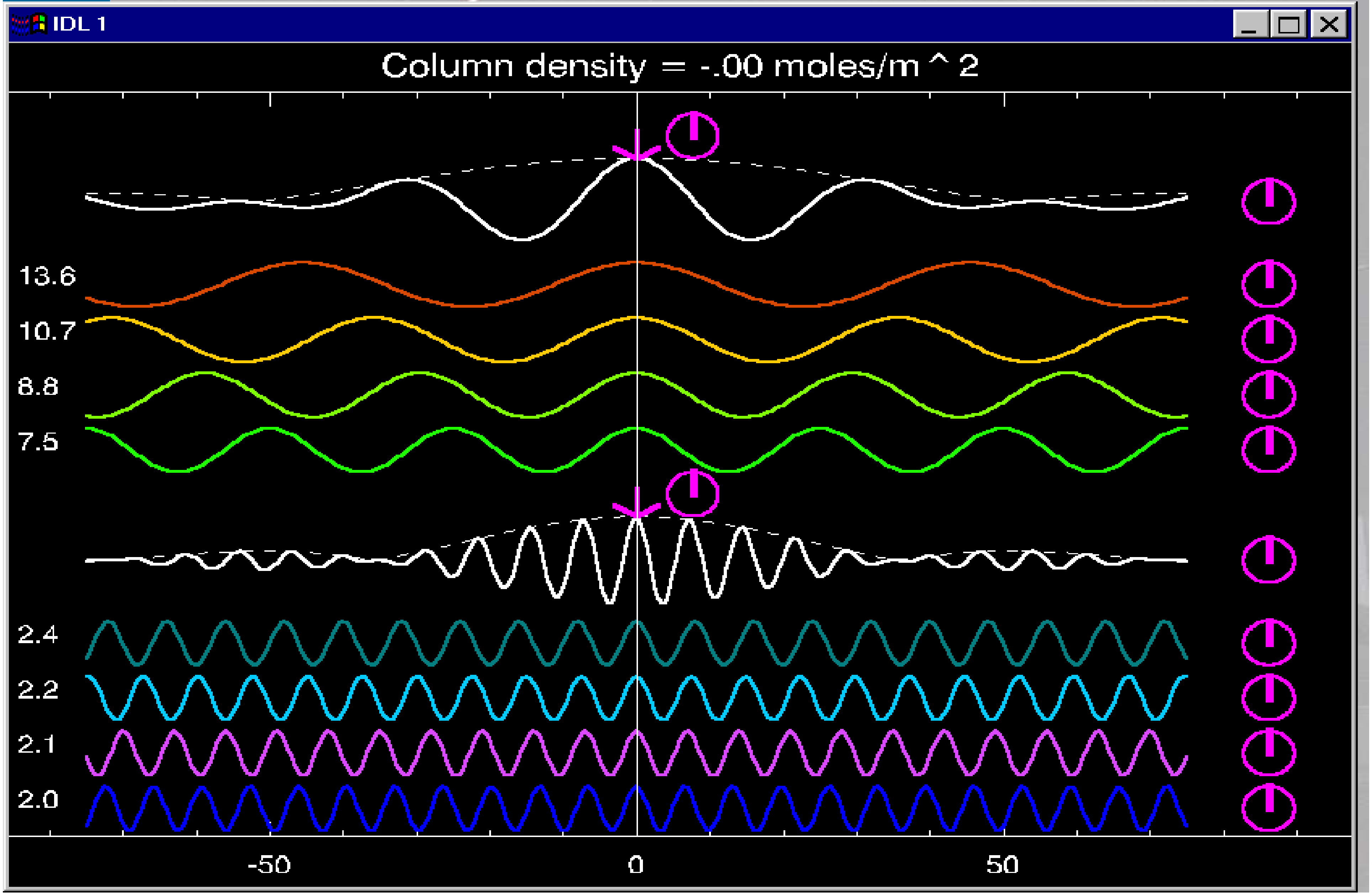
Dispersive effect between (and within) bands due to 0 – 600 mole/m^2 of additional dry air. (= 20 meter delay-line offset) (©J. Meisner)

Note that dispersion from dry air increases rapidly at short wavelengths



(Tracking at the group-delay in K band)

Water Vapor dispersion, with phase-tracking at K band
0 – 5 moles/m² (typical p-p value due to atmosphere) (©J. Meisner)



Water Vapor dispersion, with phase-tracking at K band
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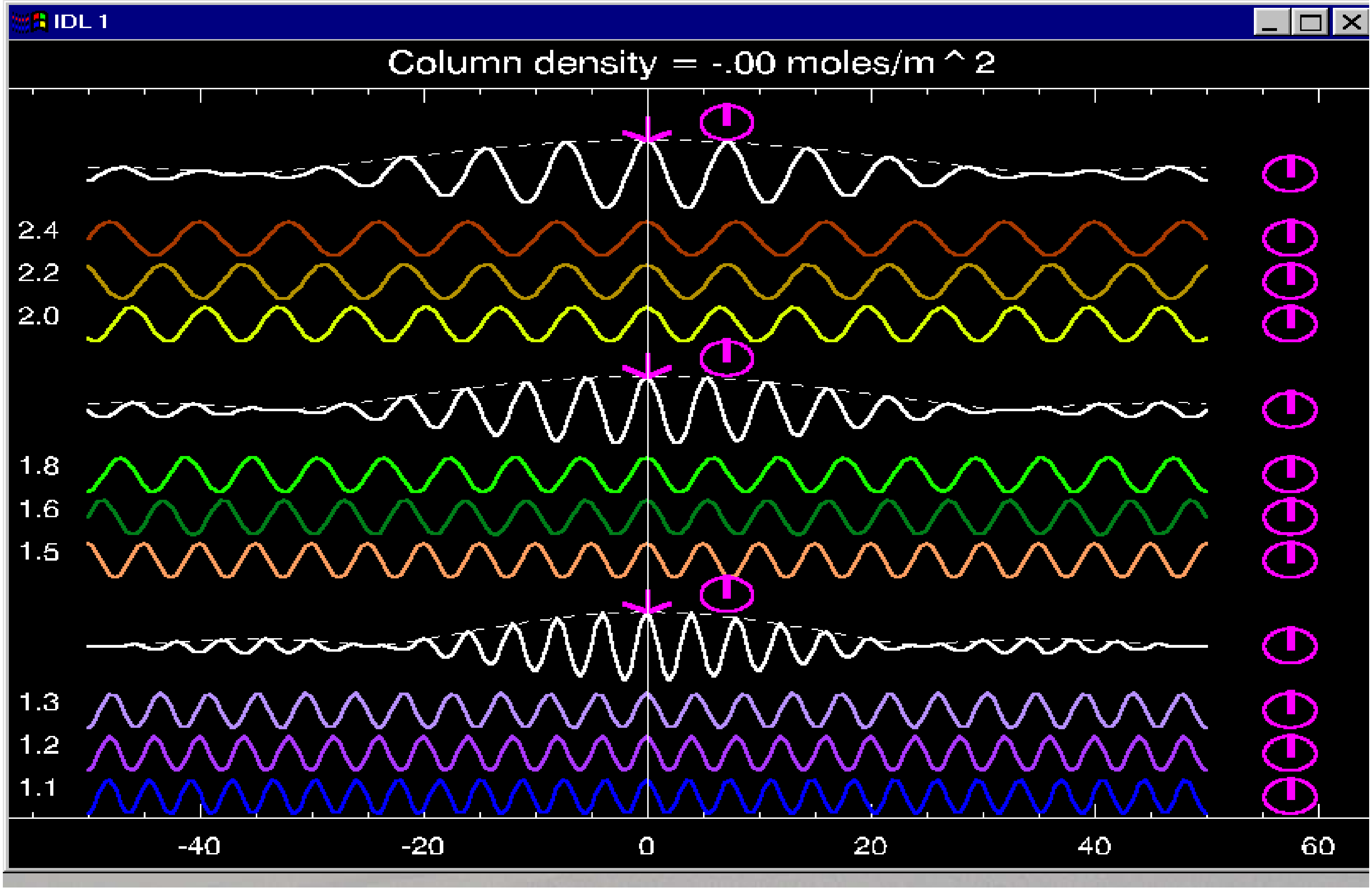
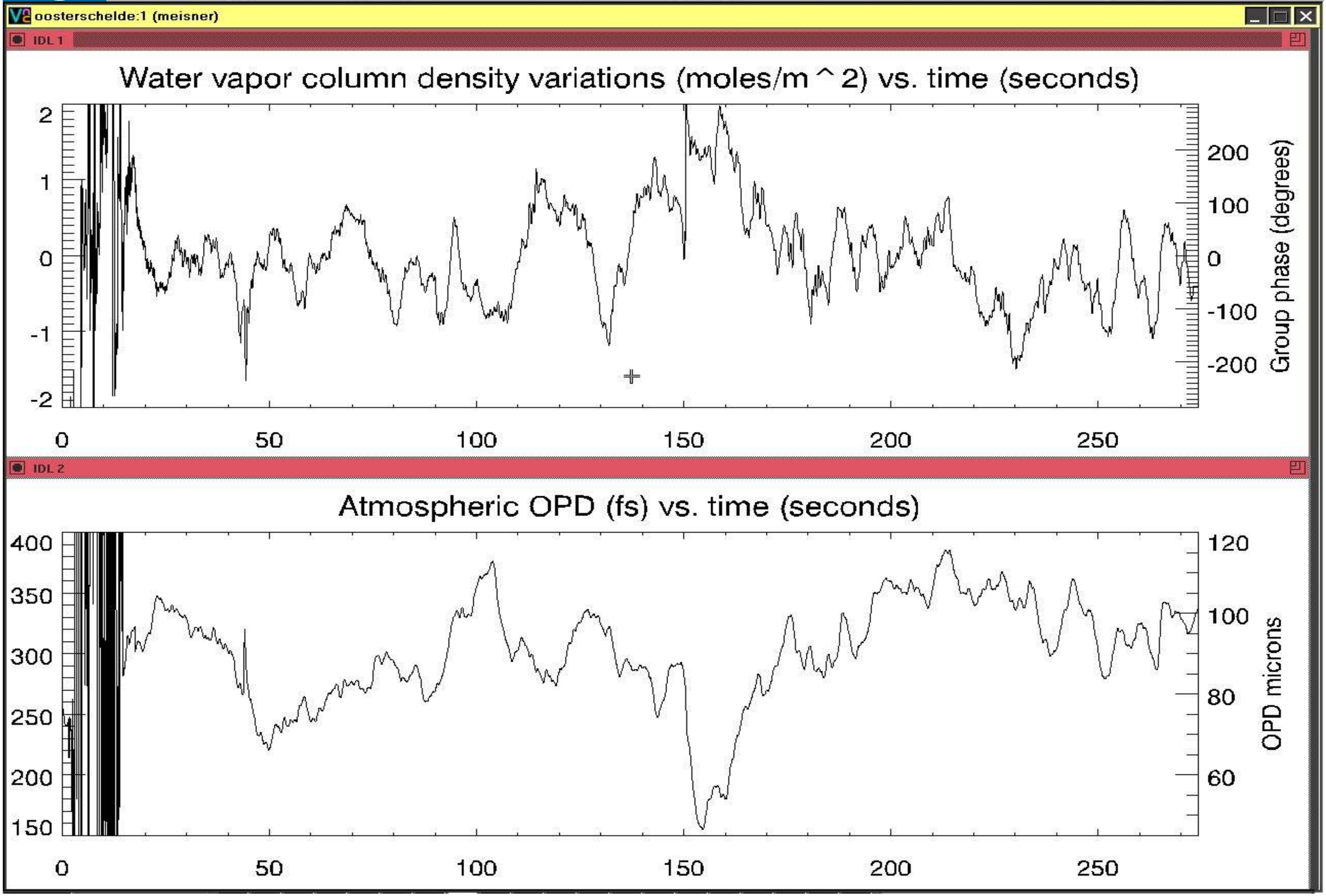


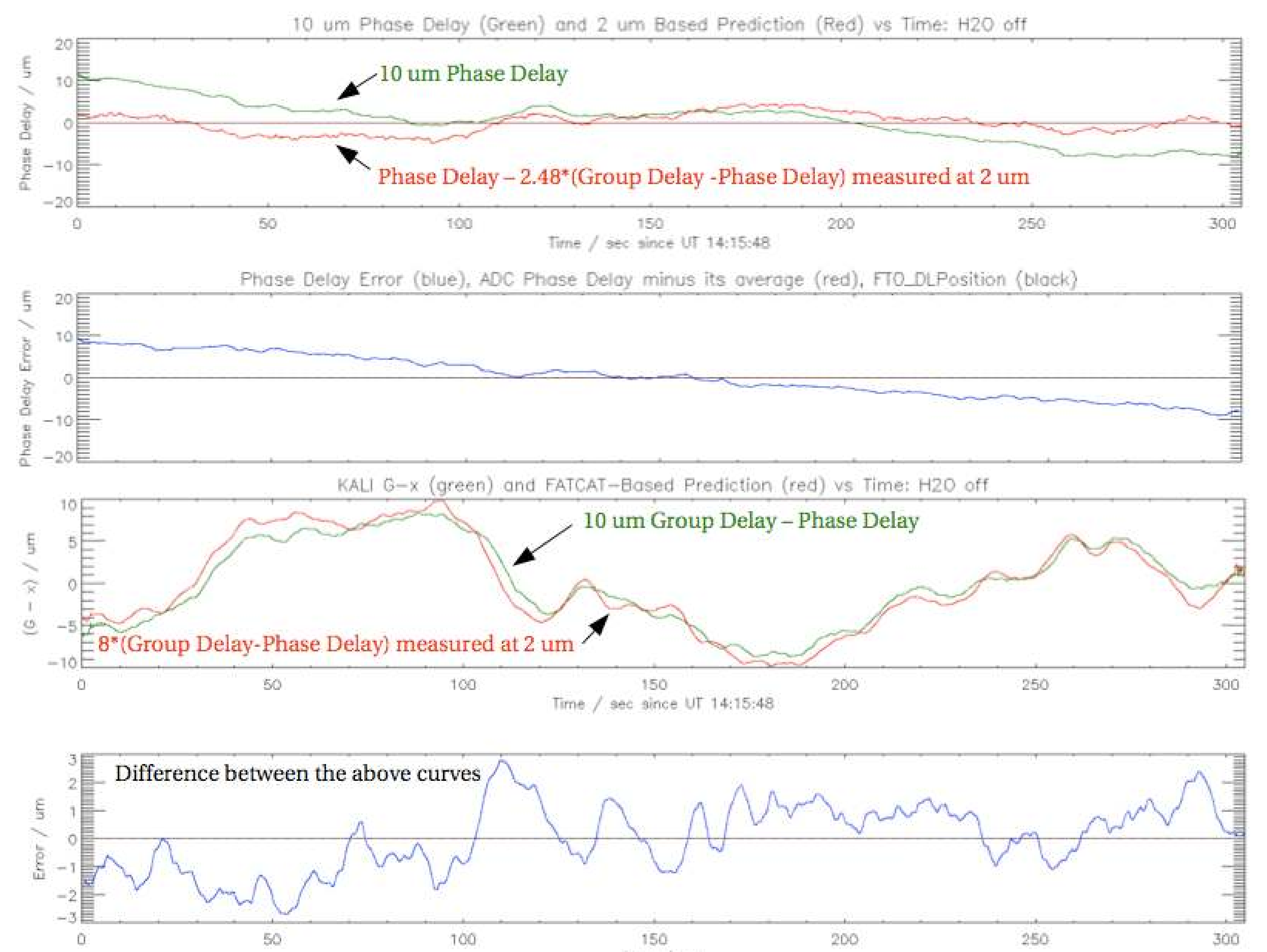
MIDI observation: OPD and water vapor (©J. Meisner)



Water vapor column density variations (moles/m ^ 2) vs. time (seconds)

Atmospheric OPD (fs) vs. time (seconds)

Keck’s results of dispersion extrapolation (©C. Koresko): estimated phase delay at 10µm vs. measured phase delay



10 um Phase Delay (Green) and 2 um Based Prediction (Red) vs Time: H2O off

10 um Phase Delay

Phase Delay – 2.48*(Group Delay -Phase Delay) measured at 2 um

Phase Delay Error (blue), ADC Phase Delay minus its average (red), FTO_DLPosition (black)

KALI G−x (green) and FATCAT−Based Prediction (red) vs Time: H2O off

10 um Group Delay – Phase Delay

8*(Group Delay-Phase Delay) measured at 2 um

Difference between the above curves

Proper phase references

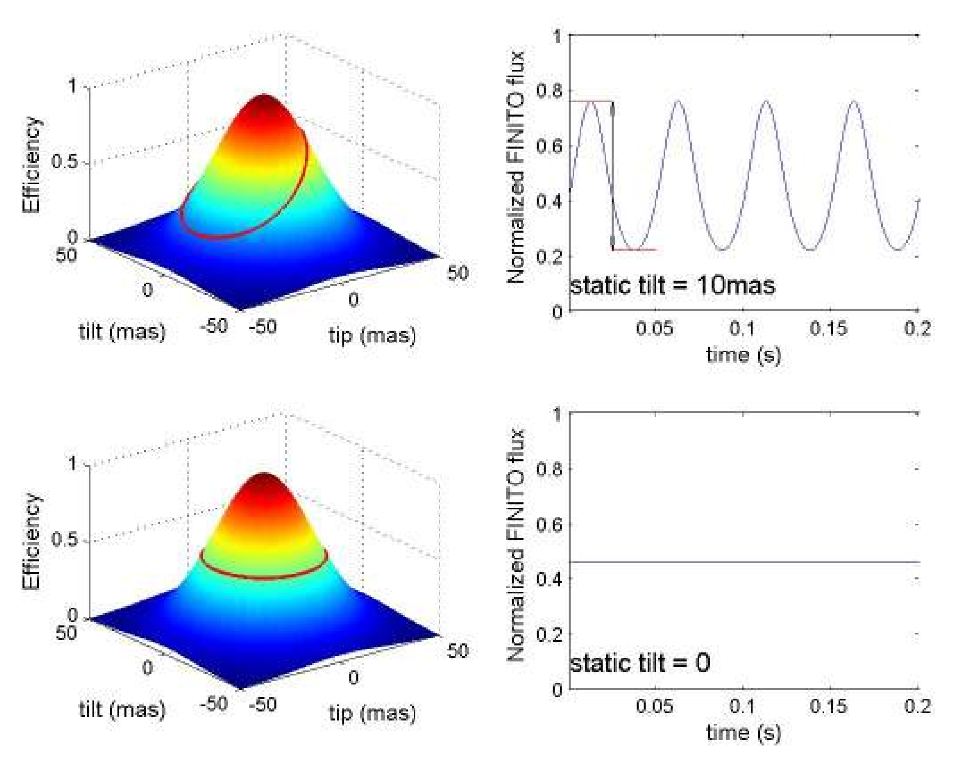
- We want to do imaging =>
  - usually the scientific target is faint =>
    - Reference star must be bright (K<10 or 13)
    - Bright stars are close and big
  - need of long baselines
- => High probability that your guide star is:
    - resolved => low visibility
    - with resolved structures => non-zero phase
- Phase-referencing cannot disentangle between target phase and reference phase
- Remedies:
  - baseline bootstrapping
  - characterize your reference star (stellar type, spectrum, interferometry) as much as possible prior to observation
  - find a faint star close to the reference one to calibrate it

Time and evolving targets

- Phase-referencing works with 2 telescopes at a time => Measurements of different u-v points are taken at different epochs
- Changing the baseline takes time (one day but not done every day)
- If the object evolves, it is a problem
- Remedies:
  - relocate more often (but overheads increase)
  - if the “evolution” is periodic (Cepheid, planet), plan the observations at the same ephemeris time
  - have more telescopes and switch from one baseline to another within one night
- No snap-shot image like with phase cl ▪ osure but better limiting magnitude

Fringe tracking problems

- See Markus Schöller's talk
- Injection stability:
  - Use of monomode optical fibers as spatial filter => wavefront corrugations and tip-tilt are transformed into photometric fluctuations
  - Strehl ratio is not stable at 10 ms timescales
  - To measure fringes with enough accuracy for fringe tracking, one needs ~ 100 photons at **any** moment



Solutions:

⇒ fast tip-tilt sensing close to the instrument

⇒ optimize injection before starting

⇒ affects limiting magnitude and efficiency or you accept a not-perfect fringe lock

Fringe tracking problems

- Vibrations affect:
  - the capability to track fringes
    if too large / too fast
  - the fringe visibility, so the SNR,
    if fast and small
  - the OPD residuals

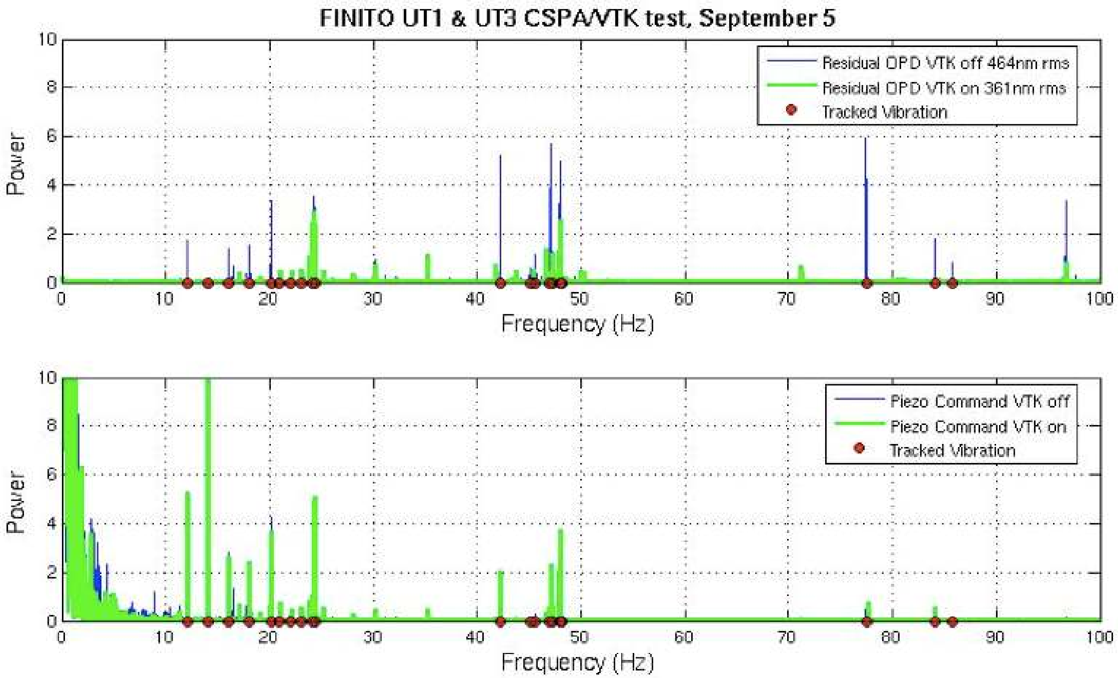
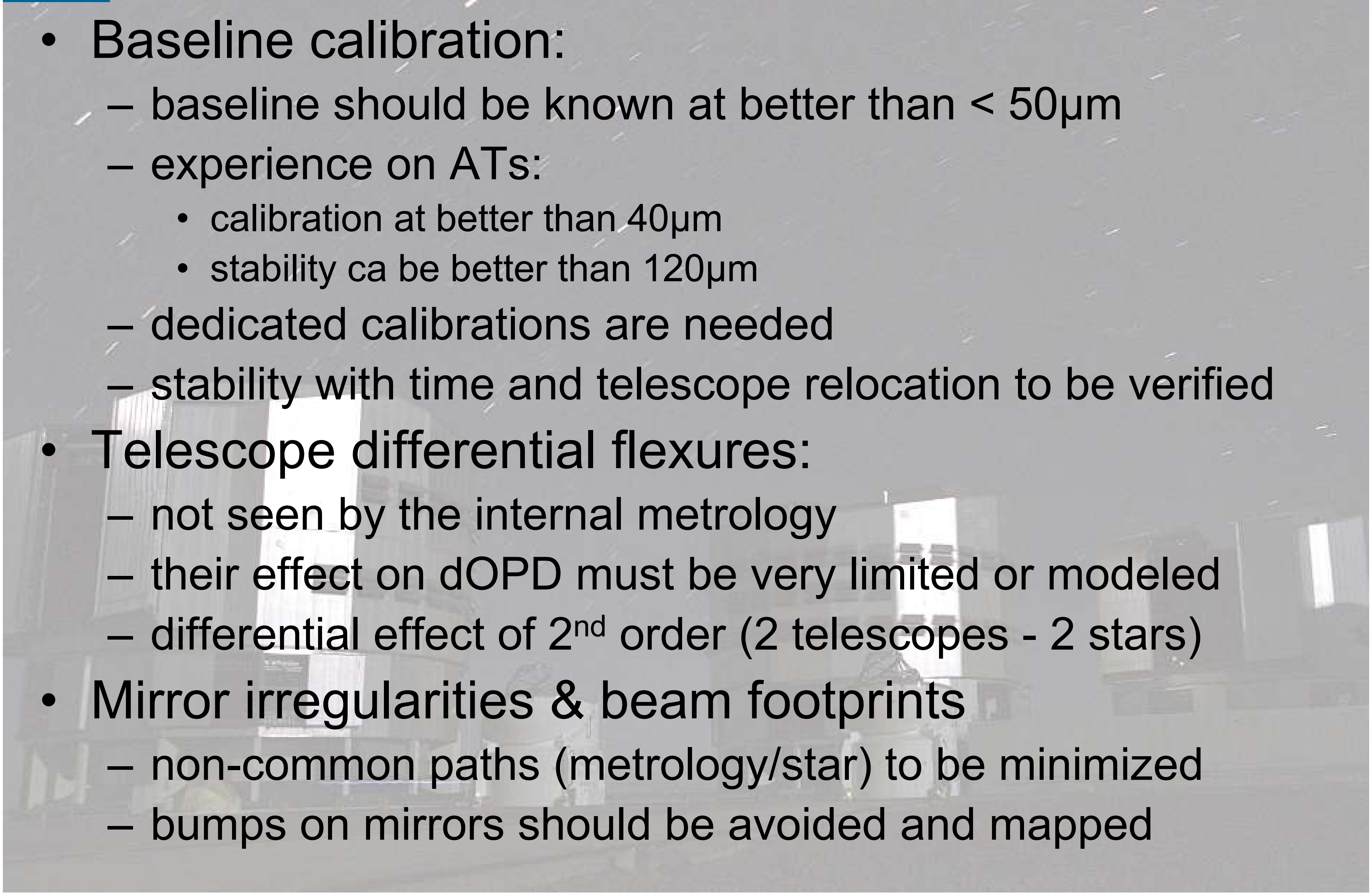


Figure 1: Phase residual (top) and DL Piezo command (bottom). Sky data obtained with UT1 and UT3, September 5th 2006. The rms residual OPD with VTK ON is 363nm, nearly 4 times above the specification.

- Remedies:
  - Reduce vibrations by passive / active damping,
  - Measure vibrations with a laser metrology & correct them
  - Measure vibrations with accelerometers & correct them

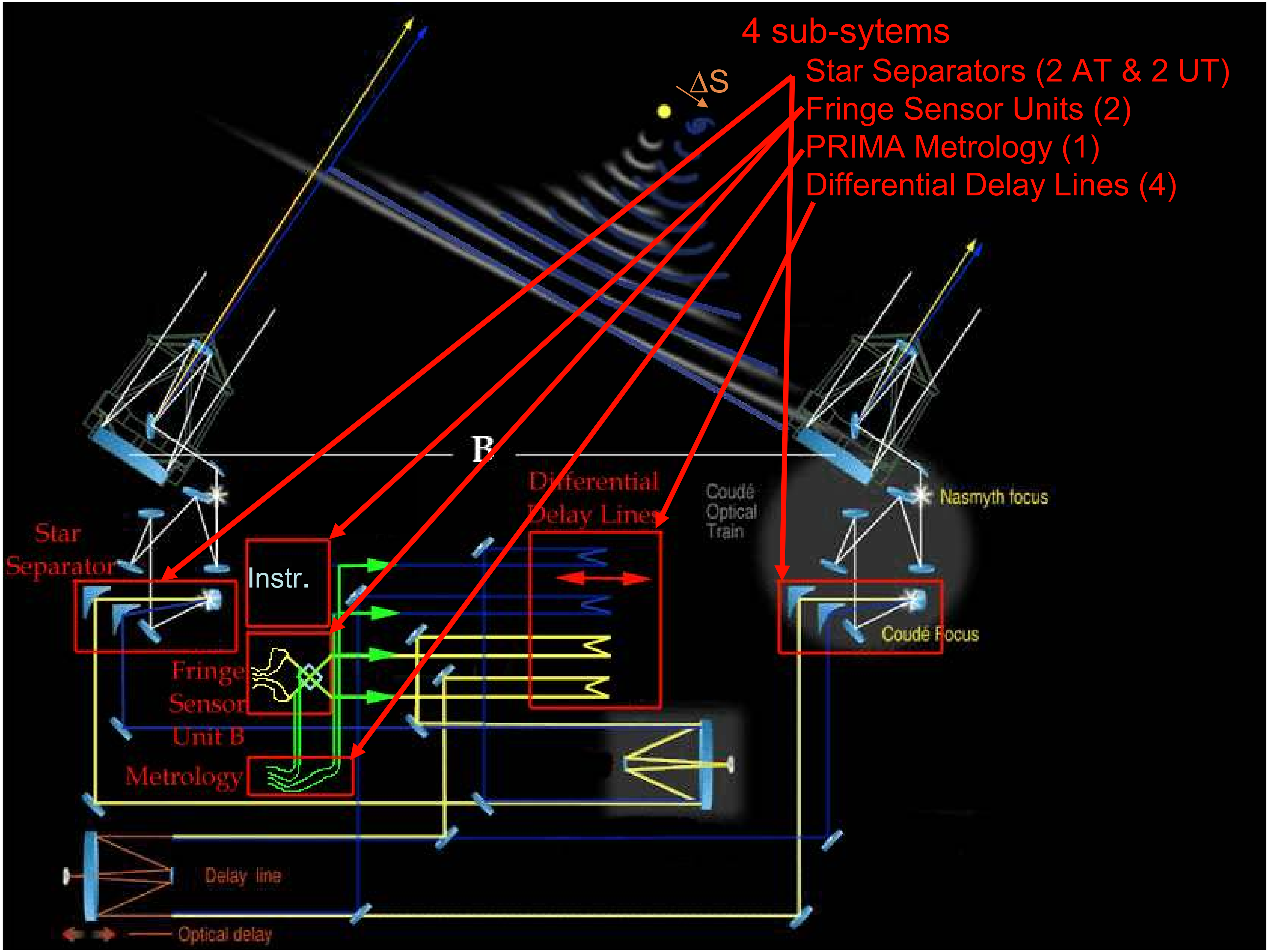
Other instrumental problems



- Baseline calibration:
  - baseline should be known at better than < 50µm
  - experience on ATs:
    - calibration at better than 40µm
    - stability ca be better than 120µm
  - dedicated calibrations are needed
  - stability with time and telescope relocation to be verified
- Telescope differential flexures:
  - not seen by the internal metrology
  - their effect on dOPD must be very limited or modeled
  - differential effect of 2nd order (2 telescopes - 2 stars)
- Mirror irregularities & beam footprints
  - non-common paths (metrology/star) to be minimized
  - bumps on mirrors should be avoided and mapped

PRIMA Facility

- PRIMA general scheme
- Sub-systems
  - Star Separators
  - Differential Delay Lines
  - Fringe Sensor Units
  - Calibration source MARCEL
  - End-to-end Metrology
  - Control Software and Instrument Software (PACMAN)

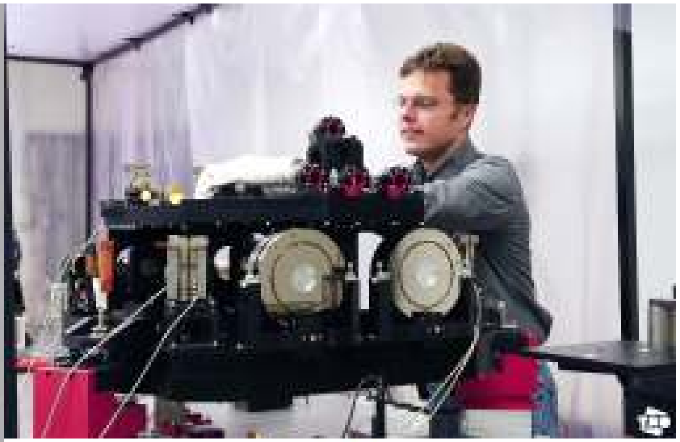


4 sub-sytems

- Star Separators (2 AT & 2 UT)
- Fringe Sensor Units (2)
- PRIMA Metrology (1)
- Differential Delay Lines (4)

Star Separators

- Star separation: from PSF up to 2’
- Each sub-field =
  - 1.5” (UT with DDL - AMBER & PACMAN)
  - 2” (UT without DDL - MIDI)
  - up to 6” (AT)
- Independent tip-tilt & pupil actuators on each beam
- 10Hz actuation frequency (could be pushed to 50 Hz)
- Pupil relay to tunnel center (same as UT)
- Chopping / counter-chopping for MIDI
- Star splitting for calibration step: 40% - 40%
- Star swapping for environment drift calibrations
- Symmetrical design for easing calibrations
- High mechanical & thermal stability
- But: many additional reflections (+8 on AT, +4 on UT)



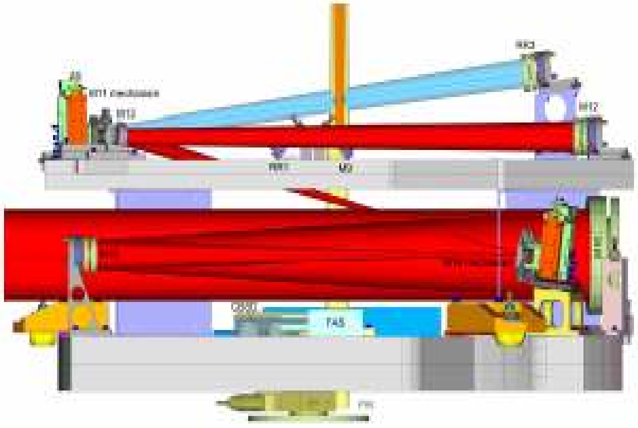


figure 9: Side view on STS

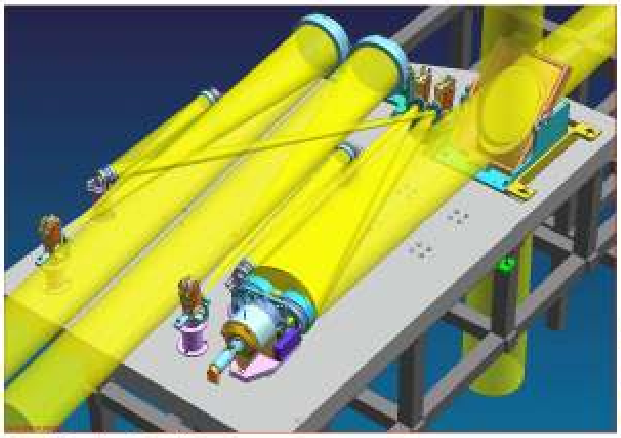


figure 1: Overview of STS-UT system

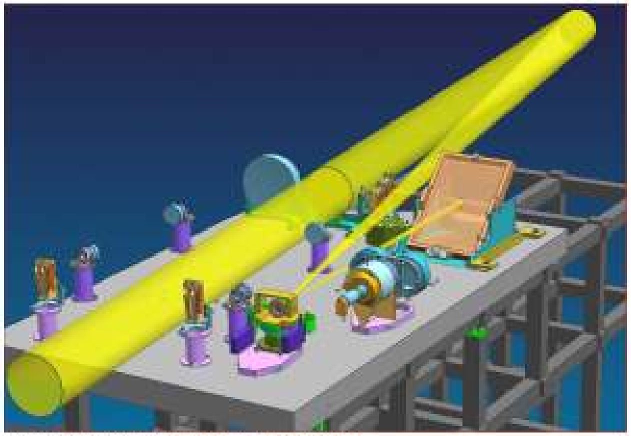


figure 2: Alternative optical configuration for STS-UT

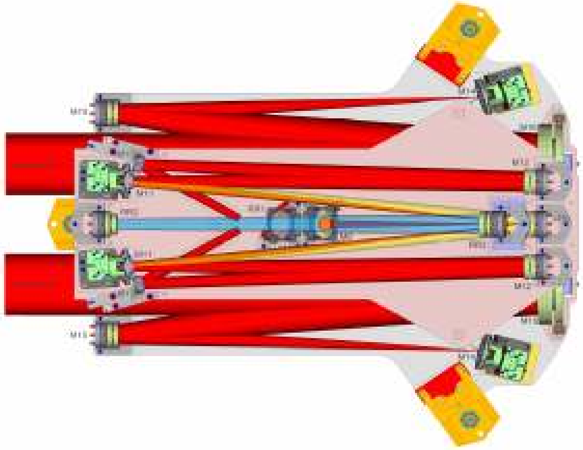
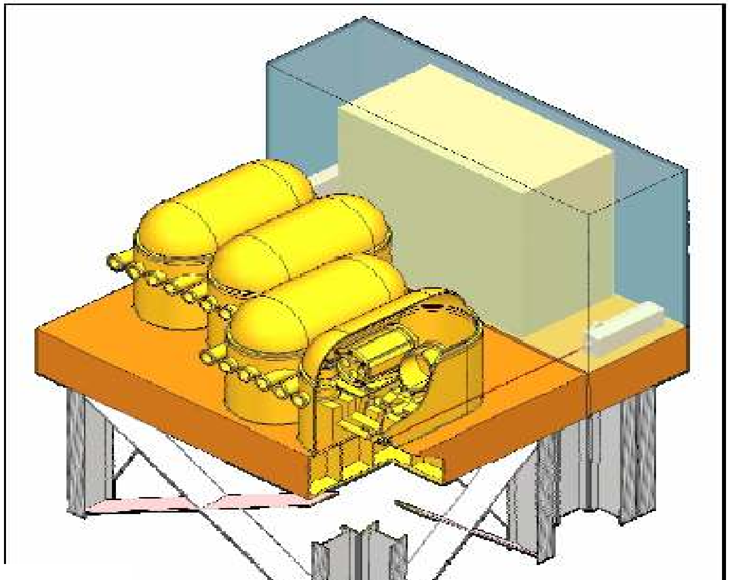
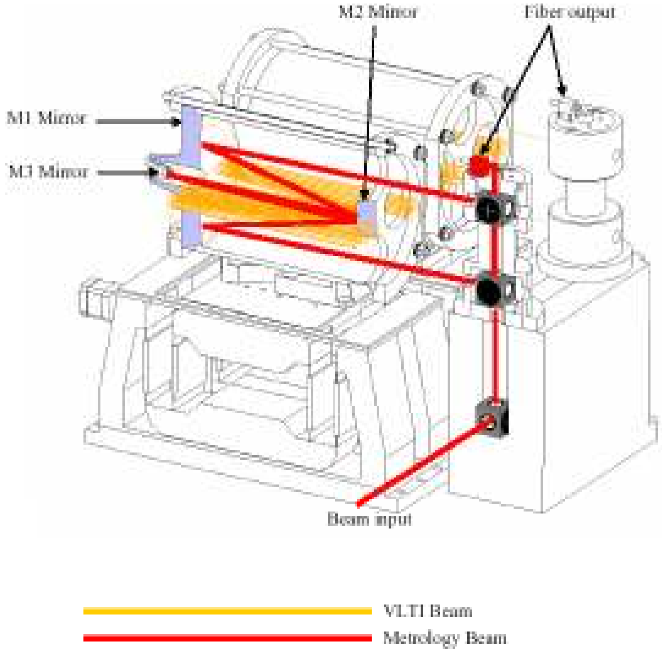


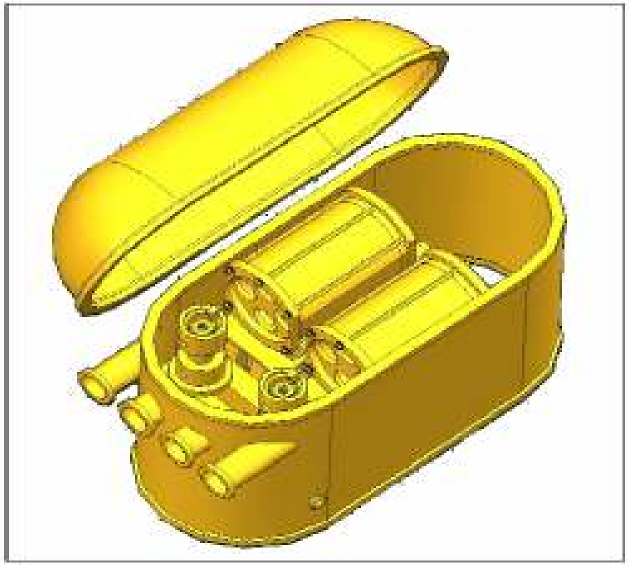
figure 8: Top view on STS

Differential Delay Lines

- To be used with PACMAN and AMBER, not with MIDI
- > 200 Hz bandwidth, < 225 µs pure delay
- Push the lab pupil to FSU (4m further than now)
- Very stringent requirement on pupil lateral motion
- Cat’s eye (3 mirrors, 5 reflections)
- 2 stage actuator (coarse step motor + piezo on M3)
- Internal metrology
- M3 can be actuated also in tip-tilt (pupil correction ?)
- under vacuum
- Prototype giving very good results

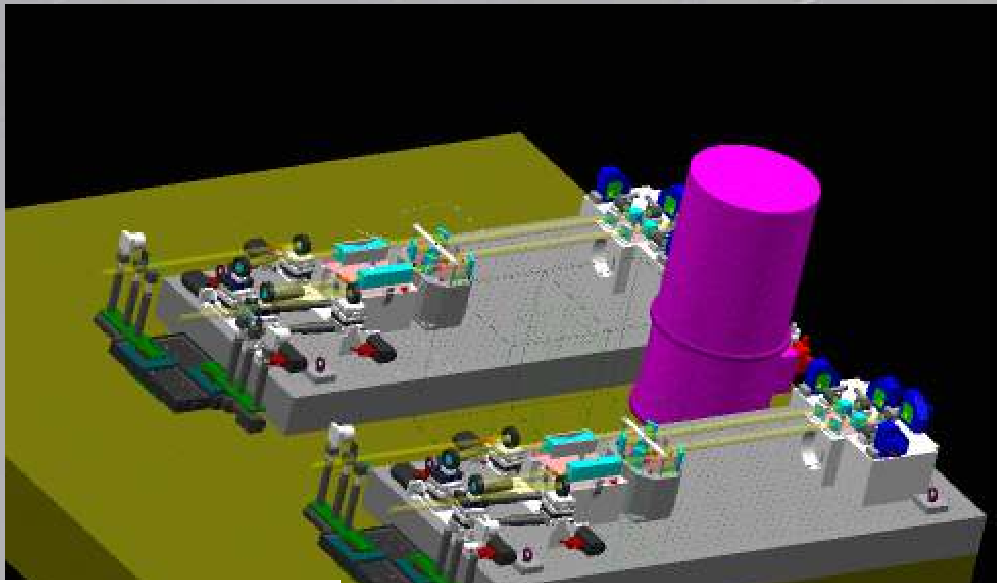


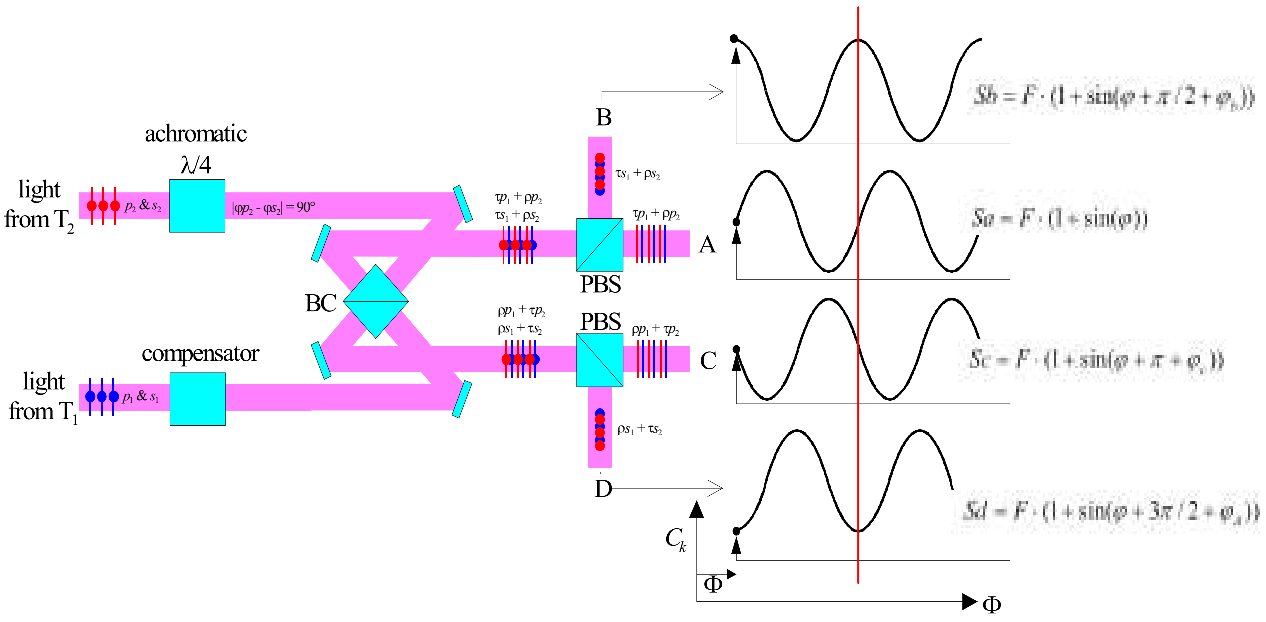




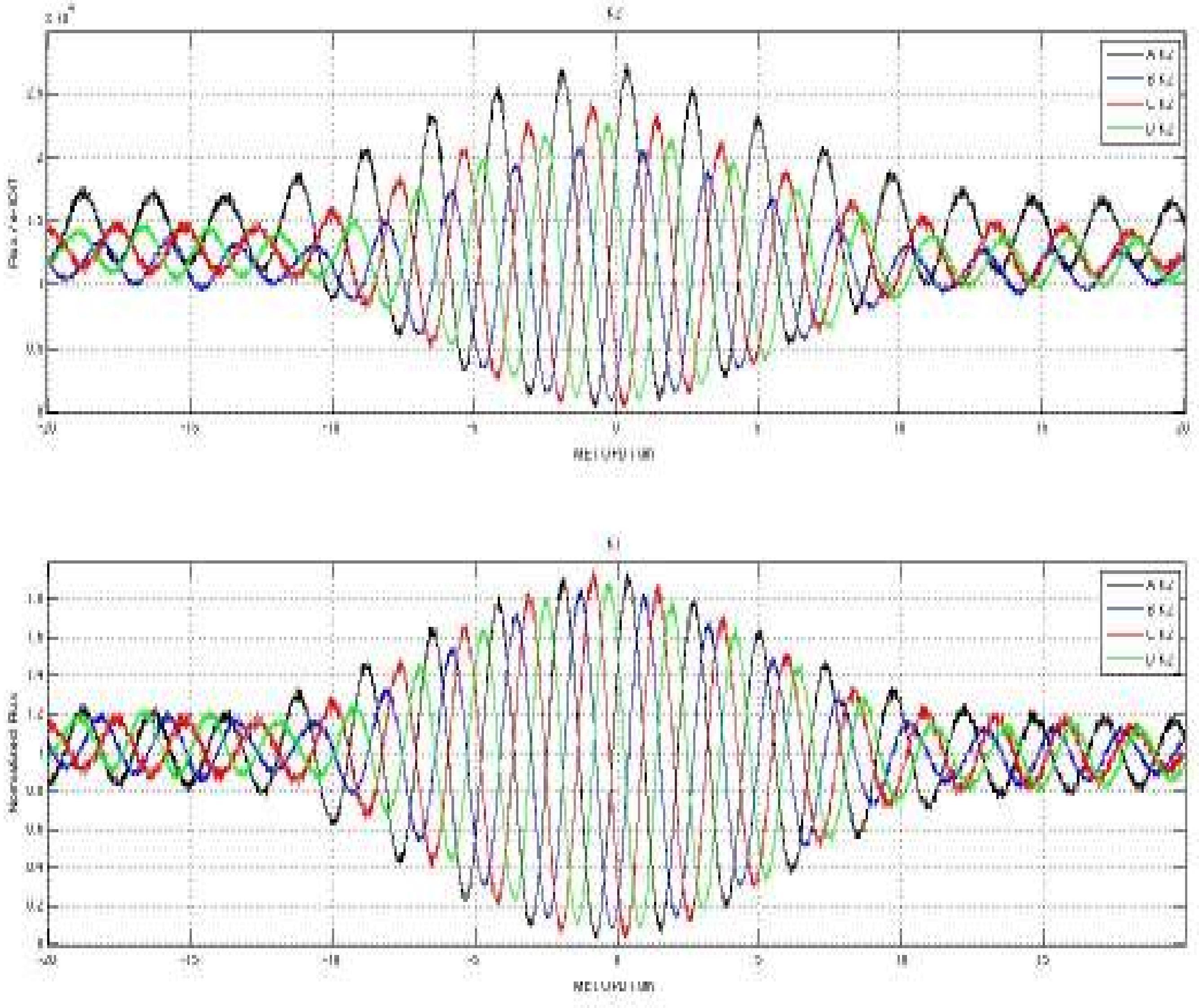
Fringe Sensor Units

- ABCD with no OPD scanning (based on polarization)
- in K band
- OPD and group delay accuracy: < 5nm bias
- up to 8kHz measurement frequency
- single mode fibers after beam combination
- no separate photometric channels
- spectral dispersion for group delay
- fibers up to cryostat to limit background
- fast active injection mirrors for injection
- integrated with PRIMET
- FSUA and FSUB = twins for astrometry

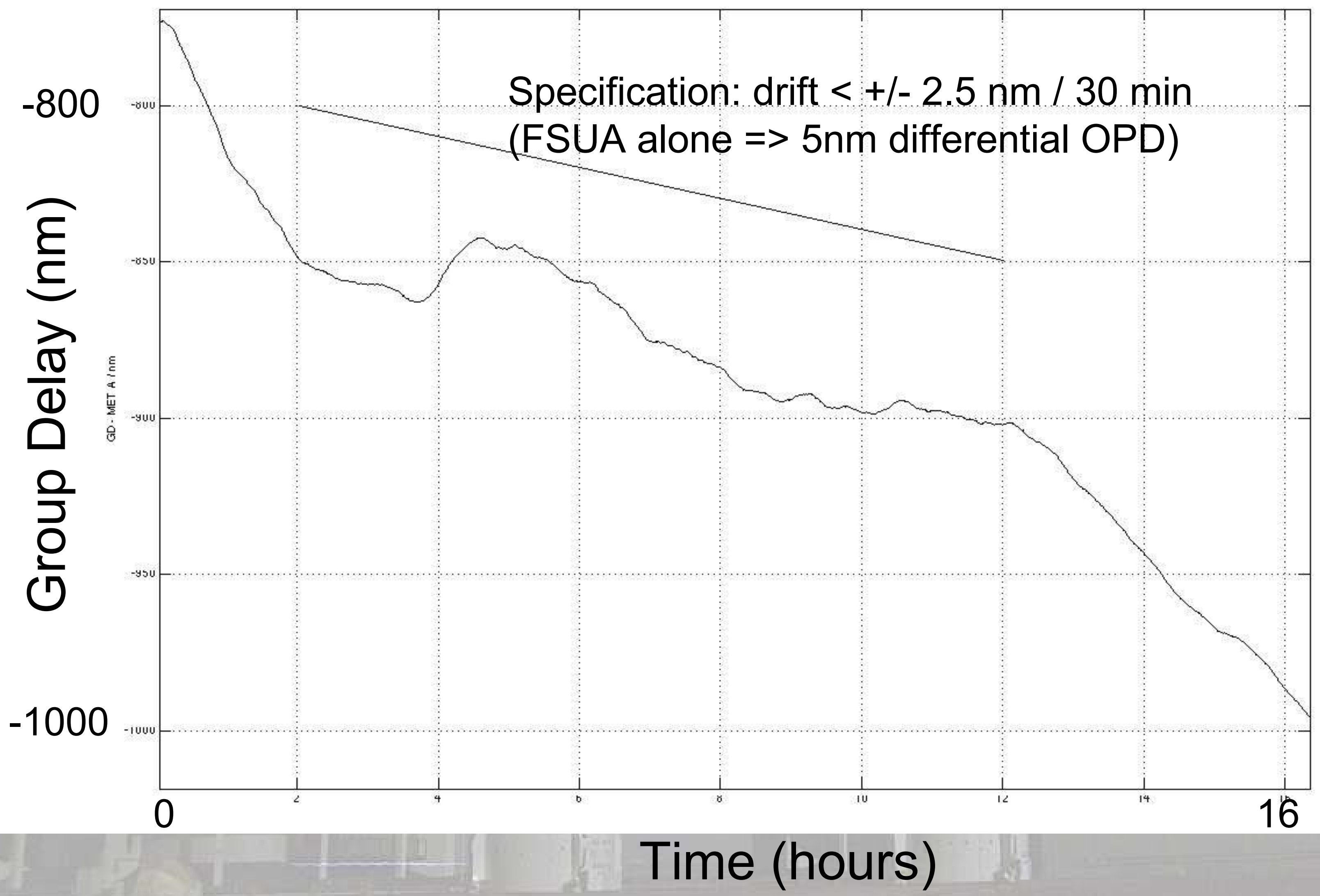




FSU calibration



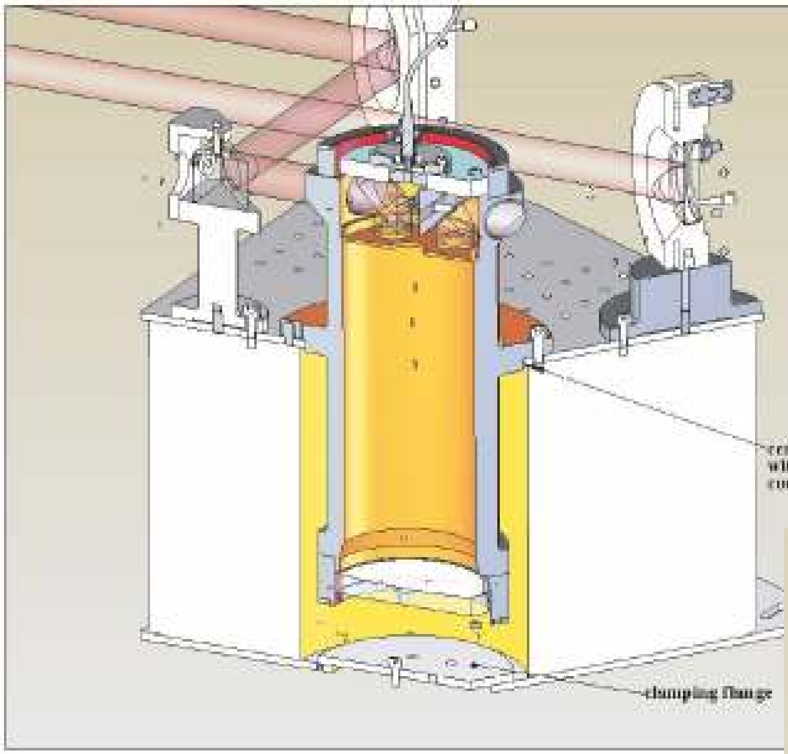
Group delay over 16 hours

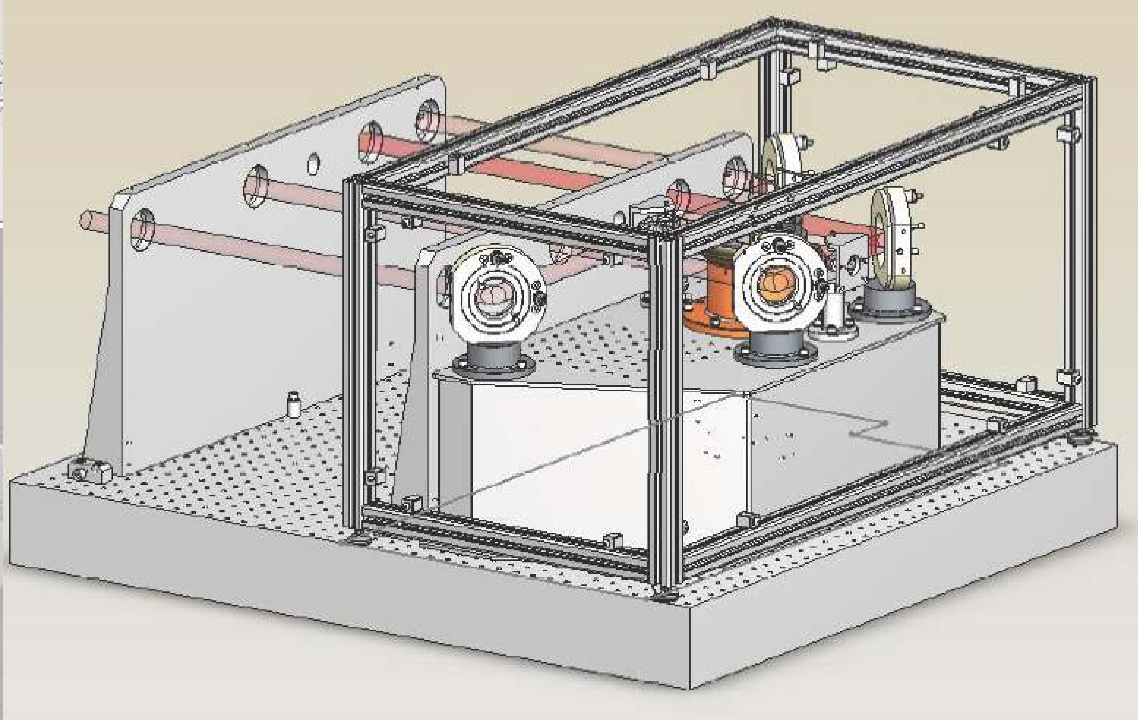


Specification: drift < +/- 2.5 nm / 30 min
(FSUA alone => 5nm differential OPD)

MARCEL = calibration source

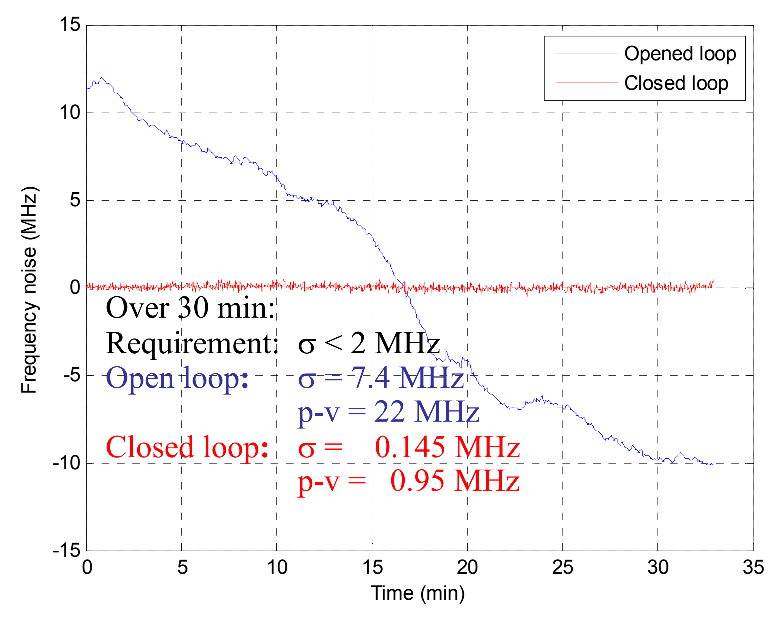
- 4 coherent beams
(2 telescopes -2 stars)
- black body source with controlled temperature
- retro-reflectors for metrology
- very stable

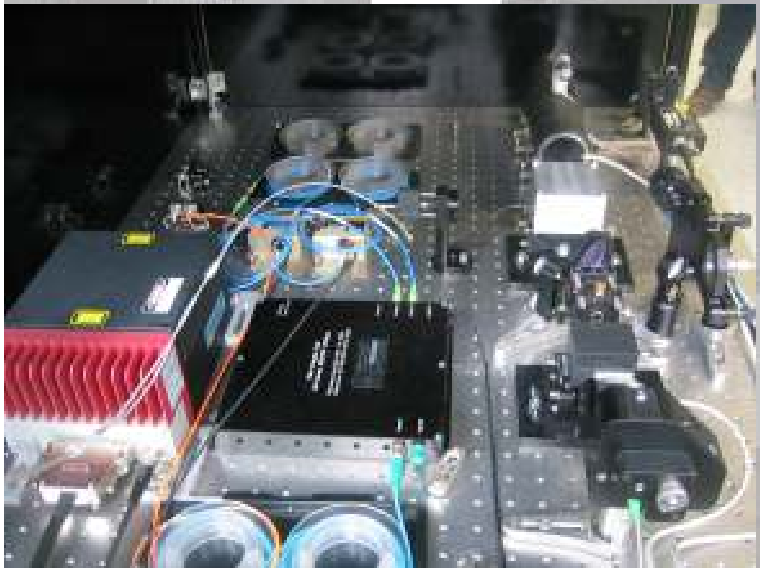


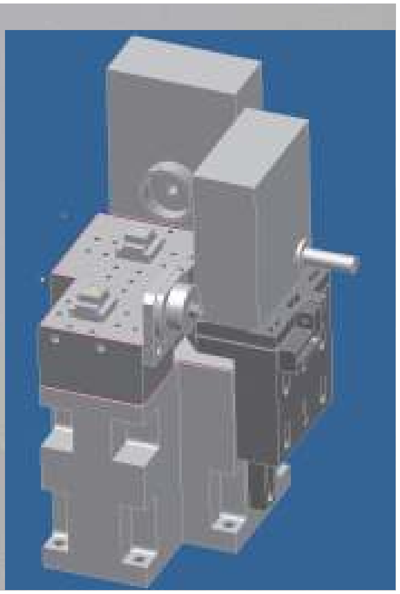


PRIMA Metrology

- Super-heterodyne incremental metrology (λ =1.3μm)
- Propagation in the central obstruction, from the instrument to the STS (Retro-reflection behind M9)
- Output measurement (dOPD **and** OPD on one of the stars) written on reflective memory for the OPD/dOPD controller
- Laser frequency stabilization on I_2 at $d\nu/\nu<10^{-8}$ level
- Phase detection: accuracy <1nm rms
- Pupil tracking: Custom low noise 4-quadrant detectors (InGaAs): $\delta d<$ 100 μm Pk
- Working on absolute metrology upgrade



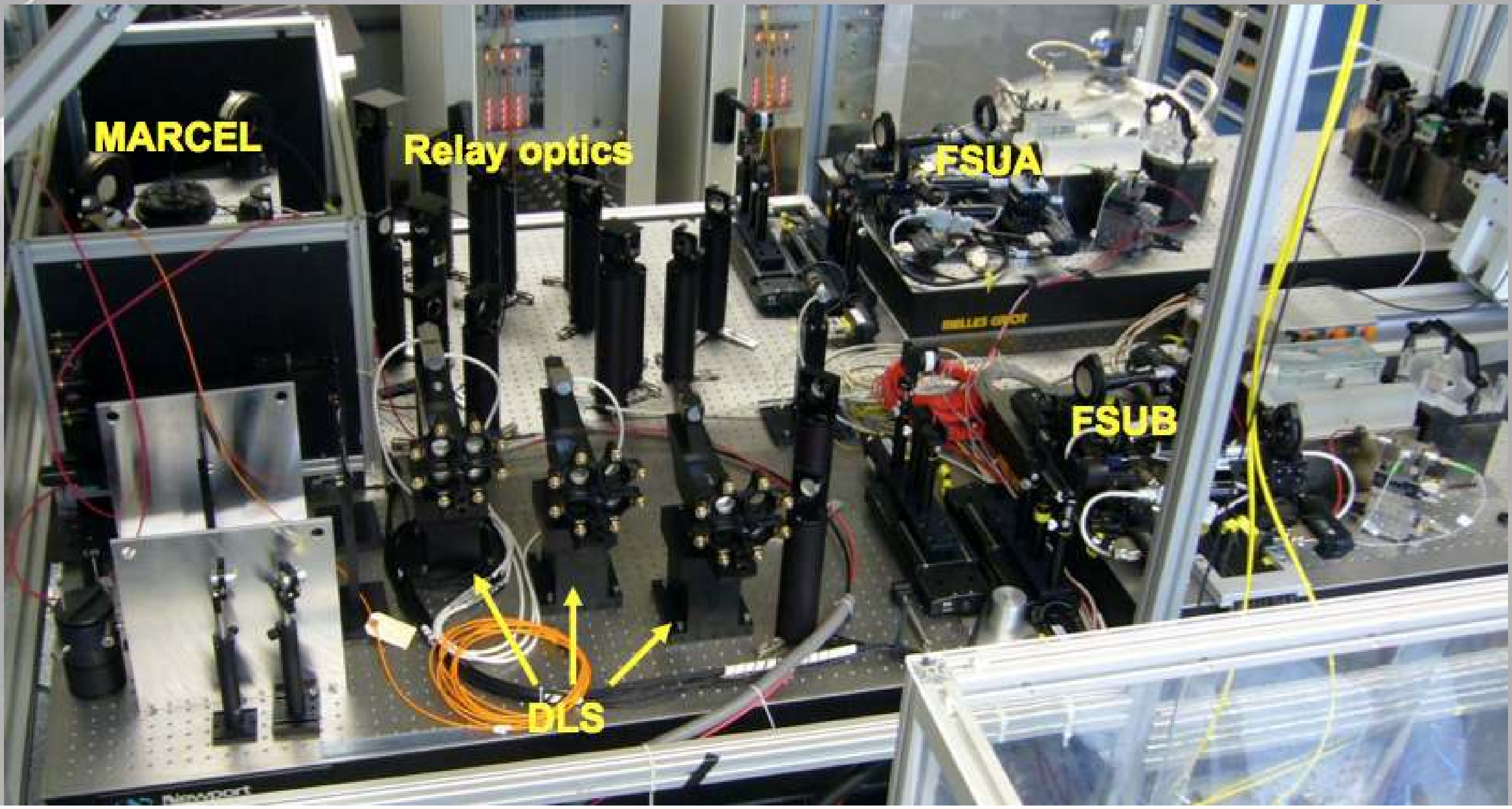




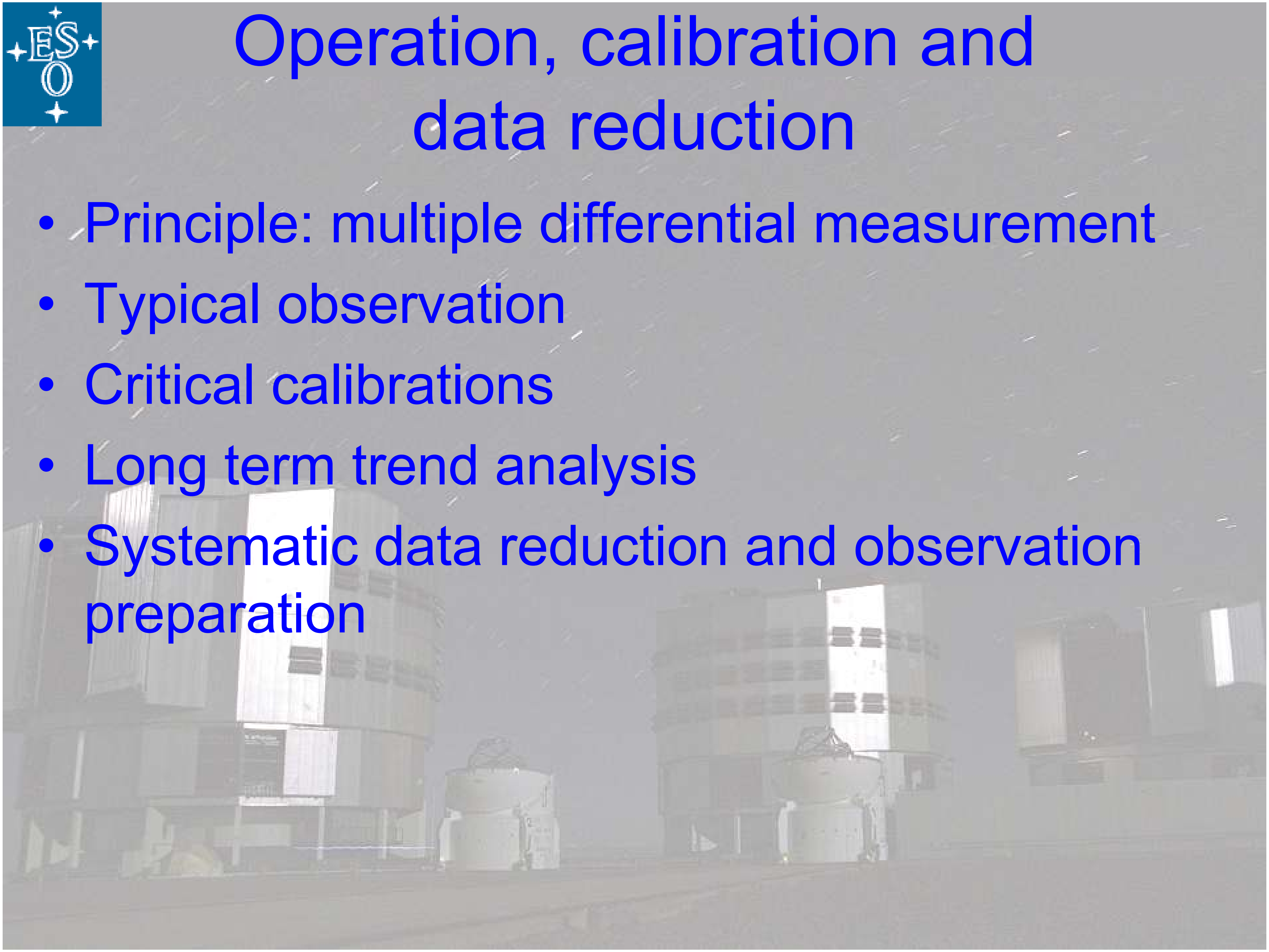
PRIMA testbed

- Testbed needed for:
  - acceptance tests of FSU (almost finished)
  - extensive system tests FSU + PRIMET + VLTI environment
- Includes:
  - MACAO high order residuals
  - tip-tilt perturbations
  - vibrations & other OPD perturbations
  - (D)DL simulators

- System tests:
  - FSU stability
  - IFG, BTK, VTK tuning
  - sensitivity (lim. mag.)
  - detector read-out optimization
  - # of spectral channels (3 / 5)
  - fringe tracking reliability
  - PACMAN & template tests
  - calibration optimization



Operation, calibration and data reduction



- Principle: multiple differential measurement
- Typical observation
- Critical calibrations
- Long term trend analysis
- Systematic data reduction and observation preparation

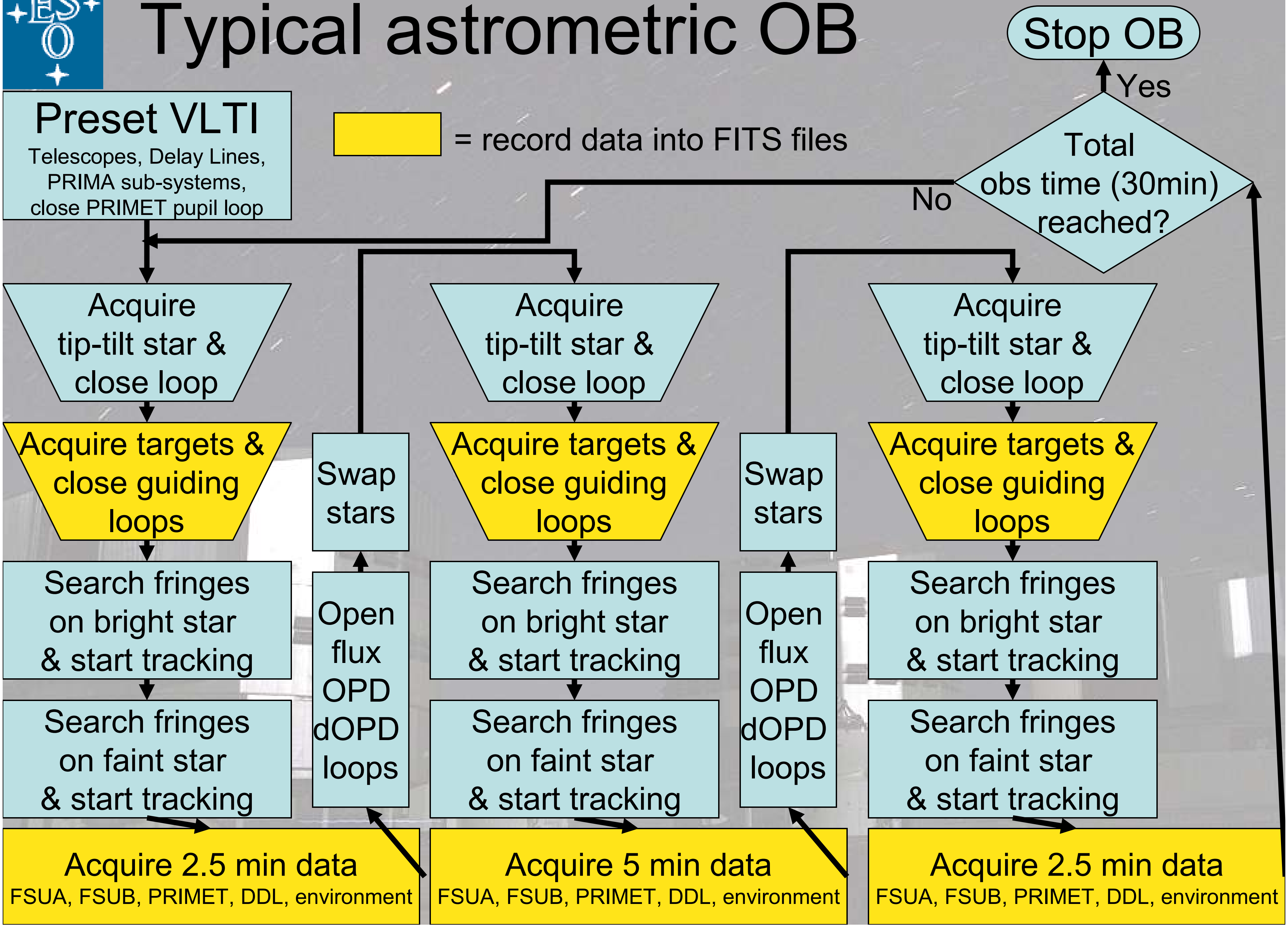
Multiple differences

- PRIMA = quintuple difference
  - 2 telescopes, 2 stars, 2 swaps, metrology/star λ, 2 moments in time
- Very differents scales:
  - 500m (metrology path) =>
  - 120m OPD =>
  - ~1cm dOPD =>
  - ~100nm fringe stabilization =>
  - 5nm measurement accuracy => 10^{-11} ratio to propagation length
- PRIMA challenges:
  - very complex system (reliability)
  - differences to be done cleanly
  - 10µas accuracy requires stability & data logging
    - PRIMA can control some things but not the environment
    - need to measure / calibrate what is not controlled
    - need to minimize by operation what cannot be calibrated
    - need of adapted data analysis and reduction software (PAOS = PRIMA Astrometric Observation & Software) for long term trends

Critical PRIMA calibrations

- Swapping beams (astrometry) =>
  - is needed to reject longitudinal differential effects between both beams and to “zero” the incremental metrology
  - no interruption of PRIMA metrology is allowed
- Injected flux and fiber alignment =>
  - no photometric channels is a weakness of the FSU
  - relative stability of the 4 FSU fibers has to be measured
- FSU / VLTI spectral calibration =>
  - fundamental for the group delay bias / stability
- Baseline calibration =>
  - to be known with an accuracy better than 50µm
  - dedicated observations / calibrations are needed
- Polarization calibration of the VLTI =>
  - potential cyclic errors => dedicated observation mode

Typical astrometric OB



Preset VLTI

Telescopes, Delay Lines, PRIMA sub-systems, close PRIMET pupil loop

🟨 = record data into FITS files

Acquire tip-tilt star & close loop

Acquire targets & close guiding loops

Search fringes on bright star & start tracking

Search fringes on faint star & start tracking

Acquire 2.5 min data

FSUA, FSUB, PRIMET, DDL, environment

Open flux OPD dOPD loops

Swap stars

Acquire tip-tilt star & close loop

Acquire targets & close guiding loops

Search fringes on bright star & start tracking

Search fringes on faint star & start tracking

Acquire 5 min data

FSUA, FSUB, PRIMET, DDL, environment

Open flux OPD dOPD loops

Swap stars

Acquire tip-tilt star & close loop

Acquire targets & close guiding loops

Search fringes on bright star & start tracking

Search fringes on faint star & start tracking

Acquire 2.5 min data

FSUA, FSUB, PRIMET, DDL, environment

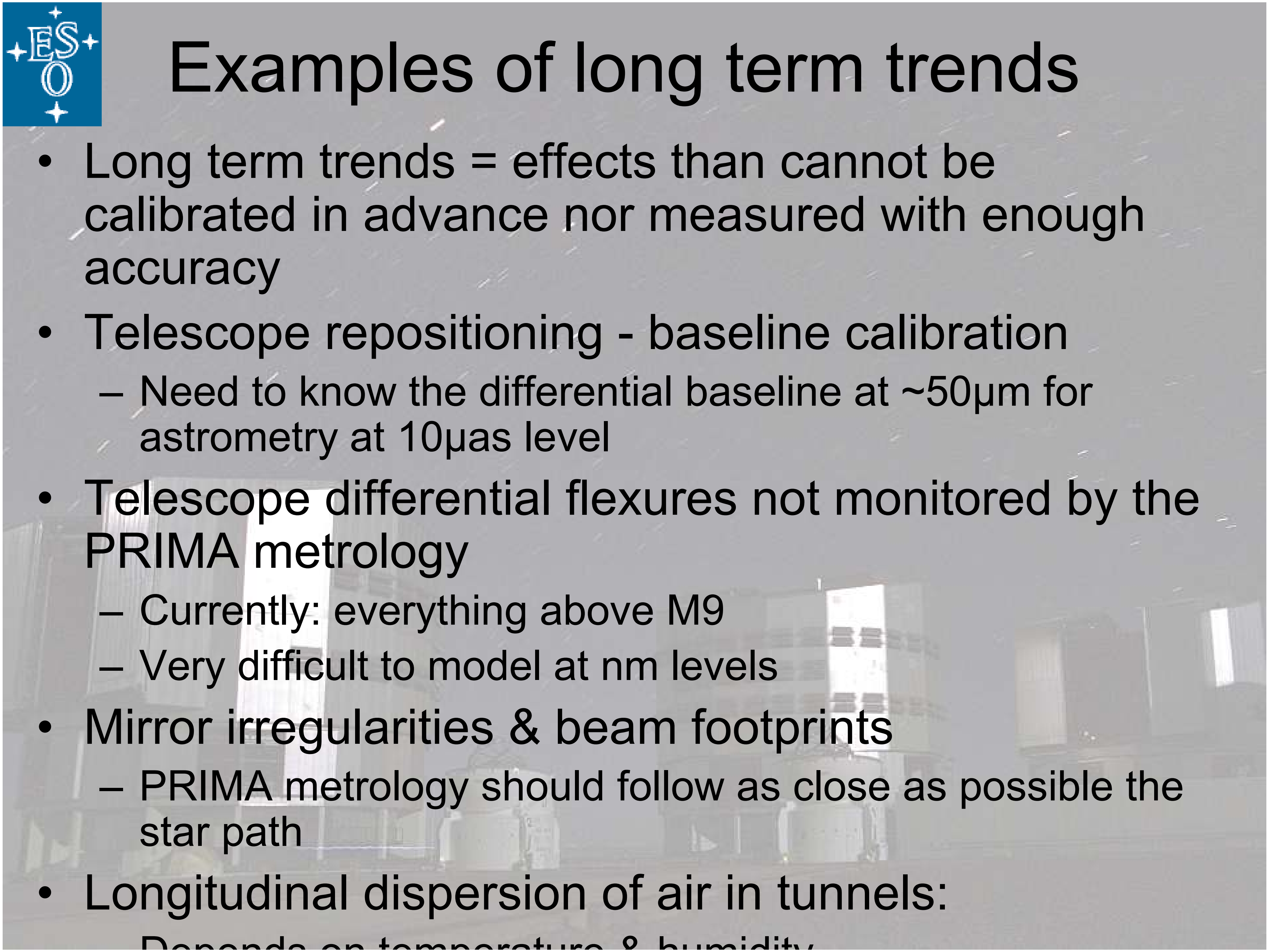
Total obs time (30min) reached?

No

Yes

Stop OB

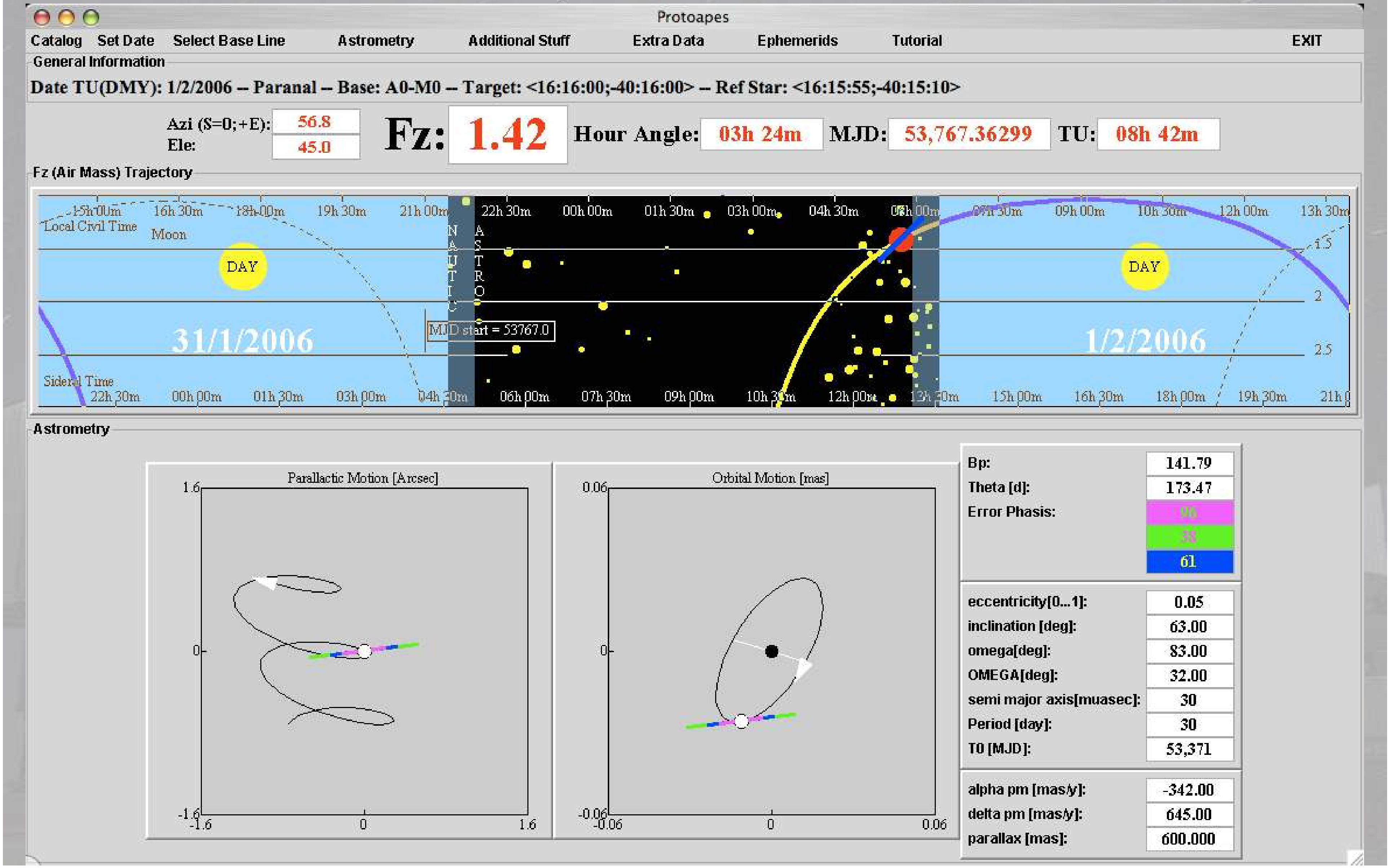
Examples of long term trends



- Long term trends = effects than cannot be calibrated in advance nor measured with enough accuracy
- Telescope repositioning - baseline calibration
  - Need to know the differential baseline at ~50µm for astrometry at 10µas level
- Telescope differential flexures not monitored by the PRIMA metrology
  - Currently: everything above M9
  - Very difficult to model at nm levels
- Mirror irregularities & beam footprints
  - PRIMA metrology should follow as close as possible the star path
- Longitudinal dispersion of air in tunnels:
  - Depends on temperature & humidity

Astrometric PrEparation Software

developed by the DDL-PAOS Consortium



Date TU(DMY): 1/2/2006 -- Paranal -- Base: A0-M0 -- Target: <16:16:00;-40:16:00> -- Ref Star: <16:15:55;-40:15:10>

Azi (S=0;+E): 56.8
Ele: 45.0

Fz: 1.42

Hour Angle: 03h 24m

MJD: 53,767.36299

TU: 08h 42m

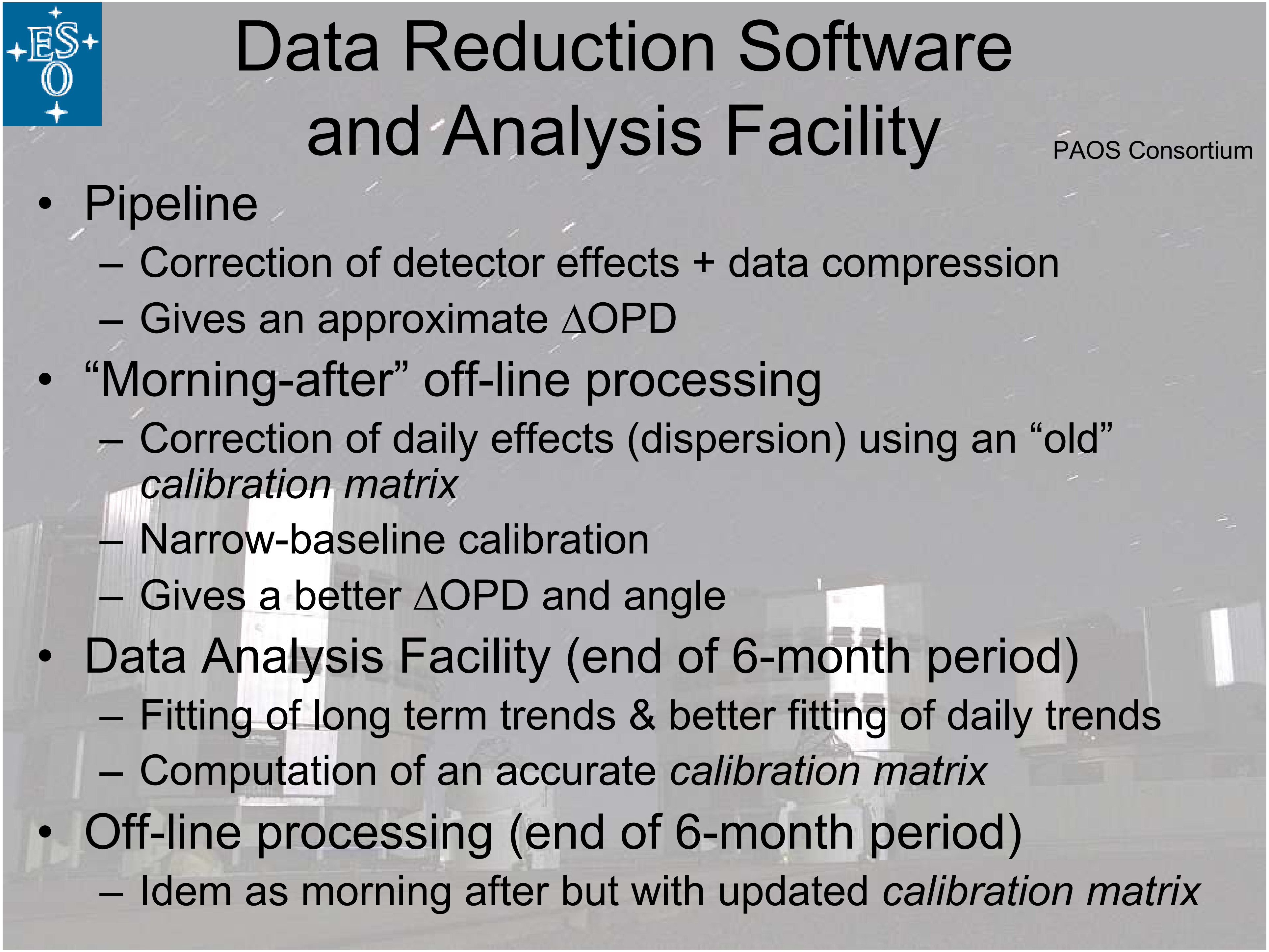
Bp: 141.79
Theta [d]: 173.47
Error Phasis: 96
38
61

eccentricity[0...1]: 0.05
inclination [deg]: 63.00
omega[deg]: 83.00
OMEGA[deg]: 32.00
semi major axis[muasec]: 30
Period [day]: 30
T0 [MJD]: 53,371

alpha pm [mas/y]: -342.00
delta pm [mas/y]: 645.00
parallax [mas]: 600.000

Data Reduction Software and Analysis Facility

PAOS Consortium



- Pipeline
  - Correction of detector effects + data compression
  - Gives an approximate ΔOPD
- “Morning-after” off-line processing
  - Correction of daily effects (dispersion) using an “old” *calibration matrix*
  - Narrow-baseline calibration
  - Gives a better ΔOPD and angle
- Data Analysis Facility (end of 6-month period)
  - Fitting of long term trends & better fitting of daily trends
  - Computation of an accurate *calibration matrix*
- Off-line processing (end of 6-month period)
  - Idem as morning after but with updated *calibration matrix*

Conclusions

- PRIMA is aimed at boosting VLTI performances (limiting magnitude, imaging) + bringing new feature (astrometry)
- PRIMA is making VLTI more complex but brings also solutions to current problems
- PRIMA challenges:
  - fringe tracking and limiting magnitude
  - long term stability
- Scientific objectives are worth the effort
- ESO will provide tools to reduce data and prepare observations (see summerschool next year)
- => do not be discouraged and enjoy the challenge !