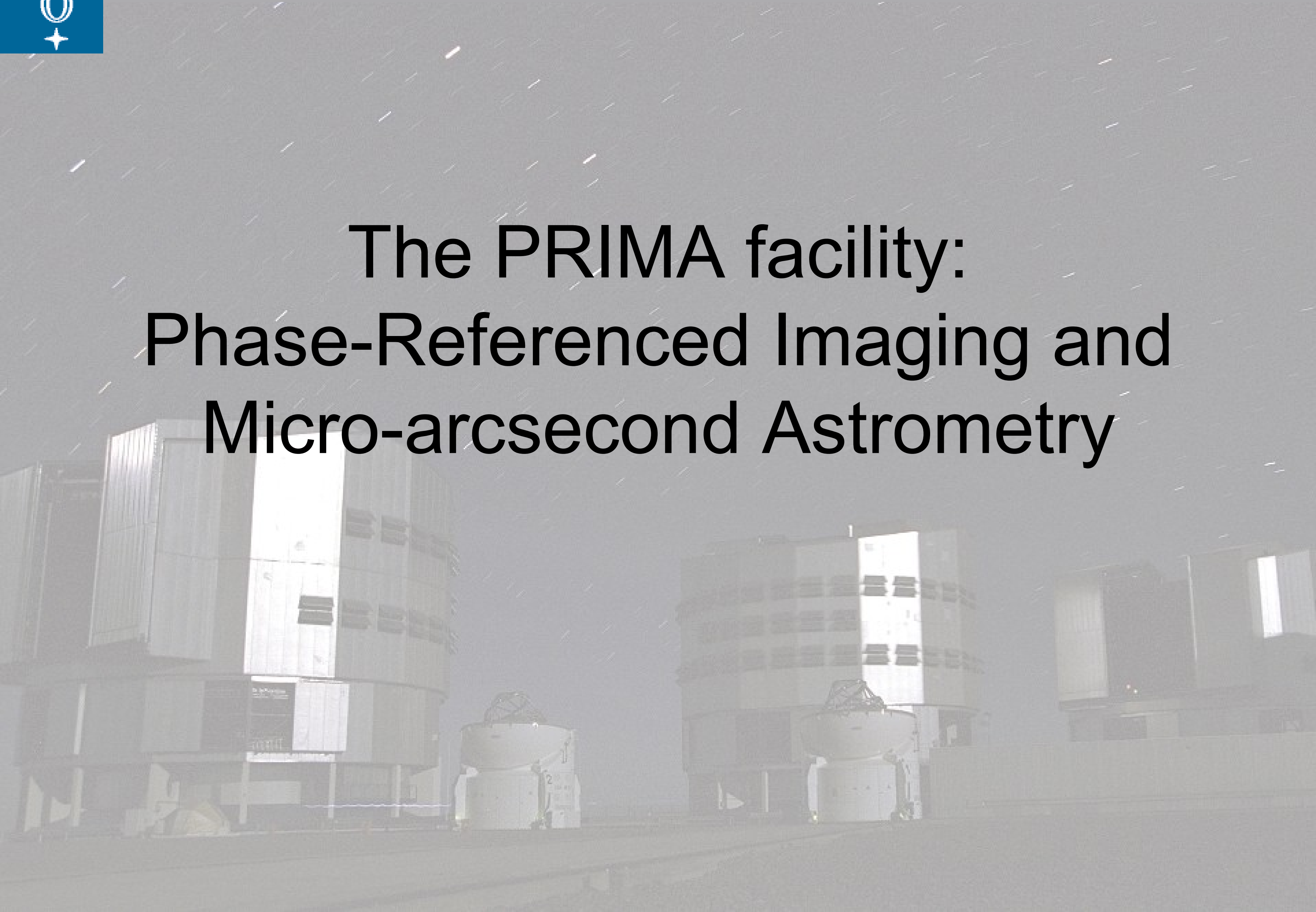
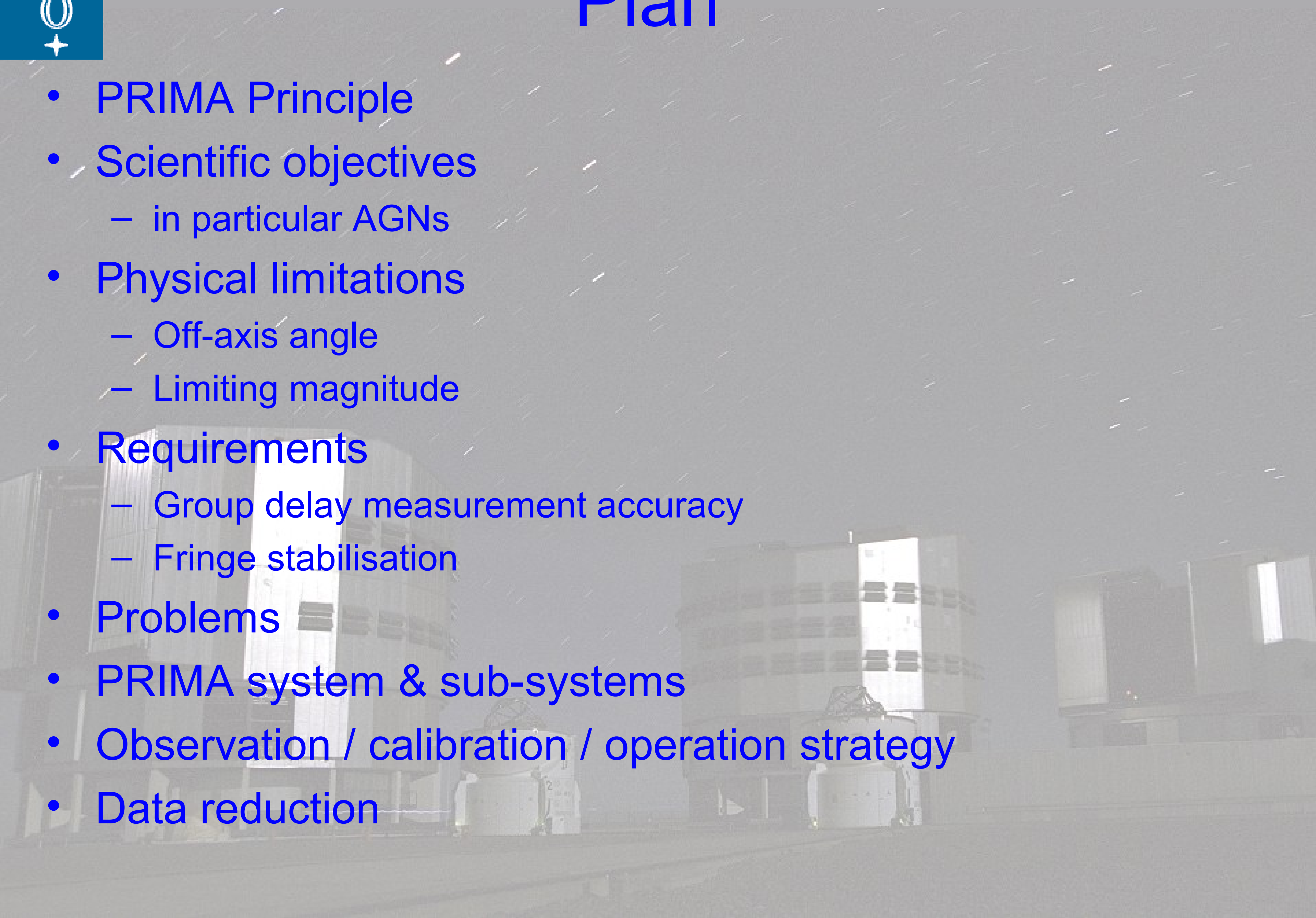


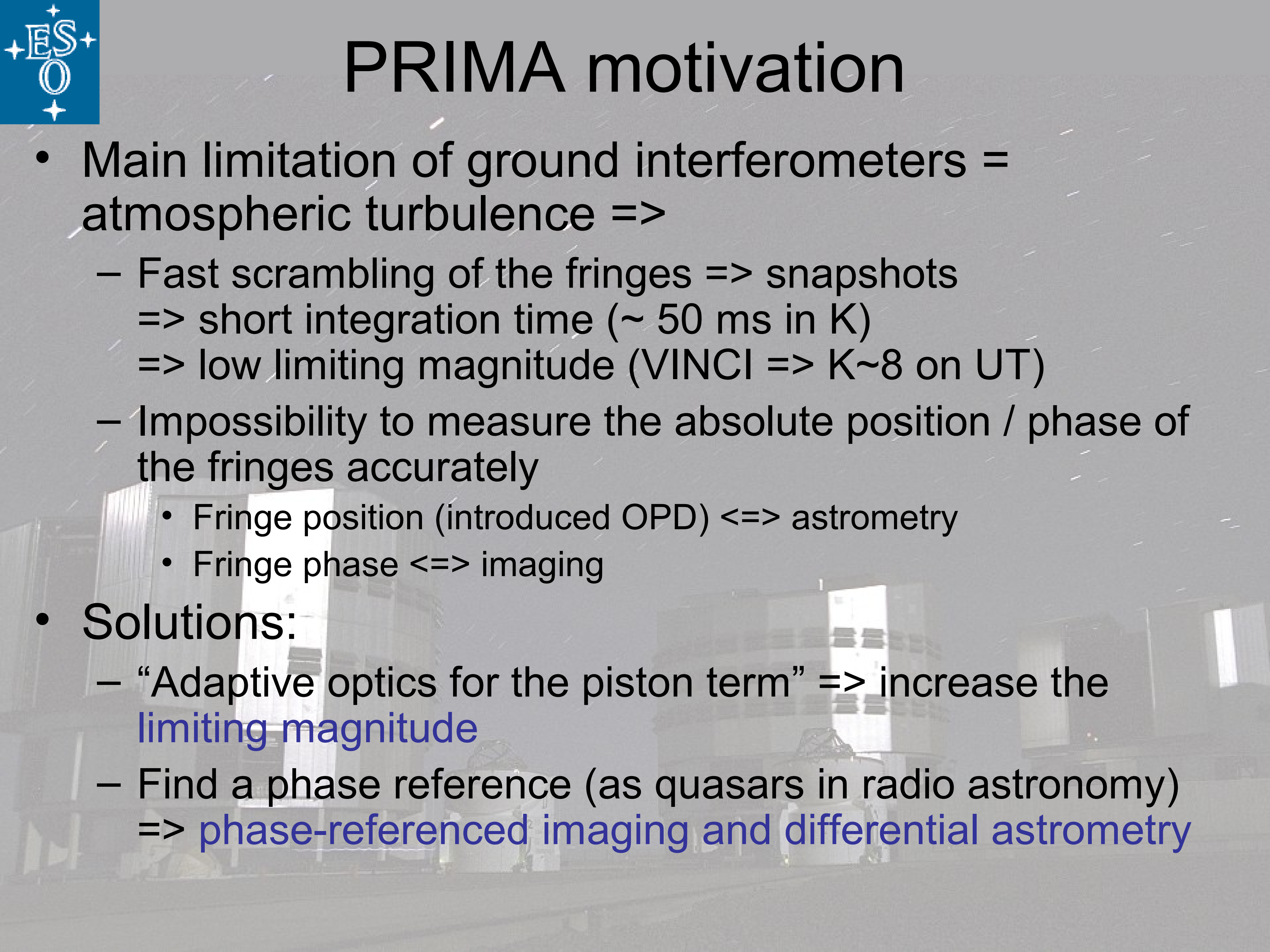
The PRIMA facility: Phase-Referenced Imaging and Micro-arcsecond Astrometry

Plan



- PRIMA Principle
- Scientific objectives
  - in particular AGNs
- 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 =>

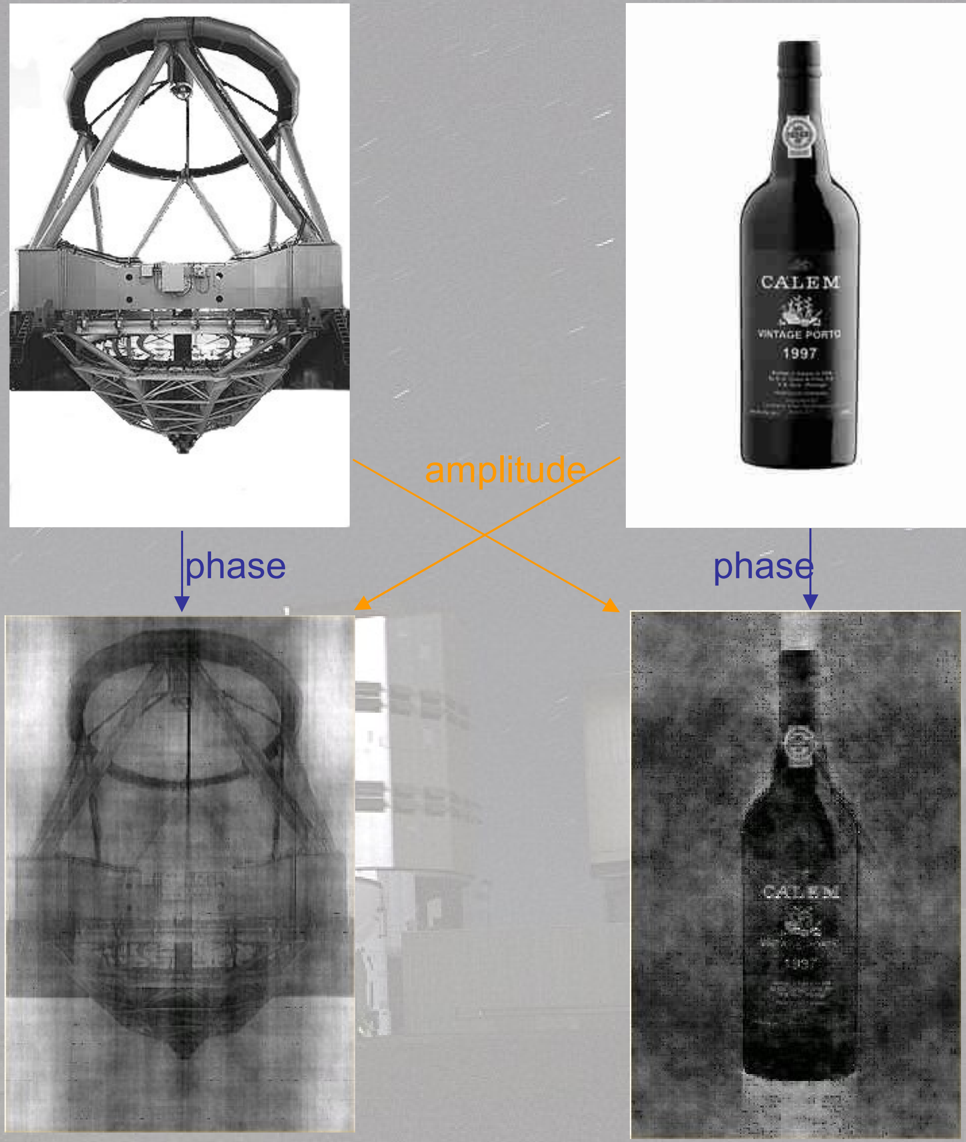
- take their Fourier Transform => amplitude part (squared visibility) and phase part

- cross the phase of one image with the amplitude of the other

- reconstructed images =>

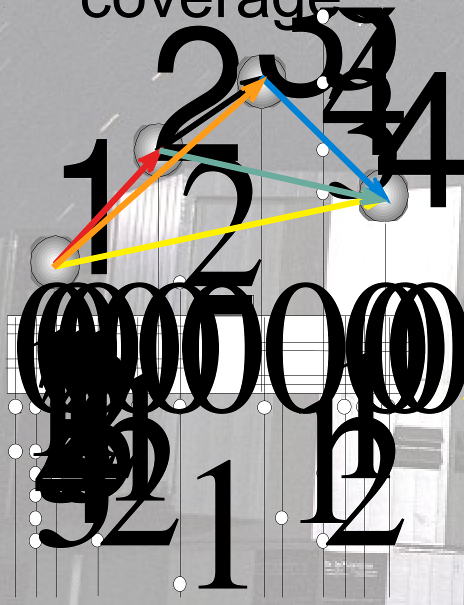
Conclusion: the phase of the image contains the most important part of the information on its shape !

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

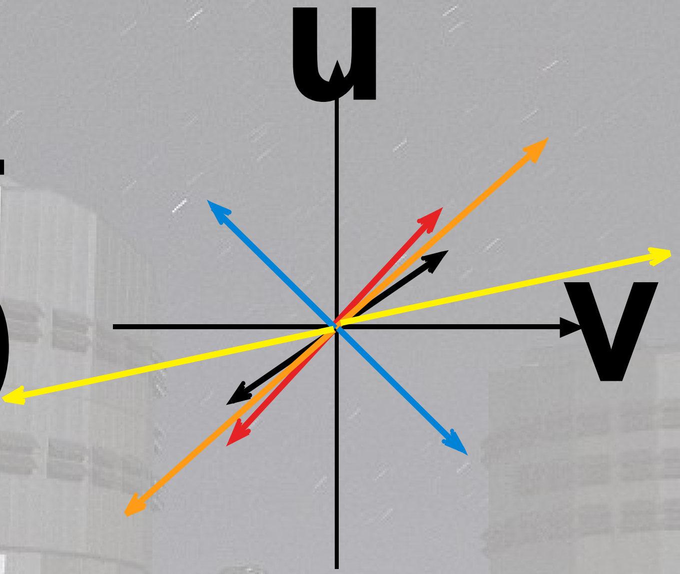


u-v plane and reconstructed PSF

- 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

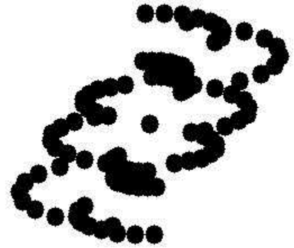


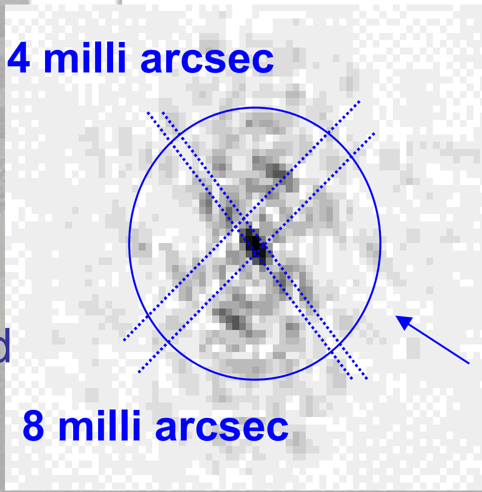
This is NOT the u-v plane



This IS the u-v plane

u-v coverage
(UT 8 hours δ =-15º)





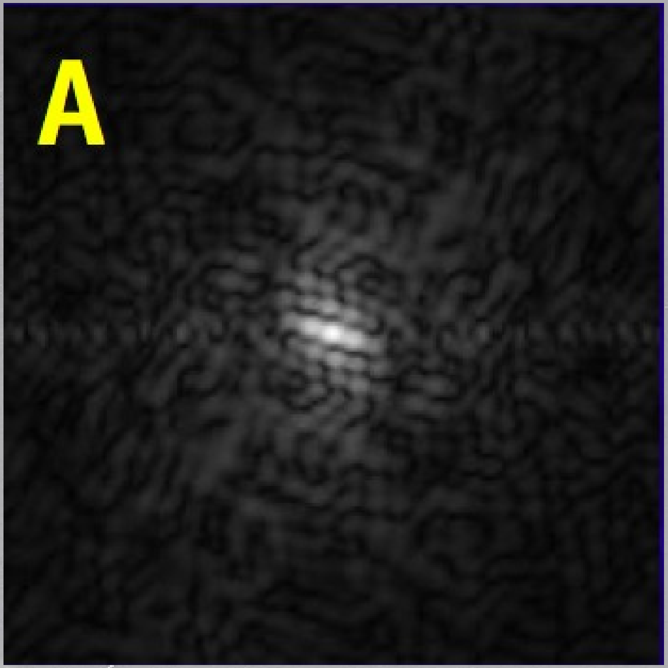
Reconstructed
PSF
K-band

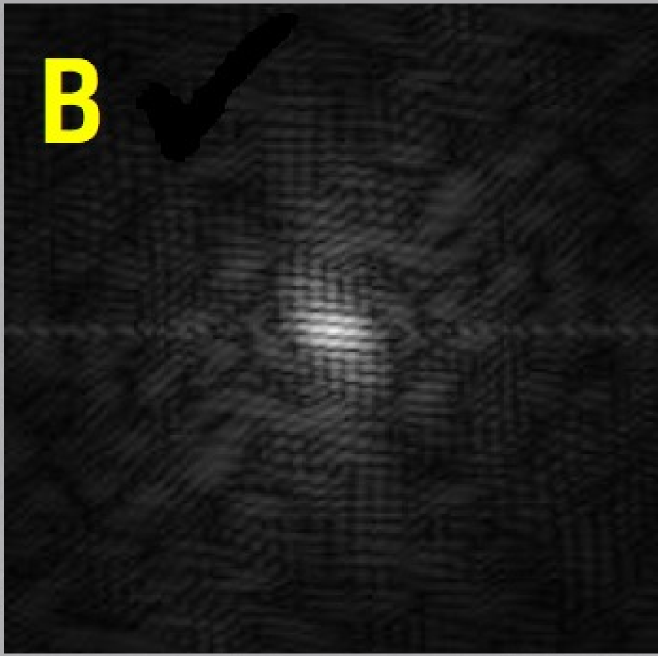
Airy disk
UT

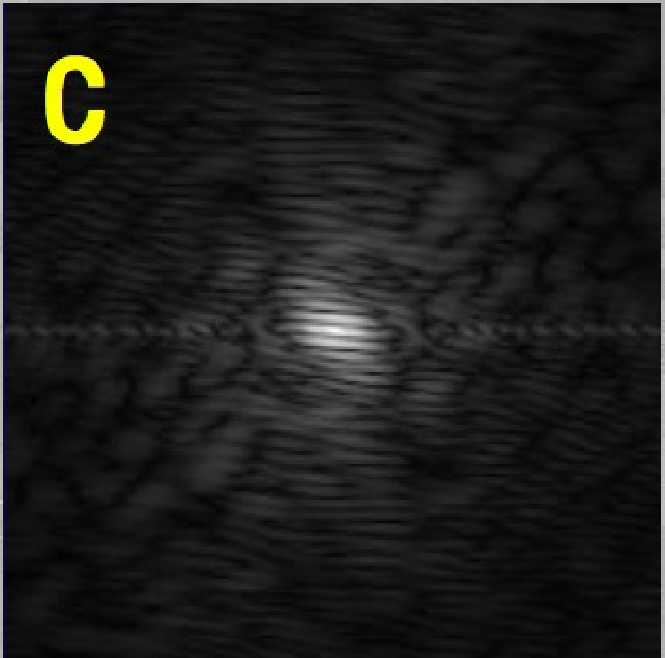
Quizz

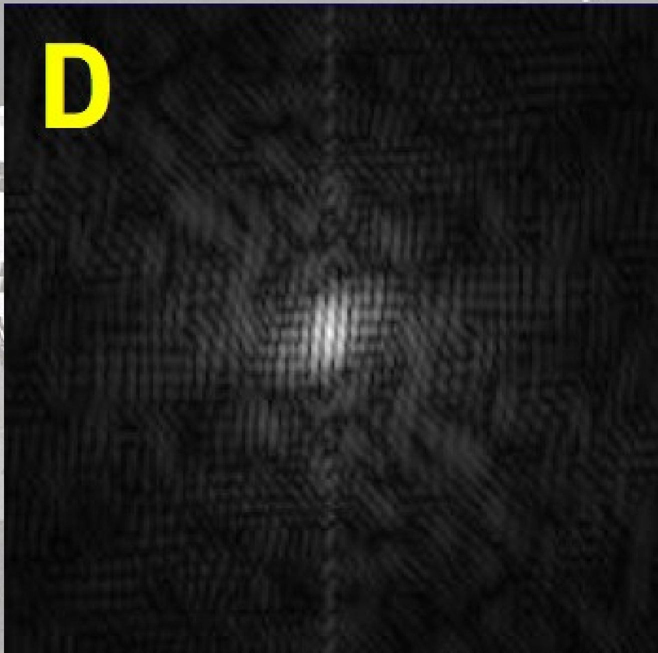
What’s the Fourier transform (so in u-v plane) of Michelson’s picture?

Copyright: P. Tuthill

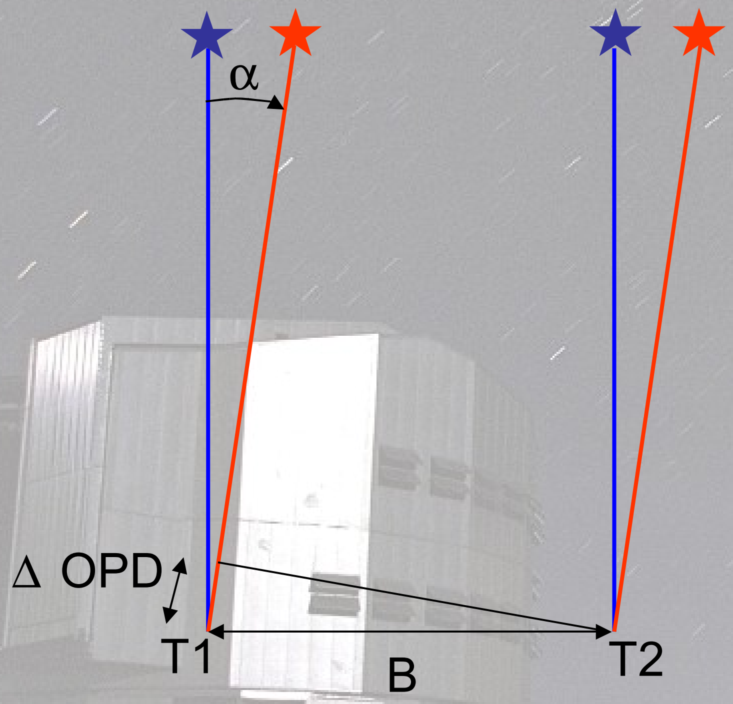








Narrow-angle differential astrometry



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

$$\Delta\ \mathrm{OPD} = B \,.\, \sin \alpha$$

- 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

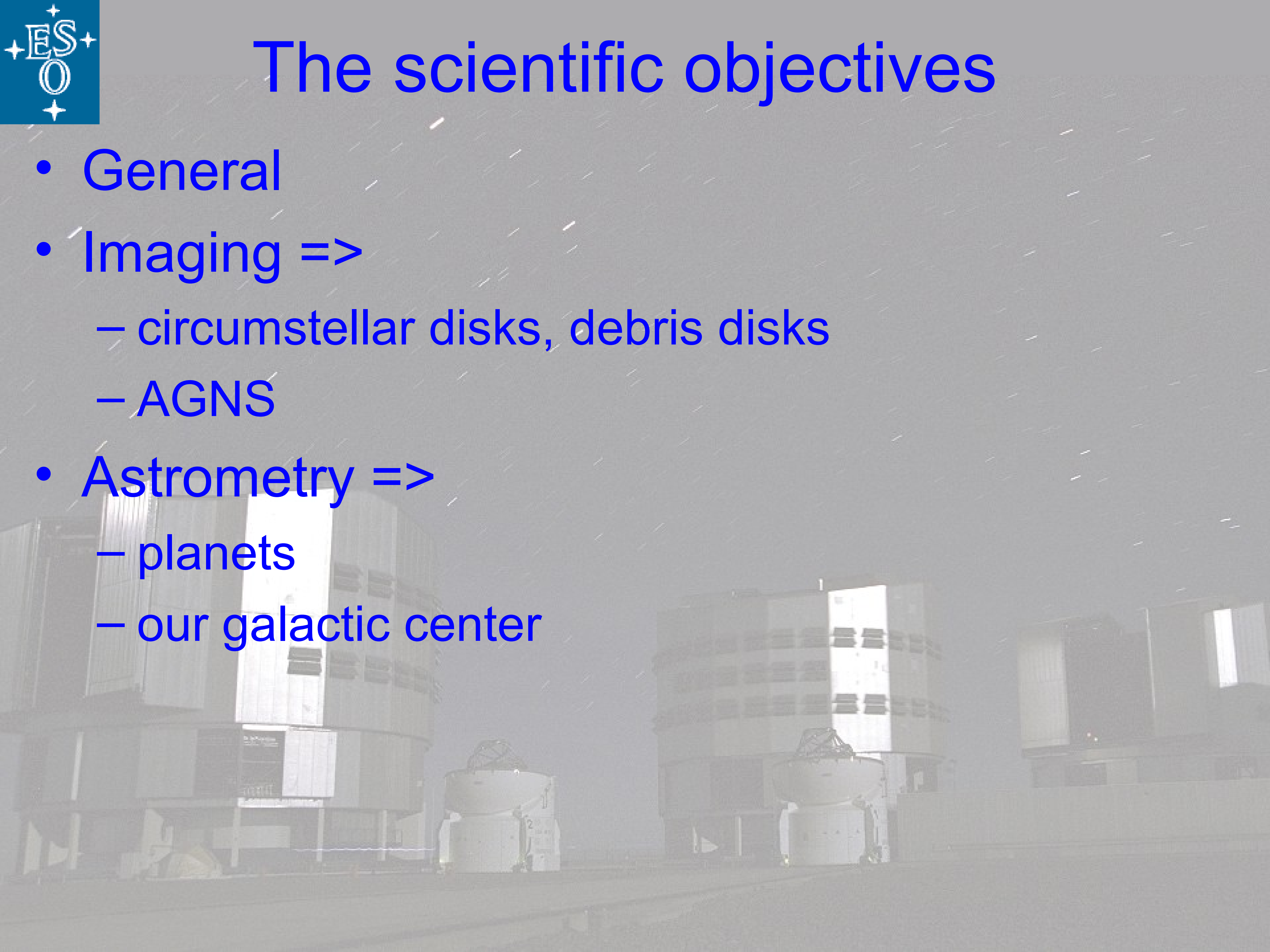
- Pick up 2 stars in a 2 arcmin field
  - bright star for fringe tracking
  - faint object / star

- Δ OPD = Δ **S.B** + ϕ + OPD_{turb} + OPD_{int}
  - OPD_{int} measured by laser metrology
  - OPD_{turb} mean tends to 0
  - Δ OPD measured by VINCI / AMBER / MIDI / FSU
  - Δ **S** => object position => astrometry
  - ϕ => object phase => imaging

- complex method but very powerfull
  - many baselines => many nights

- synthetic aperture imaging @ 2mas resolution
- astrometry @ 10 μ as precision

The scientific objectives



- General
- Imaging =>
  - circumstellar disks, debris disks
  - AGNS
- Astrometry =>
  - planets
  - our galactic center

PRIMA goals

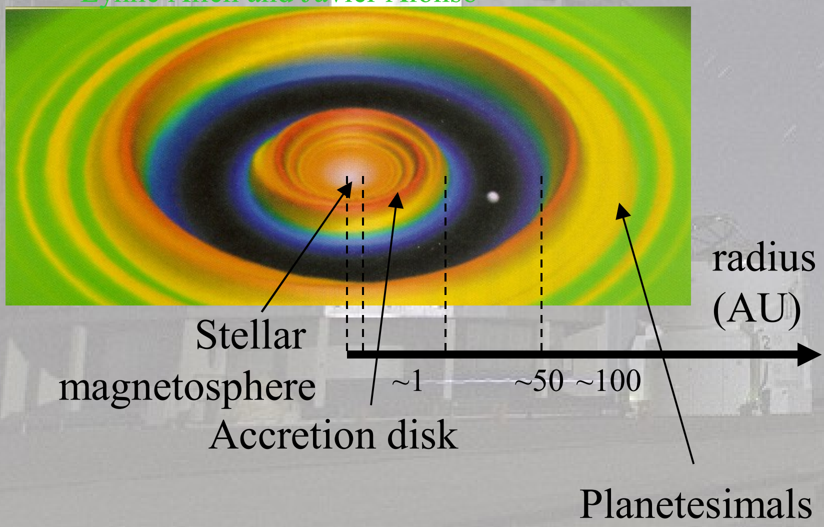
- 3 Aims:
  - faint object observation (by stabilizing the fringes)
    - dual-feed / dual-field : 2’ total FoV (2” FoV for each field)
    - K= 11? (guide star) - K=18? (object) on UTs
    - K= 8? (guide star) - K=15? (object) on ATs
  - phase-referenced imaging
    - accurate (1%) measurement of the 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)

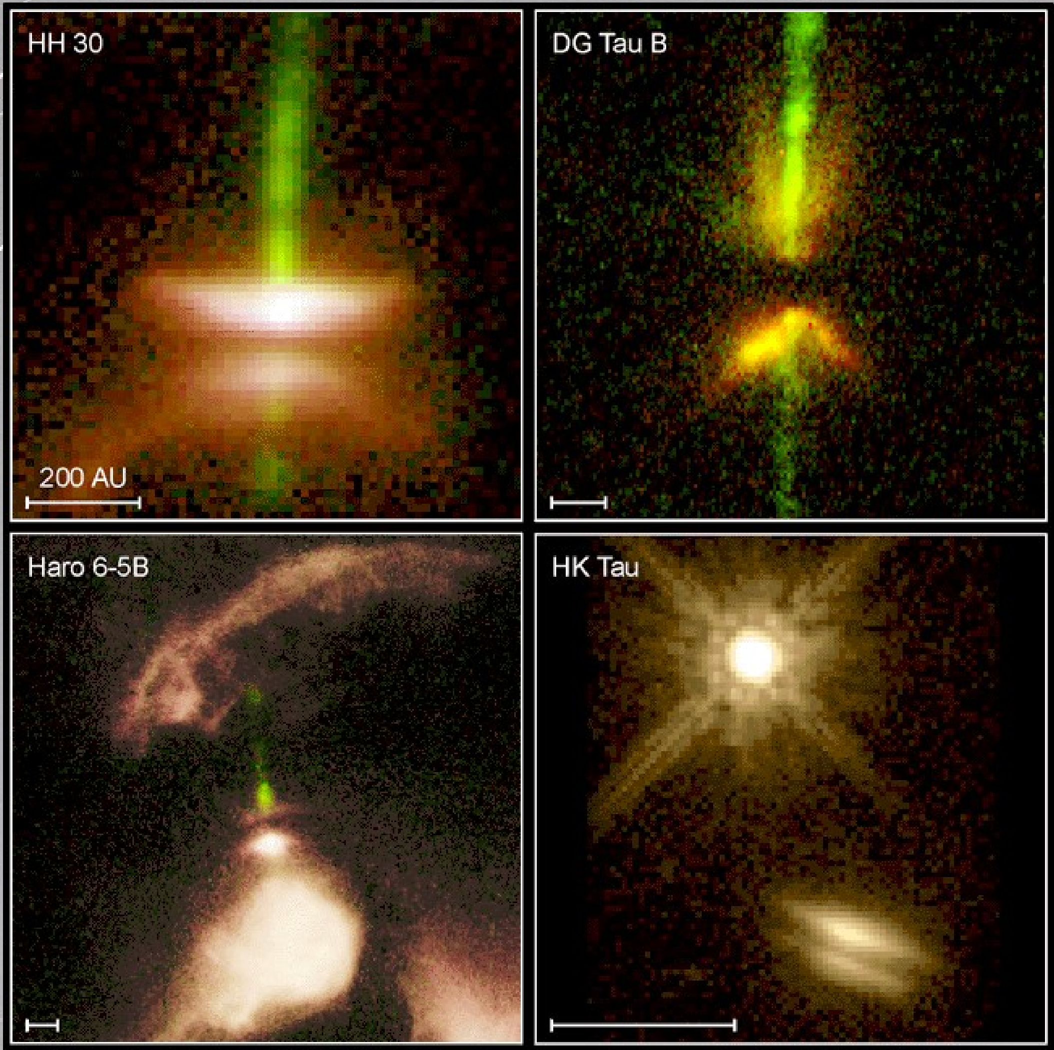
Scientific objectives - stars

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

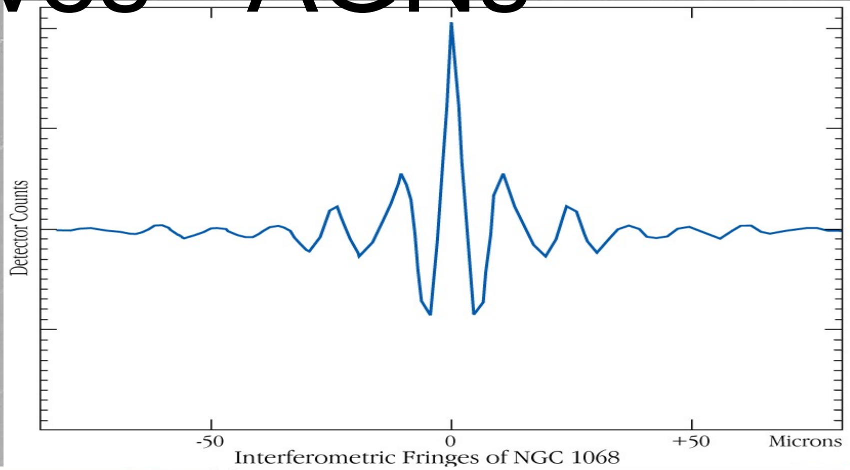




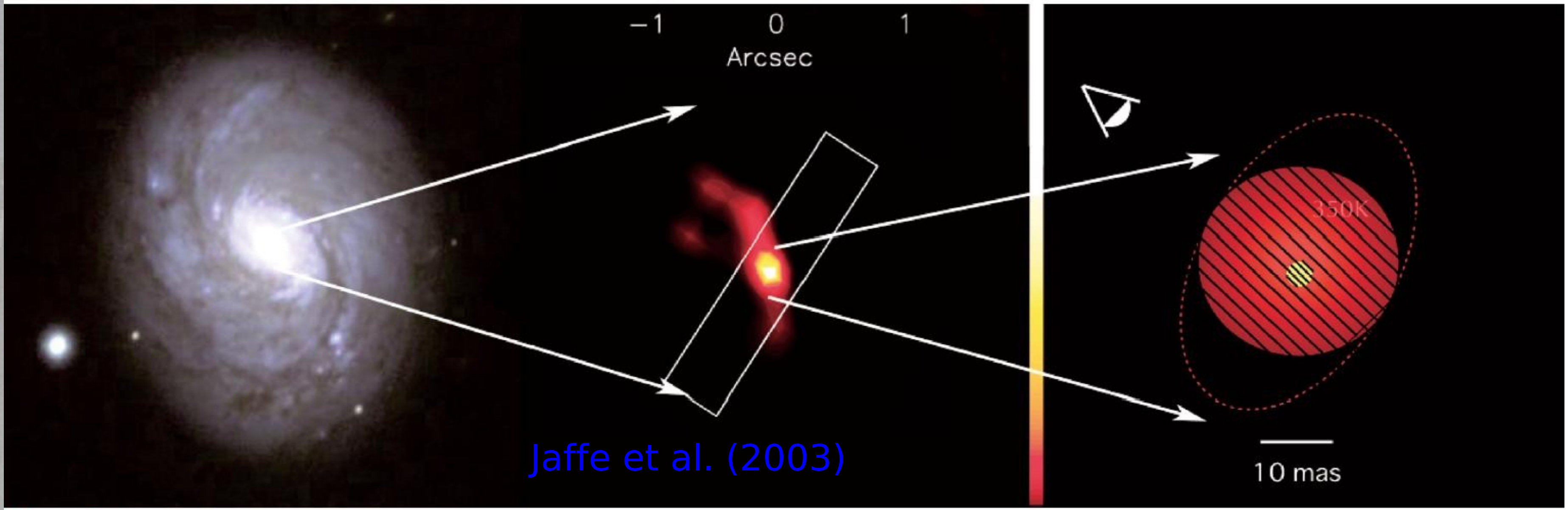
Disks around Young Stars **HST • WFPC2**
PRC99-05b • STScI OPO
C. Burrows and J. Krist (STScI), K. Stapelfeldt (JPL) and NASA

Scientific objectives - AGNs

- Observation of central core elongation, jets, dust torus...
- Currently ~7 objects observable with MIDI (e.g. NGC 1068), 0-1 with AMBER
- With PRIMA: hopefully >~50 with each => better sample, better spectral coverage



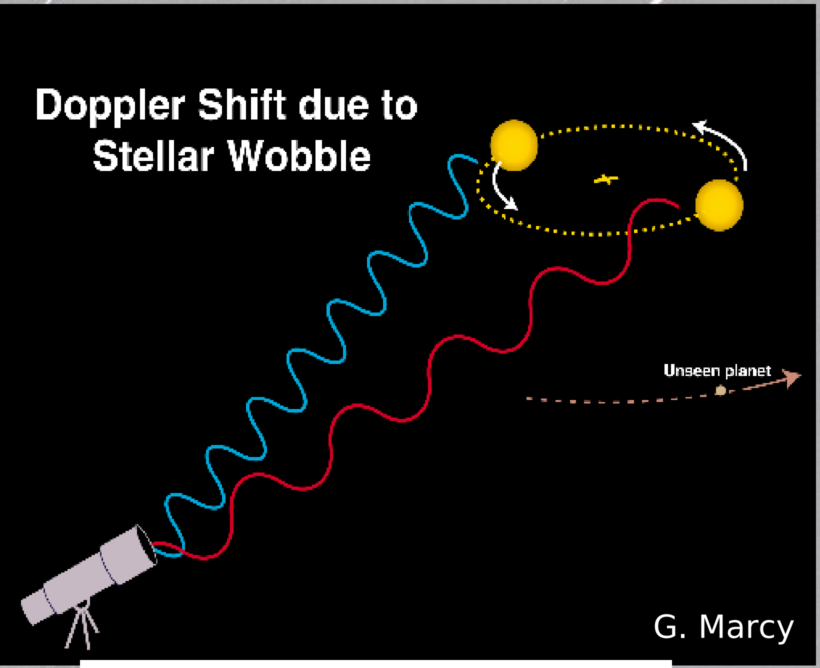
Interferometric Fringes of NGC 1068

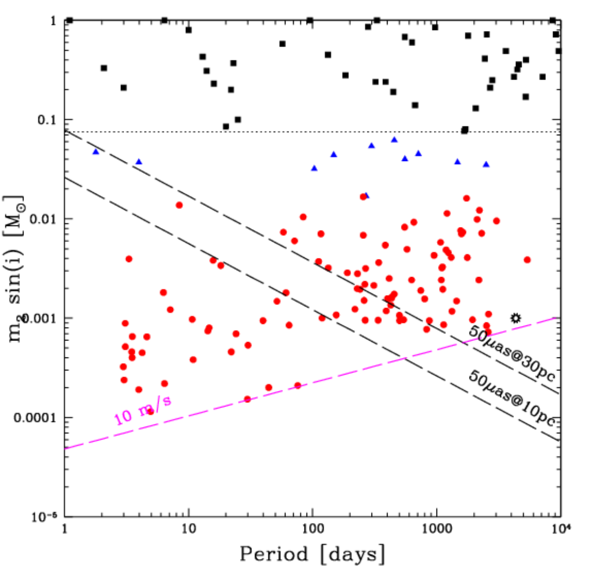


Jaffe et al. (2003)

Figure 9: Left: 3.4 × 3.4 arcmin optical image of NGC 1068, (NOAO/AURA/NSF). Centre: non-interferometric acquisition image of NGC 1068 taken by MIDI with a 8.7 micron filter, showing the structures on arcsec scales. Also shown are the position of the spectroscopic slit used in the interferometric observations and the directions of North (toward top left) and East (toward bottom left) on the sky. The projected baseline was essentially North/South and the fringe spacing in this direction was 26.3 mas at 10 micron wavelength. Right: sketch of the dust structure in the nucleus of NGC 1068, as derived from modeling the MIDI observations. It contains a central hot component (T > 800 K, yellow) which is significantly smaller than the interferometric beam, and a much-larger well-resolved warm component (T=330 K, red) of diameter 33±5 mas, corresponding to 2.8 pc at the distance of NGC 1068. From Jaffe et al (2003).

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 !

Scientific objectives: Sgr A*

- IR imaging of the matter around the black hole (see J-U. Pott's poster)
- 10 μas astrometry of the stars in the central cusp

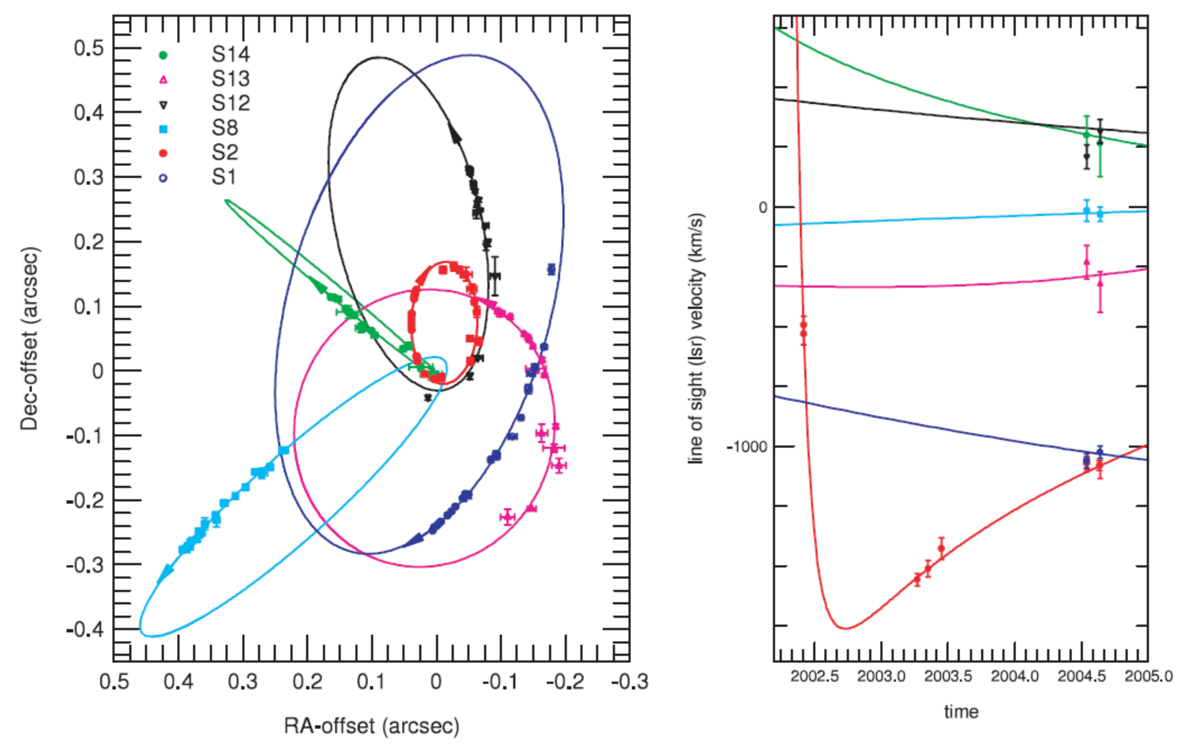
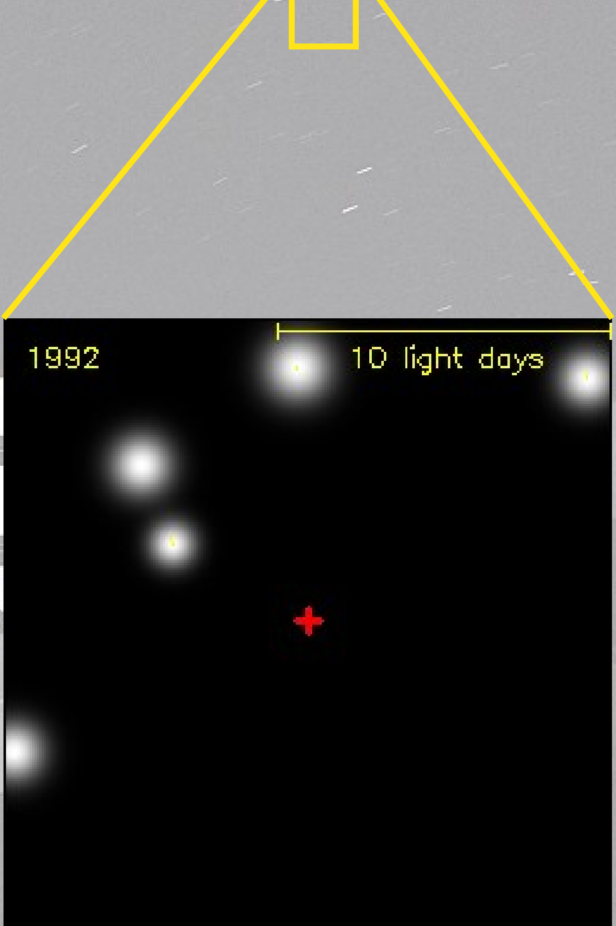
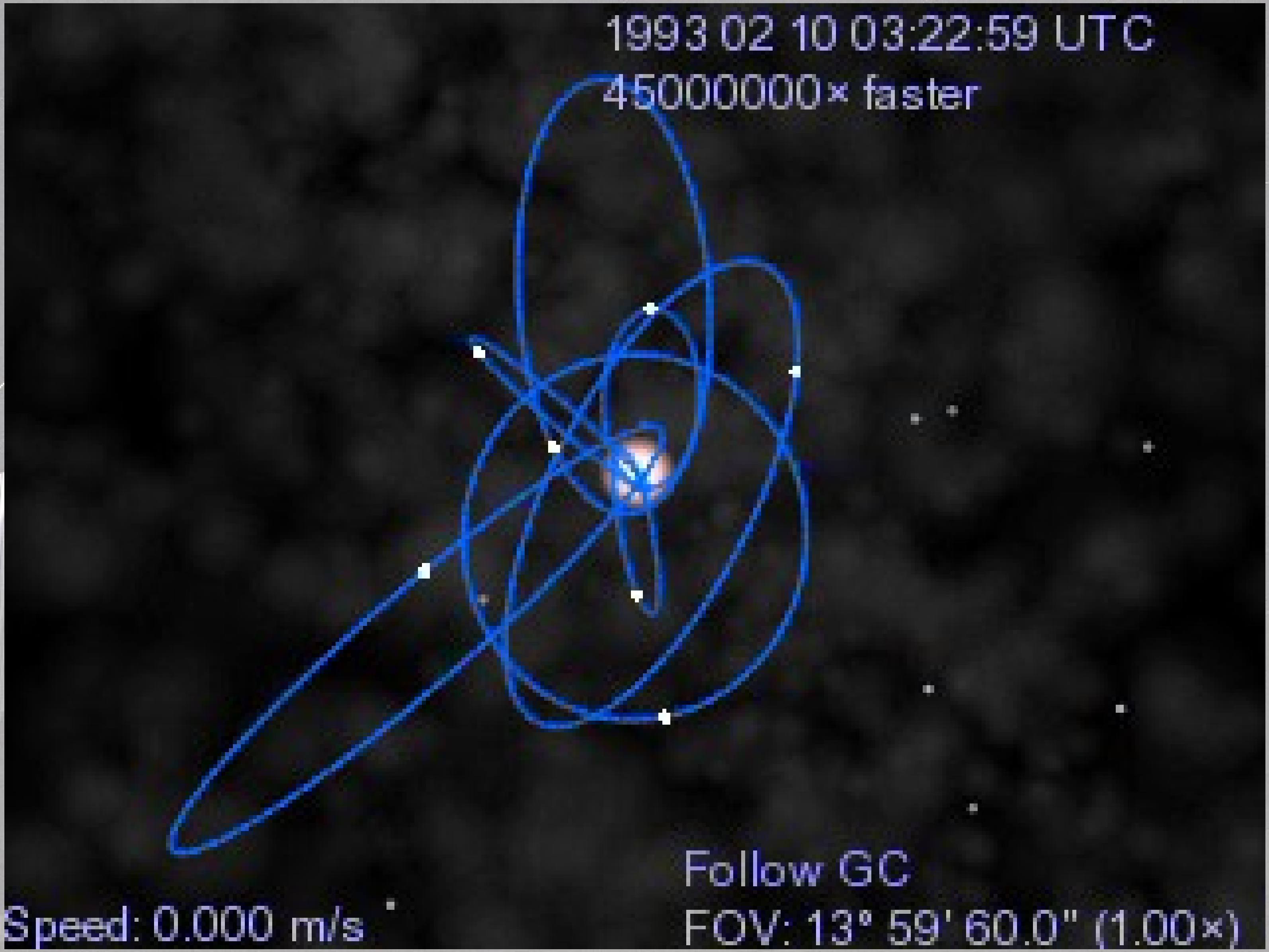


FIG. 7.—Projection on the sky (*left*) and in time/radial velocity (*right*) of the six S stars included in the fitting (see also Schödel et al. 2003). The measured radial velocity of S2 for epoch 2002 is taken from Ghez et al. (2003). The various color curves are the result of the best global fit to the spatial and radial velocity data of S1, S2, S8, S12, S13, and S14. The orbital parameters are listed in Table 2.

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.



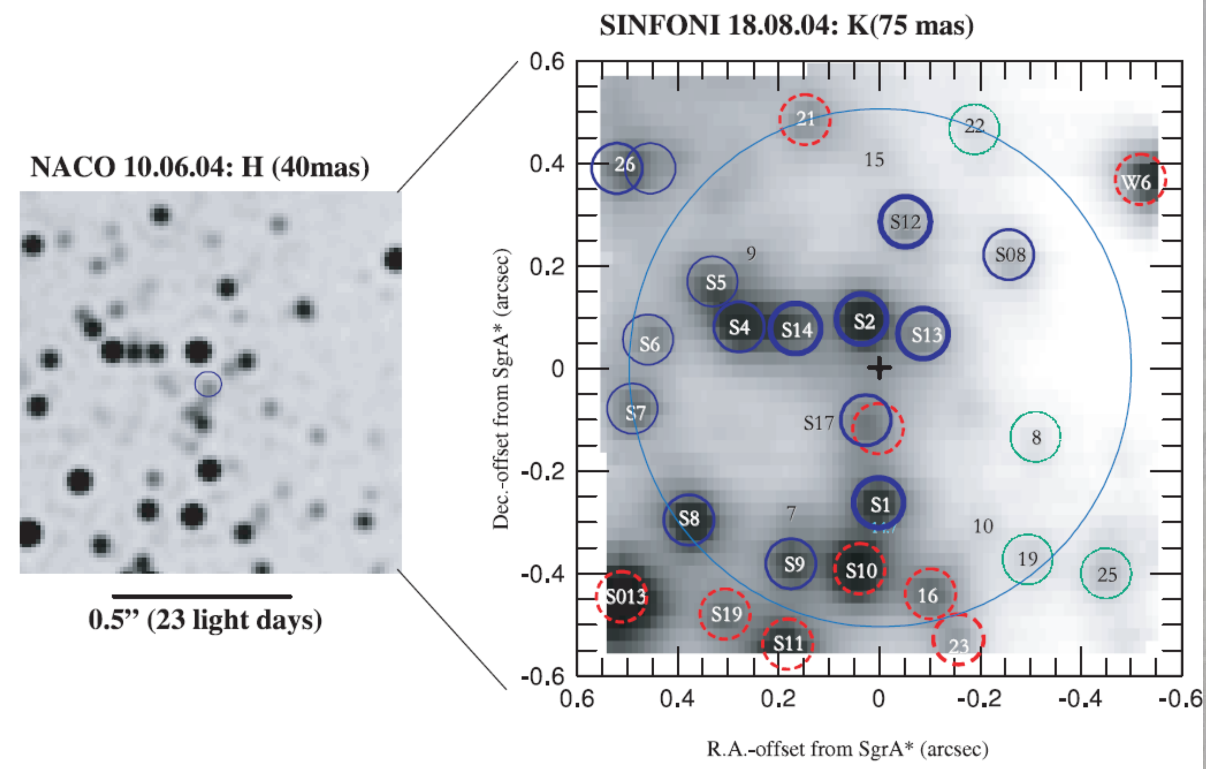
Distance R_0 = 7.62 +/- 0.32 kpc



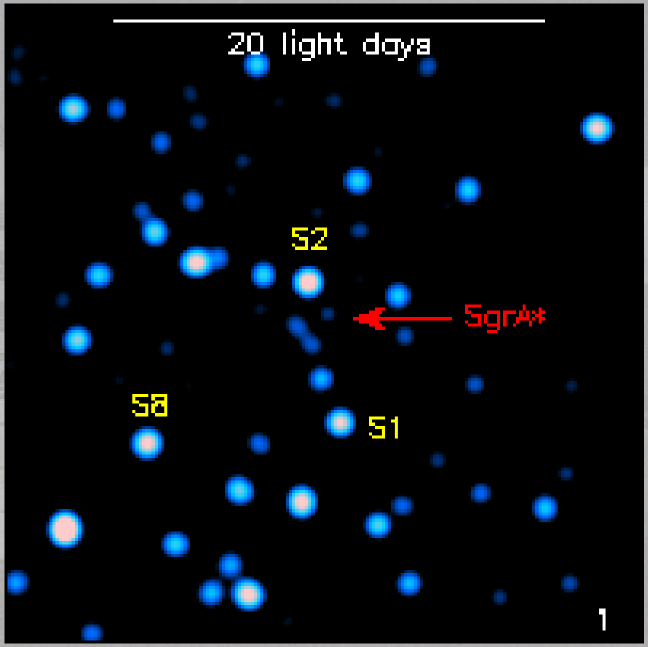
courtesy: F. Eisenhauer (MPE)

Scientific objectives: GC flares

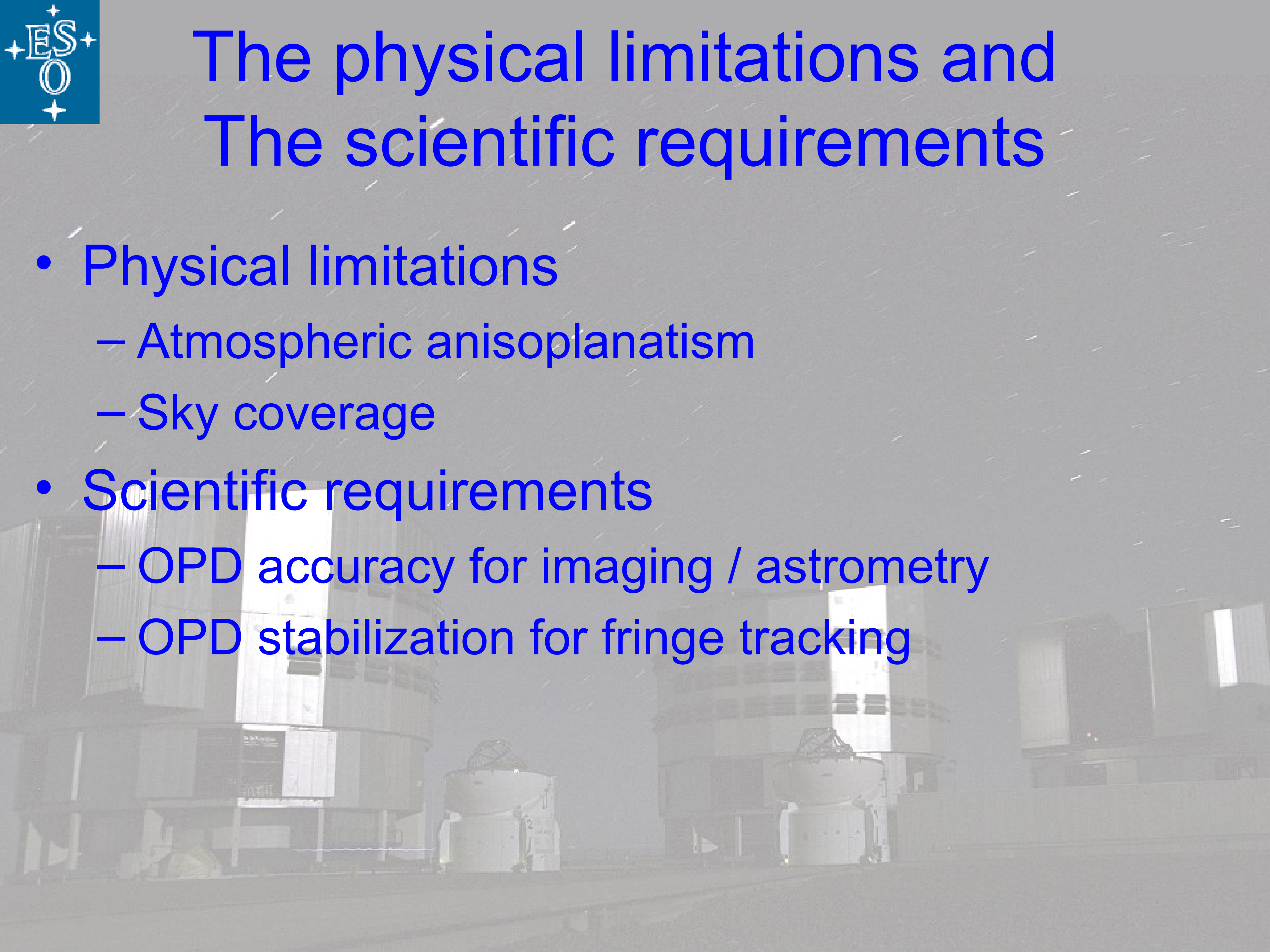
- 10 µas astrometry of the galactic center flares
  - PRIMA can only give partial information on them (1D measurements <=> 1 baseline)
  - if PRIMA can reach the appropriate limiting magnitude (UTs needed, also because of confusion) and accuracy in 30 min (time scale of flare)
  - a better instrument for it would be Gravity



courtesy: F. Eisenhauer (MPE)

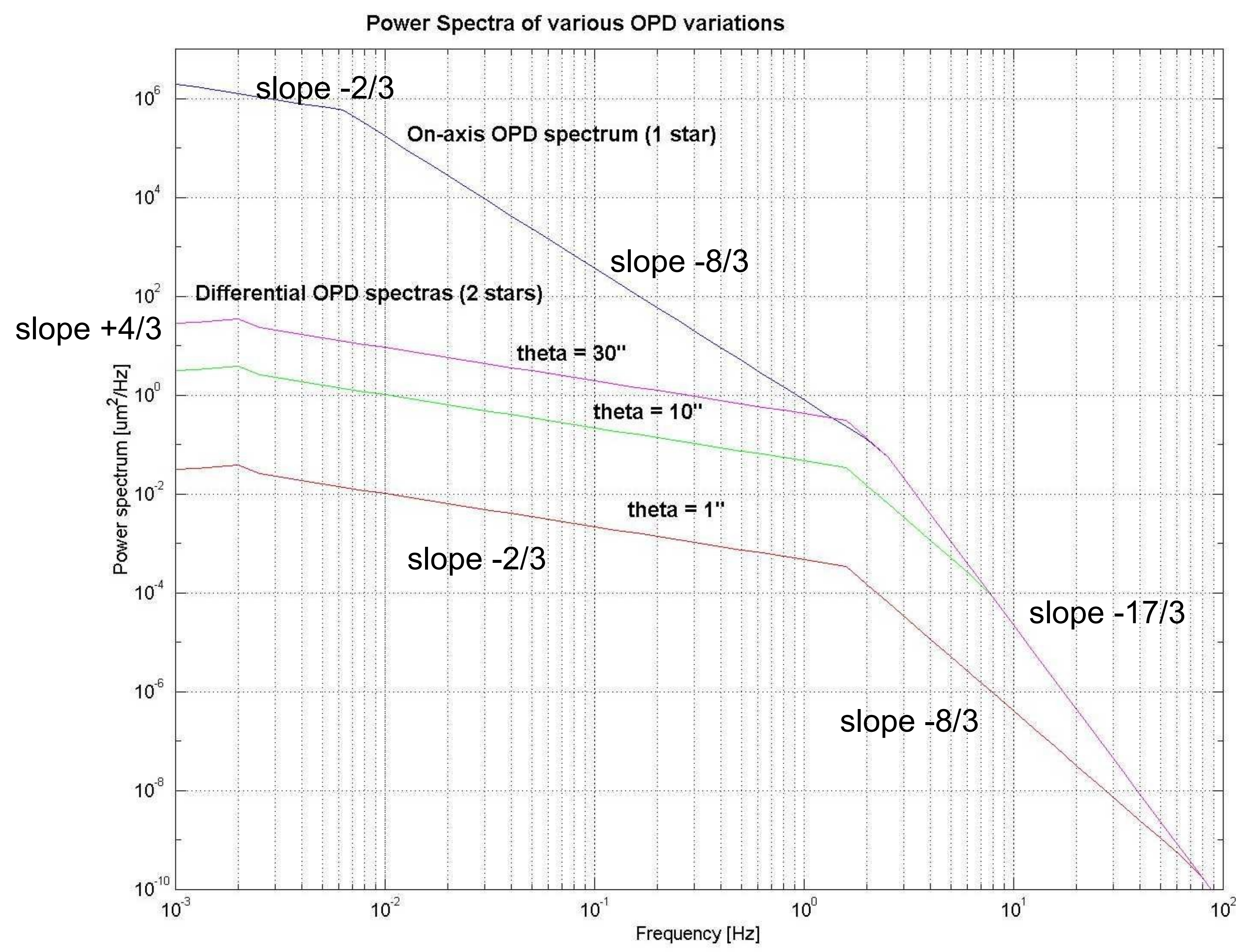


The physical limitations and The scientific requirements



- 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 (but it is rare !)

Atmospheric anisoplanatism 2

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

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

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

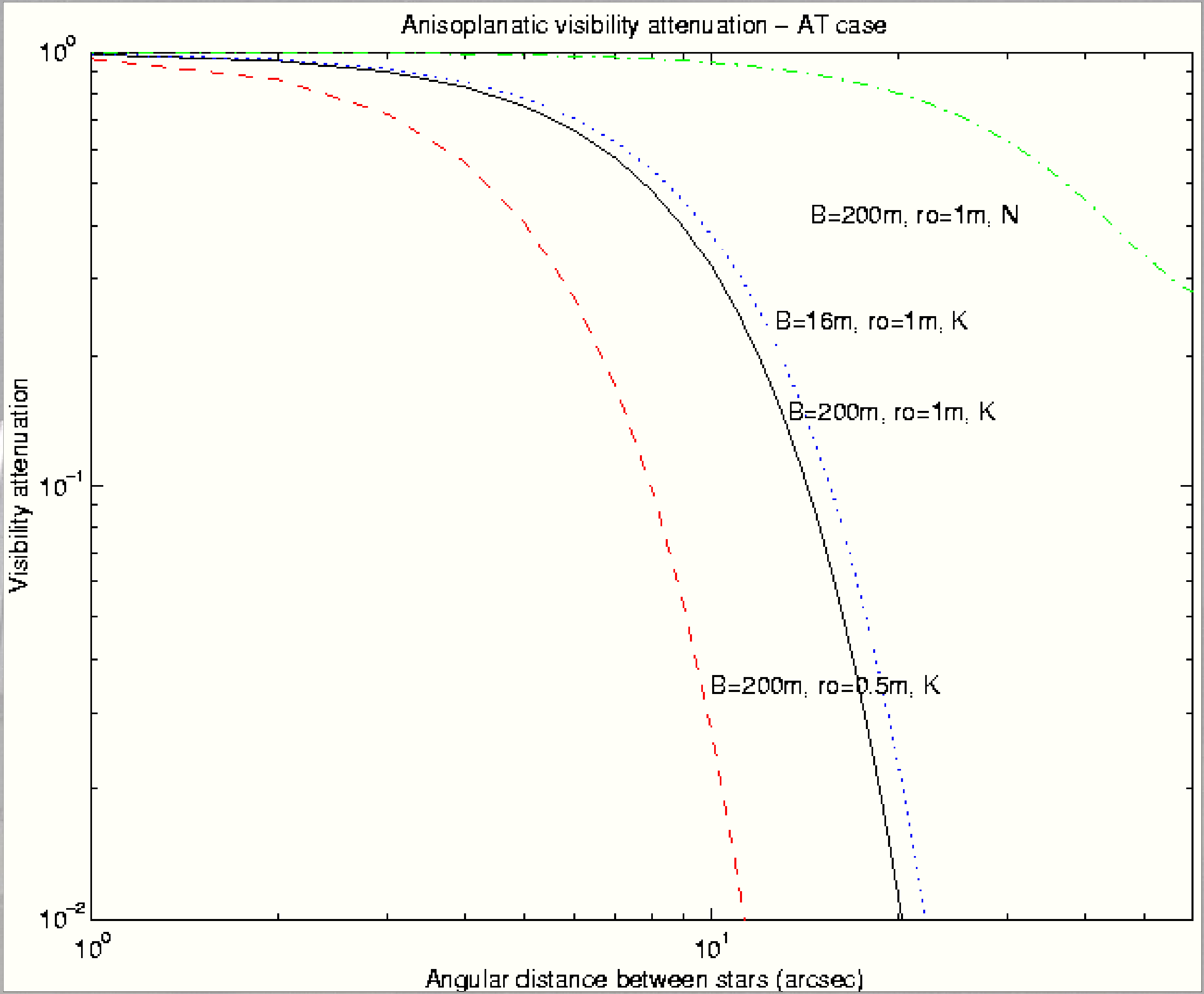
for Paranal seeing = 0.66” at 0.5µm, τ_0 = 10 ms at 0.6µm (L. d’Arcio)

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

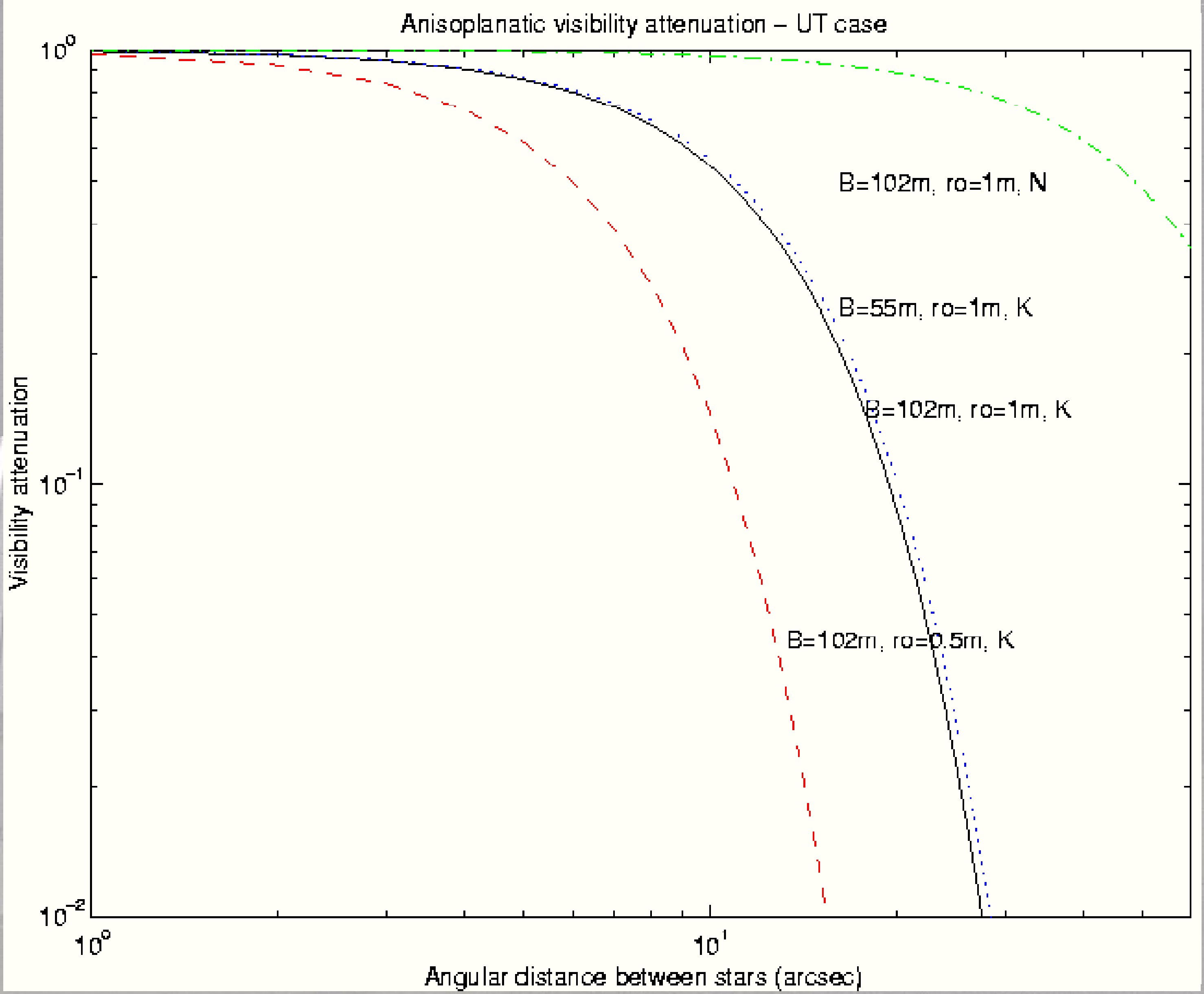
  - Increases with star separation
  - Decreases with telescope aperture (averaging)
  - High impact of seeing quality
- Translates into off-axis maximum angles to limit visibility losses (< 50 to 90%):
  - K-band imaging (2 µm)
    - Bright fringe guiding star within 10-20”
  - N-band imaging (10 µm)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

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

Anisoplanatism AT

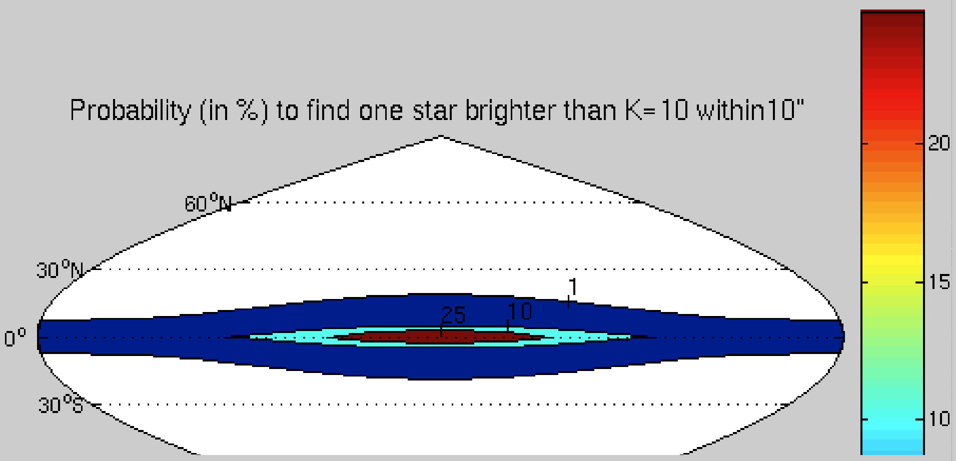


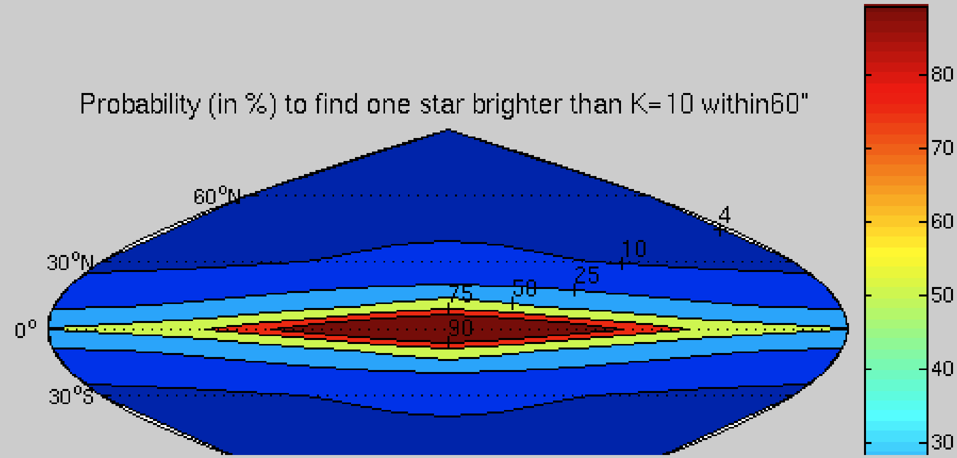
Anisoplanatism UT

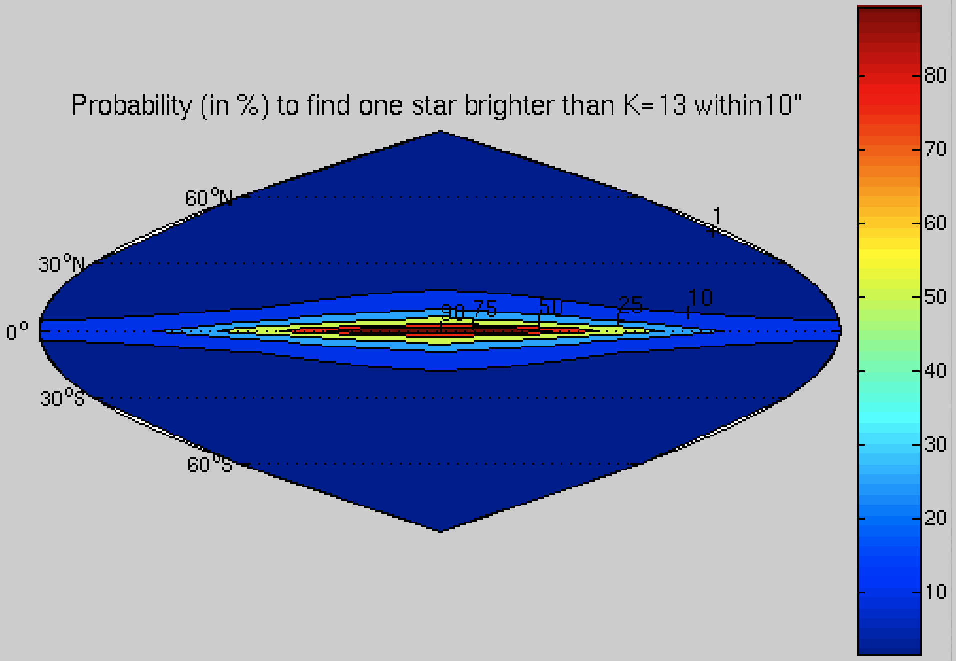


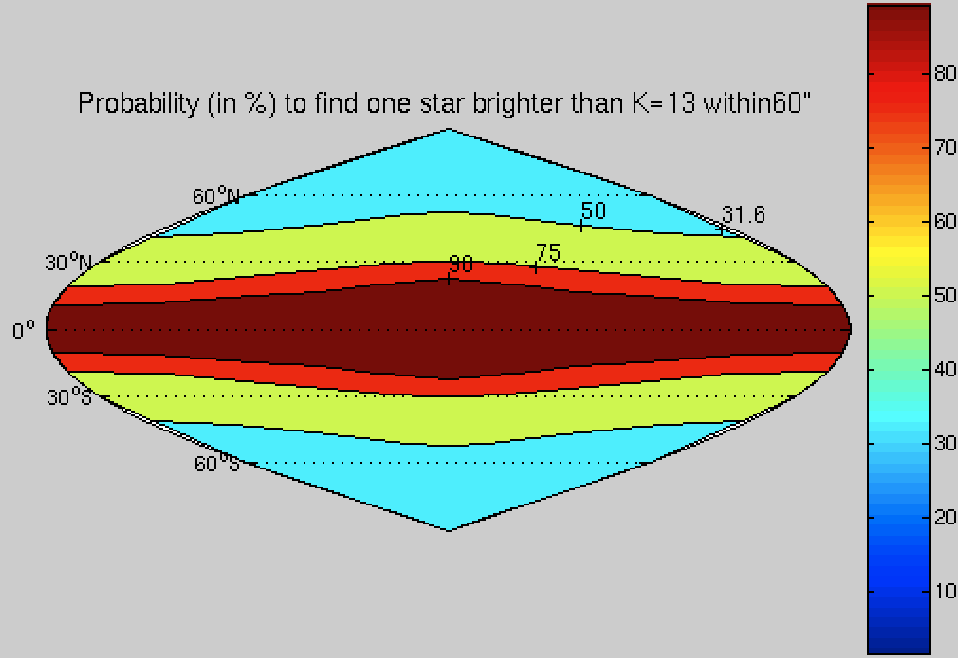
Sky coverage

- 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

$$\Delta\ OPD = \Delta\ \mathbf{S.B} + \phi + OPD_{turb} + OPD_{ant}$$

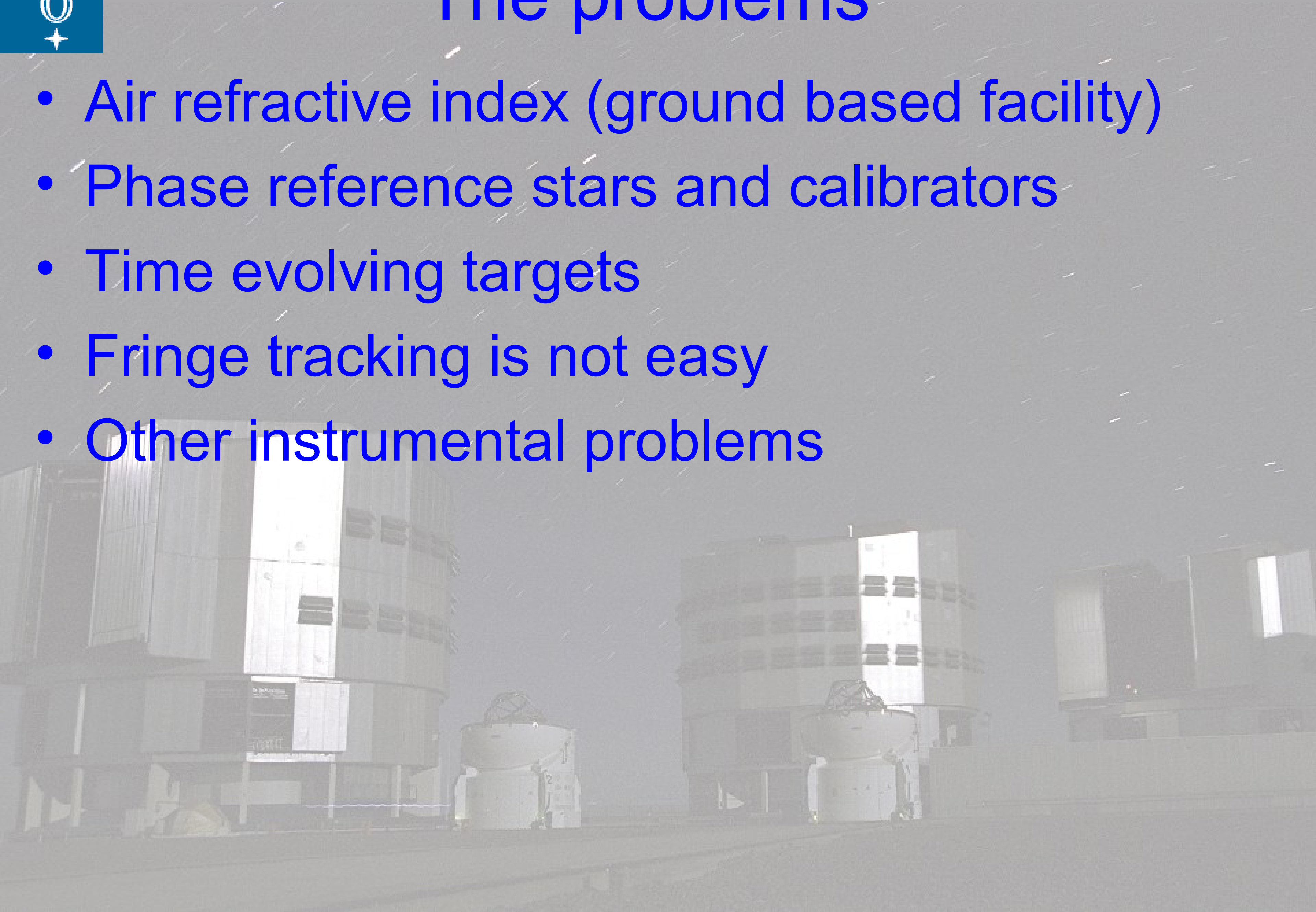
Fringe sensor   astrometry   imaging   atmosphere   Internal metrology

- 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 ~ $\sqrt{M}\ .\ \phi\ /\ \Delta\ \phi$ 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
  - $$\sigma_{residual\_OPD} @ 2.54.10^{-6}.\frac{1}{D}.T^{11/6}$$
  - 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

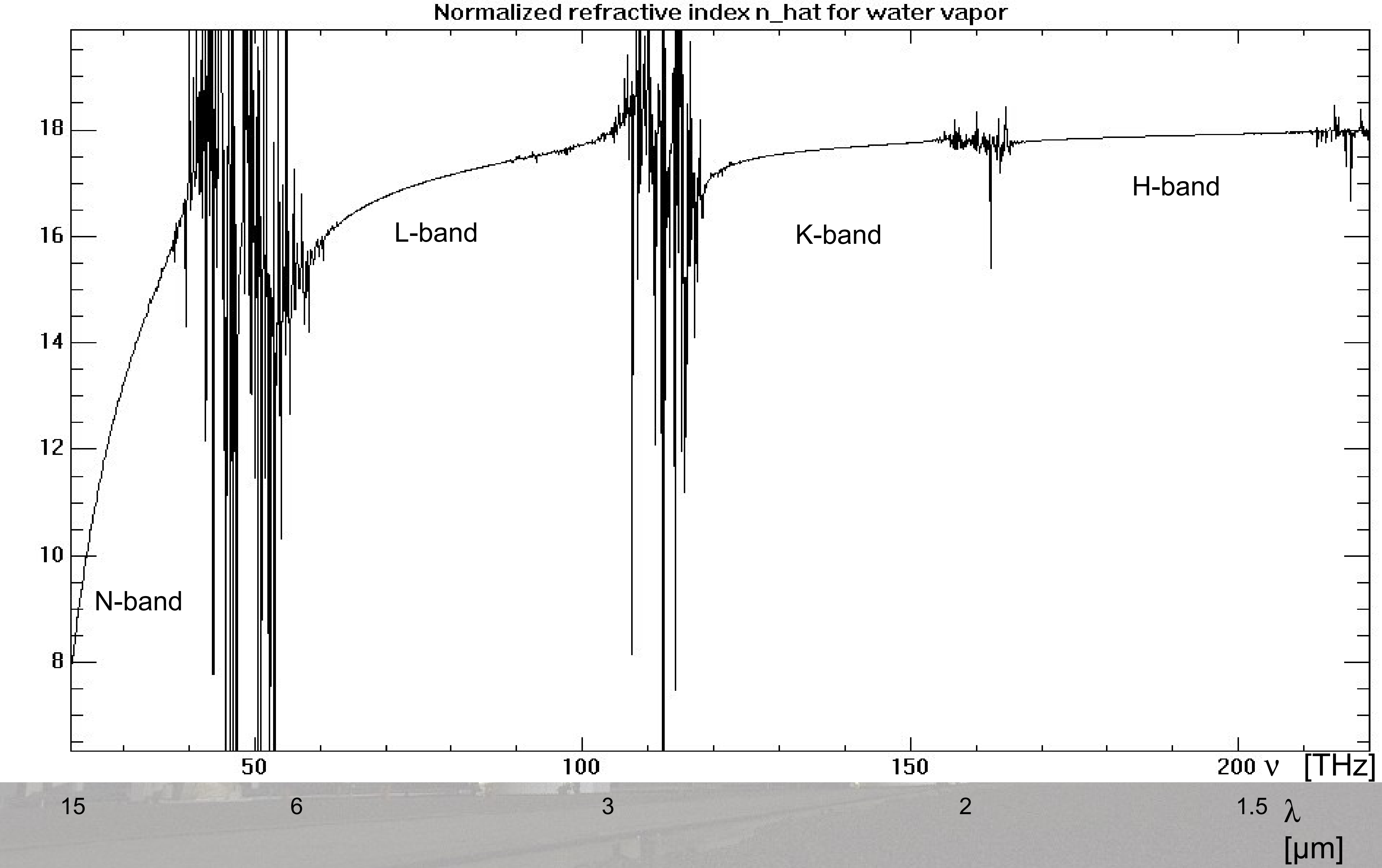


- Air refractive index (ground based facility)
- Phase reference stars and calibrators
- Time evolving targets
- Fringe tracking is not easy
- Other instrumental problems

Dispersion and H_2O seeing

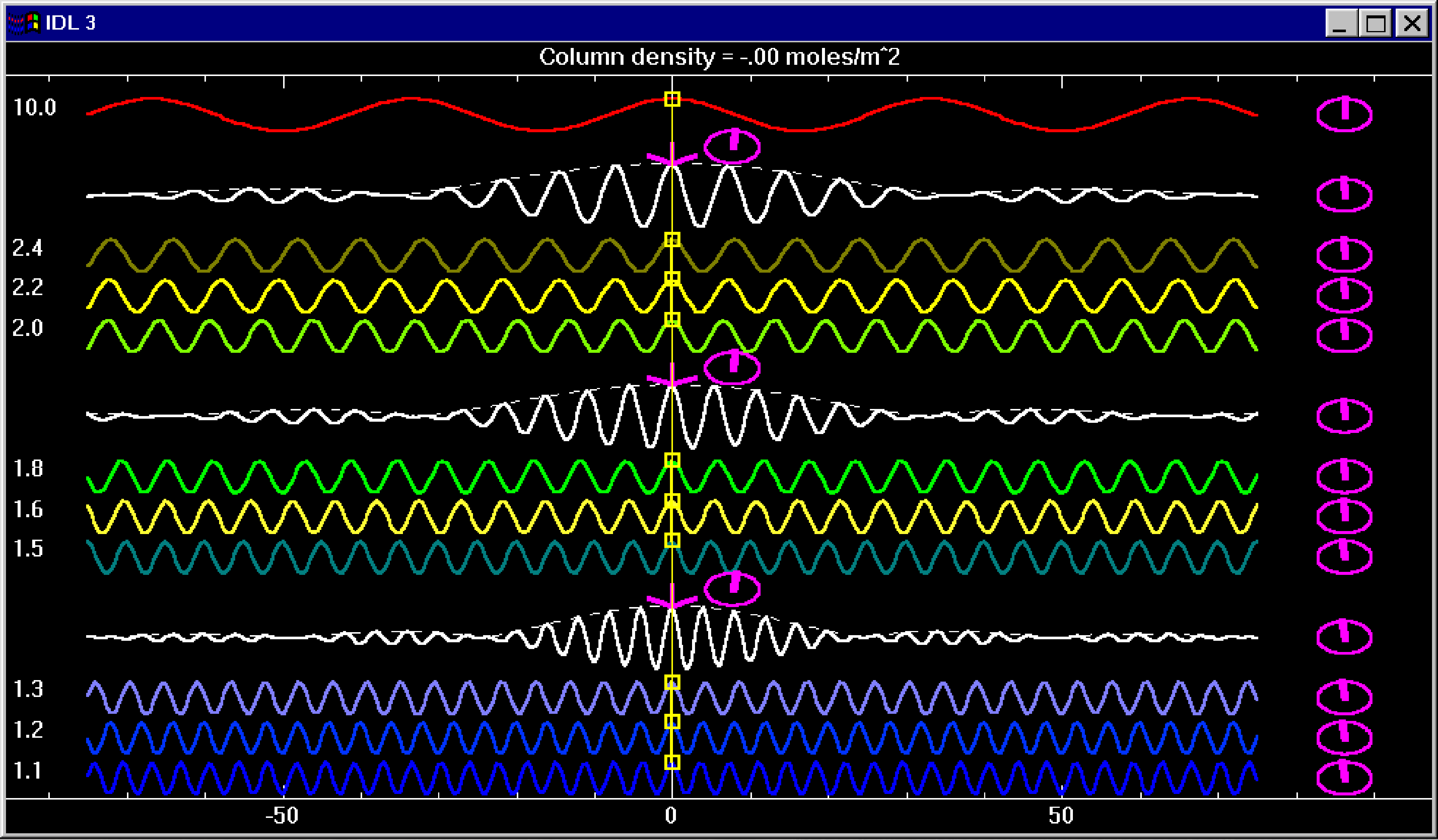
- Transversal & longitudinal dispersion
- Fringe tracking and observation at different λ
- Air index of refraction depends on wavelength =>
  - phase delay ≠ group delay
  - group delay depends on the observation band
  - fringe tracking in K does not maintain the fringes stable in J / H / N bands
- 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)



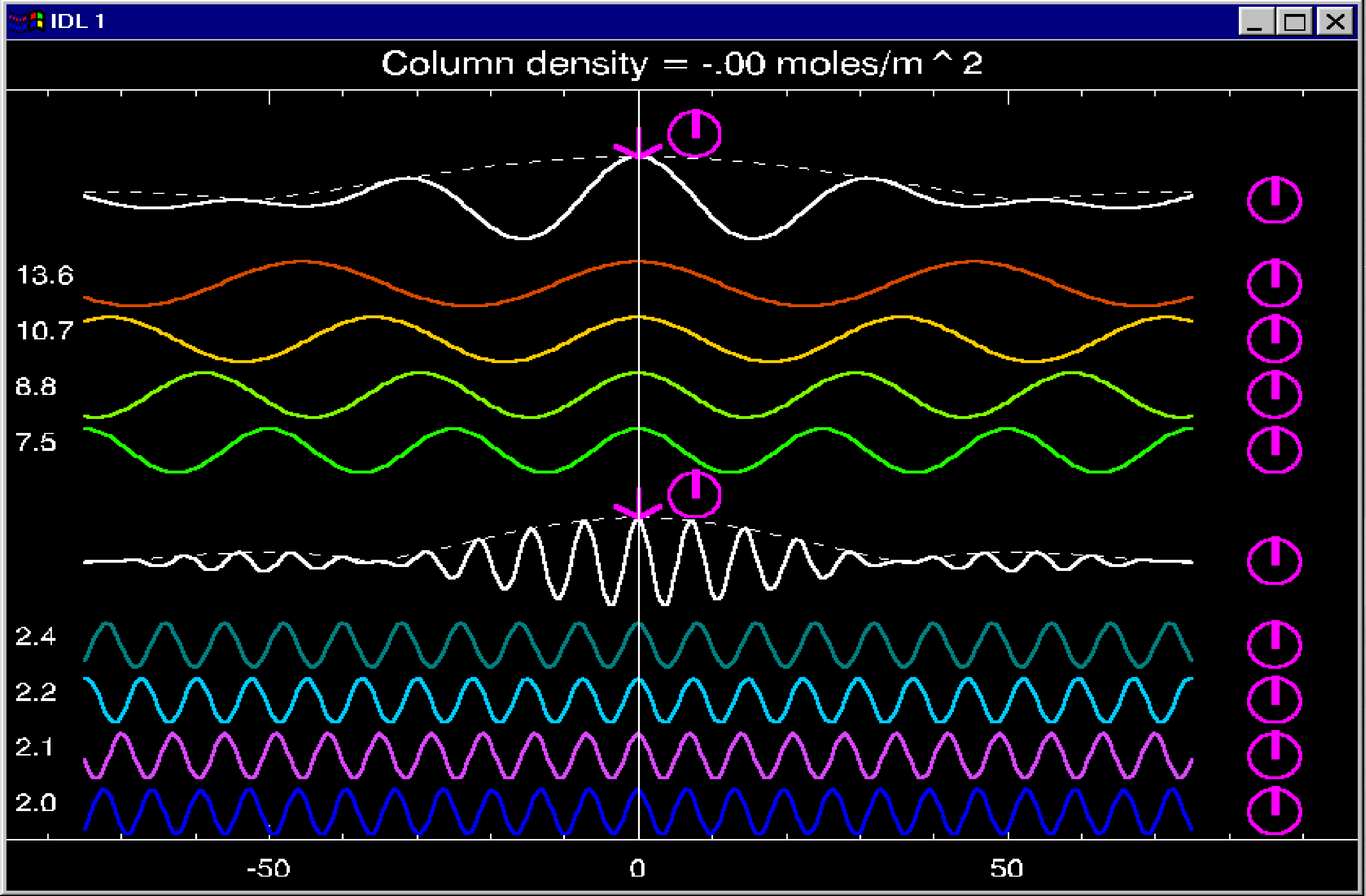
Dispersive effect between (and within) bands due to 0 – 600 mole/m^2 of additional dry air. (= 20 meter delay-line offset) (©J. Meisner)

Note that dispersion from dry air increases rapidly at short wavelengths

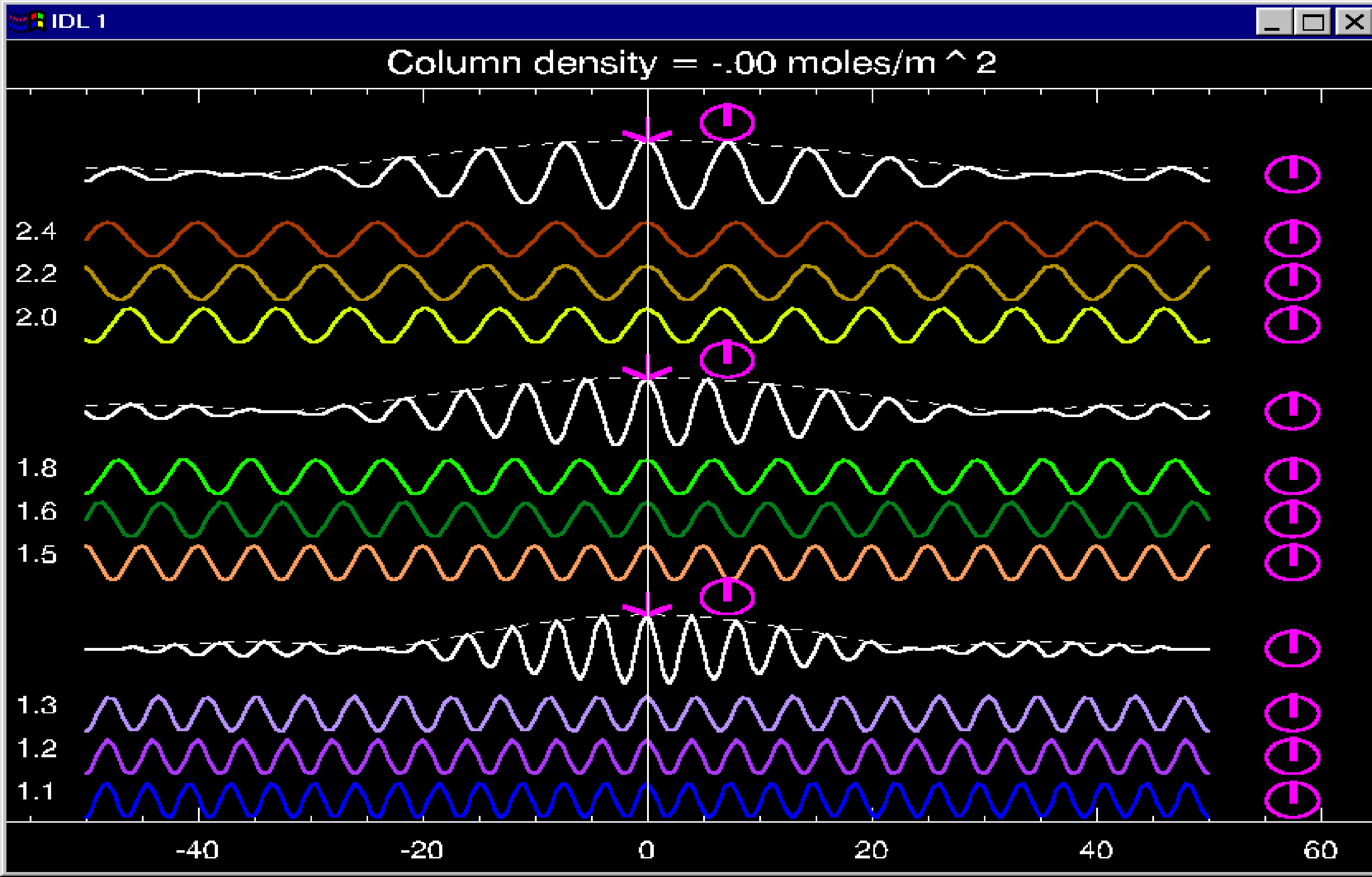


(Tracking at the group-delay in K band)

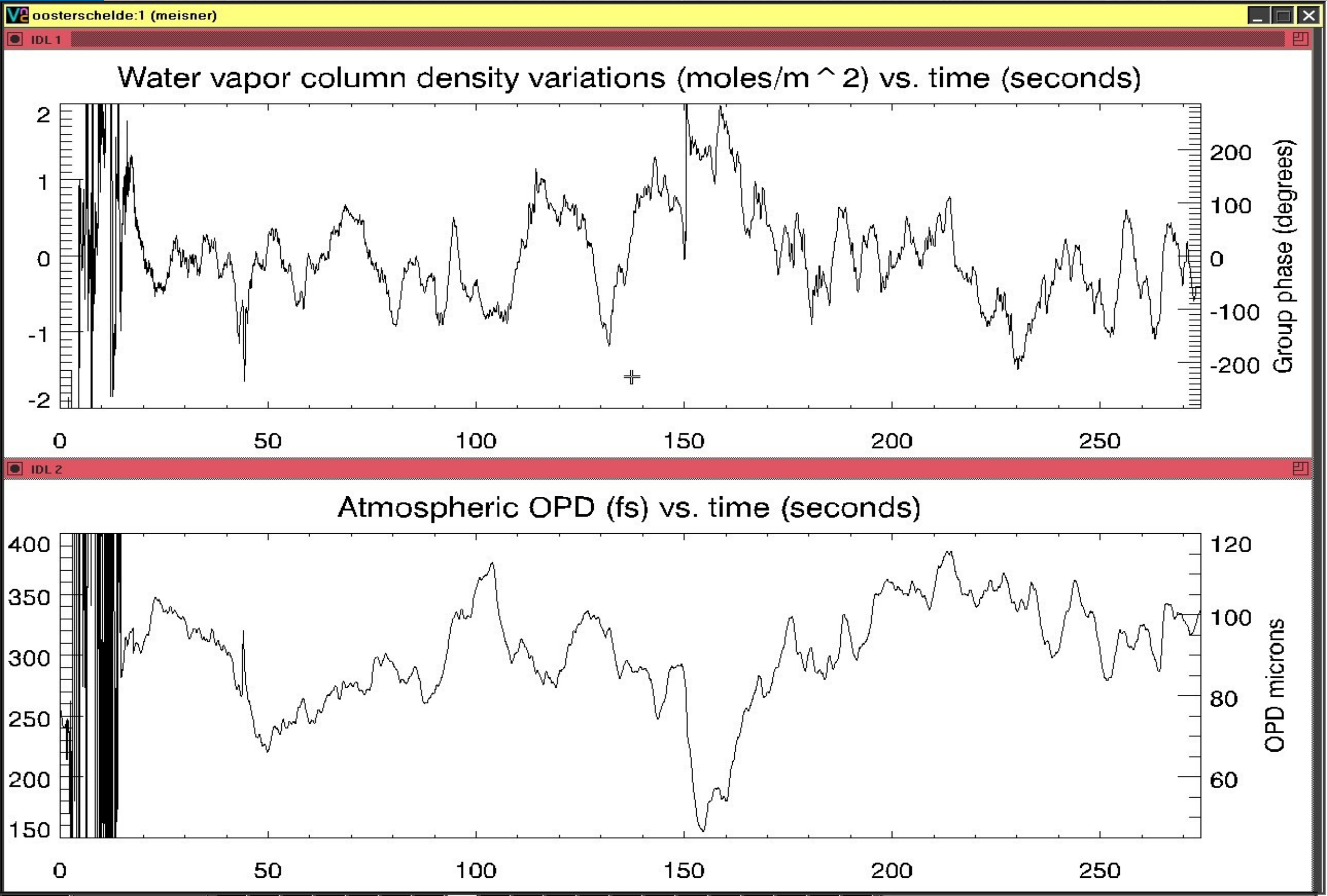
Water Vapor dispersion, with phase-tracking at K band
0 – 5 moles/m² (typical p-p value due to atmosphere) (©J. Meisner)



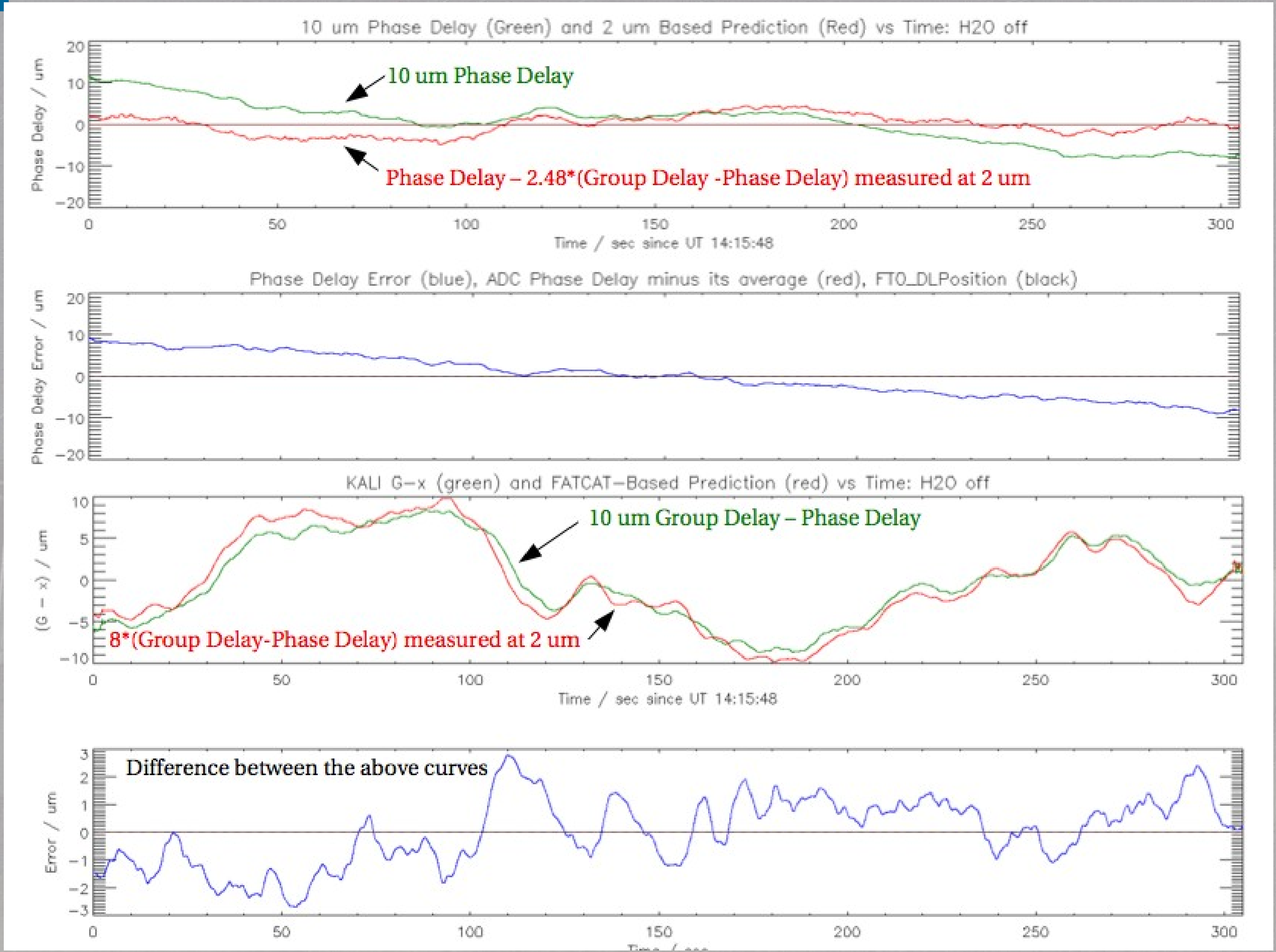
Water Vapor dispersion, with phase-tracking at K band
0 – 5 moles/m^2 (typical p-p value due to atmosphere) (©J. Meisner)

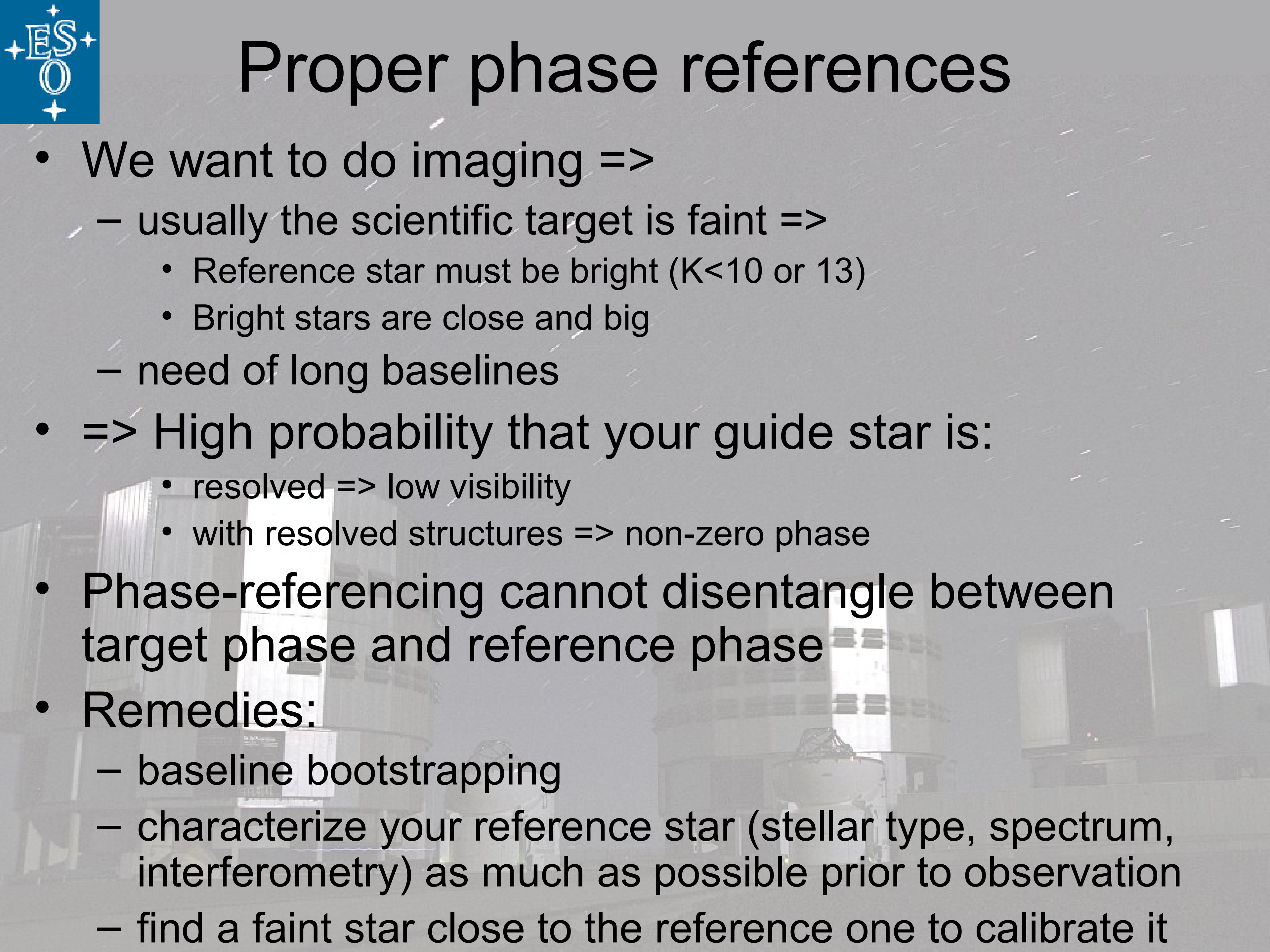


MIDI observation: OPD and water vapor (©J. Meisner)



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





Proper phase references

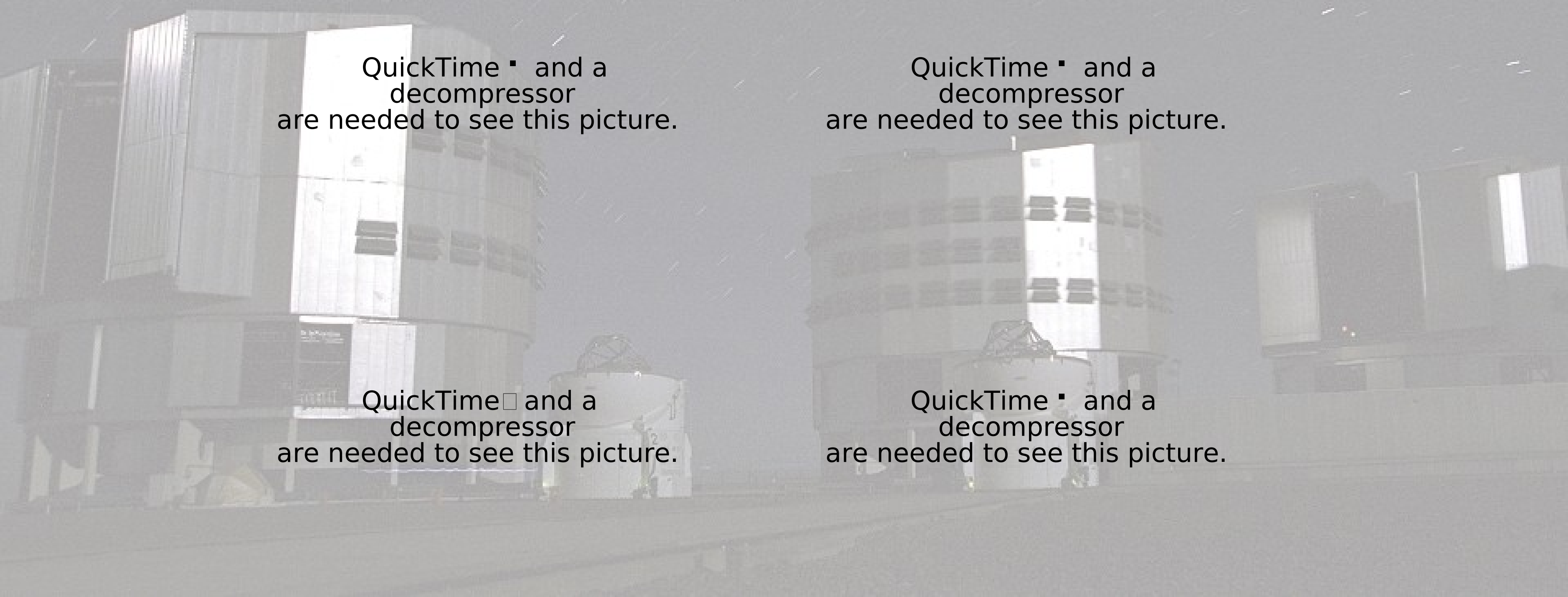
- We want to do imaging =>
  - – usually the scientific target is faint =>
    - Reference star must be bright (K<10 or 13)
    - Bright stars are close and big
  - – need of long baselines
- => High probability that your guide star is:
    - resolved => low visibility
    - with resolved structures => 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 or develop a 4-beam PRIMA
- No snap-shot image like with phase closure but better limiting magnitude

Fringe tracking problems

- 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



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

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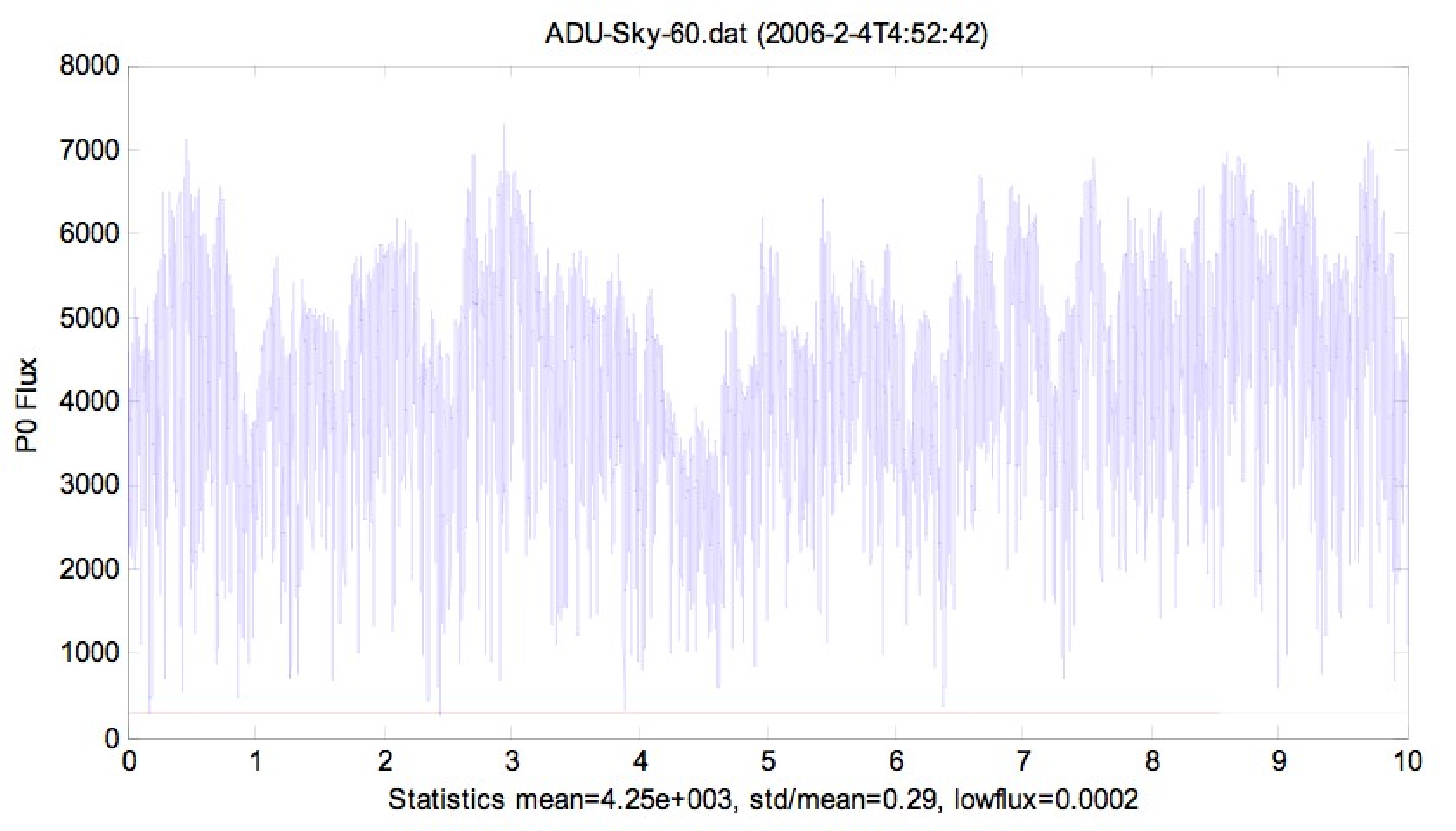
Injection stability



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

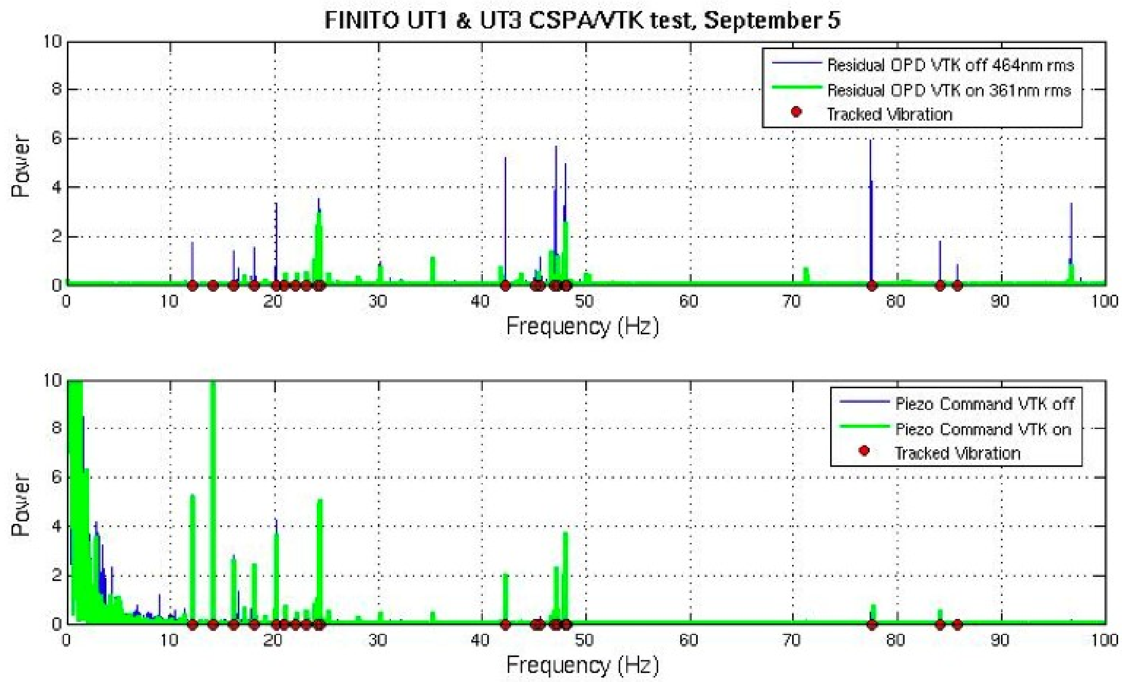
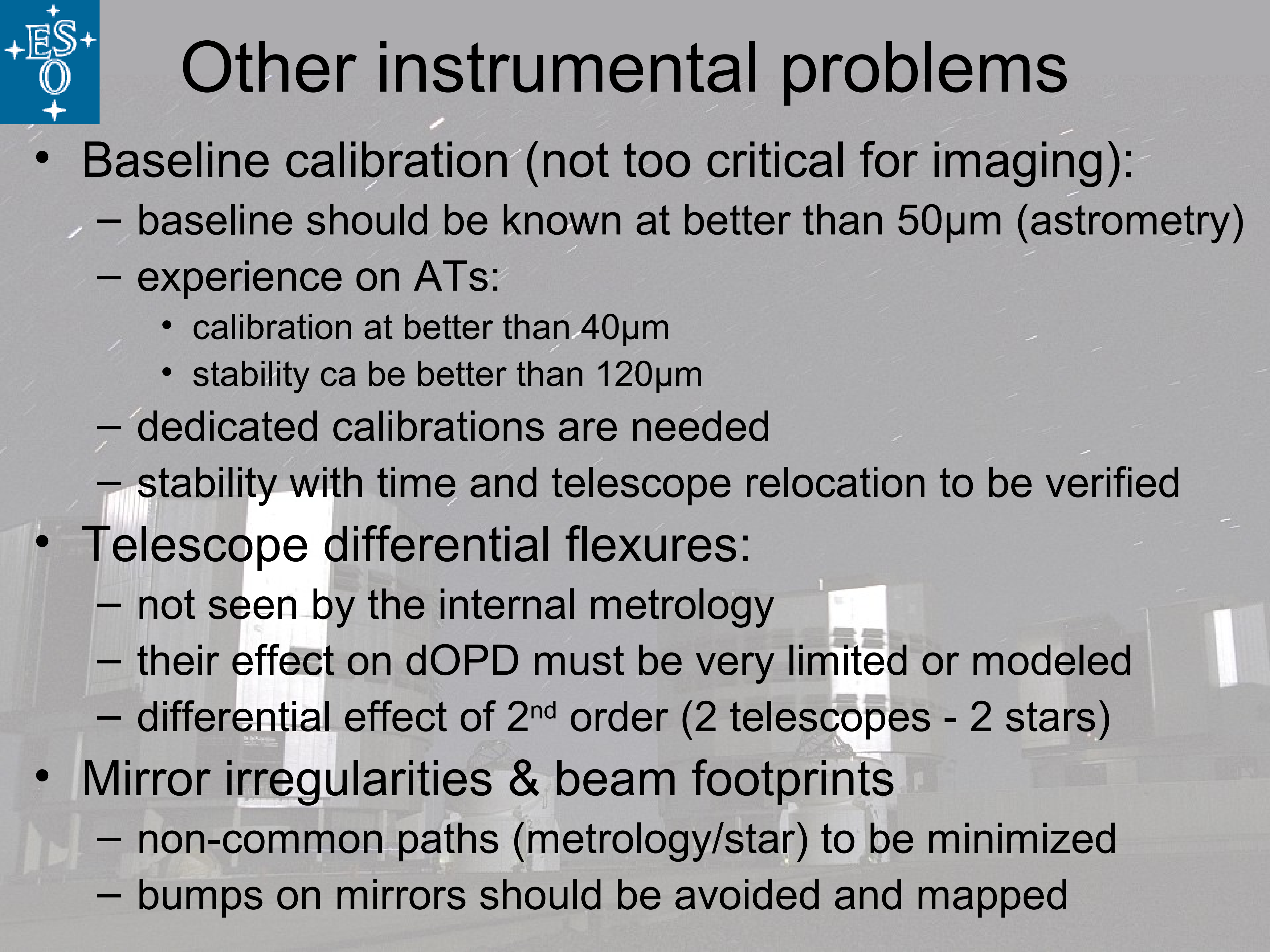


Figure 1: Phase residual (top) and DL Piezo command (bottom). Sky data obtained with UT1 and UT3, September 5th 2006. The rms residual OPD with VTK ON is 363nm, nearly 4 times above the specification.

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

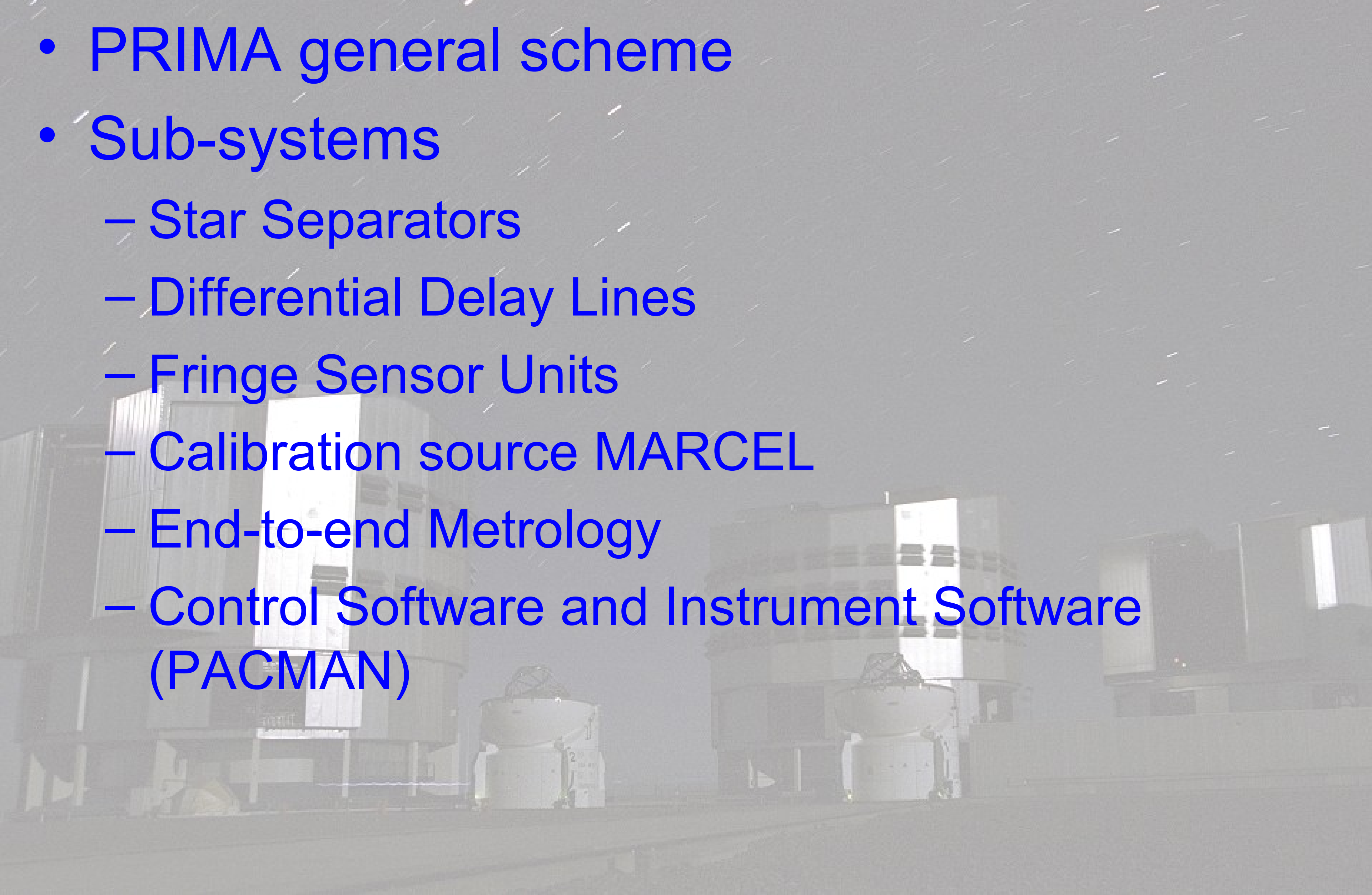


Other instrumental problems

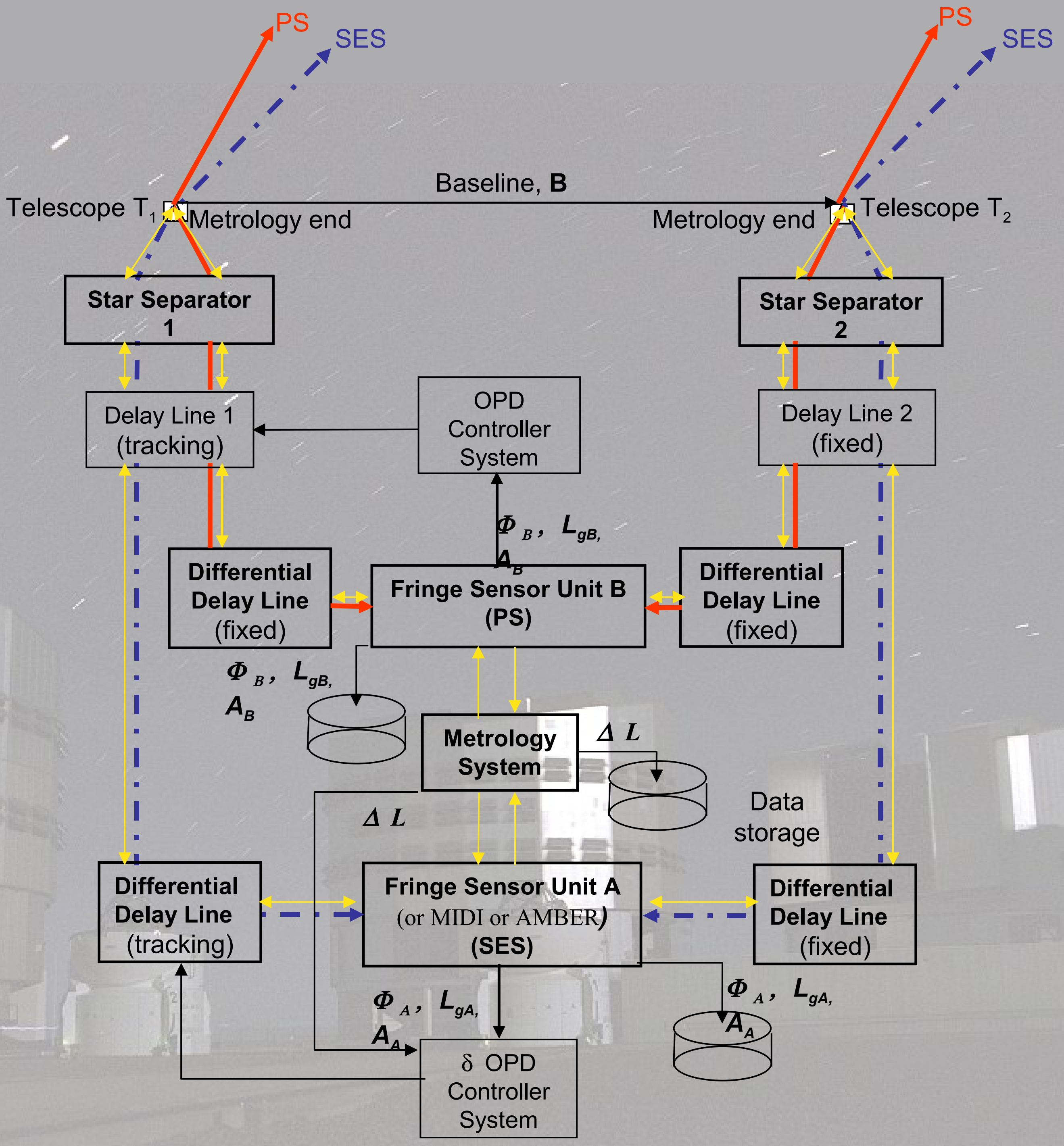
- Baseline calibration (not too critical for imaging):
  - baseline should be known at better than 50µm (astrometry)
  - experience on ATs:
    - calibration at better than 40µm
    - stability ca be better than 120µm
  - dedicated calibrations are needed
  - stability with time and telescope relocation 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)



PRIMA Scheme



PS

SES

PS

SES

Baseline, **B**

Telescope T_1

Metrology end

Metrology end

Telescope T_2

Star Separator 1

Star Separator 2

Delay Line 1 (tracking)

OPD Controller System

Delay Line 2 (fixed)

Φ_B, L_{gB}, A_B

Differential Delay Line (fixed)

Fringe Sensor Unit B (PS)

Differential Delay Line (fixed)

Φ_B, L_{gB}, A_B

Metrology System

ΔL

Data storage

ΔL

Differential Delay Line (tracking)

Fringe Sensor Unit A (or MIDI or AMBER) **(SES)**

Differential Delay Line (fixed)

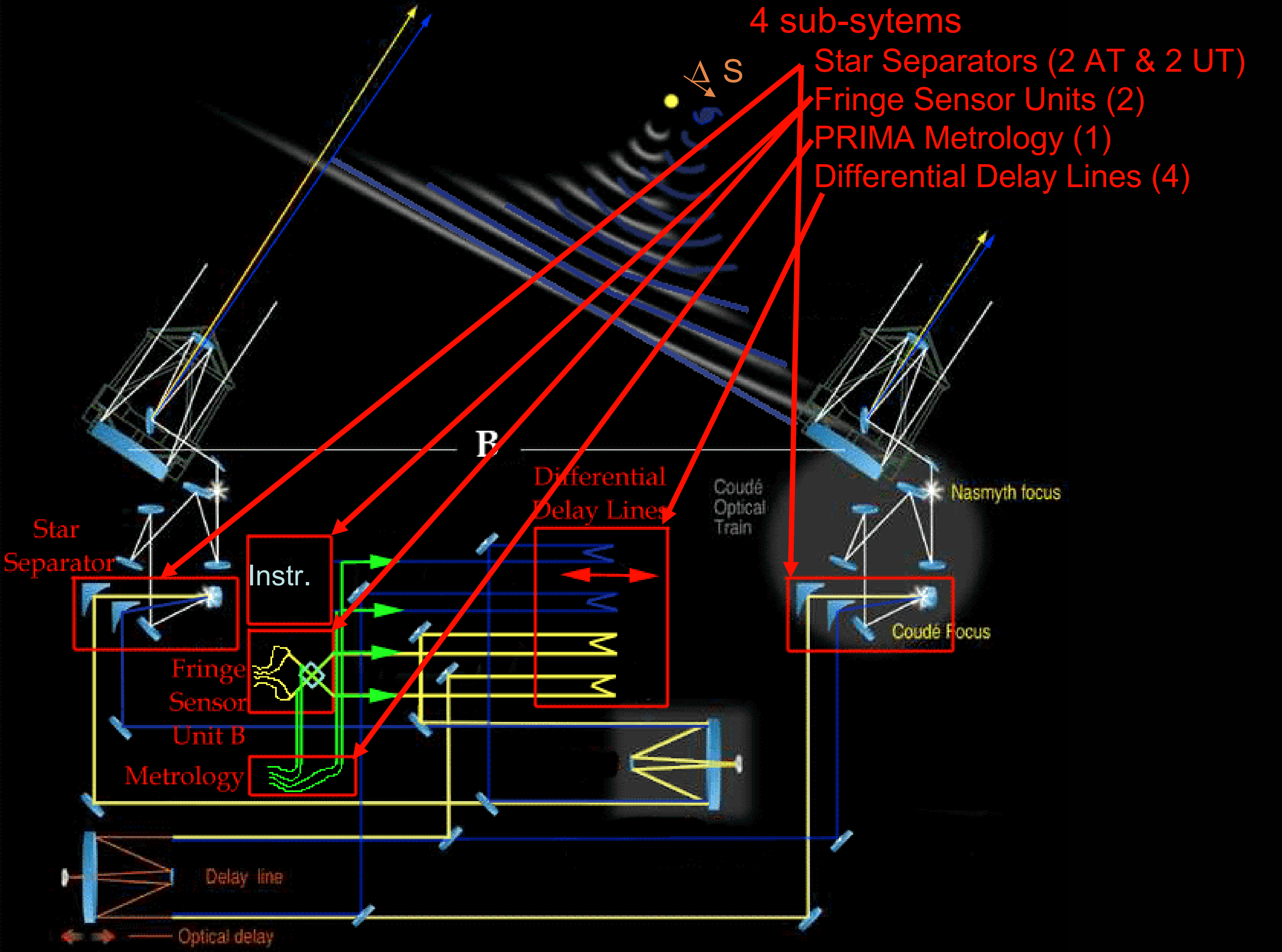
Φ_A, L_{gA}, A_A

Φ_A, L_{gA}, A_A

δ OPD Controller System

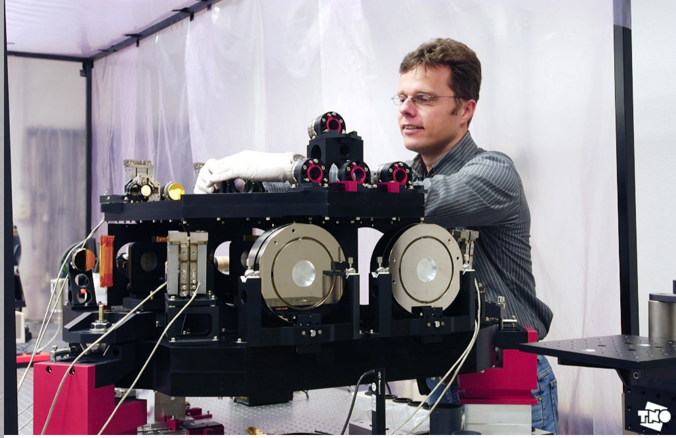
4 sub-sytems

- 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)



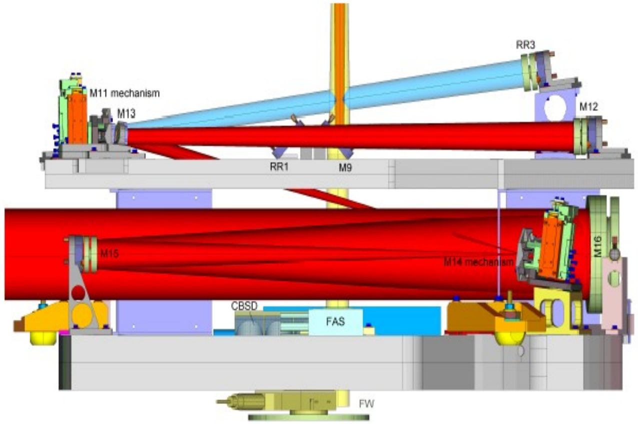


figure 9: Side view on STS

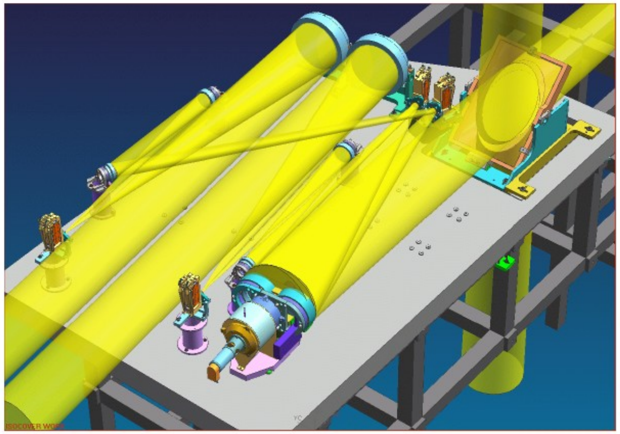


figure 1: Overview of STS-UT system

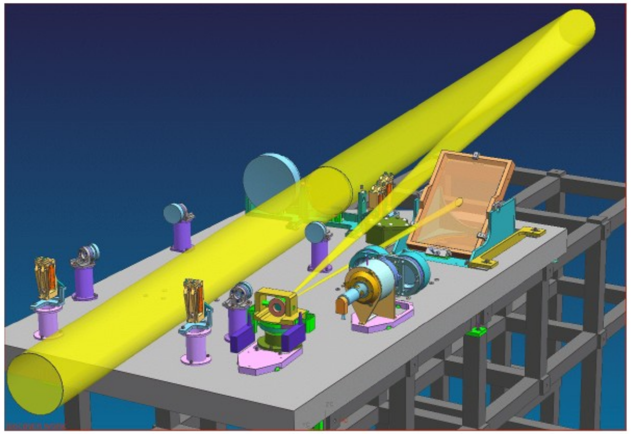


figure 2: Alternative optical configuration for STS-UT

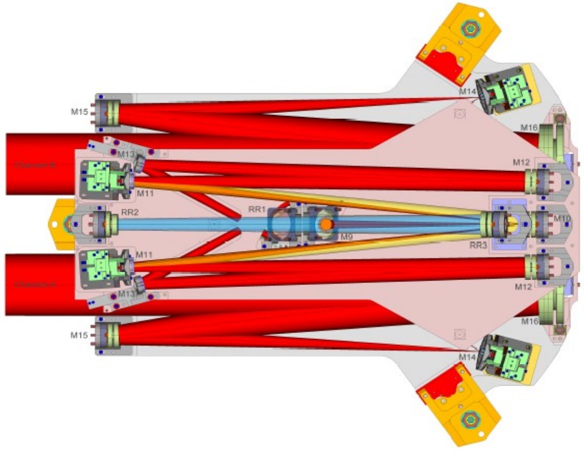
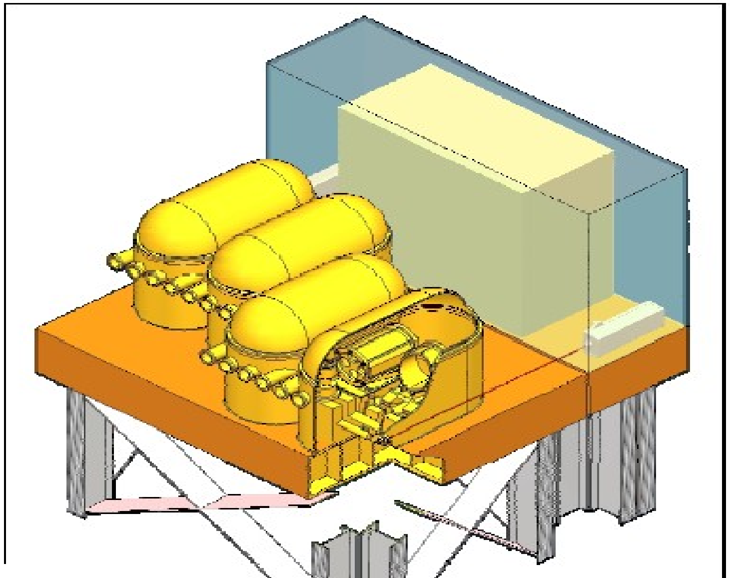
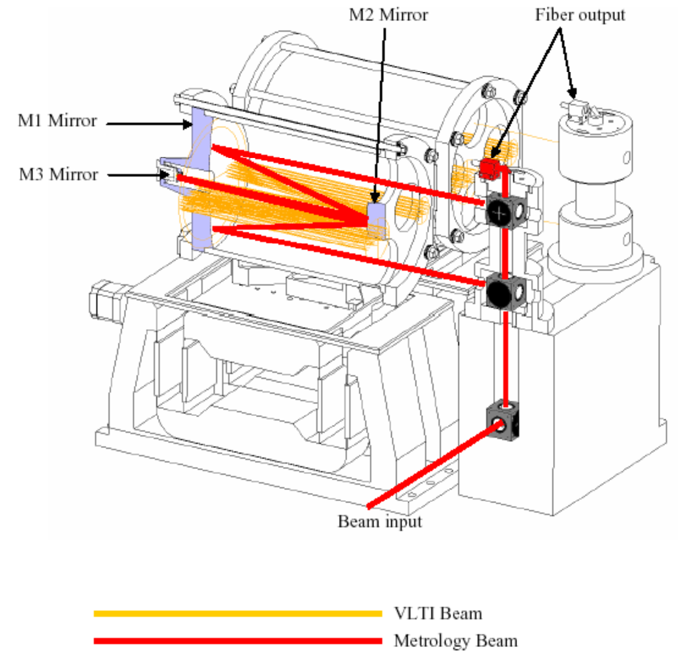


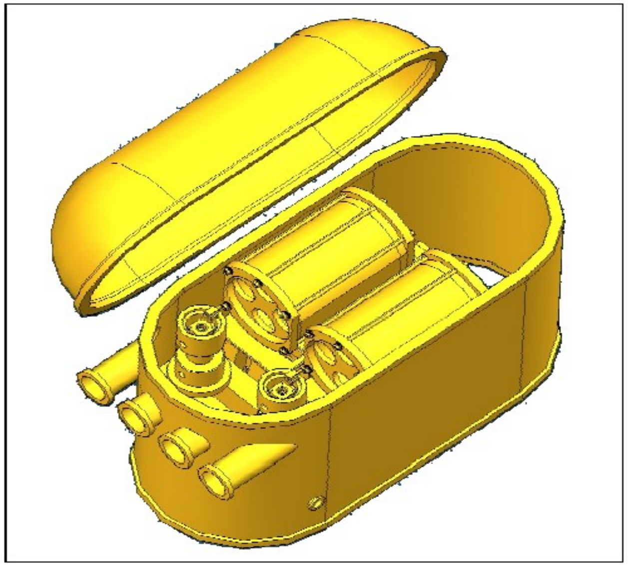
figure 8: Top view on STS

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

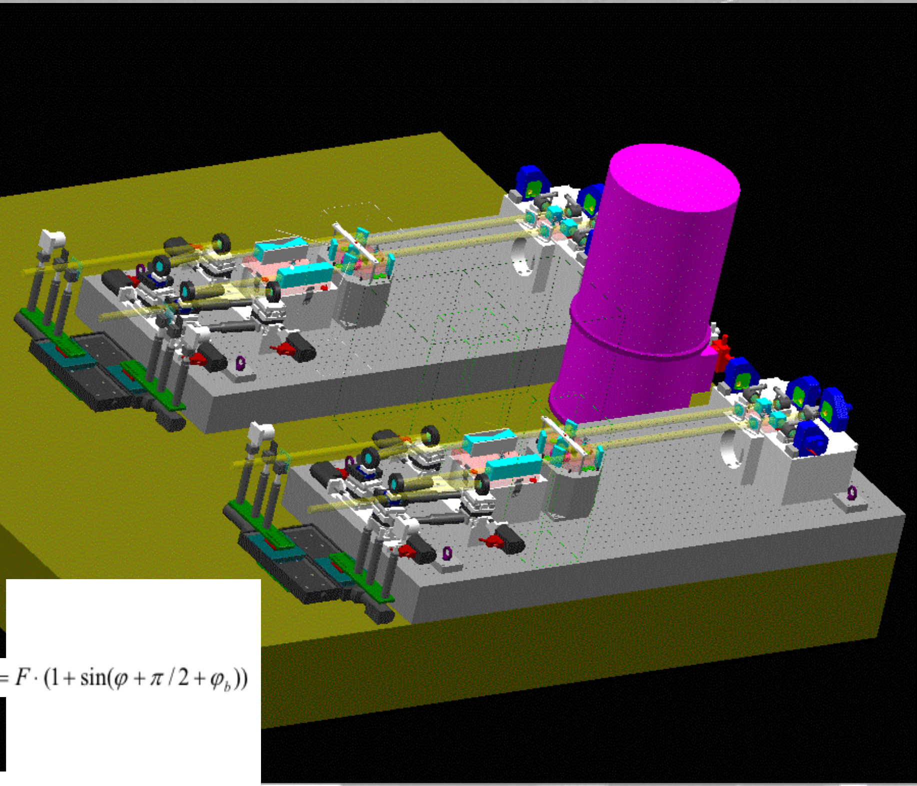


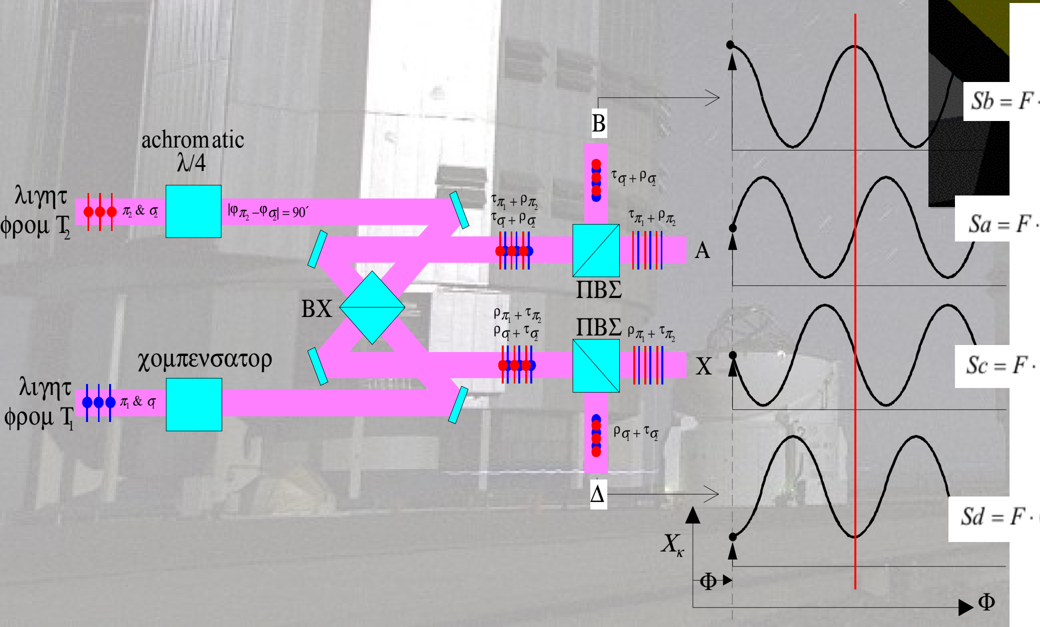




Fringe Sensor Units

- 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





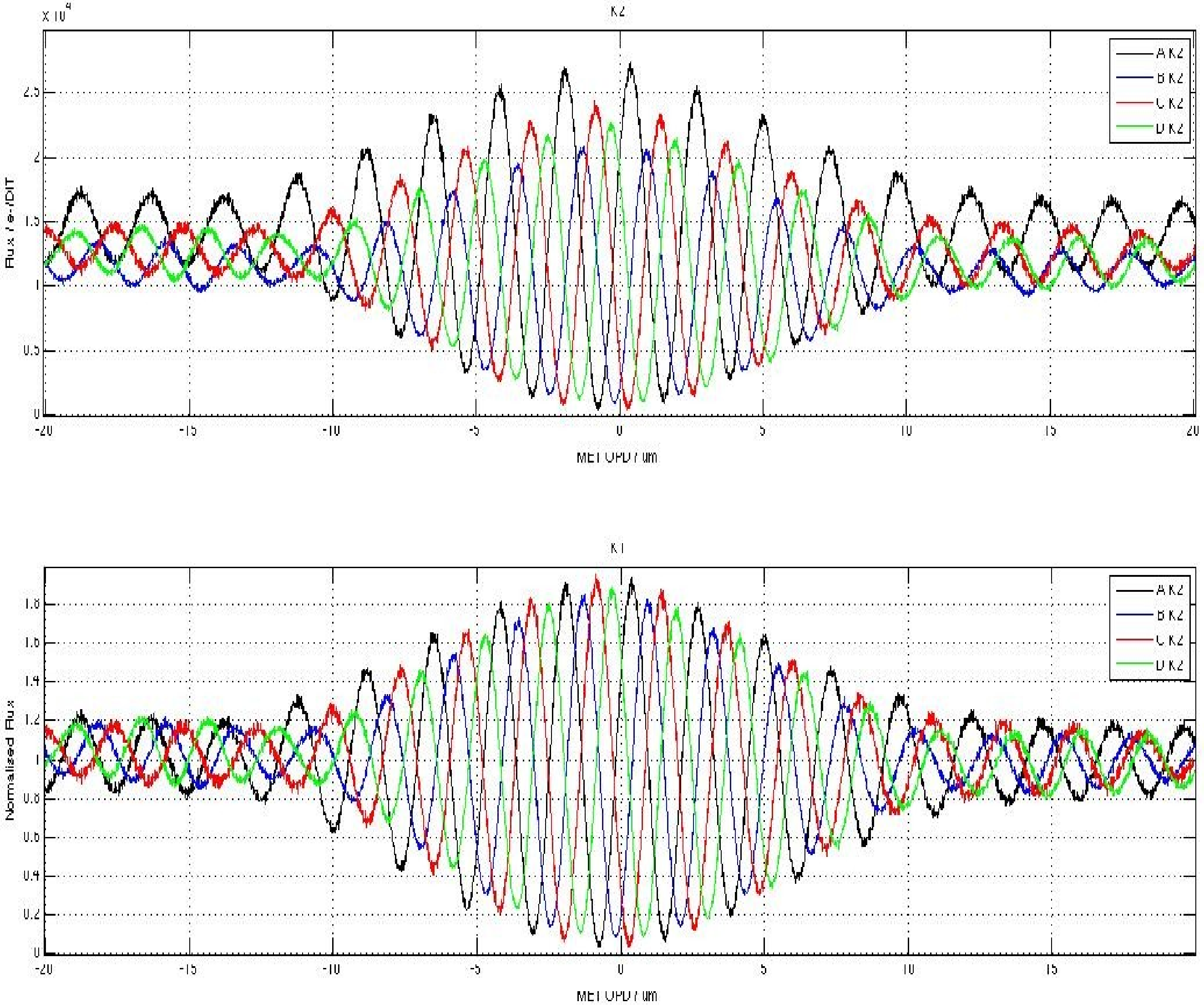
$Sb = F \cdot (1 + \sin(\varphi + \pi/2 + \varphi_b))$

$Sa = F \cdot (1 + \sin(\varphi))$

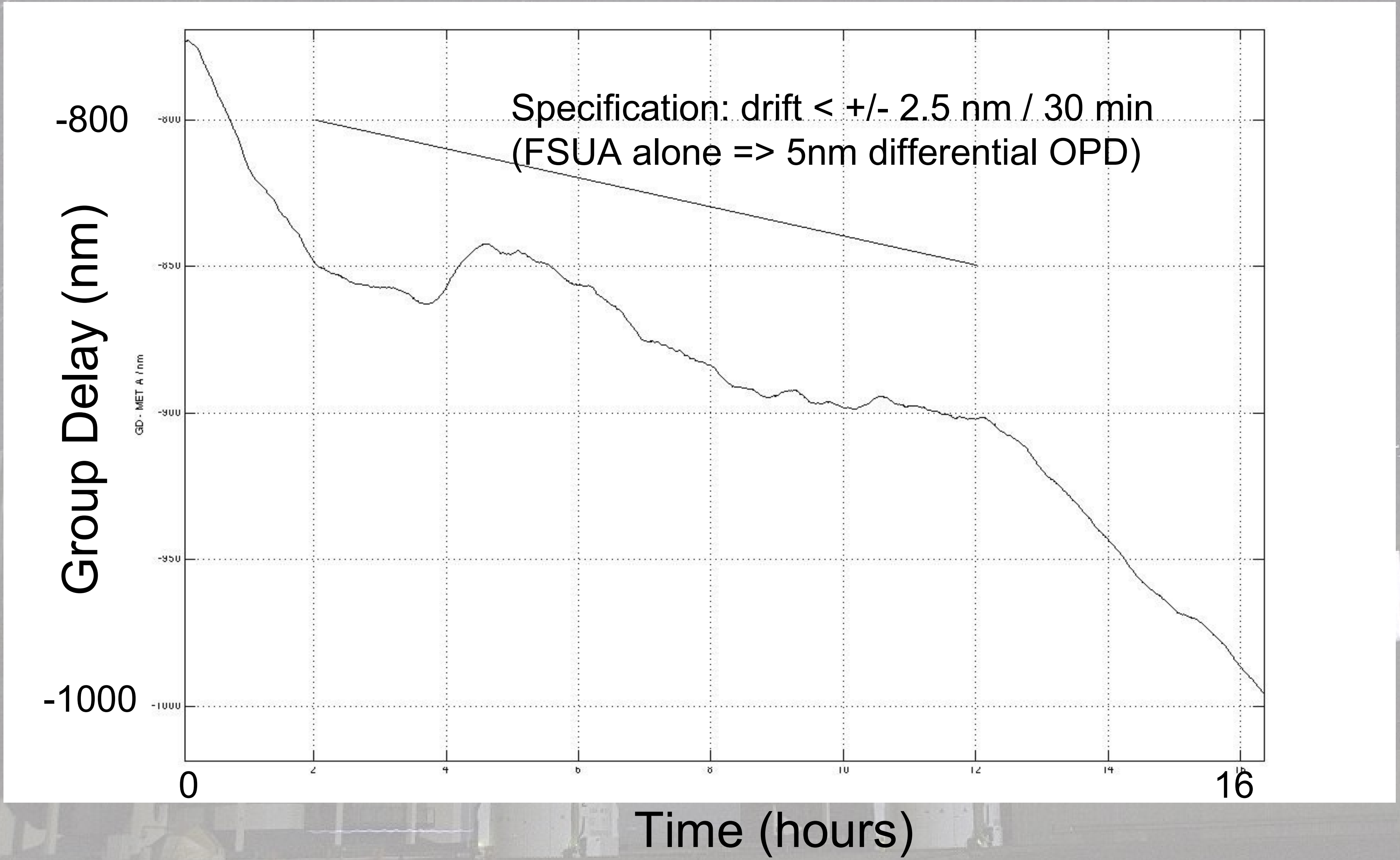
$Sc = F \cdot (1 + \sin(\varphi + \pi + \varphi_c))$

$Sd = F \cdot (1 + \sin(\varphi + 3\pi/2 + \varphi_d))$

FSU calibration

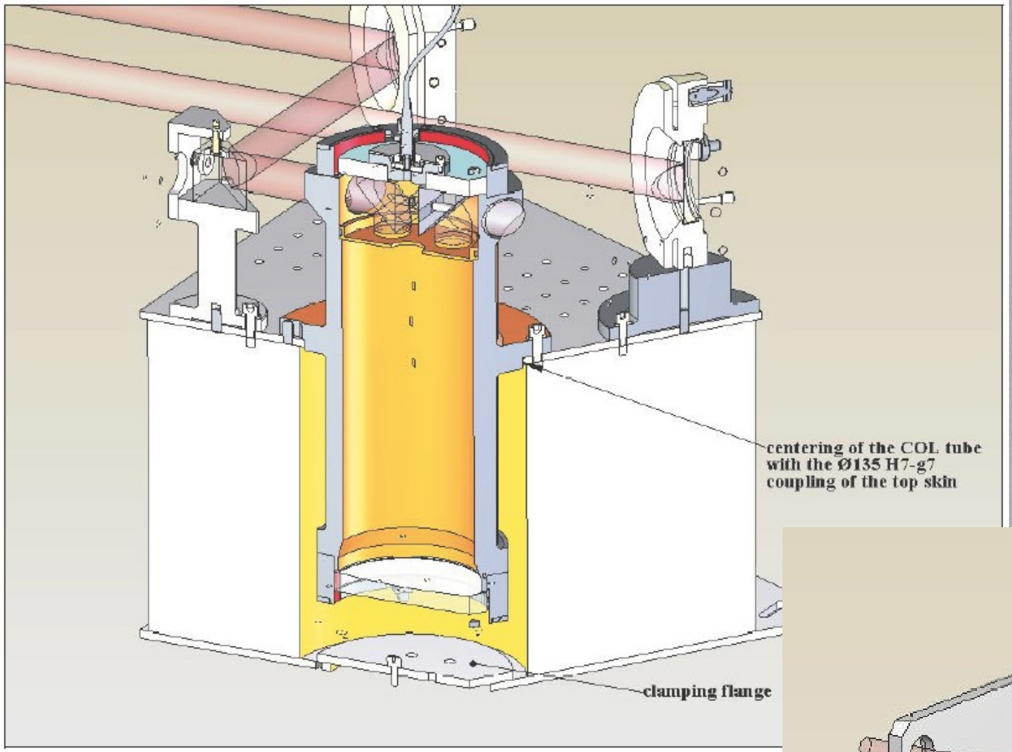


Group delay over 16 hours

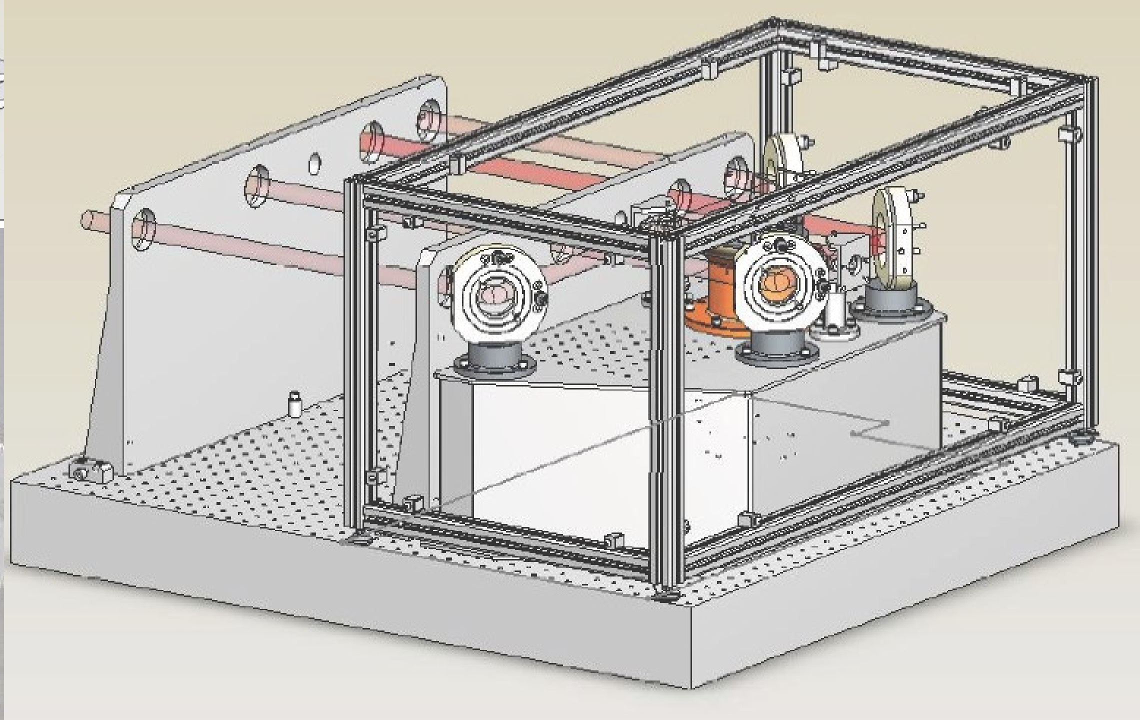


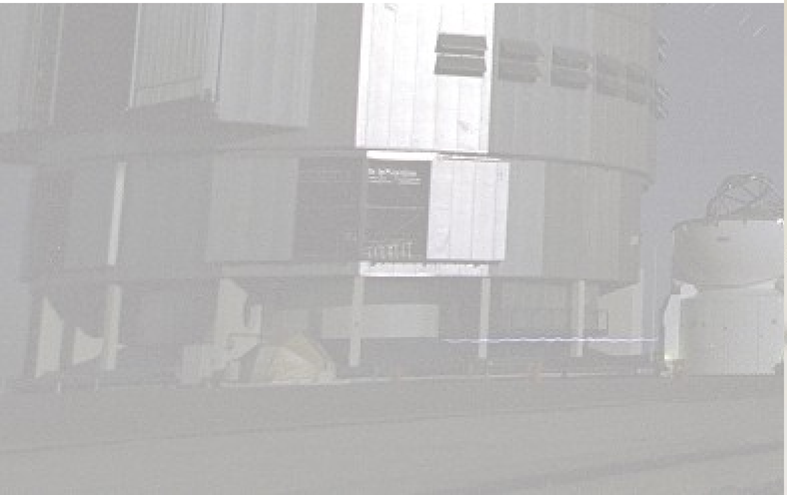
Specification: drift < +/- 2.5 nm / 30 min
(FSUA alone => 5nm differential OPD)

MARCEL = calibration source



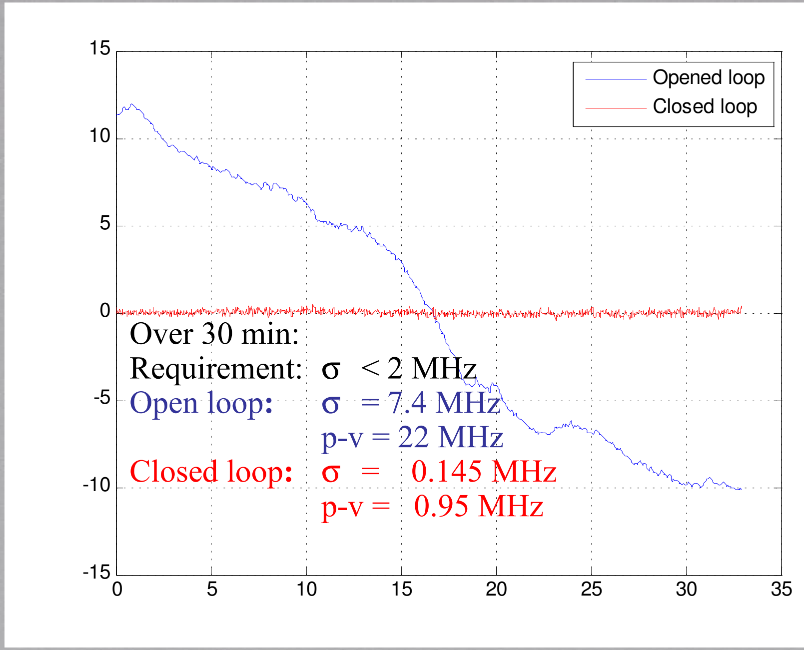
- 4 coherent beams
(2 telescopes -2 stars)
- black body source with controlled temperature
- retro-reflectors for metrology
- very stable



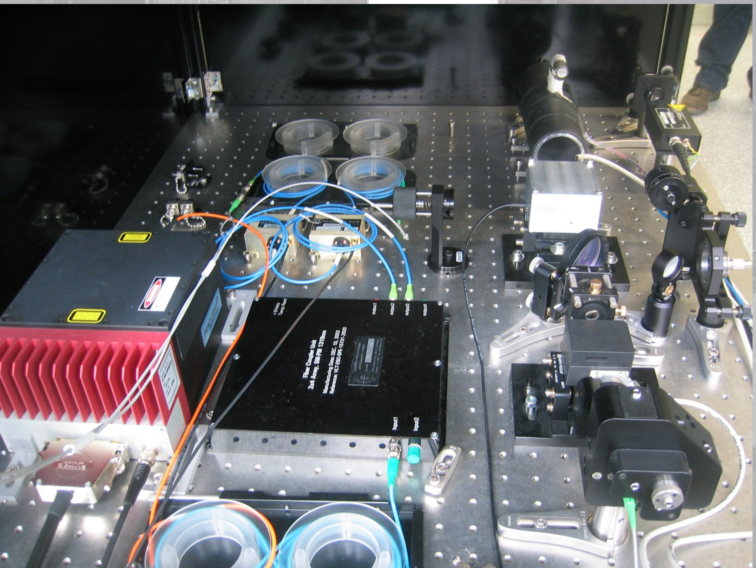


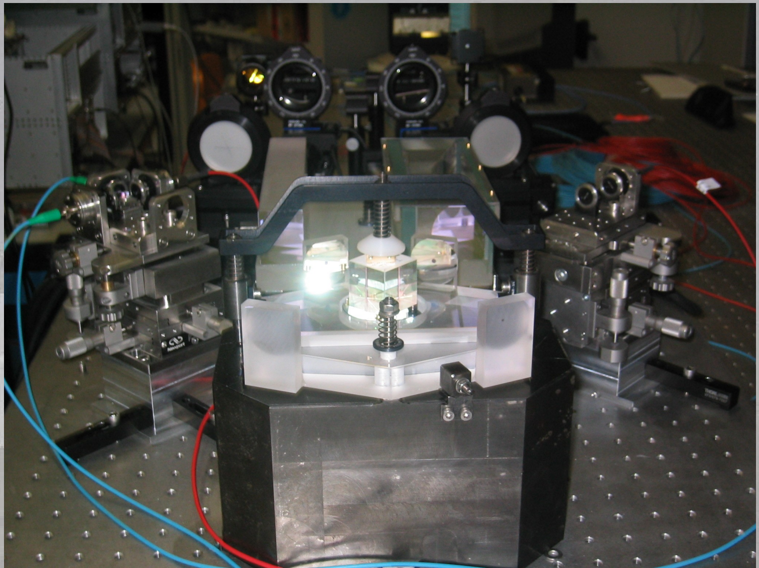
PRIMA Metrology

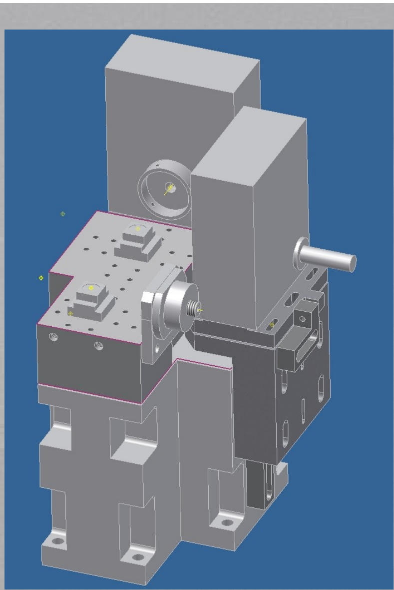
- Super-heterodyne incremental metrology (λ =1.3μm)
- Propagation in the central obstruction, from the instrument to the STS (Retro-reflection behind M9)
- Output measurement (dOPD **and** OPD on one of the stars) written on reflective memory for the OPD/dOPD controller
- Laser frequency stabilization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



Over 30 min:
Requirement: σ < 2 MHz
Open loop: σ = 7.4 MHz
p-v = 22 MHz
Closed loop: σ = 0.145 MHz
p-v = 0.95 MHz



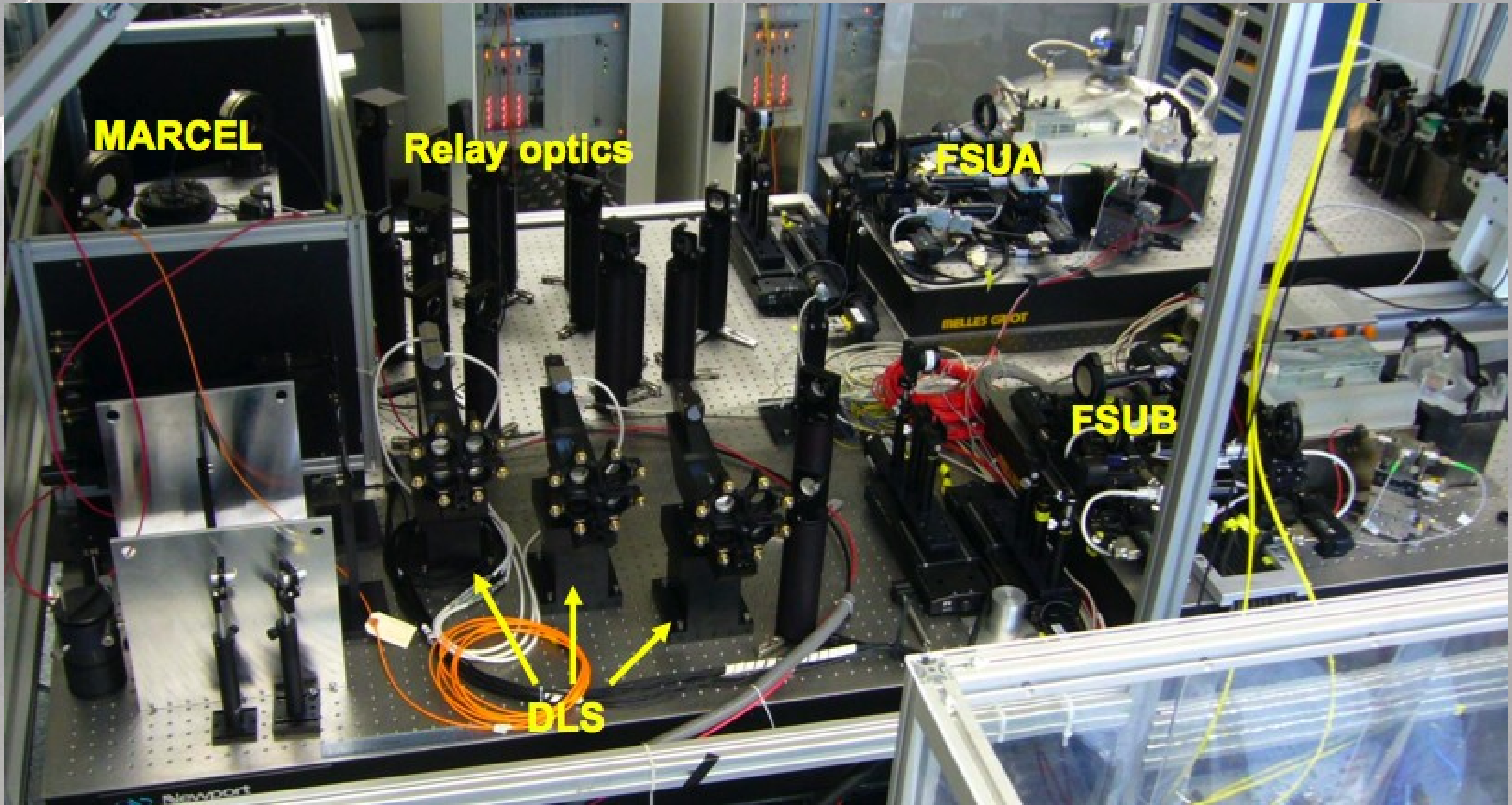




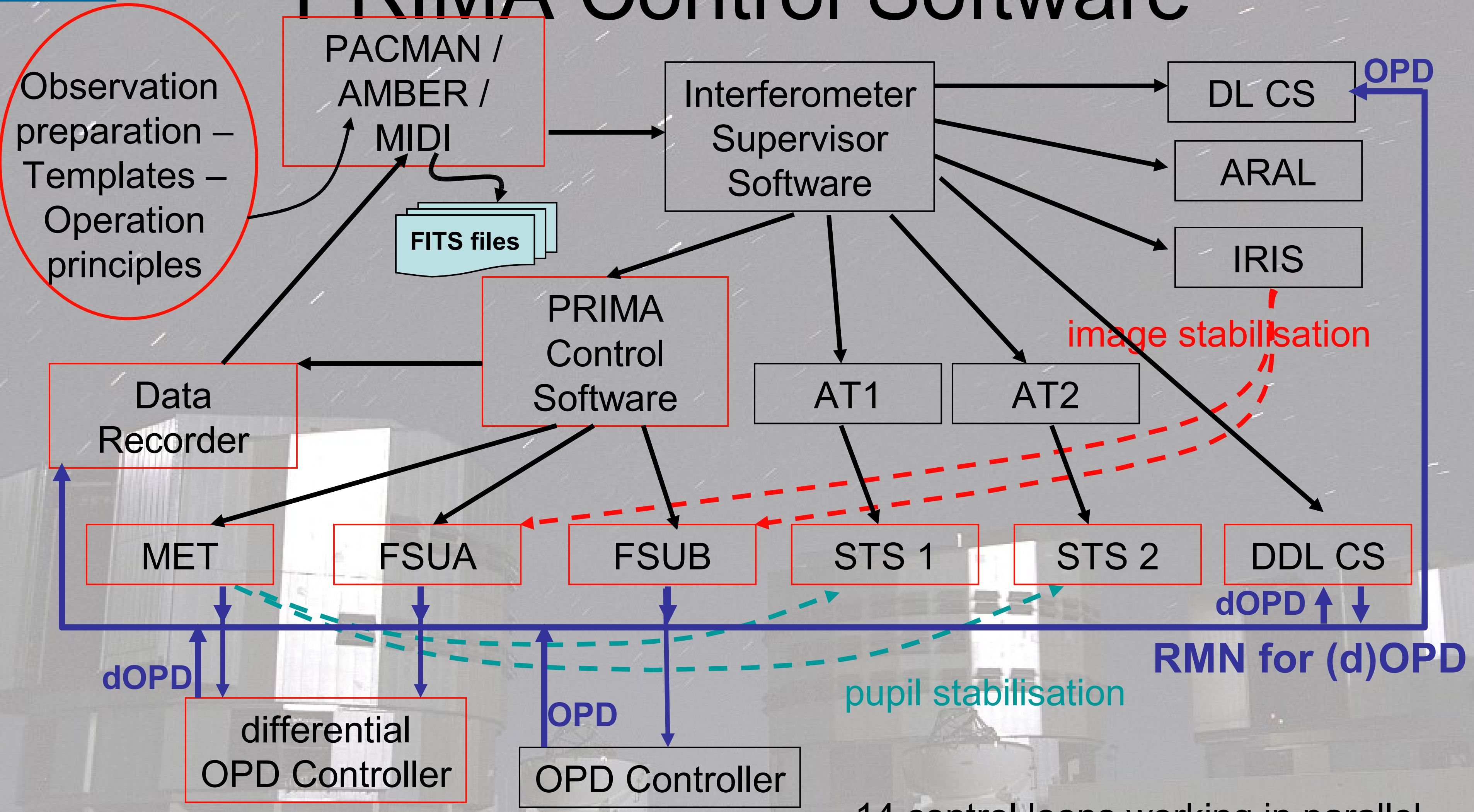
PRIMA testbed

- 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



PRIMA Control Software



Observation preparation – Templates – Operation principles

PACMAN / AMBER / MIDI

FITS files

Interferometer Supervisor Software

DL CS

ARAL

IRIS

OPD

PRIMA Control Software

Data Recorder

AT1

AT2

image stabilisation

MET

FSUA

FSUB

STS 1

STS 2

DDL CS

dOPD

RMN for (d)OPD

pupil stabilisation

dOPD

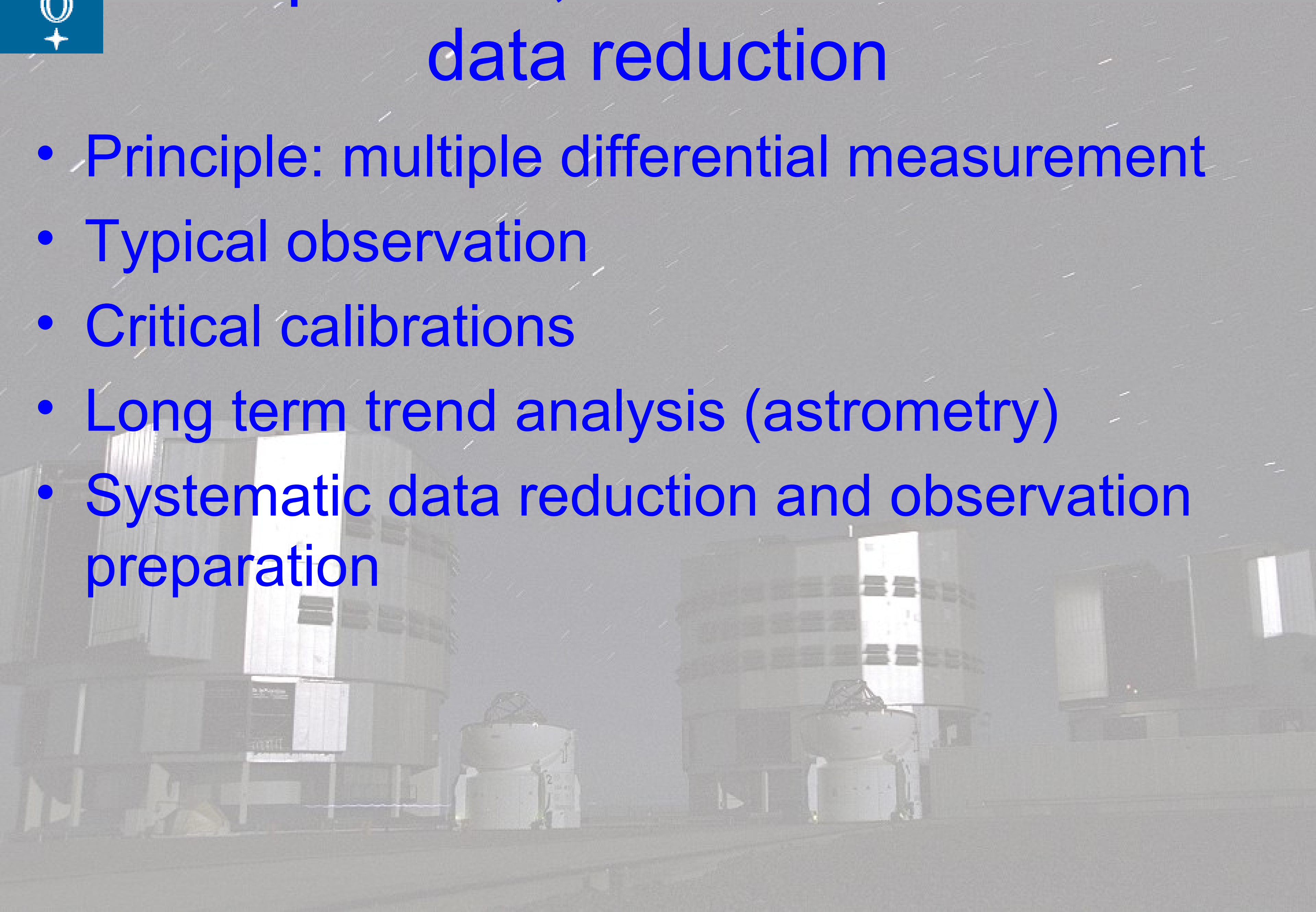
OPD

differential OPD Controller

OPD Controller

14 control loops working in parallel

Operation, calibration and data reduction

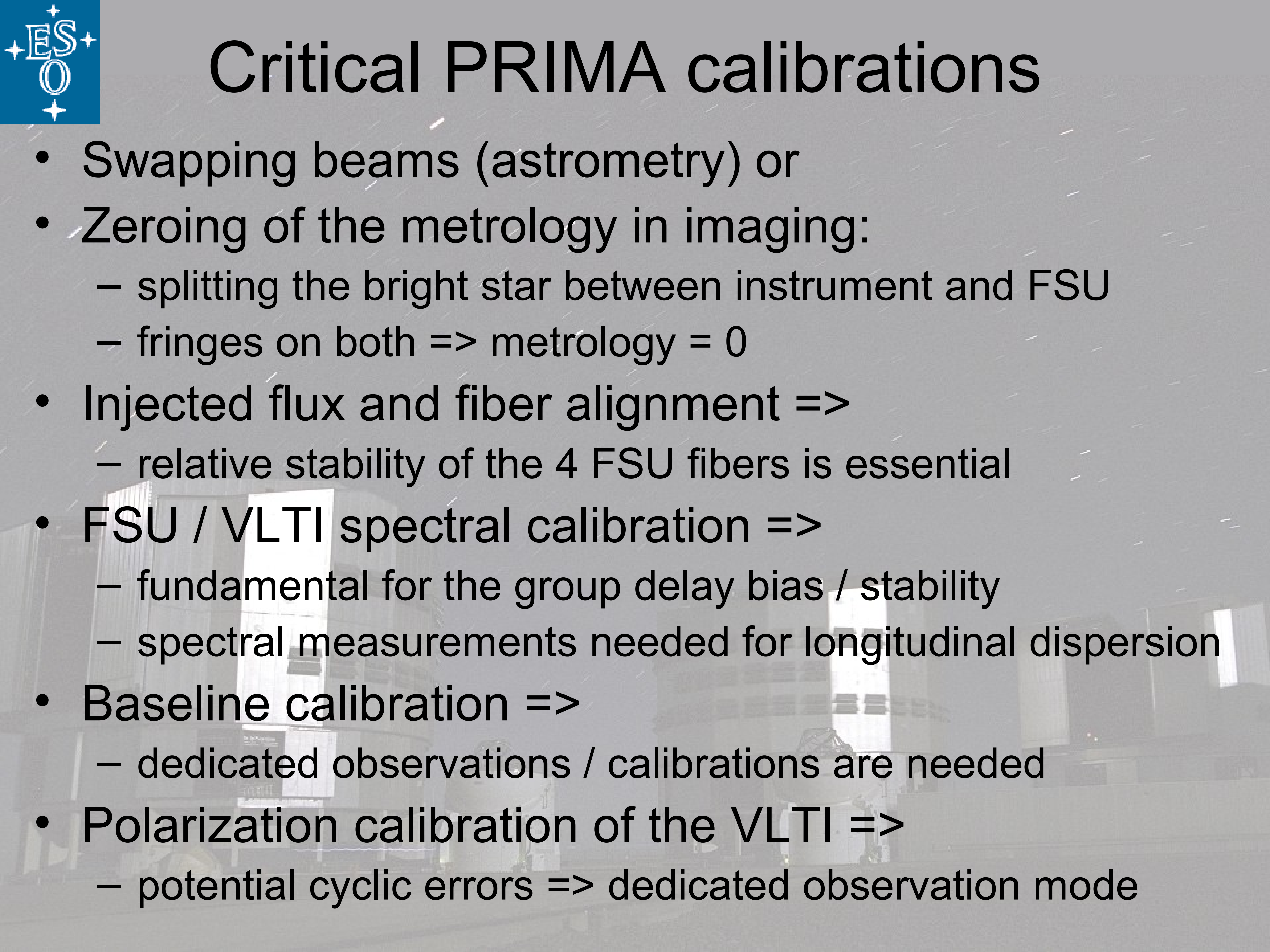


- Principle: multiple differential measurement
- Typical observation
- Critical calibrations
- Long term trend analysis (astrometry)
- Systematic data reduction and observation preparation

Multiple differences

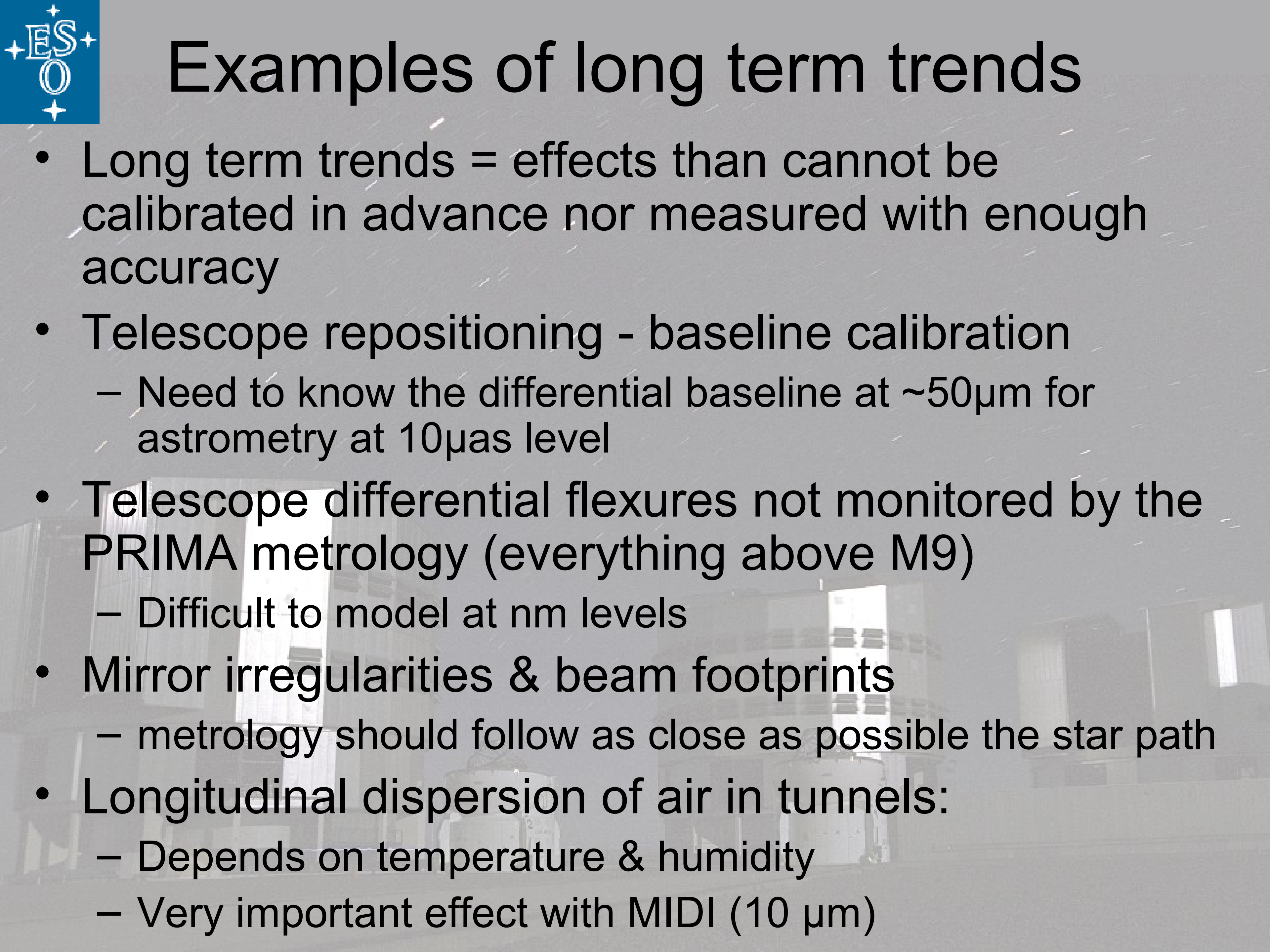
- PRIMA = multiple difference
  - 2 telescopes, 2 stars, metrology/star λ , 2 moments in time
- Very differents scales:
  - 500m (metrology path) =>
  - 120m OPD =>
  - ~1cm dOPD =>
  - ~100nm fringe stabilization =>
  - 5nm measurement accuracy => 10^{-11} ratio to propagation length
- PRIMA challenges:
  - 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) or
- Zeroing of the metrology in imaging:
  - splitting the bright star between instrument and FSU
  - fringes on both => metrology = 0
- Injected flux and fiber alignment =>
  - relative stability of the 4 FSU fibers is essential
- FSU / VLTI spectral calibration =>
  - fundamental for the group delay bias / stability
  - spectral measurements needed for longitudinal dispersion
- Baseline calibration =>
  - dedicated observations / calibrations are needed
- Polarization calibration of the VLTI =>
  - potential cyclic errors => dedicated observation mode

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 (everything above M9)
  - Difficult to model at nm levels
- Mirror irregularities & beam footprints
  - metrology should follow as close as possible the star path
- Longitudinal dispersion of air in tunnels:
  - Depends on temperature & humidity
  - Very important effect with MIDI (10 μm)

Data Reduction Software and Analysis Facility

PAOS Consortium

- Pipeline
  - Correction of detector effects + data compression
  - Gives an approximate Δ OPD
- "Morning-after" off-line processing
  - Correction of daily effects (dispersion) using an "old" *calibration matrix*
  - Narrow-baseline calibration
  - Gives a better Δ OPD 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 (astrometry)
- 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 !