The VLTI and its Subsystems

EuroWinter School

Observing with the Very Large Telescope Interferometer

Les Houches, France
February 3-8, 2002

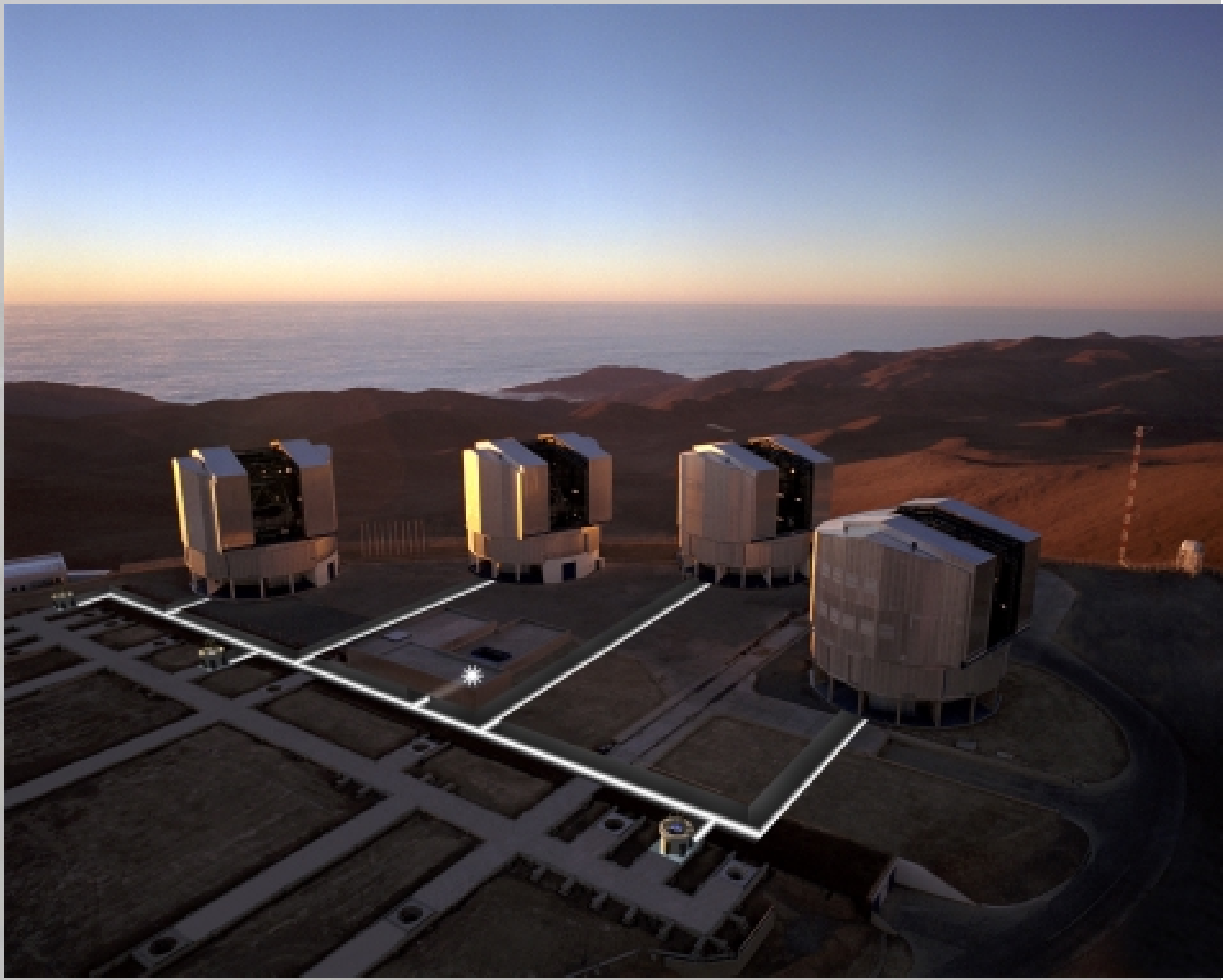
Andreas Glindemann
European Southern Observatory
February 6, 2002

Outline

1. Layout of the VLTI
2. VINCI
3. First Fringes
4. Performance
5. Adaptive Optics and Fringe Tracking
6. Scientific Instruments
7. Going faint - PRIMA
8. Call for Proposals - Performance

The VLT Interferometer

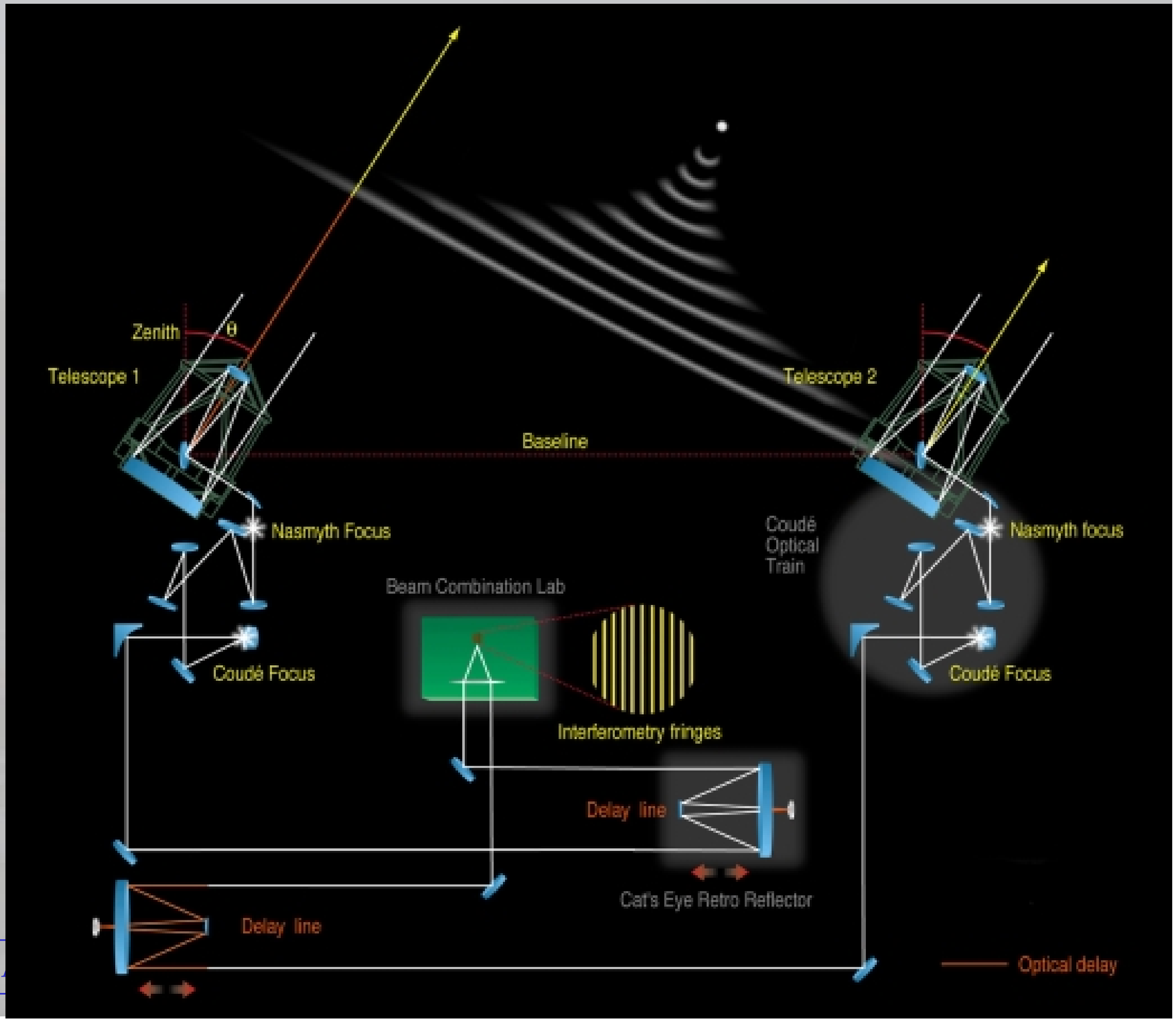
- Four 8-m Unit Telescopes
  Max. Baseline 130m
- Three 1.8-m Auxiliary Telescopes
  Baselines 8 – 200m
- Near IR to MIR (angular resolution 1-20 milli arcsec)
- Dual Feed Facility
- Excellent uv coverage



Optical Layout and Sub-systems

- Field of view in Coudé focus: 2 arcmin
- Field of view in VLTI lab: 2 arcsec
- Fringe Tracker
- Adaptive optics with 60 actuator DM

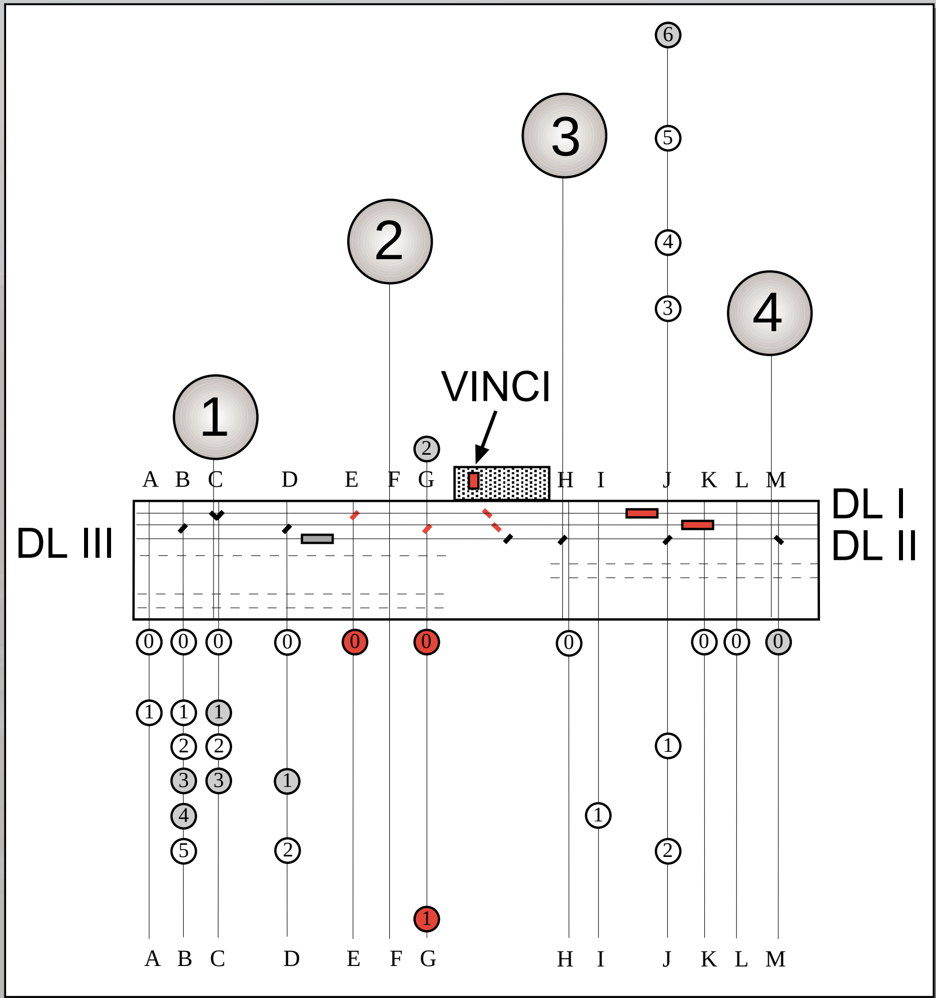
Strehl >50% in K
Guide Star $m_V < 16$



Delay Line Tunnel

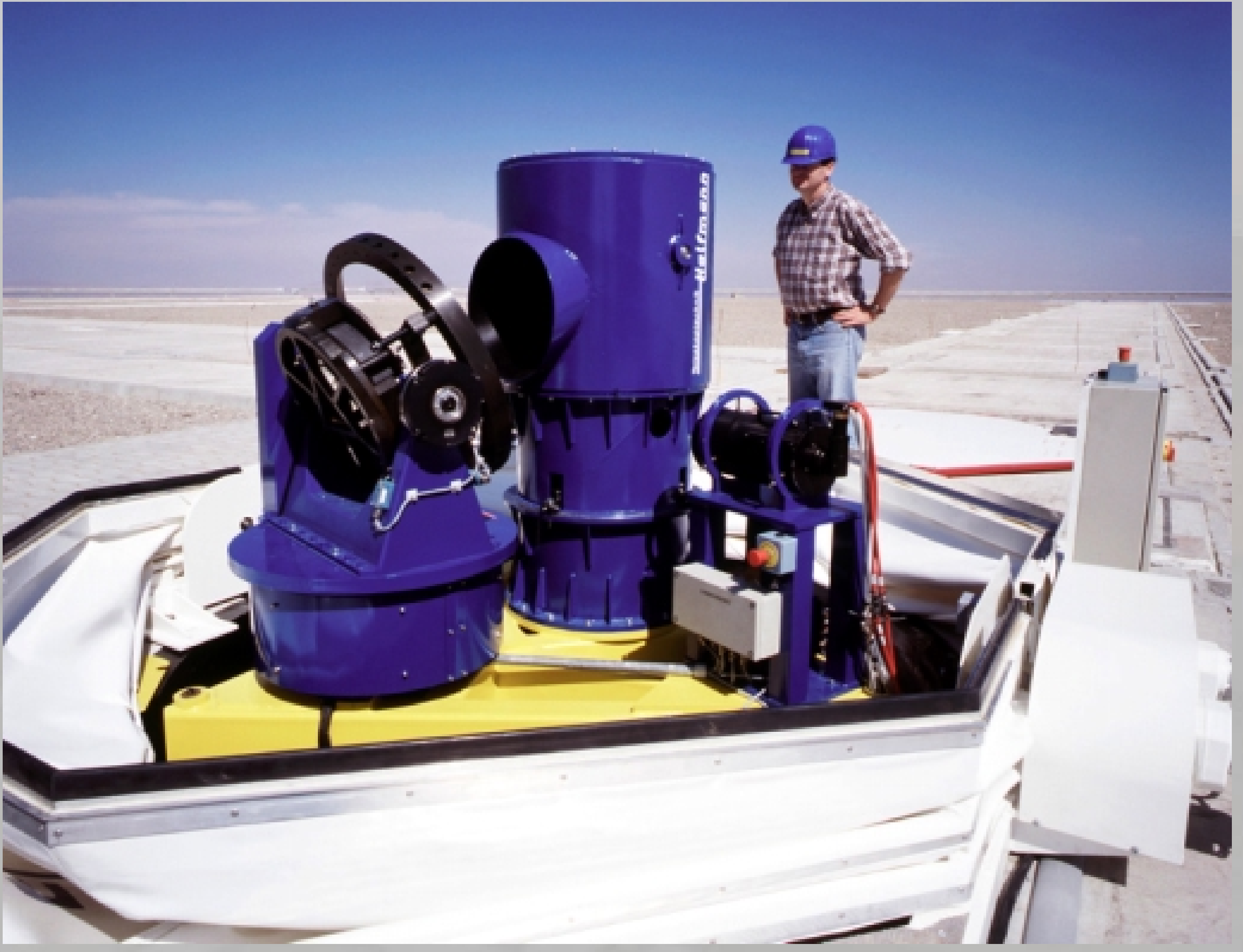
- ‘Wine cellar approach’
- Flatness of rails better than 25μm over 65m.
- Cat's Eyes v_{max} = 0.5m/sec
- Beam tilt < 1.5 arcsec
- Absolute position accuracy 30μm
- Rel. position error about 20nm
- Optical system with VCM on a piezo mount
  - Reimaging of telescope pupil
  - Fast adjustments of OPL

The VLTI sub-systems and VINCI



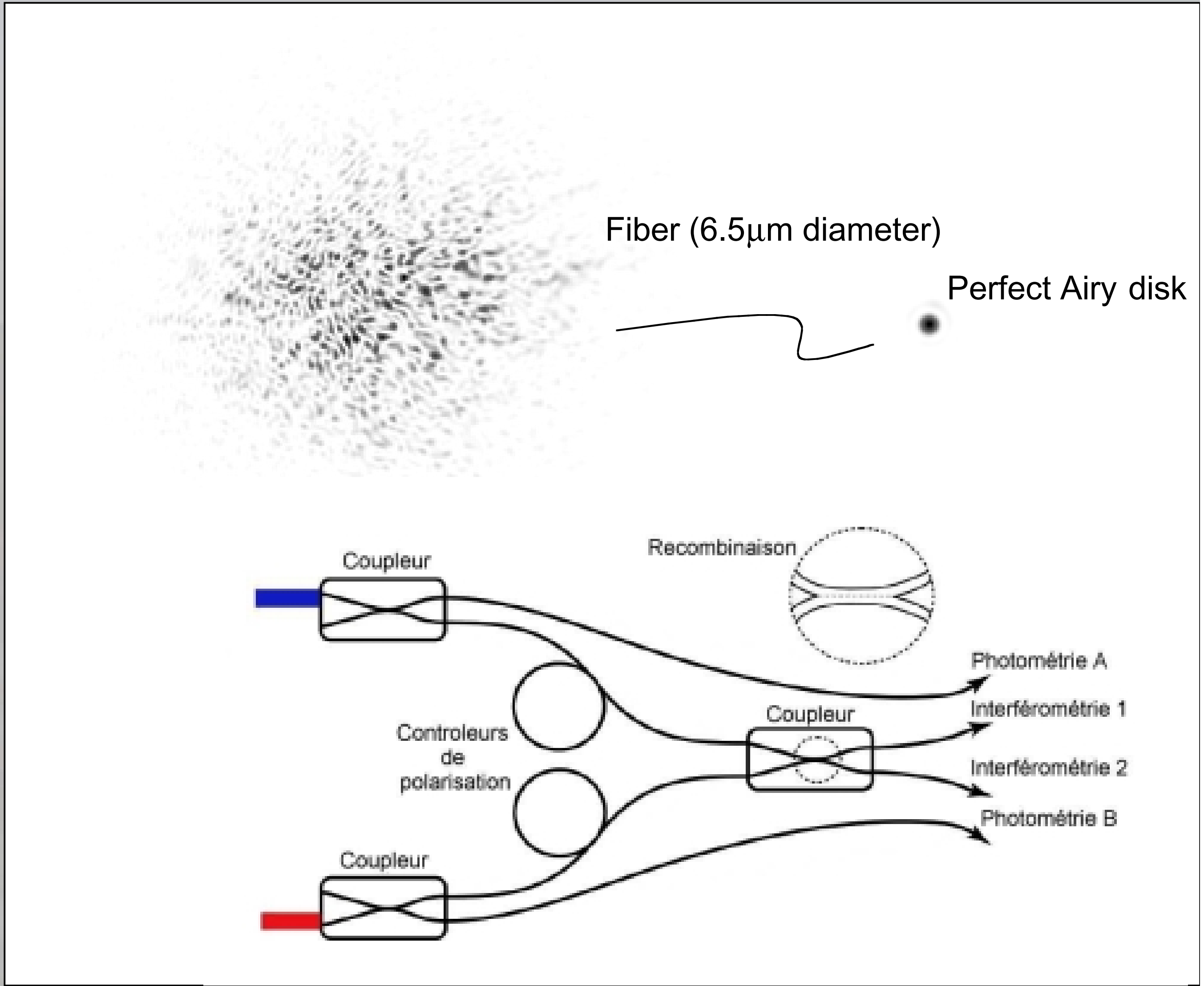
- 3 Delay Lines, 2 Siderostats and VINCI commissioned ✔
- 3 more DLs ordered
- 2 Coudé optical trains commissioned in UTs ✔
- 2 more being installed
- 2 tip-tilt systems tested in UTs ✔

Siderostat at AT station G0



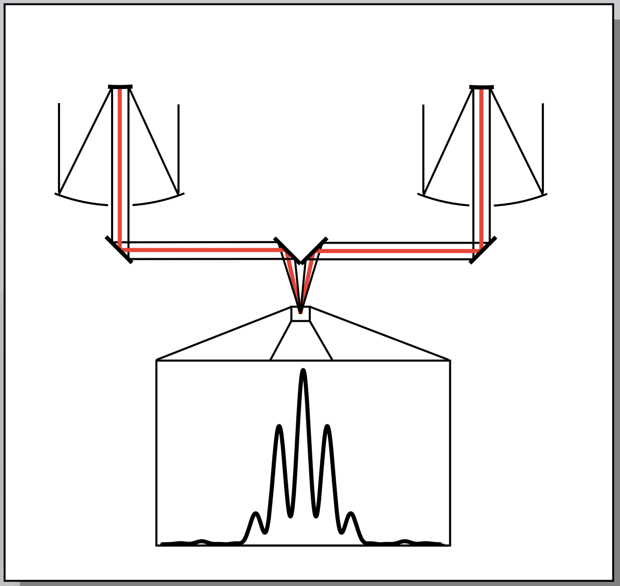
2. VINCI – The VLTI test instrument

- Light is fed into two monomode fibers (Concept adopted from FLUOR at IOTA)
- Fiber coupler acts as beam combiner for coaxial beam combination
- Temporal fringe pattern measured in I1 and I2
- Modulation performed at fiber feed

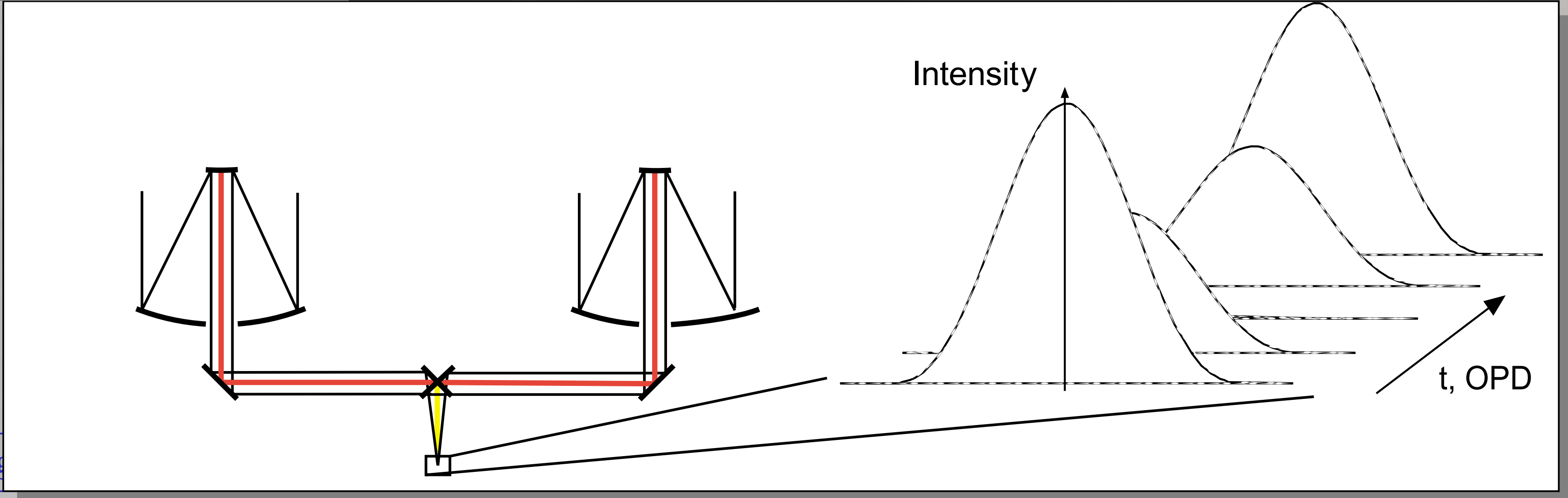


Spatial vs temporal fringe patterns

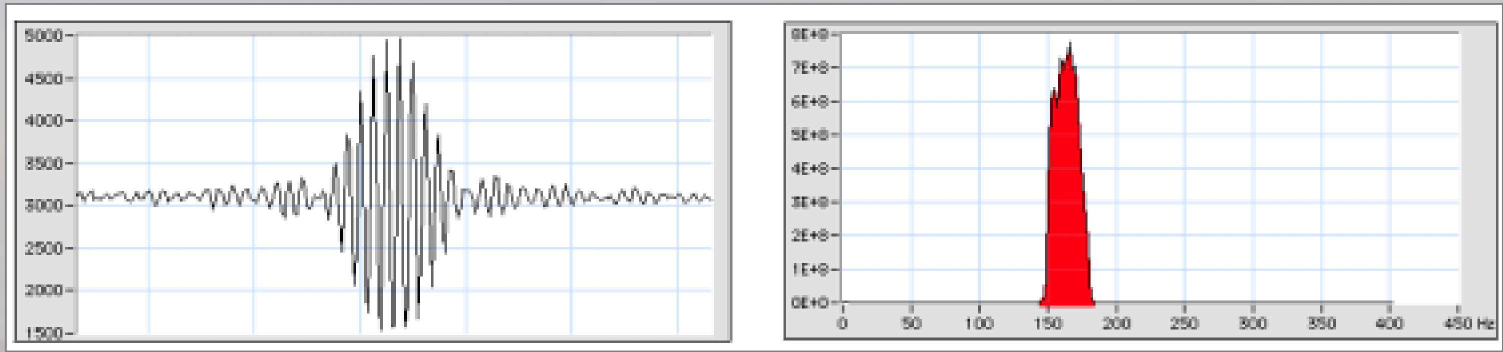
(aka image plane vs. pupil plane interferometry)



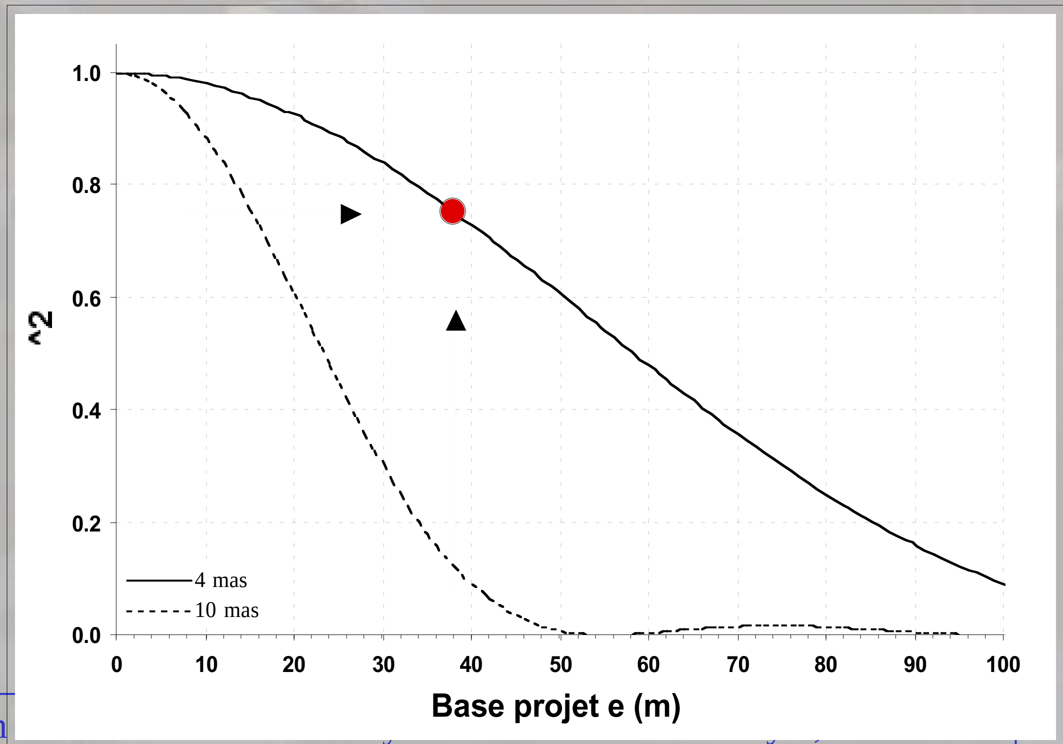
- Multi-axial beam combination shows an Airy disk with fringes
- Co-axial beam combination produces Airy disk without fringes.
- Fringes appear through temporal OPD modulation
  (Compare to Michelson Fourier Spectrometer)



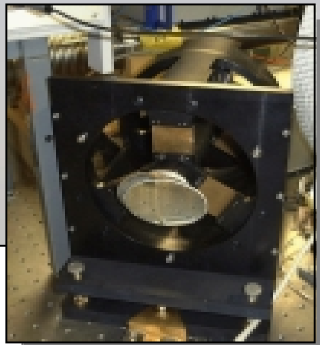
Measurement of the Visibility function with VINCI



- The power spectrum is masked with the K-band spectrum
- The integrated power determines V^2 the square of the visibility

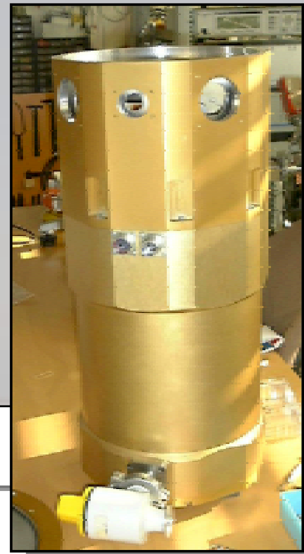


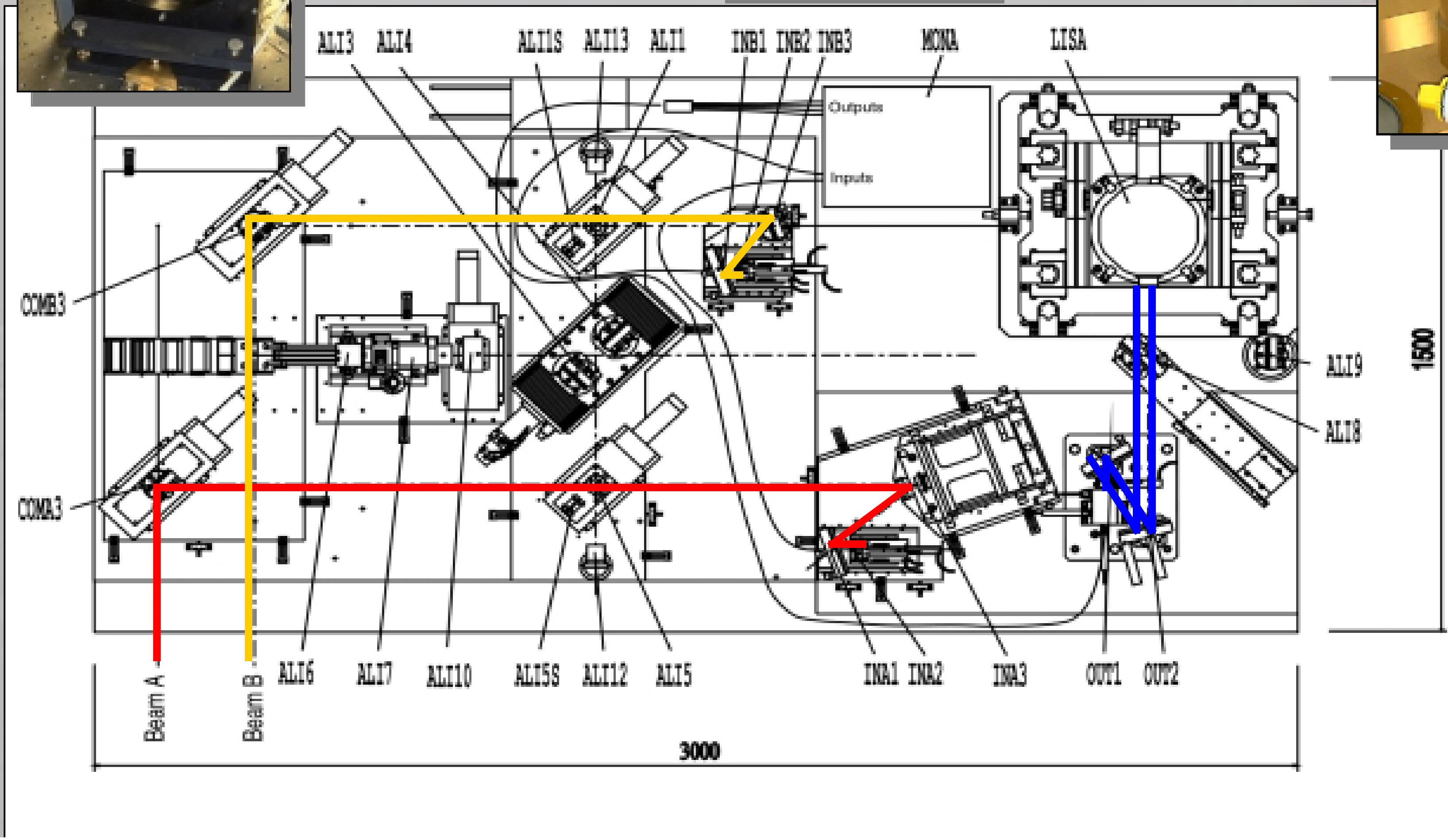
VINCI - Optical Setup



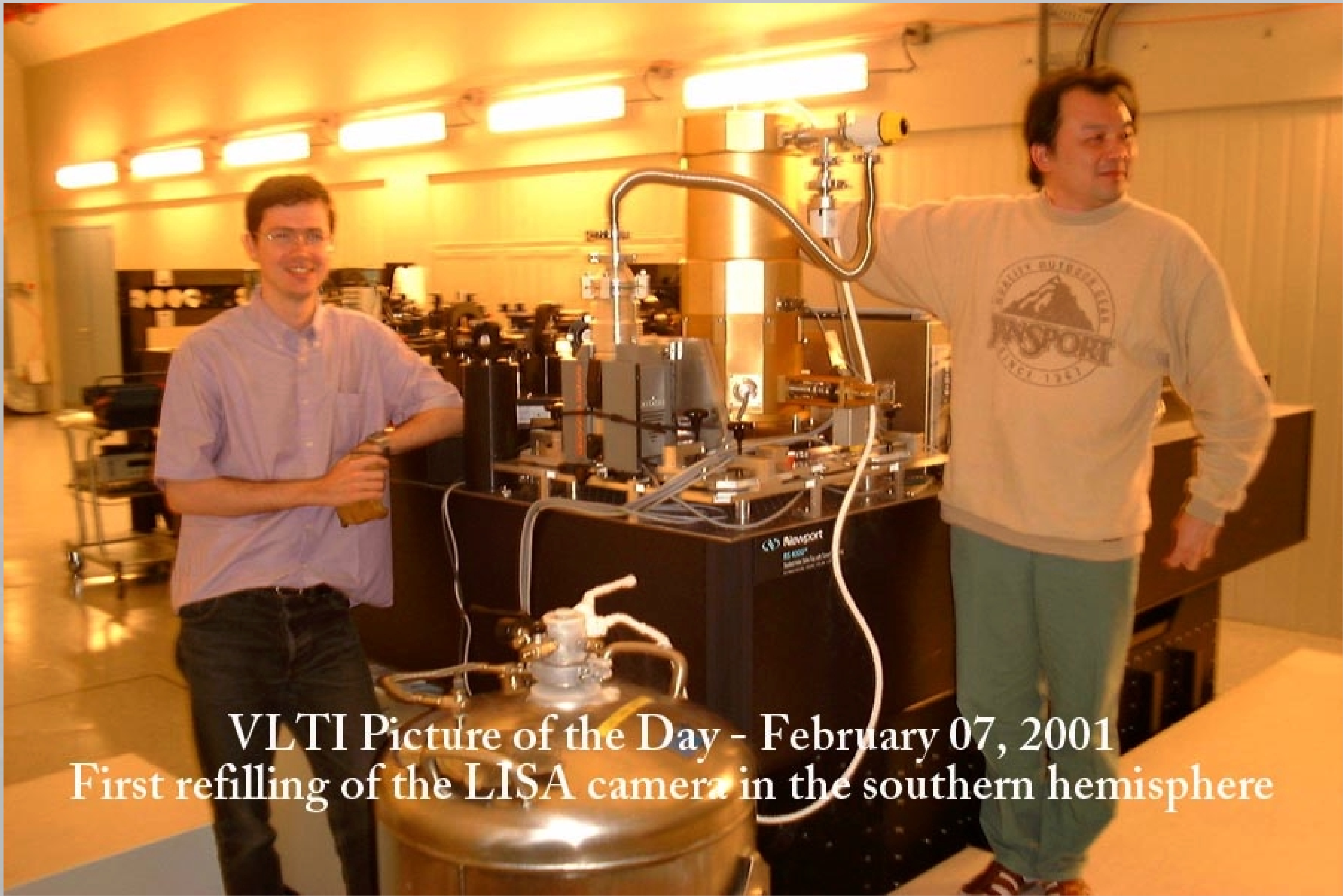
MONA

LISA



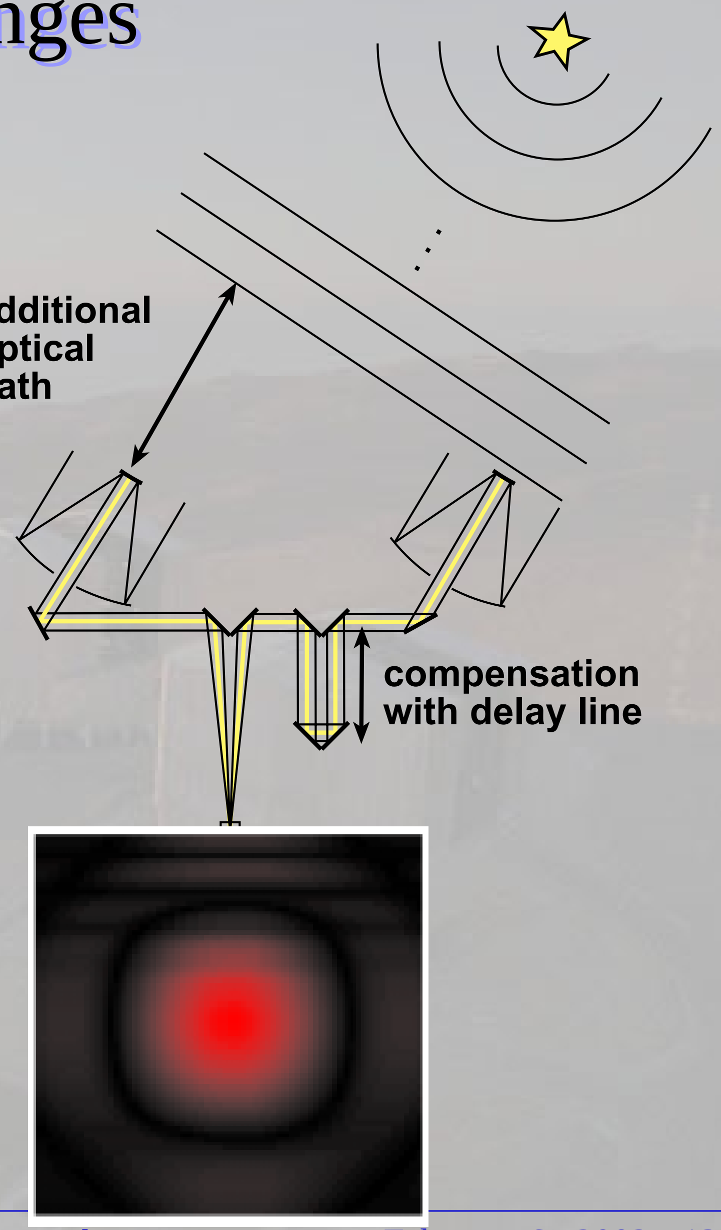


VINCI in the Beam Combination Lab

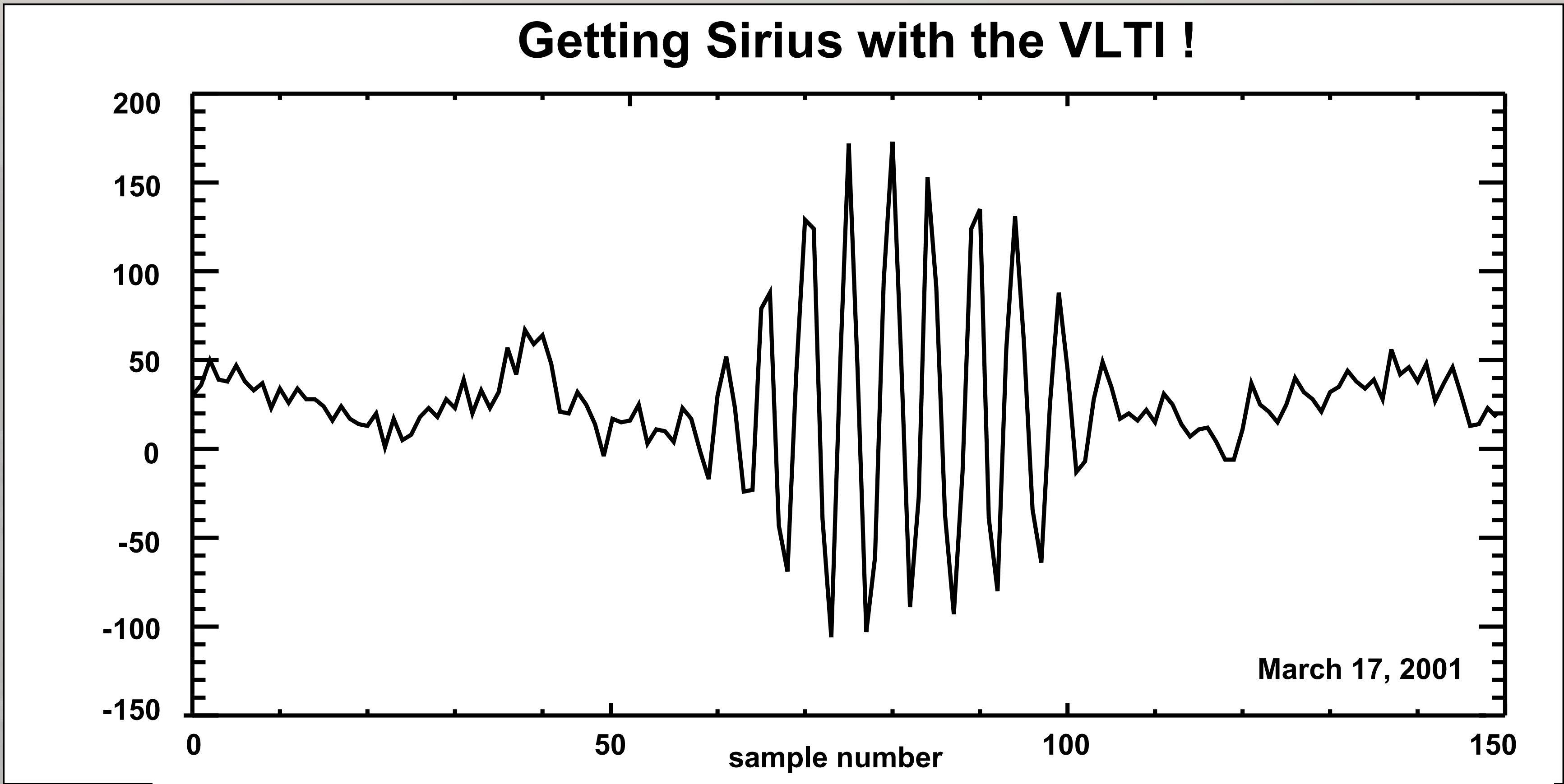


Finding fringes

- Adjust star on detector
- Follow trajectory with Delay Lines
- Scan starts, sweeping around calculated
  0 OPD position
  (scanning 10mm takes about 5min)
- After first few observations
  calculate new OPD model
  ⇒ Fringes found within <100µm
- Observations executed by BOB



3. First Fringes with VINCI and Siderostats

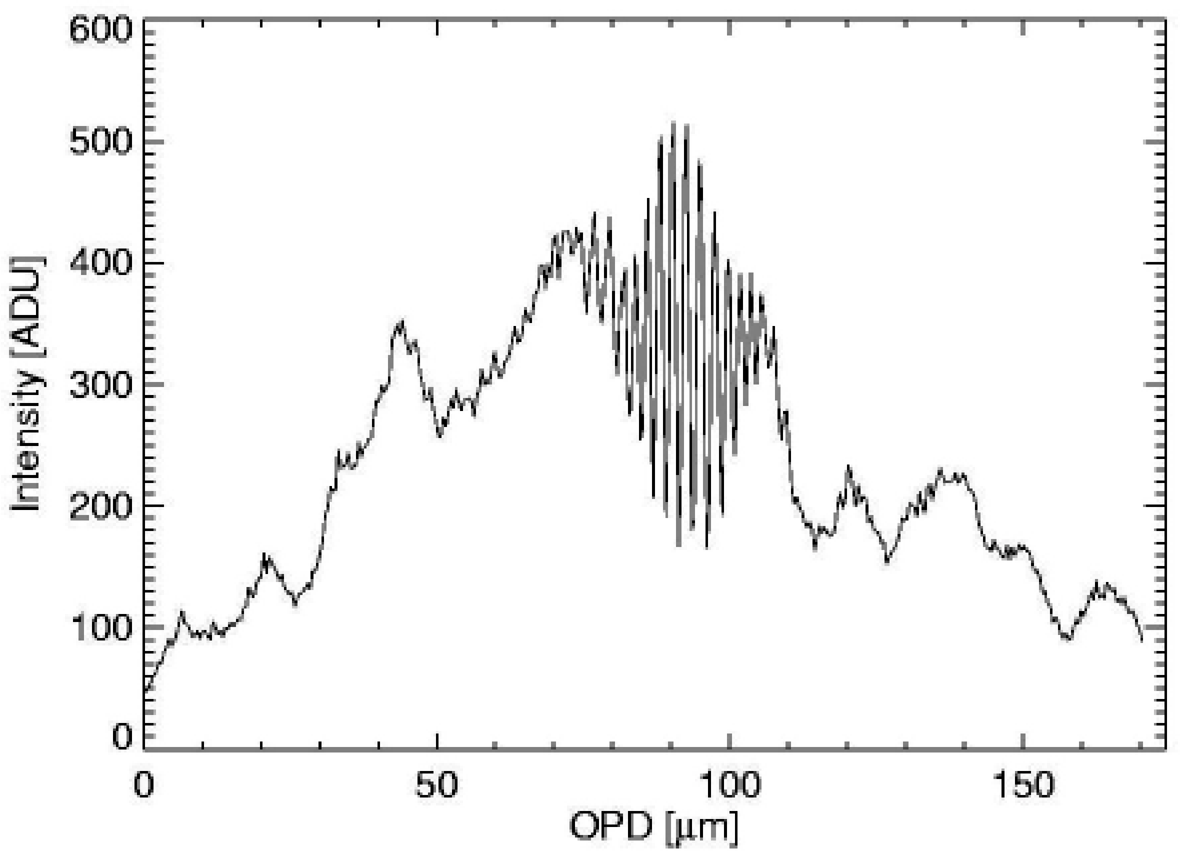


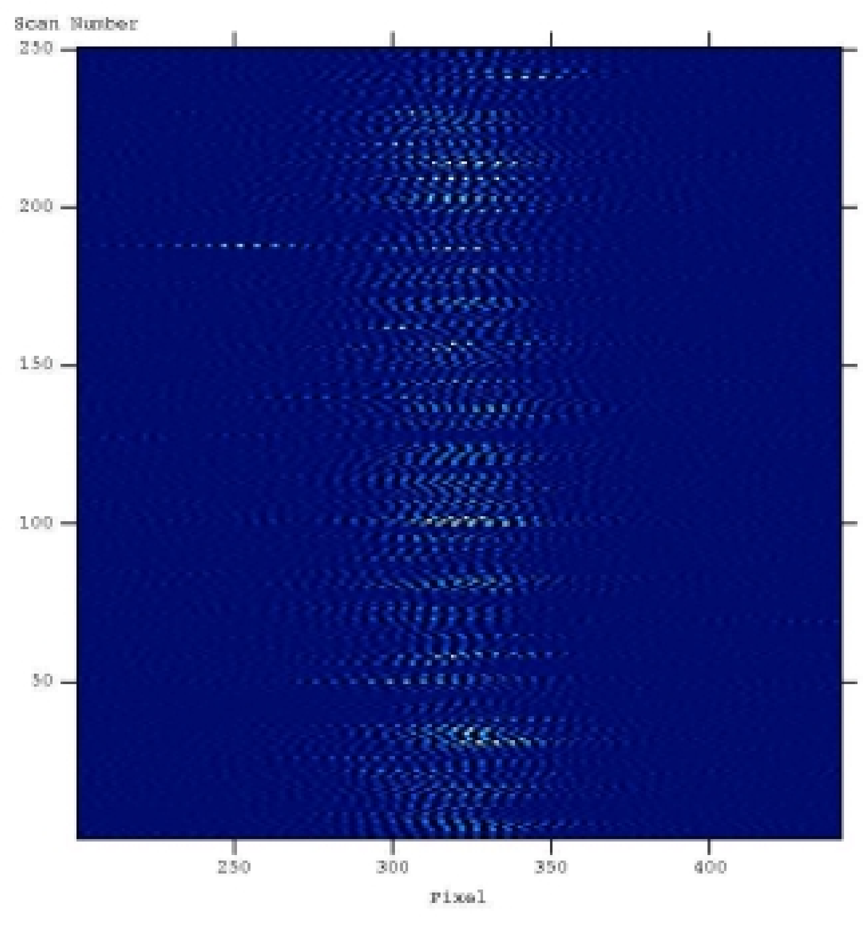
More stellar diameters

- γ Cru: 24.7±0.35 milli arcsec
- α Cen: 9.6±0.5 milli arcsec
- δ Vir: 10.4±0.6 milli arcsec
- R Leo: 24.3±0.4 milli arcsec

(resolution limit on 8-m telescopes 57 milli arcsec)

First Fringes with the UTs

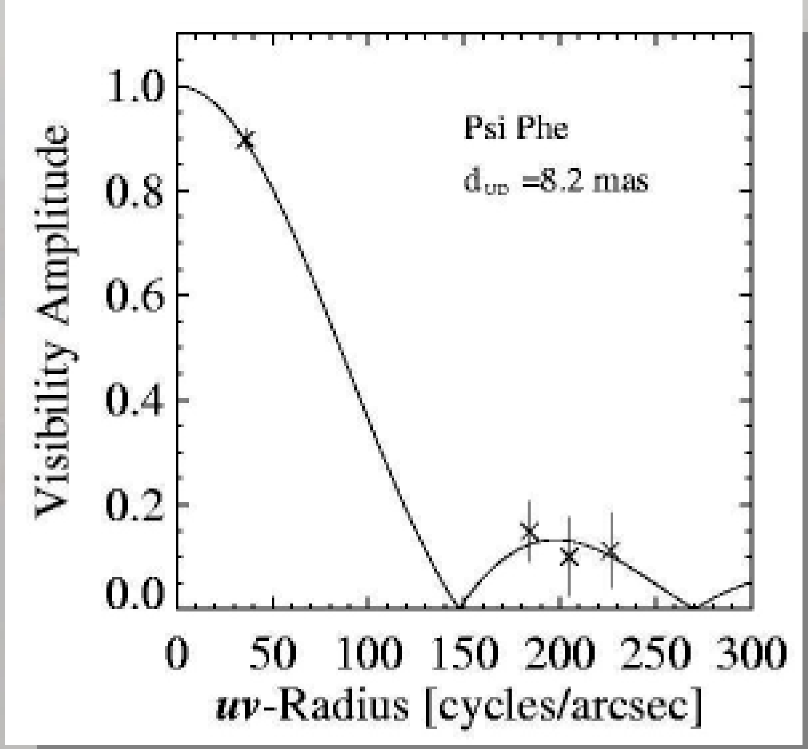




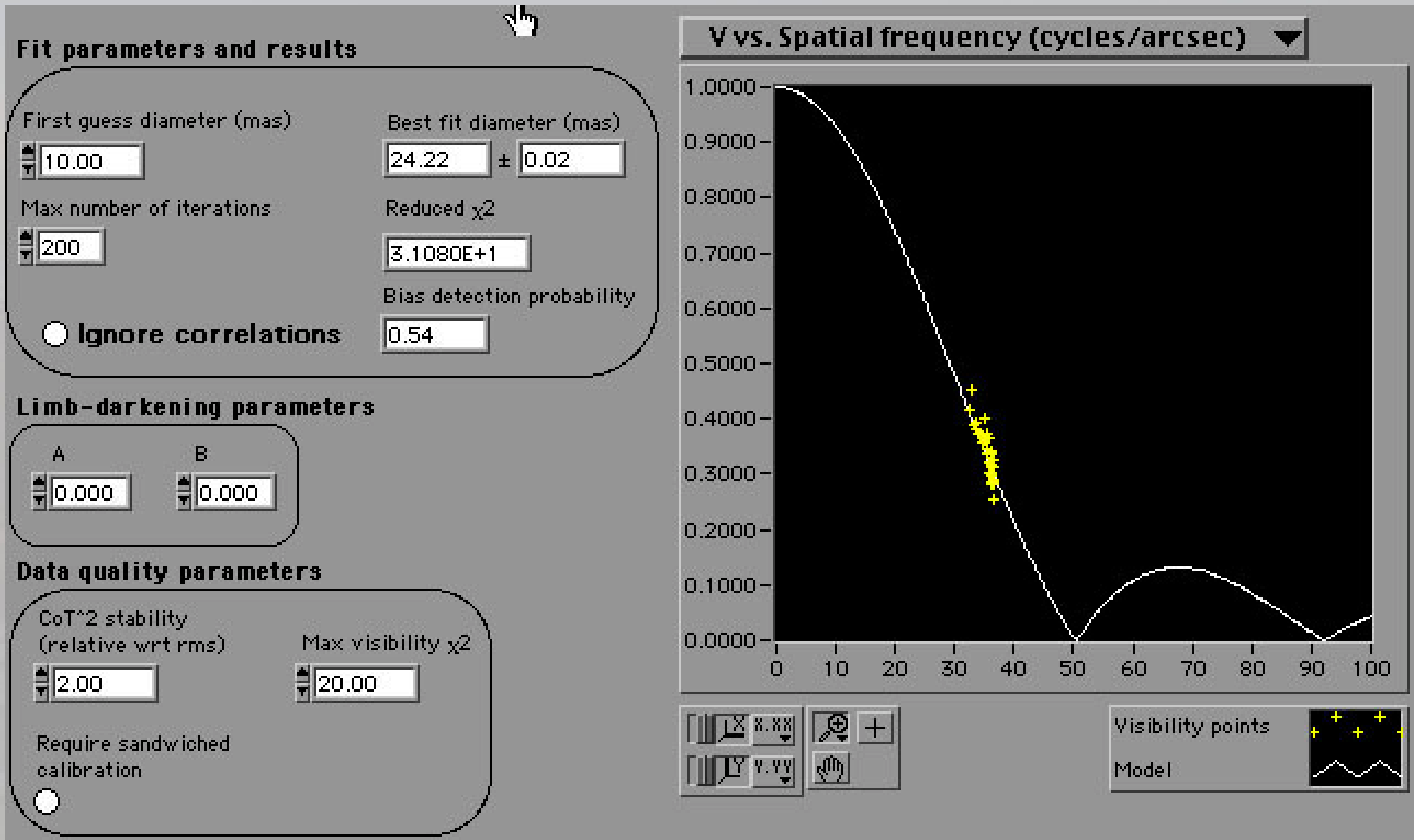
Achernar on Oct 30, 2001, at 1 am,
scan on the left chosen from 'waterfall' display on the right

The diameter of a red giant

- Psi Phoenicis observed with siderostats (baseline 16m), and with UT1 and UT3 (baseline 102m)
- Differences in projected baselines provide different baseline vectors
- Preliminary result for diameter: 8.21 marcsec



R Leo over several nights (April 1-3, 2001)

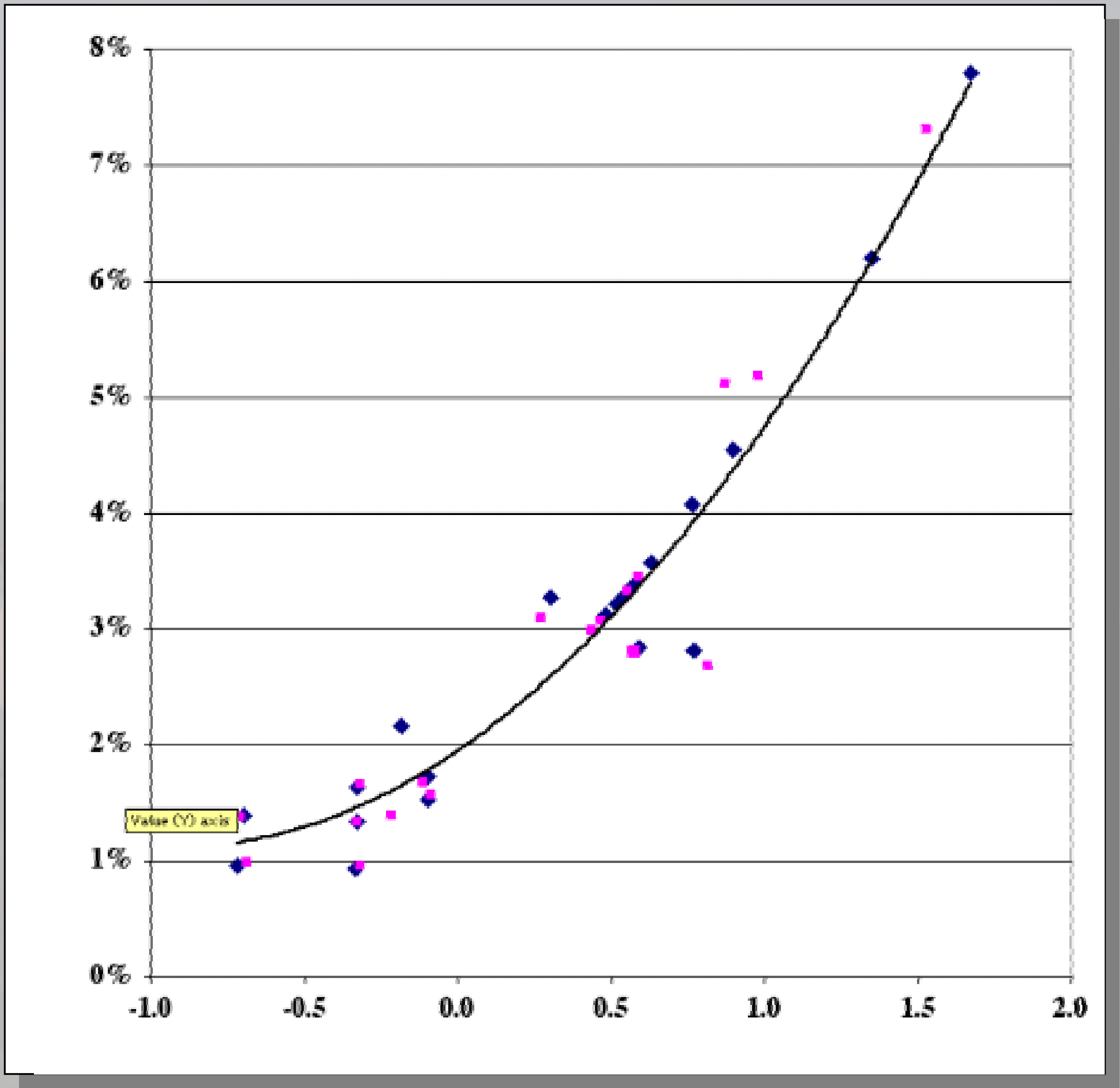


FLUOR Data analysis package provided for VINCI by the Obs de Paris for the JMMC

4. VLTI Performance

Error in V^2
for 100 scans

- Transfer function of 0.7 (V^2=0.5)
- Stability: 0.7±0.04
- Smallest $V^2=0.05^2$
- Accuracy for measurements of star diameter: <± 0.5 milli arcsec (on typical diameters of 10–25 milli arcsec)
- Slow fringe tracking with VINCI (max 4 Hz bandwidth)



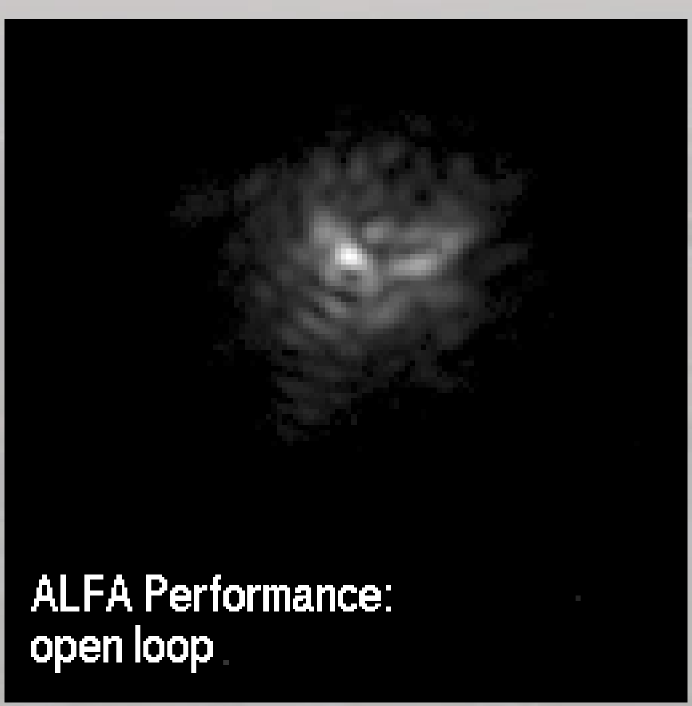
Correlated K magnitude

Control and operations

- Remote control of VLTI
  - No visits to the VLTI Lab required during night time !
- OB in VLT style
- Data Pipeline
- Data Archive
- Interferometric FITS format

All data between First Fringes in March 2001 and Dec 7 are now on the web.

5. Adaptive optics and interferometry

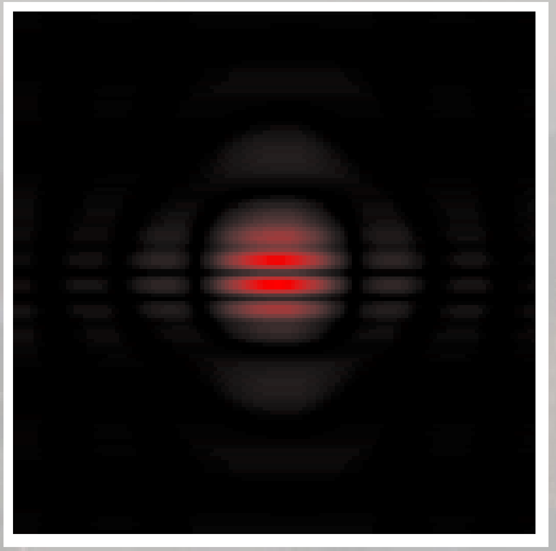


Calar Alto 3.5m telescope
MPIA Heidelberg

- 'Fishing' for intensity with monomode fibers or using an area detector both loses sensitivity
- Perfect Airy disk has all aberrations removed, except for piston

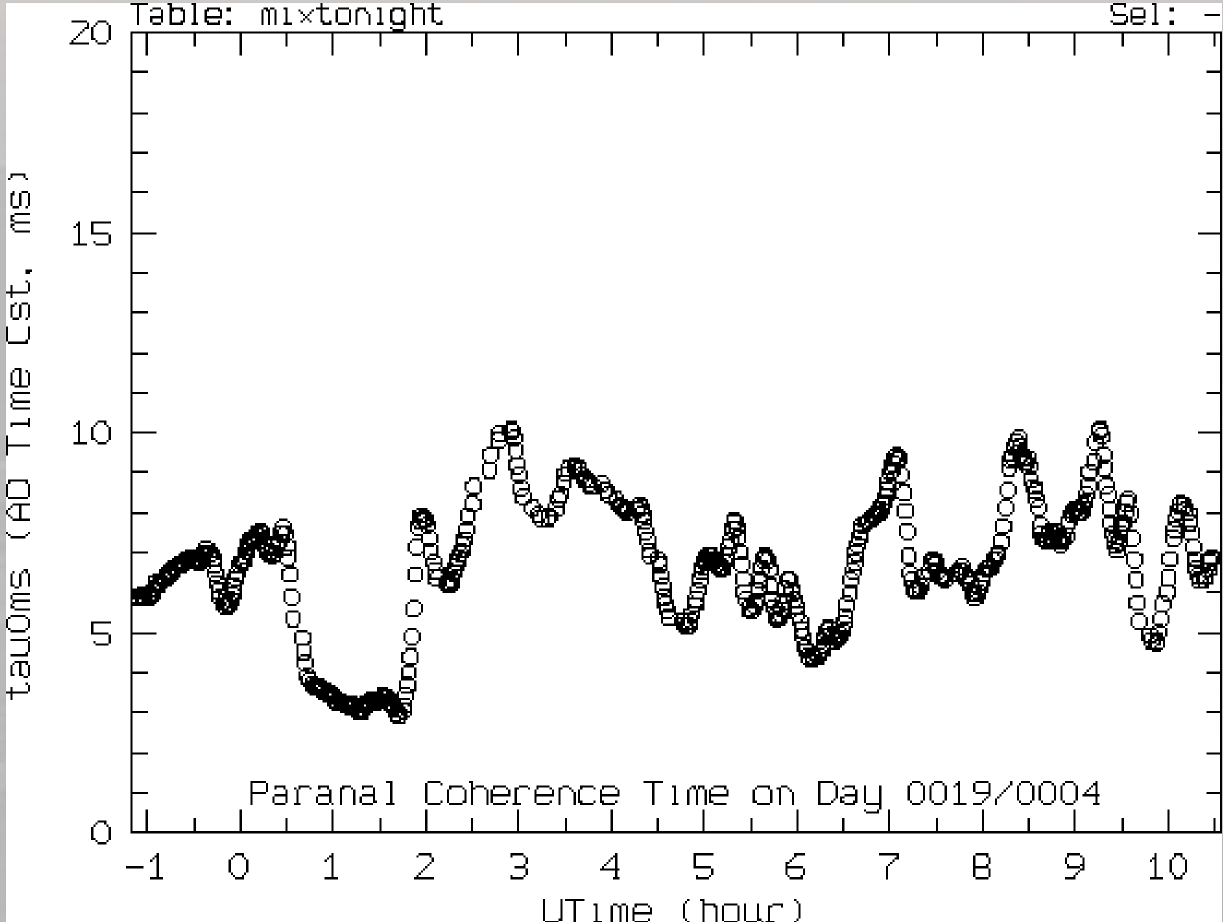
Fringe tracking

- Remaining atmospheric piston causes fringe wobble
  ⇒ exposure time limited to some 10msec depending on λ
- Solution:
  Bright guide star for fringe tracking
  Integrate fringes on science object
- Concept similar to Adaptive Optics
- Note: Individual Telescopes can observe faint stars without AO,
  Interferometers cannot go faint without a fringe tracker!



Spatial fringe pattern

Atmospheric Coherence Time



Median value:

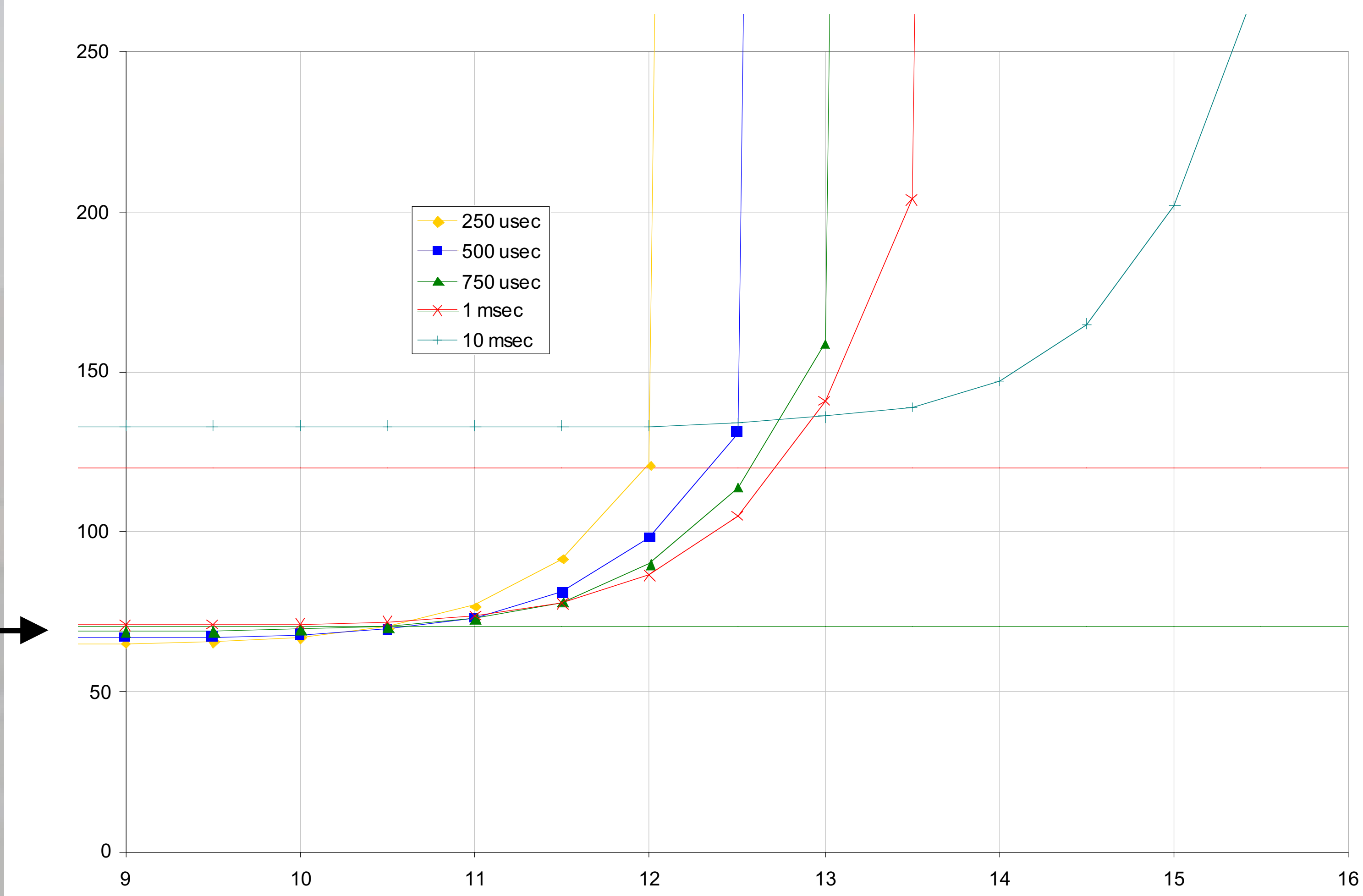
22 msec for 2.2µm

Daily variations can be ±10msec

FINITO – Expected Performance

Fringe-Tracking Instrument of Nice and Torino

Residual OPD



H Magnitude (UT)

OPD = 70nm corresponds to $\Delta V/V = 2\%$

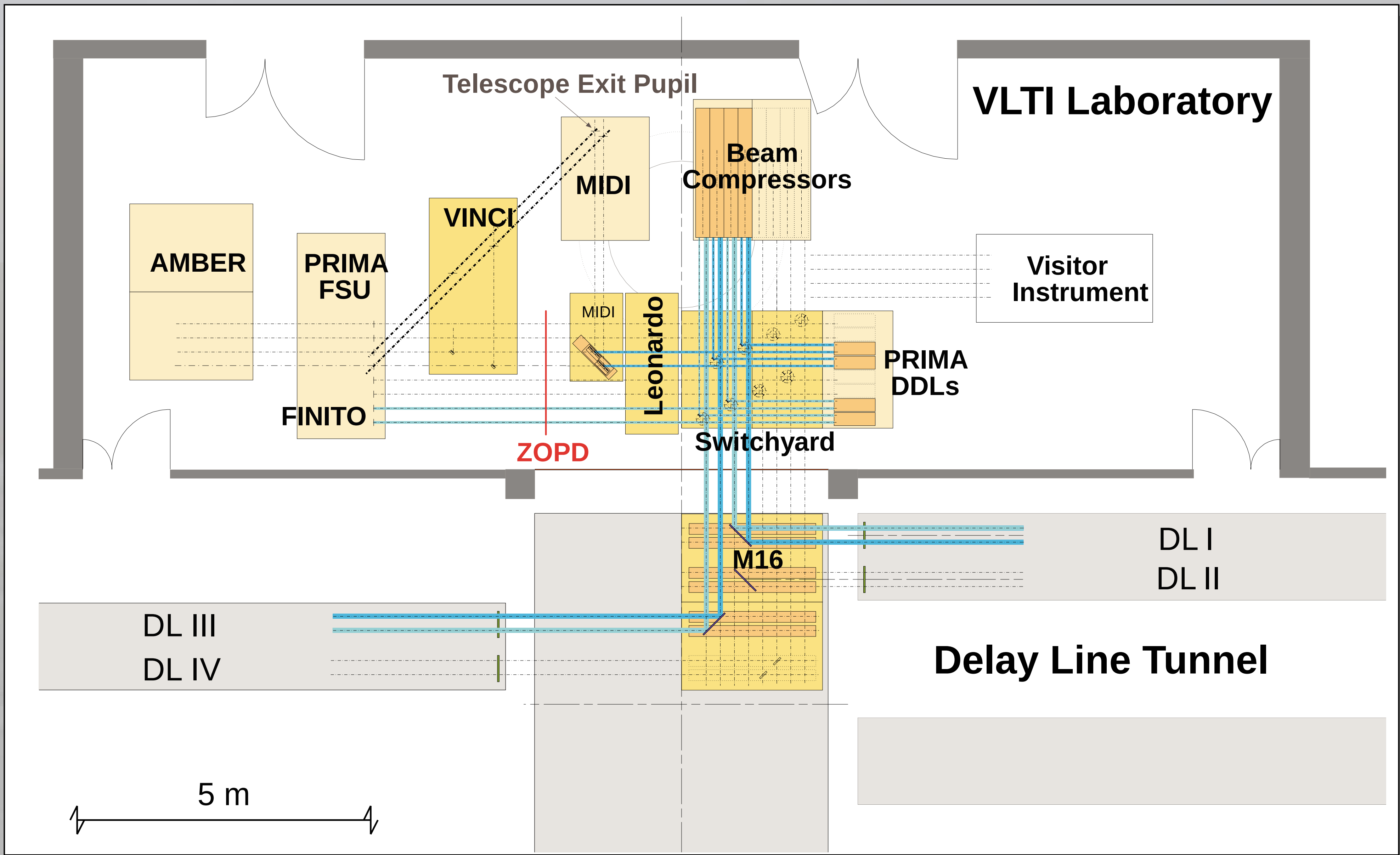
τ = 50 msec at 2.2µm

Error budget

Error budget quantified in visibility (contrast) loss $\Delta V/V$ at 2.2µm

- Largest contributor is atmospheric turbulence:
  - $\Delta V/V$ = 25% (residual of adaptive optics correction for 75% Strehl)
  - $\Delta V/V$ = 2% (with fringe tracker)
- Optical aberrations contribute $\Delta V/V$ = 6%
- Differential incident angles and/or coatings on mirrors affect polarisation and cause $\Delta V/V$ = 6%
- Unequal beam intensities $\Delta V/V = 1 - 2\,(\sqrt{I_1} \times \sqrt{I_2})/(I_1 + I_2)$
  The exact figures depend on the beam combination scheme
- Total loss: $\Delta V/V$ ~ 40% (i.e. ΔK= 1)

VLTI Laboratory



6. VLTI Instrumentation 1

MIDI (Germany, France, Holland; PI: Ch. Leinert, U. Graser)

Delivery: Q4 2002

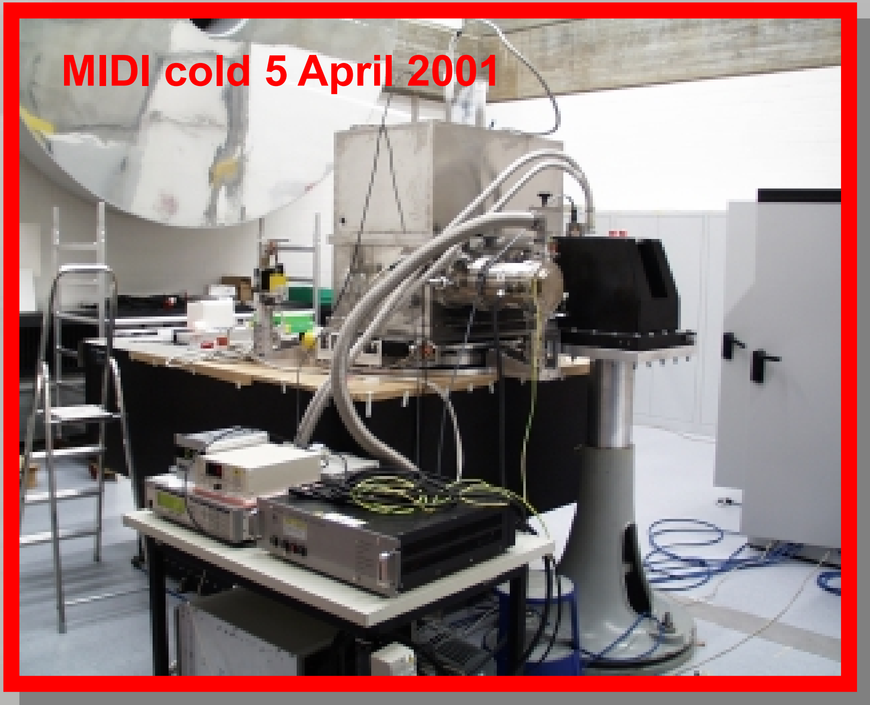
First Fringes with UTs: Dec. 2002

Mid IR instrument (10–20 µm)

Limiting Magnitude N ~ 3–8 (UT)

Two beam design

Challenge: Signal detection and Chopping



VLTI Instrumentation 2

AMBER (France, Germany, Italy; PI: R. Petrov, F. Malbet)

Delivery: Q1 2003

First Fringes with UTs (AO): July 2003

Near IR Instrument (1–2.5 μm)

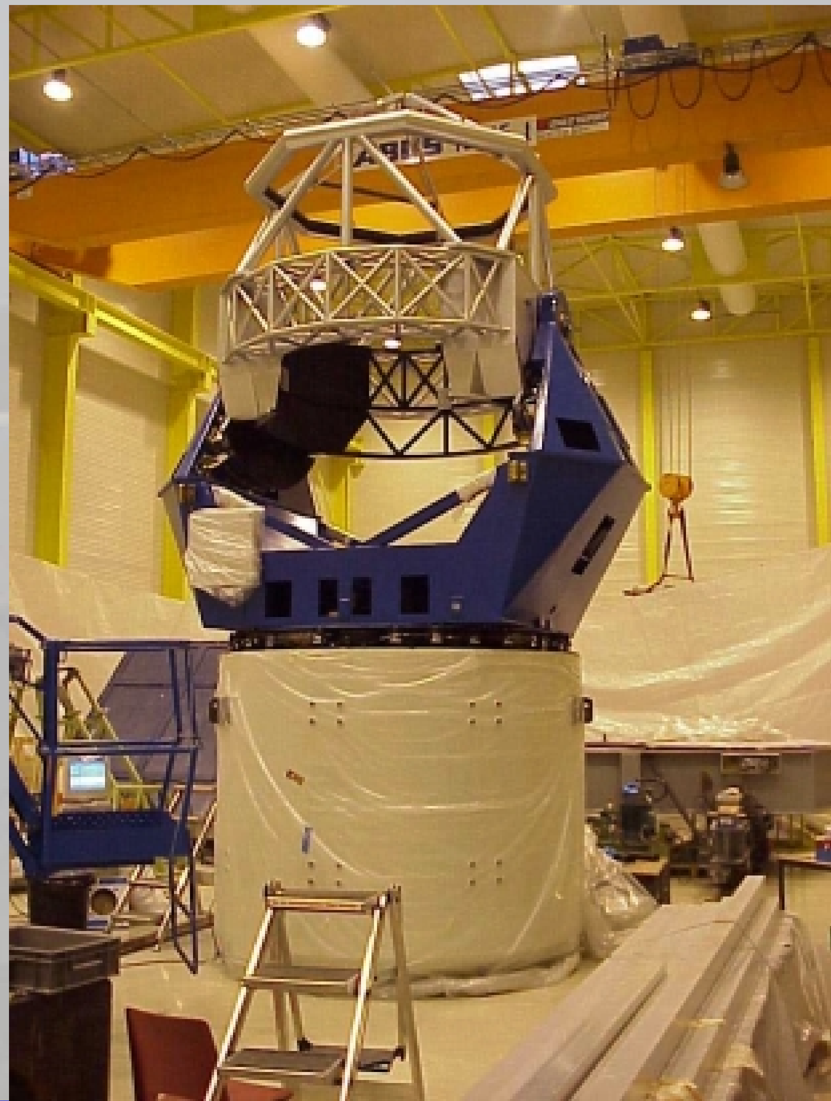
Limiting Magnitude K ~ 11–20 (UT), R ~ 10000

Three beam combination (closure phase)

Challenge: Beam combination (AO)

1.8-m Auxiliary Telescopes

- Manufactured by AMOS, Liège
- All optics completed
- Integration and tests in progress
- AT1 and 2 ready for interferometry in May 2003

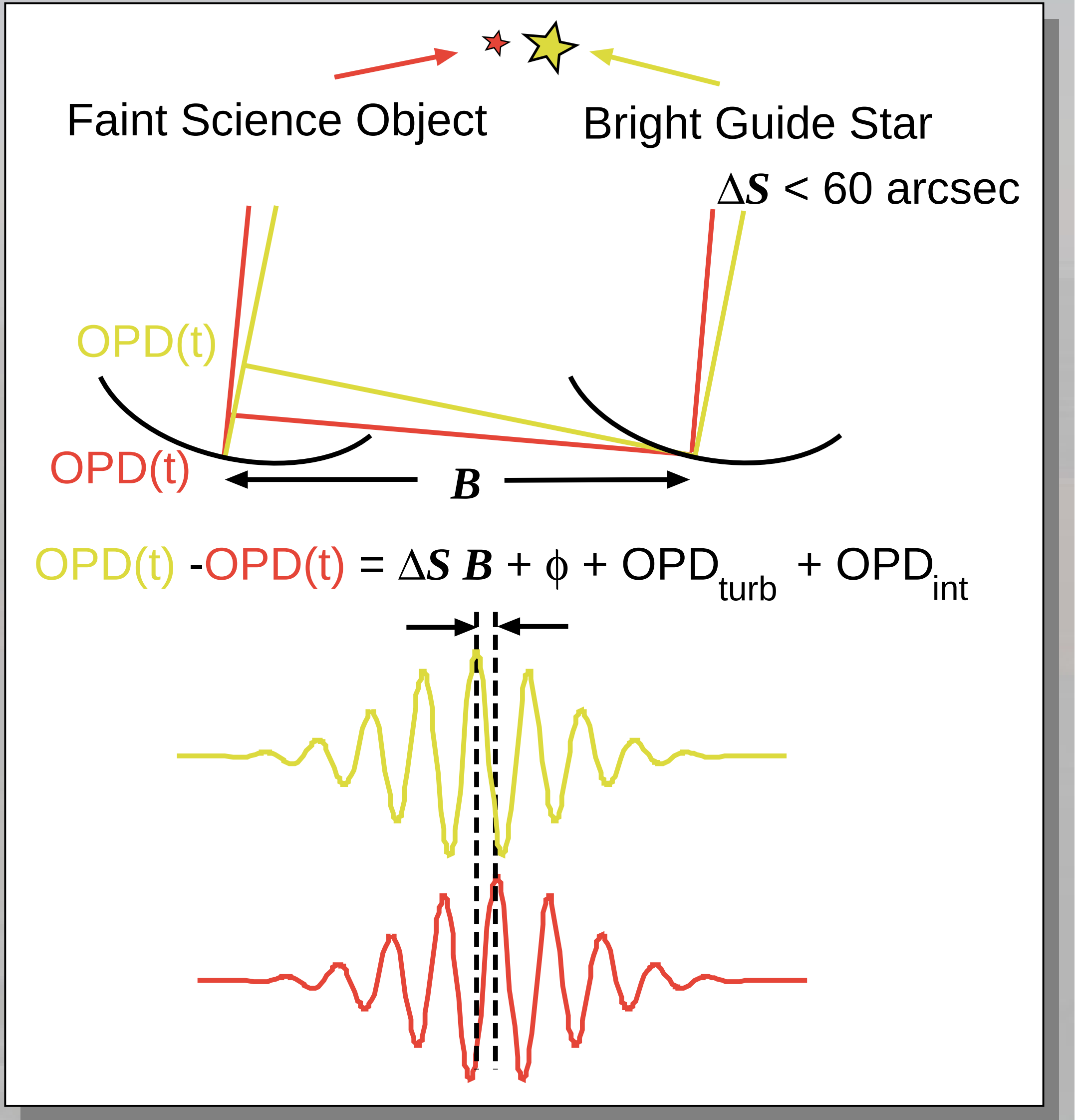


7. Going faint - PRIMA

- Two methods for imaging:
  - Closure phase observations (AMBER)
  - Phase referenced imaging requires a hardware extension of the VLTI
- PRIMA opens the door for faint object science:
  - Observations of faint objects (K ~ 20) with MIDI and AMBER
  - Imaging of faint objects (UTs and ATs) with MIDI and AMBER
  - Astrometry on ATs (10 μarcsec) with dedicated camera

PRIMA – the VLTI dual feed facility

- Tracking the fringes on the guide star
  ⇒ Fringes of science object are stablised
- PRIMA picks two stars in the Coudé, feeds them into the Delay Lines



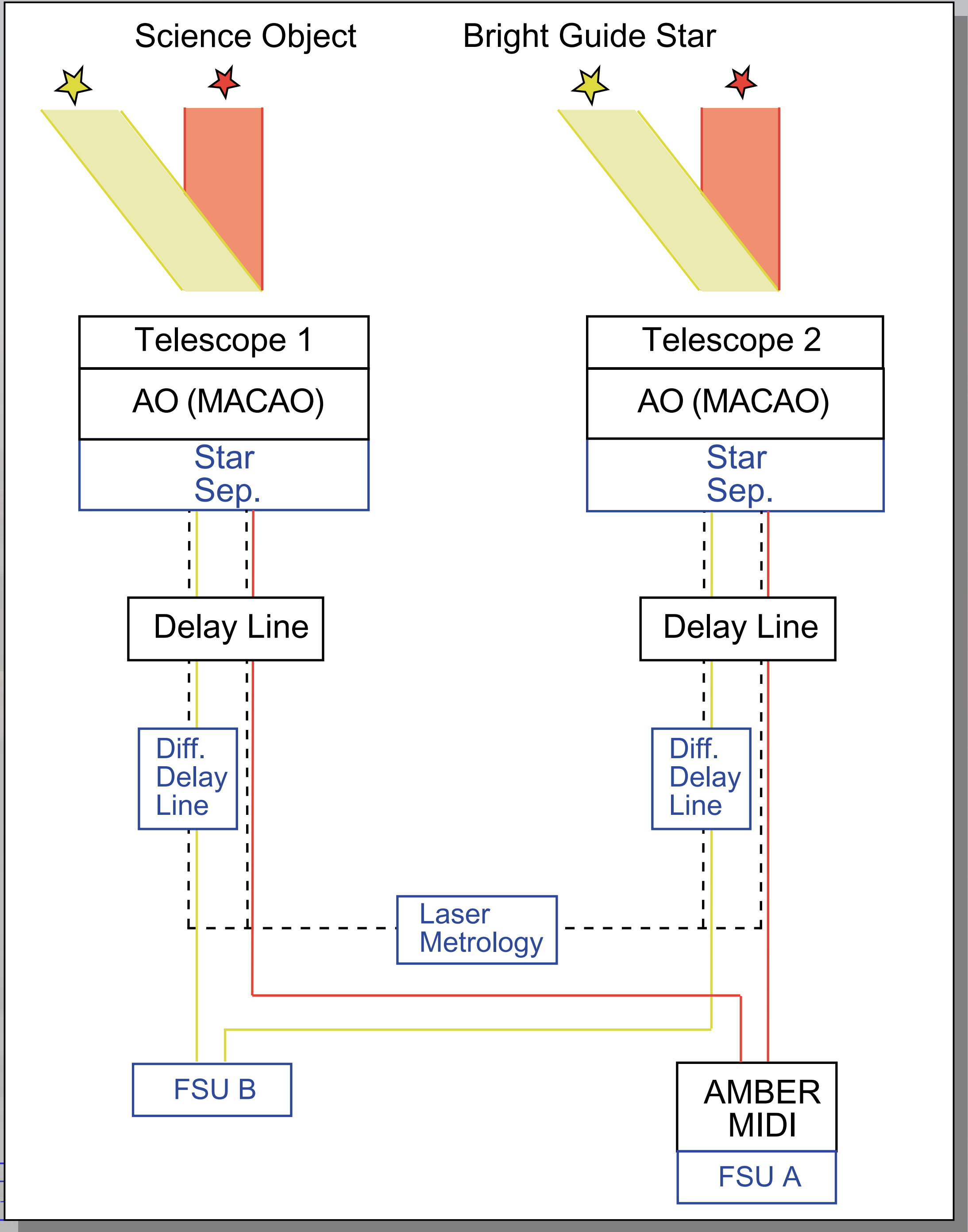
- OPD_{int} measured with laser metrology
- OPD_{turb} averaged by long integration
- $\Delta S\ B + \phi$ determined by interferometric instruments
- ΔS gives the astrometry, ϕ the imaging

The VLTI + PRIMA

Standard Components

+ PRIMA Subsystems

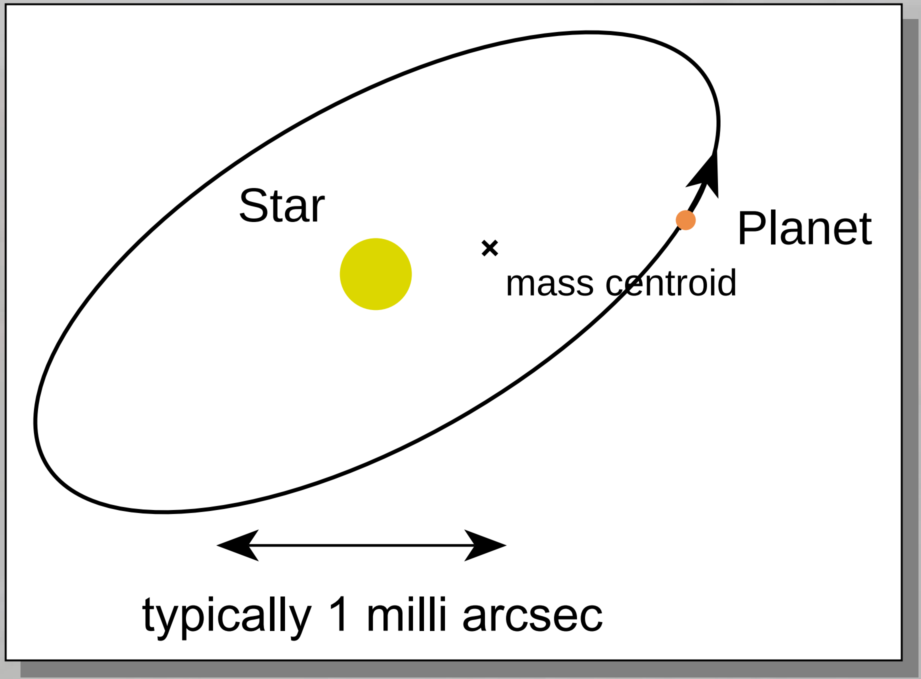
- Star separator
  - –Complex opto-mechanical system at Coudé focus of ATs (UTs)
    Two fields of 2’’ separated by up to 1’
- Laser metrology system
  - –Monitor internal OPD with 5 nm rms over 30 min
- Fringe sensor unit
  - –Measure fringe position with 30 nm rms on H = 13 (UTs)
- (Differential delay lines
  - –Provide differential delay with 5nm rms, maximum stroke 65mm)



PRIMA Science Drivers: Planet Search

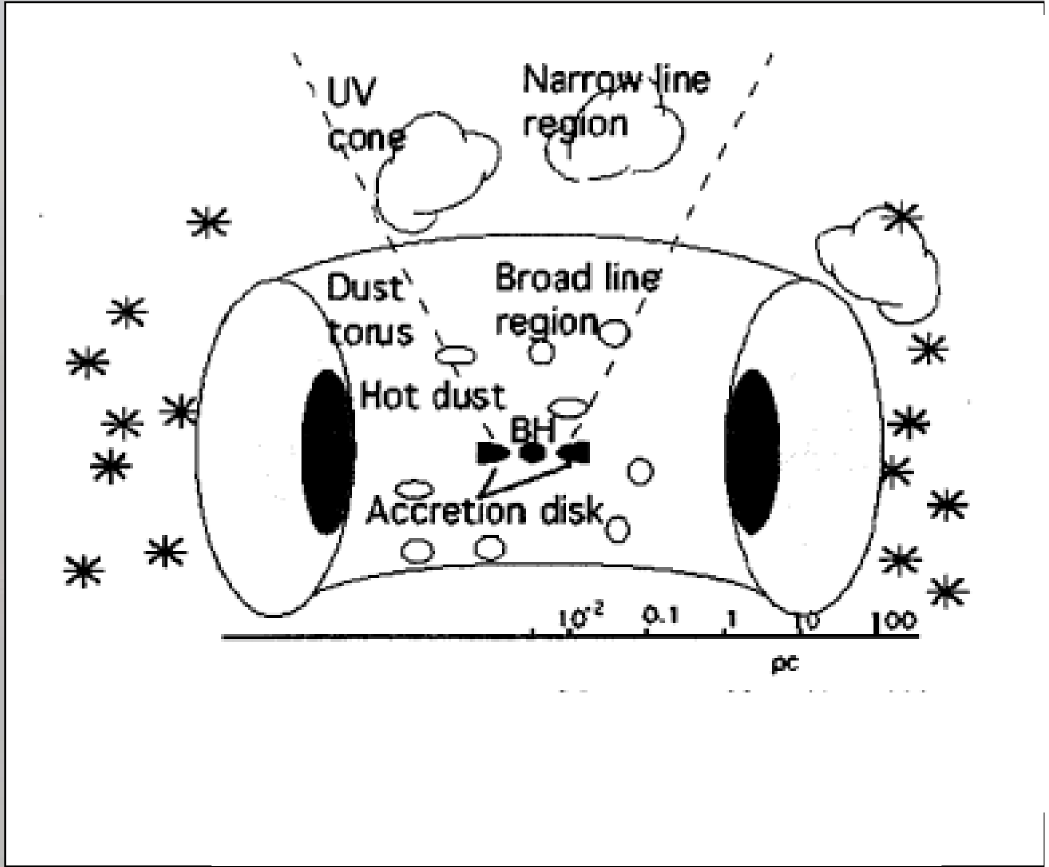
Search of exoplanets and brown dwarfs:

1. Visibility measurements
   PRIMA provides improved accuracy
   Planets with ~20M_J at ~10pc observable if:
   - N ~ 11 and
   - dynamic range >100
2. Astrometric measurements
   - resolve 1 milliarcsec motion



Extragalactic Science with PRIMA

Name	Type	m_K	θ[mas]	D[Mpc]
H307-739	Seyfert	15-20	30	110
E141-655	"	"	22	147
NGC4593	"	"	9	35
Molonglo 1411-192	Radio-lobe gal.	18.3	10	1000
1232+1325	BLR, QSO	17	4	1000
PC1247+3406	Radio quiet QSO	18	10	854

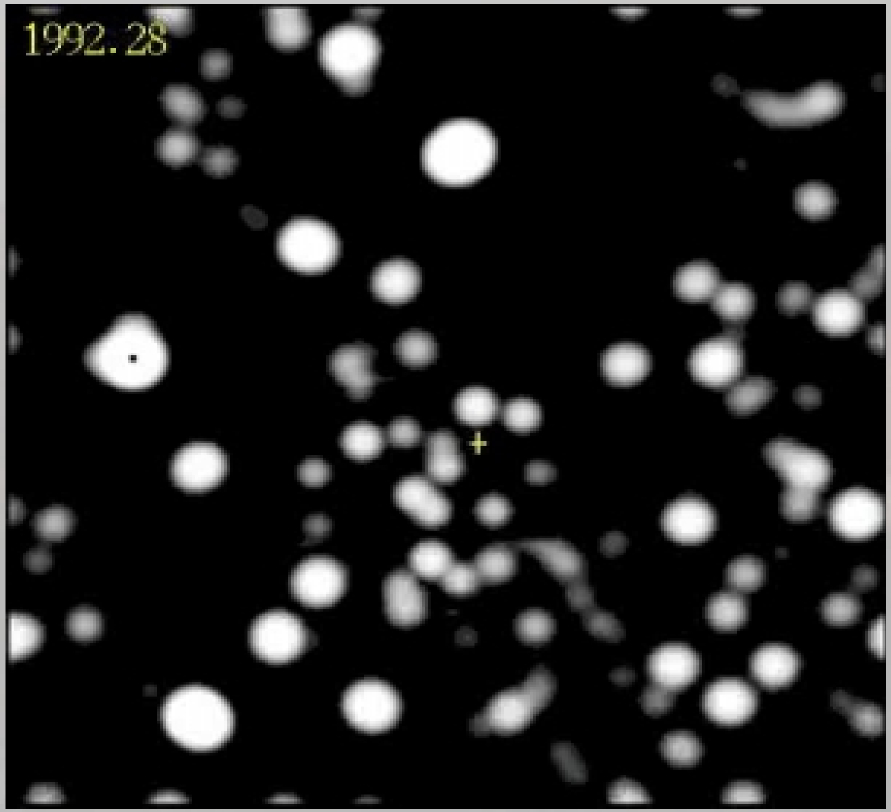


- Observing the AGN dance
- Resolving broad line region
- Detection of dust tori at 10 micron

Note: θ is the radius of the region with most of the mass. In this simple model, it is the region inside the dust torus.

The Galactic Center

- PRIMA measures proper motion and orbits of stars down to 15 AU (2 mas) of the Galactic Center
  ⇒ Precise position and mass of the black hole
- 10µarcsec = 10 Schwarzschild radii – relativistic effects?



~2 arcsec

Source: Eckart/Genzel, MPE Webpage

Call for Proposals – Performance

- Oct 2002: Observing with VINCI and the siderostats
  - Limiting magnitude: K ~ 3-4, V^2 accuracy: 1% for K=1, 5% for K = 3
  - Baselines: ~12 on offer of which ~5 will be chosen depending on proposals
- April 2003: Observing with VINCI, siderostats and FINITO:
  - On axis fringe tracking
  - OPD 100nm with H<12 (UTs), 150nm with H = 14 and 250nm with H = 16
- Oct 2003: Observing with everything except PRIMA:
  - MACAO: K-band Strehl 50% for V<13, 25% for V<16
    Isoplanatic angle 30” (for 50% reduction of above Strehl)
- April 2005: PRIMA
  - Fringe tracker performance 1-2mag better than FINITO
    Isoplanatic angle: 25” for 50% reduction of Visibility (i.e. OPD 400nm)
    ⇒ reduction of sensitivity through V^2N

Note: For MIDI isoplanatic angles are about 5 times larger
However, if fringe tracking is required the K-band restrictions apply!