Metrology for Phase-referenced Imaging and Narrow-Angle Astrometry with the VLTI

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Introduction

The "Phase-Referenced Imaging and Micro-arcsecond Astrometry" (PRIMA) facility [1] of the VLTI is based on the simultaneous coherent observation of two celestial objects in which the two interferometric signals are tied together by an internal metrology system. The role of this metrology system is to monitor the PRIMA instrumental optical path errors to possibly reach a final instrumental phase accuracy limited by atmospheric piston anisoplanatism[2].

Requirements and Constraints

$$OPD_1 = B.\vec{S_1} + \vec{L_1}$$

$$OPD_2 = B.\vec{S_2} + \vec{L_2}$$

$$\Delta OPD = \vec{B}.(\vec{S_2} - \vec{S_1}) + \Delta L$$

Accuracy Goal: 5 nm (driven by Astrometry at 10 μarsec accuracy, B=100m)

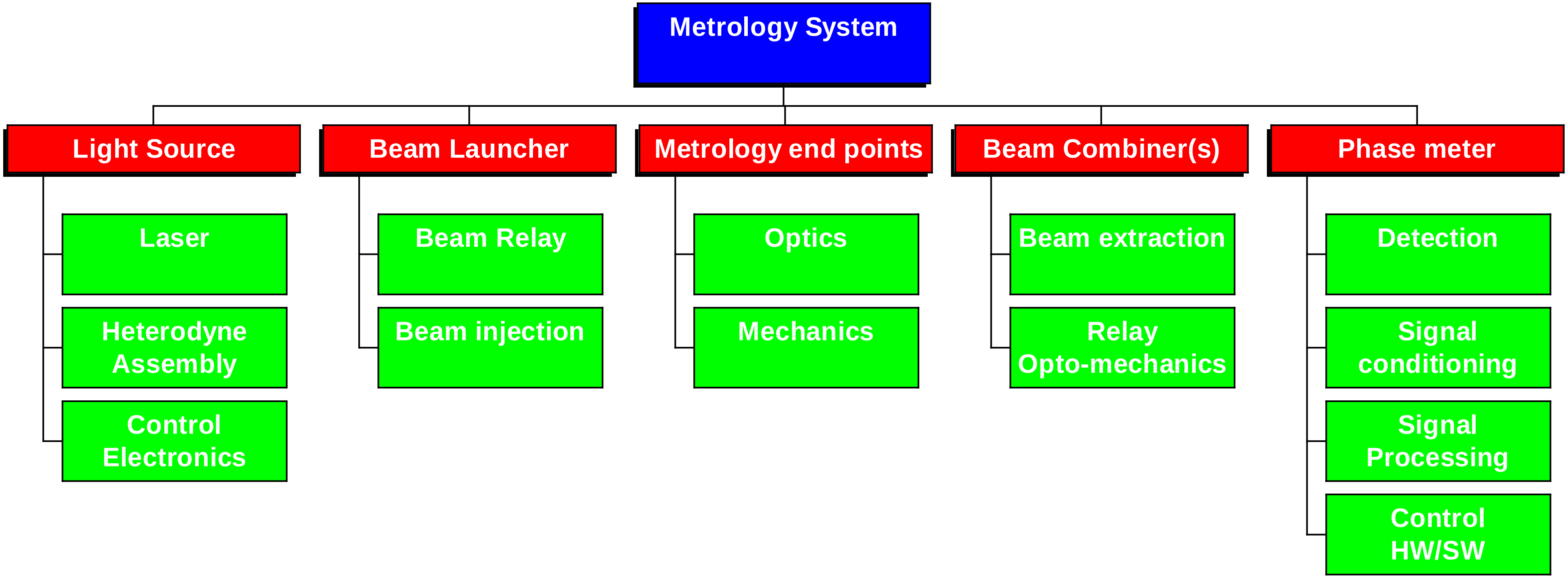
Range: 60 mm

- Long propagation paths: $L_{1,2}$ >276m (1 way)
- The beams are relayed through air as opposed to vacuum
- Metrology beam and the stellar beams must share the same internal path down to the beam combiners
- Careful management of the interfaces with all VLTI sub-systems is required including possible straylight contamination on existing detectors

Implementation Baseline

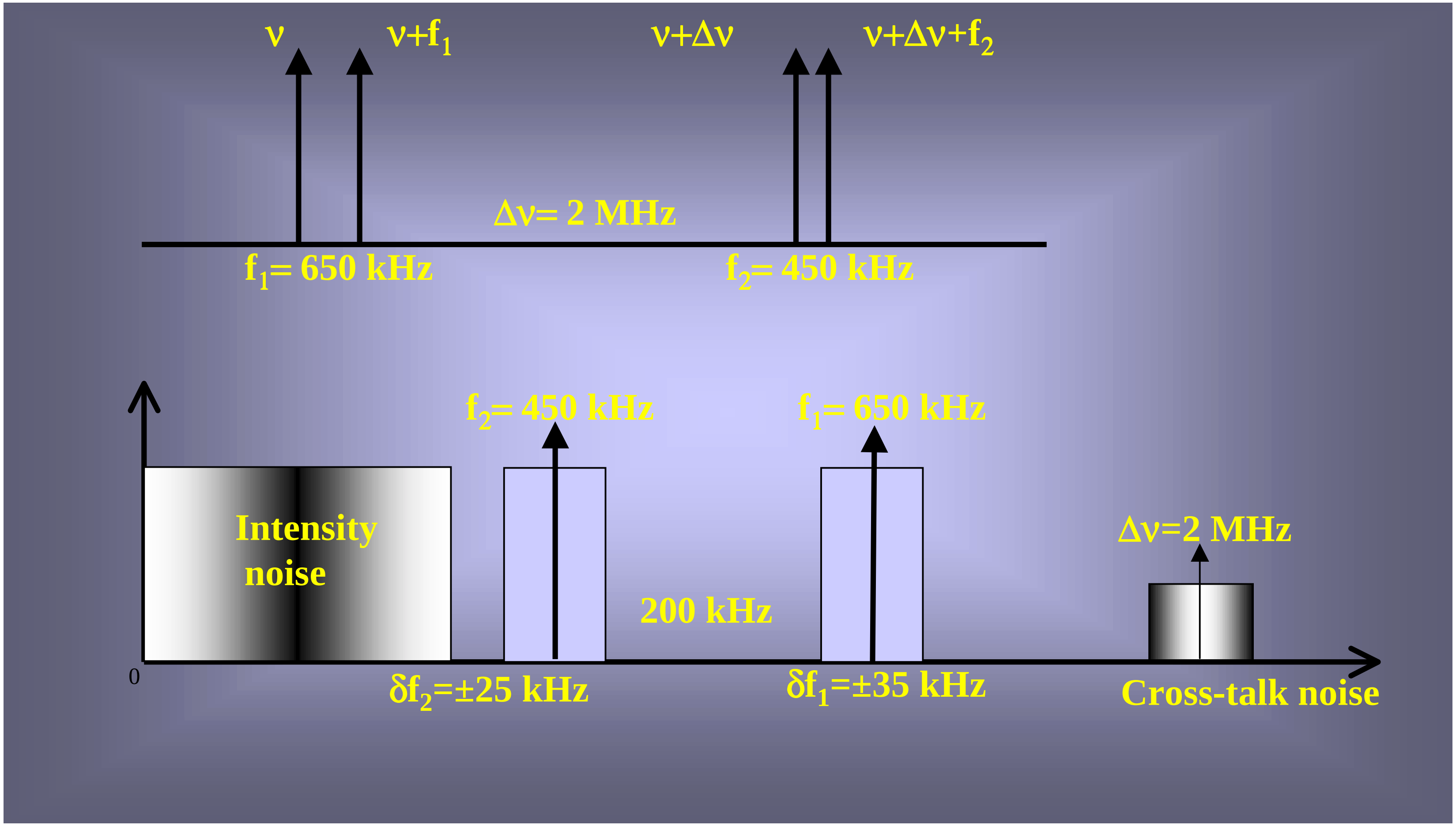
- Telescope Pair-wise configuration (L_1 and L_2 are individually monitored)
- Incremental Heterodyne interferometry with zero point calibration using stellar reference source
- Super-heterodyne phase detection
- Nd-Yag laser compatible with 500nW detected power, stability imposed by ΔL only
- Common mode injection using central obscuration
- Metrology end points installed in the image of the telescope's central obscuration

Sub-system Breakdown



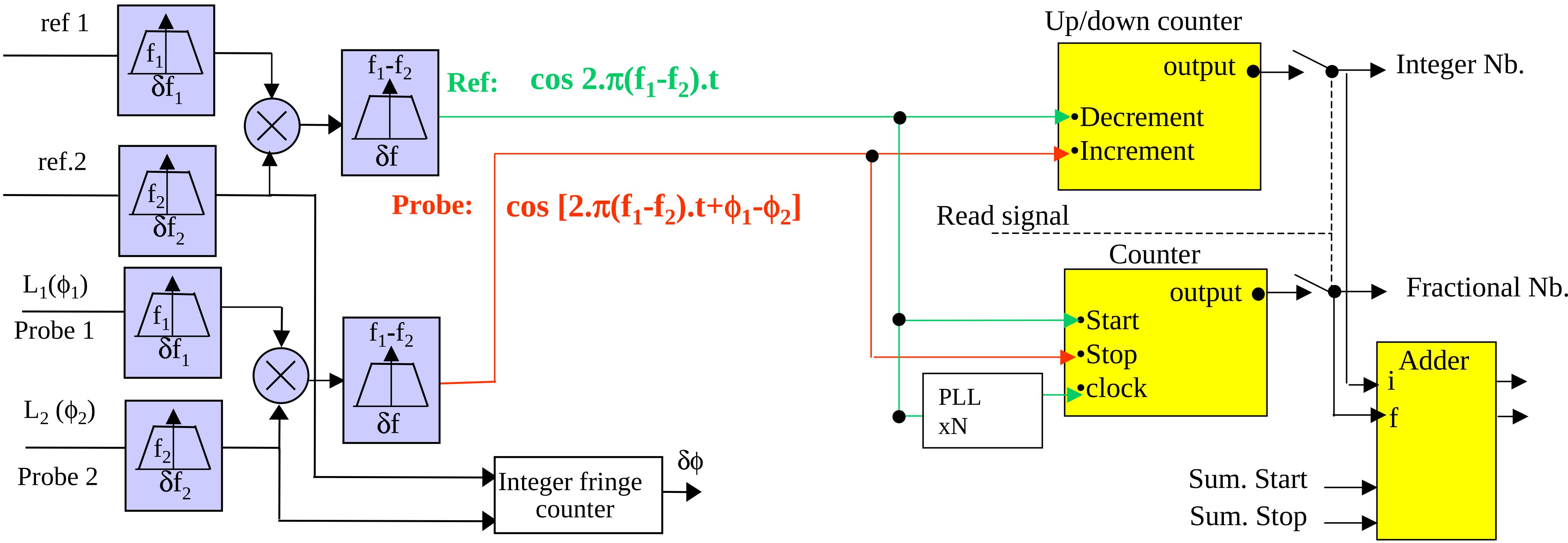
Allocation of heterodyne frequencies

- Cross-talk minimized by operating with different heterodyne frequencies $f_{i=1,2}$ separated by $\Delta\nu$
- $L_{i=1,2}$ coded at frequency $f_{i=1,2}$
- $\delta f_{i=1,2}$ given by dynamic requirements driven by the PRIMA differential delay lines



Phase Meter

- Direct measurement of ΔL using super-heterodyne detection [7]
- Digital phase meter: Phase difference given by counting number of clock cycles
- Clock generated from reference signal using PLL to avoid phase drifts

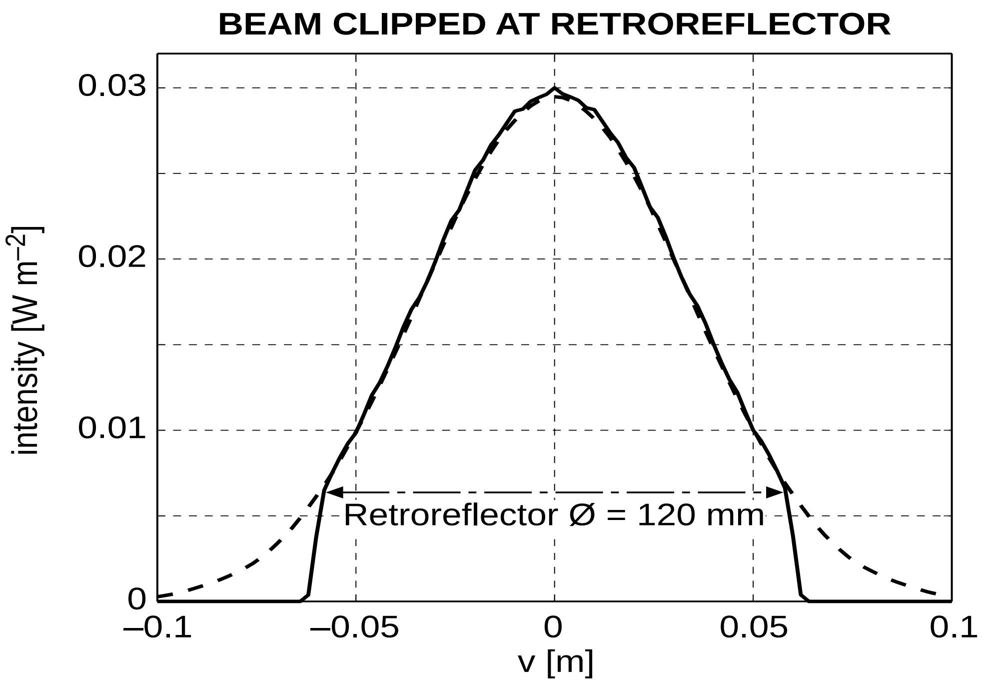


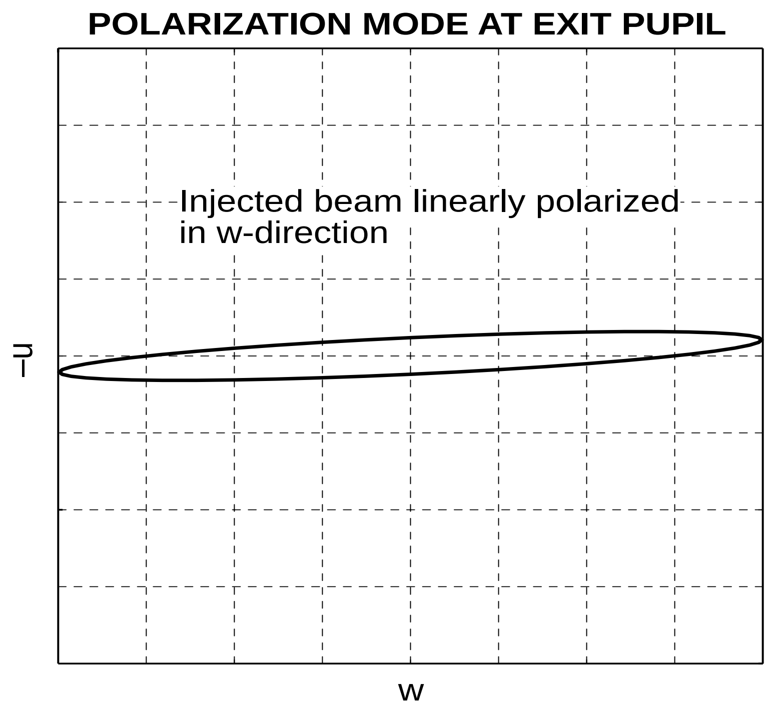
Laser beam propagation simulation

Gaussian Beam superposition algorithm [8] used to simulate diffraction effects induced on laser beam propagating through overall VLTI optical train (return way):

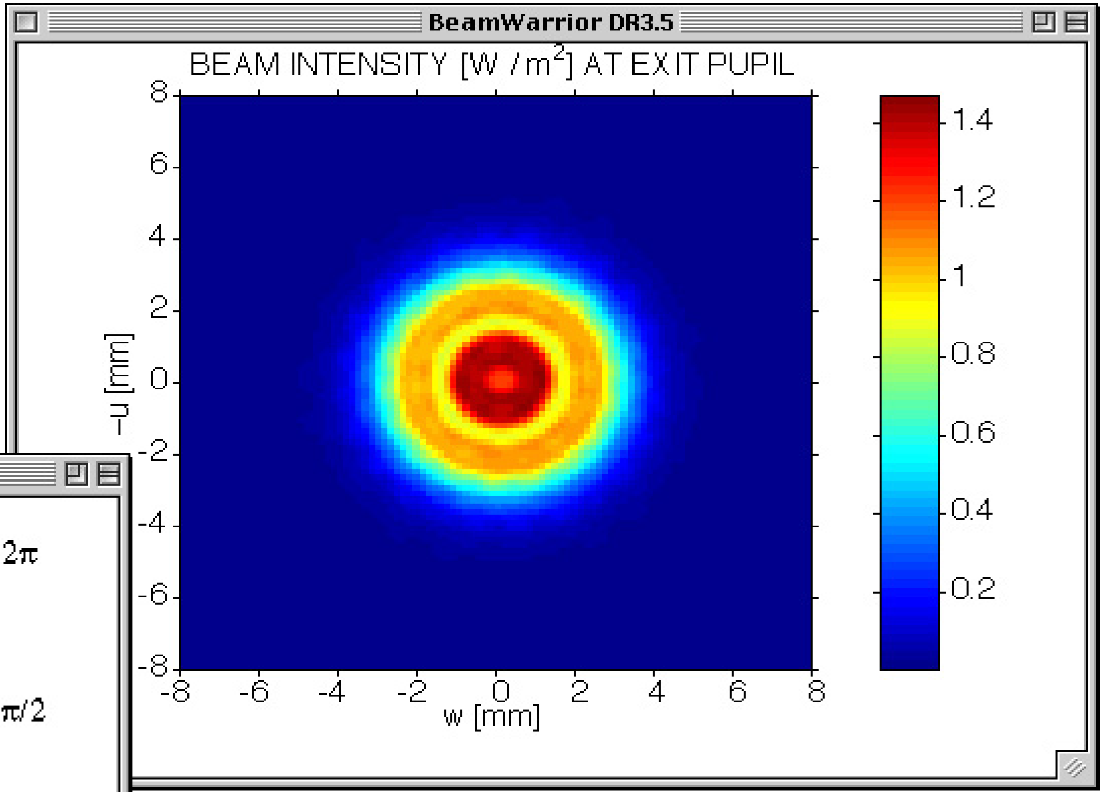
- Characteristics of injected laser beam:

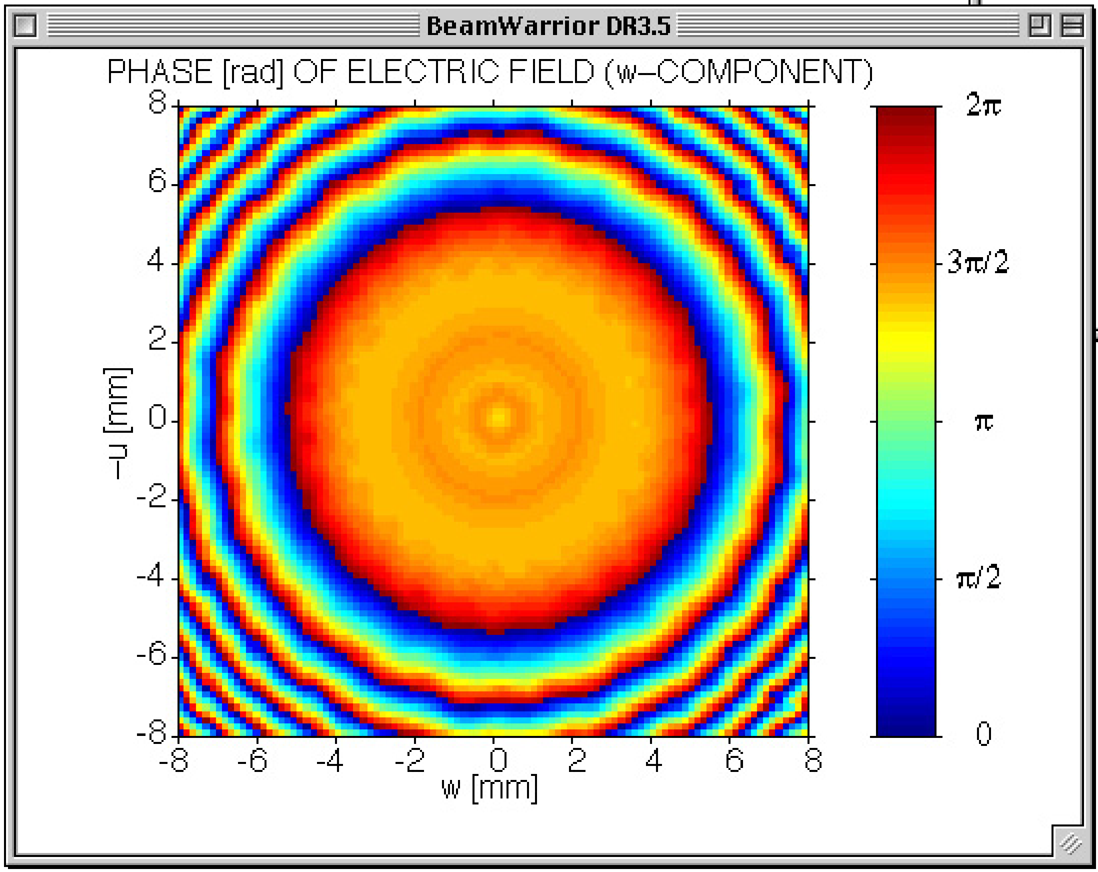
  Mode: Gaussian TEM_{00}
  Polarization: Linear (W-direction)
  Wavelength: 1 μm
  Power: 1mW
  Waist size: 4.1 mm (image of central obscuration for the UT's)
- Propagation distance : 177 mx2= 354m (return way)
- "Perfect" Retro-reflector located at the center of the Telescope's secondary mirror





Returned intensity and phase map of laser beam after 354 m propagation (return way) through the VLTI optical train





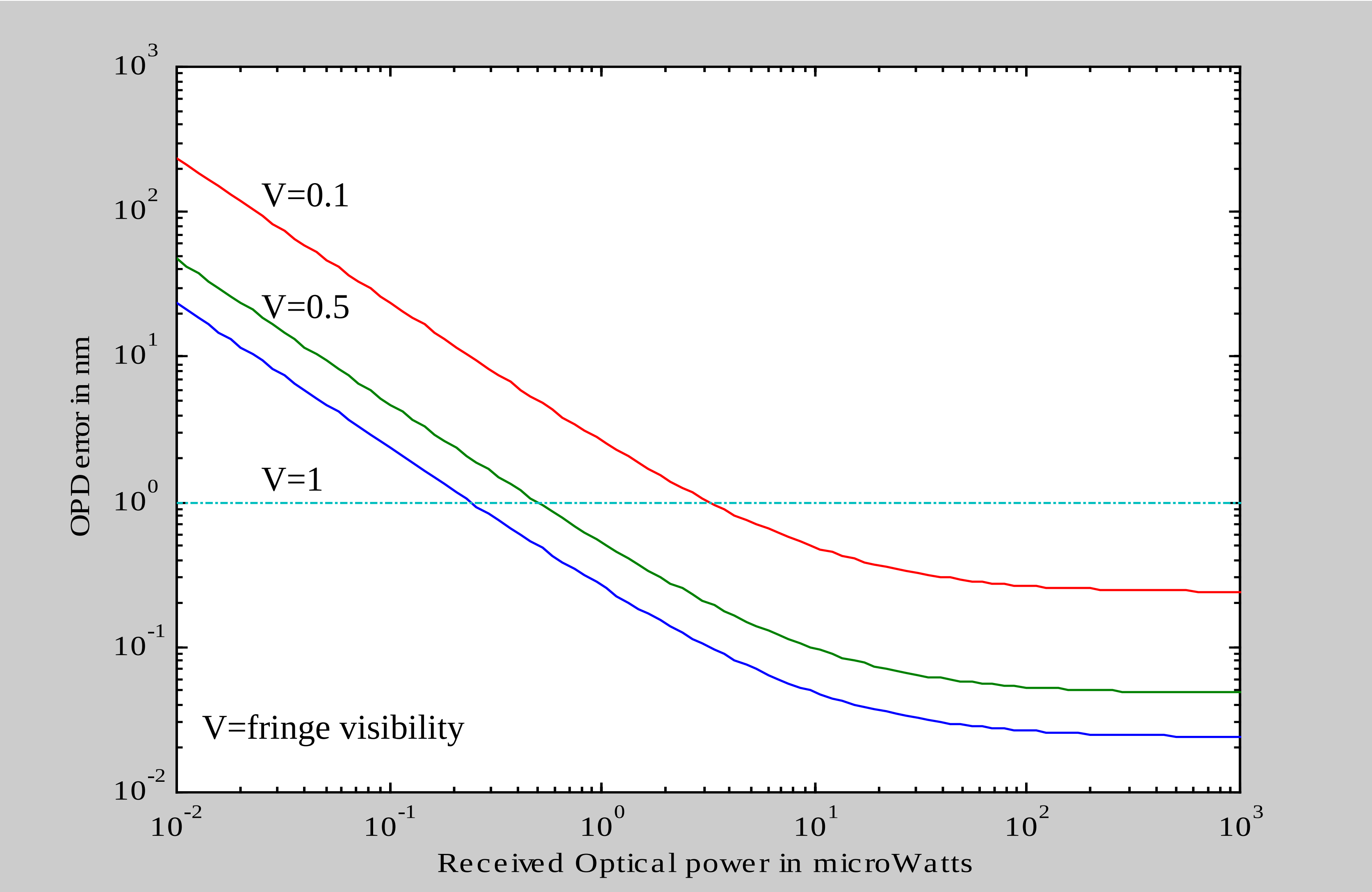
Conclusion:

Polarized heterodyne interferometry using telescope's central obscuration feasible from diffraction point of view

Identification of error sources

Error sources on ΔL	
Layout errors	**Instrumental errors**
• Beam routing (OPL offsets and misalignments) *Retro-reflector* *Beam injection/combination* *VLTI optical train* *Active mirror* *Air turbulence* *Mechanical stability* *Thermal effects* • Wavefront distortion *Deformable mirror* *Internal air turbulence* • Figuring errors associated with beam walk • Field dependent errors	• Laser head *Frequency stability* *Power stability* • Electronics *Detection noise* *Signal conditioning noise* *Demodulation noise* • Optical cross-talk • Metrology Wavelength dependent errors *Chromatic errors on coatings* *Air dispersion* • Drift of "zero" point (dead path)

Example of detection noise for a given laser fringe visibility



Conclusion

The PRIMA metrology system must clearly meet an ambitious accuracy goal. A baseline for this metrology system has been identified, including a phase demodulation architecture. The next steps will include the consolidation of the metrology error budget. The development of a prototype of the phase meter is planned in the course of this year and measurements will be performed at Paranal to characterize in more detail the effect of internal turbulence in the context of PRIMA.

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