Astrometric Survey for Extra-Solar Planets with PRIMA

Documents Spawned off the Error Budget for Astrometry

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Classification of Error Sources.

Top-down approach (Geometry).

Principle of Operation: two interferometers (dual beam mode). Astrometric angle on the sky and fundamental variables:

$$\tau = \frac{\Delta D}{b} \frac{1}{\cos(pos.\,angle, Proj.\,baseline\,vector)}$$

10 μas $\sim$ 5 nm in ΔD, $\sim$ 50 μm in b @ 100 m, $\sim$ 0.1" in A, z

- differential OPD ΔD: statistical (atmospherical + tunnel piston); biases/systematic (opto-mechanics, dual-beam asymmetries, atmospheric lensing)
- baseline b: calibration (inverse astrometry); reference frames
- resolution cosine: diurnal motion (scheduling, AT station choice)

Classification of Error Sources.

Top-down approach (Optics).

Measured

- FSU, three spectral channels, two stars:

$$A, B, C, D = \int e(k)\,[1 + \cos\{n(k)kD_t - kD(k) + \varphi(k)\}]\,dk$$

$e(k)$	spectrum (star, atmosphere, VLTI transmission Beam Combiner, fiber coupling efficiency, detector QE)
$n(k)$	humid air dispersion
D_t	position of (differential) DL
D	**wanted** "external" delay, w/o atmospheric lensing
φ	K-prism, VLTI polarization, pistons

- PRIMET, one differential value:

$$n(1.3\mu)kD_t$$

AT mirror train unseen by PRIMET.

1. Delays observed by LCU but not PRIMET: OPL leakage.

Path differences introduced by AT M1–M9 are hidden variables: they are measured by the FSU but not seen by PRIMET. The threat and ambiguity: false interpretation as originating from angular position on the sky.

Classification:

- By design: (i) at least one star is off-axis (optics astigmatism) (ii) STRAP $\rightarrow$ M6 offloads
- By tolerances as build, by vibrations, by temperature sensitivity: finite AT skeleton stiffness, 10 μm spec in design

Notes:

- Need 4-beam (AT) asymmetry to take influence on ΔD.
- M1–M9 **rotations hurt too** because beam centers hit off-axis.

AT mirror train unseen by PRIMET.

2. Sensitivities to Displacements and Tilts.

Both beams generally hit (powered) optics M1–M9 off-center: $\Delta D = 5$ nm in 2-beam OPD are equivalent to

- 0.2μm motions of M1, M2, M5 and M7; two insensitive directions.
- $0.1''$ rotations of M1, M2, M5; $0.01''$ rotations of M7, M8

for star separation $\tau = 60''$. Beneficial

- scales $\propto 1/\tau$ (relaxed by factor 3 if $\tau \searrow 20''$)
- net effect is differential residual between two AT's. "Common mode" static flexures for AT's at the same zenith angle z, same wind load, same temperature T cancel in ΔD.

Mechanical stability supra-challenging.

Tentative AT mirror calibrations.

Extended PRIMET pointer STS→M2, RR3→ M2R.

Proposal of placing PRIMET point of return to M2: Problems

- Split ($\sim$ bi-spherical) retro-reflector in M2 center hole must co-rotate with STS to accommodate both metrology legs (M2 not an image plane of M10).
- 1 : 20 undersized central laser beam diameter is 20$\times$ less sensitive to translations and rotations
- Need circularly polarized PRIMET beam (otherwise polarization a function of A, z). Returned PRIMET power down to 15% (50% absorption, 30% clipping at M2).
- UT tests with 11 mm $\emptyset$ metrology beam (to M4 Nasmyth): **Large telescope run-outs** with loss of overlap.

Or: Dedicated off-axis local metrology laser?

Tentative AT mirror calibrations.

Calibration by Inverse Astrometry. Software.

Calibration: Complementary version of the baseline calibration and yet another form of inverse astrometry: For known τ, b and position angle, the expected ΔD can be deferred and compared with the signature generated by moving the star pair across the FOV (wobbling as compared to chopping or nodding: yet another "differential" mode, but only M1–M3).
Software: Low-frequency vibrational modes of the AT's seen in the two FSU phases can be "counter-rotated" in software (in f-space) prior to co-phasing. Restriction: frequencies well separated from stepping modes. Time signature in the FSU phases eliminated by tracking (algorithm?): and the single-beam PRIMET readings not available, this method **needs DDL re-positioning file** since single-leg PRIMET readings unavailable (or coarse to 1.3μm/2).

Differential OPD. Summary.

Error source air dispersion.

Explicit fringe position and control of the phase $n(\bar{k})\bar{k}D_t$ happens by precise movement of (geometric) delay lines D_t. An **implicit** contribution to the differential phase: difference in refractive index $n(k_{\rm PS}) \neq n(k_{\rm SS})$ implied by $k_{\rm PS} \neq k_{\rm SS}$. A contribution by horizontal T-gradients of $\sim$ 400 nm is canceled by the beam interchange/swap technique; residuals depend on products of these T-gradients by T-drifts on the time-scale of the swap-periods and are **not critical**.

Summary:
The VLT is not an astrometric telescope (J Spyromilio, VLTSW20040232)