Astrometric Survey for Extra-Solar Planets with PRIMA
Documents Spawned off the Error Budget for Astrometry

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Oct 14, 2005 / PRIMA PAOS
Classification of Error Sources.
Top-down approach (Geometry).

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

\[ \tau = \frac{\Delta D}{b \cos(\text{pos. angle, Proj. baseline vector})} \]

10 \( \mu \text{as} \) \( \sim \) 5 nm in \( \Delta D \), \( \sim \) 50 \( \mu \text{m} \) in \( b @ 100 \text{ m} \), \( \sim \) 0.1” in A, z

- differential OPD \( \Delta D \): 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:

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

- \( e(k) \) 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
- \( \varphi \) 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 → 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 $\Delta D$.
- 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:

- 0.2$\mu$m 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 $\tau \downarrow 20''$)
- 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 $\Delta D$.

Mechanical stability supra-challenging.
Proposal of placing PRIMET point of return to M2: Problems

- Split (∼ 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× 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 ∅ 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 $\tau$, $b$ and position angle, the expected $\Delta D$ 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 1.3 $\mu$m/2).
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 $n(k_{PS}) \neq n(k_{SS})$ implied by $k_{PS} \neq k_{SS}$. 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)