MIDI performance enhancement with FINITO and PRIMA

Ringberg meeting - September 01-05, 2003

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MIDI needs

- Exposure time limited by the background (~800ms)
- If no fringe tracking: need to find the 10\(\mu\)m fringes in each frame =>
  - Limiting magnitude \(N = 5\) (8) with the ATs (UTs)
- If external fringe detector: coherent frame addition in post-processing =>
  - Limiting magnitude \(N = 8\) (11) with the ATs (UTs)
- If dual-feed and phase-referencing:
  - Aperture reconstructed imaging
  - Differential phase measurements
  - Access to objects with no near-IR counter-part
- On-axis fringe tracker
- H-band
- 3-way beam combiner
- LAD and TAD compensation
- No recording of delay
- Installed in Paranal
- Under commissioning
- OPD time scanning
FINITO (2)

- Phase Delay = OPD mod δ
  - High frequency (up to 2kHz)
  - Low noise
  - Small range (Δ)
- Group Delay or Coherence = “white” fringe position (LAD)
  - Low frequency (up to 50Hz)
  - Higher noise
  - Large range (10 Δ) for fringe jump detection & correction
- Limiting magnitude: H=9 to 11 (UT)
PRIMA (1)

- VLTI *Dual-Feed* facility => off-axis fringe tracking
- 3 aims:
  - faint object observation (by stabilising the fringes)
    - dual-feed / dual-field : 2’ total FoV (2” FoV for each field)
    - K=13 (guide star) - K=20 (object), N=11 on UTs
    - K=10 (guide star) - K=16 (object), N=8 on ATs
  - phase-referenced imaging
    - accurate (better than 1%) measurement of the visibility modulus and phase
    - observation on many baselines
    - synthetic aperture reconstruction at 10 mas resolution (10 μm)
  - micro-arcsecond differential astrometry
    - very accurate extraction of the astrometric phase:
      - 1<sup>st</sup> phase ~ 2006 : 100 μas
      - 2<sup>nd</sup> phase ~ 2008 : 10 μas
    - 2 perpendicular baselines
    - 2 phase-reference stars (2D-movement of photocenter)
4 sub-systems:
- Star Separators (2 on ATs during phase A)
- Differential Delay Lines (4) (not in phase A unless…)
- Fringe Sensor Unit(s) (2)
- PRIMA Metrology (1)

For phase B & C:
- 2 Star Separators on UTs
- 4 Differential Delay Lines
- upgrade Metrology

\[ \text{OPD} = \text{S.B} + f + \text{OPD}_{\text{turb}} + \text{OPD}_{\text{int}} \]
PRICS: Control S/W

14 control loops working in parallel
PRIMA performance

- **Fringe tracking in K-band:**
  - **Phase delay:**
    - Measurement frequency up to 8 kHz (closed loop residuals 70nm rms)
    - OPD measurement noise on the ATs =
      - 70 nm rms at K=7 (0.25 ms)
      - 140 nm rms at K=11 (2 ms)
    - Maximum allowable closed loop residuals ~ 370 nm rms (fringe jumps)
  - **Group delay:**
    - Measurement frequency up to 200 Hz
    - GD measurement noise on the ATs =
      - 900 nm rms at K=7 (5 ms)
      - 1900 nm rms at K=13 (200 ms)
      - 2300 nm rms at K=16 (2 s)

- **Incremental Metrology at 1.3 µm:**
  - Resolution = 1nm
  - Accuracy on 30 min = 5nm <=> 0.05% on phase in N-band
  - Measurement frequency = 200 kHz

- OPD, GD, metrology are stored at max 8 kHz
PRIMA Performances

FSU B – Limiting Magnitude

AT case

Limit OPD where probability of fringe loss is too high

OPD residuals on axis for the optimum integration time [microns rms]

Star K magnitude

6  7  8  9  10  11  12  13  14  15

10^0  10^1  10^2  10^3
PRIMA Performances (2)

Instrument integration time - anisoplanatic differential OPD

AT case

AT case, B=210m, 3 different off-axis angles

Anisoplanatic differential OPD jitter during the exposure [um rms]

Integration time on the off-axis object [seconds]
Sky coverage (1)
Sky coverage (2)

Limiting magnitude = 13 - K-band - radius = 60 arcsec

galactic inverse latitude (radius, in degrees)
MIDI Performances with Fringe Tracking

- **With FINITO**
  - Available in 2004
  - H-band
  - Fringe stabilisation at 100nm (370) rms on-axis (closed loop)
  - Needs star brighter than H=6 (8) on ATs
  - Blind adding of stabilised frames in post-processing
  - Fringe visibility loss =
    - 0.2% (0.5%) on-axis
  - Increase of MIDI limiting magnitude by 3 magnitudes

- **With the FSU**
  - Available mid-2005
  - K-band
  - Fringe stabilisation at 70nm (370) rms on-axis or off-axis
  - Needs star brighter than K=8 (12.5) on ATs
  - Coherent adding of frames in post-processing (slight improvement)
  - Fringe visibility loss =
    - 0.1% on-axis
    - + 3% at 10"
    - + 80% at 60"
  - Increase of MIDI limiting magnitude by 3 magnitudes + of near-IR counter-part
Imaging dynamic range $D$ is given by:

$$D \sim \sqrt{M \cdot \sqrt{N_{\text{baselines}}}} / (\sqrt{I} + \sqrt{N})$$

- Where
  - $M =$ number of observations
  - $N_{\text{baselines}} =$ nb of independent baselines
  - $\sqrt{I} =$ error on phase
  - $\sqrt{V} =$ error on visibility modulus

Very important:
- Increase the number of independent baselines
- Well distribute the baselines (not especially uniform)
- Keep a very good accuracy on the phase (1% error on visibility modulus $\leq 0.01$ rad error on phase)
Potential risks & limitations

**FINITO**
- Use not possible on siderostats (photometric variations too high)
- Current absence of an IR tip-tilt tracker in the lab (IRIS)
- Larger detector noise than expected (=> limiting magnitude)
- To be commissioned soon => then the performances will be known

**PRIMA & FSU**
- Currently only for the ATs in PRIMA mode (on-axis with the UTs is allowed)
- IRIS should be installed and running by 2005
- Detector noise at longer $T_{\text{int}}$
- Group Delay bias long term stability is critical for phase-referencing (large number of baselines = long observation programme) => FSU calibration is essential
- Still to be built and installed but thorough modeling

The accurate knowledge of the atmospheric dispersion (LAD-TAD) will probably be essential to reach the ultimate accuracy.