Concept for Fiber-Based Near-Infrared Interferometry of Highest Frequency Resolution

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***Abstract* - We are presenting first experimental results for subsystems of a low-cost near-infrared heterodyne interferometer concept based on commercial 1.55μm fiber-components with relative phase-stabilization between both telescopes, a shot noise limited heterodyne scheme with ambient temperature operated photodiodes, an ultra-coherent fiber laser, and a ROACH-based correlator. After a first demonstration with two 14" amateur telescopes on Betelgeuse, the concept should be upgradable to connect mid- or large-class telescopes, also given that the employed fiber phase stabilization scheme will enable the operation of long baselines.**

MOTIVATION AND GENERAL CONCEPT

❑ **HETERODYNE DETECTION**

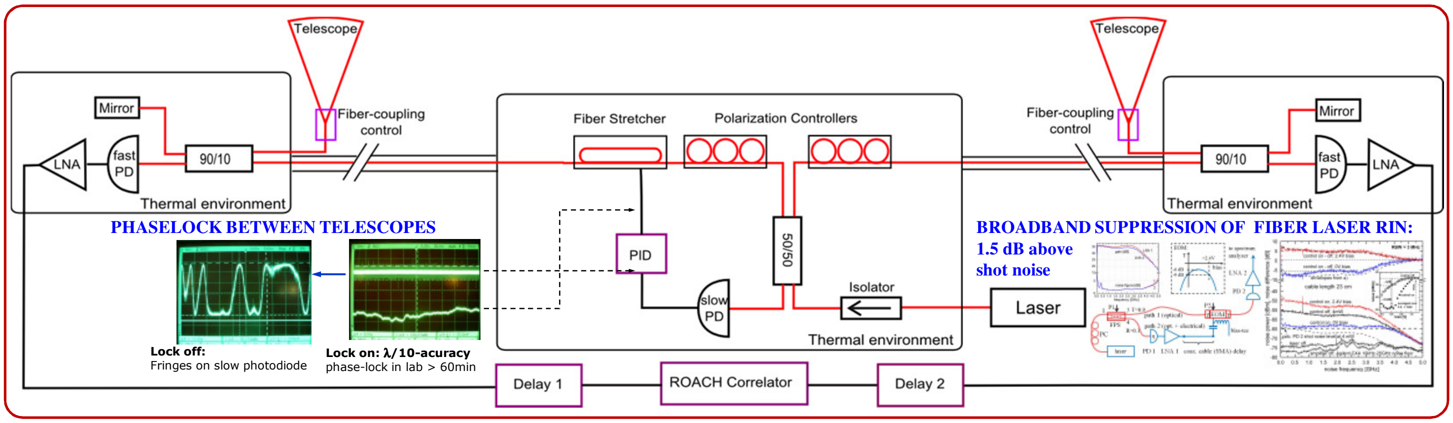
- finally highest spectral resolution possible (line emission dynamics)
- Larger coherence length due to bandwidth reduction (e.g. 3 GHz DSB) → easier delay tracking
- IF can be amplified and split up for any number of baselines
- Available digital correlation bandwidth ever increasing

❑ **FIBER DISTRIBUTION OF LOCAL OSCILLATOR TO TELESCOPES:**

- More precise phase stabilization possible with fiber-stretcher (like ALMA)
- fast 90° phase switching possible (e.g. for nulling interferometry)
- fringe stopping by LO-offset generation with fiber-frequency shifters
- mobility: connect any group of existing less used medium size optical telescopes (e.g. at La Silla, Las Campanas, or Tololo, Chile), or mobile telescopes (ISI)
- baselines of many km: use ALMA buried fibers (also w/ with 14"-Dobsonians)

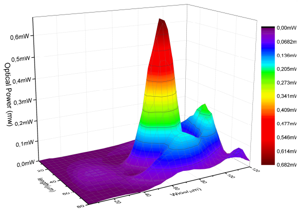
❑ **DO FIRST A PROOF-OF-PRINCIPLE IN H-BAND AT 1.55 μm**

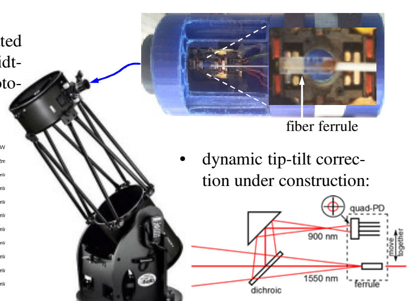
- affordable telecom-components available (good for a start-up project)
- H-band (1.4 – 1.8 μm) is an atmospheric window with >95% transmission
- Astrometry tasks for first developments (e.g. spectroscopic double-stars)
- Long-term monitoring of variable star diameters
- Planet detection over albedo comparable to thermal emission



1. FIBER COUPLING CONTROL AND TIP-TILT CORRECTION

- Low-cost electro-magnetic actuator
- Static experiment result with collimated laser from 8" Meade Schmidt-Cassegrain coupled to 14" Orion Goto-Dobsonian (parabola) [1] :





- dynamic tip-tilt correction under construction:

- for larger telescopes AO necessary

2. PHOTODIODE RECEIVERS

- Currently 3 GHz InGaAs photodiodes (Thorlabs), nominal NEP 1 fW/Hz$^{-1/2}$, optimal LO power 3 mW
- LNAs: 0.02 – 3 GHz, G=35 dB, NF=1.4 dB (two in series)
- Local oscillator: NKT-Photonics fiber laser, fixed frequency 1555.8 nm, slightly tunable by termal control (1 nm) and piezo modulation (20 pm) with up to 1 MHz speed. Linewidth: < 0.1 kHz = coherence length of > 3000 km
- Problem: Laser ASE noise 10dB over shot noise limit: developed broadband suppression to near shot noise limit [2].
- System-NEP of 0.3 nW / 3GHz, equivalent to noise temperature of 90.000 K, 3 times above quantum limit (without laser noise suppression)
- Ongoing investigation if this is due to the observed laser excess noise, and if NEP will be better with reduction of the broadband excess noise
- Optional: Characterize cryogenic cooling of PD + LNA

3. BROADBAND SUPPRESSION OF FIBER LASER RIN

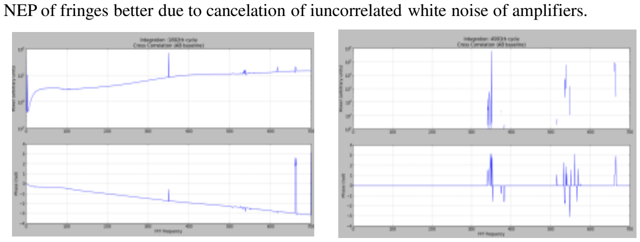
- 1.5dB near to shot noise suppression (by 8 dB at 3mW laser power) of the intensity noise from the fiber laser was demonstrated up to 3 GHz using feed-forward phase-matched destructive noise interference impressed onto the optical signal with a fiber electro-optic power modulator. [2]

4. PHASELOCK BETWEEN TELESCOPES

- Achieved in the lab λ/10 over more than an hour with two 5m fiber arms, using a simple PID-lock-loop and a kHz-fast fiber-stretcher.

5. ROACH CORRELATOR

- ROACH-board Xilinx FPGA-board with two 3 GSPS iADC cards.
- Compilation of open-source correlator models with Xilinx Simulink in Matlab/Linux environment, and development of own improved models (work in progress)
- NEP of fringes better due to cancelation of iuncorrelated white noise of amplifiers.



***Left:** Cross correlation of the two photodiode signals w/ SLED +laser illuminating both detectors. **Right:** just the amplifier noise correlated. Upper traces: amplitudes, lower traces: phase.*

5. NEXT STEPS

1. Stationary demonstration: thermal or SLED source on next building, atmospheric fluctuations.
2. Quasi-stationary interferometry w/ baseline in north-south orientation (Betelgeuse or Sirius).
3. IF delay banks w/ coax switches, w/ fibers, or program digital delays in a ROACH-board
4. Experiments with broadband (e.g. 20 nm) fiber-based fringe-tracker (correct piston phase fluct.)
5. Experiments with phase-switching and frequency offset, to obtain alternatively fringe tracking

6. LONG-TERM VISION

- "Plug in" to medium-sized telescopes in Chile, testing at ISI-Interferometer Mt. Wilson
- For larger wavelengths (e.g. 3 μm or 9-13 μm), use 1.55 μm laser to lock individual lasers (e.g. mid-IR QCLs) at the telescopes (like in the ISI-Interferometer)
- Increase of detection bandwidth with multiple LO lines or ultrafast photodiode with multiple 2. LO frequencies and individual fringe-stopping
- Nulling interferometry experiments with phase chopping
- Detect absorption / emission spectral lines

ACKNOWLEDGEMENT

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LITERATURE

[1] F. Besser, E. A. Michael, and L. Pallanca, A low-cost fiber positioner, submitted

[2] E.A. Michael and L. Pallanca, Near to shot noise suppression of arbitrary laser excess intensity noise in the gigahertz range, submitted