Implementing Multi-wavelength Fringe Tracking for the Large Binocular Telescope Interferometer's Phase Sensor, PHASECam

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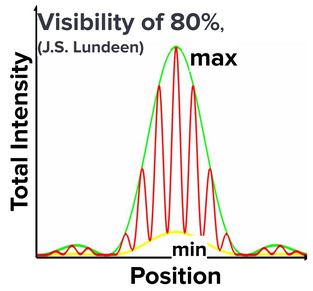
INTRODUCTION

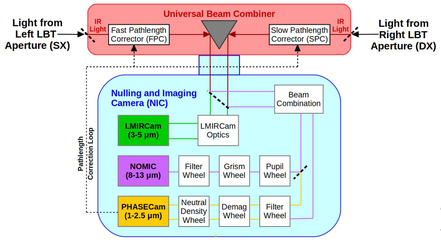
- Critical interferometric observables: fringe visibility (contrast) and phase. Max visibility requires stable fringe phase.
- Atmospheric turbulence ➔ rapid Optical Path Difference (OPD) variations between apertures.
- OPD variations ➔ fringe phase variation, bigger than fringe spacing ➔ blurred fringes, less visibility.
- 2 solutions: short integrations at cost of sensitivity, or a fringe tracker, which measures fringe phase and sends real-time OPD corrections.



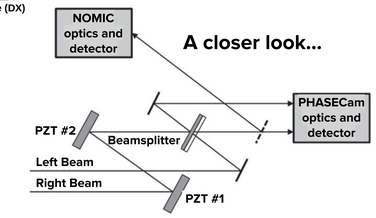
- **But phase is degenerate**: **360°** ambiguity in monochromatic fringe phase = **λ** ambiguity in OPD correction ➔ big atmosphere variations lead to **fringe jumps**.
- **Break the degeneracy by tracking at multiple wavelengths.**

THE LBTI'S FRINGE TRACKER: PHASECAM

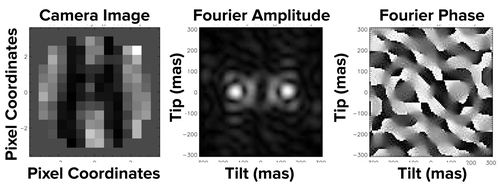
- PHASECam is near-infrared (1.5-2.5 μm) camera for tip/tilt and phase sensing.
- Receives/re-images both outputs of the Universal Beam Combiner (UBC).
- Calculates and sends tip/tilt and OPD corrections to the Fast and Slow pathlength correctors in the UBC (FPC/SPC). **Figures adapted from Defrère et al. (2015,2016).**



LBTI block diagram



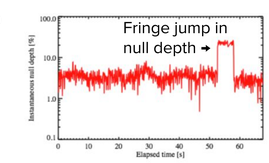
Position of peak amplitude of Fourier transform measures tip/tilt, argument at that location measures the "raw" phase.

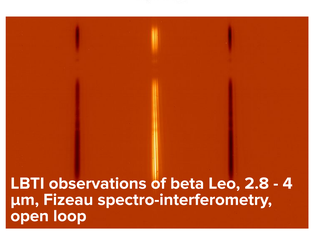


PROBLEM: Raw phase wrapped to **[-180°, 180°)**. due to nature of FT. Must "unwrap" phase

FRINGE JUMPS ON PHASECAM

- Unwrapping algorithm assumes large but slow OPD variations ➔ large raw phase change is a wrap.
- **This isn't always true, even at 1 kHz! So we see fringe jumps!**
- Before, manually corrected, but can't do this with new modes coming online.
- LBTI needs automated, observing mode-independent jump detection and correction.
- **Wait:** PHASECam collects phase data in both the H (1.65 μm) and K (2.2 μm) bands, but only uses the K-band telemetry
- **We have the data for multi-wavelength fringe tracking, so let's use it!**



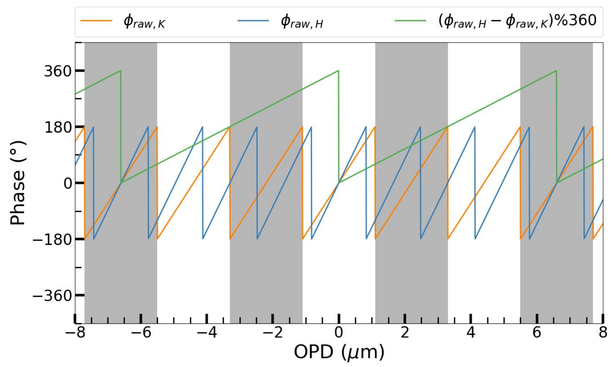


LBTI observations of beta Leo, 2.8 - 4 μm, Fizeau spectro-interferometry, open loop

THE MULTI-WAVELENGTH APPROACH

$$(\phi_{raw,H} - sp_H - \phi_{raw,K}) \,\%\, 360$$

The **Difference-Modulo Metric ➔ Diffmod**



(Maier et al. in prep)

- Linear metric, can tell if PHASECam is locked on the fringe it should be or +/-1 fringe.
- Diffmod should average to the same value over time unless there's a fringe jump.
- **The diffmod will change by 120° if a fringe jump occurs!**

IMPLEMENTATION

1. CLOSE THE DIFFMOD LOOP

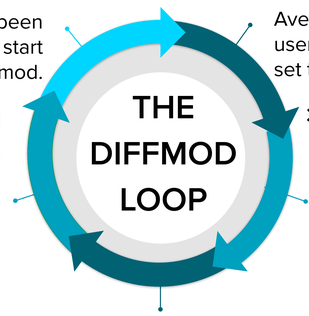
Once the phase loop has been closed and the setpoint found, start actively analyzing the diffmod.

2. WHAT IS THE REFERENCE?

Average the diffmod over a user-defined period of time to set the reference value.

3. WHAT IS THE CURRENT DIFFMOD?

Continuously average the diffmod over a user-defined period of time to find the current diffmod value to be compared to the reference.



4. COMPARE AND DECLARE

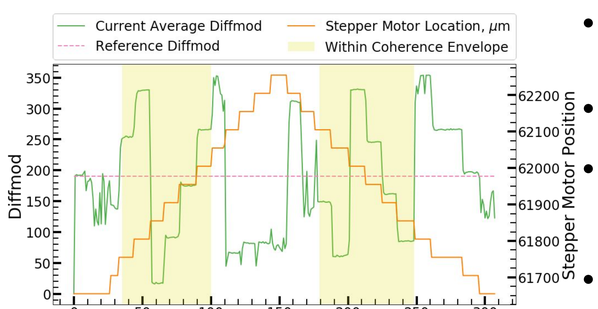
Compare the current diffmod to the reference diffmod and determine whether the system is in the central (0) fringe, +1 fringe, or -1 fringe.

5. SEND CORRECTION

If the algorithm declares the fringe to be non-zero a user-defined number of times on a sliding scale, declare a fringe jump and adjust the OPD correction by +/- λ accordingly.

(Maier et al. in prep)

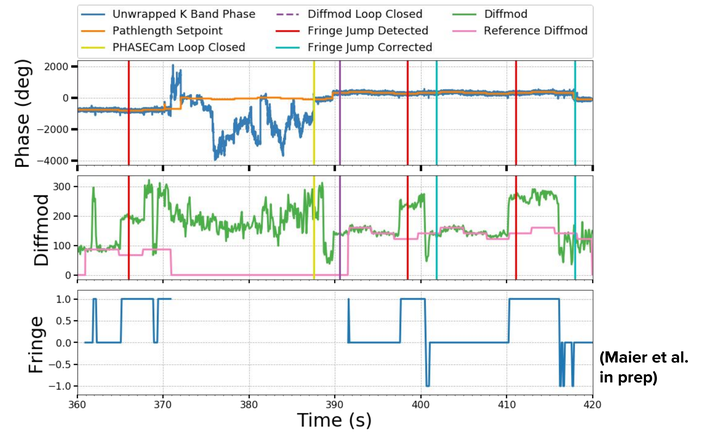
ARTIFICIAL SOURCE TESTING



(Maier et al. in prep)

- **Consistent but smaller than expected change** in diffmod for 2 μm OPD.
- Should be **≅110°**. We measure **75-80°.**
- Source (Nichrome wires) is very red in the K bandpass, essentially centered at 2 μm.
- Expected change for 2 μm OPD with 1.65 μm (H band) and 2 μm data is **≅75°.**

ARCHIVAL TELEMETRY TESTING



(Maier et al. in prep)

≅20 fringe jump events in 8 minutes ➔ ≅30% data loss

- Diffmod identified all except a few (telemetry is immutable, sometimes operator is fast).
- **Multiple cases of successive fringe jumps** (initial fringe jump detected in all cases.) Missed jumps likely to be detected in live observations with active correction.
- **Slow water vapor variations** caused some detections.

CONCLUSIONS AND FUTURE WORK

- **The diffmod is viable!** Detects fringe jumps much faster ➔ will increase average cophasing time ➔ decrease data loss.
- Qualitative check on stability of pathlength correction loop/observing conditions
- **Currently being integrated into PHASECam codebase**, relatively computationally inexpensive to implement.
- Will be implemented as a closable loop independent of the pathlength correction loop so operator can revert to manual correction if conditions are unsuitable.
- **Next step: on-sky testing at full 1 kHz data rate,** with active correction of fringe jumps. Point of investigation for testing: **1)** limits of diffmod as a function of observing conditions **2)** successive/simultaneous fringe jumps, and **3)** water vapor variations.
- **The diffmod algorithm should be fully operational sometime in the Fall 2019-Spring 2020 observing semesters.**

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