

Laboratory Demonstration of an All-Fiber-Based Focal Plane Nulling Interferometer

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Abstract

Starlight suppression techniques for High-Contrast Imaging (HCI) are crucial to achieving the demanding contrast ratios and inner working angles required for detecting and characterizing exoplanets with a wide range of masses and separations. The advent of photonic technologies provides new opportunities to control the amplitude and phase characteristics of light, with the potential to enhance and control starlight suppression. Here, we present a focal plane optical-fiber-based nulling interferometer working with commercially available components for amplitude and phase modulation. The instrument implements single-mode fiber-coupled elements: a MEMS variable optical attenuator (VOA) matches the on-axis and off-axis starlight amplitude, while a piezoelectric-driven fiber stretcher modifies the optical path difference between the channels to achieve the π phase shift condition for destructive interference. We show preliminary lab results using a narrowband light source working at 632 nm and discuss future opportunities for testing on-sky with the Parallel Lantern Injection Unit (PLIU) at the Shane 3-m Telescope.

Nulling interferometry and photonics

- **Nulling interferometry:** combines light collected from separate telescopes or sub-apertures to destructively interfere, resulting in suppression of the on-axis starlight while the companion's off-axis light remains

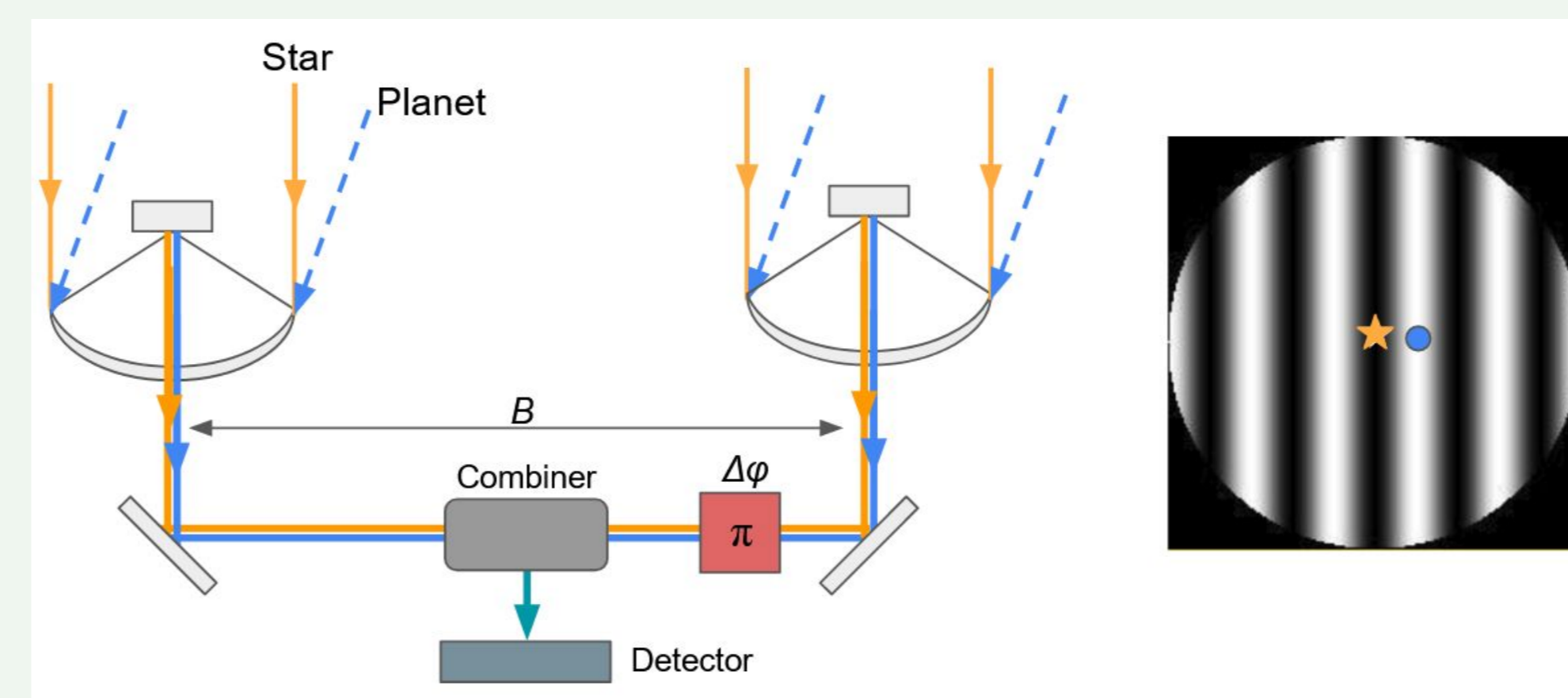


Image adapted from D. Rouan (2011)

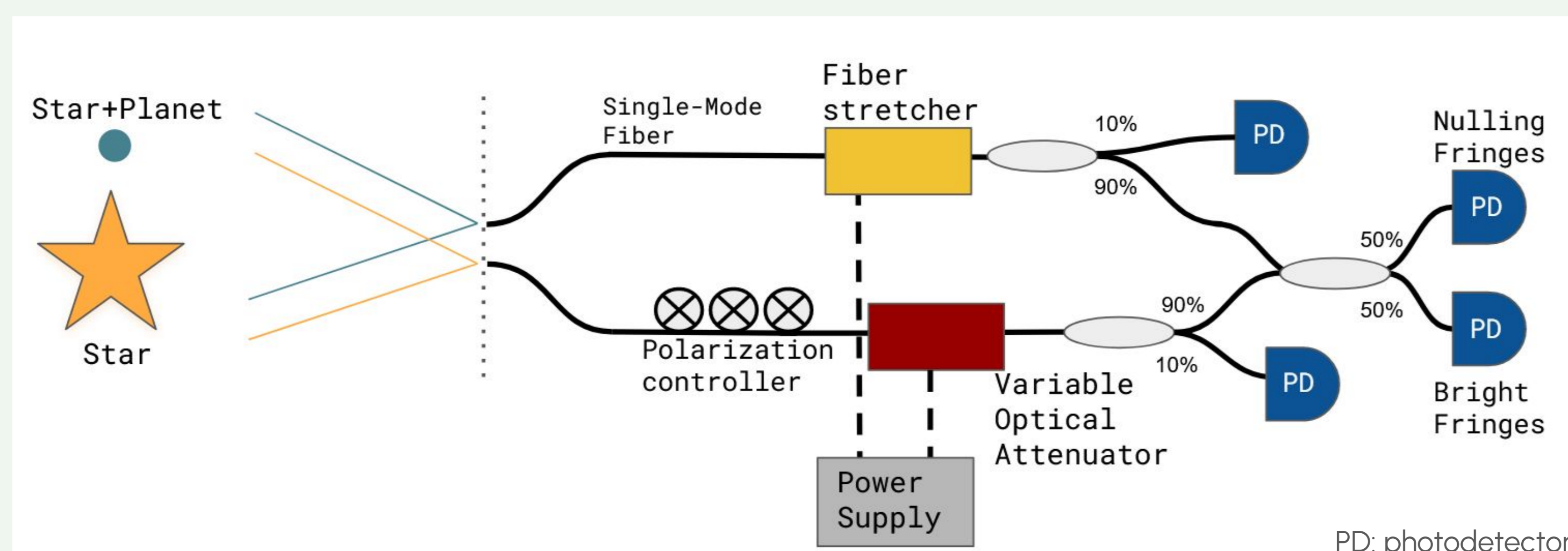
- Smaller Inner Working Angle (IWA) than coronagraphs, depends on baseline B :

$$IWA = \frac{\lambda}{2B}$$

- Single Mode (SM) devices are inherent spatial filters, improving nulling performance and enable light manipulation functionalities

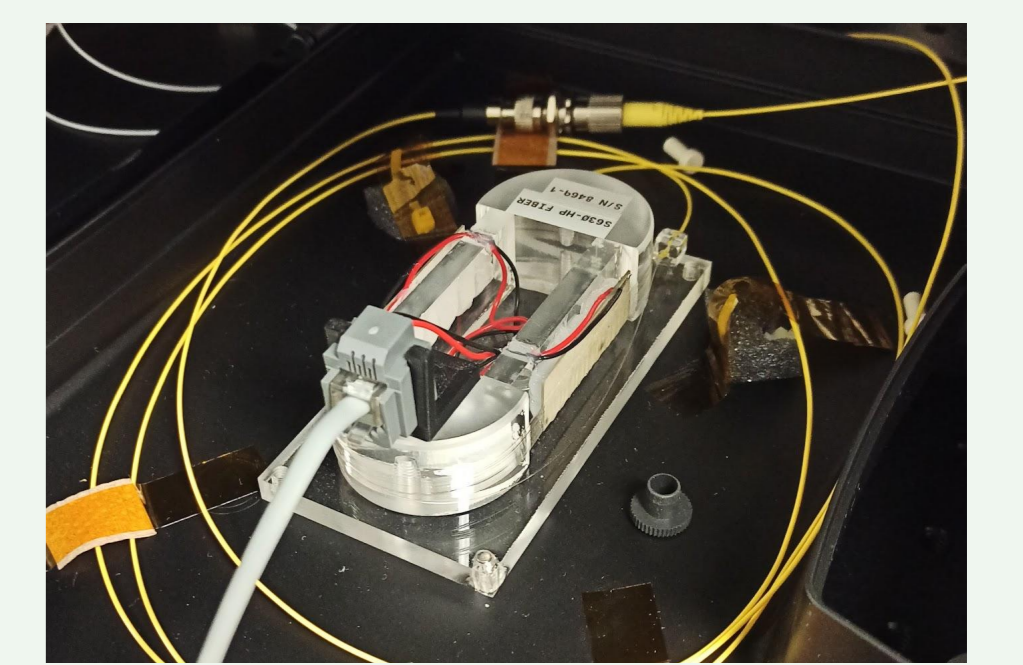
Concept and design

- Light from the (i) on-axis star and (ii) the companion + contaminating starlight is collected with SM fibers at the focal plane
- Destructive interference of starlight is ensured using phase and intensity modulation fiber components
- **Goal:** proof-of-concept using monochromatic light (632 nm) and off-the-shelf laboratory components and devices controlled via a PC



- Laboratory demonstration used a 25/75 splitting coupler: 25% - upper arm, 75% lower arm

Phase modulation - fiber stretcher



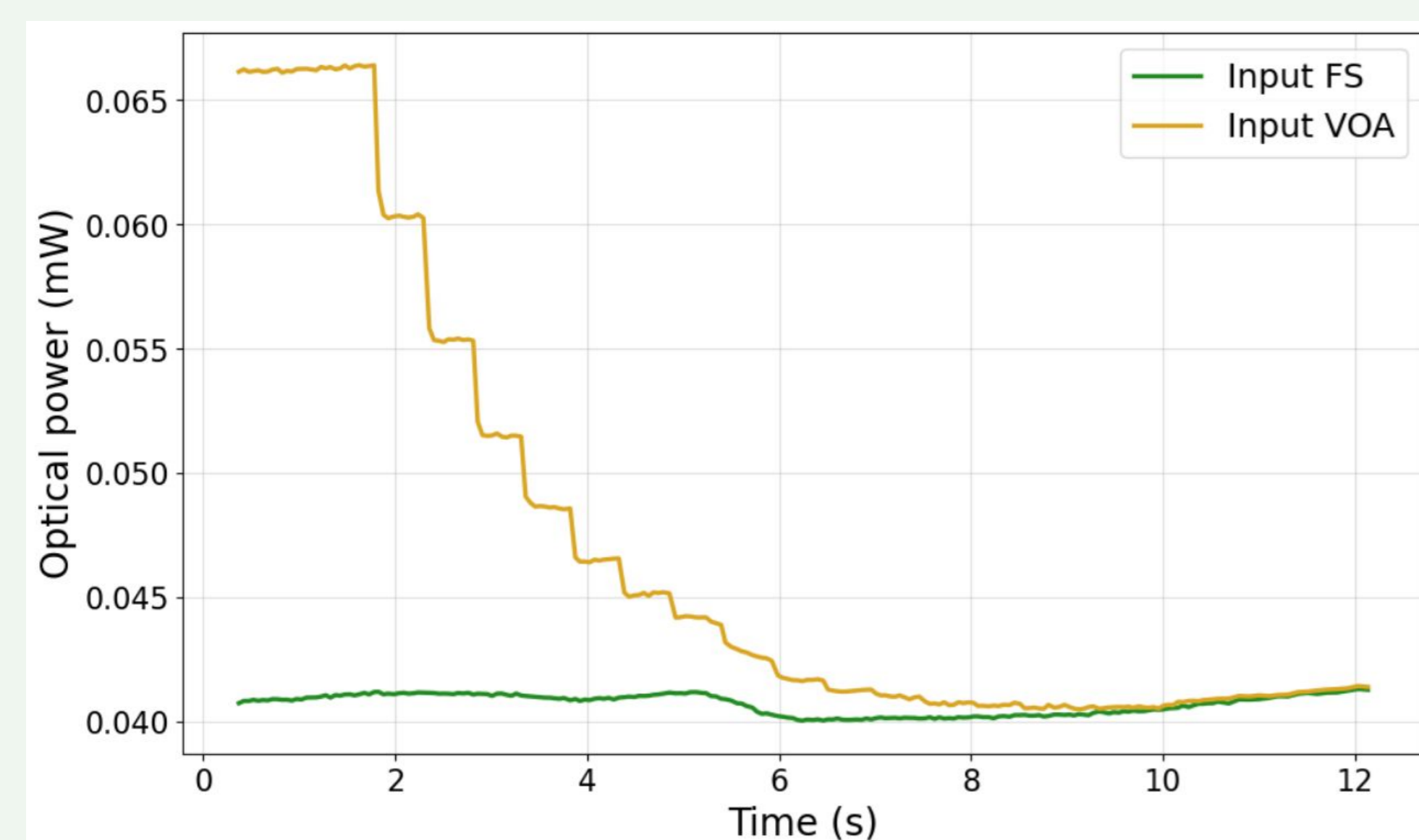
Intensity modulation - variable optical attenuator



Image: Thorlabs

Preliminary results

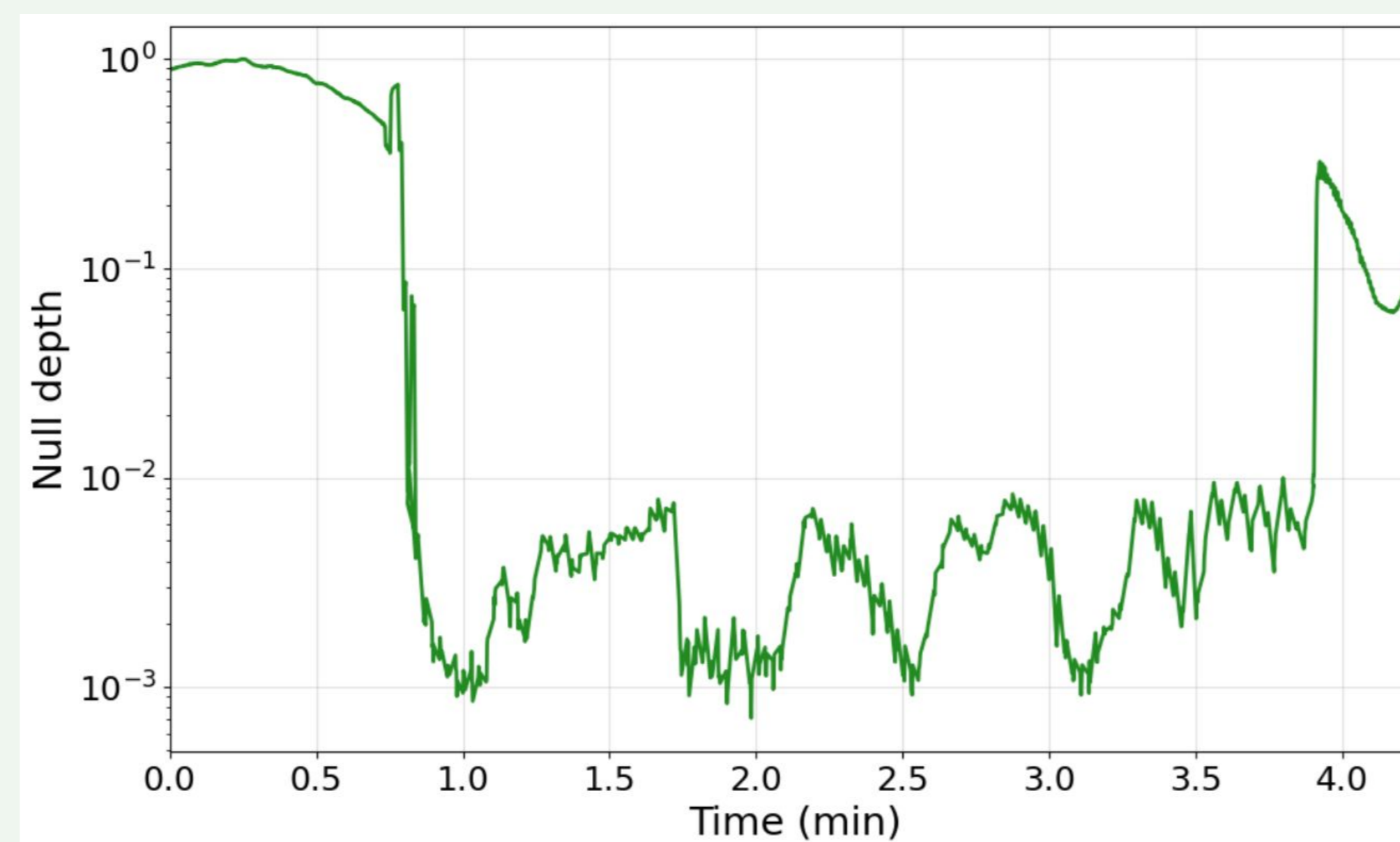
Matching input intensities



- Closed the loop for intensity stabilization using the VOA
- Monitoring done using 10% of interference input channels

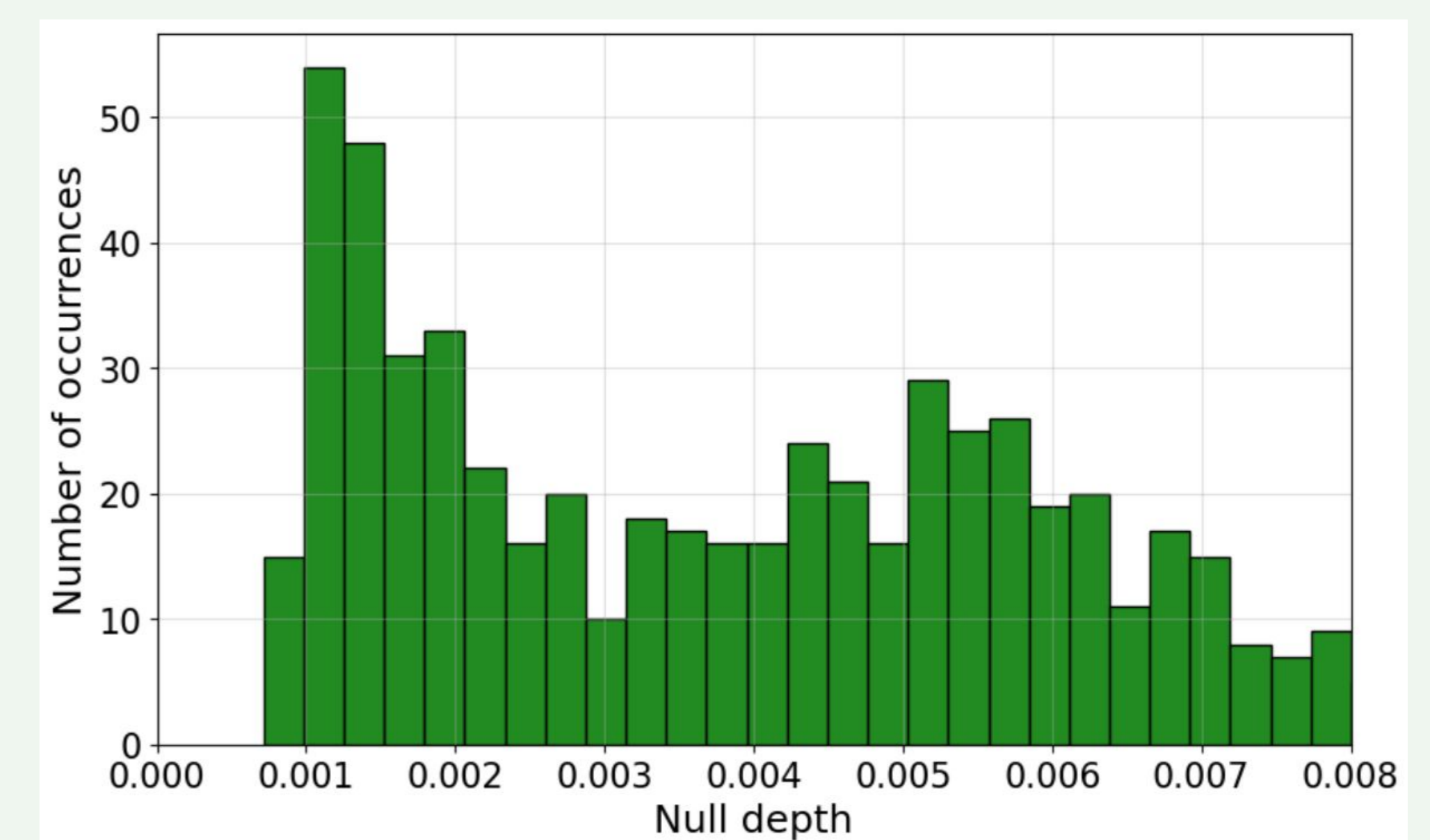
Nulling

- Contrast between dark and bright fringes is increased reducing path length difference ΔL



- Closed the loop for phase stabilization with the fiber stretcher
- Fringe tracking is done using the "bright fringe" output channel

- Improved visibility: $V=88.9\% - \Delta L \sim 6m \rightarrow V=99.8\% - \Delta L < 5cm$



- Figure of merit $N = \frac{I_{min}}{I_{max}}$
○ **Null-depth**
 $N \sim 10^{-4}$ levels reached

Conclusions & Future Work

- Demonstrated nulling interferometer proof-of-concept with monochromatic light using off-the-shelf optical fiber components with null depths $\sim 10^{-3} - 10^{-4}$
 - Null depth limited possibly by remaining path length difference ($< 5cm$) and power supply (controller) update rate of a few Hz
- Expand the concept to a multi-wavelength approach using a different wavelength to perform phase tracking
 - On-sky testing on Shane 3-m telescope using the PLIU (DeMartino, 2022) and photonic lanterns

Selected references

- R. Bracewell. *Nature* **274**, 780-781 (1978)
- E. Serabyn.. "Nulling Interferometry." In *The WSPC Handbook of Astronomical Instrumentation*, 71-89. WORLD SCIENTIFIC (2021).
- N. Jovanovic et al. *J. Phys. Photonics* **5** 042501 (2023)