# Exoplanet Detection and Characterization: Development and Results of a New Generation Imaging Fourier Transform Spectrometer

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## Overview

- An Imaging Fourier Transform Spectrometer (IFTS) extracts all wavelength information from each pixel instead of spreading it across multiple pixels, like typical dispersive spectrographs
- It is used to acquire exoplanet spectra and aid in spectral differential imaging (SDI) over a wide FOV on SPIDERS [1]

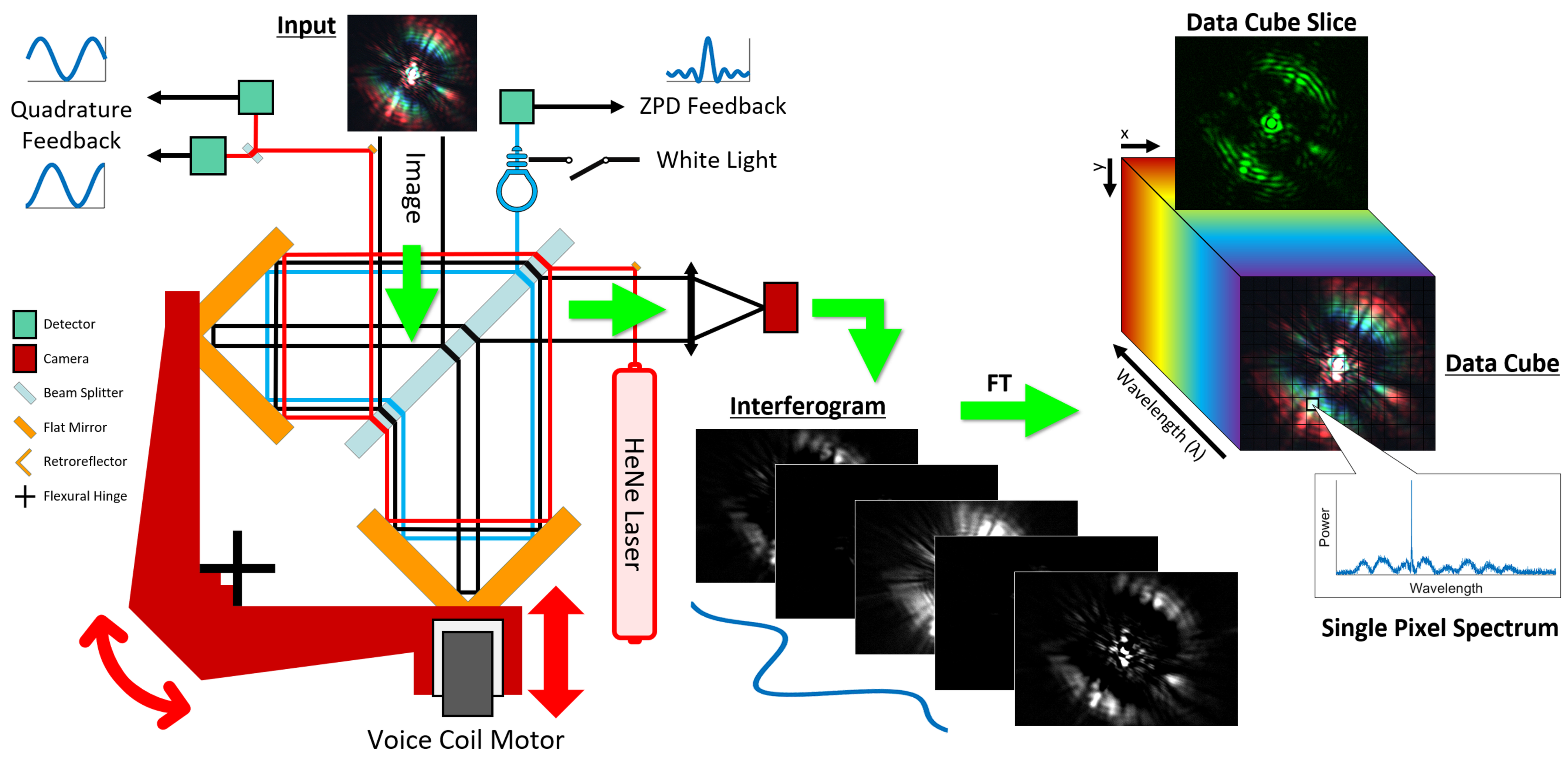


**Figure 1** – A Michelson interferometer continuously scans about the Zero Optical Path Difference (ZPD) using a voice coil motor to drive and HeNe laser for positional feedback. An incoming image is interfered with itself to produce an interferogram on the detector of a camera, and then Fourier Transformed (FT) to produce a spectrum of the image at each pixel. The resulting stack of wavelength specific images represent the spectral components (slices) of the original image and is called a data cube.

## Control System Design

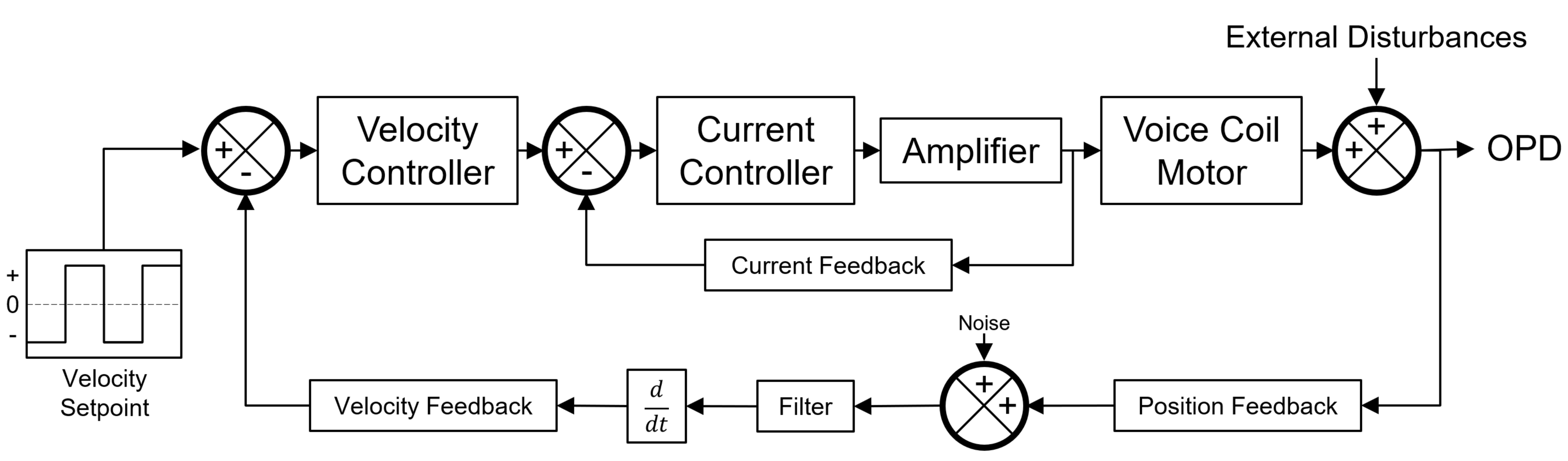


**Figure 2** – A closed-loop velocity-current cascade controller that regulates the voice coil motor trajectory to match the reference scan velocity input.

- Initial testing and implementation of PI-Velocity controller proved quadrature algorithm and effective controller regulation
- Operational range:
  - 0.18mm/s - 1.5mm/s OPD scan speed (any shape)
  - 0.078mm - 10mm (128cm$^{-1}$ - 1cm$^{-1}$) OPD scan length
  - R40 – R20,000 spectral resolution

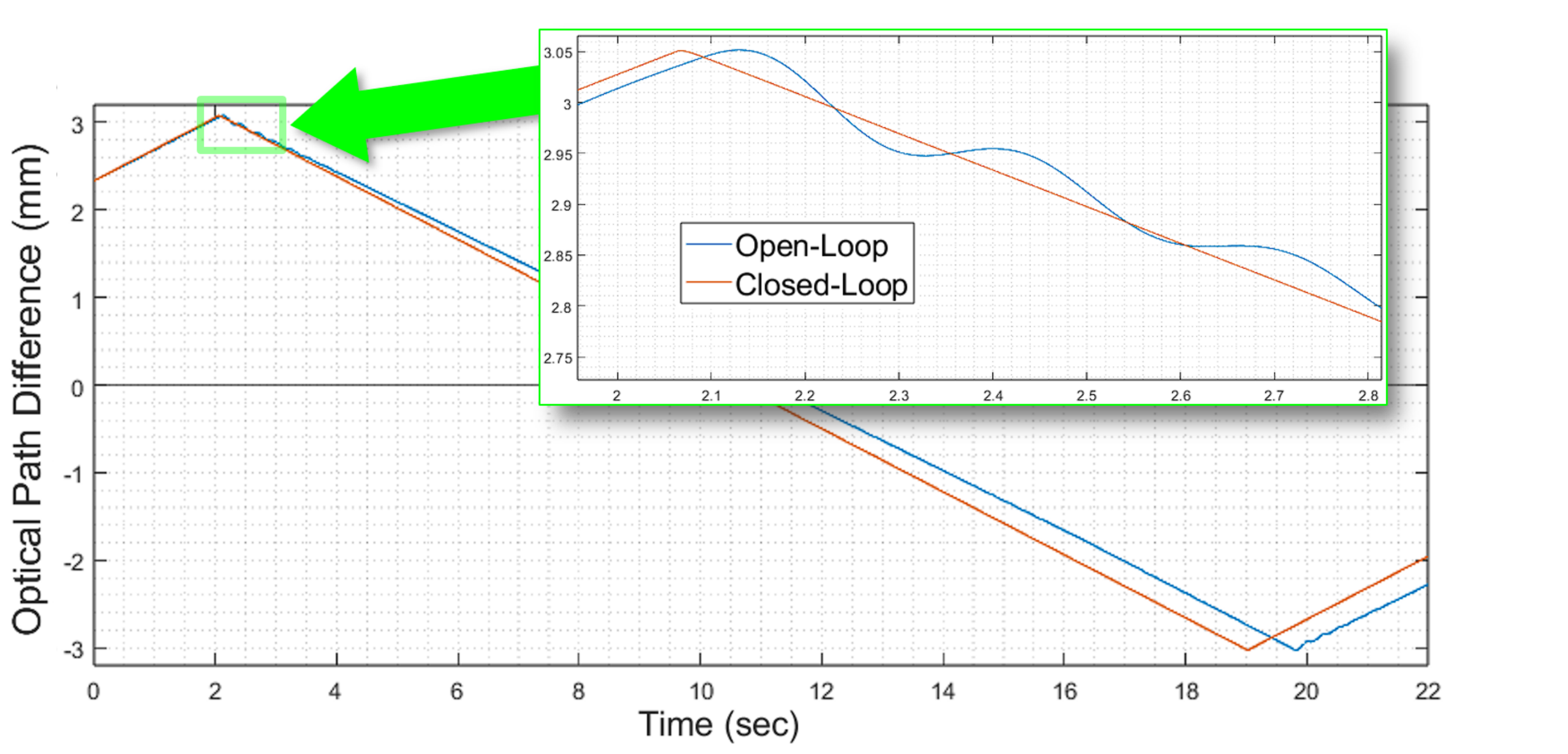


**Figure 3** – The closed-loop position response versus the open-loop response. Steady-state velocity error results in the scan taking longer to complete.

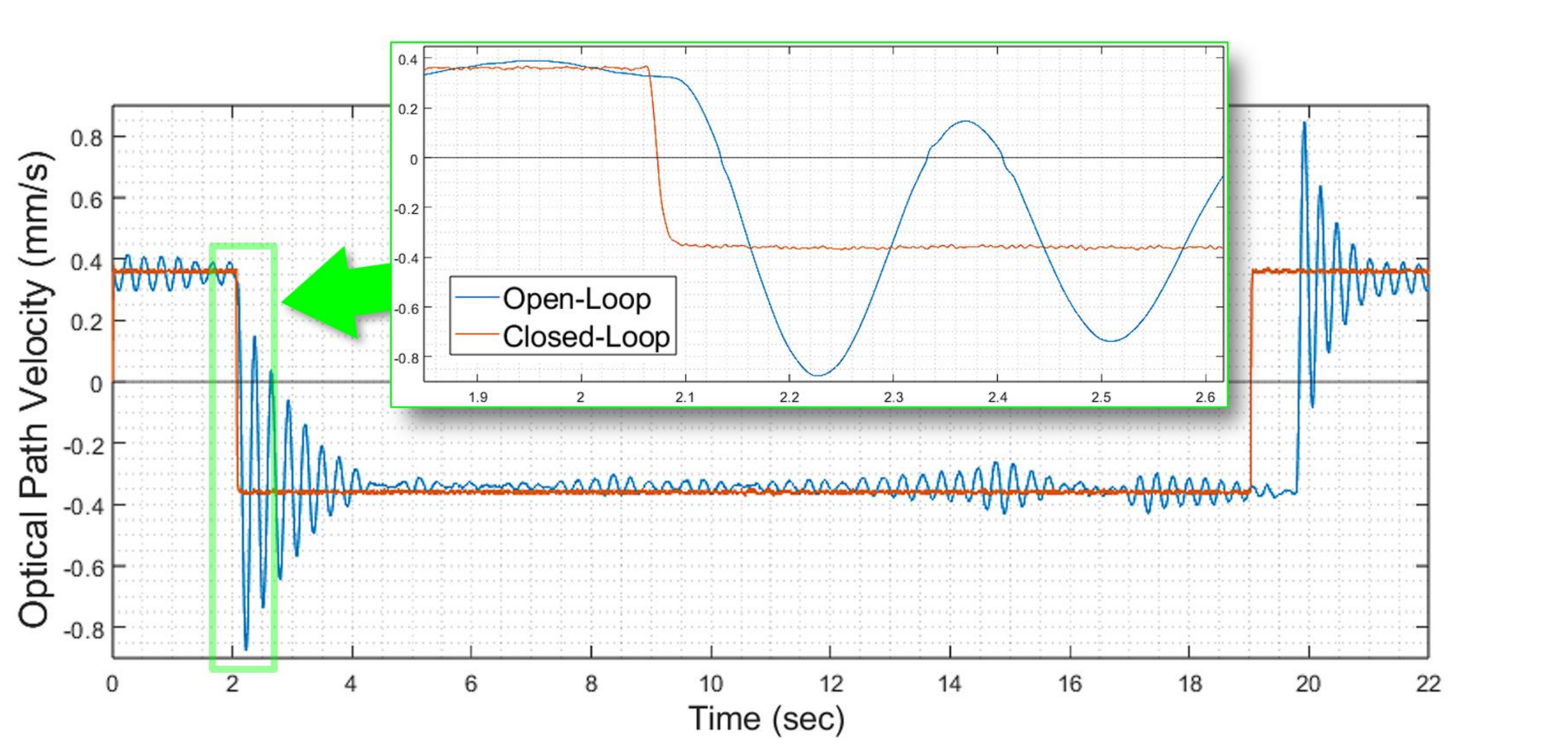


**Figure 4** – The closed-loop velocity response versus open-loop response. The closed-loop system settles quickly and maintains control even with benchtop vibrations.

1. Lardière, O. et al., AO4ELT7, 457763 (2023)

## Development and Implementation

- Custom electronics and software developed to control the system in real-time at 100kHz sampling and command rates

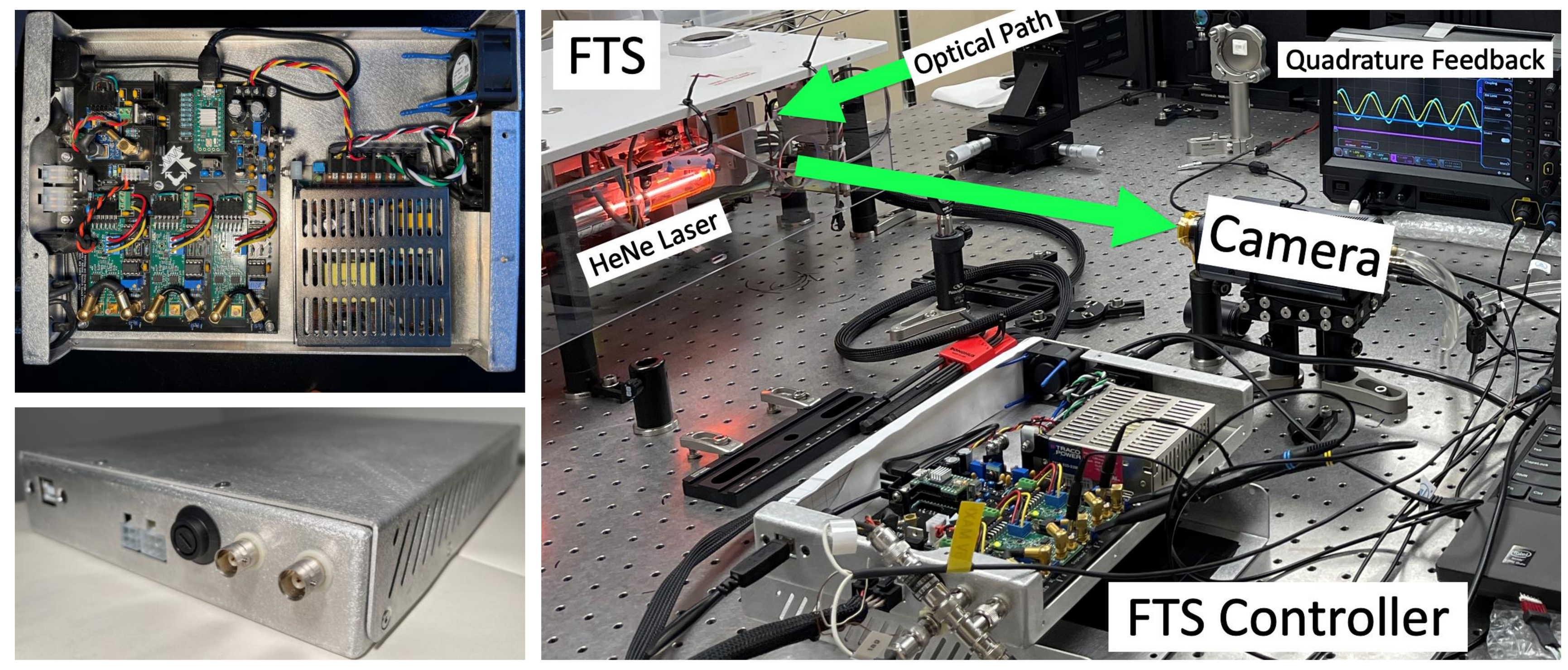


**Figure 5** – Top left: custom driving PCB and electronics. Bottom left: sheet metal enclosure with ports for PC communications, voice coil power, quadrature signals, and output triggers for a light source and camera. Right: the experimental setup to test the IFTS controller and oscilloscope to monitor feedback.

## Initial Results

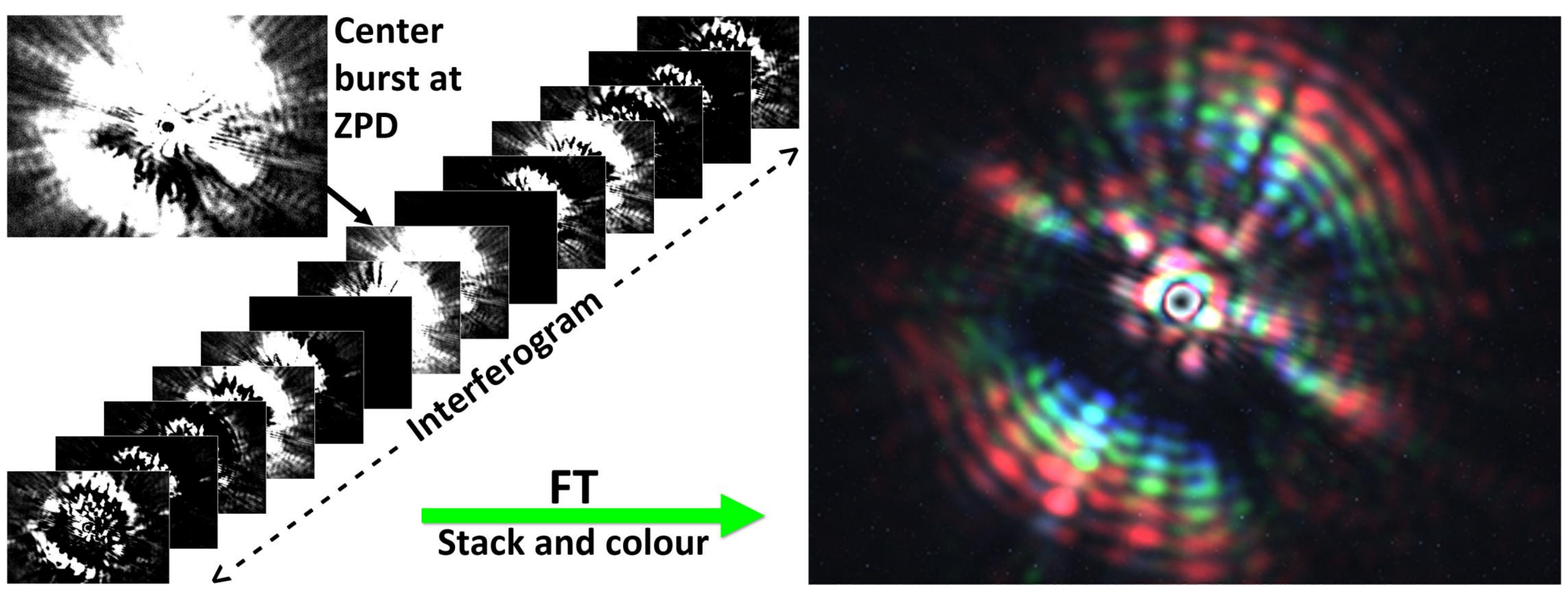


**Figure 6** – An interferogram image stack (right) produced by the IFTS is Fourier transformed to create the collapsed data cube image (left) at ~R4800 spectral resolution over a 1cm$^{-1}$ scan. The collapsed cube image is the broadband image of the source and is colored from blue to red by ascending wavelength (0.8μm ~ 1.8μm) for visual clarity.

- The interferogram images are stacked and each pixel Fourier transformed to produce the data cube
- The data cube is coloured to represent the wavelength components present at each pixel in the image

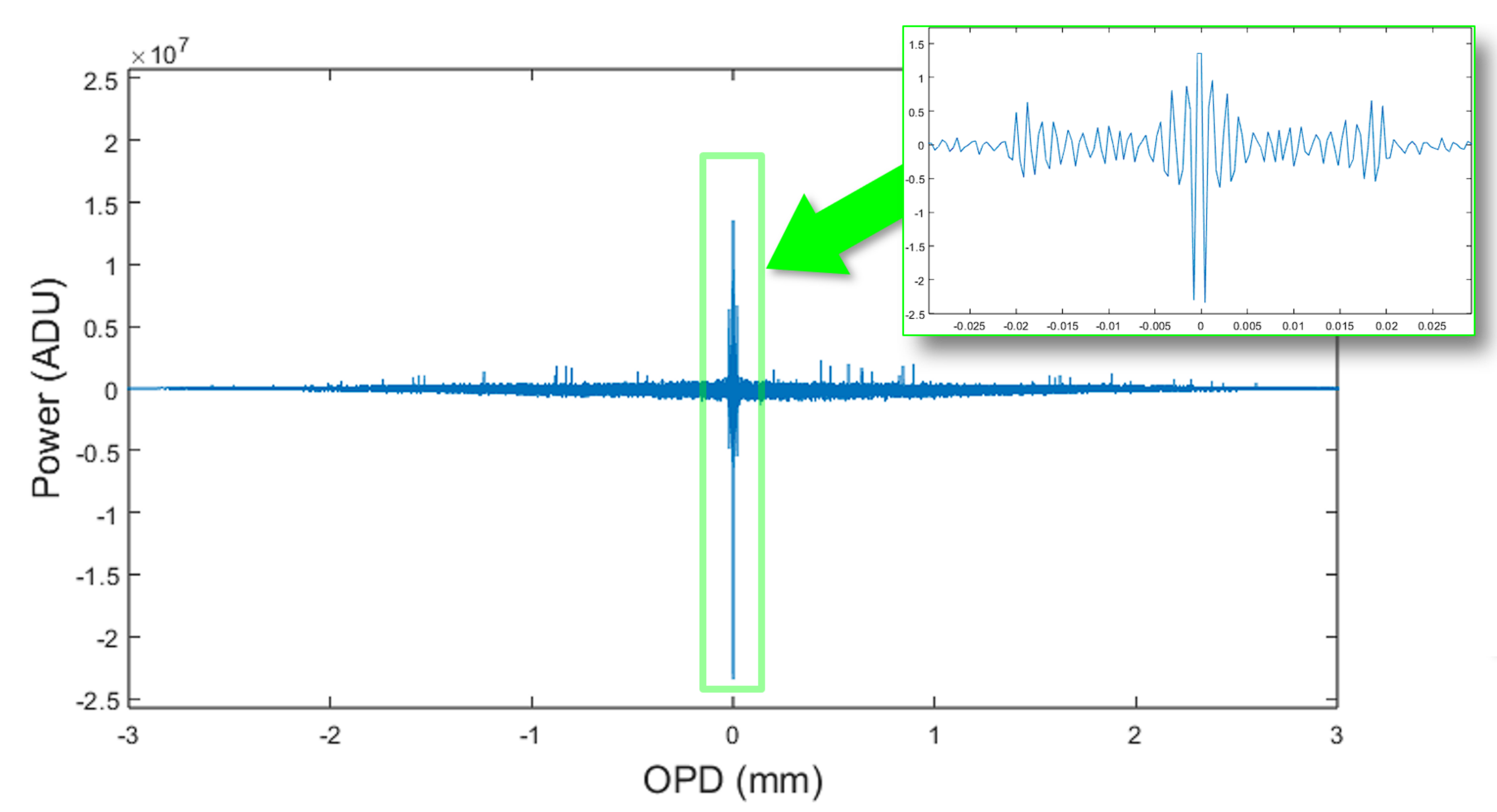


**Figure 7** – The interferogram signal obtained from an average of many pixels in the captured images for a 3mm scan.

- A wavelength spectrum of the image is obtained for every pixel, but an average taken over the image shows the spectrum of the benchtop light source

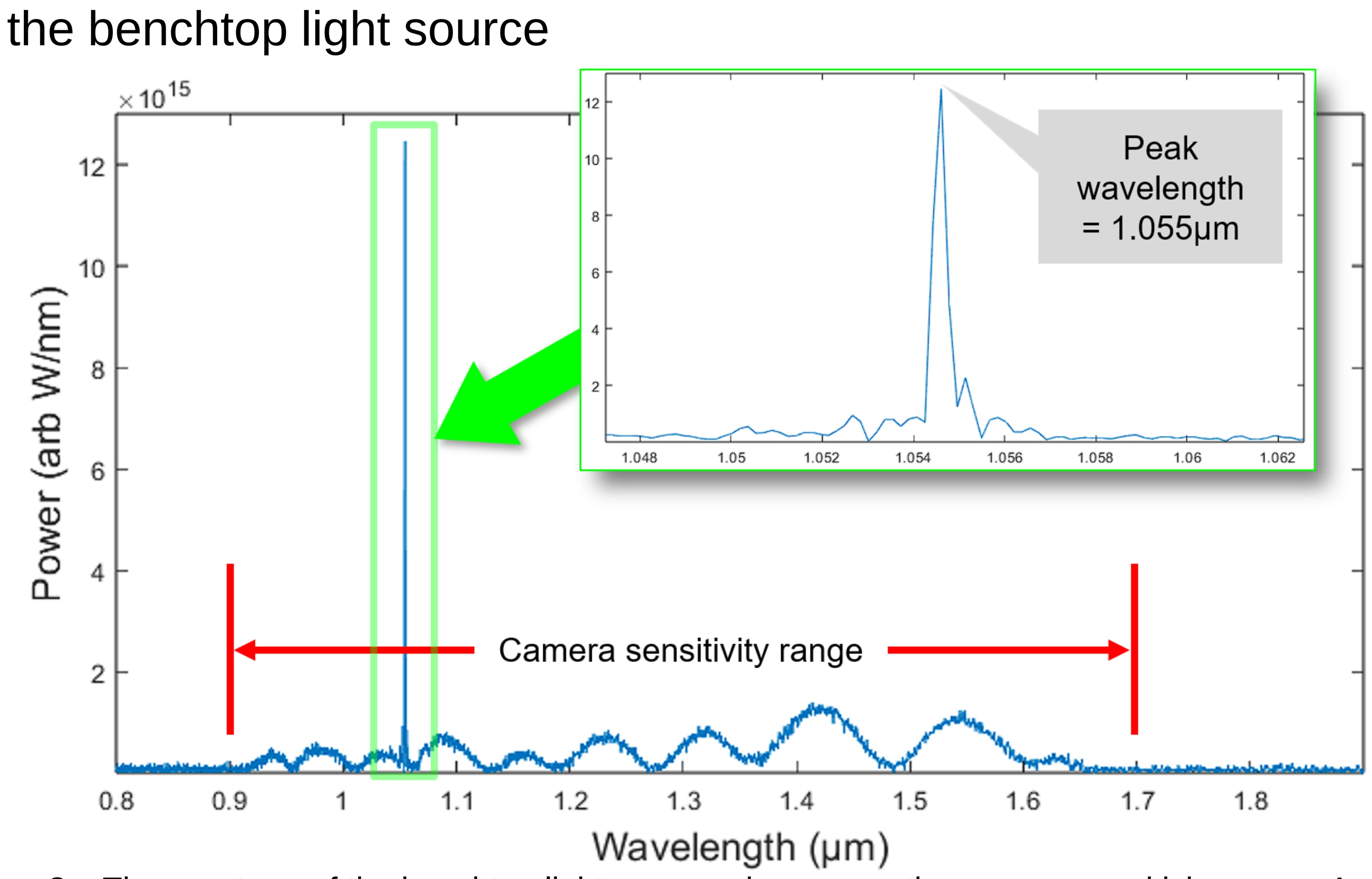


**Figure 8** – The spectrum of the benchtop light source, shown over the camera sensitivity range. An optic in the system not optimized for IR wavelengths is shown to cause ripples in the spectrum.