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Low-Signal Phase Shift: Characterizing an Unexpected Detector Deterioration of the ICON/MIGHTI Instrument

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Abstract: The Michelson Interferometer for Global High Resolution Thermospheric Imaging (MIGHTI) successfully measured thermospheric winds onboard the NASA ICON mission. We present an unexpected detector deterioration and its on-orbit characterization using calibration lamps. © 2023 The Author(s)

1. Introduction

The Michelson Interferometer for Global High-resolution Thermospheric Imaging (MIGHTI) instrument has flown successfully on the NASA Ionospheric Connection Explorer (ICON) mission for about three years. The instrument was designed to measure thermospheric horizontal wind velocity profiles between 90 km and 300 km, during day and night, observing the Doppler shift of the atomic oxygen red and green lines at 630.0 nm and 557.7 nm wavelength using the Doppler Asymmetric Spatial Heterodyne (DASH) technique. MIGHTI uses a Charge Coupled Device (CCD) sensor to image a quasi-monochromatic, heterodyned interferogram and the Doppler shift information is fundamentally contained in the phase of the interferogram fringes. Figure 1 below shows a typical daytime observation. The horizontal dimension corresponds to optical path difference and the vertical dimension to tangent point altitude on the Earth's limb [1, 2].

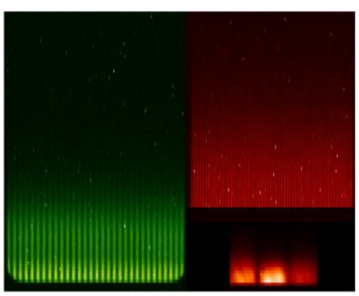

Figure 1: Typical MIGHTI daytime observation. The left half of the image shows the quasi-monochromatic interferogram versus altitude for the oxygen green line (557.7 nm) and the right side shows the equivalent interferogram for the red line (630.0nm). On the bottom right, five different interference filters are used to sample the molecular oxygen A-band for the retrieval of atmospheric temperature [3].

2. Low signal phase shift

As limb observations were obtained on orbit, over a wide range of limb brightnesses, it became apparent that there was an unexpected, systematic shift in fringe phase depending on the signal strength on the detector, which was determined to be a characteristic of the instrument/detector rather than geophysical. This shift was strongest for the dimmest signals and tended toward zero shift at the brightest signals. Figure 2 shows the difference of the measured red-line wind at 244 km binned as a function of signal level and the corresponding winds from the empirical model HWM14 [4]. The binning is done separately for each 48-day precession cycle, each of which is shown as a colored

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line. The multiple curves are for different time periods, coded by color, with darker colors representing times later in the mission. These curves clearly indicate that the low-signal phase shift is increasing with time.

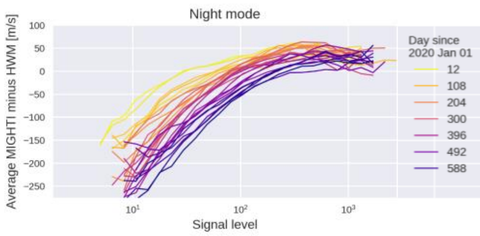

Figure 2: The difference between red line MIGHTI-A wind estimates at ~244 km altitude and HWM14, binned as a function of signal level. Data between Jan 2020 and Oct 2021 are analyzed, with each 48-day precession cycle analyzed independently, resulting in the colored lines. The signal level is equivalent to the DC value of the interferogram. A clear negative systematic error is seen at low signal levels. Green-line and MIGHTI-B results are qualitatively similar.

To further investigate this effect, special observations of the on-board calibration lamps have been made with eight different exposure times to produce different total signal levels at the CCD. Figure 3 is a plot of the MIGHTI-A neon calibration lamp fringes from these calibration-lamp-only measurements obtained on January 2, 2022. The different colors correspond to the exposure time of the observation, bracketed by the red curve at 240 seconds and blue curve at 2 seconds. The vertical axis is in ADU per second which normalizes each of the curves to exposure time. As the exposures become shorter (less total signal) there is clearly a progressively larger phase shift and a decrease in fringe amplitude. The cause for this behavior is under investigation but these results indicate the shift is consistent with a linear "smearing" of the fringes, perhaps in the readout process along the rows, which affects the faint, short exposures (blue curve) more than the bright, longer exposures (red).

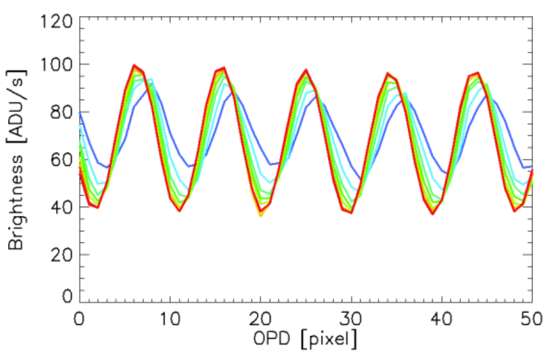

Figure 3: Sample fringes indicating fringe phase shift depending on the total signal detected in a given CCD row. The measurements were made on January 2, 2022 using only calibration lamp signal. The colors represent different exposure times (total signals) bracketed by red at 240 seconds and blue at 2 seconds. For clarity, only about one eighth of the row is plotted (OPD: Optical Path Difference).

Using the information gathered by calibration lamp observations throughout the later part of the mission, the on-orbit wind observations could be corrected for this effect, using a time-dependent correction. An additional uncertainty, corresponding to the estimated error of the correction was included in the reported data [2].

3. References

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