Fringe Correction for USNO 61" CCD Images

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1. INTRODUCTION

A significant source of noise in long wavelength optical images are atmospheric emission lines, particularly from atmospheric O and OH molecules. CCD detectors often display a complex pattern known as "fringes" that arises due to these telluric night-sky emission lines produced in Earth's atmosphere. These emission lines undergo multiple internal reflections within the silicon detector leading to constructive and destructive interference. Variations in the thickness of the silicon layer produce a complex wood-grain-like pattern across images. Fringing begins to be an issue for CCDs when the absorption depth within the silicon becomes comparable with the thickness of the CCD, which generally occurs at red-optical wavelengths (e.g., $i-$ or $z-$band). Further, because the strength of the telluric lines can depend on atmospheric conditions, the amplitude of the fringe pattern can be variable in a given night.

We describe below a fringe mitigation technique designed to work with and tested on $z-$band images from the 61" Kaj Strand Telescope at the US Naval Observatory Flagstaff Station. We note here that fringe patterns and mitigation techniques are very likely instrument, telescope, and site-specific. Therefore, while the process described below was found to have satisfactory results for these specific images, this strategy may not be applicable to other observations.

2. FRINGE CORRECTION FOR USNO Z-BAND OBSERVATIONS

The US Naval Observatory Flagstaff Station has initiated a program to investigate the photometric variability of substellar objects using the 61" Kaj Strand Telescope using a $z-$band photometric filter. Numerous $z-$band images are acquired for each target throughout the night, with the goal of creating light curves and examining them for evidence of periodic variability. The upper left panel of Figure 1 shows a raw science frame from this observing program, where artifacts, fringes, and variations of the detector response can be seen.

While some artifacts and brightness fluctuations are mitigated by flat-fielding science frames, fringes remain in the image and must be addressed in a separate reduction step. The upper right panel of Figure 1 shows a science frame that as been debiased and flat-fielded, highlighting the fringes that are still present in the data.

For this project, we use a 3×3 dither pattern with offset moves of $30''$(9 pointings total). These dithered images are used to create a "fringe-frame" for each science image, that when subtracted results in a fringe-free image that is suitable for photometric measurements. The first step in creating a fringe frame to be subtracted from a science frame is the removal of point sources. This is accomplished by creating a masked image where point sources are removed via sigma-clipping. Tests showed that using a sigma clip of 2σ was the most efficient for removing point sources. The resulting sigma-clipped images are median combined to create the final fringe frame that is subtracted from the science images.

We initially attempted a single "master" fringe frame for each night of observations that included every science frame from that night. However, when this master flat was subtracted from the science images, residual fringes could be seen by eye in several (if not most) science frames. This test confirmed that the amplitude of the fringes varies throughout the night, and each science frame therefore requires its own unique fringe frame for subtraction.

We then tested fringe frames that included the science frame in question, and the images immediately preceding and following that science frame. We tested fringe frames that combined 3, 5, 7, and 9 total images. We evaluated each fringe combination by inspecting the photometric RMS of stars in the science images, where the smallest RMS values indicated a more efficient removal of fringes. We found the best results when 7 or 9 images were used, with a marginal difference between the two. We therefore chose 7-image fringes as a balance between the potential of fringe amplitudes to vary during the night and having enough images to create a robust median. An example fringe frame can be seen in the bottom left panel of Figure 1. The bottom right panel of Figure 1 shows a final, fringe-subtracted science image. Science frames that occur at the beginning (end) of the night do not have three preceding (following) images. In these circumstances, we use as many frames as possible that exist around the science frame in question

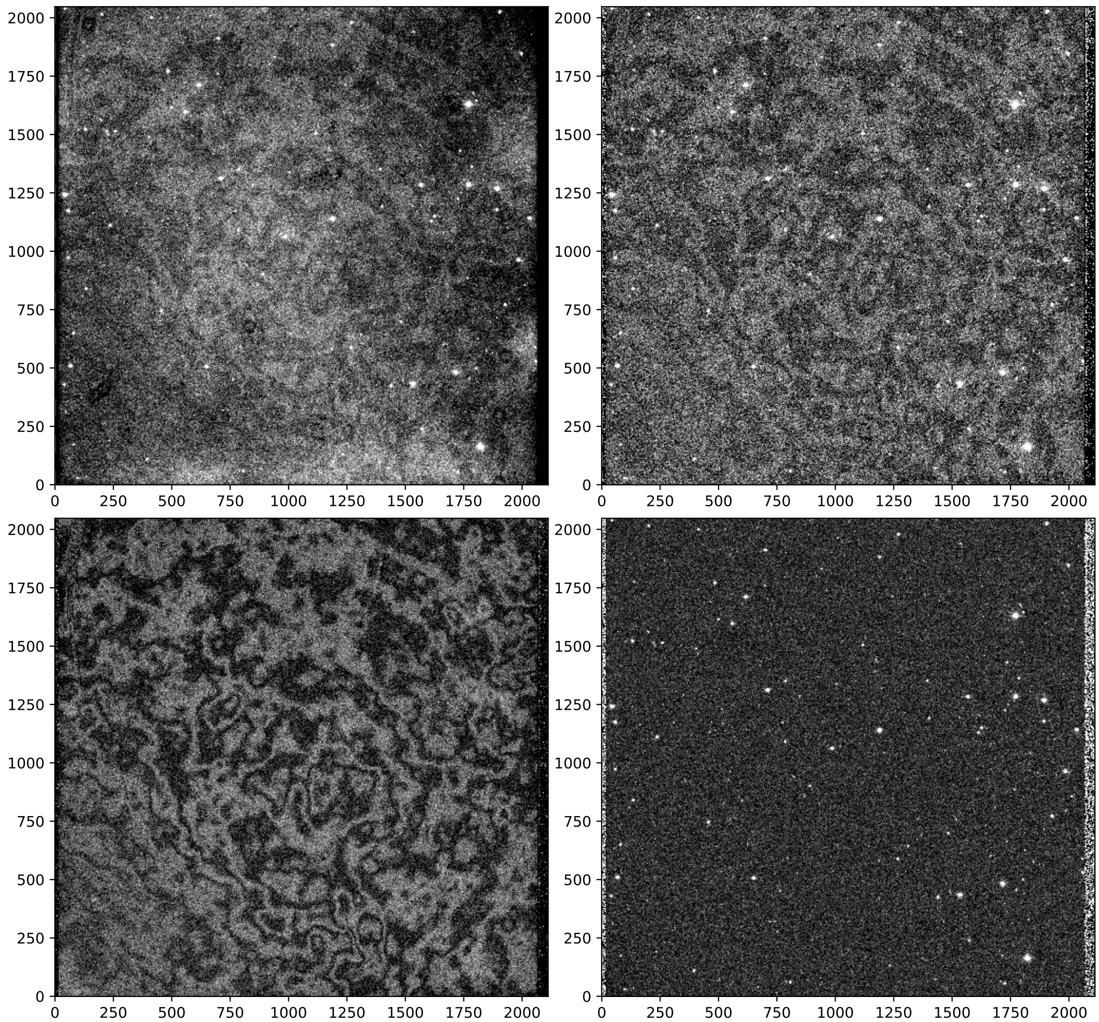

Figure 1. *Upper Left:* Raw $z-$band science image. *Upper Right:* Debiased and flat-fielded science image which shows significant fringing throughout the image. *Lower Left:* Fringe frame. Note the complete lack of point sources in this image. *Lower Right:* Final, de-fringed science frame.

that occur within a maximum of 3 preceding and following images. Thus the first (last) science frame has a fringe frame that uses the 3 following (preceding) images.

While the above method generally produces good results for most observing nights, it is good practice to visually check all final, defringed science images for any fringe residuals.