Hawkeye Filter Ghosts

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Overview: The Hawkeye filters define the passband and have stringent specifications on out-of-band leakage, band centers, spectral width, and peak transmission. And, they also have a tight specification on parallelism of the two exterior surfaces. The specification is that the exterior surfaces be plane parallel to less than 5 microns across the part, a spec that required post processing of each filter stack. Unfortunately, I did not recognize that since the filter is constructed of multiple layers the wedge of the internal layers must also be controlled. Some of the internal layers, used to provide blocking, have substantial wedge, and reflectivity near the passband. Most dichroic filters are constructed of thin film layers with little absorption. As a result, at any point where the transmission is 50% the reflectivity is also near 50%. Light reflected out of the filter can be reflected again by another layer back into the filter and through the rest of the optics. As a result, we have filter ghosts – secondary reflections caused by multiple layers. These ghosts typically have about 2-4% of the source beam in total power, but this is enough to be a problem in ocean color where one has to contend with cloud edges and shorelines near dark lake or ocean water surfaces. Figures One and Two show the ghosts for all 8 bands for Units One and Two. Each thumbnail image is 200x200 pixels in extent, to give the reader a sense of scale.

Figure One: Unit One Filter Ghosts

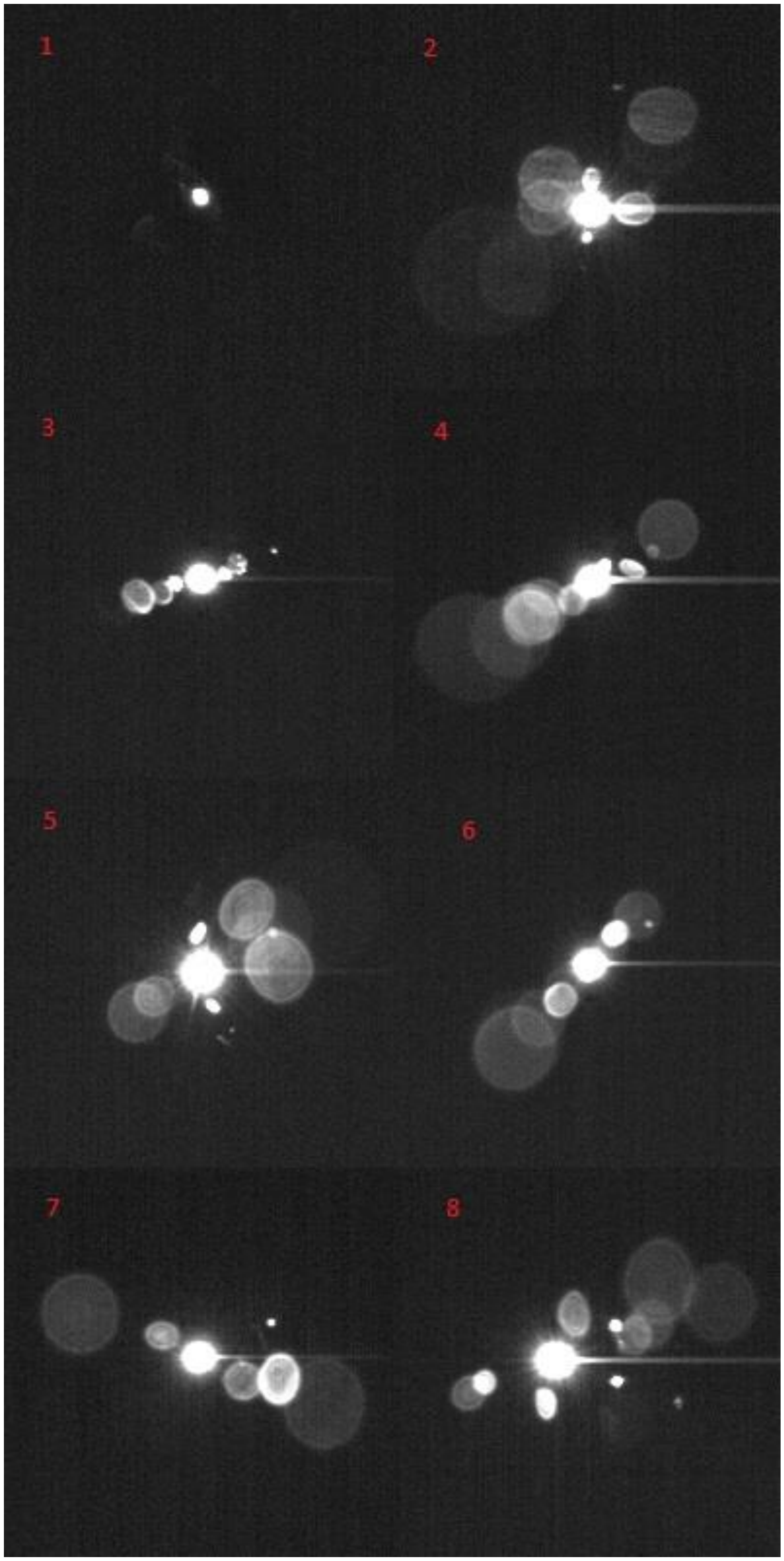
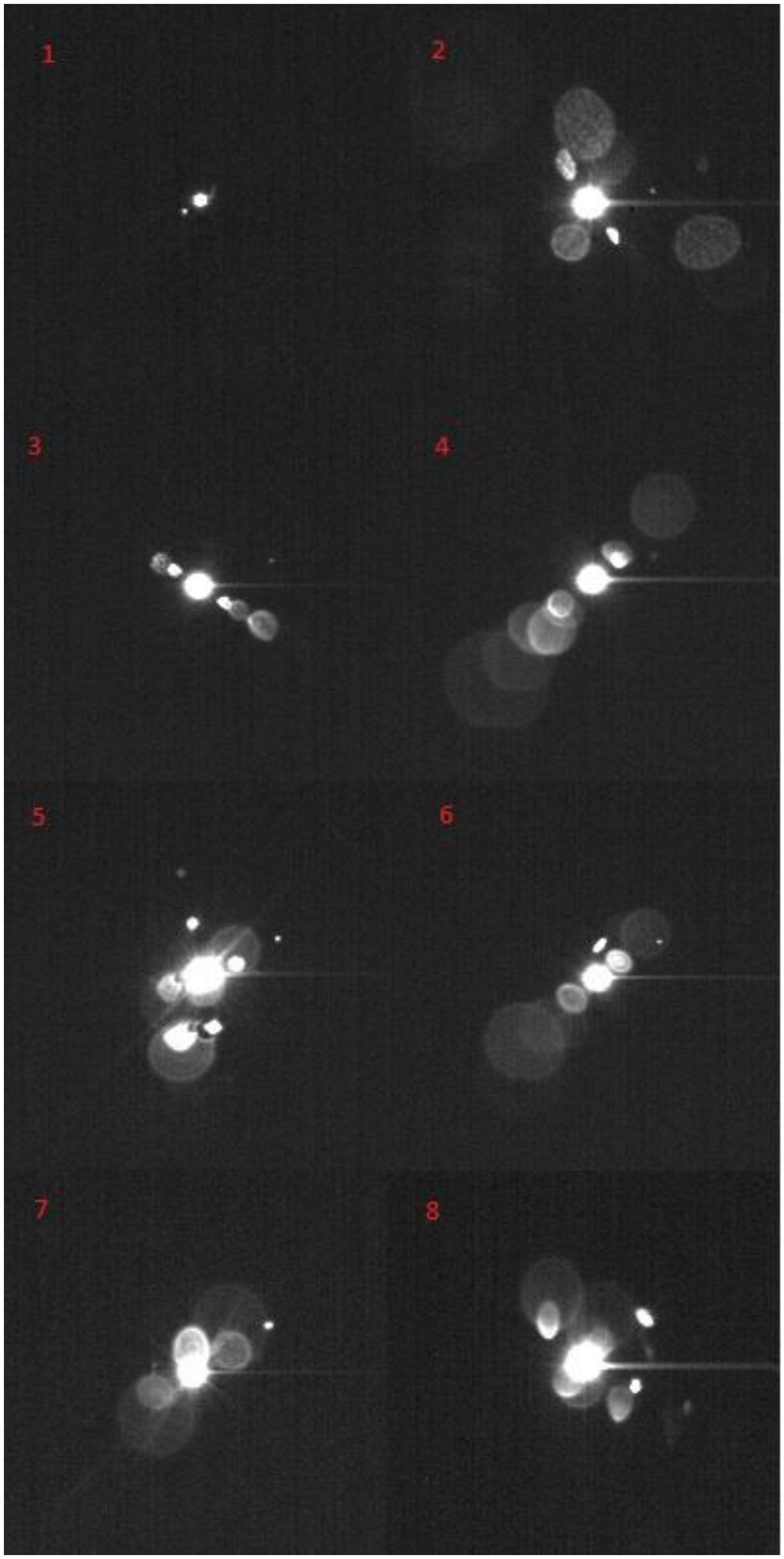


Figure Two: Unit Two Filter Ghosts



These images were taken with high light levels to saturate the core, and the contrast is pushed to highlight the ghosts. As one can see, the patterns can be quite complex. I don't think Unit 1-Band 1 is as good as it looks – I simply did not have enough source power to reveal the ghosts. The images were captured while using a Televue NP101 telescope to collimate the light out of a 62 micron fiber and project it into the Hawkeye instrument. Either an LED white light source (Bands 1 through 6) or a tungsten lamp (bands 7 and 8) was used to illuminate the fiber. This data is found in folders labeled "TelescopeStrayLight" in the archived data.

Quantitative data: typically in processing ocean color images one applies a cloud mask, to delete an area of the sky near a cloud from contributing to the data products. In this case that can be a significant portion of the image: Table One lists the distance, in pixels, that one must be away from an edge or other bright feature to ignore the scattering from filter ghosts. This number ignores the orientation of the ghosts.

Table One: Radius of Cloud Mask to eliminate Filter Ghost corruption of a Region

Band	Unit 1 Max Radius (Pixels)	Unit 2 Max Radius (Pixels)
1	42	10
2	99	79
3	41	45
4	98	97
5	54	56
6	79	68
7	83	48
8	107	56

Unit 2 Band 7 was originally quite bad (105 pixels radius) and this band was reworked to change the filter. In the process of this the scrambler was scratched. However, the rather nasty scratch was determined to be less of a problem that the original Band 7 filter. Bands 7 and 8 are particularly important since the ocean is quite dark at these wavelengths and they will be most corrupted by stray light from nearby jungle foliage.

In order to better visualize the impact of this problem on the data I have written a computer program that can calculate a two-dimensional model of the scattering from my stray light measurements, and apply it to an arbitrary scene. First, I construct an "impulse function" for each band, which is the amount of scattered light in neighboring pixels scaled by the total energy in the core of the image. Typical values are quite small, around 1 part in a million, so floating point math must be used. I zero out the core of the impulse function so only the stray light and ghosts remain. I then take the starting scene image and, for each pixel, overlay the impulse function on it and calculate what the impulse function contribution to nearby pixels would have been. I sum these impulse function contributions in a separate image file and save them. For a 200x200 pixel impulse function file and a 600x600 pixel image the algorithm takes about three minutes to compute. The astute reader will note that there is an inherent error in my thinking here, since, the original scene image is already corrupted, and yet I use it to calculate the corruption. This works since the stray light is only on the order of a few percent, and a 2% error times a 2% scattering level is ignorable. Figure Three-A and Three-B show the results for an ideal "hole in the clouds" scenario, where I calculate the stray light found within a 400 pixel diameter circle with 50,000 counts per pixel light intensity outside of it in the surrounding area. The contrast is set so 3% stray light is completely white.

Figure Three-A: Unit Two – Band 4 "Hole in Cloud"

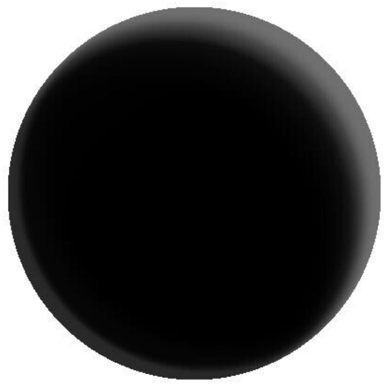
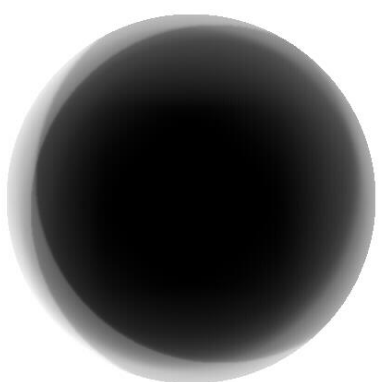


Figure Three-B: Unit Two – Band 8 "Hole in Cloud"



Note that Band 8 (Figure Three-B) shows more sharp-edged features. If you look at the ghost pictures in Figure Two you will see that this band shows a few star-like ghosts, which produce a focused, but displaced image of the scene. Band 4 has more diffuse ghosts. The Band 4 corruption is at most 1.25%, and for Band 8 is 2.3% of the intensity of the surrounding area.

This same technique can be used to correct the stray light. In Figure Four-A I show a picture of the moon captured with the engineering model Band 6. Figure Four-B shows the derived stray light estimate, and Figure Four-C shows the original image with the estimate subtracted from it. All are displayed at the same contrast. This fairly simple technique reduces the stray light by a factor of 5 to 10.

Figure Four-A: EM - Lunar image with contrast pushed to show ghosts

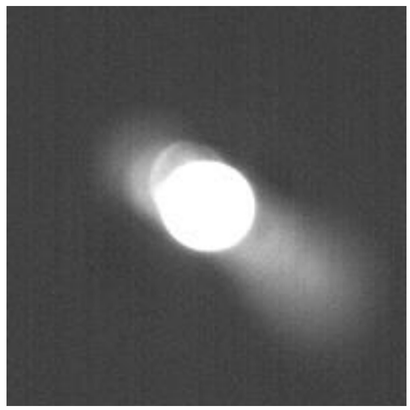
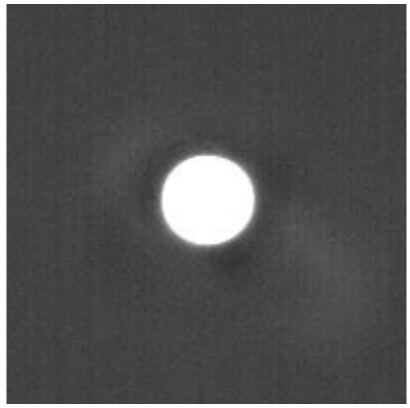


Figure Four-B: Derived Ghosts from Impulse Function

Figure Four-C: Lunar Image Minus Derived Ghosts



I am most concerned about a scenario where the instrument is used to image a lake from orbit, where a situation much like the “hole in the cloud” is found. So, I took the engineering model instrument out for a field test to image a lake as seen from above. Santa Barbara has a lot of ocean vistas, but not too many lakes. However, I found a reservoir that was visible from above, Lauro Canyon reservoir. Figure Five shows a cropped RGB image of this reservoir, 600 x 600 pixels in size. Band 7 is rendered as red, Band 5 is green, and band 3 is blue.

Figure Five: Lauro Canyon reservoir

Note that the stray light is not exactly jumping out at you in this image, and it has not been corrected in any way.

In Figure Six-A below I show the Band 6 image, and in Figure Six-B shows the corrected image. Figure Six-C shows the derived stray light. The contrast is pushed very hard for Figure Six-A and B to show the lake surface.

Figure Six-A: Lake as seen in Band 6

Figure Six-B: Lake Image with Stray Light Removed

Figure Six-C: Derived Stray Light Image

The result from this exercise is that the stray light was basically invisible in the uncorrected image. The lake surface had a 30% variation in signal level across it for other reasons. And, the stray light comes from an area, so it is substantially diffused. We may well find in orbit that the stray light, as bad as it may look when imaging in a darkened room, is just not that obvious in the presence of natural variations. I expect it will only be an issue in Bands 7 and 8. By the way, inspection of Band 7 for the lake image gave the same result – no obvious improvement when corrected. There was a somewhat uniform level of radiance across the lake surface, though.