Hawkeye Instrument – Integrated Diffuse Stray Light

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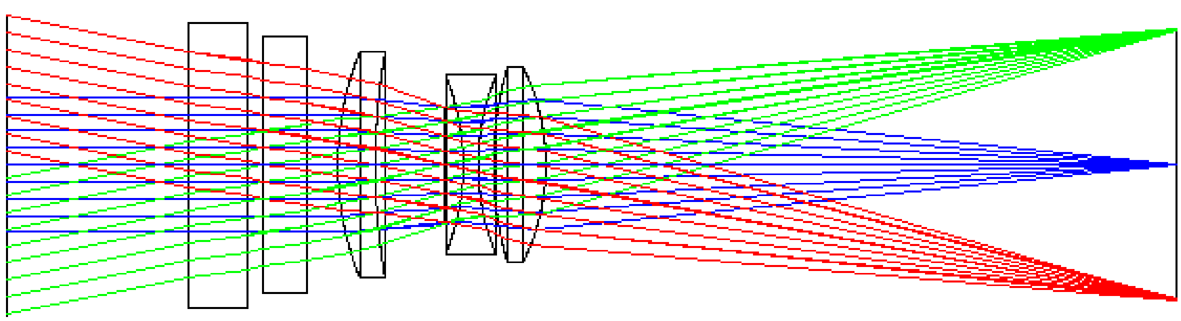
Overview: this technical report concerns itself with diffuse stray light in Hawkeye Optical System. This stray light could be due to out-of-focus reflections of light off the AR coated lens surfaces, light from illuminated baffles lighting up the CCDs with a diffuse glow, or dust and particulates on the lens surfaces itself. Concern about this effect was a HUGE design driver for previous ocean color instruments, such as MODIS or SeaWiFS. The concern over lens reflections forced the designs to use off-axis reflective mirrors, and anxiety over the effect of a hair or dandruff on the optical surfaces led to great emphasis on cleanliness. It is important to remember that all these instruments view the sunlit earth, subtending 130 degrees, almost a hemisphere of light, while trying to measure the brightness of a patch of dark ocean in this scene. The signal in one pixel is only about one ten-millionth of the light through the aperture, and you would like to reduce stray light to about 0.1% of the expected signal!

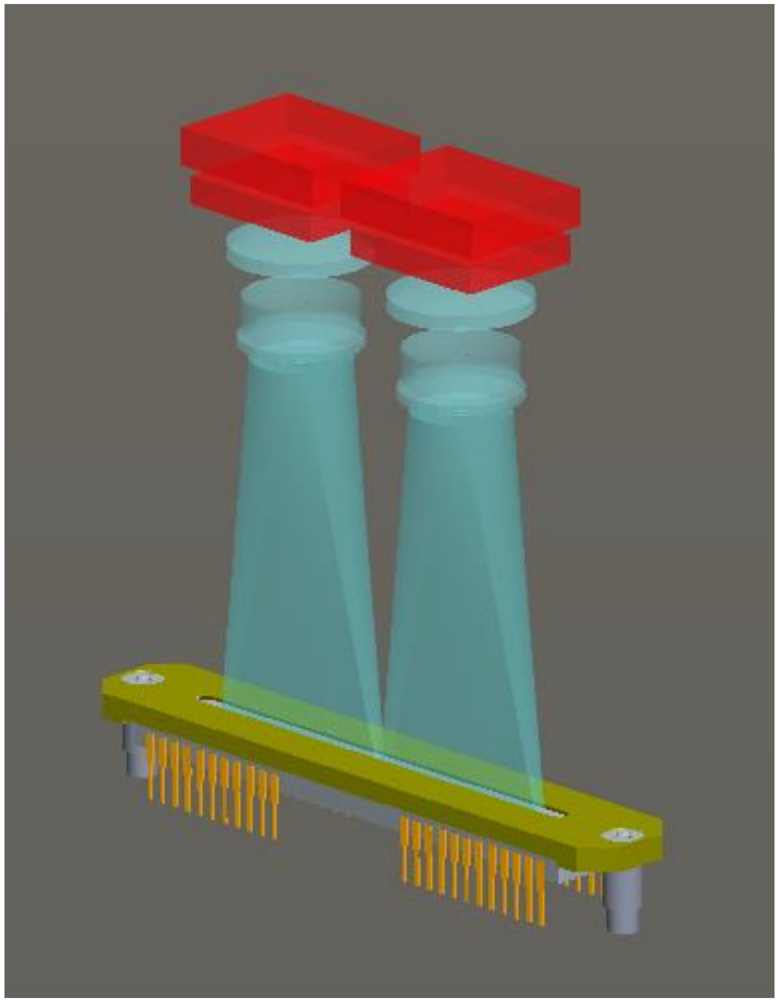
Design Considerations: Each of the 8 optical bands in Hawkeye has the optical configuration shown in Figure One. The light first encounters an aperture, and then the polarization scrambler, a narrow band filter, and then the three elements of the triplet lens.

Figure One: Optical Configuration of each Band



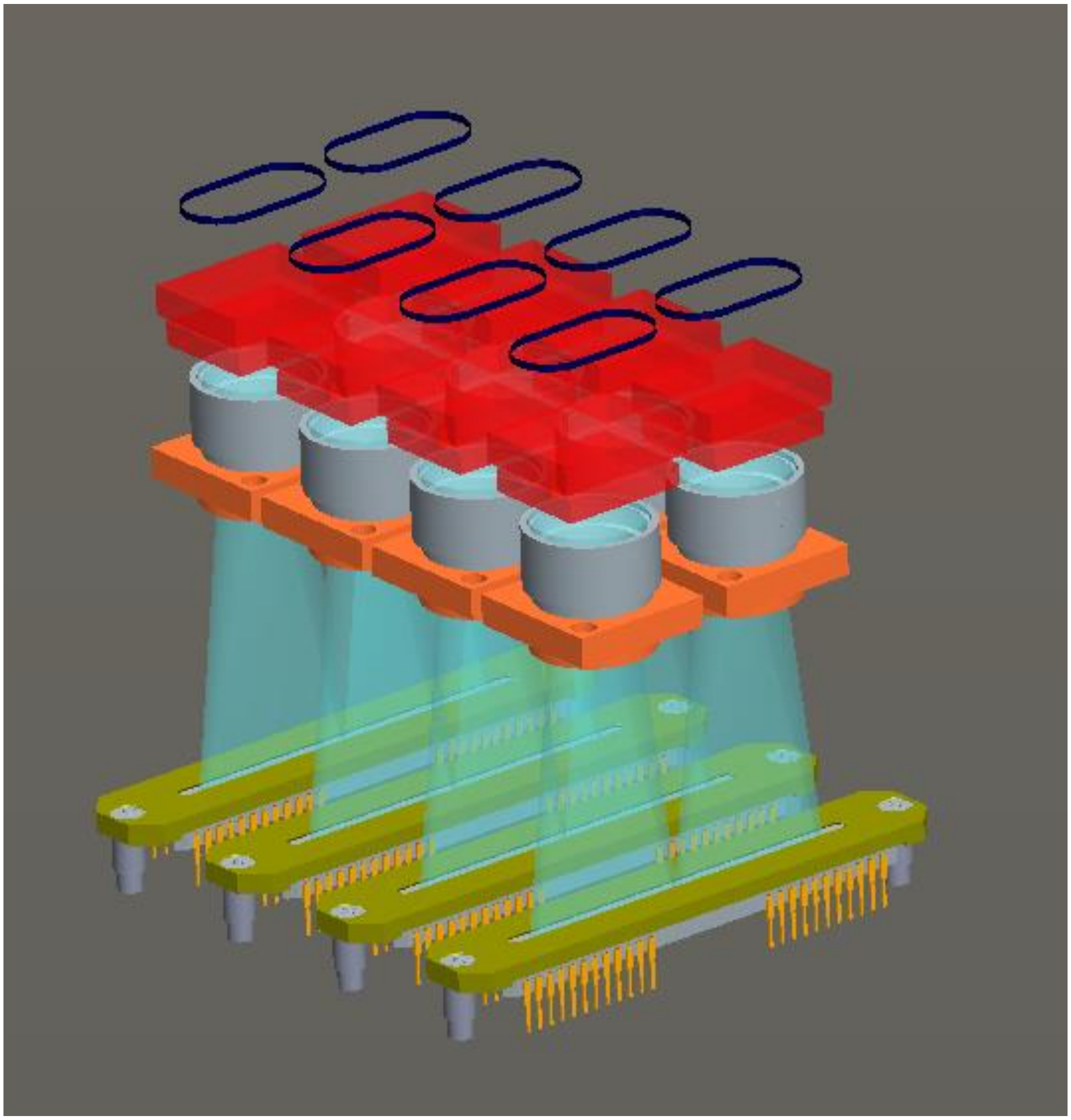
Two bands share one CCD detector array, as shown in Figure Two.

Figure Two: Two bands share one CCD



The eight bands are closely packed, as shown in Figure Three.

Figure Three: 4 CCDs are used for 8 Bands



Three flat baffles were used to separate adjacent bands, as shown in Figure Four A, B, and C.

Figure 4-A Baffle closest to lenses

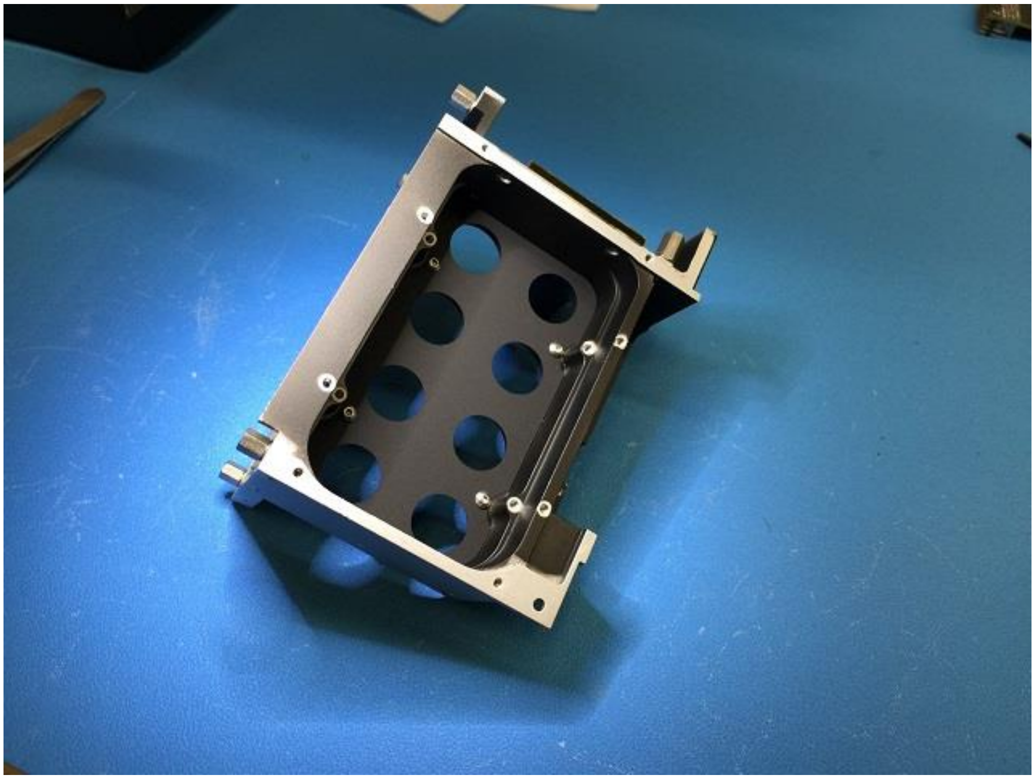


Figure 4B: Middle Baffle

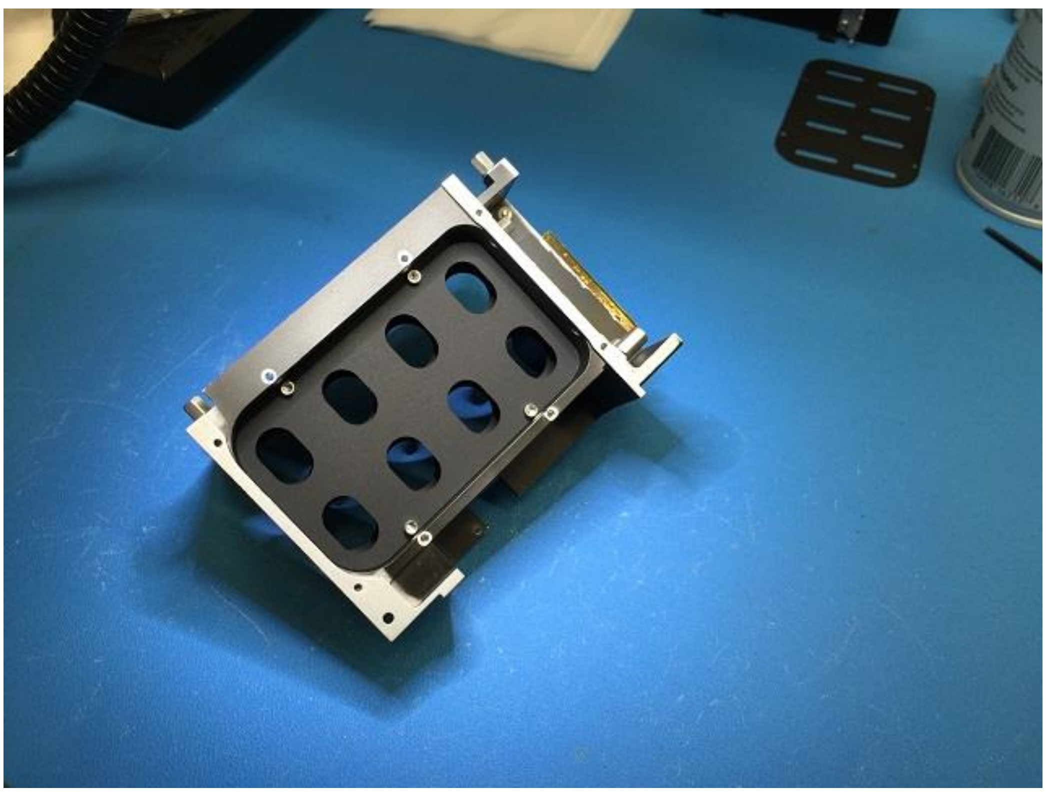


Figure 4C: Baffle closest to CCDs

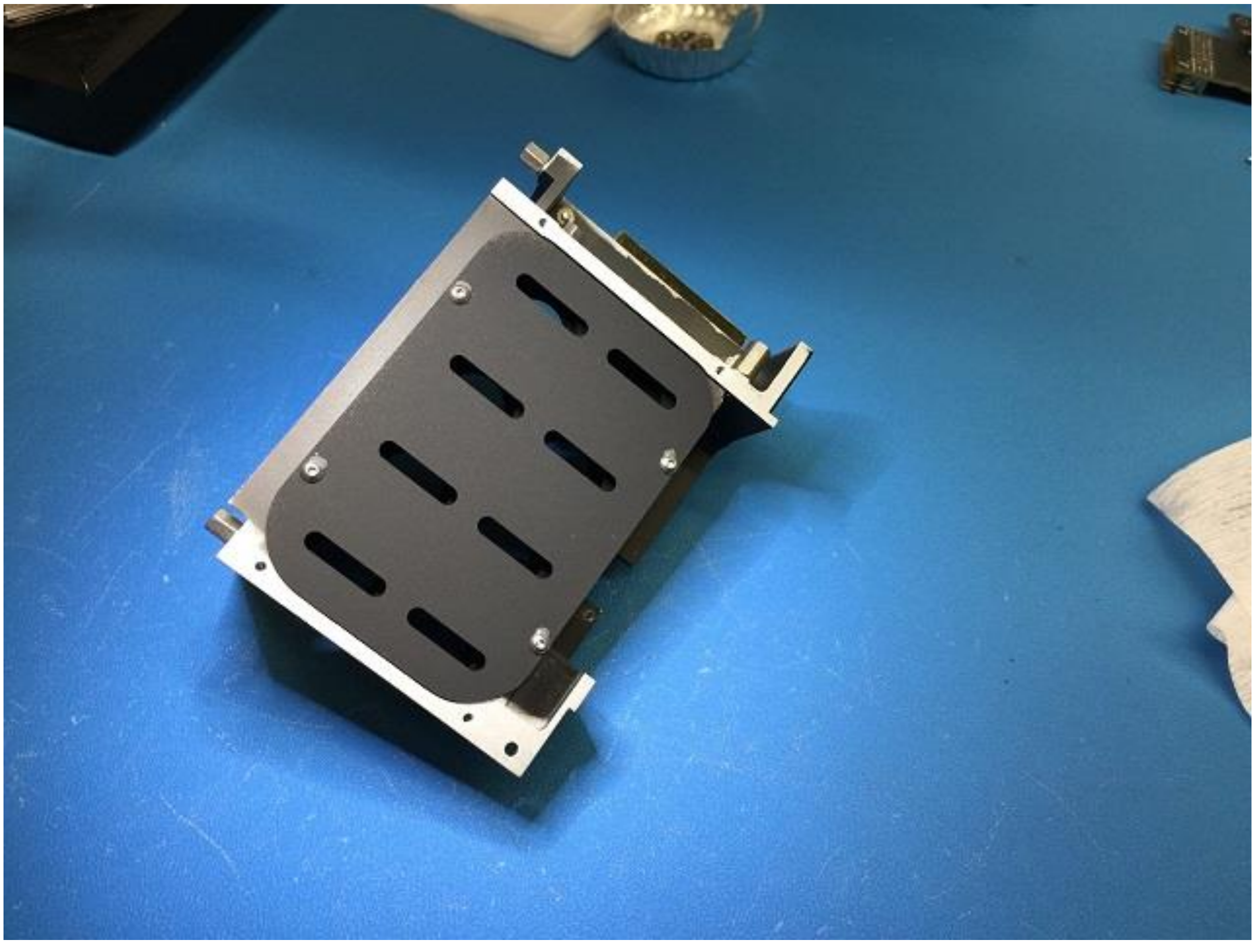


Figure 5 shows the only vertical septum, atop the shutter blade, to block light traveling horizontally between bands sharing a CCD. Figure 6 shows the shutter atop the four CCD assembly.

Figure 5: Shutter showing septum (left to right in this view)

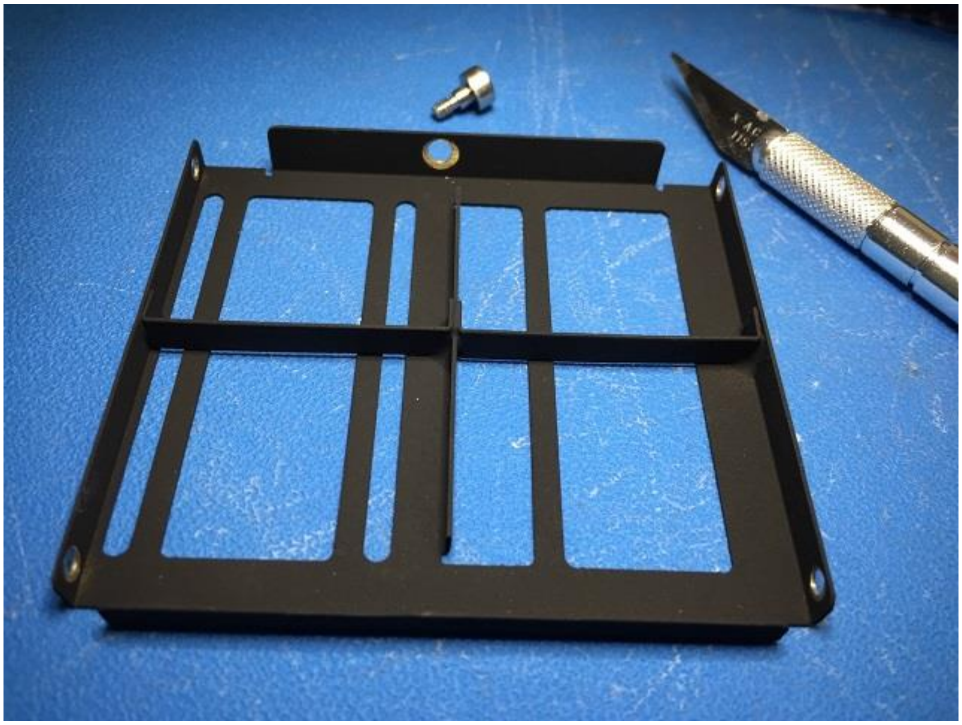


Figure 6: Shutter atop CCDs, in OPEN position. Note – circuit board is painted black, as is most of the CCD ceramic substrate. The vertical silvery stripes are the CCD silicon. Detectors are windowless.

The finished instrument was used to image a bright source at a distance to measure the stray light. This is a bit tricky. Normally in a BRDF measurement you have a laser illuminating the optical aperture, and your dial down the intensity by inserting attenuators such as neutral density filters into the path. This does not work well for CCDs since CCDs tend to bloom in an ugly manner when heavily saturated with light. So, in order to get a lot of counts in a source, but with known, diffuse intensity, I imaged the NASA sphere at a distance of about 22 feet to produce a four inch (10 cm) diameter source with known instrument response. However, this tends to light up the whole room, so a cardboard box was put in front of it that was painted black on the inside. The box was 48 inches (122 cm) long, and had an aperture of about 2 inches (5 cm), so it acted like a flashlight illuminating the sensor on a rotary table. The distance from instrument to box aperture was 18 feet, which results in the image being out of focus, producing about 6 pixels of blur. This was ignored, since we are really trying to measure the stray light further off-axis. A different setup was used for closer to on-axis stray light. This is discussed in the test report entitled “Hawkeye Filter Ghosts.

A visual light image is shown in Figure Seven with the box in place and the sphere on.

Figure Seven: Visual Light Image

Figure Eight shows the field of view scanned by the instrument with the room lights on. The cardboard box is not in place in this image. Images shown later in this report are to exactly this scale.

Figure Eight: Band 5 image of setup while Room Lights are On

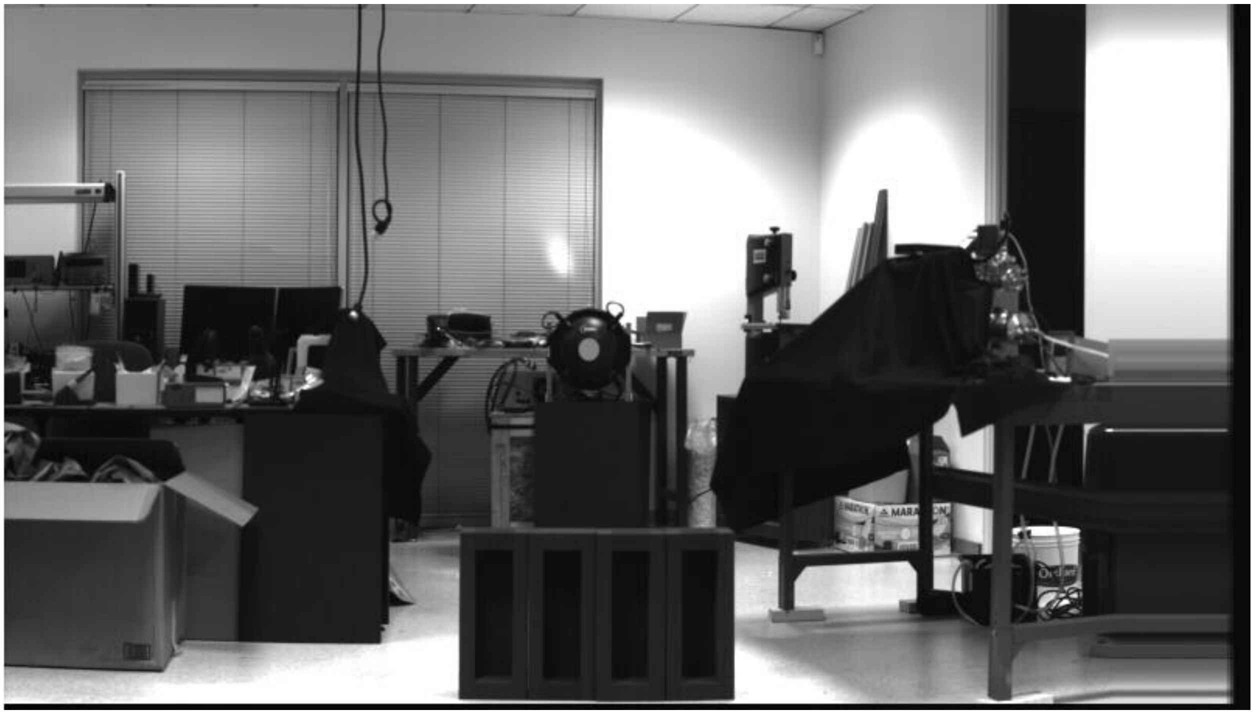
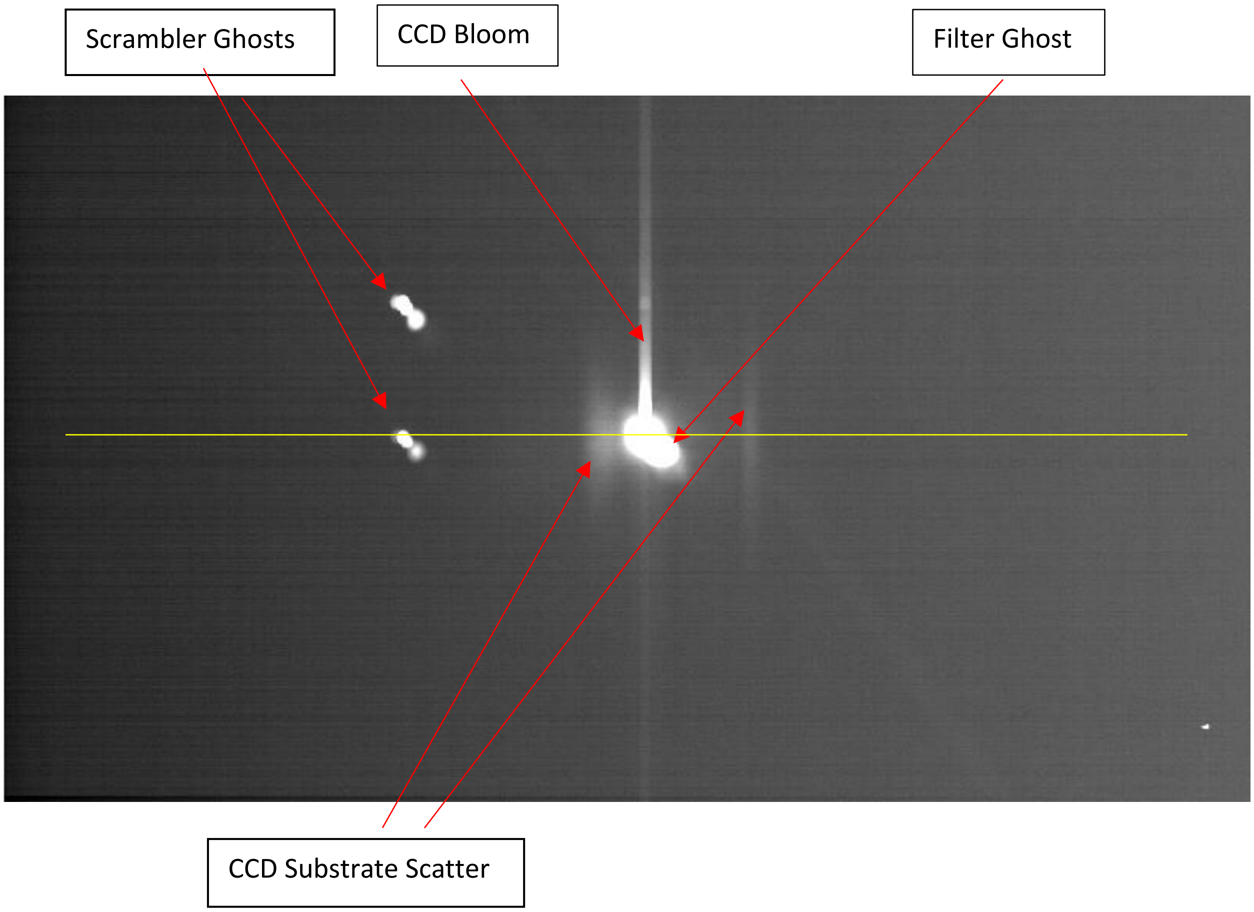


Figure Nine shows an unsaturated image recorded for Band 6, with the contrast adjusted to show the full range of values.

Figure 9: Short Exposure using Band 6

Figure Ten shows a 32X longer exposure, with the contrast pushed hard to show faint details.

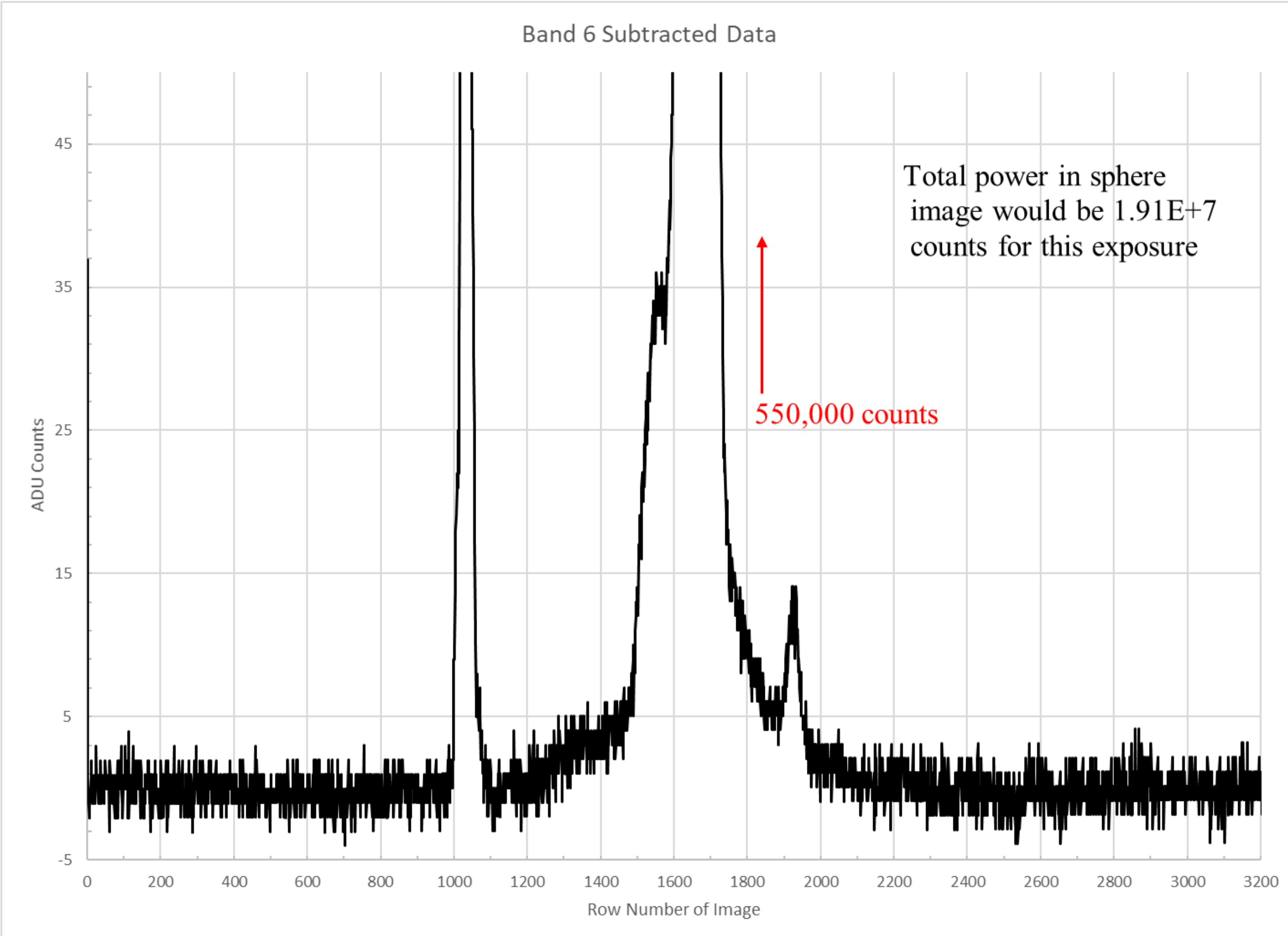
Figure Ten: Image showing Stray Light Effects



This picture illustrates the significant stray light effects in the instrument. First of all, it is worth noting that no stray light level above 0.4% of the aperture levels appears in Figure Ten – the situation is not as grim as it looks. CCD Blooming, caused by saturating the CCD, will be discussed in another report (CCD Blooming-Unit2), but will not occur like this in normal operation. The scrambler ghosts are caused by specular reflections off the wedged and tilted scrambler surfaces. This will also be discussed on another report. Here they are only 0.09% in brightness. The filter ghost is the worst effect, and is nearly on-axis, and will be discussed in another report, as mentioned previously. This report is focused on effects such as the CCD substrate scatter, and the diffuse glow across the image. Here the diffuse glow is hidden by the left-right wedge, which is due to the CCD substrate heating up during the long integration time for this test, approximately 10X what will be used in orbit. The wedge was subtracted in data analysis. Finally, the little blip in the lower right corner is a neon indicator light on a power strip that was in the field of view.

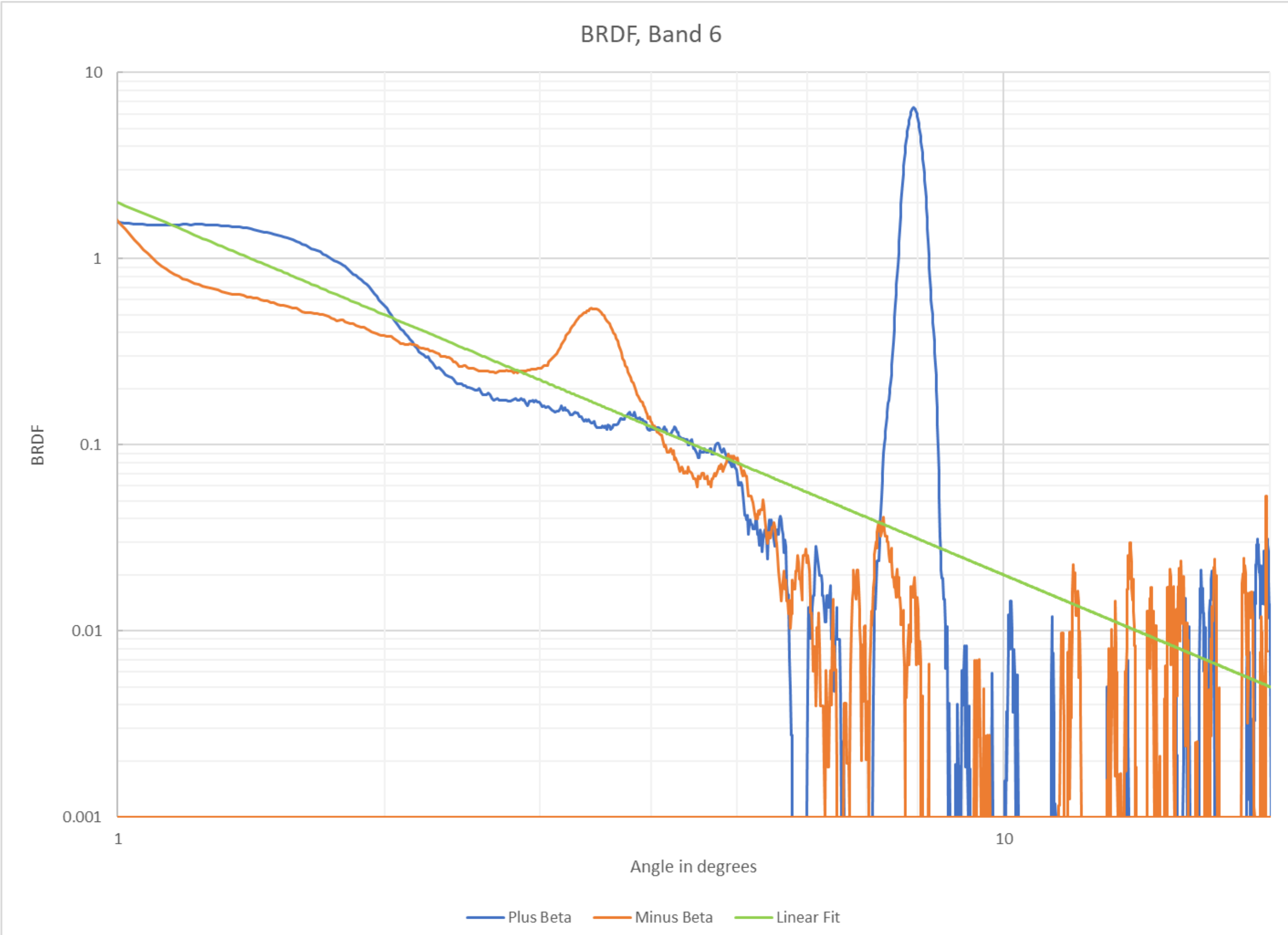
Our analysis will focus on a strip 31 pixels tall, through the aperture image, as illustrated by the yellow line in Figure Ten. A graph showing that strip is shown in Figure Eleven. The blip around image row number 1100 is the scrambler ghost, to help one orient the graph to Figure Ten.

Figure Eleven: Graph of Stray Light near Sphere Aperture Image



Our main interest in this report is the shoulders of the main peak, since they are large in angular extent and can integrate up to a significant effect. It is easier to perform comparisons of this data with other bands if we put the results in terms of BRDF (Bi-directional Reflectance Distribution Function), and plot the data on a log-log scale. When this is done the graph in Figure Twelve results. The green line on this graph shows the best fit for a line to the log-log data.

Figure Twelve: Band 6 BRDF



Bands 8 and 4 are shown in Figures Thirteen and Fourteen respectively. Band 2 data was too weak to allow a graph to be useful. The main point of showing these other bands is that the curves are very similar in magnitude and shape. This would imply a common physical process is occurring. At this time I believe that what is seen is that the image of the sphere aperture, as it moves off-axis, illuminates the black surfaces around the detector substrate. These surfaces, even though painted with 2% reflectivity paint, then scatter light to illuminate the back side of the shutter, which is also painted. However, that surface is seen directly by the CCD pixels. One can see a change in the slope of the BRDF function at about 5 degrees in all three graphs. I believe this occurs since the sphere aperture image no longer makes it to the CCD area, but is blocked by the shutter, and the only scatter remaining is due to the lens surfaces or very diffuse baffle scatter.

Figure Thirteen: Band 8 BRDF

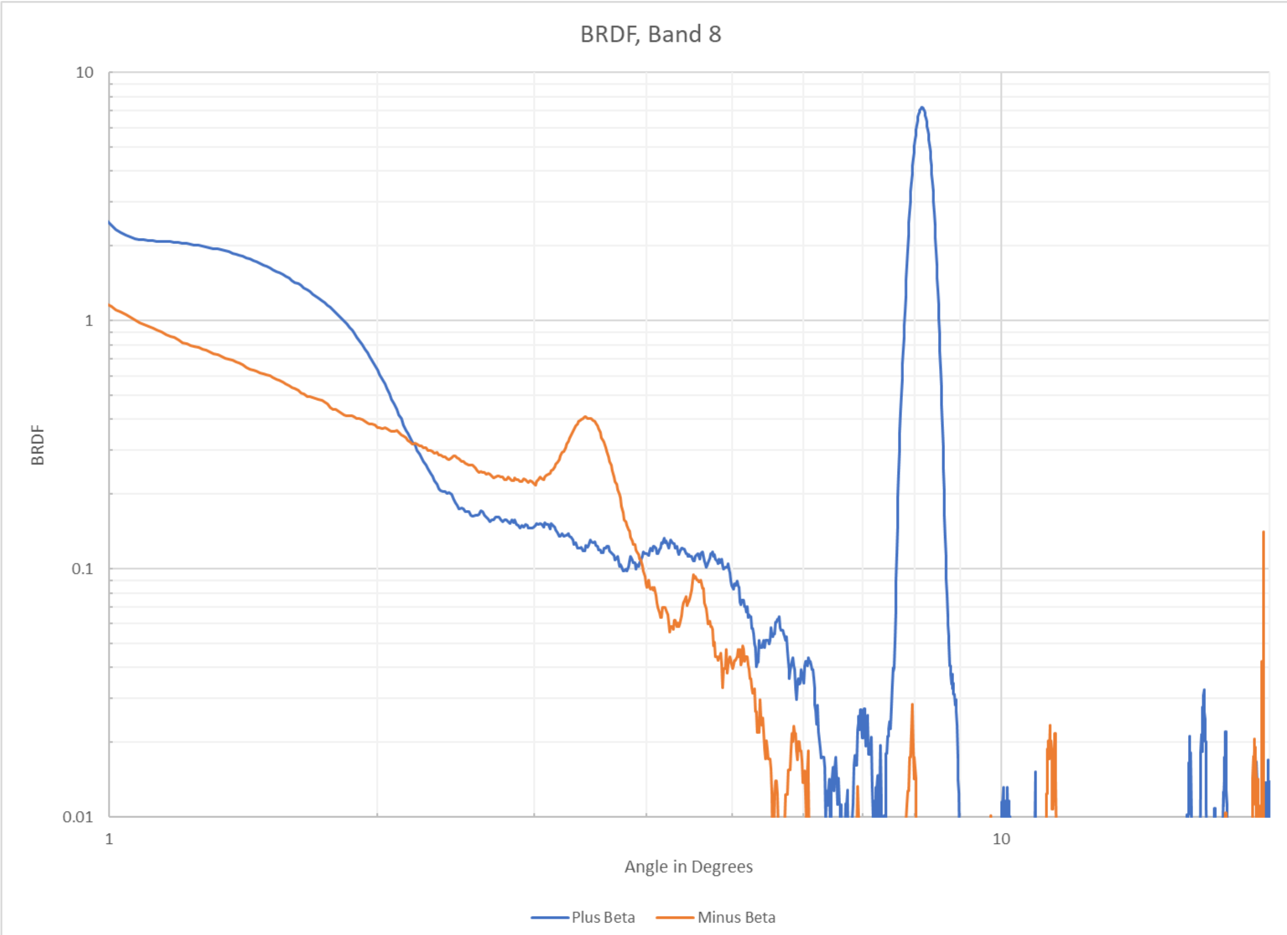
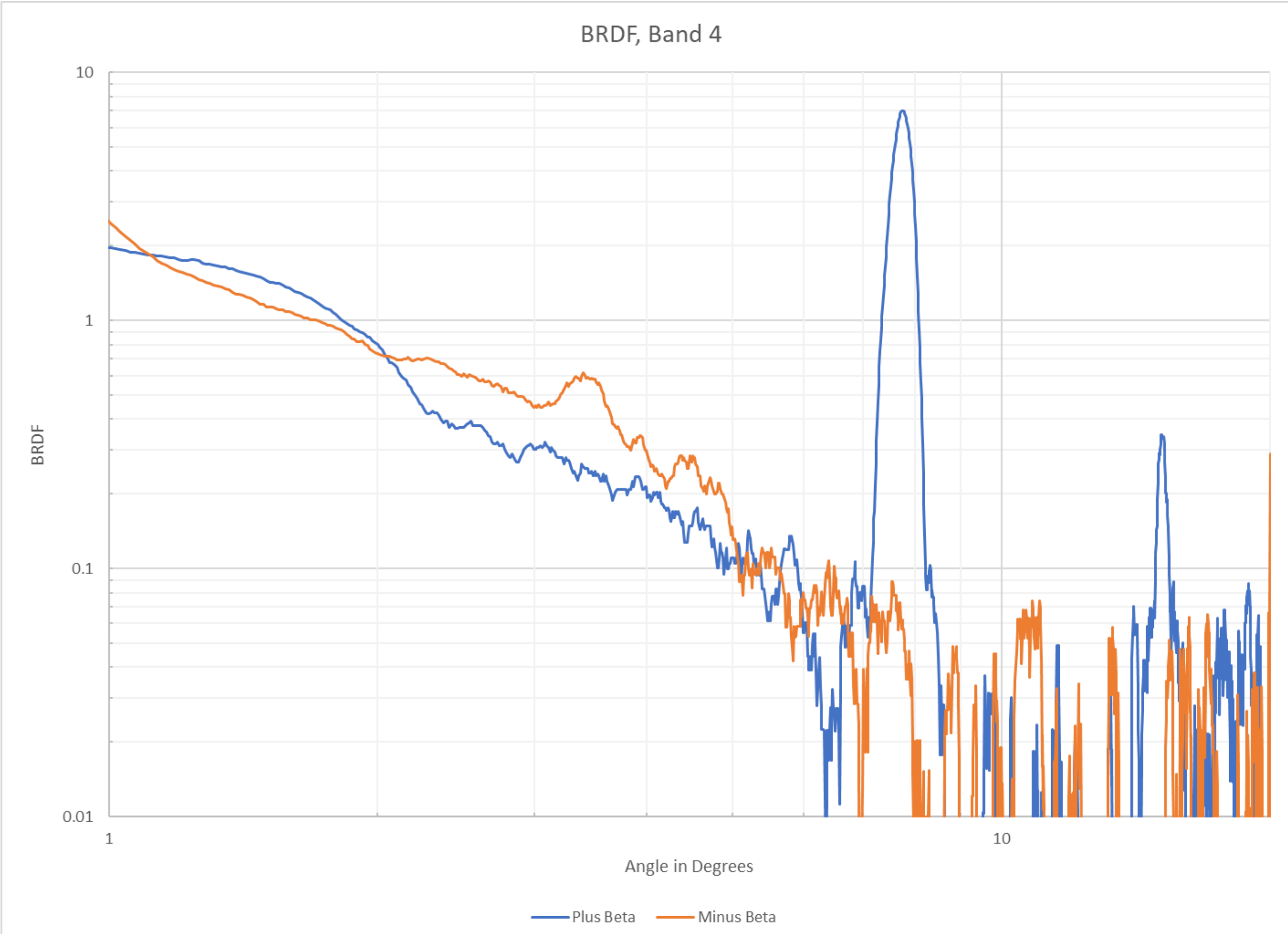


Figure Fourteen: Band 4 BRDF



What does this mean in a practical sense? Using the linear fit from Figure Twelve, one can integrate up the scatter to determine the response of a band to an infinite cloud edge, or to a hole in a cloud bank. I believe the most relevant data point here is the response to a cloud edge, which would be similar to looking at coastline near a desert region with bright soils, or a jungle region where the foliage would be quite bright in bands 7 and 8. My equation for the linear fit is:

BRDF = 10 ^ (BRDF Slope *Log(PixelSeparation) + BRDF Intercept))

Where: BRDF Slope = -2

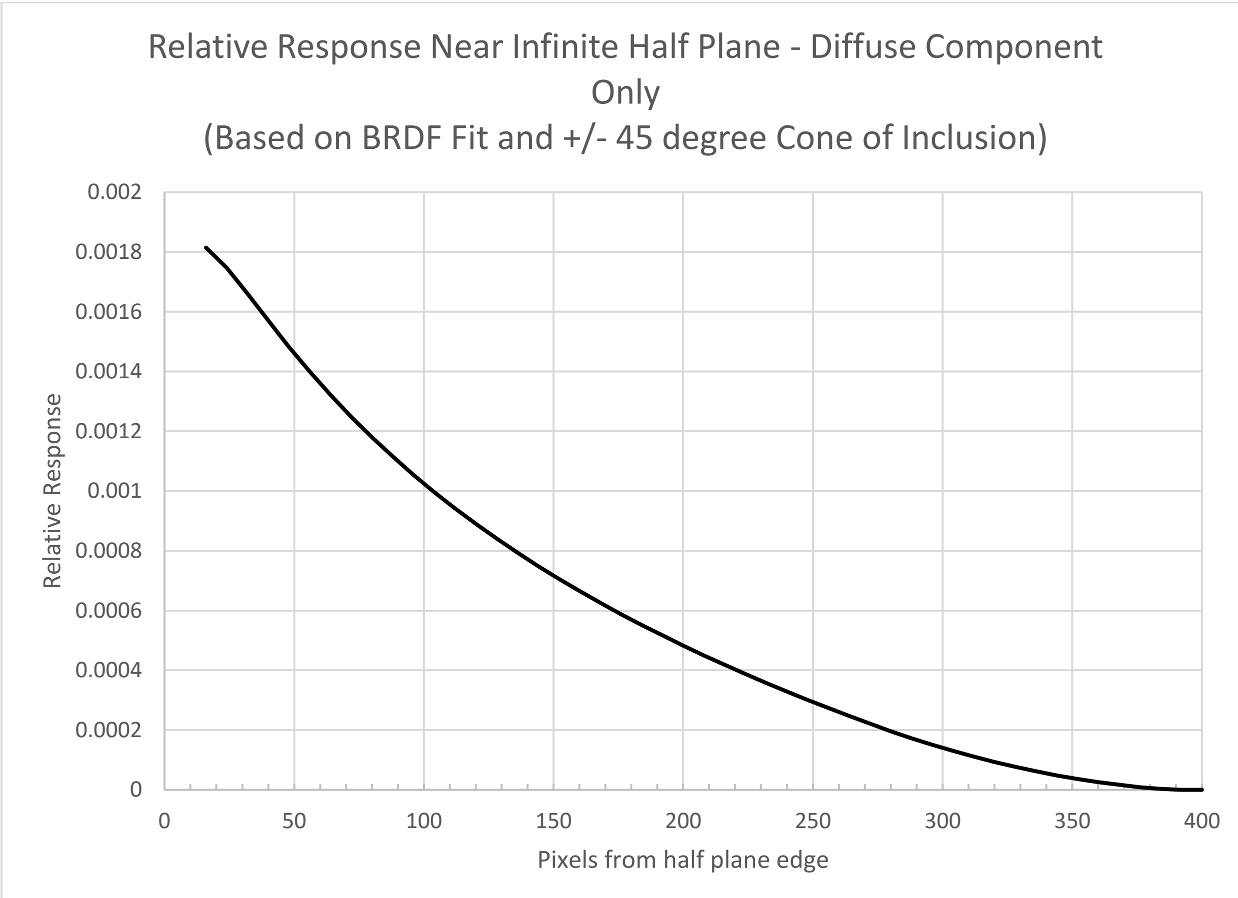
BRDF Intercept = 4.0912

Pixel Separation is the number of pixels separating the source pixel to the observation pixel

Using this equation, the response to a cloud edge for Band 6 is shown in Figure Fifteen. I have cheated a bit with this analysis since my summation assumes circular symmetry and Figure Ten shows that is an approximation. However, I truncated the values used to that encompassed by a

+/- 45 degree cone, based on inspection of the diffuse substrate ghosts of Figure Ten. My graph below is an estimate.

Figure Fifteen: Estimate of Edge Response



Note that the filter ghost scatter effect will sum with this diffuse component, and it is significant, generally greater in magnitude. The curve above is an estimate of what could be achieved if the filter ghost problem was solved. It is also what will be left once one gets more than 80 pixels from the infinite edge – the filter ghost is more confined to the edge. For comparison, the MODIS instrument typically achieved a stray light level of about 0.00075 to 0.0005 near an edge at 10 pixels distant, which would be 80 pixels for Hawkeye. While these numbers sound pretty low, in practice the desert or foliage region contributing to the scatter may be many times greater than the ocean surface, aggravating the effect and corrupting to the water leaving radiance determination by magnitudes of 5 or 10% in bands 7 and 8.

Mathematical reduction: this effect, because it is diffuse, with no sharp features, lends itself well to correction by a subtractive technique such as was employed by SeaWIFS. A reduction by a factor of 5 should be straightforward across most of the image. This technique is more important for the filter ghosts. It is described in the filter ghost report.