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## Rapid Pinhole Growth in the F160BW Filter

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### ABSTRACT

*The WFPC2 Filter F160BW, also known as WOOD's filter, was designed to transmit UV emission around 150nm and strongly block all other wavelengths. The filter has a unique construction where a thin film of sodium metal serves as the spectral element. However, sodium is a highly unstable and reactive metal, which makes the filter susceptible to changes over time. Herein we report a rapidly growing pinhole in the filter located in the field of view of the WF2 CCD. Observers requiring a high rejection of out-of-band light (i.e. red leak) should take note of this feature, and avoid the affected region in the field-of-view.*

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### Introduction

WFPC2 was installed into HST in December 1993 and continues to operate well. One of the more specialized and experimental filters on-board WFPC2 is the so-called "Woods Filter" or F160W filter (see Section 3.7 in the WFPC2 Instrument Handbook). It is designed to transmit far-UV emission around 150nm, and to strongly block visible and near-IR wavelengths where the CCDs are highly sensitive. The filter is made of two pieces of glass with a very thin sodium film ( $\sim 5000\text{\AA}$ ) deposited on the internal surface. The space between the glasses is evacuated and sealed to help stabilize the filter. However, sodium is a very soft and highly reactive metal, hence the filter is very delicate and strongly susceptible to the formation of holes in the coating due to both mechanical (abrasion) and chemical effects. The sodium atoms are only weakly bound to the glass surface and each other, and can migrate with very little provocation. For these reasons, there has always been concern about the longevity of this filter and the possible spontaneous formation of pinholes in the coating.

Even very small pinholes can have dramatic effects, since the system throughput at visible wavelengths (system QE  $\sim 14\%$ ) is much higher than in the UV passband (system QE  $\sim 0.07\%$ ).

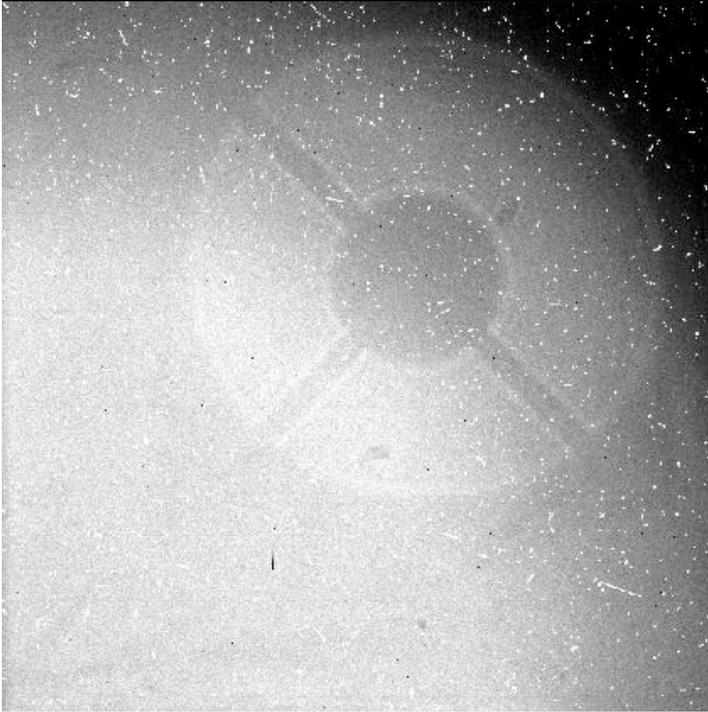
Due to these concerns, two Wood's filters were flown inside WFPC2 – the F160AW and F160BW filters. During pre-launch ground tests, the F160AW filter was found to contain serious pinholes, and hence has not been used on-orbit. The F160BW filter was relatively free of pinholes, and has been used for  $\sim 1229$  external WFPC2 images.

## **A Rapidly Growing Pinhole**

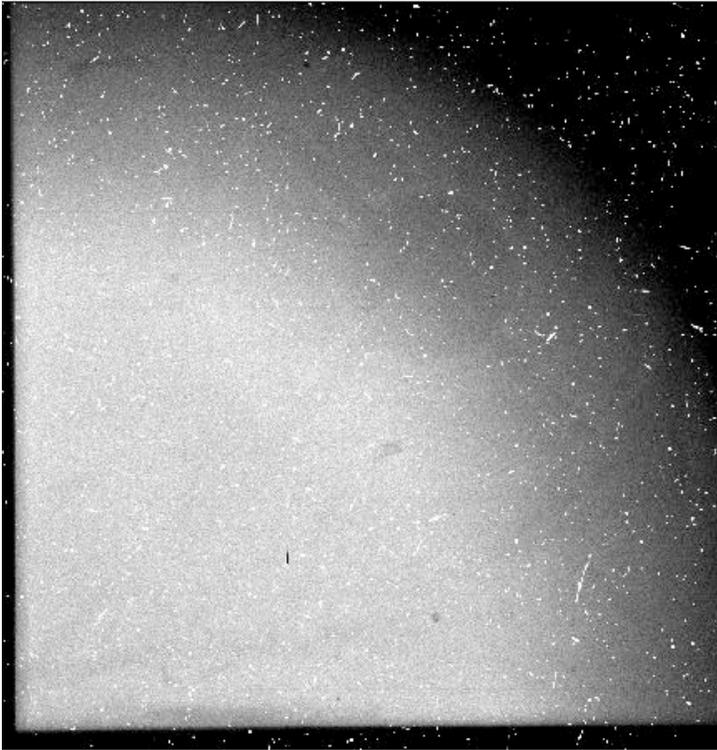
The F160BW filter has been monitored throughout the WFPC2 lifetime by taking internal flats – so called UVFLATs – where the entire field of view is illuminated by a deuterium lamp. Lenses and diffusers in the Calibration Module provide a collimated light beam approximating that of the HST OTA. Inspection of UVFLATs taken in late 2008 revealed a strong pinhole affecting the WF2 CCD field-of-view (Figure 1). Since the filter is far from the focal plane, the pinhole appears as a large, bright donut roughly 50 arcseconds in diameter. Obstructions from the three-arm spider and secondary mirror of the WFPC2 Cassegrain relay optics can also be seen within the donut. (The OTA spider does not appear, of course, since this is an internal exposure taken entirely within WFPC2.) These UVFLATS have been obtained with very long exposures that make the image filled with cosmic rays.

Apparently this pinhole is not entirely new, but can be faintly seen in images throughout the WFPC2 mission. Figure 2 shows a similar flat taken early in the mission from 1994. A ratio of the 2008 and 1994 flats is shown in Figure 3. This figure also illustrates the location of the pinhole in the WFPC2 field-of-view. Only WF2 is affected; the other three CCDs are completely unaffected.

Another detail of the F160BW filter construction is apparent in Figure 3. While the other “normal” WFPC2 filters are square and approximate the shape of the WFPC2 field-of-view, the F160BW filter is round and does not fully illuminate the corners of the WFPC2 field. Hence the noise is elevated in the outer corners. Also the pinhole donut appears brighter in the ratio image towards the outer corners, since the pinhole counts in the 2008 image are being divided by smaller illumination values in the outer corners of the 1994 image. In some sense the location of the pinhole is fortuitous – it is towards the outer part of the field-of-view, which is already vignetted by the filter construction – hence it is in a region which observers should already be avoiding. It would have much greater impact if it were located near the center of the field where the four CCDs adjoin.

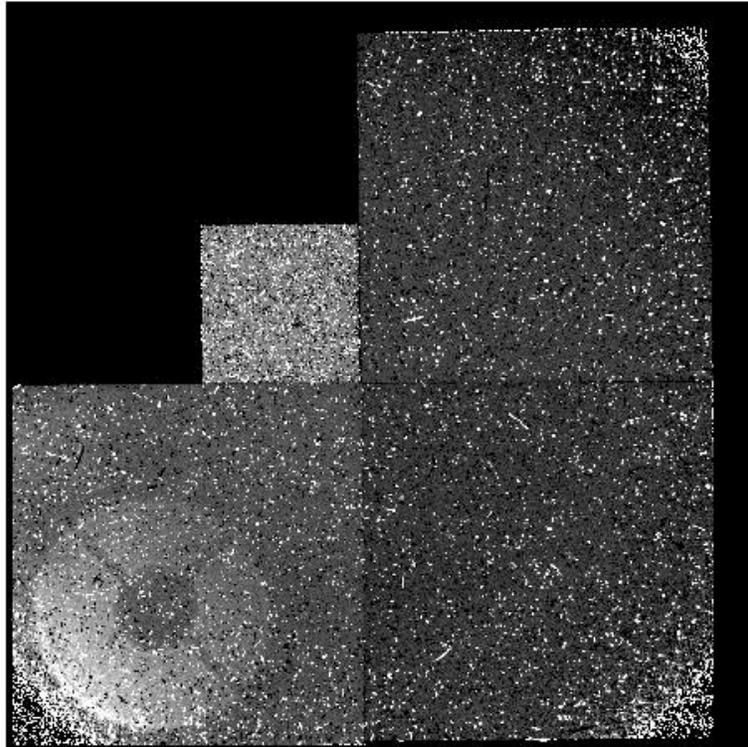


**Figure 1. WFPC2 WF2 CCD UVFLAT in F160BW from late 2008.**



**Figure 2. Same as Fig. 1, but from 1994.**

As a next step we investigated the time behavior of the pinhole using UVFLATs taken throughout the WFPC2 mission. We measured the average counts in a region inside the pinhole donut, and the average counts in a similar region just outside the donut. We then computed the relative counts due to the pinhole as  $[(\text{donut} - \text{background}) / \text{background}]$ , and present these in Figure 4. Two sets of numbers are plotted – these values using the average (labeled “mean”) and a second set of results where the median statistic is used instead. The median is less sensitive to anomalous pixels (due to cosmic rays, etc.), but the results are similar for both sets of numbers. As can be seen, this pinhole grew slowly over the first eight years of the WFPC2 mission, and then the growth rate dramatically increased after 2006. The last few years of data appear to define an exponential growth with a doubling-time of about 18 months. Extrapolating the trend seen in recent years, we would estimate that about 20% of the UVFLAT counts come from the pinhole by May 2009 (projected SM4 date).



**Figure 3. Image-ratio (2008 Flux over 1994 Flux) of two observations combined into mosaic.**

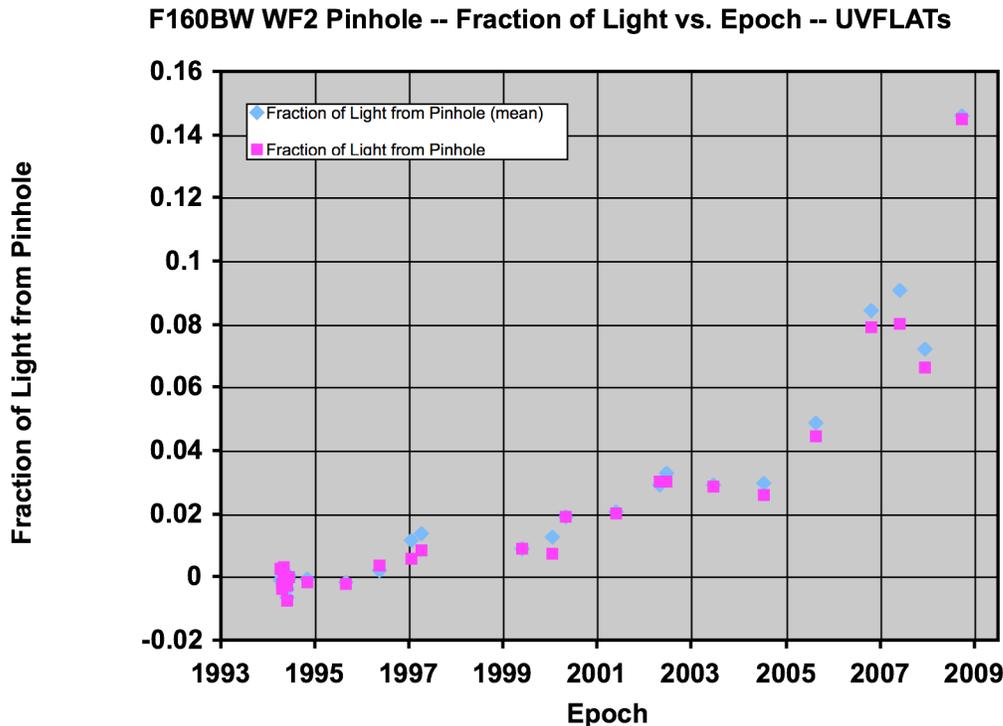


Figure 4. Fraction of UVFLAT light due to pinhole vs. epoch.

### Impact on Observers

It is difficult to fully assess the impact of the pinhole on science observations using the available data. This is because the exact size of the pinhole is not known. However we can make some general predictions. If we assume the pinhole is large enough to avoid diffraction effects, then any stellar object falling within the donut in Figures 1 and 3 will have out-of-band light added to the image. The exact amount of light is difficult to predict, but will correspond roughly to the area of the pinhole, times the area of the target, divided by the area of the 50 arcsecond OTA pupil at the filter surface. The effect of the pinhole will tend to be very small for stellar sources, since the point source target projects to a large (50 arcsec) domain at the filter. However, for large sources (i.e. planets or large nebulae), the fraction of out-of-band counts will begin to approach the values shown in Figure 4 (e.g. 15% at late epochs). If the pinhole is small enough for diffraction effects to be important, that would further reduce the impact, as light passing through the pinhole would be diffracted out of the F/24 OTA beam, and hence miss the relay optics, and not reach the detectors.

Obviously the effect of the pinhole will also depend on the spectrum of the target and any background objects present. As mentioned earlier, the CCDs are much more sensitive in the

visible and red, than in the UV, and this will dramatically amplify the relative counts contributed by the pinhole.

For now, we suggest that observers avoid the affected region of the WF2 field-of-view. If large targets or regions are being studied, a second telescope pointing might be used to move the affected target area to a better region in the field-of-view (e.g. WF3).

We plan to obtain additional on-orbit data to quantify the properties of the pinhole. We will attempt to better quantify the spectrum of the UVFLAT (deuterium) lamp in the visible and red, which will allow us to better quantify the fraction of out-of-band light passing through the pinhole, and hence the size of the pinhole. In addition, post-SM4 ground inspections of the filter could directly give the size of the pinhole, and hence constrain the impact on science observations.

## **Conclusions**

A previously weak pinhole in the F160BW filter began to grow exponentially with time in 2007, and presents potential issues for science observations. We recommend that future observers avoid placing targets in the affected area of the WF2 CCD field-of-view as defined by Figures 1 and 3. Additional calibration observations are planned to better assess the impact of the pinhole on science.