Abstract
The purpose of this ISR is to study the sensitivity of the WFC3 UVIS and IR channels to the focus and tilt of their correctors in preparation for the optical alignment of the instrument. This study is done by using the same IDL routines which will be used during the instrument optical alignment at Ball and at GSFC. The IDL encircled energy routine developed by G. Hartig provides excellent performance and is insensitive to under-sampling provided the center is chosen carefully. The IR channel will be aligned at Ball by using a silicon MUX instead of a HgCdTe FPA. We also explore the effect that this will have on the channel focus.

1. Introduction
In a previous ISR (WFC3 2002-04 “Using global PSF properties to probe the WFC3 UVIS alignment and focus) we concluded that the PSF sharpness is more sensitive to the properties of the PSF than the Encircled Energy. We also saw that both were limited in their accuracy by PSF under-sampling. This conclusion was reached by deriving the encircled energy using an IRAF routine and by using a relatively large aperture of 6 pixels in diameter. In preparation of the WFC3 optical alignment at Ball we decided to carry out more detailed tests of the response of the PSF to changes in the WFC3 corrector mechanisms. In addition to the sharpness we adopted a routine developed by George Hartig in IDL to derive the encircled energy of an under-sampled PSF. This routine handles fractional pixels more effectively than the IRAF routine and allows sub-pixel centering of the PSF. Given that the instrument alignment will be performed using IDL, we have converted to IDL the routines used to generated a PSF from the ZEMAX output data. Our method is described in detail in Section 2.

For each of the two channels we mapped the variation of PSF properties as the two tilt angles and the focus were scanned around their nominal values. The results are presented in Sections 3 and 4, respectively, for the UVIS and IR Channels.
An additional complication is that the IR Channel will initially be aligned by using a silicon MUX. The real detector is back-illuminated and is characterized by a up to 1mm thick substrate in high refractive index CdZn. In section 5, we have explored the effect on the IR Channel focus that such a substrate would have.

2. The method

PSFs are computed using the ZEMAX 10.0 model for the WFC3 UVIS channel adapted by J. Krist from the original Code V prescriptions and described in the ISRs WFC3 2001-17 and WFC3 2002-04. The ZEMAX PSFs are computed without considering pixellation due to the detector. These files are used as input by an IDL routine that projects the PSFs onto pixels. Other IDL routines determine the PSF center, sharpness, encircled energy. All calculations are done for a monochromatic filter at 633nm. This is within the sensitivity range of the UVIS channel and within the sensitivity range of the silicon MUX used for the early alignment activities of the IR channel.

The aperture diameter for the encircled energy calculation has been reduced to 3 pixels to increase the sensitivity of the method. The routine \textit{acs\_ee} has been developed by George Hartig and has been used for this study. Proper treatment of fractional pixel contributions ensures that the negative effects of under-sampling – and in particular the dependence on the precise sub-pixel centering – are corrected for. In addition to the encircled energy we also consider sharpness, which is defined as the sum of the squares of the normalized PSF. Sharpness gives the inverse of the effective number of pixels.

![Graph showing sharpness and encircled energy for various X-axis tilts of the UVIS M1 mirror.](image)

Fig 1: sharpness (times 10) and encircled energy for various X-axis tilts of the UVIS M1 mirror. Sharpness does not have as good a discriminating power as the encircled energy.
3. UVIS Channel

We have decided to focus on the enclosed energy and the sharpness. We have considered a monochromatic light source at 633nm since this is what will be used during the initial optical alignment. We have changed the corrector mirror M1 tilts and z-position and determined how the encircled energy and sharpness change. The results are shown in Figures 1, 2, and 3, respectively, for the X-axis tilt, Y-axis tilt, and Z-shift.

![Graph showing encircled energy and sharpness for various Y-axis tilts of the UVIS M1 mirror.](image)

In contrast to the sharpness measured with IRAF/imexam case, the measurements with acs_ee appear to be independent of sub-pixel centering and allow one to use a small aperture radius, thus maximizing the sensitivity to misalignments. Sharpness is still an acceptable method but remains more sensitive to centering problems.

The figures show that the encircled energy can be used effectively to correct tilts smaller than 0.5 arcmin and focus to better than 0.5 mm. Considering the complete degradation of the PSF quality for tilts exceeding 3 arcmin off the nominal position, we expect that a variability range of +/- 3 arcmin should be adequate for the UVIS M1 corrector. The present design should provide a range of +/- 6 arcmin.
On the basis of the results for the UVIS channel and of those in ISR.2002-04 proving that sharpness is negatively affected by under-sampling we have focused only on the encircled energy for the IR channel. The initial optical alignment of the IR channel will be carried out using a silicon MUX and a laser operating at 633nm. For this reason we have initially focused on operations at this wavelength. The element that is tilted and shifted in the IR channel is the M2 corrector mirror.

The sensitivity of the encircled energy to tilts and focus are illustrated in Figure 4 and 5, respectively. We find that the IR channel image quality is comparatively less sensitive to tilts than that of the UVIS channel. This is understood in terms of the geometry of the two channels. In fact, a tilt by 3 arcmin will create a pupil shear by 1.2% of the pupil diameter in the IR channel and by 2.2% in the UVIS channel. The lower sensitivity to tilts makes it more likely that we will use a larger fraction of the +/- 6 arcmin tilt range for the IR channel. In contrast, sensitivity to focus is increased. This is also understood in terms of the geometry of the two channels. The (F/12) geometry of the IR channel increases its sensitivity to focus relative to the slower (F/31) UVIS channel.

4. IR Channel

Fig 3: sharpness (times 10) and encircled energy for various Z-axis positions of the UVIS M1 mirror.
Fig 4: encircled energy for various X-axis and Y-axis tilts of the IR M2 mirror. Notice how the encircled energy degradation is not as strong as in the UVIS channel for comparable tilts.

Fig 5: encircled energy for various focus positions of the IR M2 mirror. Notice how the encircled energy degradation is stronger than in the UVIS channel for comparable defocus.
6. Using a HgCdTe FPA instead of a silicon MUX

After the initial alignment activities the IR channel will receive an IR FPA. These arrays are characterized by the presence of thick substrate of high refractive index CdZn material. We have used the model for the refractive index of CdZn presented in ISR 2000-01 “Consequences of the WFC3 IR 24 degrees detector tilt” to add this new material to the Zemax glass catalog and studied the impact that it would have on the channel alignment. In the worst case this substrate could be 1 mm thick and thus have a large impact on focus. Since the IR FPA is blind at 633nm we have computed the focus at 1000nm. The result is shown in Figure 6 and implies a sizeable focus shift of 0.65 mm.

![EE with CdZn substrate](image)

Fig 6: encircled energy at 1 µm for various focus positions of the IR M2 mirror once a 1mm thick substrate of high refractive index material is included. Notice how the PSF quality at the nominal focus position is now substantially degraded. The lower maximum value of the encircled energy is due to the longer wavelength compared to previous plots.

7. Acknowledgements

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