Operated for NASA by AURA

Instrument Science Report WFC3 2007-04

Evaluation of Selection Criteria for WFC3 Replacement IR Grisms

S. Baggett, T. Brown, G. Hartig, M. Robberto (STScI),
R. Boucarut (GSFC), R. Telfer (OSC/GSFC)
March 16, 2007

ABSTRACT

This report describes the rationale for recommending focus as the primary selection criterion in choosing the final IR replacement grisms.

Introduction

Instrument-level imaging during the first thermal vacuum ground test of the WFC3 IR channel in the fall of 2004 revealed that while the IR filters performed as expected, well within specification, the grisms produced significantly out-of-focus, slightly tilted spectra (Bushouse & Hartig 2005). The problem was found to be due to an error in the installation procedure (a coordinate axis mixup) and an erroneous assumption concerning the orientation of the IR detector relative to the filter wheel (Turner-Valle 2005), both easily rectified in the procedures. However, lab testing revealed an additional issue with the grisms themselves: they were considerably out of focus (>200 μ) even when used in the correct orientation. Subsequent interferometry and optical modelling confirmed that the focus of the grisms was too short as a result of the manufacturing process. The initial bandpass coatings deform the substrate, by itself not an issue since the shape is effectively a meniscus. However, later application of the resin and grating to one side of the substrate in order to complete the grism produces a plano-convex lens shape, which shortens the focus.

As a result, with WFC3 Science Oversight Committee (SOC) approval, the acquisition of new grisms was pursued, with allowances made for the coating stresses. Several possible solutions were developed and implemented in parallel in order to have a selection of candidates from which to choose: 1) a thicker prism substrate, to better resist the distortions from the coating process as well as add optical path which would restore the focal length; 2) a compensating focal plate which could be used in conjunction with the original grisms; and 3) lower stress optical coatings to eliminate the stress and resulting surface bending. Due to manufacturing and scheduling details, the final pool of candidate grisms consisted of primarily the first type (thicker substrates, using a variety of thicknesses spanning the predicted ideal), along with one of the second type (thin grism + compensator plate) for each of G102 and G141. The resulting grism candidates were extensively tested in the lab, evaluated in light of the requirements, and the final choice of which specific grisms to use as flight determined by the SOC, with input from the WFC3 team at GSFC and STScI. This report summarizes the rationale for recommending focus as the primary discriminant in selecting grism replacements.

Analysis

A variety of tests were performed on the replacement candidate grisms in the lab, including inspections, verification of physical dimensions, wavefront quality, focus shift, throughput, dispersion, ghost levels, and environmental tests. Individual lab reports detailing all test procedures and results for each grism are archived on the private GSFC WWW site and are available upon request. Details of the characterization results for the grisms ultimately chosen for flight have been documented in ISR 2007-03 (Baggett et al. 2007). Some of the primary results for all the candidates are discussed in the following sections.

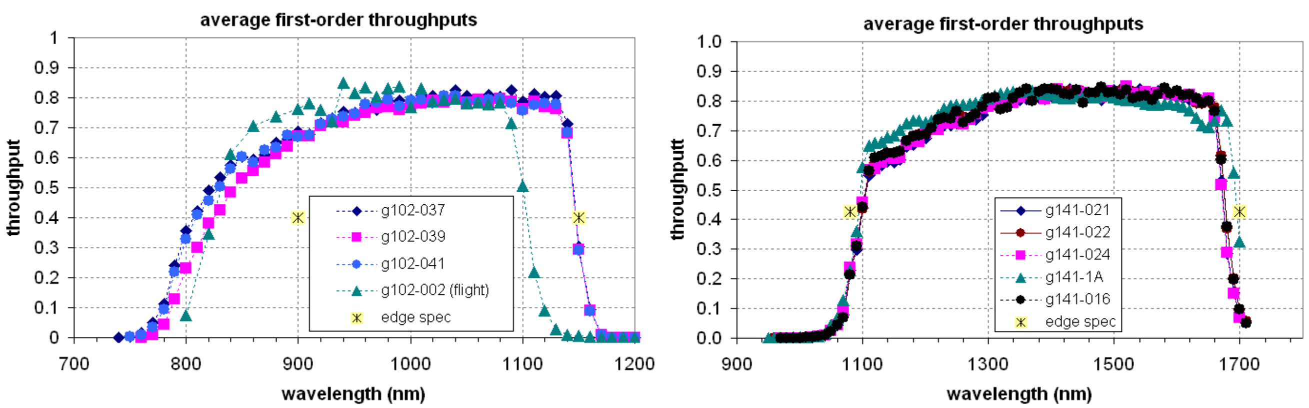
Throughput

The first-order throughput curves for the available G102 and G141 candidates are presented in Figure 1; the data acquisition and analysis have been described in Baggett et al. (2007) and Telfer (2007a, 2007b).

For G102, all elements, including the original grism (labeled as 002-flight) showed similar efficiencies between ~850-1100 nm. There were slight variations shortward of ~850 nm, which although they appeared to be real, were not deemed significant enough to serve as a selection criterion. The new grisms provide a better match to the red edge requirements than the original flight element (the longer red cutoff assures overlap with G141, for complete coverage of the WFC3 IR range). The new G102s have a slightly bluer edge than the original grism (#2), which takes advantage of the improved detector sensitivity. Out-of-band performance is excellent in all candidates, as the grism substrate is Hoya IR80, an IR-transmitting glass which does not transmit lower than ~800 nm.

For G141, the first-order efficiencies of the new grisms (#21, 24, and 16) are effectively the same to within the measurement error. The G141-1A has a few percent less throughput than the new grisms at 1400-1700 nm and a few percent more throughput than the new grisms at 1100-1400 nm; including the necessary compensator plate will reduce 1A's throughput a bit further. Overall, however, there does not appear to be a significant difference between the grism throughputs.

Figure 1: Throughput curves for candidate G102 and G141 grisms. The G102 grism marked as flight (#2) was the original flight grism; the original G141 flight grism is not included in the plot below (it was not a candidate due to the lack of a red edge cutoff).



Background levels

Estimates of the expected background light levels were computed via the standard WFC3+HST model (Robberto 2003), using FPA129 and the grism coating-only throughput data (spectral scans taken before application of the grating) . The zodiacal light contribution (zodi) was calculated using backgrounds from Giavalisco et al. 2002 along with results from a new, improved analytical fit between 600 and 2200 nm. Results of the new fit for the zodi at 1200 and 1600 nm compared favorably to previous estimates produced using the Stiavelli/Robberto Excel model (based upon Stiavelli 2002).

The thermal background levels were found to be effectively identical for all candidate G102 grisms (0.034 e^-/s/pix). The zodi light levels for the new G102 grisms were higher (0.457 e^-/s/pix) than the G102-002 original flight grism (0.363 e^-/s/pix), not unexpected given the wider bandpass in the new grisms. There were slight differences in the thermal and zodi background levels between the candidate G141 grisms, but the magnitude of those variations (~0.005 e^-/s/pix level) was not considered significant enough to make it a driver for selecting the new flight element. The background values have been listed in Table 2.

Encircled energy and focus

To quantify the effect of defocus, model encircled energy (EE) curves were run with the optical design software Zemax, using a variety of focus settings and central wavelengths. The EEs were converted to PSFs and a rectangular box extracted; the results for a 1 pixel wide box are tabulated below. Larger boxes could have been extracted but given that more pixels provide only modest improvement over the 1-pixel case while including additional background, it is expected that most observers would choose 1 pixel extraction or an optimally weighted extraction. The results are summarized in Table 1; listed are the wavelength, focus, EE at field center, standard deviation in EE for the 9 field points, and finally, the difference between the maximum and minimum encircled energies across the field. The largest differences are seen in G102: increasing the defocus by ~100 μ results in a couple percent of the light being lost from field center, a significant increase in variation across the field, and a general decrease in the EE at any field position Overall, varying the focus does not appear to be a large effect but is at about the same level as the variation seen in the measured throughputs.

Table 1. Encircled energy for G102 and G141 as a function of wavelength and defocus.

G102					G141				
wavelength (microns)	**focus**	**EE center**	**EE sigma**	**max(EE) - min (EE)**	**wavelength (microns)**	**focus**	**EE center**	**EE sigma**	**max(EE) - min (EE)**
0.85	-200	0.63	0.03	0.10	1.1	-200	0.61	0.02	0.05
0.85	-100	0.66	0.03	0.09	1.1	-100	0.63	0.01	0.05
0.85	-50	0.67	0.02	0.08	1.1	-50	0.64	0.01	0.05
0.85	0	0.68	0.02	0.07	1.1	0	0.64	0.01	0.05
0.85	50	0.68	0.02	0.07	1.1	50	0.64	0.01	0.05
0.85	100	0.68	0.02	0.07	1.1	100	0.64	0.02	0.05
0.85	200	0.66	0.02	0.07	1.1	200	0.63	0.02	0.06
1.0	-200	0.60	0.04	0.11	1.4	-200	0.56	0.02	0.06
1.0	-100	0.63	0.02	0.07	1.4	-100	0.58	0.01	0.04
1.0	-50	0.64	0.02	0.05	1.4	-50	0.58	0.01	0.03
1.0	0	0.64	0.02	0.05	1.4	0	0.58	0.01	0.03
1.0	50	0.65	0.02	0.06	1.4	50	0.59	0.01	0.04
1.0	100	0.65	0.03	0.08	1.4	100	0.59	0.02	0.04
1.0	200	0.64	0.04	0.10	1.4	200	0.58	0.02	0.06
1.15	-200	0.57	0.04	0.11	1.7	-200	0.51	0.02	0.06
1.15	-100	0.60	0.03	0.08	1.7	-100	0.52	0.01	0.04
1.15	-50	0.60	0.02	0.07	1.7	-50	0.52	0.01	0.04

G102					G141				
wavelength (microns)	**focus**	**EE center**	**EE sigma**	**max(EE) - min (EE)**	**wavelength (microns)**	**focus**	**EE center**	**EE sigma**	**max(EE) - min (EE)**
1.15	0	0.61	0.03	0.08	1.7	0	0.53	0.01	0.05
1.15	50	0.62	0.03	0.09	1.7	50	0.53	0.02	0.05
1.15	100	0.62	0.04	0.11	1.7	100	0.53	0.02	0.06
1.15	200	0.61	0.06	0.14	1.7	200	0.53	0.03	0.08

Other characteristics

No other measured parameter of the candidate grisms showed enough variation or exceeded the specifications significantly enough to merit use as a discriminant. Ghost levels and wavefront errors, for example, all easily met the requirements. Characteristics such as dispersion, blaze angle and groove period were identical for the candidates as the same master templates were used to replicate the gratings.

Impact to typical science programs

Finally, consideration was given to which of the two criteria that showed the most variation from grism to grism (throughput amd focus) would be best as a discriminator, given the likely science projects that may be performed with the WFC3 grisms. Conceivably, the grisms could be used to observe targets at two extremes: observations of bright point sources and observations of faint point sources possibly embedded within extended sources. The former type of program is relatively unaffected by some defocus: a small decrease in EE with radius implies that a larger extraction aperture must be used, which in the case of a bright point source would involve little penalty. On the other hand, faint point sources would profit from better focus by allowing smaller extraction apertures, thus minimizing noise effects due to the surrounding background. Assuming that the majority of WFC3 IR grism imaging will be done on faint targets, this leads to a preference for focus as the selection criterion. Improved focus would also minimize the effects of focus variations due to telescope breathing as well as benefit science programs attempting to separate distinct, closely-spaced sources.

Summary

The table below summarizes some of the key parameters discussed in this report. Given that 1) the measured first-order throughputs are all relatively similar to each other, 2) the thermal and zodi backgrounds are similar, 3) the dispersion, blaze angle, wavefront, cosmetics, ghosting, and other characteristics of all the grisms meet specifications, 4) defocus increases EE variations across the field of view (while decreasing the EE at any field position), and 5) defocused images will be more susceptible to variations in performance due to telescope breathing, the STScI and GSFC WFC3 team recommends using focus as the prime selection criterion for the choice of flight grism. Beyond focus, preference should be given to the thick single-substrate grisms, as opposed to the grism+compensator plate pair, in order to facilitate installation into the filter wheel.

Table 2. Key measured characteristics of the candidate grisms.

grism	defocus (microns)	1st order throughput (max, %)	throughput blue edge (nm)	throughput red edge (nm)	background thermal (e^-/s/pix)	background, zodi (e^-/s/pix)	ghost (%)
g102-037	-100	82	807	1148	0.034	0.457	<0.05
g102-039	20	79	824	1147	0.034	0.457	<0.05
g102-041	126	81	808	1147	0.034	0.457	~0.1
g102-002[a]		84[b]	824	1104	0.034	0.363	<0.05
g141-016	3	85	1099	1678	0.092	0.852	~0.1
g141-021	-148	84	1099	1674	0.088	0.846	<0.05
g141-022	-162	84	1097	1678	0.092	0.853	<0.05
g141-024	-40	85	1099	1674	0.088	0.855	<0.05
g141-1A[a]		83[b]	1093	1696	0.108	0.864	<0.05

a. Grisms require compensator plate to achieve proper focus; measurements of the defocus of the grism + compensator plate are still to be obtained.

b. Upper limit to the peak efficiency, as throughput was measured without the compensator plate.

References

Baggett, S., et al., “Performance of the WFC3 Replacement Grisms,” WFC3 Instrument Science Report WFC3-2007-03.

Bushouse, H., and Hartig, G., “WFC3 Thermal Vacuum Testing: IR Grism Focus and Tilt Anomalies,”, WFC3 Instrument Science Report WFC3-2005-06, Feb 2005.

Giavalisco, M., Sahu, K., and Bohlin, R., “New Estimates of the Sky Background for the HST Exposure Time Calculator,” WFC3 Instrument Science Report WFC3-2002-12, Oct 2002.

Robberto, M., “Model of thermal background at the focal plane of the WFC3-IR channel,” WFC3 Instrument Science Report 2003-09, Aug 2003.

Stiavelli, M., “Expected WFC3-IR count rates from zodiacal background,” WFC3 Instrument Science Report 2002-02, Jan 2001.

Telfer, R., “The FilterGEISt Setup for WFC3 Filter and Grism Image Testing,” Orbital Sciences Corp. Technical Memo WFC3-577-RCT-011, Jan 2007a.

Telfer, R., “Analysis of FiterGEISt Data on WFC3 Candidate Filters and Grisms,” Orbital Sciences Corp. Technical Memo WFC3-577-RCT-012, Jan 2007b.

Turner-Valle, J., “WFC3 IR Grism Modeling and Rotations,” Ball Aerospace and Technologies Corp. Systems Engineering Report OPT-079, March 2005.