NUV Grating Performance Summary

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1. INTRODUCTION

The NUV gratings for the COS instrument are all planar gratings with parallel, uniformly spaced grooves. The gratings are replicated onto circular fused silica substrates that are 15 mm thick. The gratings support the G185M, G225M, G285M, and G230L channels. The "M" denotes a channel with medium or moderate resolution of $\lambda/\Delta\lambda$~20,000. The "L" indicates that the channel has low resolution, $\lambda/\Delta\lambda$ ~2000. The gratings were all fabricated using holographic manufacturing techniques by Jobin-Yvon, Inc. (JY) in France.

The efficiency of the "M" gratings is controlled by a complex interaction between the groove shape and the optical properties of the applied coatings. The gratings for the "M" channel gratings use laminar groove profiles to enhance the groove efficiency of the gratings. The "L" grating has traditional triangular groove profiles to increase the groove efficiency.

The original intent was to apply standard aluminum with a magnesium fluoride overcoat (Al/MgF_2) to all of the gratings to provide excellent performance for $\lambda > 1700$Å. However, when the first NUV grating, G185M-A, was coated and tested the efficiency of the grating was substantially below the net efficiency predicted by scalar theory. An exhaustive investigative program ensued to understand why the net efficiency was so low. In fact, we found that all three of the "M" mode gratings had substantially lower net efficiency than predicted by multiplying the groove efficiency, as measured by JY, by the reflectivity of the Al/MgF_2 coating. The "L" mode grating performance was as expected.

In the end, we identified the MgF_2 coating as the source of the problem. The MgF_2 coating is applied as an overcoat to keep the Al sublayer from oxidizing. The AlO_2 layer that forms immediately upon exposure to air drastically decreases the reflectivity at wavelengths shorter than about 1700Å. Thus, with an MgF_2 overcoat the reflectivity of the coating remains excellent down to 1150Å. While not specifically required for this application, it is standard practice within the HST program to use Al/MgF_2 coatings on all ultraviolet optics, as the coating is known to be stable in a space environment.

As it turns out, the MgF_2 layer was creating what is known as an "efficiency anomaly". An efficiency anomaly occurs when the groove density and the index of refraction of the coating work in combination to remove energy from the diffracted beam. In essence, a wave-guide is created that siphons off the diffracted energy. This is a well known effect, however, it is very difficult to predict or model accurately. It is similar to, but not exactly the same as, a phenomenon called the "Woods Anomaly".

The fact that all three "M" mode gratings suffered from the same degradation in performance is related to the geometry of the NUV channel. The spectrograph geometry is identical for each of the gratings. β is held roughly constant by varying the groove density such that λ/d is constant for each grating. Thus the conditions for an efficiency anomaly to occur are replicated for each grating.

Part of the solution to this problem will be to fly the G225M and G285M gratings coated with bare aluminum thus mitigating the resonance anomaly. The situation for the G185M channel is more complex. A grating for the G185M channel was coated with bare aluminum and tested. The grating performance did not improve significantly. However, a G225M grating coated with Al/MgF$_2$ did have excellent efficiency at G185M wavelengths. We therefore will fly a G225M grating in the G185M slot and run the risk of losing a small (~20%) amount of spectral resolution, because COS is optimized for sensitivity. The decrease in spectral resolution ($R \geq 16{,}000$ versus the design of $R \sim 20{,}000$) was deemed an acceptable trade for a factor of 2 improvement in sensitivity.

This document presents the flight gratings, flight spares, and the measured performance of these gratings. In addition, it provides a complete inventory of all the gratings developed for the NUV channel. All the gratings have been delivered to and are stored at Ball Aerospace Technology Corporation (BATC).

1.1 RELEVANT DOCUMENTS

COS-08-0005	COS NUV Grating Specification
COS-08-0013	COS NUV Grating Substrate Specification
CASA-COS-1010	COS NUV Grating Substrate
COS-08-0008	COS Coating Reflectivity Specification
	HST/COS NUV Diffraction Grating Characterization Plan at NASA/GSFC

2. FLIGHT GRATINGS

This section presents the flight and spare gratings chosen for each of the NUV channels. The measured net efficiency as a function of wavelength and the measured grating scatter is presented. The net efficiency of each grating was measured to verify the performance of the coating. The scatter was only measured for either the flight or spare grating. Since the flight and spare gratings are replica gratings, the scatter should be identical. Thus to save time only one was measured to quantify the scatter performance.

The grating efficiencies and scatter were measured at NASA/GSFC under the direction of René Boucarut. A complete description of the test plan can be found in HST/COS NUV Diffraction Grating Characterization Plan at NASA/GSFC. In brief, the grating efficiencies were measured in a geometry that is almost identical to the NUV channel.

An NUV MAMA detector was used to acquire the diffracted images. A series of tests at GSFC, CU and Jobin-Yvon validated the accuracy and repeatability of the NASA/GSFC measurements.

The grating scatter is generally very difficult to measure, especially when the grating scatter is as low as it is in the case of the COS NUV gratings. The grating scatter was measured by acquiring deep ($\sim 10^6$ events) images and evaluating the image for scatter. In one case, a mirror was used in place of the grating to characterize the point spread function of the test set up and identify any glints or features inherent in the system. No major defects were identified, other than a non-uniform and high detector background. The specifications for the grating scatter are as follows (taken from COS-08-0005):

> "The scattered light off of the grating shall be $\leq 2\text{X}10^{-5}$/Å within 10Å from line center for the G185M, G225M, and G285M gratings. For the G230L grating the scattered light off the grating shall be $\leq 2\text{X}10^{-5}$/Å within 50-80Å from line center."

The scatter is measured using equation 1. In equation 1, E is the grating scatter, L is the total counts in the diffracted image, B is the average background counts formed by averaging two regions above (B1) and below (B2) the diffraction plane, S is the total counts in a region 10Å away from the line image in the diffraction plane, and $\Delta\lambda$ is the width of the extraction box in Å.

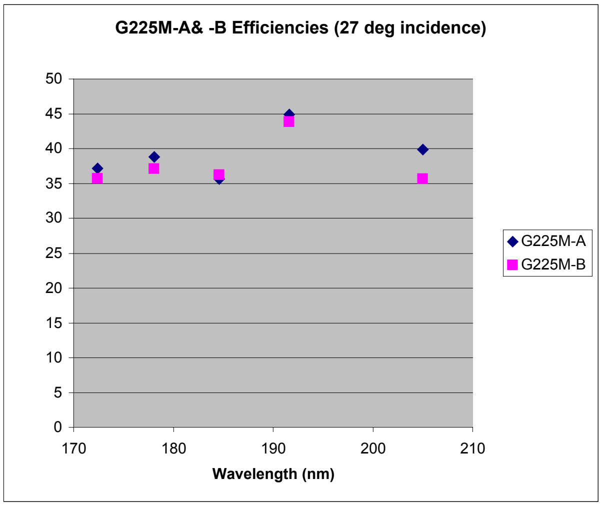
$$E = (S-B)/(L-B)/\Delta\lambda \qquad \text{Equation 1}$$

With each grating described below is a figure that shows the locations of the regions used to compute the counts in L, S, B, and $\Delta\lambda$. The general problem is that the background of the MAMA detector used in the tests was very non-uniform, so determining the background was very difficult and, in one case, precluded a detection of the scattered light. In certain cases I was forced to use either B1 or B2 and not the average B, because there were more background events than from scattered light. For those cases I recorded the number of events, but placed the value within parentheses.

2.1 G185M CHANNEL

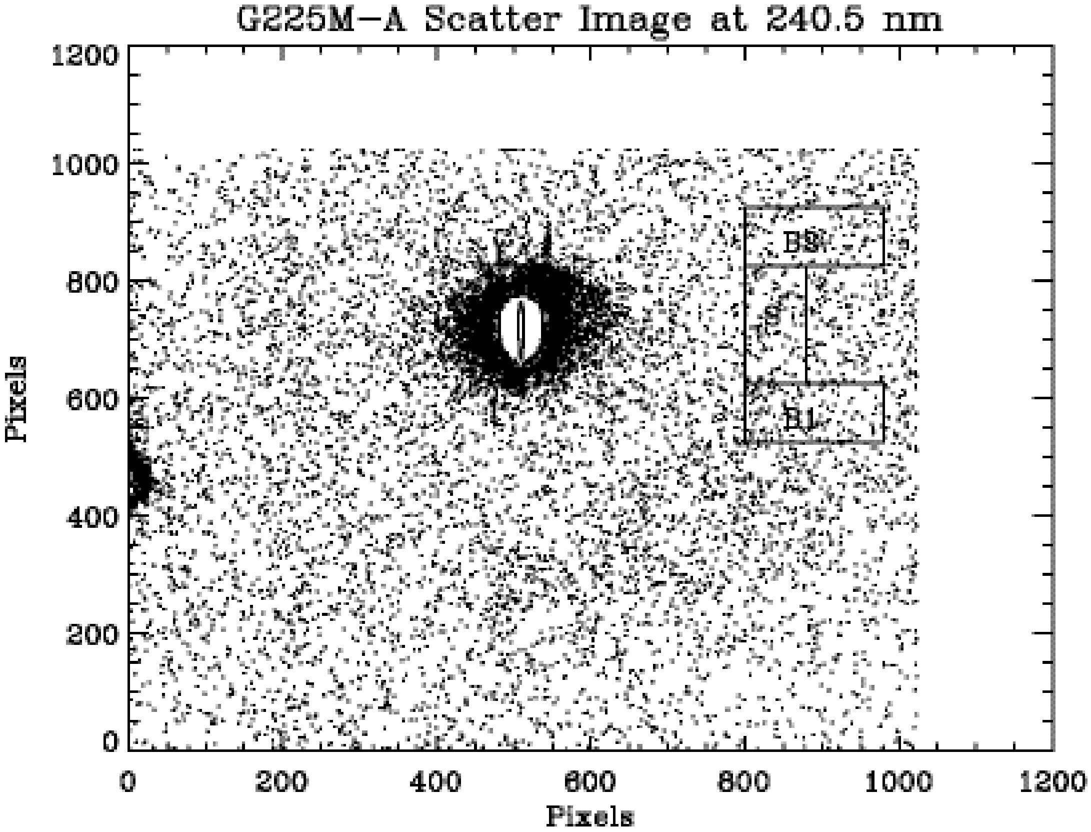
2.1.1 Net Efficiency

G225M A (spare)		G225M B (flight)	
λ (nm)	Efficiency (%)	λ (nm)	Efficiency (%)
205	39.89	205	35.63
191.6	44.9	191.6	43.81
184.6	35.6	184.6	36.2
178.1	38.82	178.1	37.11
172.4	37.16	172.4	35.69



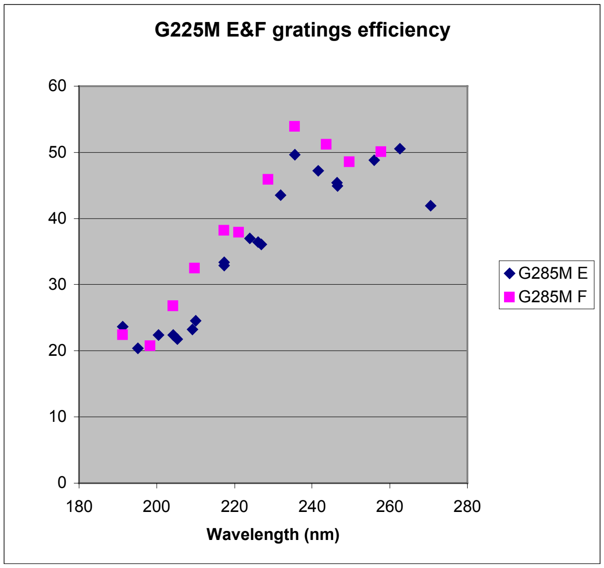
2.1.2 Grating Scatter (G225M-A)

Parameter	Value	Units
Plate scale	0.043	Å/pixels
L	4.12×10^{6}	counts
S	7072	counts
B	7586	counts
B1	7290	counts
B2	7882	counts
$\Delta\lambda$	8.8	Å
E	-1.42×10^{-6}	/Å



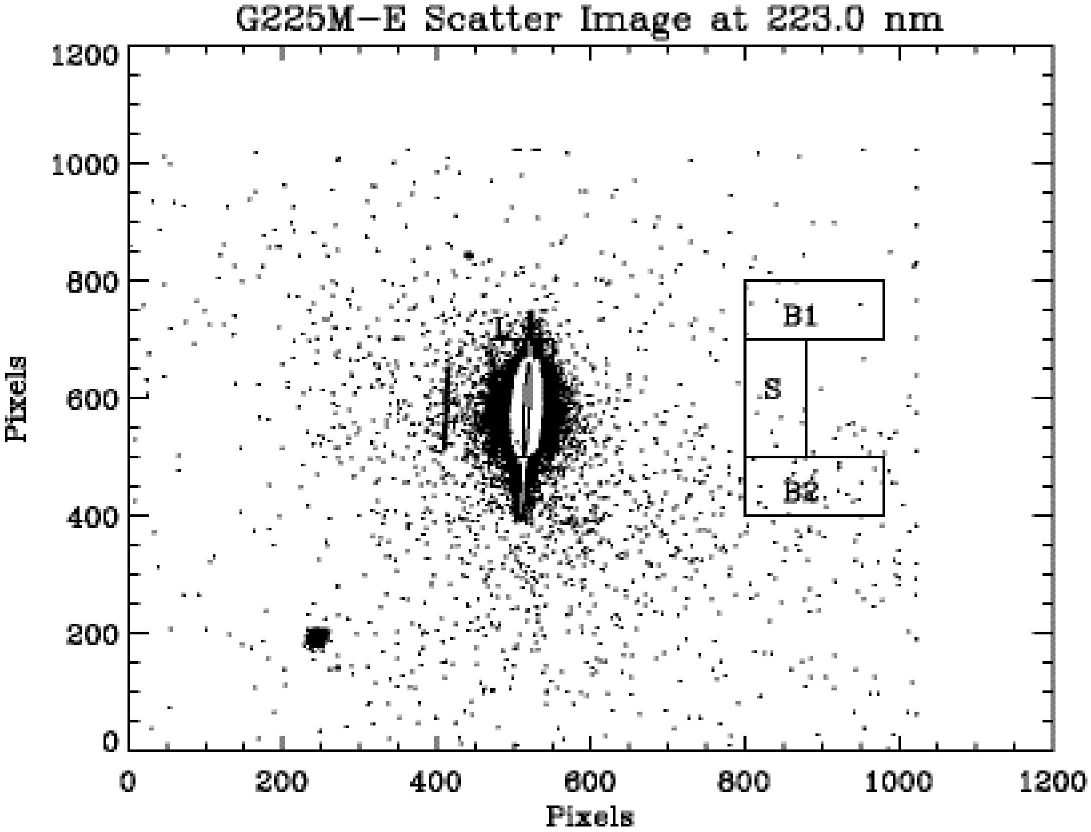
2.2 G225M CHANNEL

G225M-E (spare)		G22M-F (flight)	
λ (nm)	Efficiency (%)	λ (nm)	Efficiency (%)
191.2	23.63	191.2	22.34
195.1	20.34	198.3	20.7
200.4	22.36	204.2	26.74
204.2	22.34	209.8	32.47
205.3	21.73	217.3	38.19
209.2	23.16	221.1	37.89
210	24.49	228.6	45.88
217.3	33.39	235.5	53.87
217.3	32.89	243.8	51.16
223.9	36.99	249.6	48.51
226.1	36.46	257.8	50.1
226.9	36.11		
231.8	43.51		
235.5	49.68		
241.6	47.19		
246.6	44.95		
246.5	45.39		
256	48.85		
262.6	50.56		
270.5	41.94		



2.2.1 Grating Scatter (G225M-E)

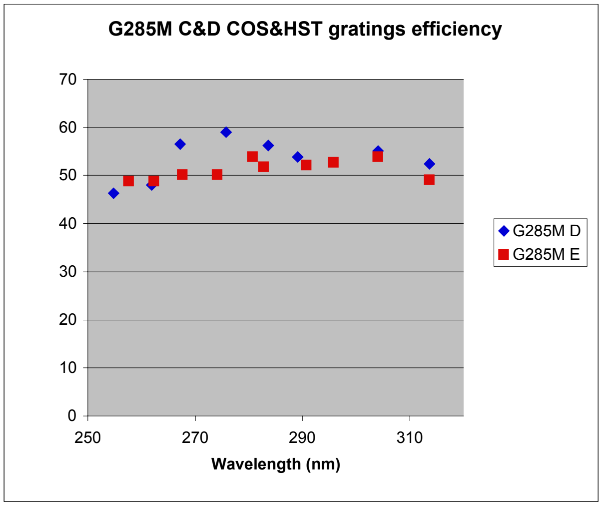
Parameter	Value	Units
Plate scale	0.043	Å/pixels
L	5.42×10^6	counts
S	18126	counts
B	17845	counts
B1	17845	counts
B2	(25764)	counts
$\Delta\lambda$	8.8	Å
E	0.6×10^{-5}	



Note: The line image to the left of the diffracted image is not a ghost image, but spectral contamination from the monochromator.

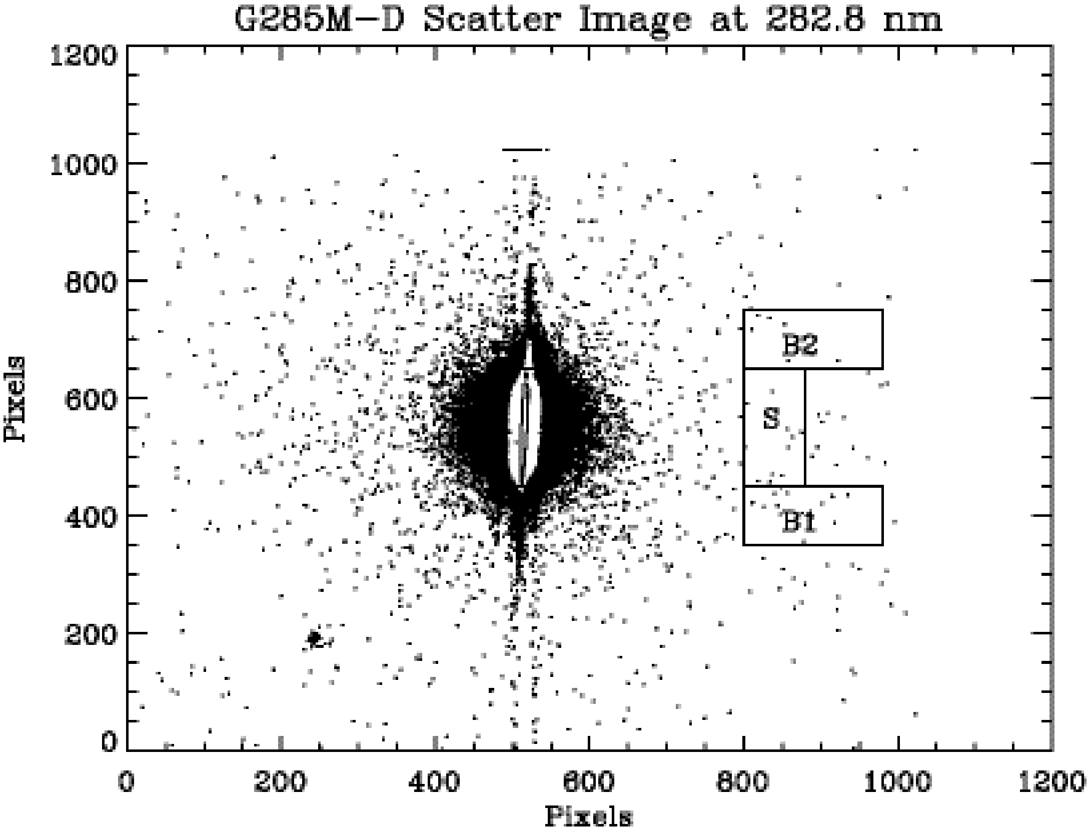
2.3 G285M CHANNEL

G285M D (flight)		G285M E (spare)	
λ (nm)	Efficiency (%)	λ (nm)	Efficiency (%)
254.8	46.34	257.6	48.84
261.9	48.05	262.3	48.81
267.2	56.57	267.6	50.11
275.8	58.99	274.1	50.11
283.6	56.21	280.7	53.85
289.1	53.87	282.8	51.76
304.1	55.09	290.7	52.16
313.7	52.39	295.8	52.73
		304.1	53.84
		313.7	49.12



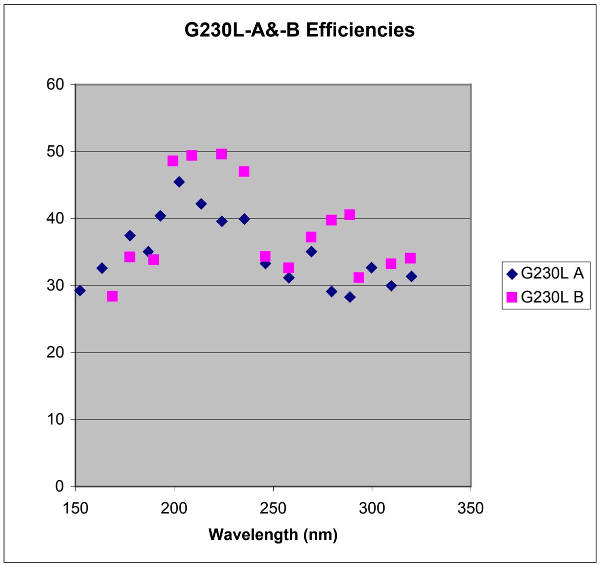
2.3.1 Grating Scatter (G285M-D)

Parameter	Value	Units
Plate scale	0.051	Å/pixels
L	9.86×10^6	counts
S	3255	counts
B	3083	counts
B1	2707	counts
B2	3459	counts
Dl	10.2	Å
E	1.71×10^{-6}	/Å



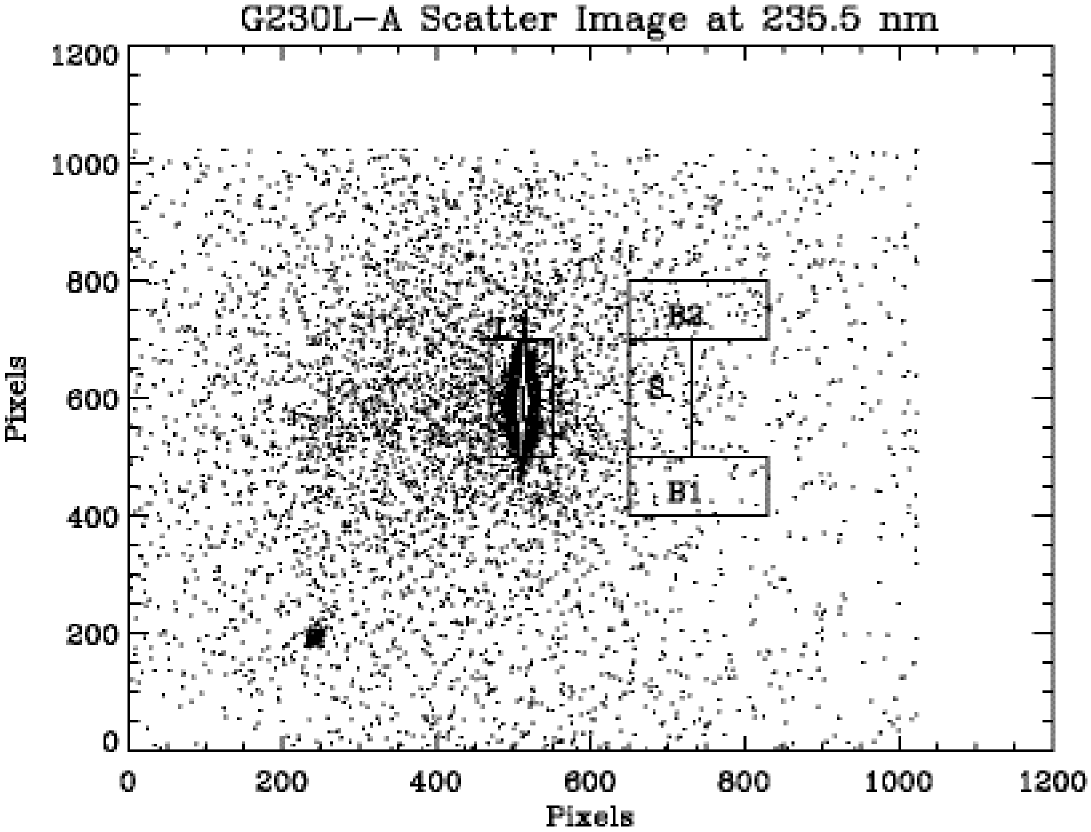
2.4 G230L CHANNEL

G230L-B (spare)		G230L A (flight)	
λ (nm)	Efficiency (%)	λ (nm)	Efficiency (%)
168.7	28.3	163.4	32.6
177.6	34.28	152.3	29.24
189.8	33.85	177.6	37.5
199.5	48.6	186.8	35.1
209	49.37	193	40.42
224.1	49.57	202.5	45.5
235.5	47.01	213.8	42.21
246.2	34.35	224.1	39.6
258	32.65	235.5	39.94
269.4	37.22	246.2	33.31
279.6	39.77	258	31.17
288.8	40.6	269.4	35.08
293.5	31.18	279.6	29.09
309.7	33.26	288.8	28.28
319.5	34.04	299.7	32.68
		309.7	29.94
		319.9	31.37



2.4.1 Grating Scatter

Parameter	Value	Units
Plate scale	0.5	Å/pixels
L	443246	counts
S	11911	counts
B	11502	counts
B1	(12685)	counts
B2	11502	counts
$\Delta\lambda$	100	Å
E	$9.5\text{x}10^{-6}$	/Å



3. COMPLETE GRATING INVENTORY

Optic SN	Channel	Coating	Designation	Testing	Location	Notes	Delivered
G130M-A	G130	Cr/Al/MgF2	ETU	e	BATC	unacceptably low efficiency, never formally delivered	yes
G130M-B	G130	Cr/Al/MgF2	flight	e/s/I	BATC	see COS-03-0002	8/17/00
G130M-C	G130	Cr/Al/MgF2	spare	e/s/I	BATC	see COS-03-0001	8/24/00
G160M-A	G160M	Cr/Al/MgF2	flight	e/s/I	BATC		7/3/01
G160M-C	G160M	Cr/Al/MgF2	spare	e/s/I	BATC		12/14/01
G140L-B	G140L	Cr/Al/MgF2	flight	e/s/I	BATC	see COS-03-0071	10/3/00
G140L-C	G140L	Cr/Al/MgF2	spare	e/s/I	BATC	see COS-03-0070	11/18/00
G185M-A	N/A	Cr/Al/MgF2	non-flight	e/s	BATC		12/14/01
G185M-B	N/A	Cr/Al/MgF2	non-flight	e/s	BATC		12/14/01
G185M-C	N/A	Cr/Pt	ETU		BATC		1/30/02
G225M-A	G185M	Cr/Al/MgF2	spare	e/s	BATC	This optic dirtier than G225M-B	9/6/01
G225M-B	G185M	Cr/Al/MgF2	flight	e	BATC		9/6/01
G225M-C	N/A	Cr/Pt	ETU		JY	not originally delivered by JY	TBD
G225M-D	TBD	Cr/Al/MgF2	spare	e	BATC	accidentally coated w/ Al/MgF2, supposed to be Al	1/10/02
G225M-E	G225M	Cr/Al	spare	e/s	BATC	blank # G225M 24	1/28/02
G225M-F	G225M	Cr/Al	flight	e	BATC	blank # G225M 21	2/8/02
G225M-G	TBD	uncoated	TBD		BATC	blank # G225M 210	1/3/02
G285M-A	N/A	Cr/Al/MgF2	non-flight	e/s	BATC		12/13/01
G285M-B	N/A	Cr/Al/MgF2	non-flight	e/s	BATC		12/13/01
G285M-C	N/A	Cr/Al	ETU	e	BATC	test piece provided by JY for Al coating tests	1/28/02
G285M-D	G285M	Cr/Al	flight	e/s	BATC	blank # G225M 211	2/1/02
G285M-E	G285M	Cr/Al	spare	e	BATC	blank # G225M 28	2/8/02
G230L-A	G230L	Cr/Al/MgF2	flight	e/s	BATC		11/26/01
G230L-B	G230L	Cr/Al/MgF2	spare	e/s	BATC		1/10/02