FUV Grating Performance for the Cosmic Origins Spectrograph

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ABSTRACT

The Cosmic Origins Spectrograph (COS) will be the most sensitive UV spectrograph to be flown aboard the Hubble Space Telescope. The COS FUV and NUV channels will provide high sensitivity at resolution greater than 20000 over wavelengths ranging from 115nm to 320nm. We present a brief review of the instrument design and grating test plan as well optical test results for the first FUV grating delivered.

Keywords: Hubble Space Telescope, Far Ultraviolet, Spectroscopy, Optical Testing

1. THE COSMIC ORIGINS SPECTROGRAPH: INSTRUMENT OVERVIEW

The Cosmic Origins Spectrograph (COS) will be a high throughput FUV/NUV spectrograph optimized for observing faint, compact objects and will be installed aboard the Hubble Space Telescope in 2003. By optimizing the spectrograph for faint UV point sources, the COS instrument will be the most sensitive UV spectrograph flown aboard HST. (Green, et. al, 1999, 2000)

The COS instrument has two channels: a far ultraviolet (1150-1775Å) and a near ultraviolet channel (1750-3200Å). Light enters the instrument through the 2.5 arc second Primary Science Aperture located on the HST focal surface. This aperture is intentionally oversized and transmits 100% of the aberrated light from a point source. Light from the entrance aperture then falls on one of the three aspheric FUV gratings for observations in the FUV band, or on an aspheric mirror which directs light into the NUV channel.

The FUV channel is a modified Rowand circle spectrograph with one reflection between the entrance aperture and the detector and three FUV gratings mounted on an optics select mechanism. Each grating is recorded onto an aspheric concave surface designed to compensate for spherical aberration and the holographically generated rulings provide astigmatism correction in addition to dispersing the light. It is this single reflection, in combination with careful selection and maintenance of the optical coatings and detector photocathode, which provides the high instrument throughput. Light diffracted from the selected grating then falls onto a crossed delay line microchannel plate detector with an opaque CsI photocathode. (Siegmund, 1999)

The NUV channel employs a Czerny-Turner design with four flat gratings and a flat mirror on an optics select mechanism. Light diffracted from the selected NUV grating falls onto a set of three camera optics and is then focussed onto a MAMA microchannel plate detector with a CsTe photocathode. COS spectroscopic modes are summarized in table 1.

Table 1: COS Spectrographic Modes

Grating	Channel	Wavelength Range	Pass Band per exposure	Resolution $\lambda/\Delta\lambda$
G130M	FUV	1150-1450Å	300 Å	20,000-24,000
G160M	FUV	1405-1775Å	370 Å	20,000-24,000
G140L	FUV	1230-2050Å	>820 Å	2500-3500
G185M	NUV	1700-2000Å	3×28Å	20,000-24,000
G225M	NUV	2000-2500Å	3×35Å	20,000-24,000
G285M	NUV	2500-3200Å	3×41Å	20,000-24,000
G230L	NUV	1700-3200Å	1 or 2×400Å	1550-2900

2. FUV GRATING REQUIREMENTS AND DESCRIPTION

The FUV gratings will be holographically ruled by Jobin-Yvon on an aspheric fused silica substrate manufactured by the SVG-Tinsly Corporation. J-Y is to deliver two gratings of each type to the COS project.

The G130M and G160M gratings will have an ion etched triangular groove profile with the blaze function providing the maximum groove efficiency within 100Å of the center of the grating's pass band. The G140L grating grove profile is yet to be determined. The minimum acceptable groove efficiency for any wavelength in a grating's passband is 45% for G130M and G160M and 30% for G140L.

The ruled gratings will then transferred to the Goddard Optical Materials and Thin Film Laboratory to receive a MgF_2 protected aluminum coating optimized for 1216Å. Finally, the gratings will be bonded to a mounting bezel at Ball Aerospace and tested at the CASA EUV/FUV test facility in Boulder, CO. Reflectivity and groove efficiency requirements are summarized in table 2. Currently, two G130M gratings have been coated and bonded, and testing on one (G130M-C) has been completed. Testing on the second is currently under way.

Table 2: FUV Grating Requirements

Grating	Blaze Efficiency	Coating Reflectivity			
		1150Å	1216Å	1608Å	2000Å
G130M	0.45	0.60	0.82	0.78	0.80
G160M	0.45	0.60	0.82	0.78	0.80
G140L	0.30	0.60	0.82	0.78	0.80

3. FUV GRATING PERFORMANCE VERIFICATION PLAN AND RESULTS

The CASA EUV/FUV test facilities include a 3.0 meter diameter vacuum chamber with a vibration isolated 1.5×3 meter optics bench. The chamber opens into a class 1000 clean room facility where the bench can removed to for initial setup and alignment. Testing at CASA is intended to verify performance of the gratings and to select the more efficient of the two gratings of each type delivered for use in the COS instrument (assuming both meet the minimum resolution and scatter requirements). The tests and success criteria are outlined in table 3 and the optical setups are illustrated in figure 1.

Table 3: FUV Grating Testing Requirements

Test	Optical Configuration	Requirement	Test Points
Imaging and Resolution	Modified Rowland Circle – Flight-like illumination using GROVER aberrated source to simulate HST optical system.	Demonstrate required resolution across passband.	3 wavelengths separated by no more than 100Å and no less than 50Å (200Å and 100Å for G140L)
Grating Efficiency	Wadsworth configuration. 10mm beam illuminates limited area of grating at several locations with grating angle and detector position adjusted to simulate flight illumination angle of incidence.	Demonstrate that grating efficiency is above specification and determine efficiency in sufficient detail to aid flight optic selection.	3×3 grid and 5 wavelengths separated by no more than 75Å (150Å for G140L)
Grating Scatter	Analysis of long integration data acquired in imaging tests near best focus.	Demonstrate that grating scatter is $\leq 2\times10^{-5}$ Å^{-1} 10Å away from test line.	Analysis of full optic at one wavelength.

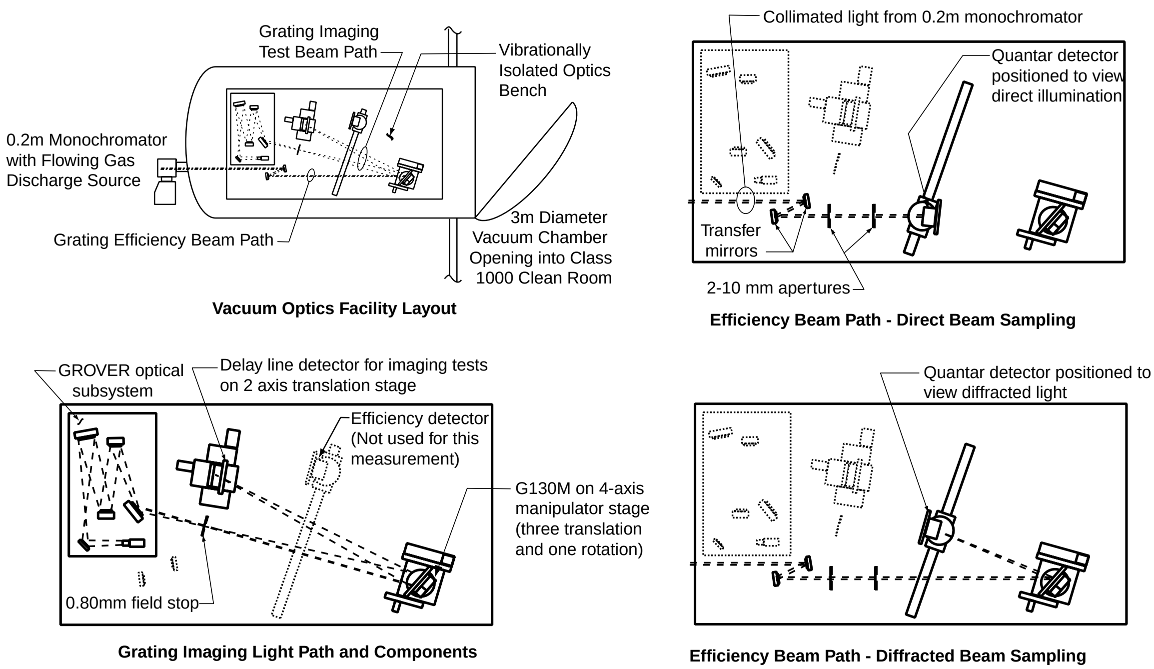

Figure 1: Grating resolution and efficiency test setups

3.1. FUV Imaging and Resolution Tests

The FUV gratings are designed to correct for the HST aberration. Consequently, it is necessary to illuminate the gratings with a similarly aberrated UV light source in order to accurately assess the grating imaging and dispersion characteristics. This is accomplished by using the Grating Optical Verification Equipment-Reflective (GROVER) optical subsystem developed by Kevin Redman. GROVER is a finite conjugate system designed to simulate the spherically-aberrated, f/24 HST image at the input aperture of the COS-FUV subsystem. It was built from the spare optics procured for the Reflective Aberration Simulator/Calibrator (RAS/CAL), which was used for testing the Space Telescope Imaging Spectrograph and the Advanced Camera for Surveys instruments. GROVER used the spare aspheric, conic, and turning mirrors in a different configuration in order to provide a chief ray to the grating under test which precisely matched the aberration content and input angle corresponding to the HST field point at the COS entrance aperture.

The aspheric mirror provides the appropriate spherical aberration into the image, while careful adjustment of the conic mirror position and tilt angles will provide the correct coma and astigmatism for the desired field point (the aperture stop is located immediately in front of the conic mirror). The turning mirrors were used to decrease the overall size of the system (in order to fit on the CU test table) and to provide the desired chief ray angle. The light source for GROVER is a sealed hollow cathode platinum lamp with a magnesium fluoride window.

Light from the GROVER optical subsystem illuminates the test optic, which then diffracts the light onto a Siegmund Scientific delay line detector with 25micron resolution in the dispersion direction. The GROVER system is placed so that it fully illuminates the test optic with the GROVER prime focus at the same distance from the grating center as the HST Cassegrain focus would be on orbit. The test optic is rotated to the nominal angle α and the detector is then located so as to be nearly tangent to the focal surface at the central β value and at the required distance from the test optic. (Note that the entrance aperture and the grating surface for COS do not lie on the Rowland circle, but rather outside and inside of the Rowland circle, respectively.). The location of the test optic and the detector relative to the GROVER prime focus and optical path are initially determined using theodolite metrology and knowledge of the GROVER system acquired prior to delivery of the system. Fine adjustment of the focus is accomplished by translating the grating and detector during vacuum testing. The focal plane of the detector is not curved to mach the focal surface of the grating. Consequently, once the best focus is determined at one wavelength, the detector must be translated both tangent to and along the beam path in order to optimize the image for any other wavelength.

3.2. FUV Grating Efficiency Testing

The purpose of these tests is to determine the grating efficiency by measuring the efficiency of a small portion of the optic at nine points spanning 50% of the blazed surface and forming a 3×3 grid and at multiple wavelengths.

The grating is illuminated by a quasi-parallel, 10mm diameter monochromatic beam at the desired test wavelength. The test detector (Quantar model 3391 MCP imaging detector) is mounted on a rotation stage on top of a translation rail. The translation and rotation stages will allow the detector to be positioned either between the test optic and the light source viewing the direct beam or close to the Wadsworth focus for the test grating viewing the diffracted beam. The translation rail is set so that it is roughly tangent to the Rowland circle at central β angle. The spatial response of the detector has been mapped and variations in the sensitivity are folded into the analysis. Grating tilt must be manually adjusted between vertical rows in order to ensure that the detector is properly illuminated. Care is taken to ensure that the detector is illuminated at the same angle of incidence for all measurements.

3.3. Grating Scatter Measurements

A set of deep images are acquired and co-registered for each grating using the GROVER subsystem near the best focus and these images are carefully analyzed to determine grating scatter.

4. RESULTS

At the present time we have taken delivery of two coated flight gratings, G130M-B and G130M-C, and have completed testing on one of them, G130M-C. Testing on the second is scheduled to begin on March 6, 2000. G130M-C was found to be acceptable with respect to all criteria. The results are summarized in figures 2 through 4 and in table 4. The grating imaging results were limited by the spatial resolution of the detector (estimated at 25µm). However, since the test detector resolution no better than the required for the flight detector, it is reasonable to assume that achieving the resolution requirement with the test detector demonstrates adequate resolution in the grating. The results of this test are summarized in table 4, and illustrated in figure 2 for one of the test lines.

Table 4: Grating Resolution Test Results

Wavelength	FWHM (mÅ)	Resolution $\lambda/\Delta\lambda$
1219.50Å	52.9mÅ	23000
1283.70Å	59.2mÅ	21700
1382.00Å	62.3mÅ	22200

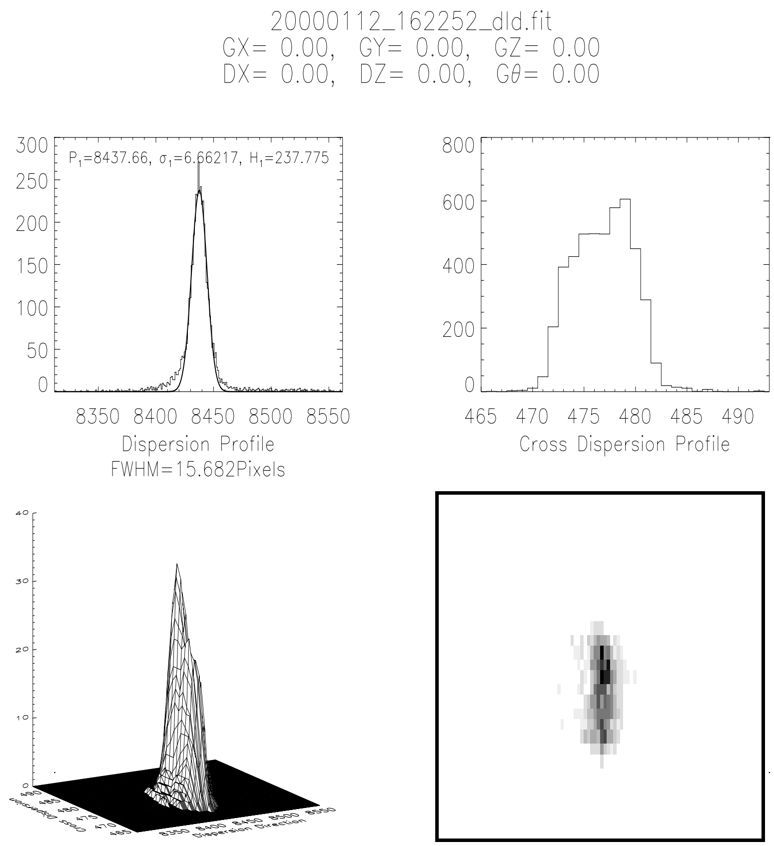

Figure 2: Sample G130M-C image of the Platinum emission line at 1283.7Å, near the center of the G130M pass band. The pixel size is approximately 2.4µm (dispersion) by 33µm (cross dispersion). The local dispersion is 1.57Å/mm.

Grating efficiency measurements showed acceptable efficiency at all wavelengths and at all tested locations, well above the minimum requirement derived from the product of the reflectivity and groove efficiency requirements. The measured efficiency was somewhat lower than expected at 1164Å and at 1236Å. This could be due to a number of things: First, the grating efficiency measurements were not taken at the same wavelengths as either the groove efficiency or the coating witness sample measurements, so some disagreement is expected. Errors in MgF_2 coating thickness could account for this discrepancy, as could a contamination event occurring some time after the grating coating was completed. Witness coupon reflectivity tests showed a 1% drop in reflectivity across the G130M pass band, which is neither sufficient in magnitude nor in spectral shape to account for the disagreement. Furthermore, non-volatile residue rinses were performed regularly throughout the testing process at CASA and showed no residue above the background level of the test. The efficiency test results for G130M-C are shown in figure 3.

The grating scatter measurement (figure 4) indicated that the grating scatter is as close to the specified level as can be easily tested using a non-coherent source. This test can only provide an upper limit on the scatter because of the possibility that there are unidentified weak platinum lines underlying the region selected as 'dark'.

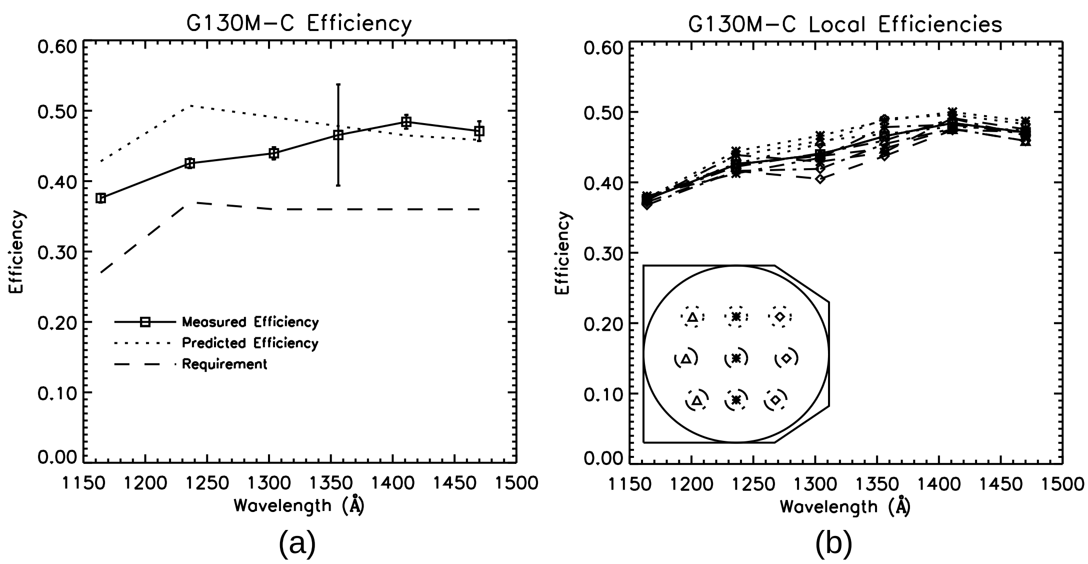

Figure 3: (a) Average grating efficiency compared to the required and predicted efficiencies. The predicted efficiency is based on the reflectivity of the coating witness coupons reported by the Goddard Optical Materials Lab and the groove efficiency reported by Jobine-Yvon. The large error bar at 1356Å is due to the uncertainties introduced by removing 1304Å monochromator scatter from the measurement. All other uncertainties are below 1% absolute.
(b) Variation in efficiency versus grating position. The figure in the lower left corner illustrates the source of each data set, and the approximate size of the illuminated spot relative to the grating surface.

5. CONCLUSION

The first delivered flight grating for the COS program meets or exceeds the mission requirements, especially with respect to efficiency. If subsequent optics perform to this level, the Cosmic Origins Spectrograph will ultimately prove to be the most sensitive medium resolution FUV spectrograph yet flown.

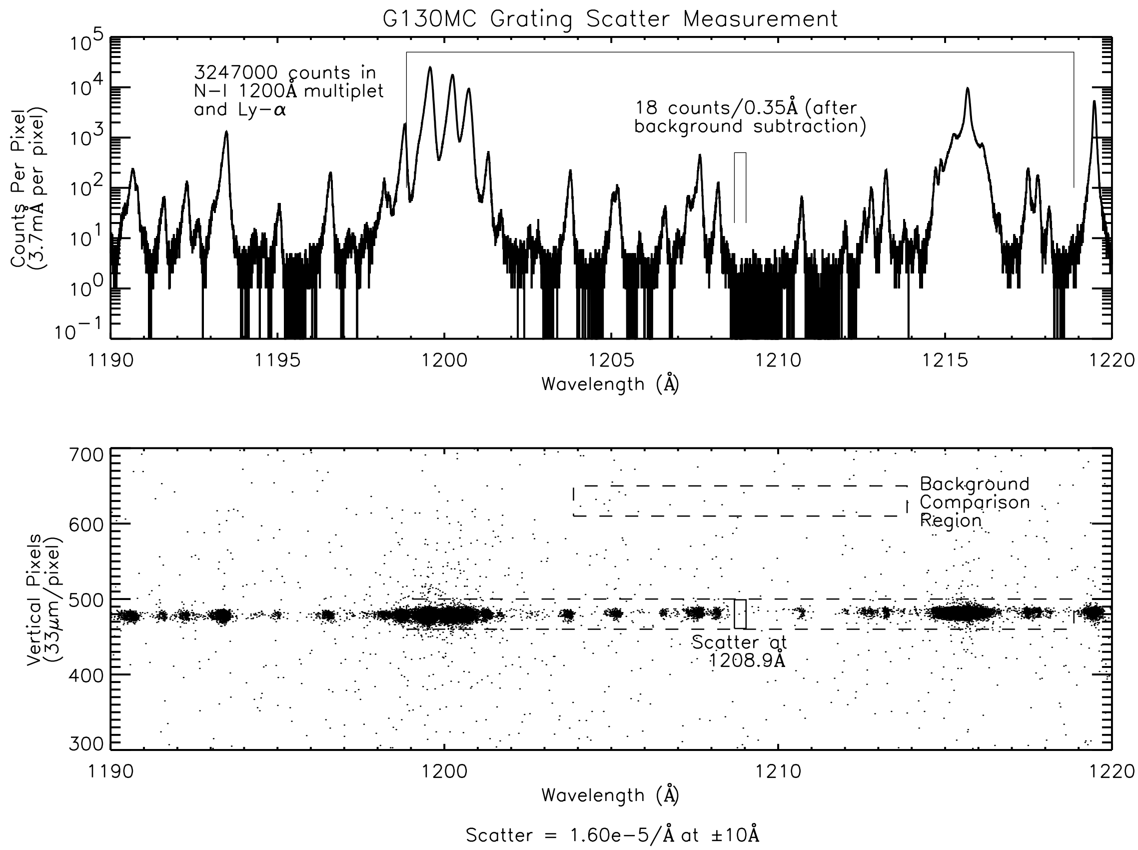

Figure 4: Grating scatter was measured to be of order $1.6{\times}10^{-5}$Å^{-1} at ±10Å. Because the spectrum in the selected 'dark' region is not well know, and because of the limitations imposed by counting statistics, this measurement represents an upper limit on the grating scatter. The dominant signal in this region of the spectrum is from nitrogen and hydrogen contamination of the platinum hollow cathode lamp used for the grating imaging tests. Note that this image is a composite of 22 co-registered focus images, so the resolution illustrated here is substantially below the best resolution obtained.

REFERENCES

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