Technical Evaluation Report
“OTA Scattered Light & Effects on COS Performance”

Date:	July 10, 2000
Document Number:	COS-11-0020
Revision:	Initial Release
Contract No.:	NAS5-98043
CDRL No.:	N/A

Prepared By: ______________________________ ________
Dr. Erik Wilkinson, COS Instrument Scientist — Date

Reviewed By: ______________________________ ________
Dr. Jon Morse, COS Project Scientist — Date

Reviewed By: ______________________________ ________
Dr. Dennis Ebbets, [illegible] Calibration Scientist — Date

Approved By: ______________________________ ________
Mr. John P. Andrews, CO[illegible] — Date

Approved By: ______________________________ ________
Dr. James C. Green, COS Principal Investigator — Date

Center for Astrophysics & Space Astronomy
University of Colorado
Campus Box 593
Boulder, Colorado 80309

REVISIONS					
Letter	ECO No.	Description	Check	Approved	Date
-		Initial Release			

Original Release Name	Date	
Drawn: Dr. Erik Wilkinson	7/10/00	
Reviewed:		
Approved:		

THE UNIVERSITY OF COLORADO

At Boulder

The Center for Astrophysics and Space Astronomy

Technical Evaluation Report

"OTA Scattered Light & Effects on COS Performance"

Size	Code Indent No.	Document No.	Rev
A		COS-11-0020	-
Scale: N/A			

1. INTRODUCTION

This TER presents preliminary analysis and results of how the wavelength-dependent point spread function (PSF) of the Hubble Space Telescope (HST) Optical Telescope Assembly (OTA) will limit the ability of the Cosmic Origins Spectrograph (COS) to do absorption line spectroscopy. Specifically, how and/or will the OTA scatter limit the minimum detectable equivalent width for an interstellar/intergalactic absorption line? The analysis and results presented herein are thought to be worst case. Efforts are currently underway to simulate the scatter performance of the OTA in the COS raytrace models and thus improve our understanding of the impact.

2. THE OTA POINT SPREAD FUNCTION

The post-COSTAR HST/OTA point spread function is wavelength dependent and is quantitatively described in the FOC Instrument Handbook Version 7.0. Longward of 2780Å the PSF is dominated by diffraction effects. Shortward of 2780Å the PSF is dominated by scatter due to mid-frequency ripple and surface roughness of the OTA and COSTAR combined. Figure 2.1 presents in graphical form the encircled energy data listed the FOC Instrument Handbook. The best point spread function occurs for 2780Å and degrades for all other wavelengths. At the longer wavelengths the first airy ring from diffraction is also apparent in the encircled energy.

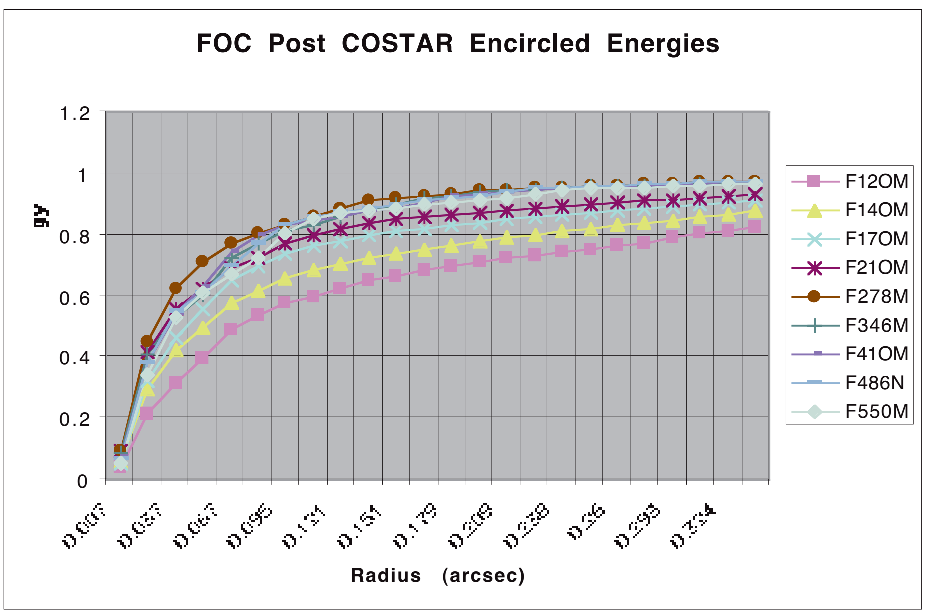

Figure 2.1 : Post-COSTAR HST/OTA encircled energies as a function of wavelength and arc-seconds away from the core.

3. EFFECTS ON COS PERFORMANCE

The object of this exercise is to quantitatively evaluate how the lower quality PSF at the shorter wavelengths will limit the detectable minimum equivalent width of an interstellar absorption line in a continuum spectrum. The maximum depth of an absorption line in a continuum spectrum is determined by two factors, the amount of intervening material along the line of sight to the target and the line spread function (LSF) of the spectrograph. The ability to accurately determine the equivalent width of an absorption line is affected by the LSF, so minimizing or understanding the effect the LSF has on the spectrum is crucial to making sound scientific measurements.

The optimum situation occurs when the entire LSF falls within a spectral resolution element, thus adjacent resolution elements are unaffected by their neighbors. In the case where the LSF is broader than a resolution element, light from neighboring resolution elements will effectively fill in an absorption line. The amount of filling that occurs, the "filling factor", for an absorption line in a continuum spectrum is computed by integrating the amount of the LSF that falls outside a resolution element and dividing by the fully integrated LSF (refer to Figure 3.1).

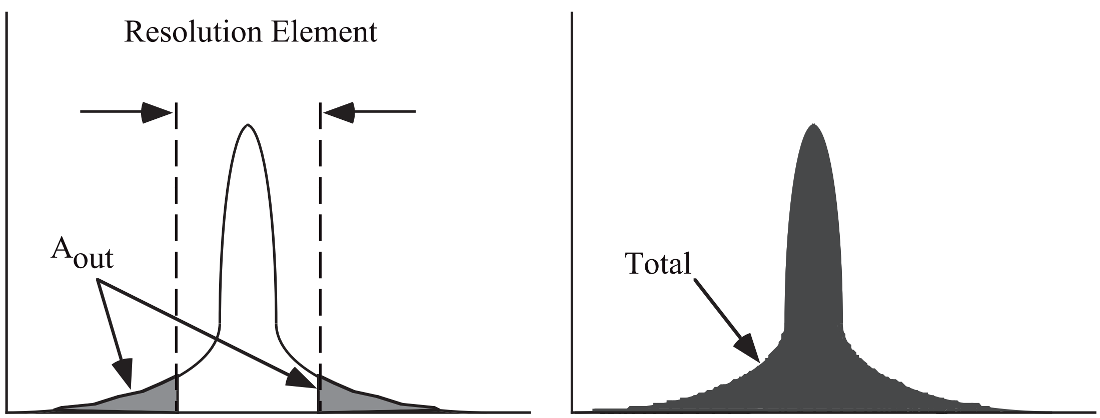

Figure 3.1 : The figure on the left shows where the LSF is integrated to calculate the filling factor of delta function absorption line. The right hand figure shows the total area under the LSF. The filling factor is then A_{out}/Total.

In traditional spectrograph designs the LSF is defined by a combination of the entrance slit width, in-plane scatter from the diffraction gratings, which contribute broad wings to the LSF, and the detector resolution. However, COS is not a traditional spectrograph in that the LSF is formed from the aberrated and scattered image at the HST focal plane rather than the slit width. The wavelength dependence of the PSF will, therefore, introduce wavelength dependence into the LSF and contribute significantly to the filling factor of an absorption line.

The unique PSF of the HST/OTA combined with the aberration-corrected, holographically ruled gratings for COS make it difficult to completely understand the LSF. This is because the mapping of the image from the COS aperture to the FUV detector focal plane is irreversible due to the nature of the aberration-corrected gratings and the effects of scatter on the directions of the light rays. Briefly, the aberration-corrected gratings focus the light from the OTA to a small line image. The aberration control only works for light rays with angular and spatial distributions that are similar to those produced by the HST/OTA. Scatter off of the OTA alters, ever so slightly, the angular and spatial distributions of the light rays incident upon the grating. Therefore, we can expect some distortion of the LSF due to scatter, but we cannot understand the magnitude of this phenomenon without detailed knowledge of the wavelength dependent angular distribution function of the OTA.

We can, however, provide an upper limit on the magnitude of the filling factor by making a simplifying assumption regarding the geometry of the scatter halo. We assume that the scatter produces a circular halo about the diffracted LSF. The amount of light and distribution of the circular halo is derived by subtracting the PSF at 1216Å (dominated by scatter) from the 2780Å PSF (dominated by geometric figure errors). Then we integrate the areas outside of a resolution element to derive the filling factor (see Figure 3.2).

Figure 3.3 shows the wavelength dependent filling factor within 0.15 arc-seconds, the width of a resolution element. Immediately apparent is that the filling factor increases rapidly below 2780Å. In Figure 3.3 are three lines. The blue line is the EE within a 0.15" LSF. The yellow line represents the calculated filling factor based on the geometry shown in Figure 3.2 and assuming that the EE reaches 100% (yellow = 1 – blue). The red line is the yellow line offset vertically so that the filling factor at 2780Å is zero. We contend that the red line more accurately represents the contribution of wavelength dependent scatter to the filling factor.

Recall that this analysis assumes that the LSF can be computed from the PSF of the FOC. The COS FUV gratings correct for the geometric distortions of the OTA . The goal of this study is to understand how the wavelength dependence in the OTA will affect the LSF of the COS. A tenet of this analysis is that the PSF of the 2780Å light is dominated by geometrical figure errors in the OTA. For wavelengths below 2780Å the wavelength-dependent scatter dominates the PSF. By subtracting off the geometrical component we can calculate the degradation of the PSF and LSF due to scatter. Figure 3.3 indicates that under the assumptions regarding the shape of the scatter halo we can expect ~25% filling at the shortest wavelengths for a 0.15" resolution element ($\lambda/\Delta\lambda \sim$ 20,000). Obviously at lower resolution, less light will fall outside the resolution element and the filling factor will decrease accordingly.

4. CONCLUSIONS

Using HST/OTA point spread functions measured by the post-COSTAR FOC with some simplifying assumptions regarding the distribution of scattered light and the diffracted image we have calculated the filling factor for an absorption line in a continuum spectrum. The filling factor is wavelength dependent and ranges from 0% at 2780Å to just below 25% at 1216Å. This will have a significant effect on the minimum detectable equivalent width for the COS instrument at $\lambda/\Delta\lambda \sim 20{,}000$.

However, we believe the assumption that the scatter halo is a circular halo defined by the PSF measured by FOC is worst case. Our intuition suggests that the scatter component of the LSF will form an elliptical halo, rather than a circular one, and will thus lower the filling factor. We are currently trying to model this qualitatively. In addition, the PSF information is derived from post-COSTAR FOC data, so the measured scatter includes the scatter from COSTAR and all the reflections internal to the FOC. This effect will hopefully not be as severe for COS, as COS has only one reflection in the short wavelength channel.

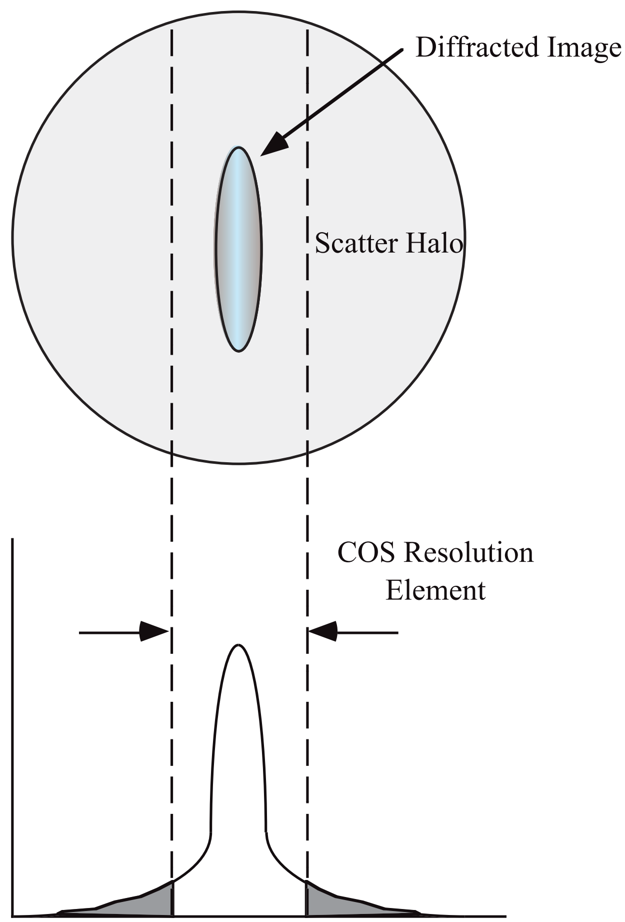

Figure 3.2 : The upper portion represents the aberration-corrected image with a circular scatter halo. The lower panel shows those portions of the LSF, which were integrated to form the filling factor.

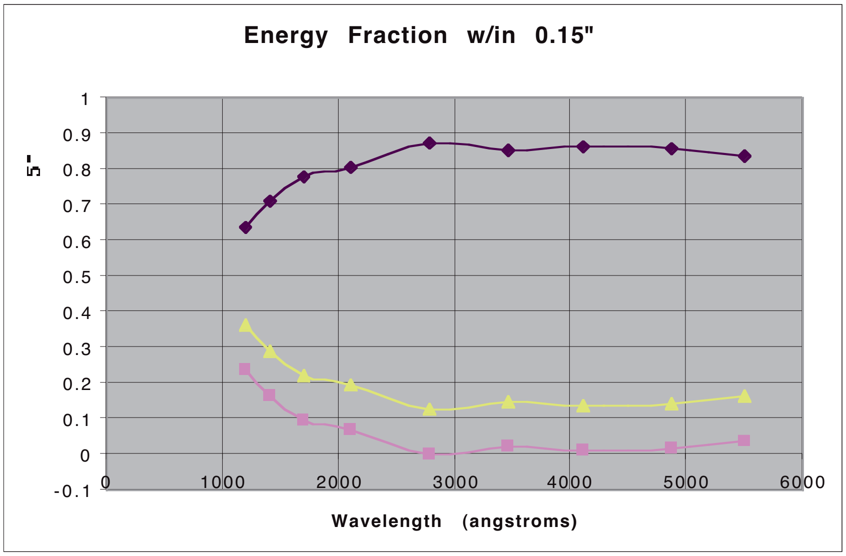

Figure 3.3 : The wavelength dependent filling factor for a 0.15 arc-second resolution element. The blue (top) line is the encircled energy within a 0.15" LSF. The yellow line represents the calculated filling factor (1 – EE for the LSF). The red line is the yellow line adjusted so that at 2780Å the filling factor is zero. The red line represents the wavelength dependent scatter contribution to the filling factor.