Recent Trends in the COS FUV Time Dependent Sensitivity

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Introduction:
Following the installation of the Cosmic Origins Spectrograph (COS) on the Hubble Space Telescope (HST) during Servicing Mission 4 in May 2009, the sensitivity of the COS far ultraviolet (FUV) detector was observed to be declining much faster than predicted. Wavelength dependent trends observed since then are consistent with the degradation of the quantum efficiency (QE) of the FUV CsI photocathode due to environmental factors encountered in flight. The degradation is dominated at early times by an outgassing product (likely water vapor) and at later times by another factor with longer timescales, likely highly reactive Atomic Oxygen (AO) in the residual Earth atmosphere at HST altitude. Degradation by AO predicts a steepening of the rate of the COS FUV sensitivity decline as the Earth’s atmospheric density increases with the solar cycle approaching maximum. We describe the latest results of our COS FUV sensitivity monitoring program, their correlation with the solar cycle activity, updates of pipeline reference files, and expectations for users in Cycle 20.

Causes of Sensitivity Loss:
The COS FUV detector is a windowless cross delay line detector made of 3 micro-channel plates. A CsI photocathode is evaporated onto the surface and partially into the pores of the front micro-channel plate. Based on ground testing and initial on-orbit sensitivity of the FUV detectors on the Space Telescope Imaging Spectrograph and Advanced Camera for Surveys which also use a CsI photocathode, the rate of sensitivity decline of the COS FUV detector was anticipated to be a few percent per year.

Regular monitoring of the sensitivity of the COS detector began in September 2009 and continued at 3 month intervals until March 2010. At this time, enough data had been collected to confirm a much steeper than anticipated decline in the detector sensitivity (5-15%/yr; see Figure 1) and an Anomaly Review Board (ARB) was formed to investigate the cause of the unexpected sensitivity loss.

The decline in sensitivity is localized and shows a strong wavelength dependence, with a steeper decline at longer wavelengths. Long wavelength photons have lower energies and are therefore more sensitive to changes in the photocathode. The ARB determined that it should be investigated further.

CsI photocathodes were created at the UC Berkeley Space Science Lab and were exposed to varying levels of AO both there and at the NASA-Ames Research Center. All samples which were exposed to AO showed QE degradation at FUV wavelengths (McPhate, Jason, et al., FUV quantum efficiency degradation of cesium iodide photocathodes caused by exposure to thermal atomic oxygen, Sept. 2009, UV, X-Ray, and Gamma-Ray Space Instrumentation for Astronomy XVII, Tsakalakos, Lotiecs, ed.).

Monitoring:
The time dependent sensitivity (TDS) of the COS FUV detector is determined by observing the same star regularly (G130M/G140L: WD0947+857 and G160M: WD1057+719) with the reddest, bluest, and middle central wavelengths of each grating. Each observed spectrum is divided by the first observed spectrum to get a relative net count rate (see Figure 1). The evolution of the relative net count rate with time is characterized by a continuous linear piecewise function. Trends are analyzed in 5Å bins for the medium resolution modes (G160M and G130M) and in 20Å bins for the G140L. Observations were taken every 3 months until March 2010, then monthly until January 2012, and bi-weekly after a COS FUV detector anomaly temporarily shut down operations on April 30, 2012. Routine monitoring will be restarted when the detector returns to operation.

Time Dependent Trends:
To date there have been 2 periods of steep decline out of 5 defined time periods (see Figure 1). Both periods show a strong wavelength dependence indicating photocathode degradation. The first of these occurs between launch in May 2009 and March 2010 when the sensitivity loss is ~10-20%/yr. This is thought to be the result of outgassing as the instrument was new and it is a time of low AO density. These trends flatten in March 2010 (see Figure 2) to less than 5%/yr and remain at that level for a year. At this time AO levels are low (see Figure 1) and the outgassing should have largely stopped. In March 2011 an increase in the level of solar activity increases the AO density in the upper atmosphere. This leads to a wavelength dependent increase in sensitivity loss to levels between 5-10%/yr. This trend continues until October 2011 when an extremely large spike in solar activity occurs causing an immediate and extreme steepening of the TDS slopes to between 10-30%/yr (see Figure 3). This trend lasts until January 2012 when the slopes decrease, again following the solar cycle.

As we approach solar maximum and the COS TDS trends follow the fluctuations in solar activity, our confidence that the degradation is due to AO is increasing. There is however, a grating and segment dependence to the trends that is not explained by AO (see Figure 3). For this reason we suspect there is at least one other component to the degradation. Additionally, the local gain of the COS FUV micro-channel plates decreases with usage, an effect known as gain-sag. When the gain drops low enough this will cause additional localized loss of sensitivity which can be mitigated by raising the voltage of a segment. For this reason, on March 26, 2012, the voltage on Segment A was raised. Localized sensitivity loss appears to have being some wavelengths on Segment A in observations prior to March 26, 2012 as the voltage increase led to a jump in sensitivity in some wavelength bins (see Figure 1).

The FUV TDS reference file currently used by the On-the-Fly Recalibration pipeline (OTFR) characterizes trends through early 2010 which are extrapolated to the observation date of the data being processed. A new FUV TDS reference file has been created which characterizes the trends through April 2012. This reference file will be delivered for use in the OTFR pipeline in the near future. Additionally, the Exposure Time Calculator (ETC) was updated both in January with the 2011.75 – 2012.0 trend (for preparation of Phase I proposals) and in April with the 2012.0 – current trend (for preparation of Phase II proposals). We will update both the pipeline and the ETC as trends continue to evolve.