

# Cosmic Origins Spectrograph Servicing Mission Observatory Verification Overview

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The Cosmic Origins Spectrograph (COS) was installed onboard the Hubble Space Telescope (HST) in May, 2009 as part of the most recent servicing mission (SM4). COS is optimized for observing faint point sources at moderate spectral resolutions and is the most sensitive UV spectrograph ever flown on HST. The FUV channel, which is 10 to 30 times more sensitive than STIS, covers the wavelength range from 1150 to 1800 Å with medium resolution gratings (G130M/G160M) and from ~900 to 2400 Å with a low resolution grating (G140L). The medium resolution gratings in the NUV channel (G185M/G225M/G285M) cover ~1700 to 3200 Å, while the low resolution grating (G230L) covers 1700 to 3200 Å. As part of the overall HST Servicing Mission Observatory Verification (SMOV), COS on-orbit functionality was verified via an extensive set of 34 observing programs comprising nearly 2800 individual exposures. Sequential activities were executed that concentrated on the general areas of initial instrument checkout; detector HV turn-on and operation; initial detector characterization; NUV focus and alignment; FUV focus and alignment; initial target acquisition verification; wavelength calibration; and thorough target acquisition assessment, all leading to enabling of basic science functionality. Finally science-related calibrations and verifications were performed including flux calibration, flat field characterization, spectroscopic performance verification, high S/N operation, and thermal and structural stability measurements. Several companion presentations describe results from specific programs and verification areas in more detail.

## SMOV Plan and Execution

During SMOV, which began following HST release from Atlantis on 21 May and ended for COS on 2 October, a highly choreographed series of activities was executed which led to the determination that COS was ready to commence its science mission. The COS SMOV plan is outlined in Figure 1 and is described in COS TIR 2009-01 (Keyes, Sahnou, et al, 2009), which provides an exhaustive compendium of all COS SMOV requirements, activity and analysis plans, targets, programs, reference file deliverables, and interactions between programs. Information on each of the individual SMOV programs can be found at [http://www.stsci.edu/hst/scheduling/program\\_information](http://www.stsci.edu/hst/scheduling/program_information).

## COS SMOV4 NUV Sequence

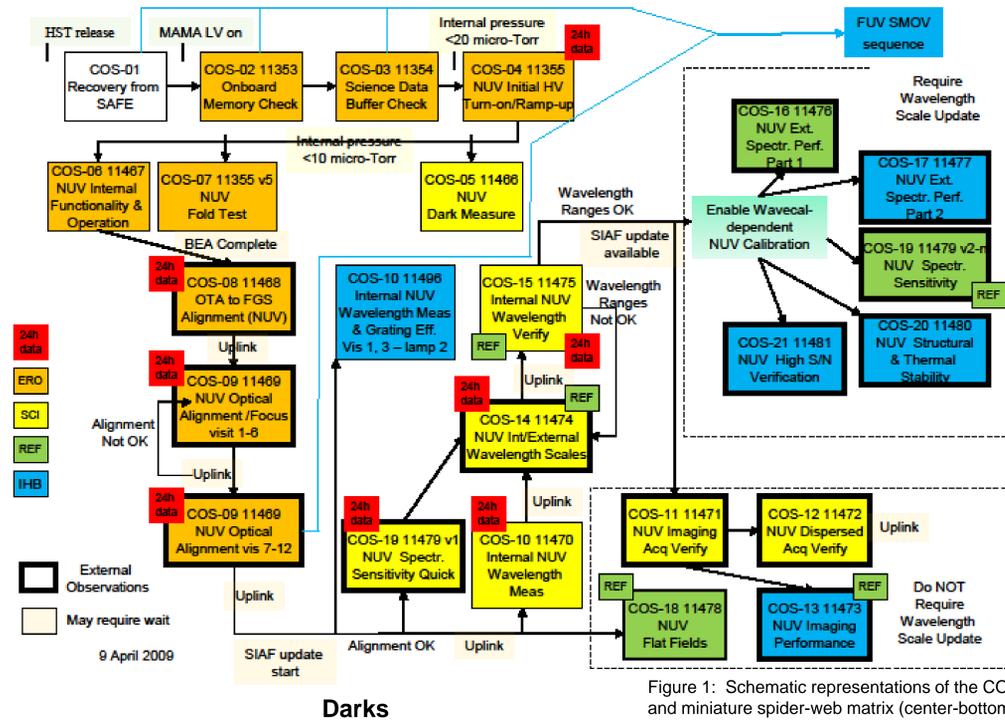


Figure 1: Schematic representations of the COS SMOV NUV program sequence (left), COS SMOV FUV program sequence (right), and miniature spider-web matrix (center-bottom) illustrating complex interaction between individual visits in COS SMOV program.

## COS SMOV4 FUV Sequence

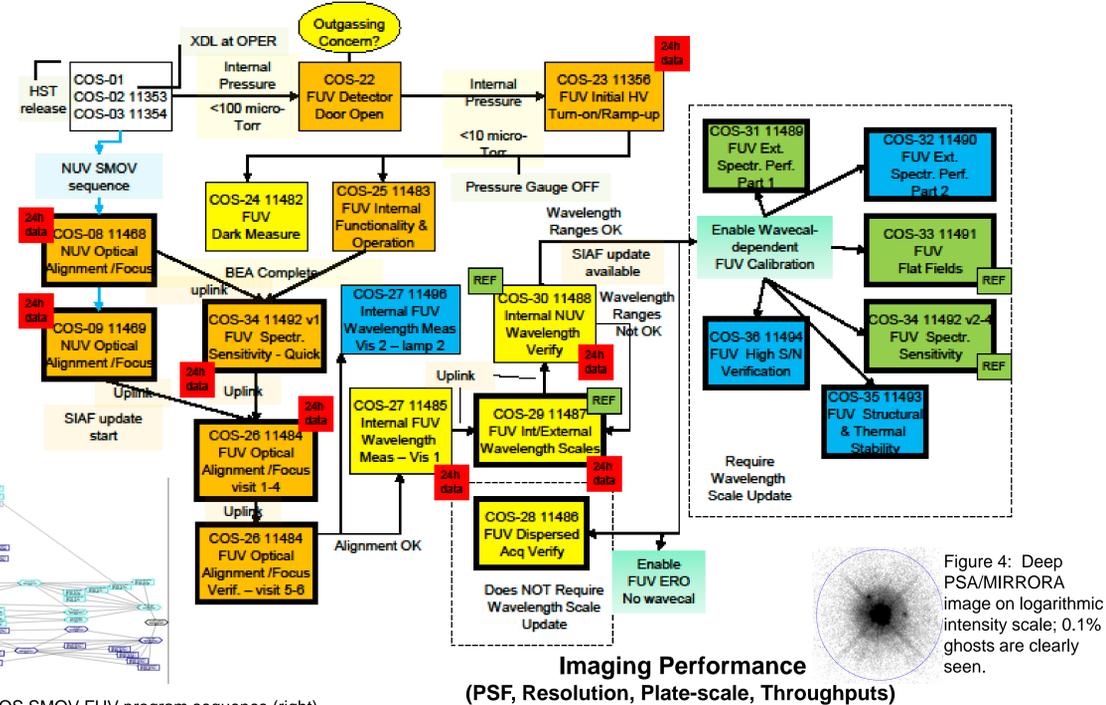


Figure 4: Deep PSA/MIRRORA image on logarithmic intensity scale; 0.1% ghosts are clearly seen.

## Darks

- TIME-TAG exposures at chosen locations in spacecraft track to map influence of SAA
- FUV darks stable on-orbit at expected low levels: 20 counts/sec/segment ( $1.5 \times 10^{-6}$  counts/sec/pixel or  $\sim 1$  count/week/pixel or 0.3 counts/resel/hour)
- NUV darks rising on-orbit, now near predicted levels: initially 70 cts/sec/detector, recently  $\sim 250$  cts/sec/detector ( $\sim 1$  count/resel in 7.5 minutes)
- Rates near the SAA can be up to 30 times higher, depending on the track of the orbit; SAA contours may be adjusted; TA can be influenced by grazing SAA passage
- Refer to Poster 464.10 for more detailed information

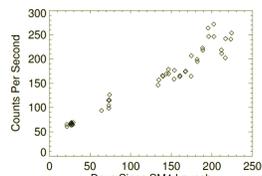


Figure 2: NUV background count rate as a function of time since SM4, last exposure executed on 21 December 2009. The approximately linear increase in rate for the first six months is not yet understood.

## Wavelengths

- Complete set of TIME-TAG on-orbit PtNe lamp template exposures obtained for all gratings, central wavelengths, and FP-POS; on-orbit radial velocity standard target exposures obtained for all gratings and central wavelengths
- All cases tested meet accuracy specifications.
- Updated on-orbit wavelength reference files delivered for most gratings; analysis still in progress for NUV G185M
- Refer to Poster 464.12 and forthcoming ISR (Oliveira et al) for detailed information

## Optical Alignments

- Use astrometric target and guide stars to determine COS aperture location relative to FGS and for focus determination using NUV imaging mode
- NUV spectroscopic alignments are known offsets from imaging alignment
- FUV focus sweeps with each grating at one central wavelength using narrow absorption line target previously observed with STIS E140H
- Refer to forthcoming ISRs (NUV: Hartig et al; FUV: Lennon et al) for detailed optical alignment information

## Target Acquisition

- Critical TA parameter determination obtained as part of all optical alignment activities and FUV flux calibration program; evaluate all quantities utilized in TA FSW algorithms, including image location subarrays for all apertures and MIRRORS; spectrum location subarrays for all apertures, gratings, and stripes (NUV); all geocoronal line spectrum exclusion subarrays
- Evaluate initial operational effectiveness of all TA modes
- Perform full characterization of accuracy of each TA method as function of initial pointing accuracy, S/N, and target morphology (point source/extended)
- Refer to Poster 464.03 and forthcoming ISR (Penton et al) for detailed information

## Fluxes

- Observed HST primary spectrophotometric standards with all gratings and central wavelengths for PSA and all gratings at representative central wavelengths for BOA; additional observations from flat, S/N, spectroscopic performance, and wavelength calibration programs.
- Sensitivity characterized for the spectral region from Lyman limit to 1150Å. See Poster 464.07 (McCandliss et al) for additional information.
- 2nd order contributions evaluated for all gratings
- Time-dependent sensitivity (TDS) evaluation: no conclusive on-orbit changes at this time; SMOV execution of Grating Efficiency Test (PtNe lamps with NUV) indicated throughputs consistent with ground trends to launch date
- Initial adopted sensitivity reference files installed in pipeline
- Refer to Posters 464.16 and 464.20 and forthcoming ISRs (Massa et al) for more detailed information

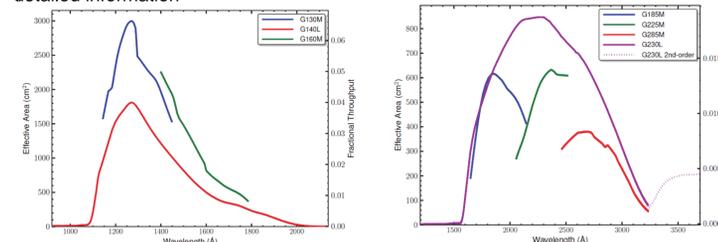


Figure 3: Plots of the effective areas and fractional system throughputs that correspond to our adopted reference file sensitivities

## Spectroscopic Performance (LSF, Resolution, Plate-scale)

- Observe narrow absorption and emission line targets at one central wavelength with each grating; targets previously observed with STIS;
- POS-TARG dithers along and across dispersion to evaluate plate-scales
- On-orbit COS LSF with the HST OTA deviates from TV06 profile due to mid-frequency wavefront errors (MFWFEs), produced by zonal (polishing) errors in the HST optical telescope assembly (OTA).
  - OTA produces non-Gaussian wings in on-orbit COS LSF, and both broadens the core of the profile and lowers its amplitude; impacts spectral resolving power and reduces detectability of faint, narrow lines
  - MFWFE effects on the LSF decrease with increasing wavelength, but are significant for both detectors shortward of 2500 Å.
  - We have produced optical models of the COS LSF that take into account the MFWFE; models are available to the community
- NUV spectroscopic plate-scale is function of cross-dispersion position
- Refer to Poster 464.08 and ISR 2009-01 (LSF) and forthcoming ISRs (Ghavamian et al) for more detailed information

## Imaging Performance (PSF, Resolution, Plate-scale, Throughputs)

- Observed WD and G-type HST spectrophotometric standard stars with MIRRORA and MIRRORB for both PSA and BOA
- Obtained deep MIRRORA exposure at aperture center and lower S/N exposures in comprehensive POS-TARG offset pattern to determine throughput and image quality as function of pointing offset from PSA center
- Compare NUV imaging PSF with models; determine plate-scale
- Refer to Poster 464.02 and forthcoming ISR (Goudfrooij et al) for more information

## Structural and Thermal Stability

- Obtain 5 consecutive orbit duration CVZ exposures with one grating and central wavelength for each detector and with MIRRORA in NUV imaging mode
- 0.5-pixel amplitude orbital variation along dispersion (both detectors) is well within specification
- Refer to Poster 464.05 and forthcoming ISR (Smith et al) for more information

## Flat Fields, S/N Evaluations

- NUV Flats: 18 on-orbit hours of D2 lamp exposures obtained to evaluate NUV flat in comparison to ground flat
  - Ground and on-orbit flats align to better than one pixel with all blemishes in same locations; no detector format shift
  - On-orbit and ground data combined to create pipeline flat reference file
- NUV observations of external targets revealed vignetting; vignetting function incorporated in NUV pipeline flat
- NUV S/N: High S/N observations of spectrophotometric standards with all FP-POS at multiple central wavelengths for all gratings, and one central wavelength and FP-POS from stability-evaluation program
  - Poisson limit can be reached for S/N < 70; S/N > 150 was demonstrated for the SMOV high S/N program
- FUV Flats: Secondary spectrophotometric WD standards observed with all gratings at multiple cross-dispersion positions to sample all Y-locations where spectra occur
  - Flat fields for each grating and segment; analysis continues
  - **NO FUV flat field correction is currently applied in pipeline**
- FUV S/N: High S/N observations of spectrophotometric standards at one central wavelength for all gratings
  - observations at one grating setting are limited to S/N~30 by inherent fixed pattern noise of the segments
  - S/N~70 was generally achieved in our test cases with spectral iteration and S/N > 100 was demonstrated in one very high signal spectral region
- Refer to Poster 464.25 for more detailed information

Figure 5: Initial 2-d flat field for G130M segments A and B; grid wire shadows are clearly seen.

## References

- Ghavamian, P. et al, 2009, COS ISR 2009-01, "Preliminary Characterization of the Post-Launch Line Spread Function of COS"
- Keyes, C., Sahnou, D., et al, 2009, COS TIR 2009-01, "COS SMOV Analysis Plan and Overview"