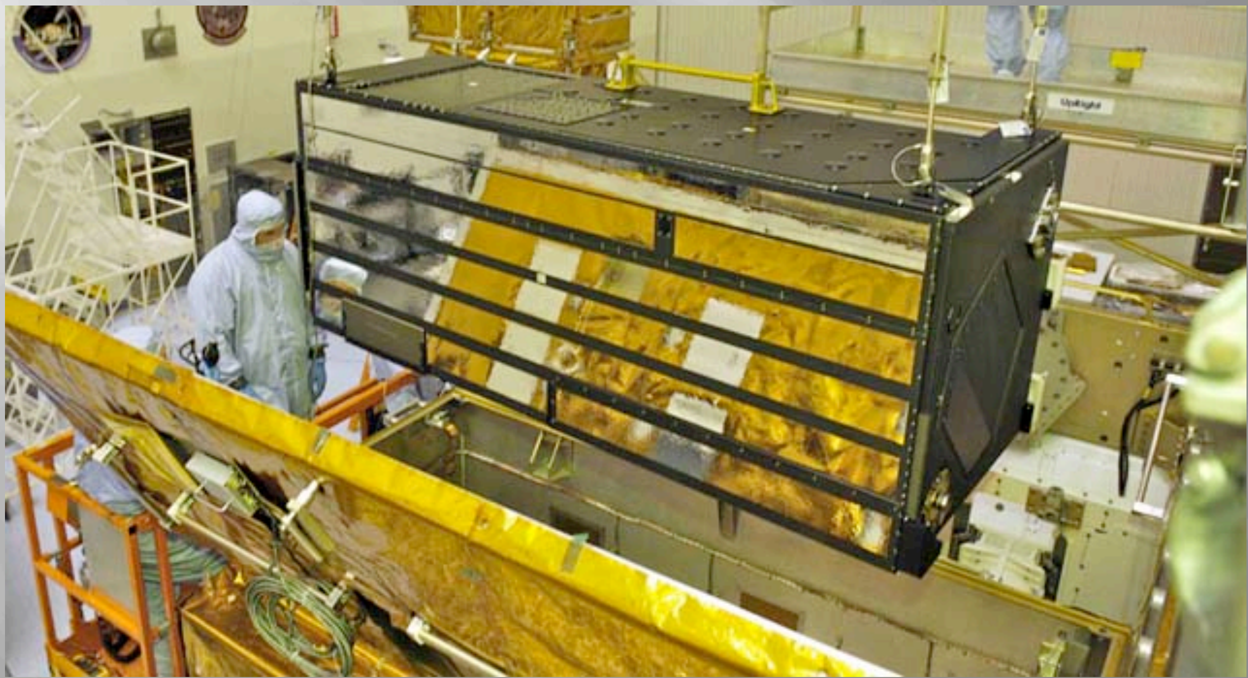
COSMIC ORIGINS SPECTROGRAPH

The Next UV Spectrograph for the Hubble Space Telescope

Stéphane Béland – ASTR-5550 – April 13, 2009



Scientific Goals

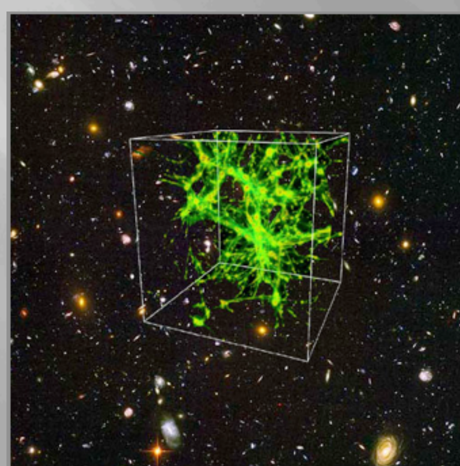
COS will help answer some fundamental questions:

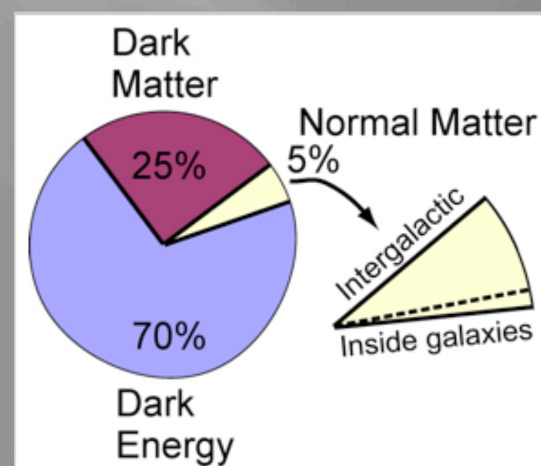
- What is the large-scale structure of matter in the Universe?
- How did galaxies form out of the intergalactic medium?
- What types of galactic halos and outflowing winds do star-forming galaxies produce?
- How were the chemical elements for life created in massive stars and supernovae?
- How do stars and planetary systems form from dust grains in molecular clouds?
- What is the composition of planetary atmospheres and comets in our Solar System (and beyond)?

Scientific Goals

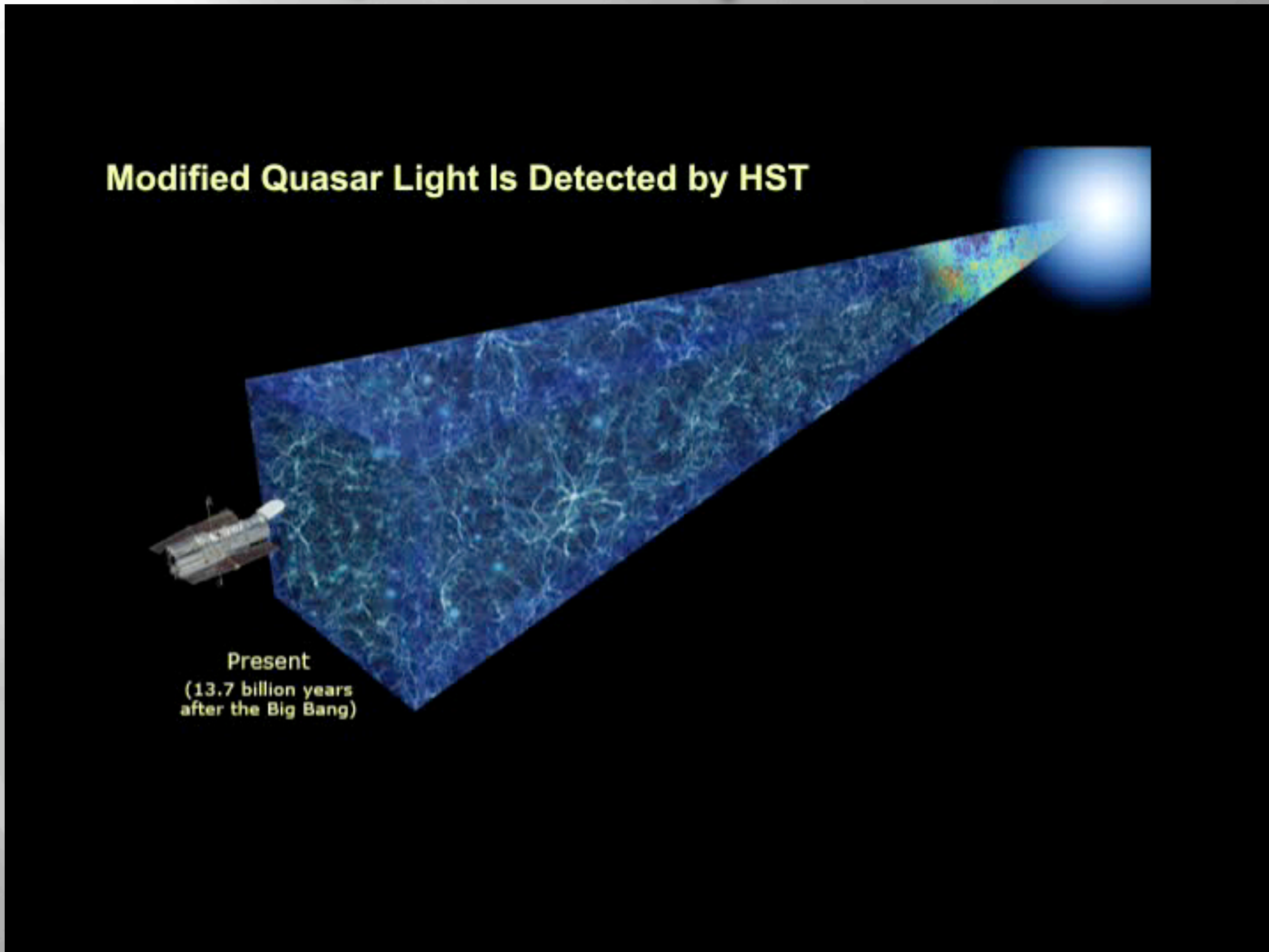
- The study of the origins of large scale structure in the universe, the formation and evolution of galaxies, and the origin of stellar and planetary systems and the cold interstellar medium.

- Measure the structure and composition of the ordinary matter concentrated in the 'cosmic web' by observing Ly α forest at low redshifts
  - The cosmic web is shaped by the gravity of the underlying cold dark matter, while ordinary matter serves as a luminous markers of the filaments.
  - Will observe faint distant quasars with absorption features from the cosmic web material (composition and its specific location in space)
  - Observations covering vast distances across space and back in time, will provide information on both the large-scale structure of the universe and the progressive changes in chemical composition of matter, as the universe has grown older

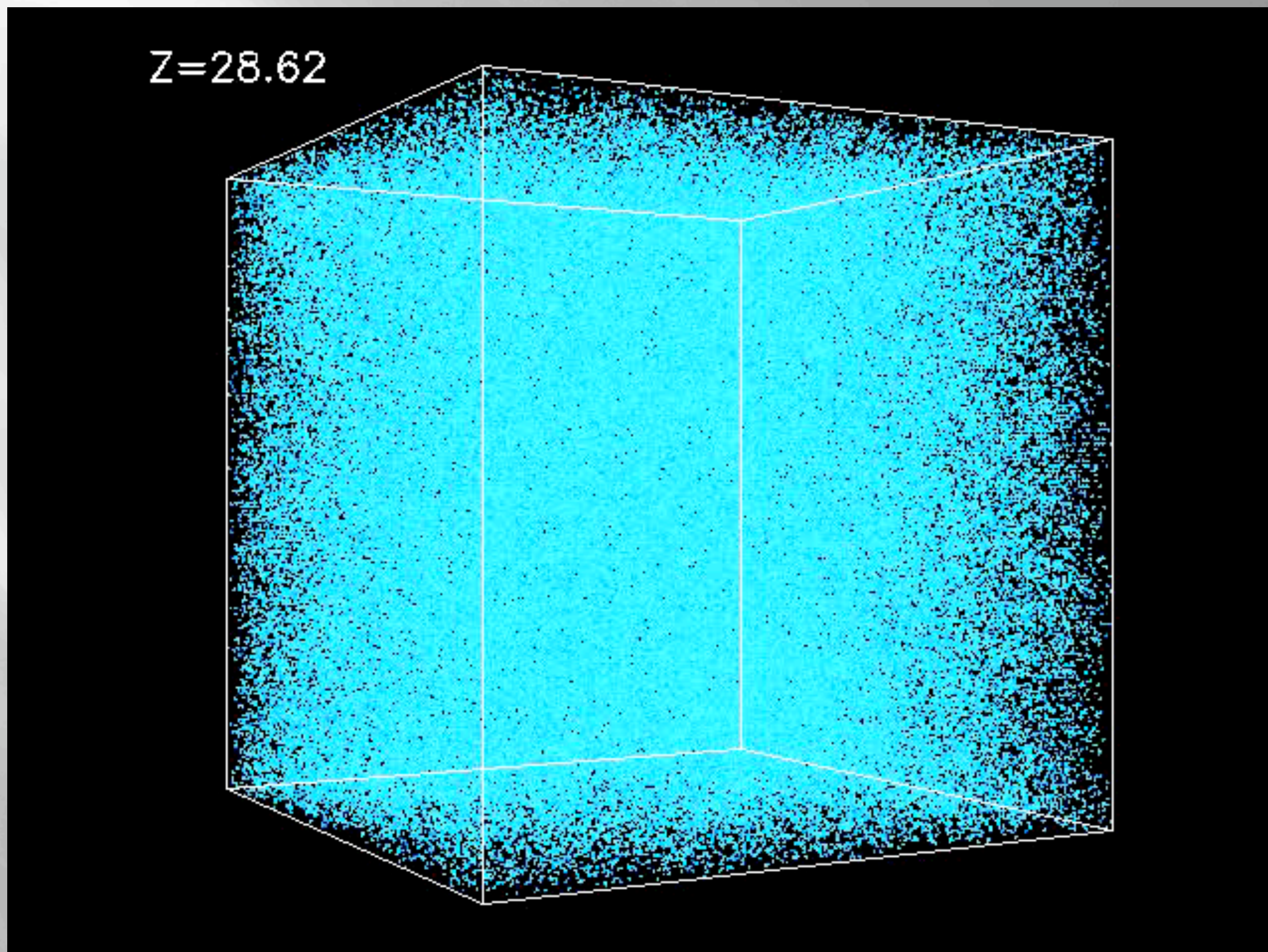




Quasar Spectra

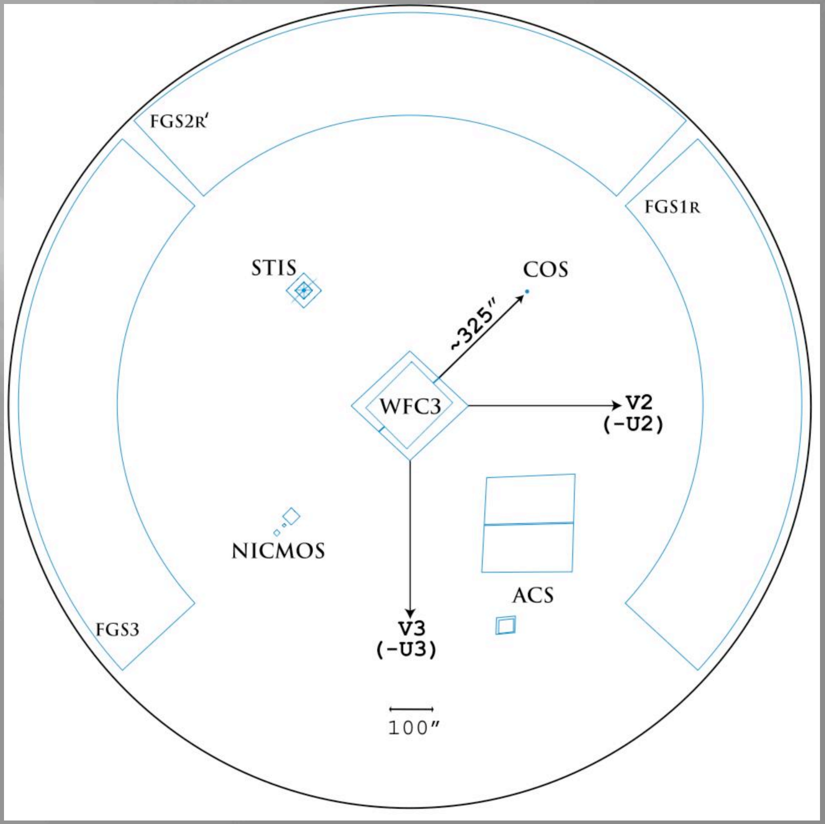


Evolution of the Cosmic Web



COS on HST

- COS will replaced COSTAR (optical corrector) during next Servicing Mission 4 – May 12, 2009



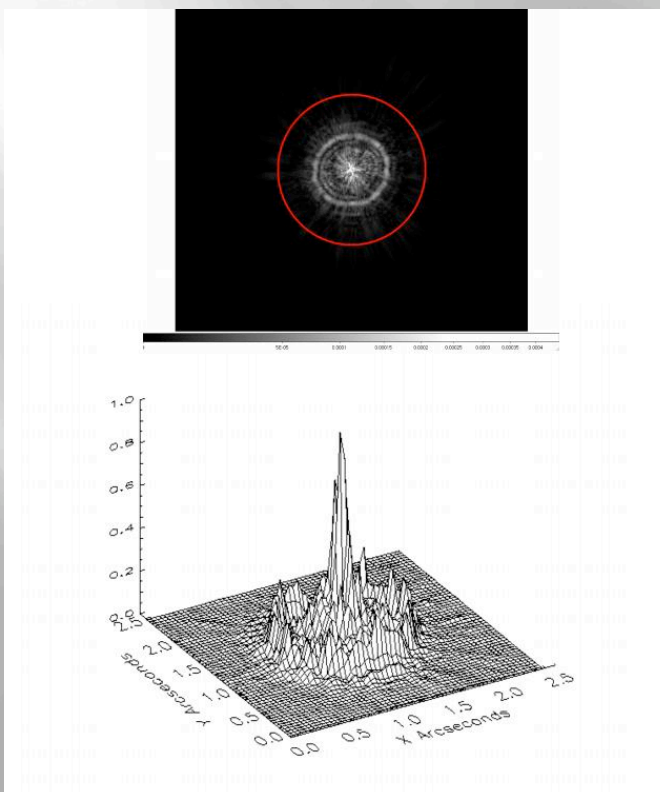
COS Instrument Description

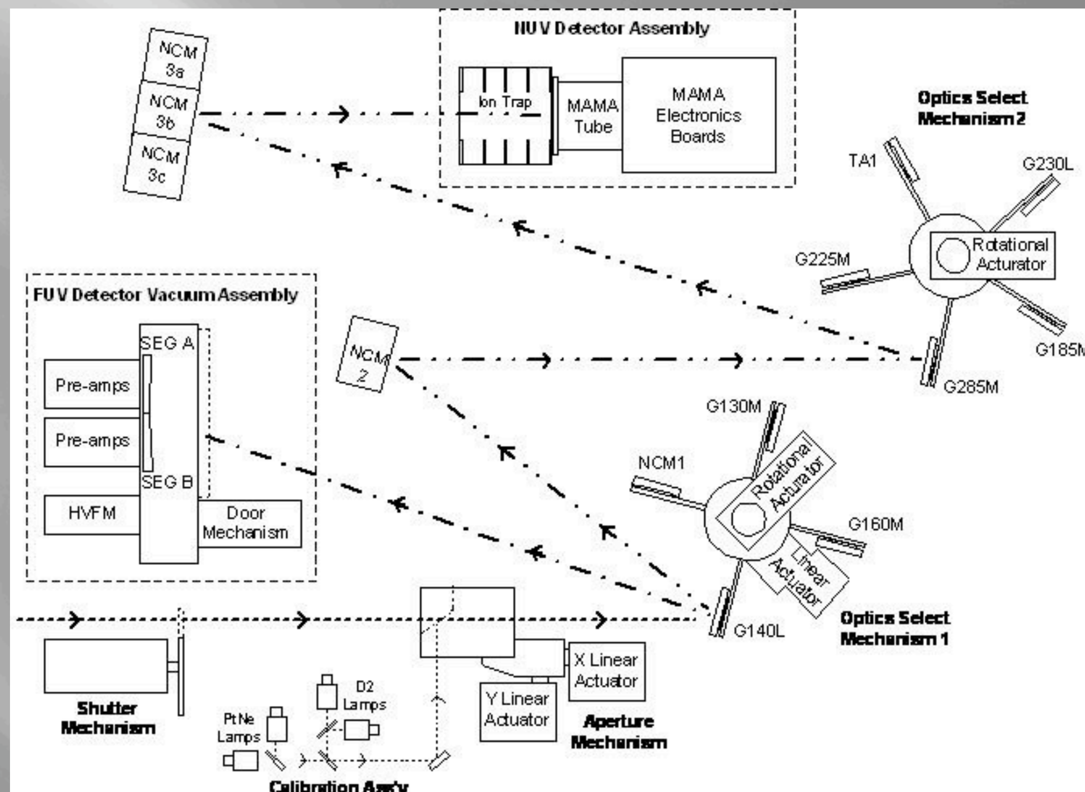
- Designed for ultraviolet (115-320 nm) spectroscopy of faint point sources with a resolving power of ~1,550 to 24,000
- Optimized for high sensitivity and moderate spectral resolution of compact objects (stars, quasars, etc.).
- COS has 2 channels:
  - Far Ultraviolet (FUV) covering 115 – 205nm with 3 gratings
  - Near Ultraviolet (NUV) spanning 170 – 320nm with 4 gratings, plus an imaging mode for target acquisition.

Grating (Channel)	Approximate Useful Wavelength Range	Resolving power ($\lambda/\Delta\lambda$)
G130M (FUV)	115 - 145 nm	20,000 - 24,000
G160M (FUV)	140 - 178 nm	20,000 - 24,000
G140L (FUV)	123 - 205 nm	2,000 - 5,000
G185M (NUV)	170 - 210 nm	16,000 - 20,000
G225M (NUV)	210 - 250 nm	20,000 - 24,000
G285M (NUV)	250 - 320 nm	20,000 - 24,000
G230L (NUV)	170 - 320 nm	1,550 - 2,900
TA1	170 - 320 nm	Target acquisition imaging mode

COS Instrument Description

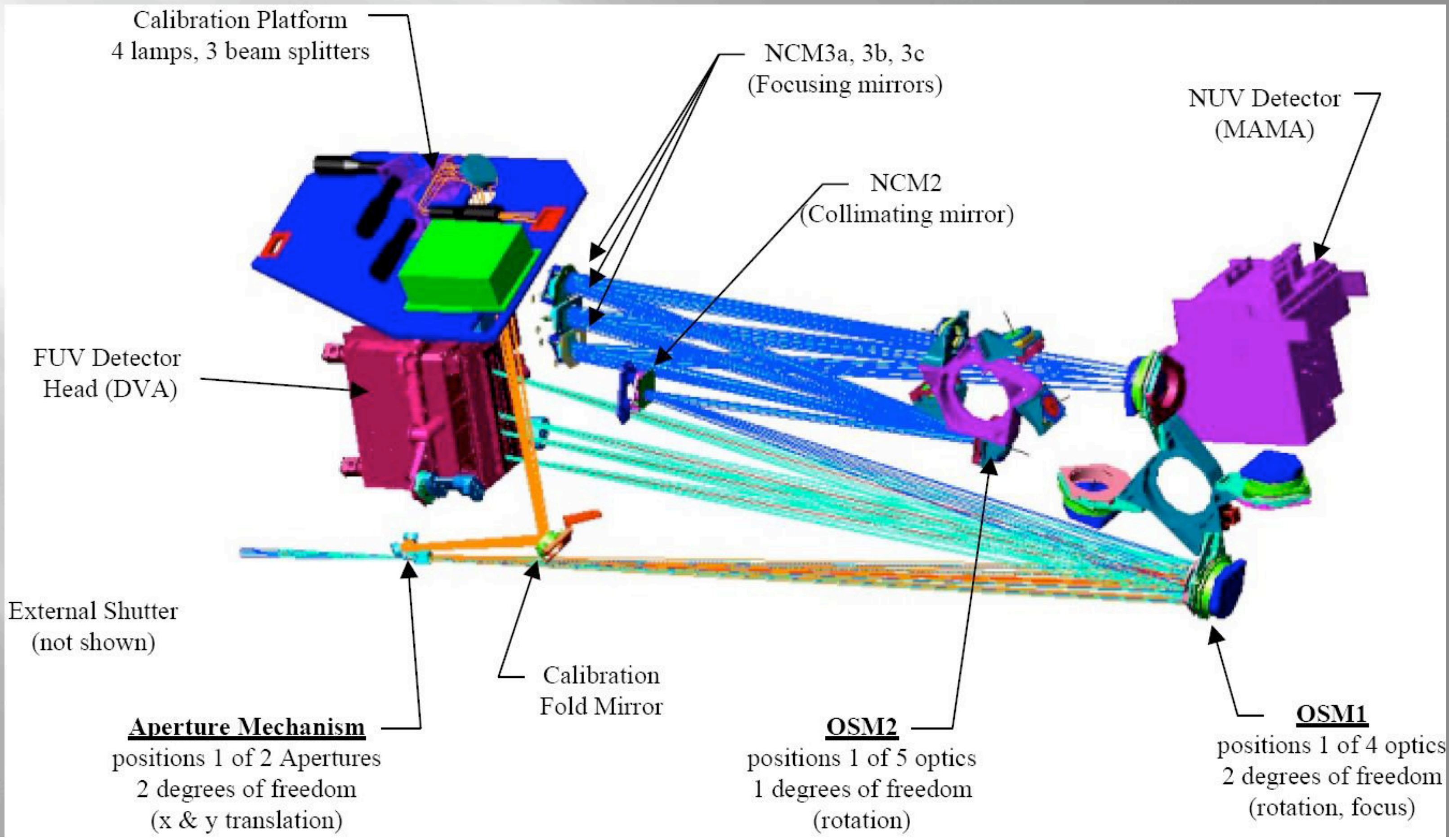
- Material reflectivity is low (~75%) in the FUV: minimize number of optics.
- Slit-less spectrograph: 2.5″ aperture lets ~95% of HST aberrated light to enter COS
- FUV: modified Rowland Circle spectrographs with holographically ruled aspheric concave grating focuses, diffracts and corrects both the HST spherical aberration and aberrations from extreme off-Rowland layout.
- Light is focused onto two 85x10 mm cross delay line micro-channel plate detectors.
- FUV detector is curved to match the spectrograph's focal plane



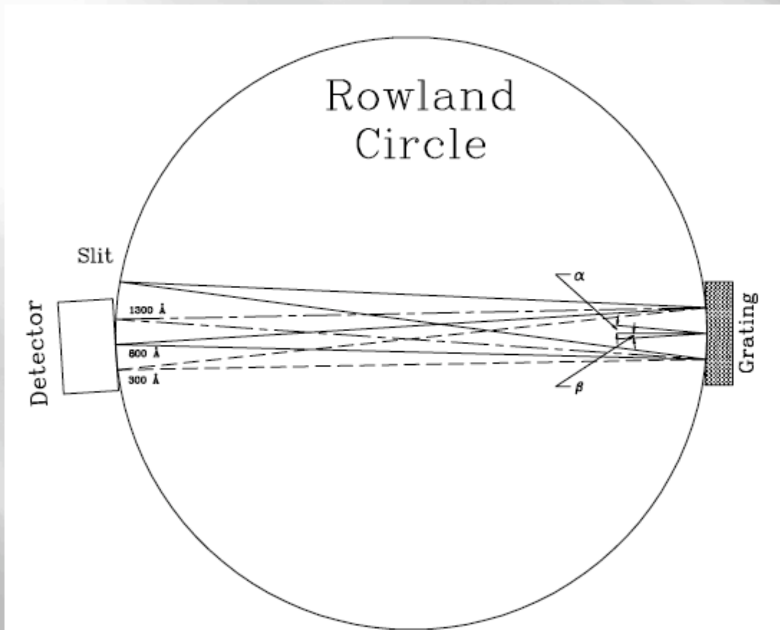


COS Instrument Description

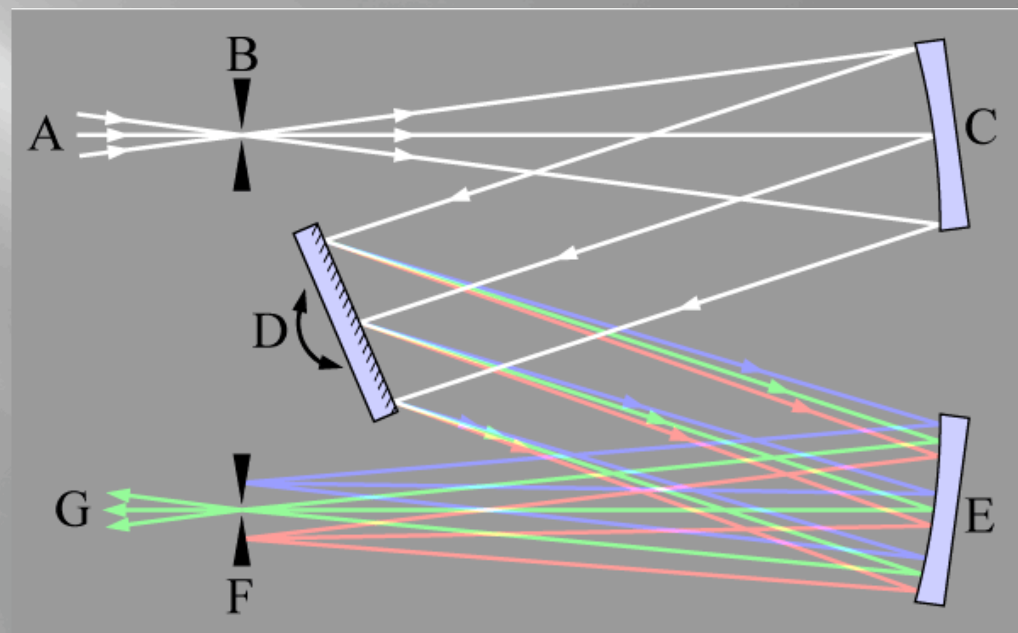
- NUV channel has 3 medium and 1 low resolution gratings
- Imaging mode with ~1.0 arc second un-vignetted FOV
- Modified Czerny-Turner design: collimated light fed to flat grating, followed by 3 camera mirrors which direct the diffracted light onto three separate regions on a 25x25 mm Multi Anode Microchannel Array (MAMA) detector.
- The imaging mode is primarily intended for target acquisition (0.0236 "/pixel over ~2")



COS Instrument Description



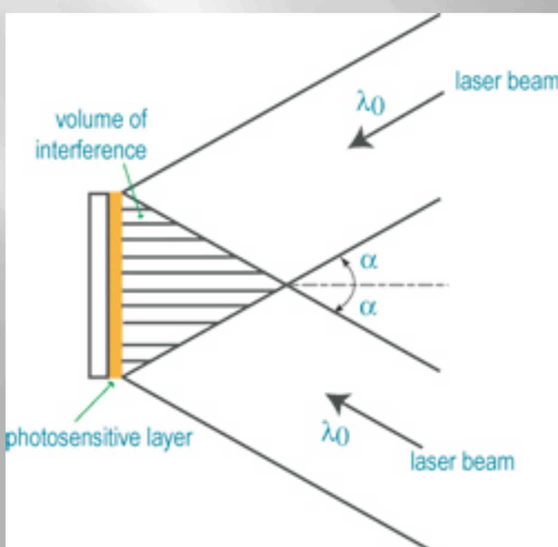
FUV Rowland-Circle Spectrograph
(curved focal plane)

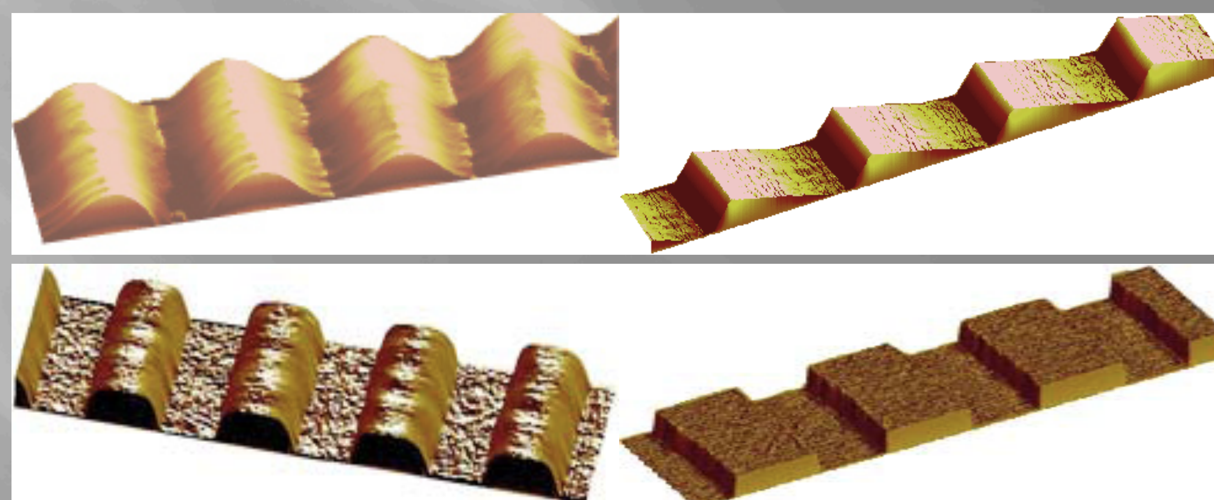


NUV Czerny-Turner Spectrograph

Holographic Grating

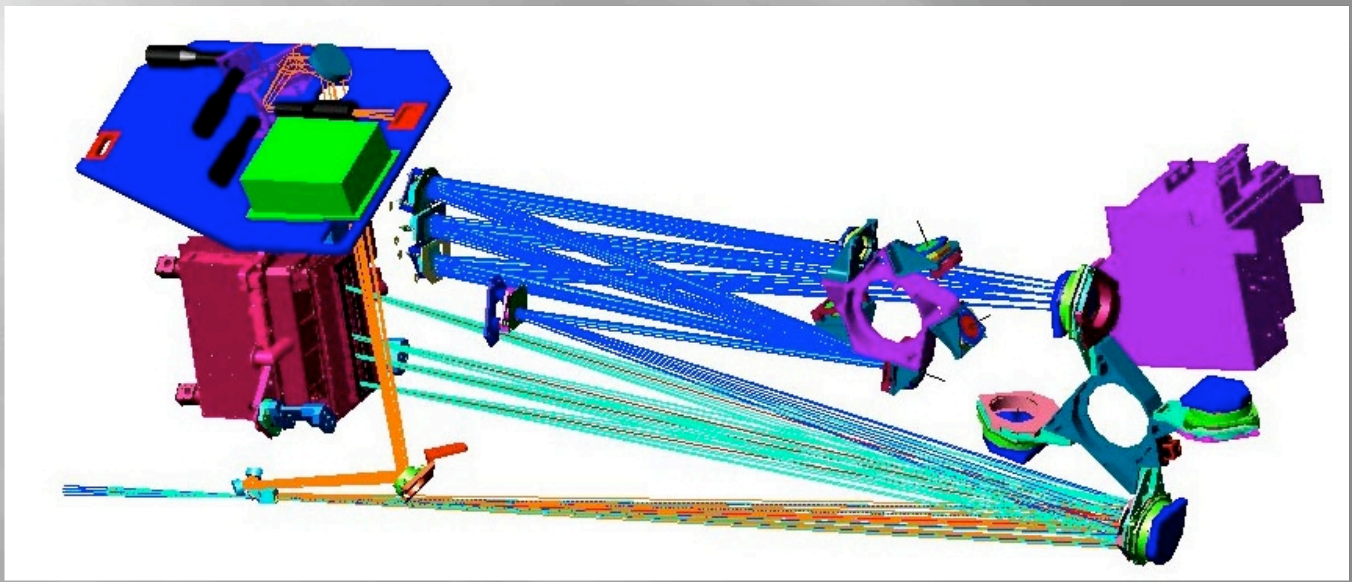
- Fabrication of holographic gratings:
  - highly-polished and precisely-figured blanks
  - coated with a layer of photosensitive material
  - exposed to fringes created by the interference of two coherent laser beams
  - chemical treatment of the photosensitive layer dissolves exposed areas, forming grooves in relief.
- Different design and configuration of holographic recordings provide:
  - plane and concave gratings (parallel grooves, uniformly spaced)
  - variable-spaced grooves gratings for full aberration correction
- Holographic recording geometry requires very stringent optomechanical stability
- The shape of the grooves produced by holographic recording is typically sinusoidal or pseudo sinusoidal (very low scatter but lower groove efficiency ~52% for COS)
- Ion etching can sculpt the shape of the grooves on a holographic master grating to increase efficiency





COS Instrument Description

- Wavelength calibration platform (2 PtNe + 2 Deuterium)
- Focus adjustment through OSM1
- Wavelength range by rotating OSM2 or OSM2
- Aperture mechanism:
  - PSA, WCA, BOA (ND2), FCA
  - Can be moved in cross-dispersion: livetime adjustment
- NCM2: mirror and rear-view mirror

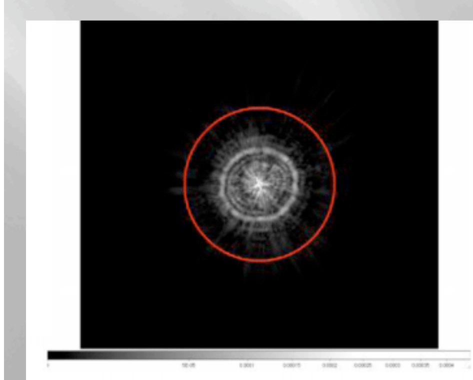


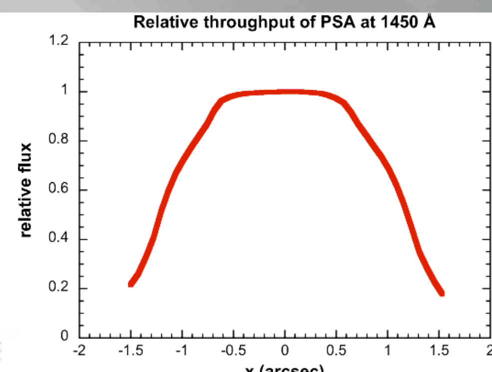
OSM Drift – Tag Flash

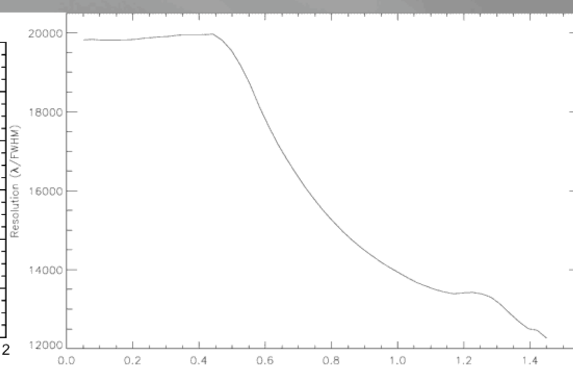
- Thermal-Vacuum tests have shown residual drift of OSM mechanisms after position reached (relaxation)
- To keep track of drift, calibration lamp is turned on numerous times during exposure
- Drift can be corrected for Time-Tag data only

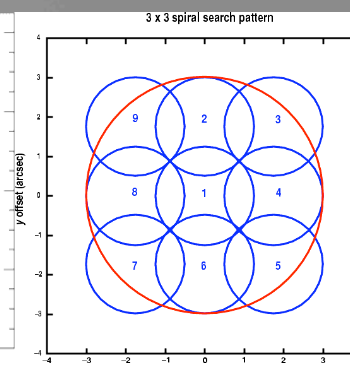
Target Acquisition

- Slit-less: absolute wavelength position on detector depends on location of target inside 2.5” aperture
- Sophisticated FSW algorithms available to ensure accurate centering
- **ACQ/SEARCH:** spiral pattern search by taking individual exposures at each point in a square grid pattern (dispersed or imaging). Returns to CENTER=FLUX-WT, or FLUX-WT-FLR, or BRIGHTEST
- AC**Q/PEAKXD:** centers target in dispersed-light spectrum in the direction perpendicular to dispersion by moving target across aperture and returning to brightest location
- **ACQ/PEAKD:** centers target along dispersion by taking individual exposures at each point in a closely-spaced linear pattern along dispersion. Returns to CENTER=FLUX-WT, or FLUX-WT-FLR, or BRIGHTEST
- **ACQ/IMAGE:** NUV image of the field after the initial HST pointing, determines the telescope offset needed to center the object (some targets may be too bright for imaging)
  - Requires precise knowledge of WCA-PSA separation: varies with installation uncertainties – orbit verification

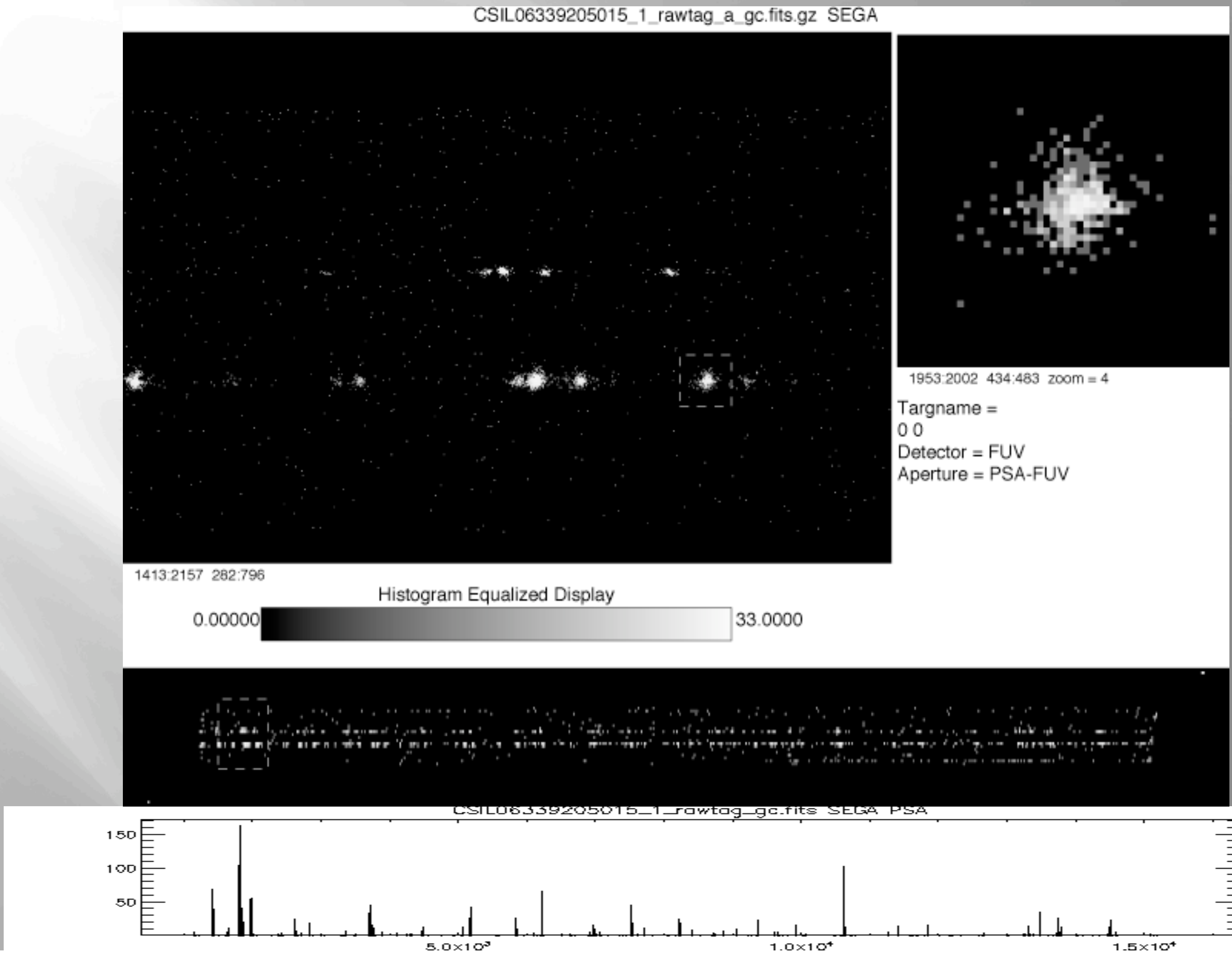






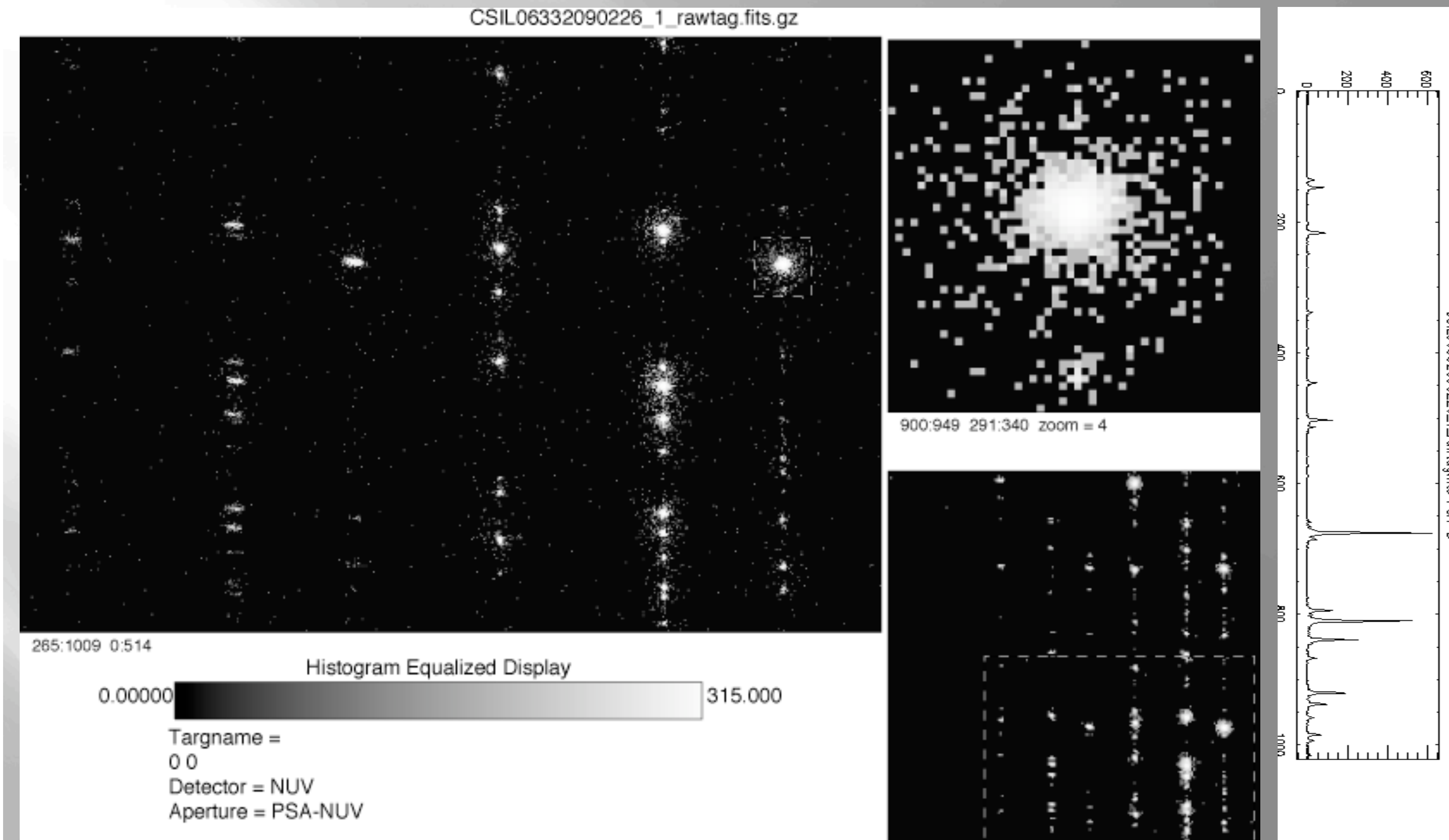


COS FUV Data

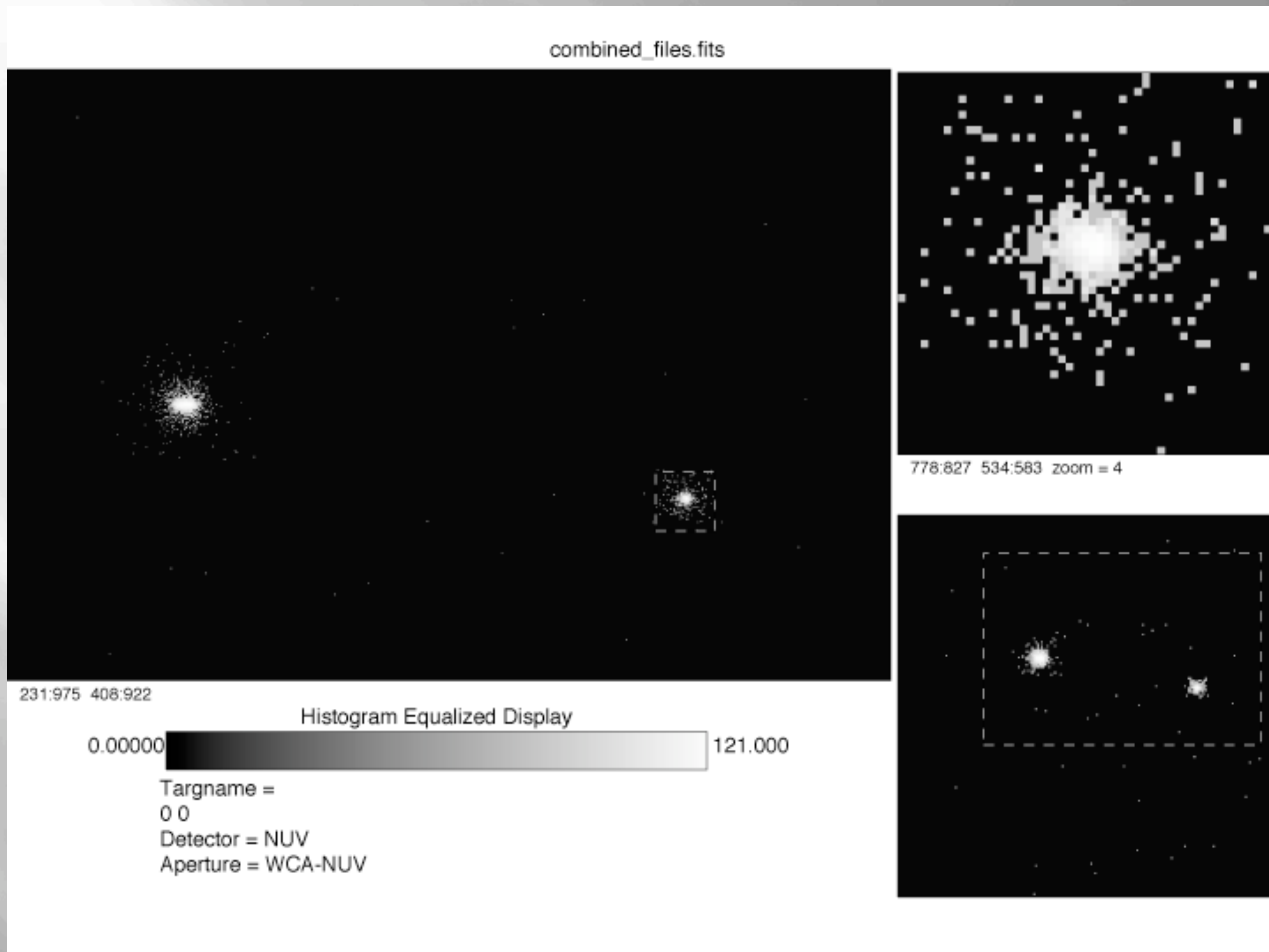


CSIL06339205015_1_rawtag_a_gc.fits.gz SEGA
1953:2002 434:483 zoom = 4
Targname =
0 0
Detector = FUV
Aperture = PSA-FUV
1413:2157 282:796
Histogram Equalized Display
0.00000
33.0000
CSIL06339205015_1_rawtag_gc.fits SEGA PSA
150
100
50
5.0×10³
1.0×10⁴
1.5×10⁴

COS NUV Data

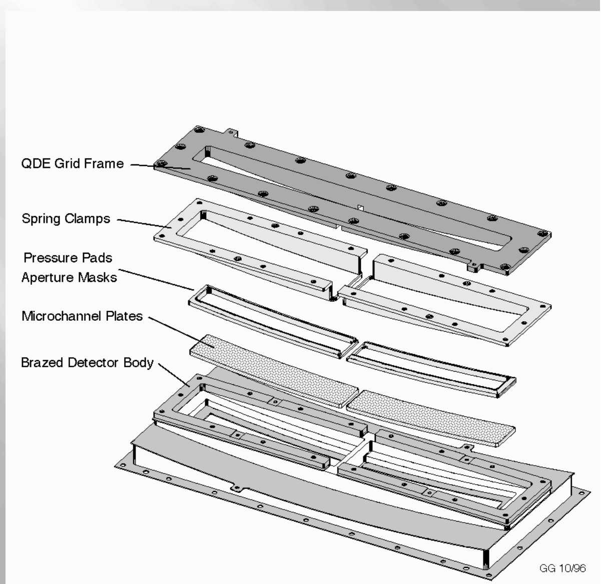

CSIL06332090226_1_rawtag.fits.gz
900:949 291:340 zoom = 4
265:1009 0:514
Histogram Equalized Display
0.00000
315.000
Targname =
0 0
Detector = NUV
Aperture = PSA-NUV

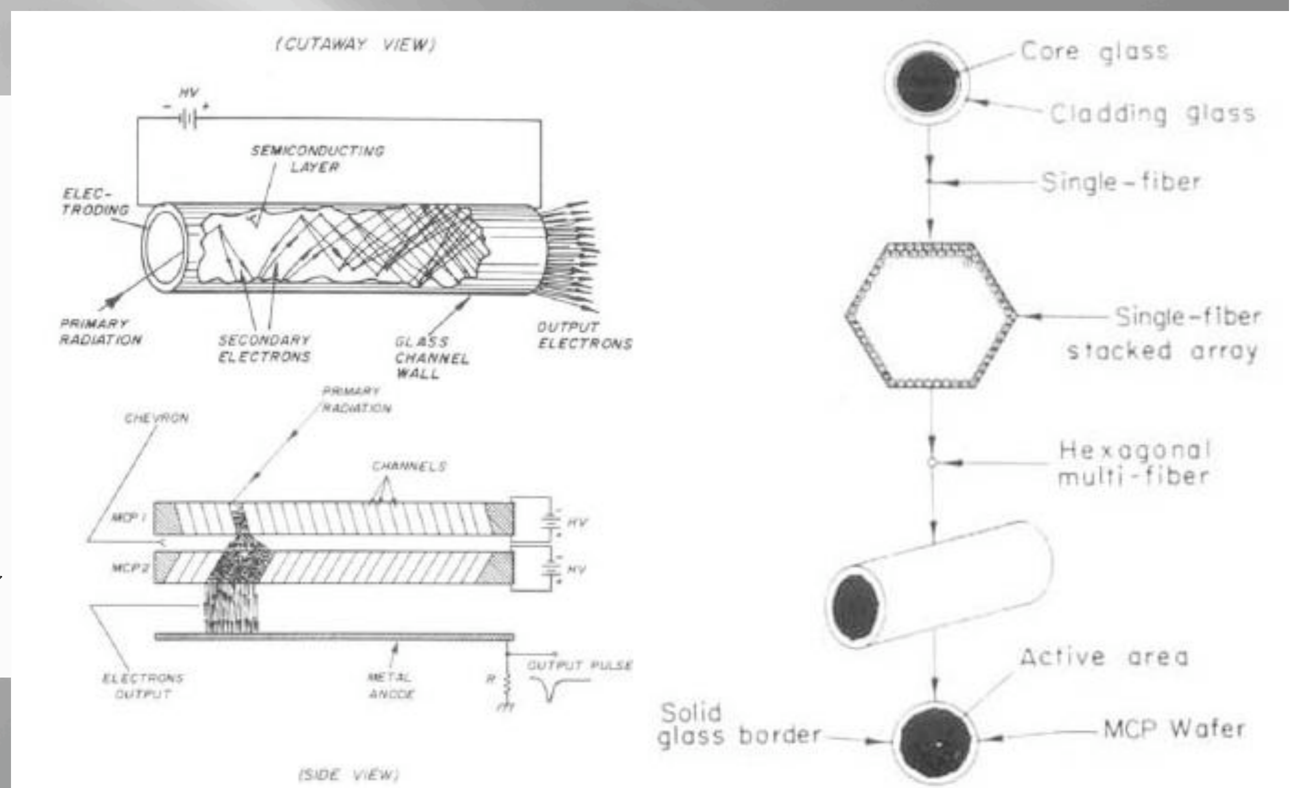
COS NUV Imaging Data



FUV Detector

- FUV detector is a windowless XDL (cross delay line) photon-counting Micro-Channel-Plate device
- Optimized for 1150 to 1775 Å, with a cesium iodide photocathode
- Surface is curved (r=826 mm) to match the curved focal plane.
- Photons striking the photocathode produce electrons which are amplified by MCPs.
- 3 curved MCP in a stack for each segment.
- Output electron cloud is several mm in diameter when it lands on the delay line anode
- Each anode has separate traces for the dispersion (x) and cross-dispersion (y) axes.
- Position in either axis is determined by difference in arrival times between the two ends of the delay line

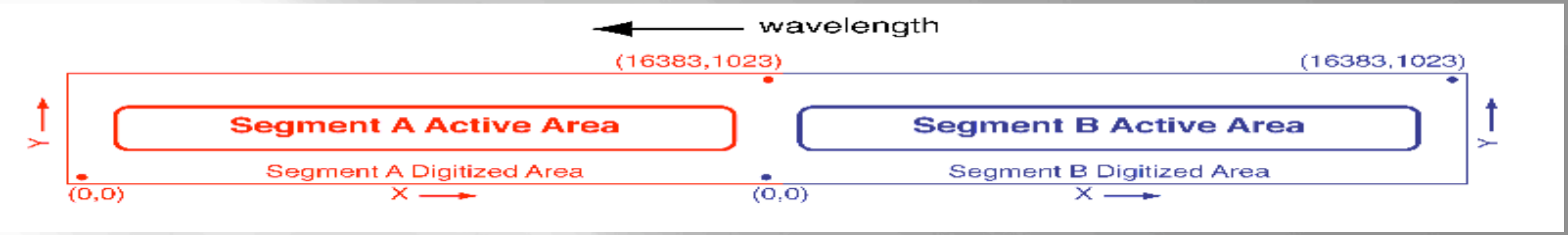


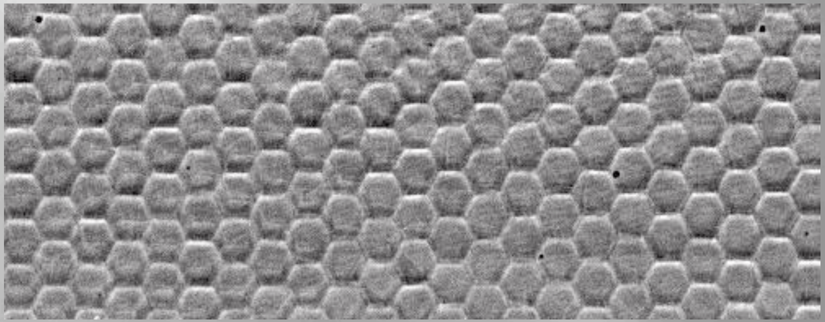


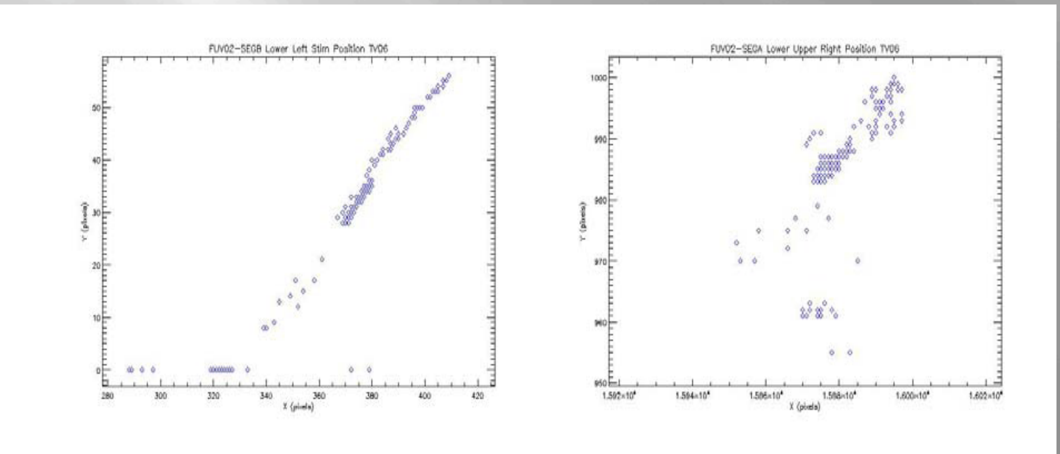
FUV Detector

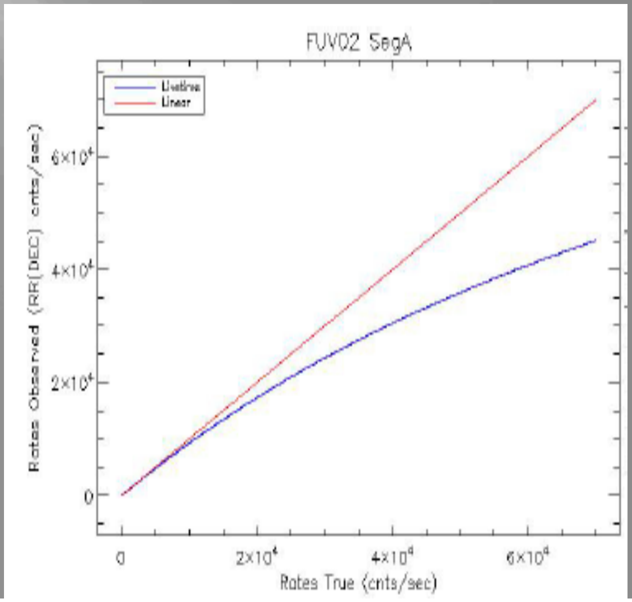
- Time-Tag or ACCUM mode: {time, x, y, ph} or 2D image (counts at each “pixels”)
- No physical pixels: location on detector determined by electronic timer (~6 x 24 μ m pixel)
- Pixel location dependent on temperature of electronics
- Injected STIM pulses used to correct for temperature drifts
- Geometric distortion depends on assembly of detector
- ACCUM mode for bright objects (limited by on board memory)
- Gain sag with photocathode depletion: the brighter the source, the faster the gain drops
- Dark counts ~1.5e-6 count/sec/pixel
- Grid shadows, hot spots, dead spots, livetime correction, pulse height filtering, OSM drift

FUV Detector

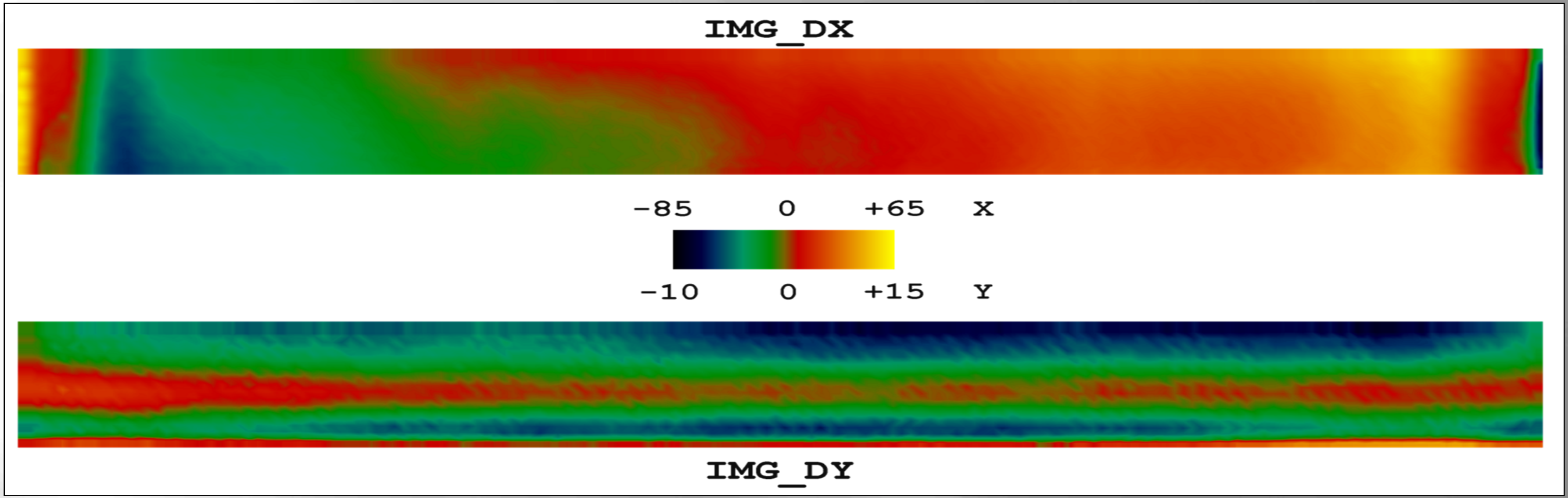


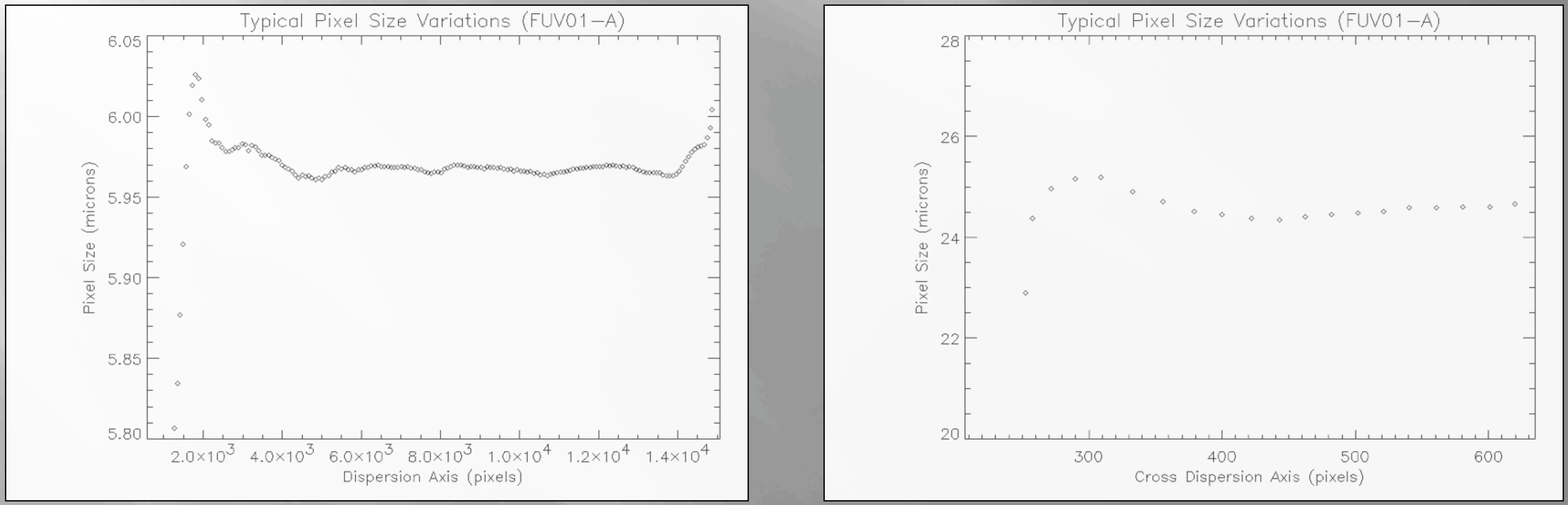






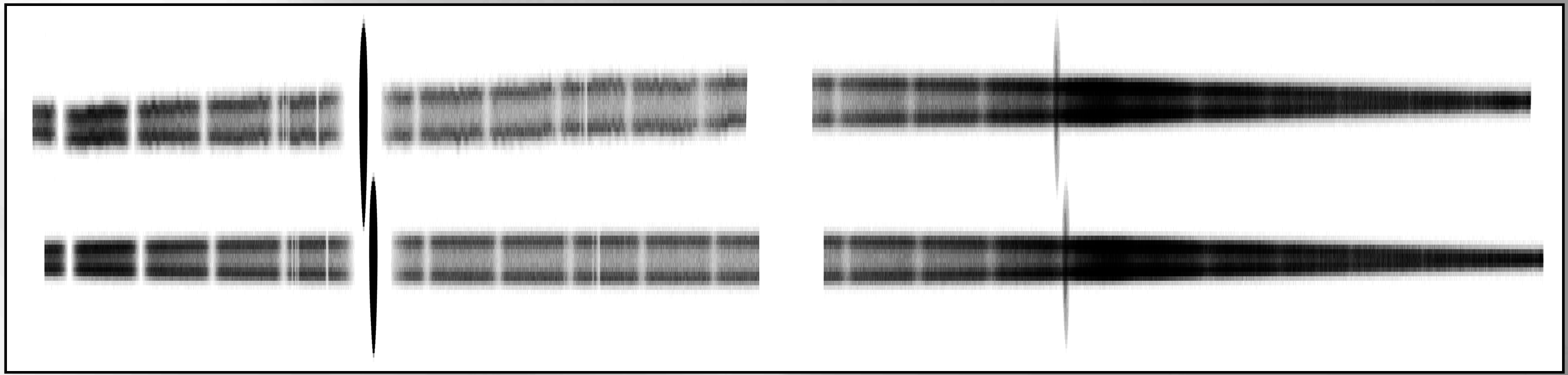
FUV Detector Geometric Distortions

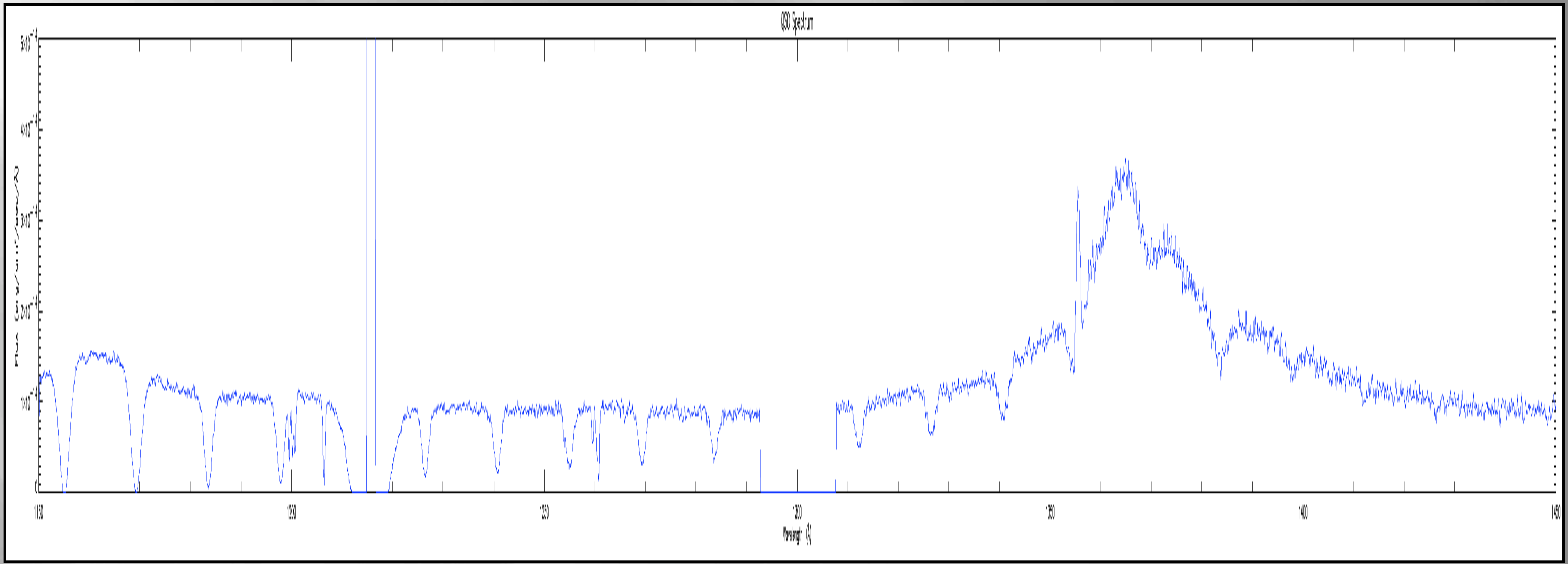




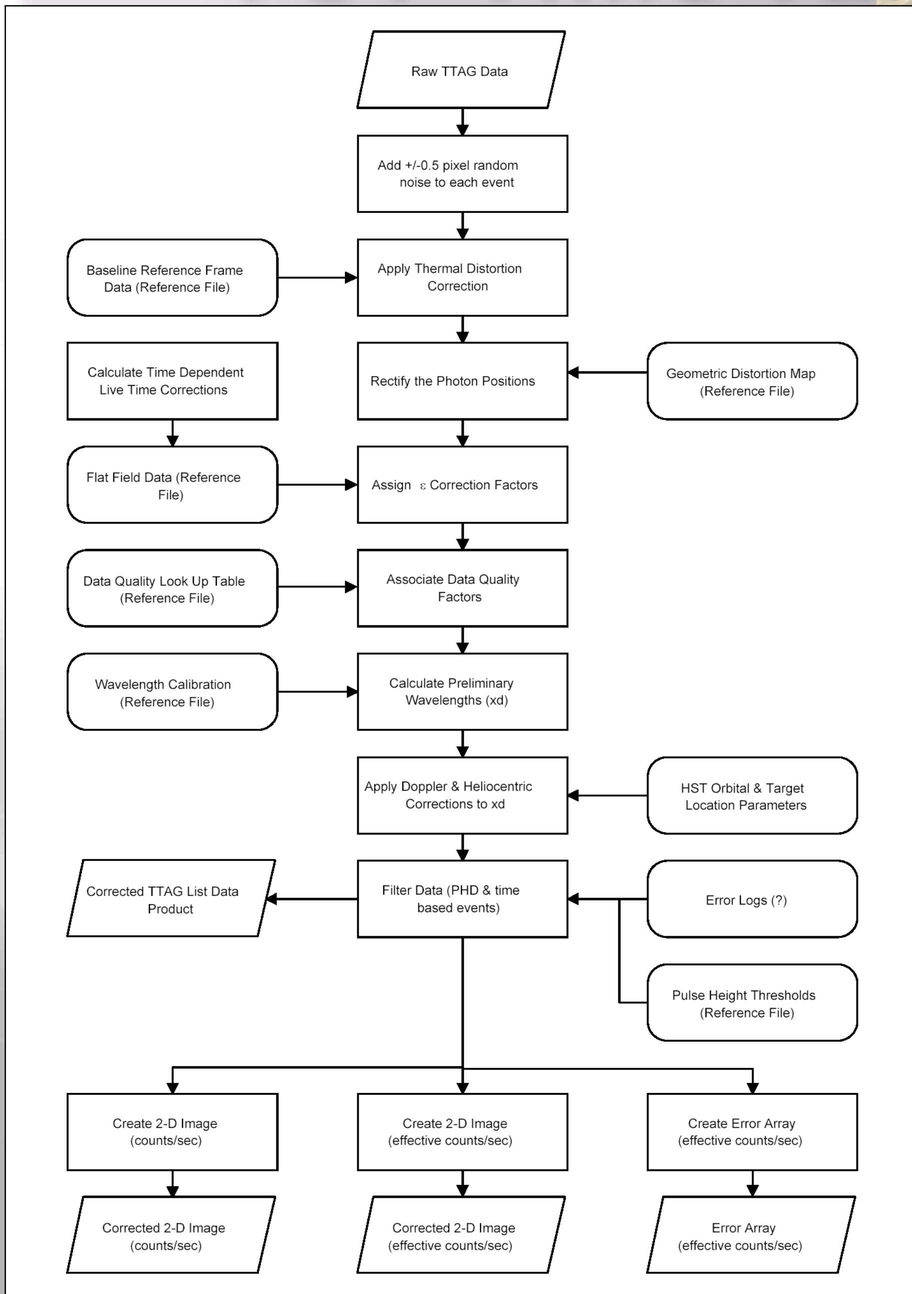
Pixel size variations for segment A of the FUV detector in: a) dispersion, b) cross-dispersion direction.

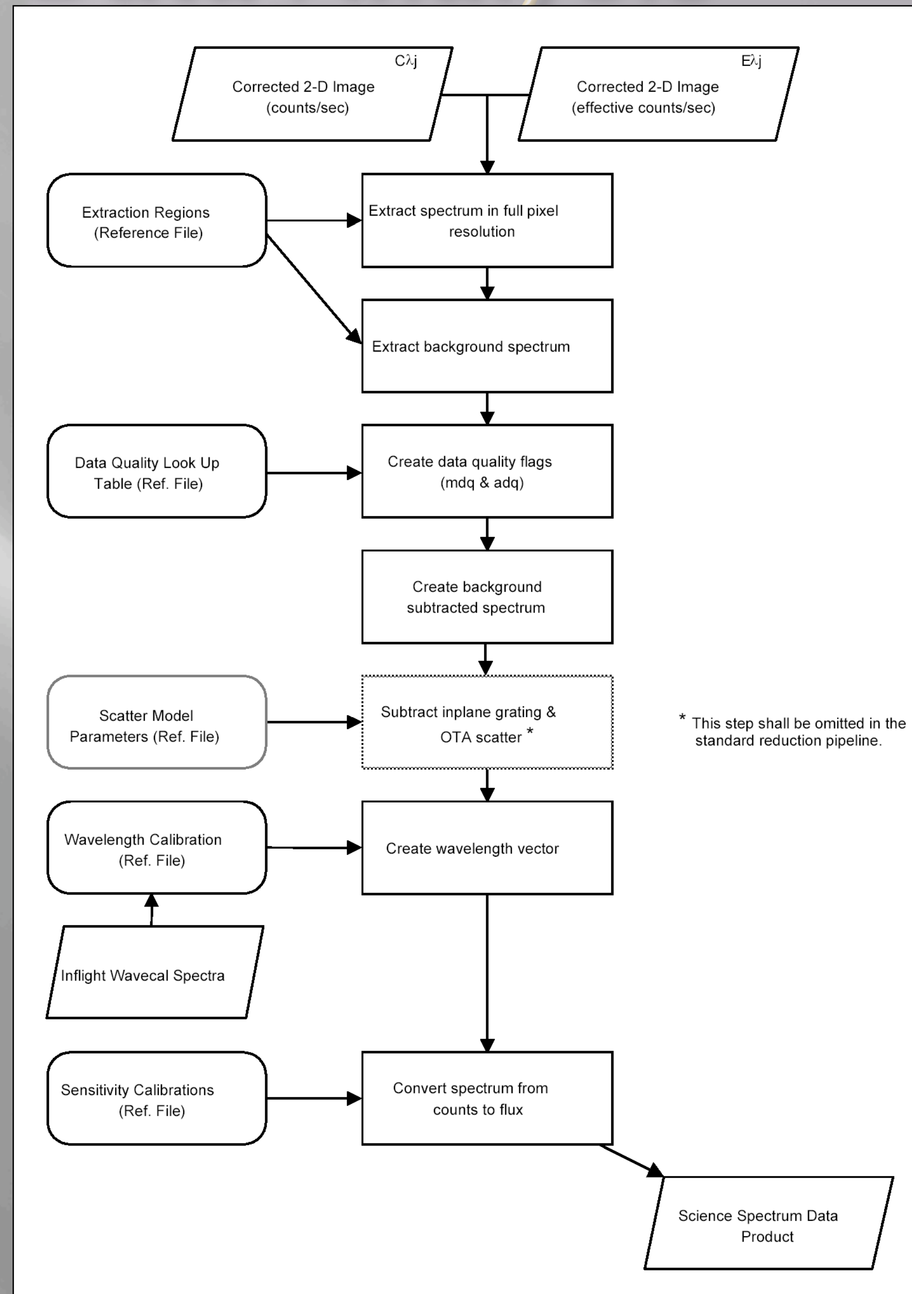
FUV Simulated Spectra





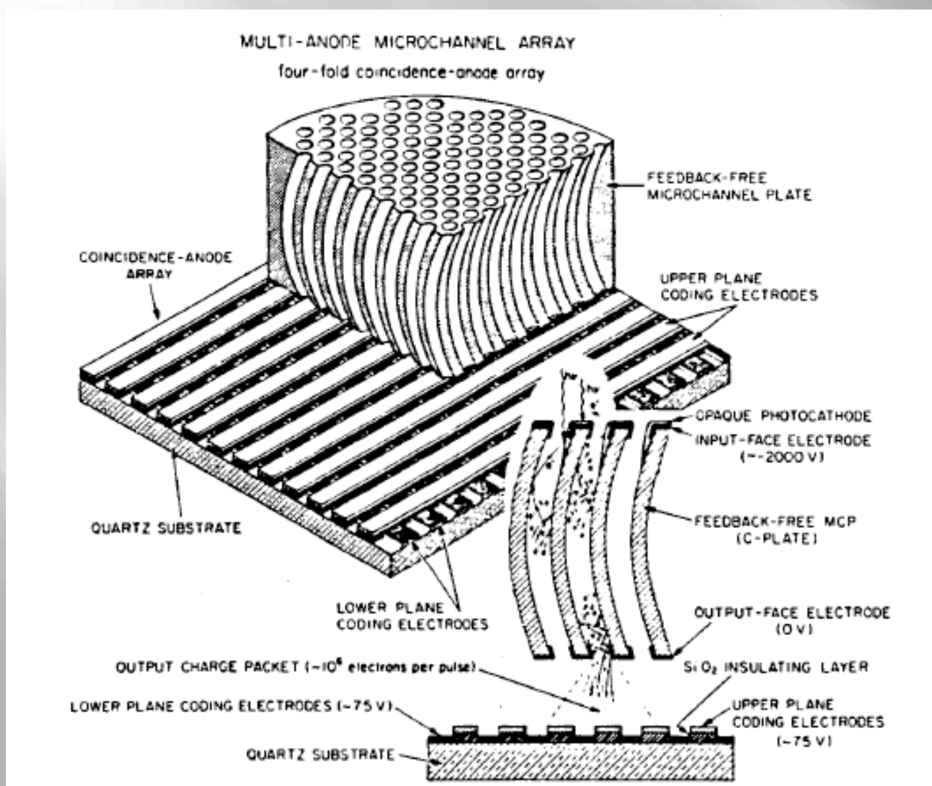
FUV Time-Tag Data Analysis





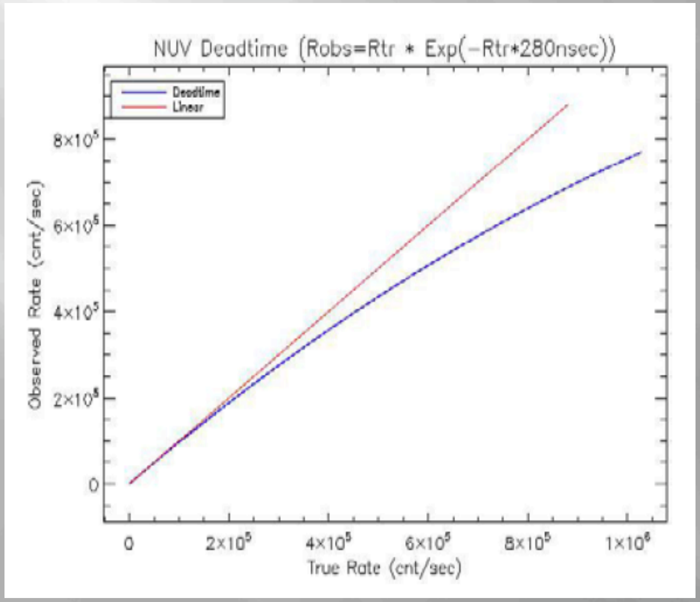
NUV Detector

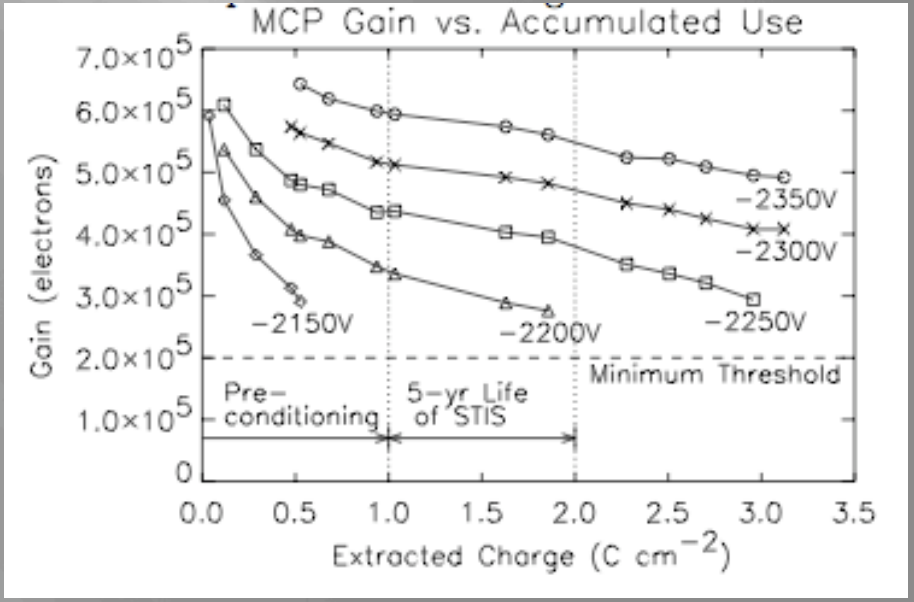
- NUV detector is a MAMA (Multi-Anode Micro-channel Array) photon-counting device
- Semi-transparent cesium telluride photocathode on a magnesium fluoride window (1150-3200Å)
- Photons striking the photocathode produce electrons which are amplified by MCPs.
- 25.6mmx25.6mm into 1024x1024, 25 μ m pixels
- Pixel location determined by anode array – fix pixel location
- Time-Tag or ACCUM mode: {time, x, y} (no ph) or 2D image (counts at each "pixels")
- No temperature correction and geometric distortions smaller than resolution



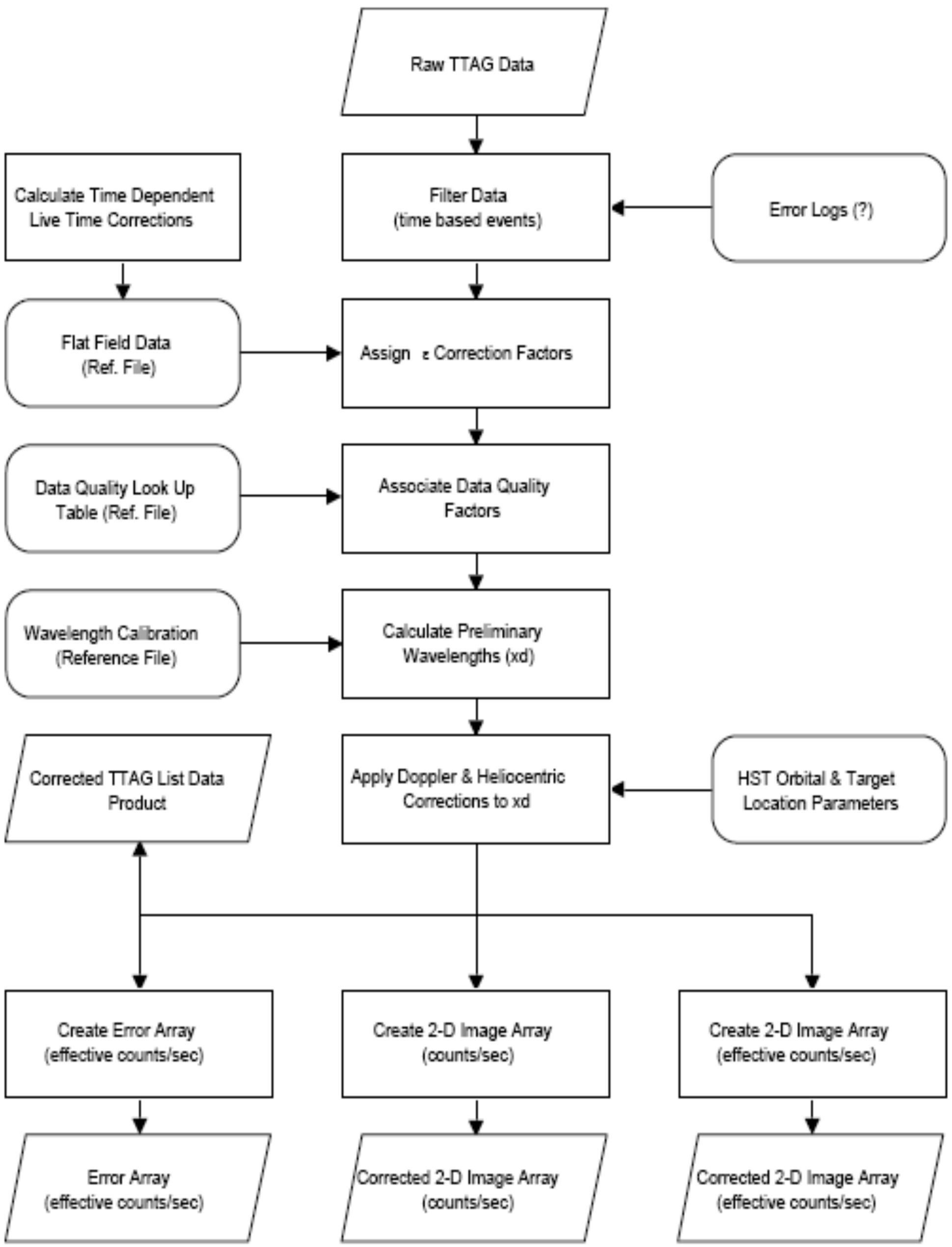
NUV Detector

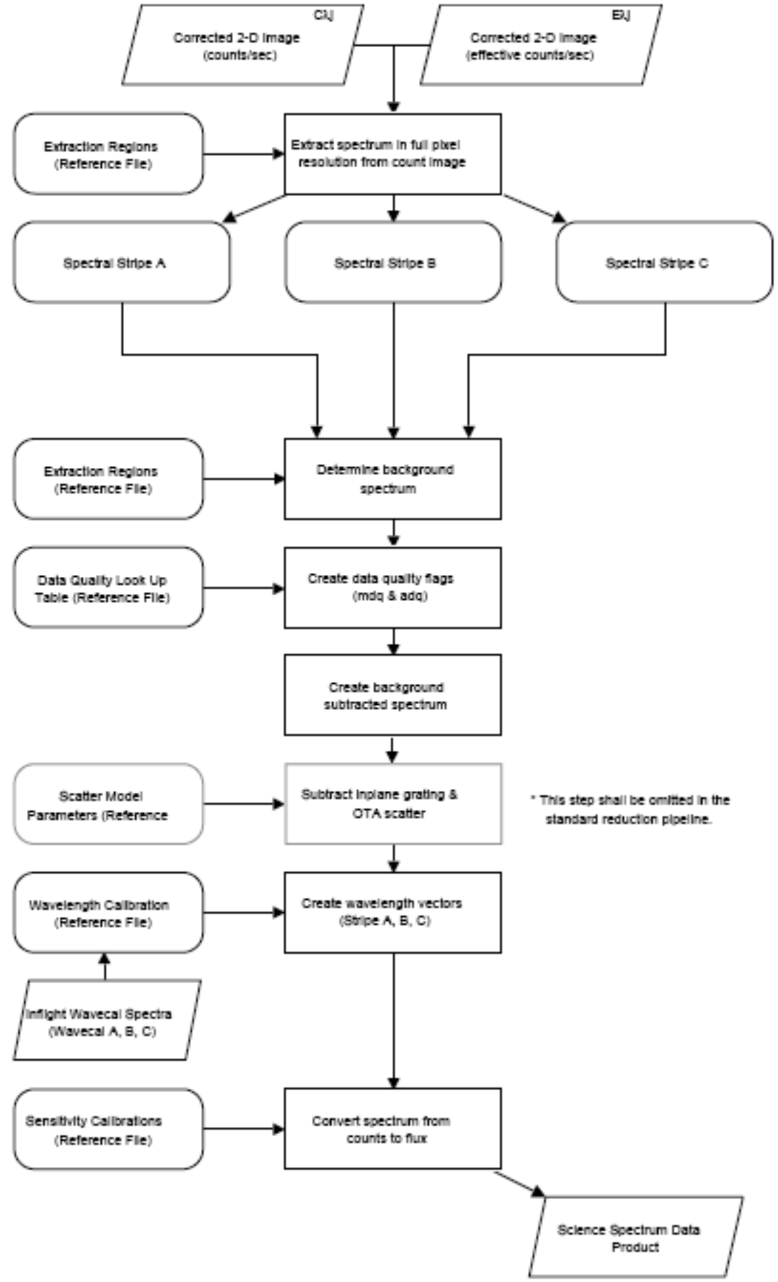
- MAMA gain sag with electron extraction
- Dark counts ~2.6e-6 count/sec/pixel
- Each stripe only covers a non-contiguous portion of the spectra
- Many central wavelengths settings to get full coverage:
  - G185M: 1670-2127Å in 15 settings
  - G225M: 2070-2527Å in 13 settings
  - G285M: 2480-3229Å in 17 settings
  - G230L: 1334-3560Å in 4 settings
- Deadtime effect with high count rates





NUV Time-Tag Data Analysis





COS Observing Strategy

- Identify science requirements and select the basic COS configuration to satisfy those requirements.
- Estimate exposure time for required S/N and check the feasibility, including count-rate, data volume, counter rollover, and bright-object limits.
- Identify any additional non-science (target acquisition, peakup, and calibration) exposures required.
- Determine the total number of orbits required, taking into account all overheads.

COS Exposure Time Calculator (ETC)

- Spectroscopy
  - Calculates count rates and S/N for a simulated spectrum of ONE source in a COS spectroscopic observation.
- Spectroscopy Target Acquisition
  - Calculates count rates and S/N for a simulated bandpass of ONE source in a COS spectroscopic target acquisition observation.
- Imaging
  - Calculates count rates and S/N for a simulated image of ONE source in a COS imaging observation
- Imaging Target Acquisition
  - Calculates count rates and S/N for a simulated bandpass of ONE source in a COS imaging TA (ACQ/Image or ACQ/Search with a mirror) observation
- COS Team ETC Help and Release Notes

- http://etc.stsci.edu/aptServer/

COS Exposure Time Calculator (ETC)

COS Spectroscopy ETC

This form will calculate the count rates and S/N ratio for a simulated spectrum of ONE source in a COS spectroscopic observation. For general help on how to use this Exposure Time Calculator or for help on various topics, click on the appropriate highlighted words.

Please read the current release notes, updated on 03/24/2008.

Submit Simulation | Reset All Parameters

1. Select one Detector+Grating and an aperture:

FUV Grating:	Cen. Wave.	NUV Grating:	Cen. Wave.
○ G130M	1309	○ G185M	1850
● G160M	1600	○ G225M	2250
○ G140L	1230	○ G285M	2850
		○ G230L	3000

Aperture ---------- Primary Science Aperture

2. Specify the exposure parameters:

● Exposure time needed to obtain a S/N ratio of 60.0

○ S/N ratio reached in an exposure time of 900 seconds.

S/N or exposure time specified for a wavelength of 1500 Å.

Select the source type:

The photometric extraction region is the same for both point and extended sources. 47 pixels high and a 6 pixel wide resolution element for the FUV. 8 pixels high and a 3 pixel wide resolution element for the NUV.

● **Point Source**

○ **Extended Source**

Diameter is 8 arcsec

3. Choose one of the following spectral distributions for the source:

Please note: for User supplied and uploaded spectrum, please use only FITS or text format files.

○ Upload Spectrum File: Browse...

○ Other HST Spectrum:

CDBS Synphot spectrum file

○ Castelli and Kurucz Models: O3V 45000 4.0 [Sp Teff log(g) log(z)=0]

○ Pickles Models: O5V 39810.7K (Sp Teff)

○ Kurucz Models: O5V 44500 5.0

○ Bruzual Synthetic Stellar Spectra: O5 V

○ HST Standard Star spectra: GD50 (DA2, 14.06)

● Non-Stellar Objects: QSO (SDSS based, [800,6000Å z=0])

○ a Black-body with temperature T = 10000

○ a Power-law: $F\lambda = \lambda$ ** -1

○ a Flat continuum in F λ

○ No continuum. *If selected, at least one emission line must be specified below, and the reference wavelength from part 2 above must correspond to one of the lines.*

Specify the extinction E(B-V) Average Galactic = 0.0

Extinction applied before normalization.

Specify the redshift z = 0.0

Add emission lines to the input spectrum (optional):

Line Center (Å) (vacuum)	FWHM Å	Integrated Flux (erg/cm^2/s)
0.	0.	0.
0.	0.	0.
0.	0.	0.

Note: integrated flux units are per arcsec^2 for extended sources. *All three of the parameters (line center, fwhm and integrated flux) must be specified for an emission line to be included.*

COS Exposure Time Calculator (ETC)

4. Normalize the target's flux:

- (●) [Johnson/V] = [15] (Vega magnitudes) (arcsec^{-2} for extended sources) **or**
- ( ) [Galex FUV] = [15] (AB magnitudes) (arcsec^{-2} for extended sources) **or**
- ( ) [1.5e-13] *ergs cm^{-2} s^{-1} Å^{-1} (arcsec^{-2} for extended sources)* at [1310] Å. **or**
- ( ) Do not Renormalize Point Source Spectrum. *Use only for User Input Spectrum or Calibration Spectra.*

5. Specify the expected background levels :

a) Specify normalization for zodiacal background

- (●) Standard zodiacal light normalizations: [Average]
- ( ) Compute zodiacal light on sky position:
  - R.A.: [00:00:00] (hh:mm:ss or decimal)
  - Dec.: [+00:00:00] (dd:mm:ss or decimal)
  - **either** ( ) $\lambda - \lambda_{Sun}$: [90] degrees
  - **- or -** (●) Date: [2005] [January] [1]
- ( ) Normalize zodiacal light to magnitude: [30.0]
- ( ) Scale zodiacal light by factor (1.56 = average): [1.0]

b) Specify normalization for earth shine background

- (●) Standard earth shine light normalizations: [Average]
- ( ) Normalize earth shine light to magnitude: [30.0]
- ( ) Scale earth shine light by factor (0.5 = average): [1.0]

c) Air Glow

[Average]

[Submit Simulation] [Reset All Parameters]

COS Exposure Time Calculator (ETC)

Exposure ID: COS103676

Requested Signal/Noise Ratio = 60.00 at wavelength 1500.00 Å (per resolution element)
gives: Time = 8,361.1893

Exposure time calculation HAD WARNINGS.

WARNING MESSAGE: Partial overlap exists between normalization band and input spectrum. This may result in over-optimistic SNR and/or exposure time estimates.

Detailed Information	Count rate (counts/s)	Total counts (counts)	Associated noise (counts)
Counts (box 47 pixels high)	(1 pixel)	(6 pix resel)	
Source	0.072	3,601.77	60.01
Background	3.525E-5	1.77	1.33
Sky	5.470E-11	2.74E-6	1.66E-3
Dark Current	3.525E-5	1.77	1.33
Total in selected region	0.072	3,603.54	60.03
Brightest Pixel (1547.49 Å)	0.015		
Count rate entire detector	1,542.855		
Count rate segment A	459.824		
Count rate segment B	1,083.031		
Buffer time (sec)		1528	

For APT purposes, the recommended buffer time should be 2/3 of the buffer time calculated above, or the exposure time, whichever is shorter. Please refer to the COS Instrument Handbook for more details

Target [point source]

Model ID = 392
+ QSO (qso_template.fits)
. Renormalized to Johnson V = 15 in magnitudes relative to Vega

Instrument name:	COS
Mode:	Spectroscopy
Detector:	FUV
Central wavelength:	1600
Grating:	[G160M] Grating (R ~ 20,000-24,000)
Aperture:	Primary Science Aperture

Selected background:	
Sky Background:	
Earth Shine:	Average
Zodiacal Light:	Average
Air Glow:	Average

View results in tabular form

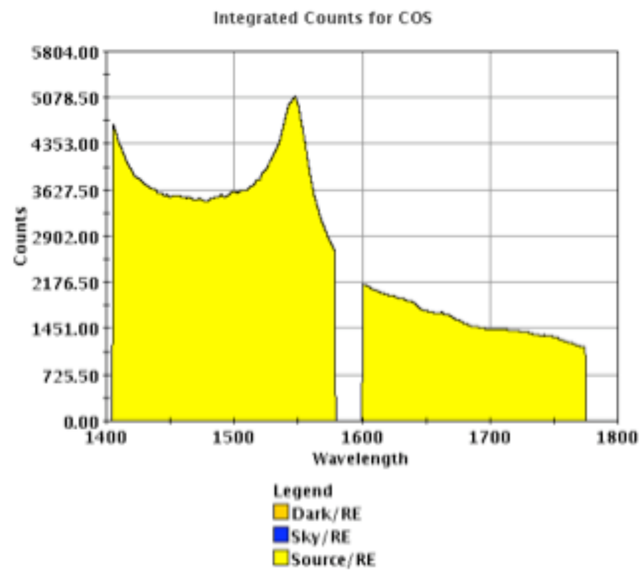
Plots

Total Counts | Signal-to-noise | Source spectrum | Throughput

Exposure ID: COS103676

View results in tabular form

Back to results page



Log X 510 X plot size

Log Y 450 Y plot size

Re-plot

Plots

Total Counts | Signal-to-noise | Source spectrum | Throughput

COS Astronomer's Proposal Tool (APT)

- Software use to submit HST Phase I and II proposals
- Integrated toolset consisting of:
  - Editors for filling out proposal information
  - Orbit Planner for determining feasibility in Phase II
  - Visit Planner for determining schedulability, diagnostic and reporting tools
  - Bright Object Protection Tool
  - Integrated tool based on Aladin for viewing exposure specifications overlaid on FITS images and querying the HST Archive via StarView.
- Downloadable from:
  - http://www.stsci.edu/hst/proposing/apt

COS SM4