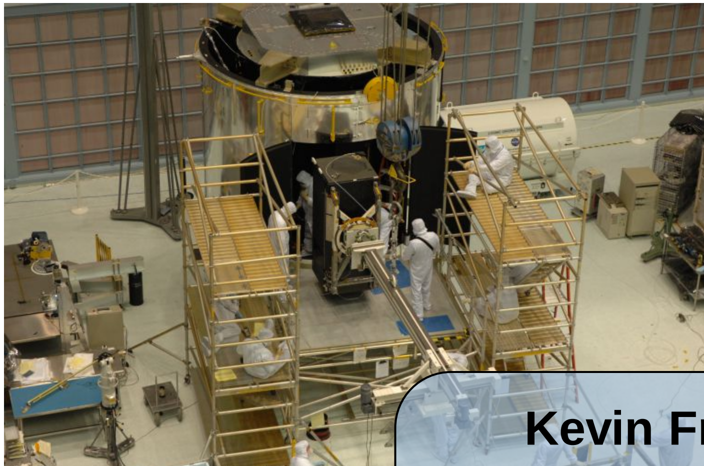
HST - Cosmic Origins Spectrograph
Assembly, Integration, and Verification Overview
NUVA Challenges in UV Astronomy 2013



Kevin France – University of Colorado

<u>co-authors</u>:
James C Green – PI
Cynthia S Froning – Project Scientist

Outline

- COS Introduction – mostly covered in science talks
- Component- and system-level testing at University of Colorado
- Thermal Vac: Ball Aerospace and Goddard Space Flight Center
- Alignment verification, sensitivity tracking, and light leak checks
- Contamination control, contamination control, contamination ….

Note: don't worry about the acronyms

COS Overview

- COS was successfully installed in 2009 and is performing well
- 153 refereed publications using COS data in the literature to date (Sept 26th 2013)
- One or more HST large programs (>100 orbits) every cycle
- Typically 22 - 25% of GO prime orbits
- 555-orbit Guaranteed Time Observing program

Principal Investigator: Prof. James Green, University of Colorado at Boulder

Project Scientist: C. S. Froning

Instrument Scientist: S. Osterman

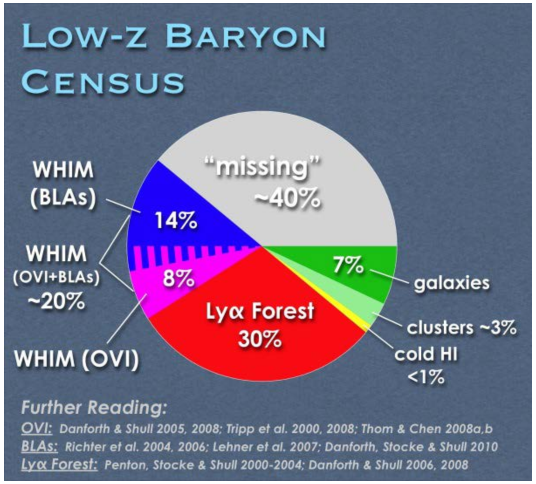
Industrial Partner: Ball Aerospace, Boulder, Colorado

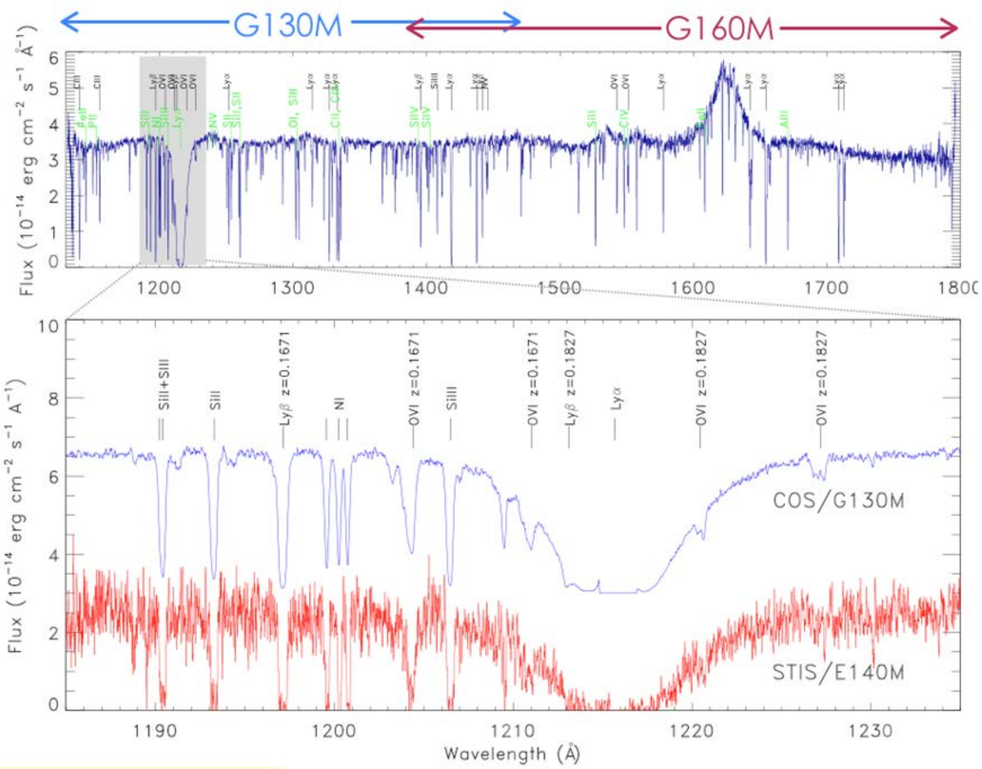
Additional partners: NASA-GSFC, STScI, UC-Berkeley, U. Wisconsin, SwRI

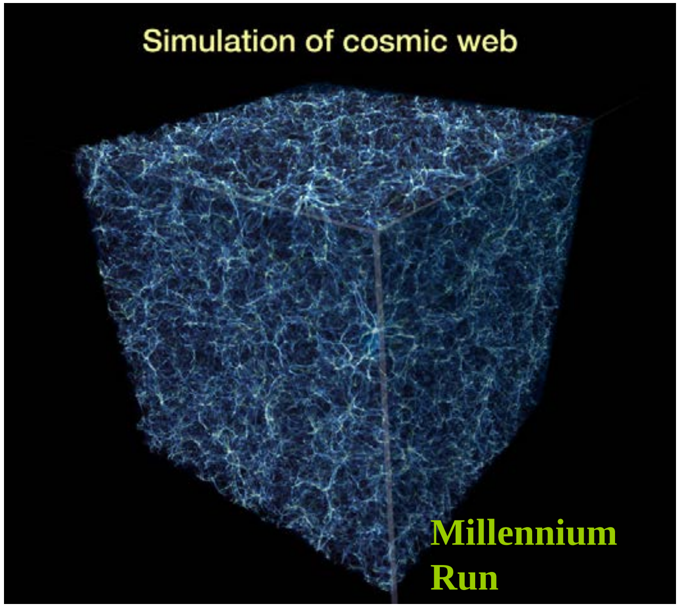
The low-z Intergalactic Medium

- Missing baryons in the local universe
- Large scale structure
- Galaxy formation and evolution
- Feedback: galaxy-IGM interactions

Simon White's Talk

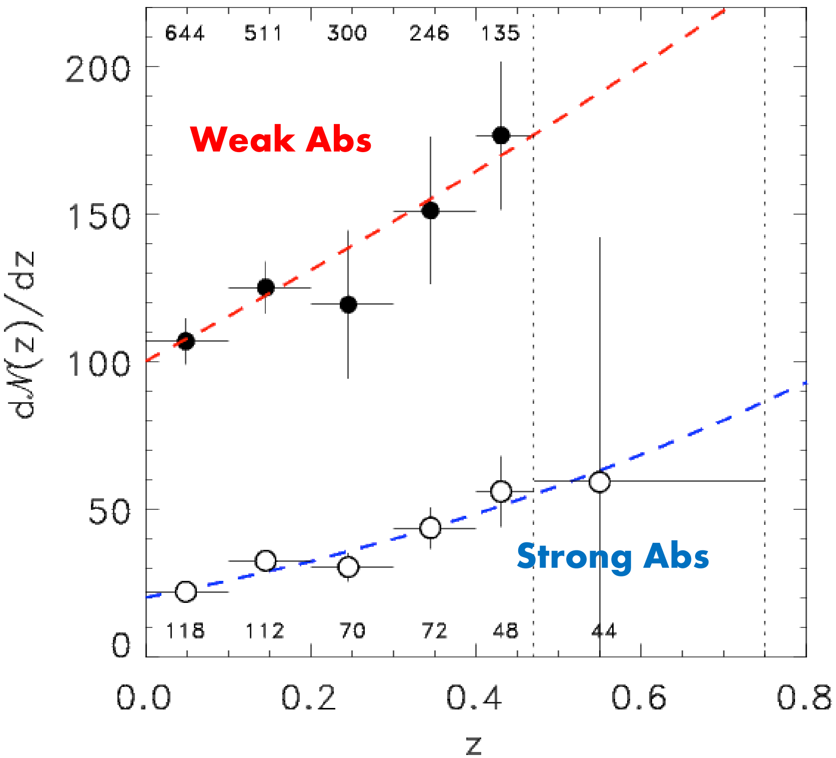






The low-z Intergalactic Medium

- Missing baryons in the local universe
- Large scale structure
- Galaxy formation and evolution
- Feedback: galaxy-IGM interactions



Danforth et al. (ApJ – 2014 in prep)

•Increased number of known IGM absorbers by factor of ~50 over all the systems observed by HST prior to 2009

• Weak IGM absorber density evolving faster than strong absorbers associated with galactic outflows

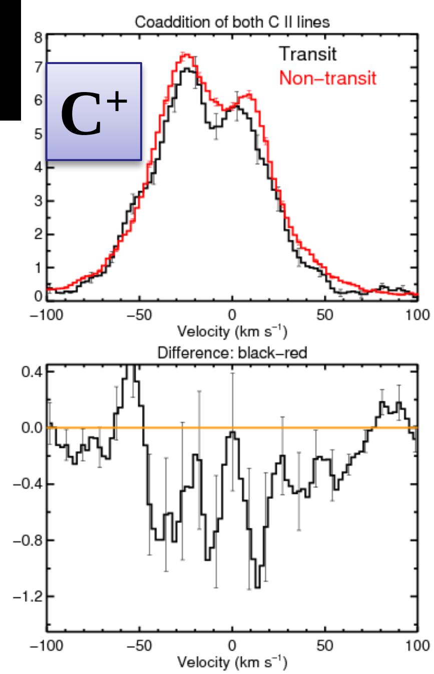
• 2500 IGM absorption systems
- **•300 OVI systems**
- **•100 CIII and SiIII systems**
- **•18 NeVIII systems**

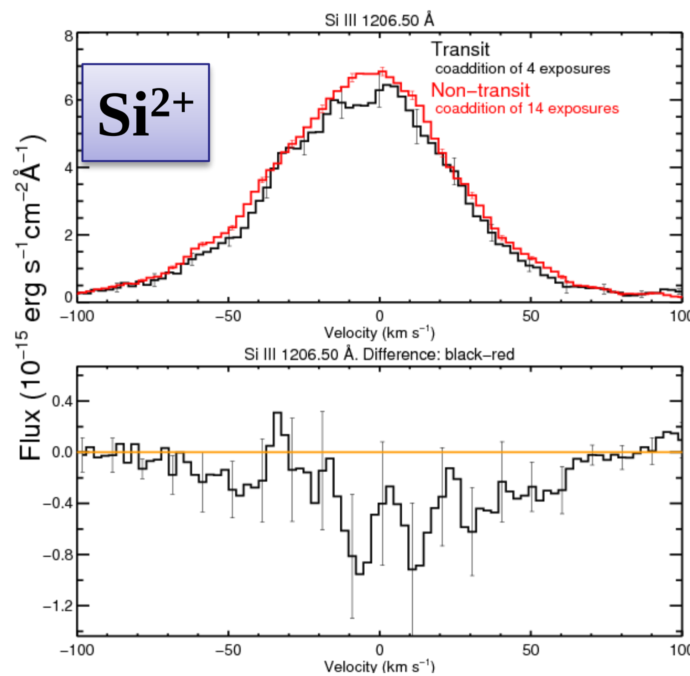
Exoplanet Atmospheres: Gas Giants

David Sing's Talk

- **1.5 % Geometric Occultation**
- **7.8 ± 1.3% CII 1335Å Occultation**
- **8.2 ± 1.4% SiIII 1206Å Occultation**
- **(0.2 ± 1.4 % SiIV 1394Å Occultation)**

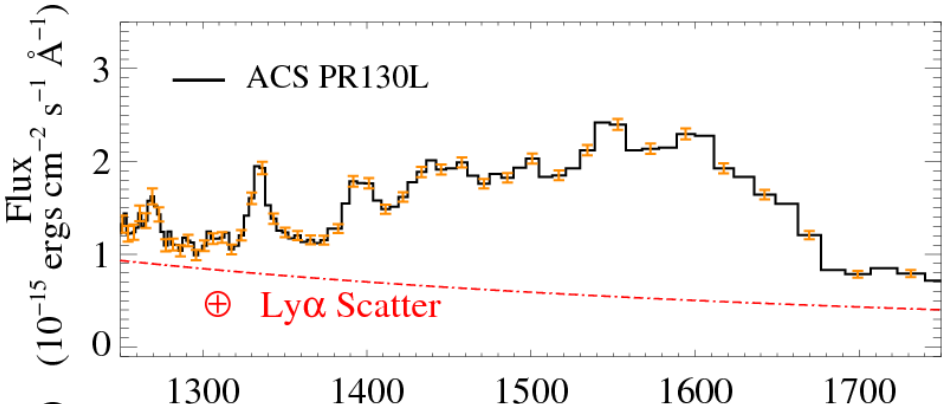
$$\frac{\dot{M}_{\rm total}}{M_{\rm planet}} = 2.0 \times 10^{-12}\,{\rm yr}^{-1}.$$





Linsky et al. 2010

Protoplanetary Disks

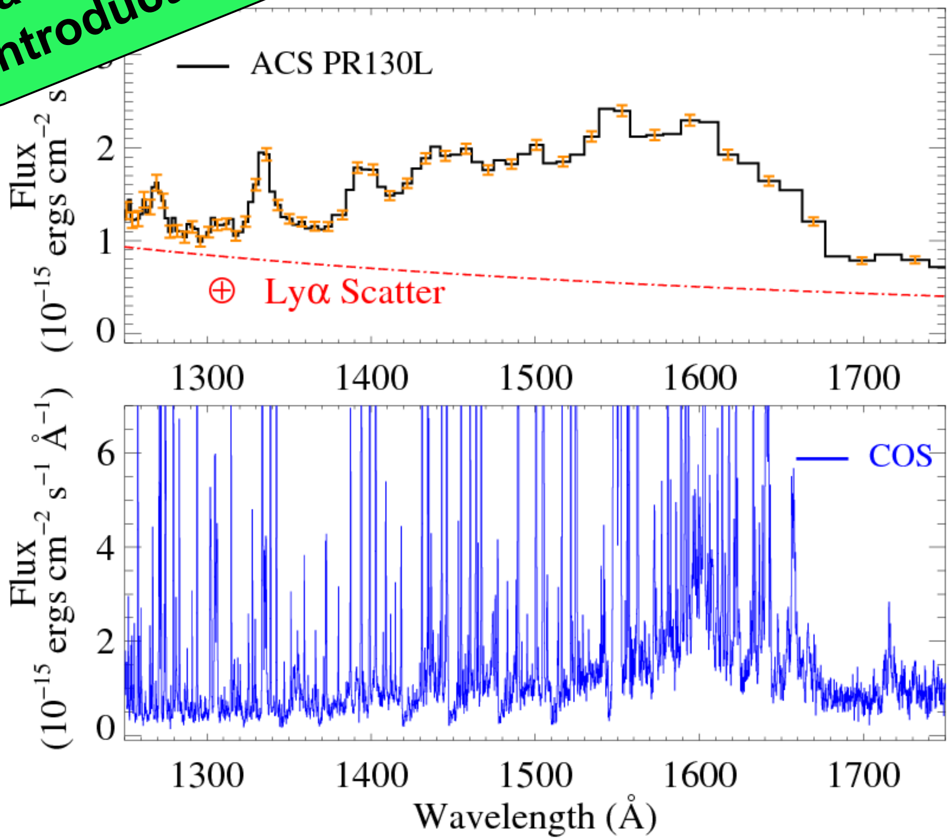


Wavelength (Å)

Typical (t < 10 Myr) protoplanetary disk

Ana I. Gomez de Castro's Introduction

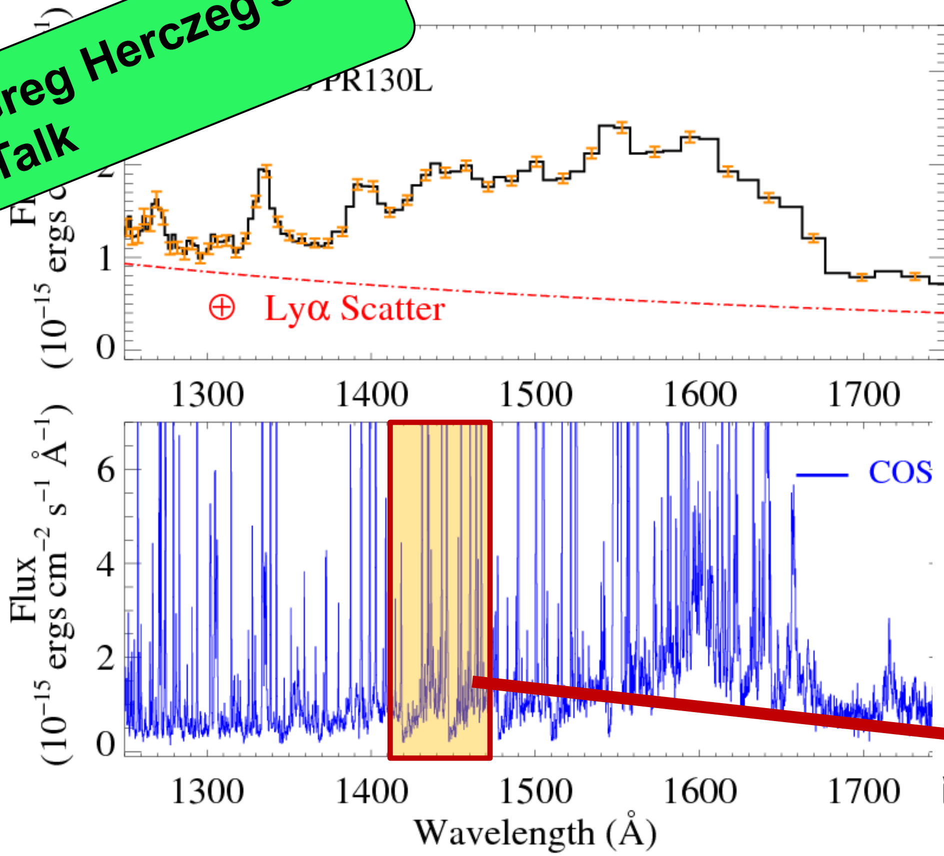
Protoplanetary Disks



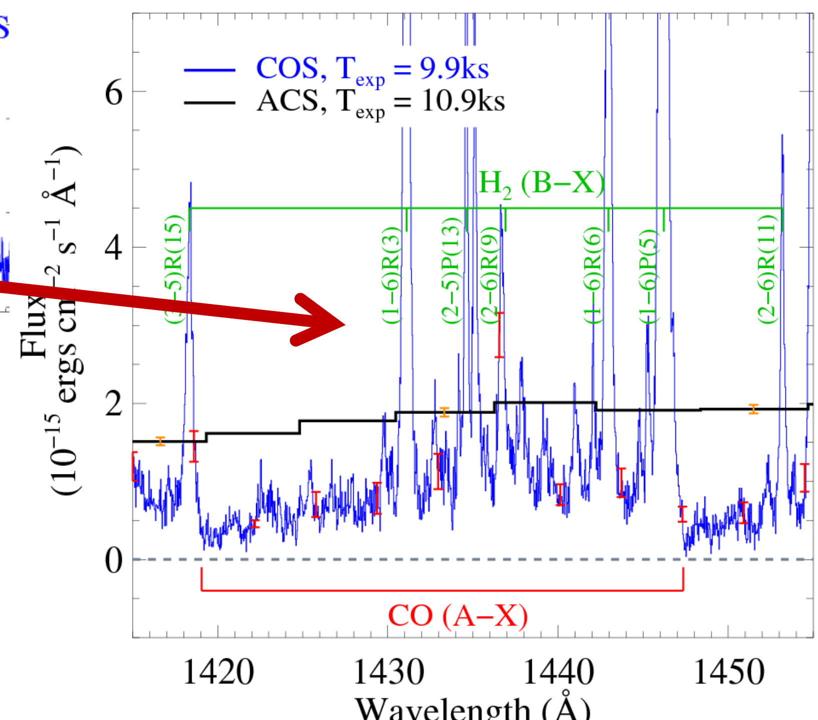
Typical (t < 10 Myr) protoplanetary disk

Molecules in Protoplanetary Disks: Ultraviolet Emission from the Inner Disk

Greg Herczeg's Talk

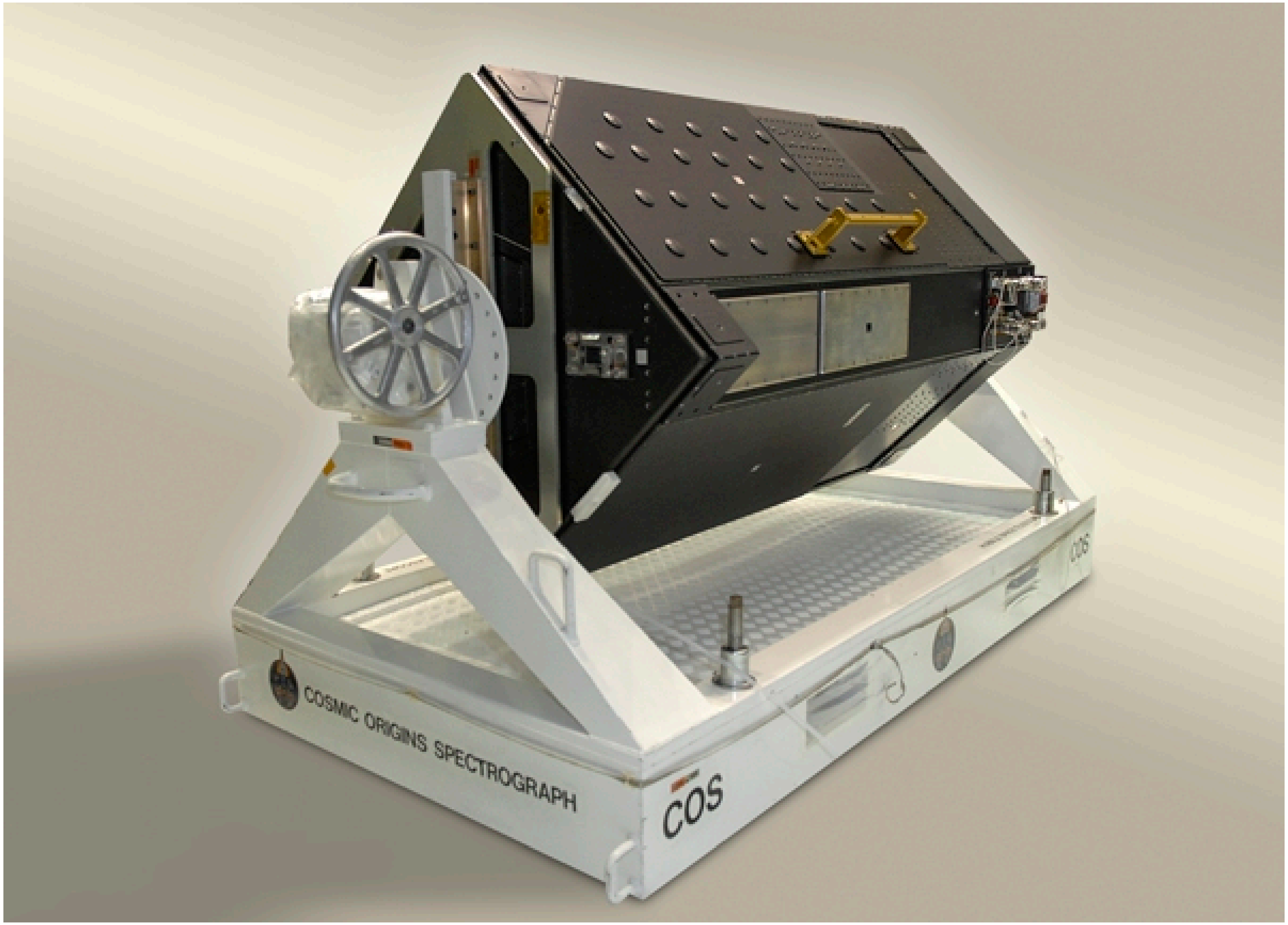


Ardila et al. (ApJ – 2013)
France et al. (ApJ – 2010)
France et al. (ApJ - 2011a,b)
France et al. (ApJ - 2012a,b)
France et al. (ApJ – 2013 submitted)
Ingleby et al. (ApJ – 2011)
McJunkin, France et al. (ApJ – 2013a,b)
Schindhelm, France et al. (ApJ/L – 2012a,b)
Schneider et al. (A&A – 2013 in prep)
Woitke et al. (A&A - 2011)

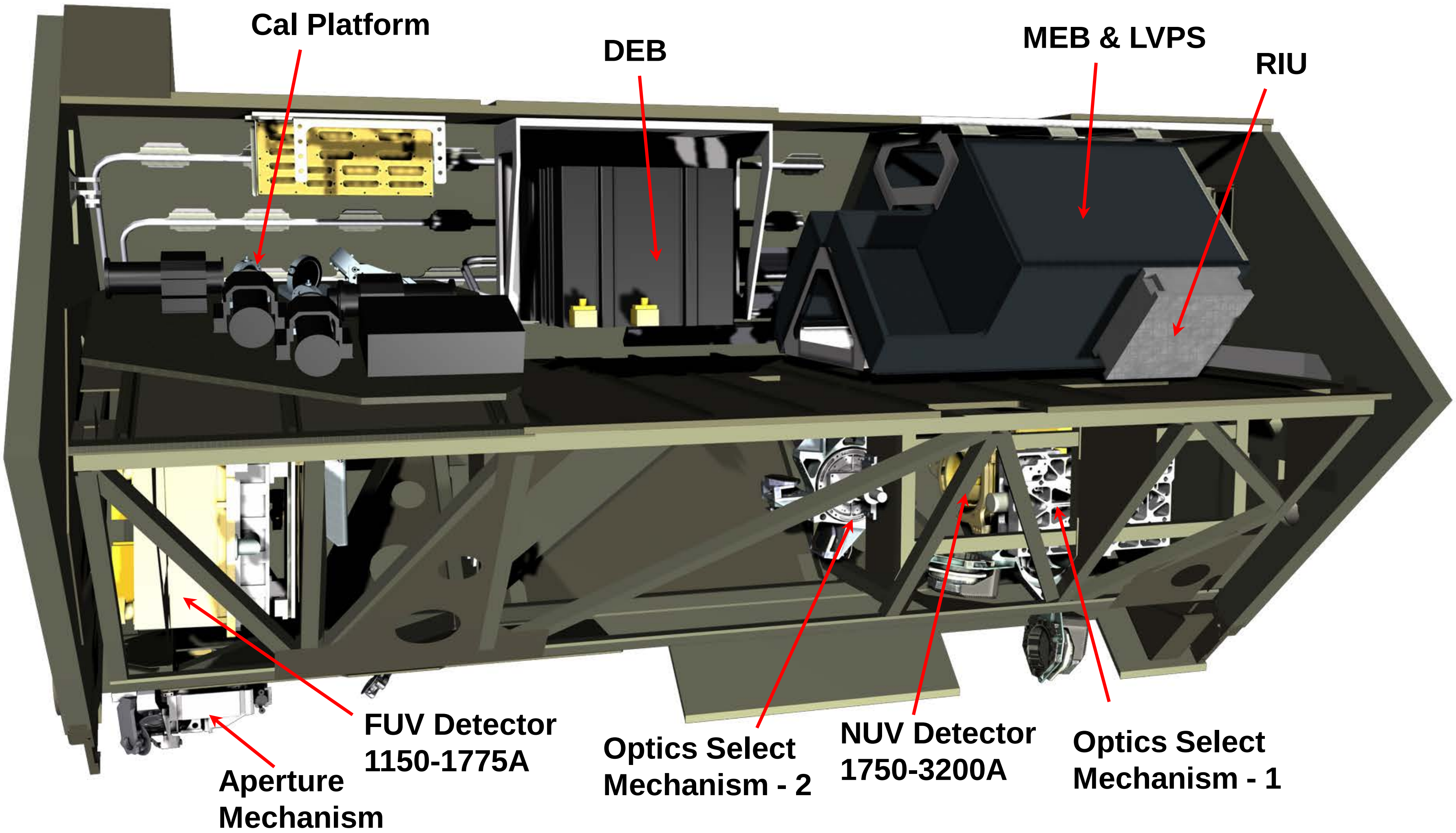


A wealth of resolved H_2 and CO emission and absorption features

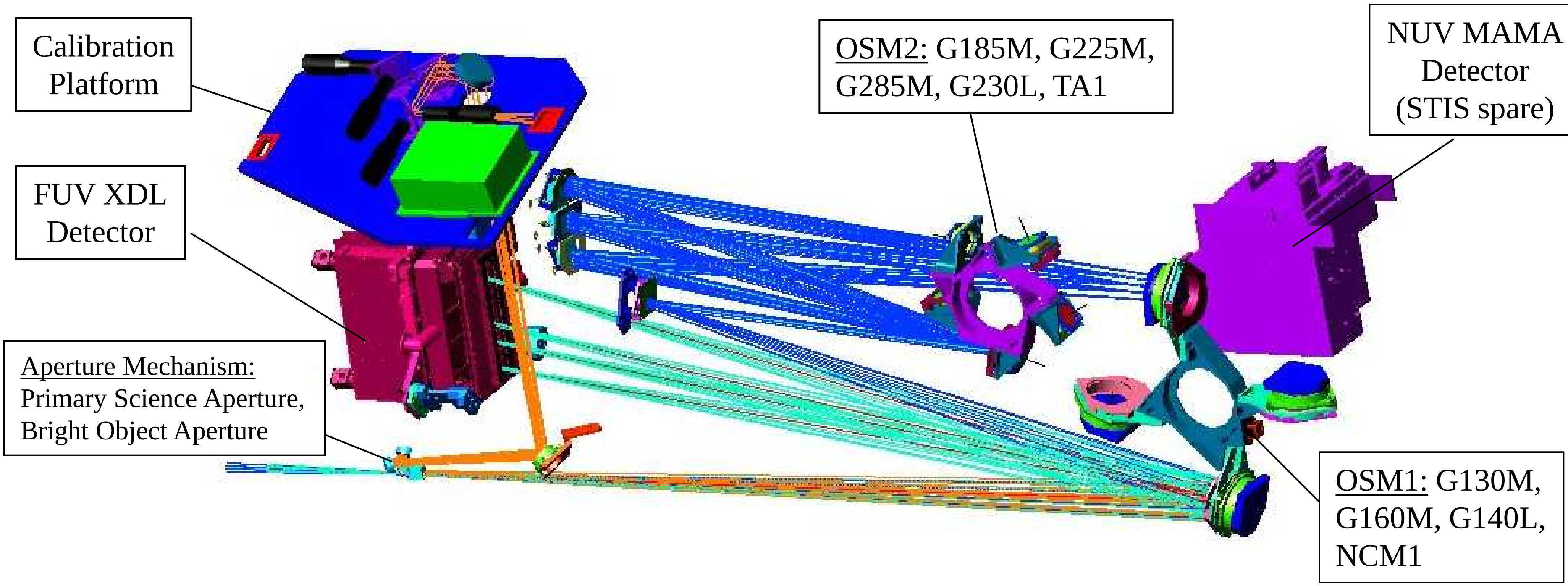
Cosmic Origins Spectrograph



COS Instrument



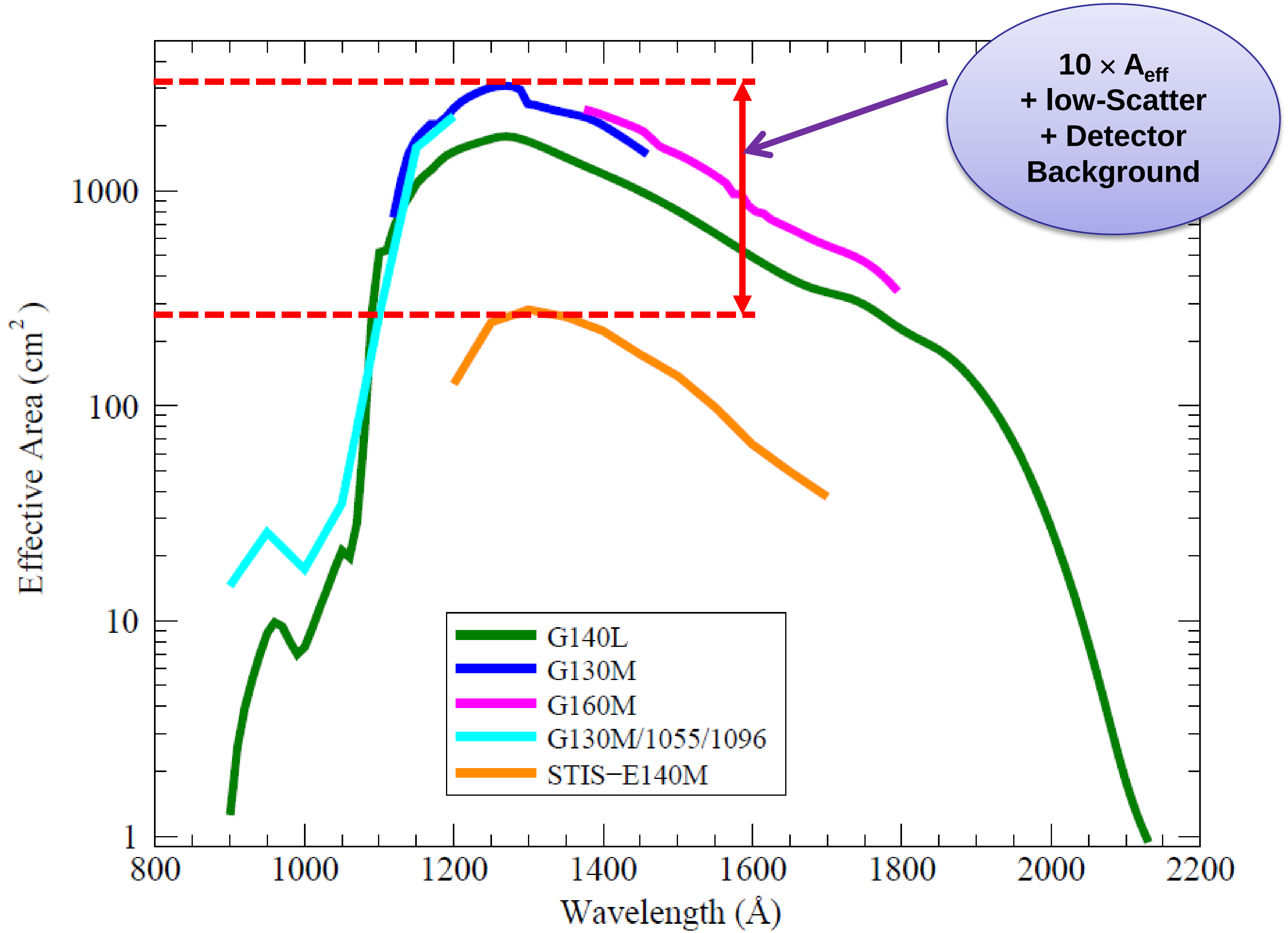
COS Optical Subsystem



Optical bench (not shown): re-use of GHRS bench

- COS has 2 channels to provide low and medium resolution UV spectroscopy
  - FUV: 800-1775Å, NUV: 1700-3200Å
- FUV gratings: G130M, G160M, G140L
- NUV gratings: G185M, G225M, G285M, G230L
  - M gratings have spectral resolution of $R \sim (17 – 20) \times 10^3$

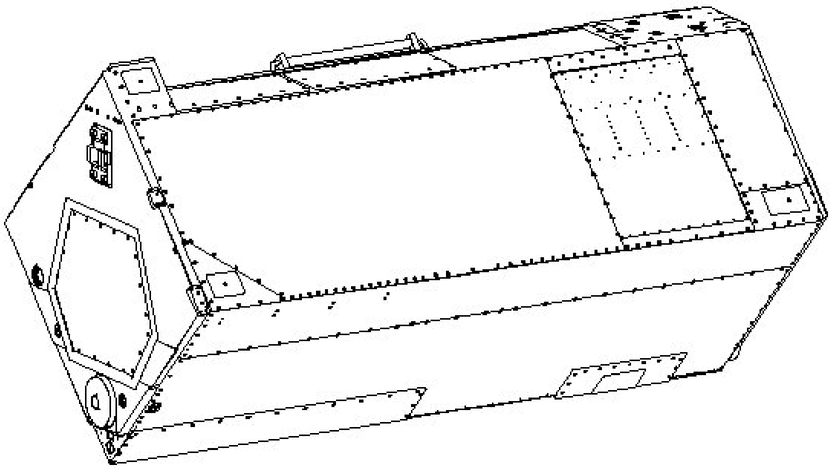
COS Optical Subsystem



COS Optical Bench & Enclosure

- **Original GHRS Optical Bench** was modified and refurbished
- The graphite epoxy material for the structural members and laminates that were added to the original GHRS bench are identical to those found in COSTAR and STIS

- Graphite epoxy honeycomb panels (aluminum honeycomb core and graphite epoxy face sheets), tubes, and sheet



Cosmic Origins Spectrograph

Initial Testing & Assembly

Cosmic Origins Spectrograph

- Square tank facilities for component-level testing

Cosmic Origins Spectrograph

- CASA FUV/EUV Optics Test Facility,
  11’ diameter, 14’ long

Cosmic Origins Spectrograph

- CASA FUV/EUV Optics Test Facility

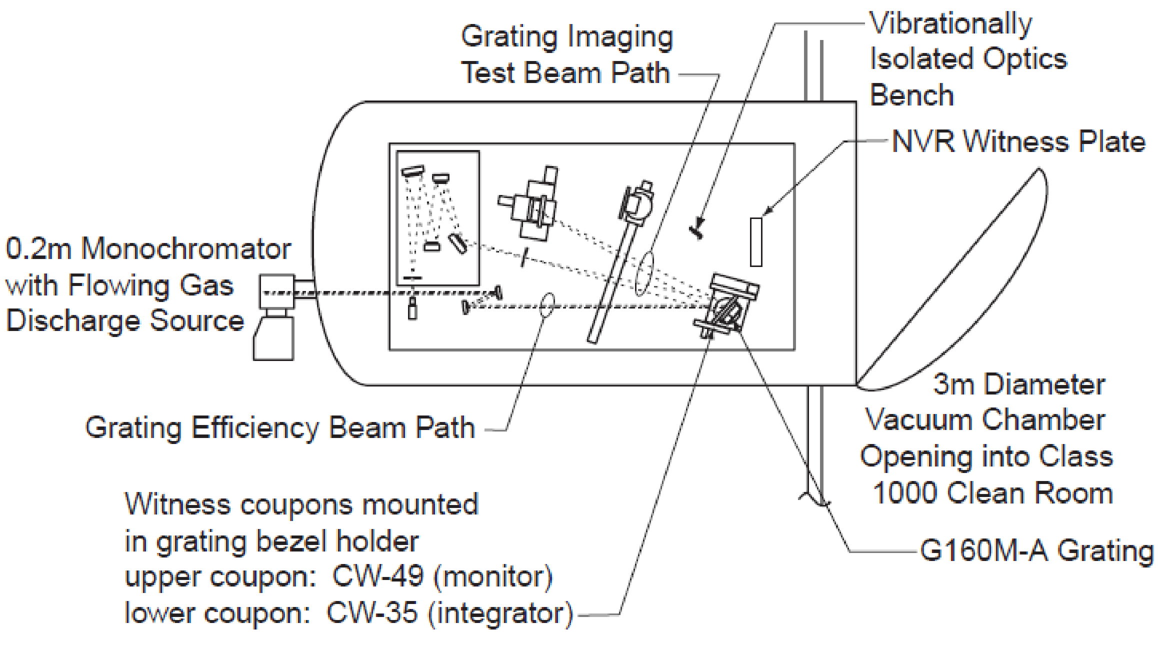
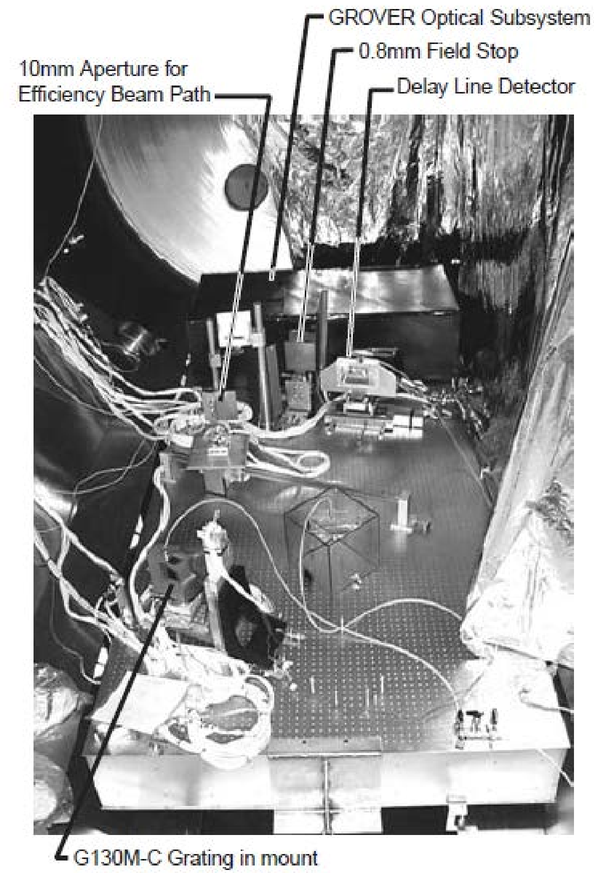
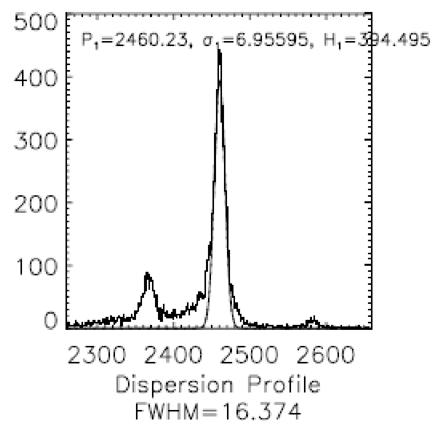


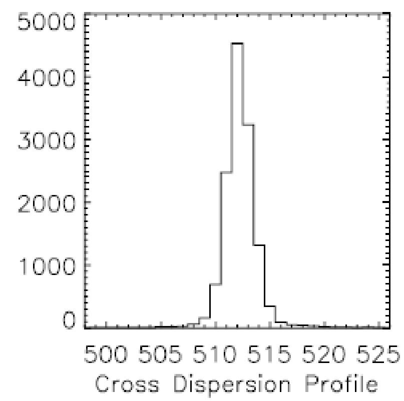
Figure 1: Optics Test Facility

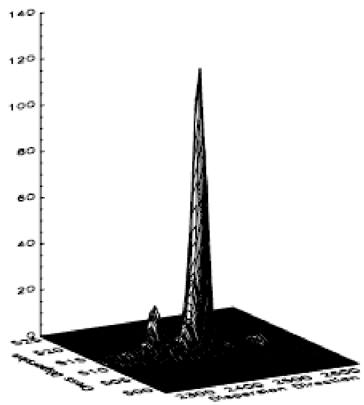


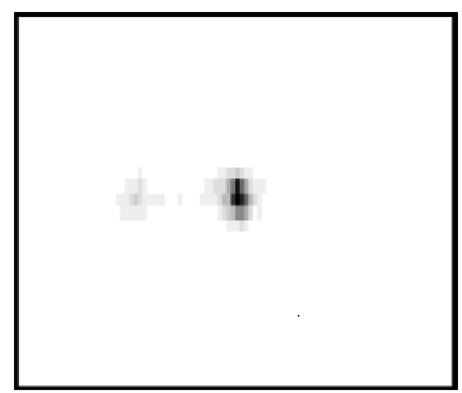
Cosmic Origins Spectrograph

- CASA FUV/EUV Optics Test Facility









System Level Test Results

COS
Thermal Balance and Thermal Vacuum

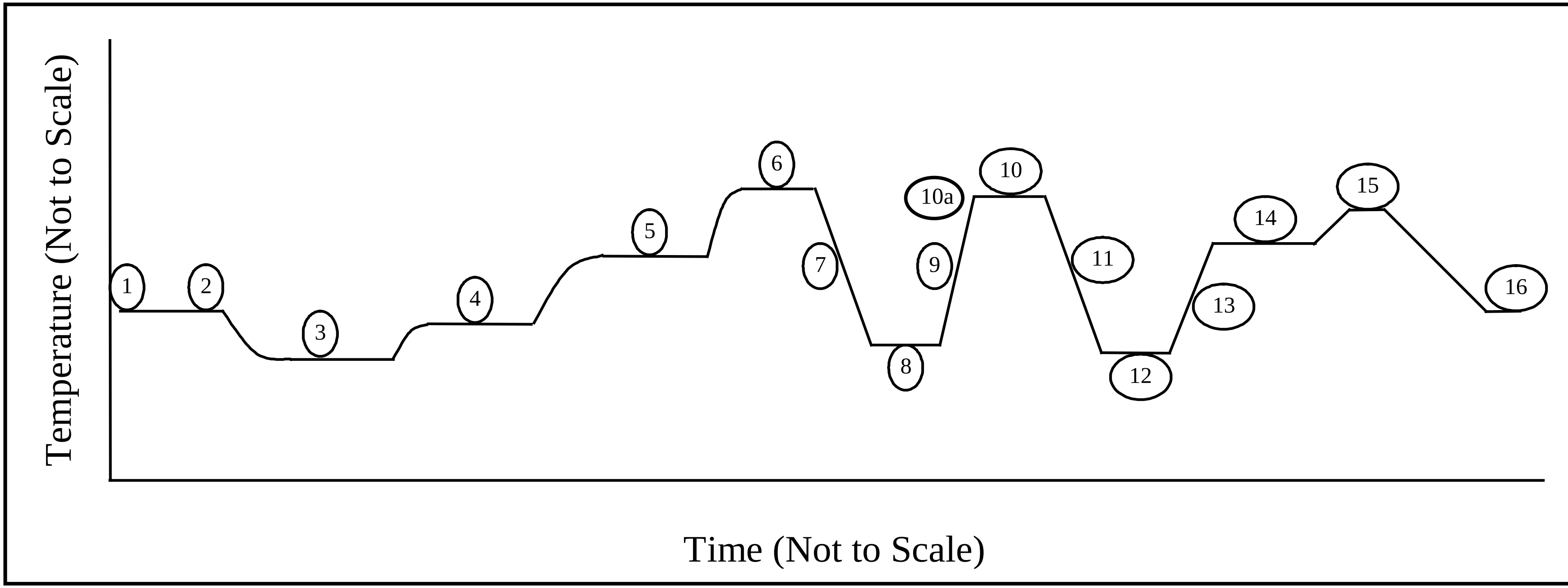
T al

Objectives and Goals

- Objectives
  - Demonstrate COS robustness by functional testing the flight system in thermal environments in excess of flight predictions
  - Verify alignment and performance of the FUV and NUV science channels
  - Verify that COS meets the HST outgassing rate (4.3E-13 $g/cm^2/sec$ at +30C/–20C)

- Goals of thermal balance test:
  - Demonstrate operation of the COS thermal control systems
  - Validate and correlate the COS thermal math model (TMM)

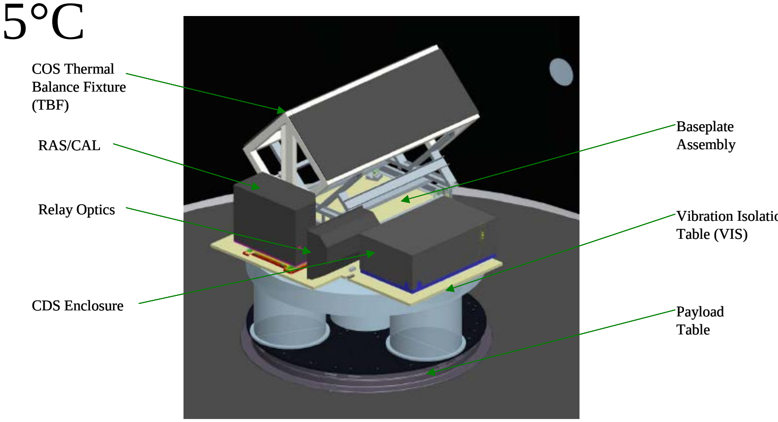
COS Thermal Vacuum Test 2006 Summary

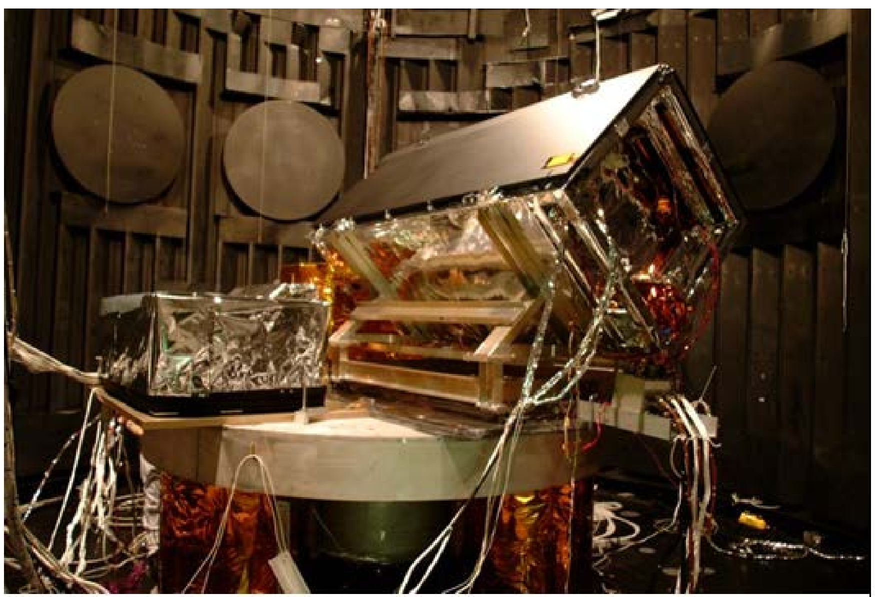


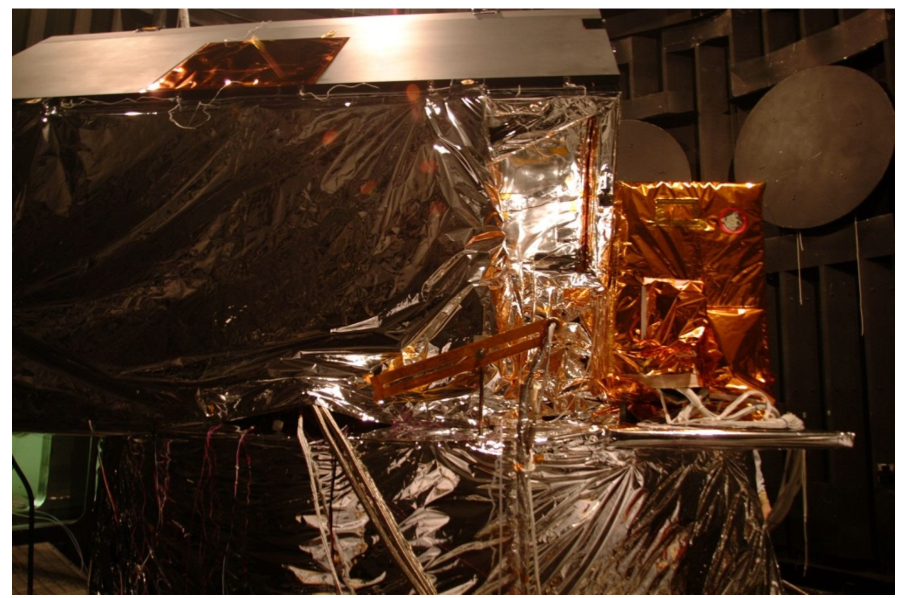
ID	Test Activity	Begin (Eastern)	ID	Test Activity	Begin (Eastern)
1	Chamber Pump Down	11/11/06 14:25	10a	Hot Thermal Balance #2, Side 1;Transition to Hot TV	11/23/06 21:50
2	Alignment Check	11/14/06 8:30	10	Hot Thermal Vac Cycle #2, COS Functional Test	11/24/06 2:00
3	Cold Safe Thermal Balance	11/16/06 8:15	11	Transition to Cold Thermal Vacuum	11/25/06 2:00
4	Cold Operate Thermal Balance	11/17/06 15:20	12	Cold Thermal Vac Cycle #2, COS Functional Test and Side 1 Cold Start	11/25/06 14:00
5	Hot Operate Thermal Balance #1, Side 2	11/18/06 14:00	13	Transition to Calibration Plateau	11/26/06 10:55
6	Hot Thermal Vac Cycle #1, COS Functional Test	11/19/06 13:00	14a	Pre-Cal Alignment Check	11/27/06 8:15
7	Transition to Cold Thermal Vacuum	11/21/06 8:30	14	Science Calibration	11/28/06 0:05
8	Cold Thermal Vac Cycle #1, COS Functional Test and Side 2 Cold Start	11/21/06 20:00	15	Contamination Certification	12/8/06 1:07
9	Transition to Hot Operate Thermal Balance	11/22/06 21:30	16	Return to Ambient and Chamber Break	12/8/06 20:42

2006 Thermal Balance Test Results

- All temperature data points correlated to within 5°C
  - Success criterion was defined to be within 5°C
  - Fewer than 7% were more than 3°C different
- All subassemblies remained within limits
- All heaters met their performance requirements







COS Power Dissipation
Cold Safe to Cold Op Transition

- Waiver IN0090-W-060D submitted to capture COS cold safe power

Power Mode	Dissipation [W]	Allowable Dissipation [W]
Peak	232	280
Max Sustained	232	280
Max Orbital Average	232	279
Cold Safe	81	76

Peak Power Summary

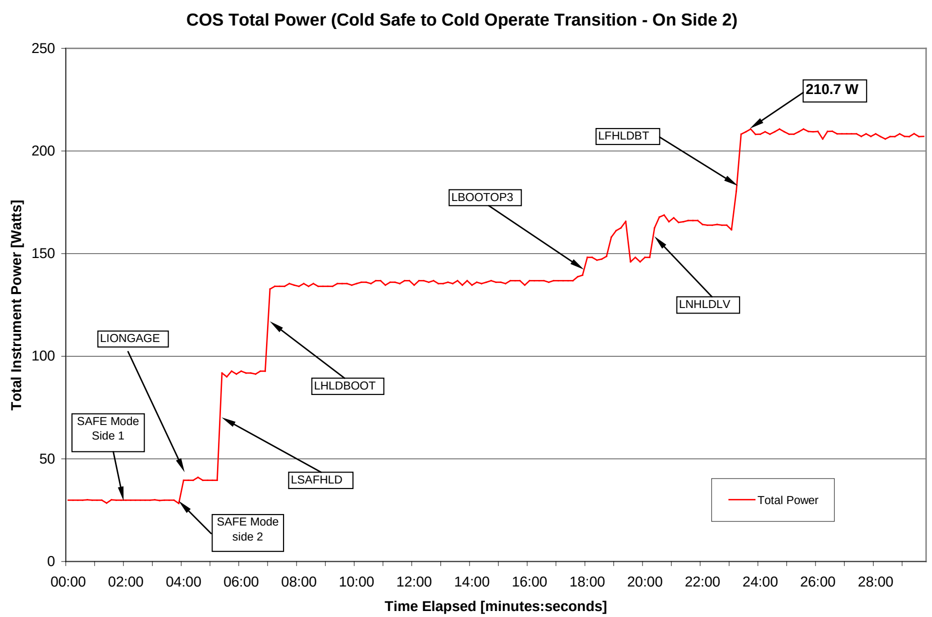
Measured power: 211 W

Mechanism op: 14 W

Calibration adjust: 1 W

RIUs: 6 W

Total: 232 W



Science Calibration

Detector Calibration

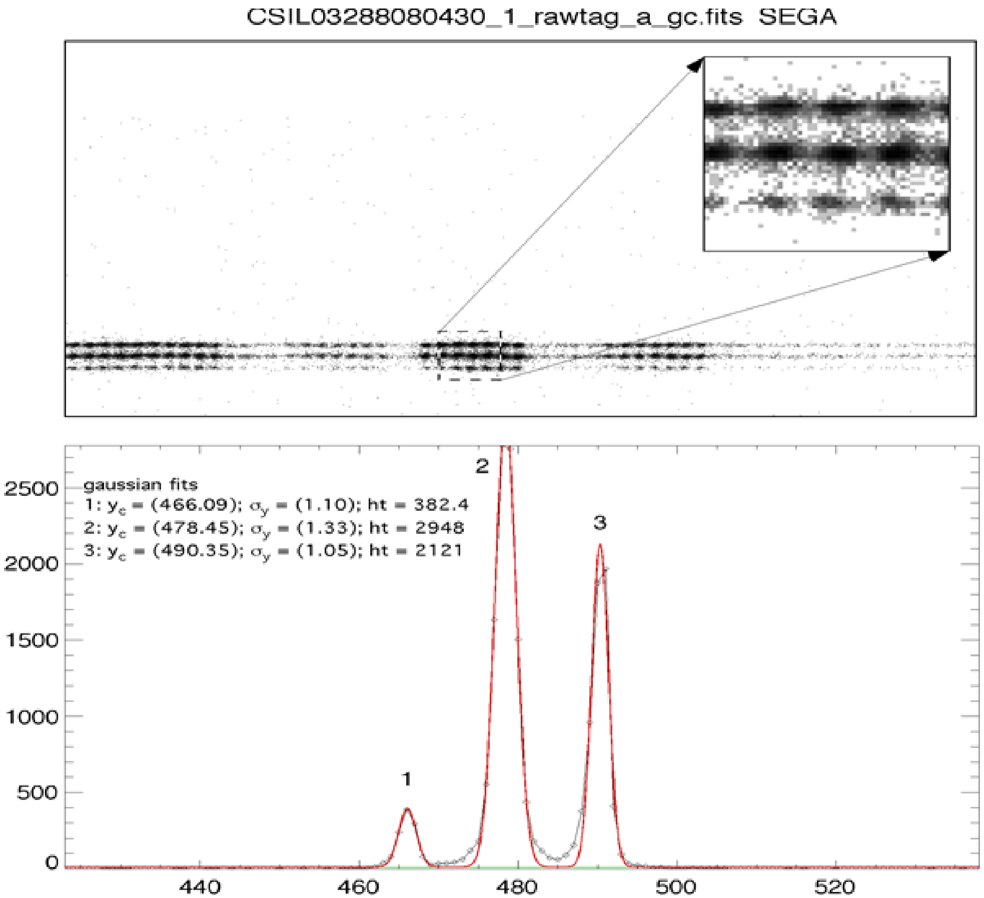
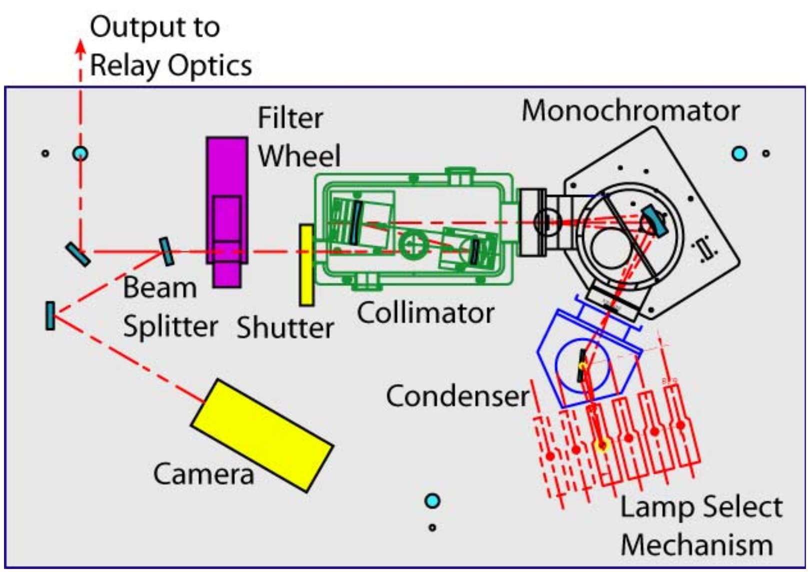
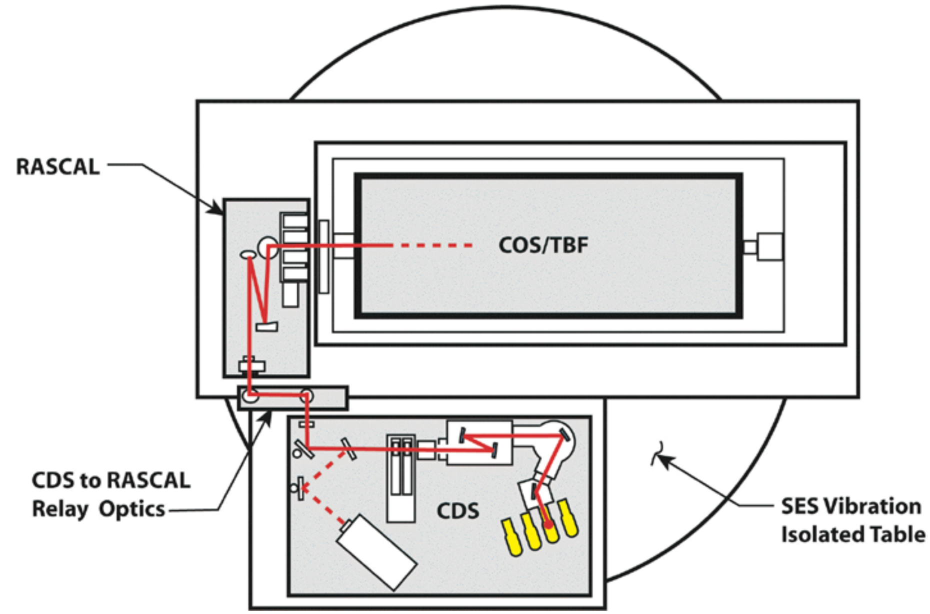


Figure 2: The spectrum of a PtNe lamp fed through a 3-pinhole aperture is used to verify the spatial resolution performance of COS in pre-launch thermal vacuum testing.

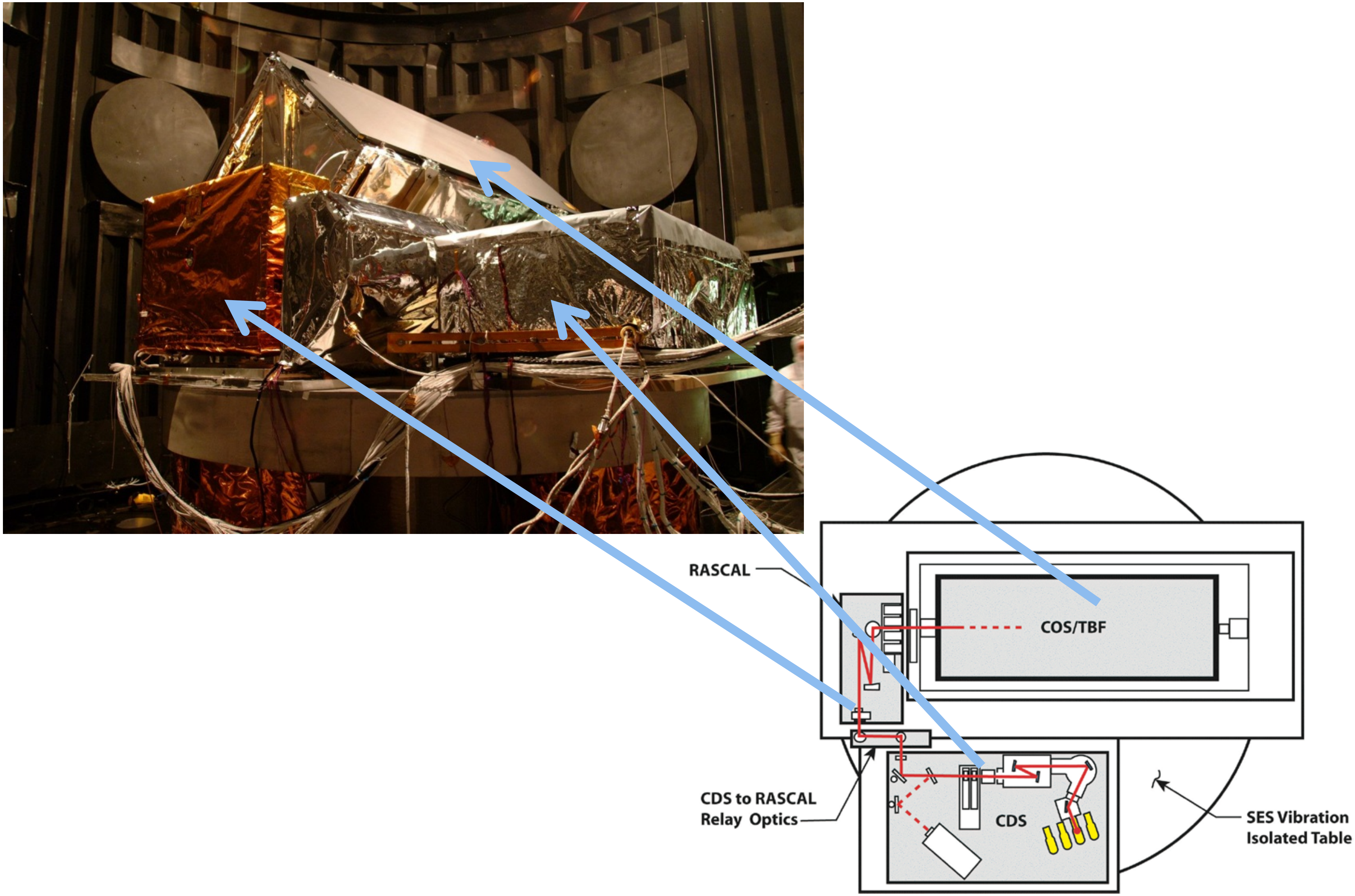
Calibration Delivery System - 2006

- TV was moved from BATC to GSFC in 2006.
- The larger vacuum chamber at Goddard required a new vacuum-compatible CDS.
- The new CDS was mounted on the same table as RASCAL and COS (improved alignment).



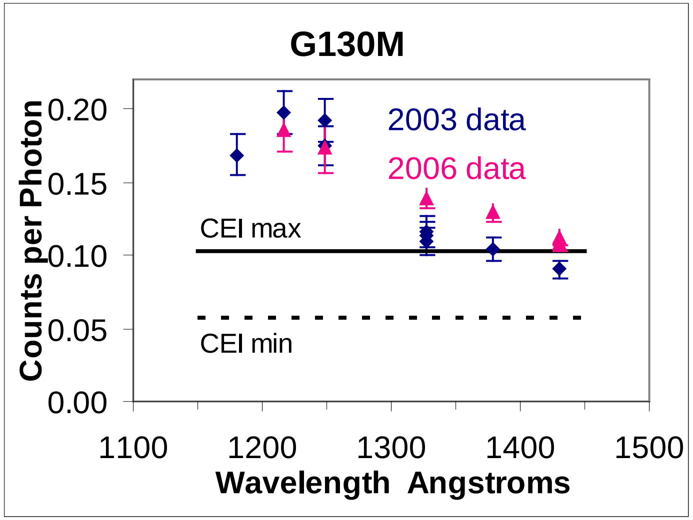


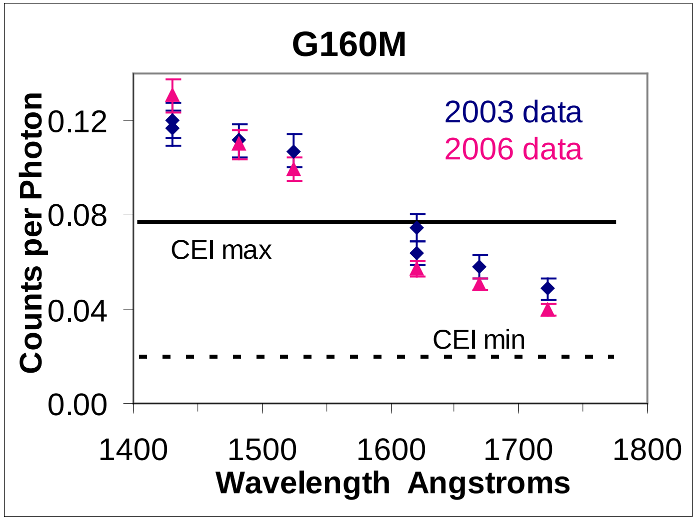
Calibration Delivery System - 2006

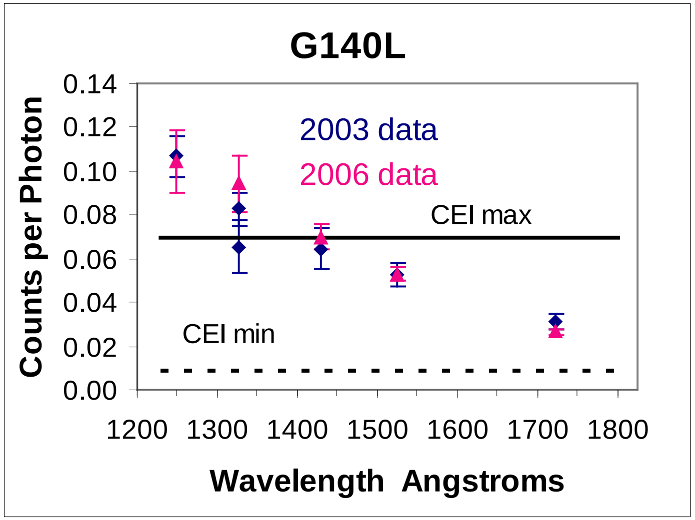


Spectrograph Sensitivity

Thermal Vacuum Sensitivity Calibration Results: COS FUV Channels

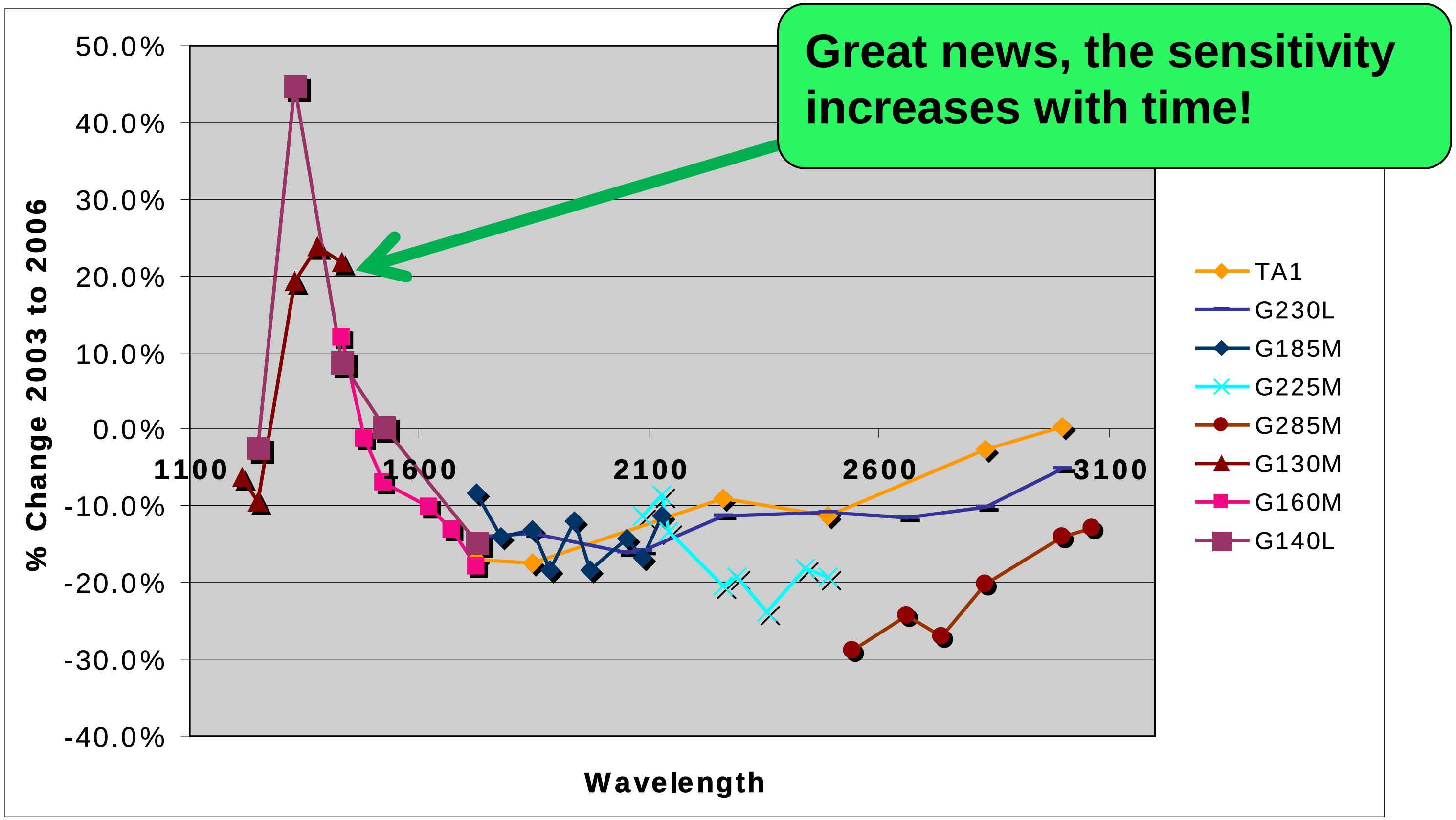






- All FUV channels meet CEI sensitivity requirements.

Apparent COS Performance Changes from 2003 to 2006



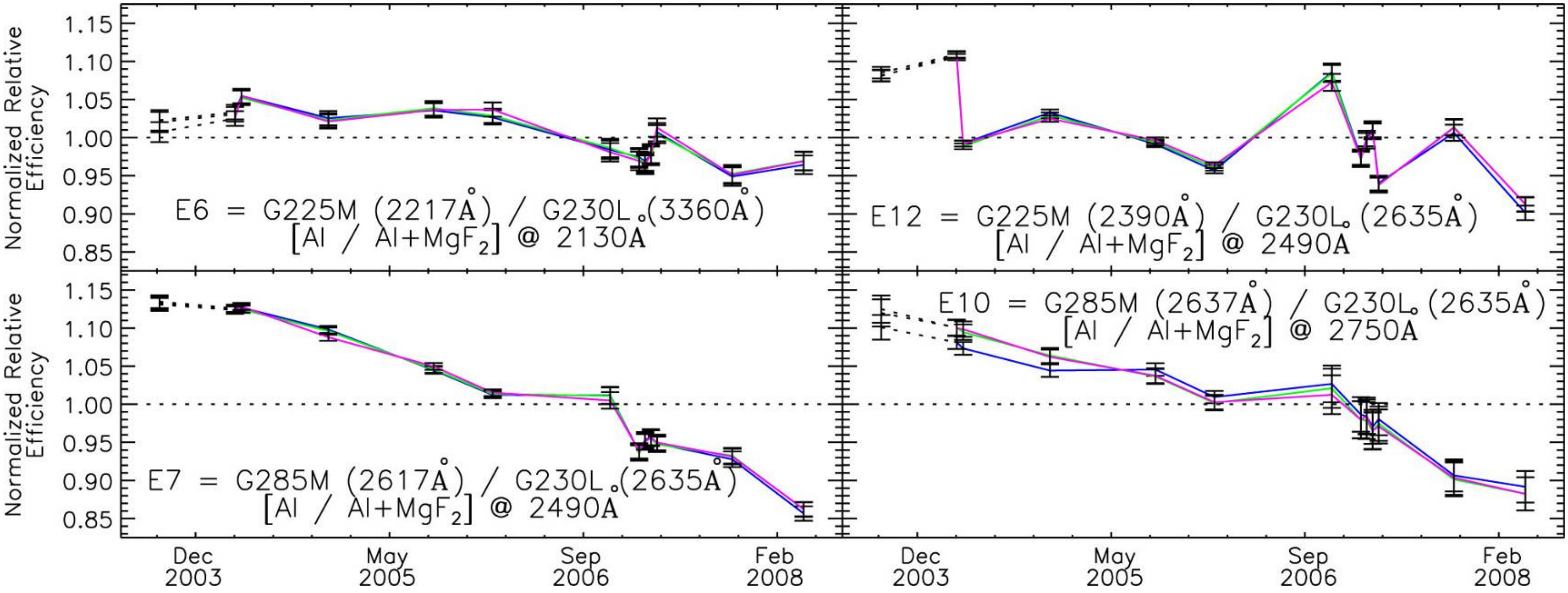
- G130M & G140L, changes in 2003/2006 measurements are the **result of changes in CDS polarization content** and do not reflect changes in COS performance.

- G225M and G285M changes are consistent a combined polarization effect plus real loss.

NUV Grating Monitoring

- G185M showed no change in performance relative to G230L (both coated aluminum gratings)

- G225M and G285M (bare aluminum) showed a consistent decrease with time.



Current Best Explanation for Changes in Performance

- What is *not* causing the change in performance
  - ***Not* hydrocarbon contamination**
    - Conventional hydrocarbon contamination would be apparent in witness coupon reflectivity – no change.
    - Resonance effect of thin layer would not impact reflectivity, but no significant buildup apparent in XPS testing of coupons or spare gratings
  - ***Not* metal migration in reflective coating**
    - No impact on reflectivity (witness coupons)
    - No Au apparent in XPS testing
  - ***Not* test setup polarization bias**
    - Direct testing of GSE showed no polarization at $\lambda > 2200$Å
- <u>**A thin oxide layer (5-10nm)**</u> will impact sensitivity to polarized light as a function of wavelength in *high ruling density* gratings while not changing witness coupon reflectivity - *Modeled performance changes are consistent with observed performance of G225M and G285M*

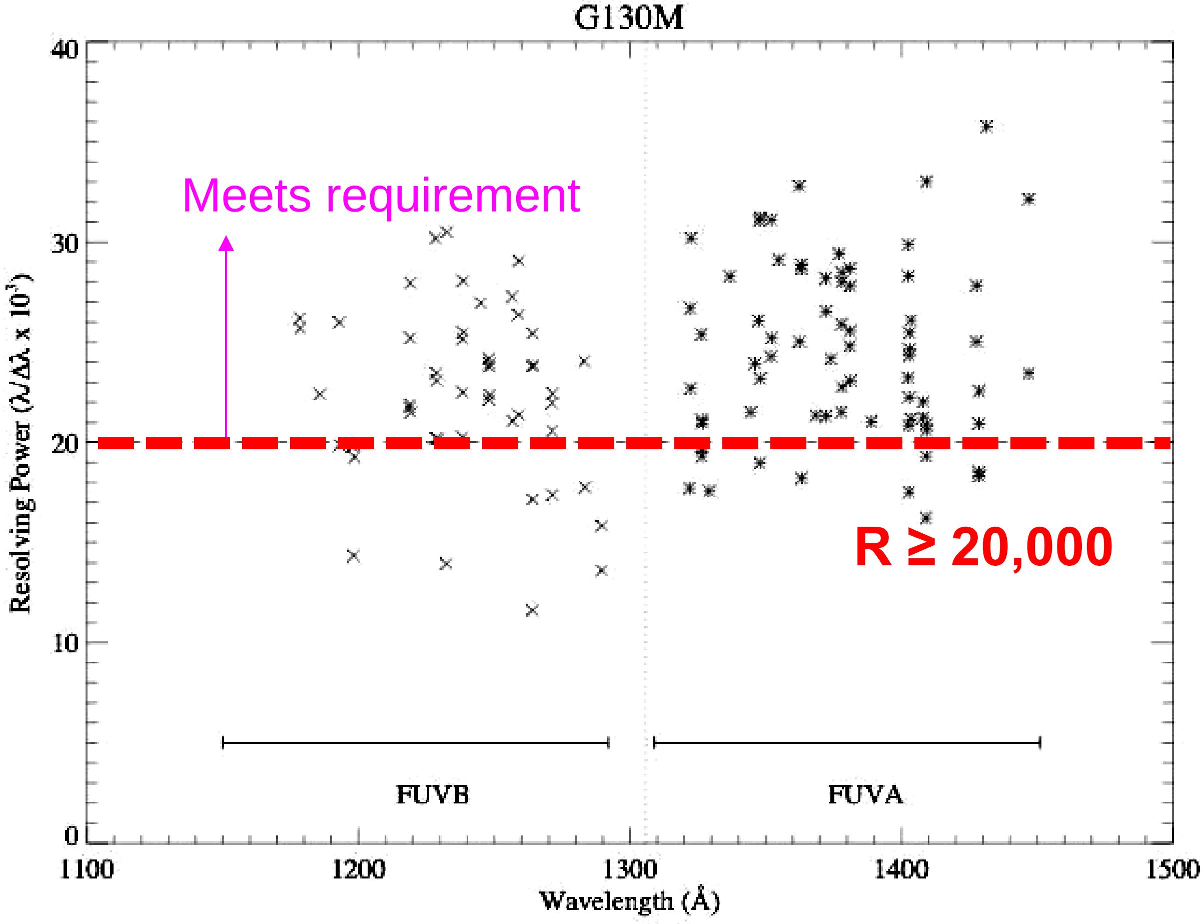
Alignment Verification

Alignment Overview

- COS alignment verified
  - Thermal Vacuum 2006
    - Stimulus (RASCAL) aligned to cubes on COS optical bench
      - COS installed in Thermal Balance Fixture
    - Thermal Balance fixture had alignment stability issues
      - When chamber went cold, structure shrunk
        - » Same issue in 2003 testing
      - Results in misalignment of stimulus relative to COS
      - Structure stabilized to 5 C
      - ~ 47 arcsec of angular motion
        - » reasonable given temperature gradient
        - » Small image quality degradation
    - Verified pre and post acoustics

Thermal Vacuum - FUV

- 2006 Thermal Vacuum Test shows FUV meets Resolution Requirement
  - G130 shown here



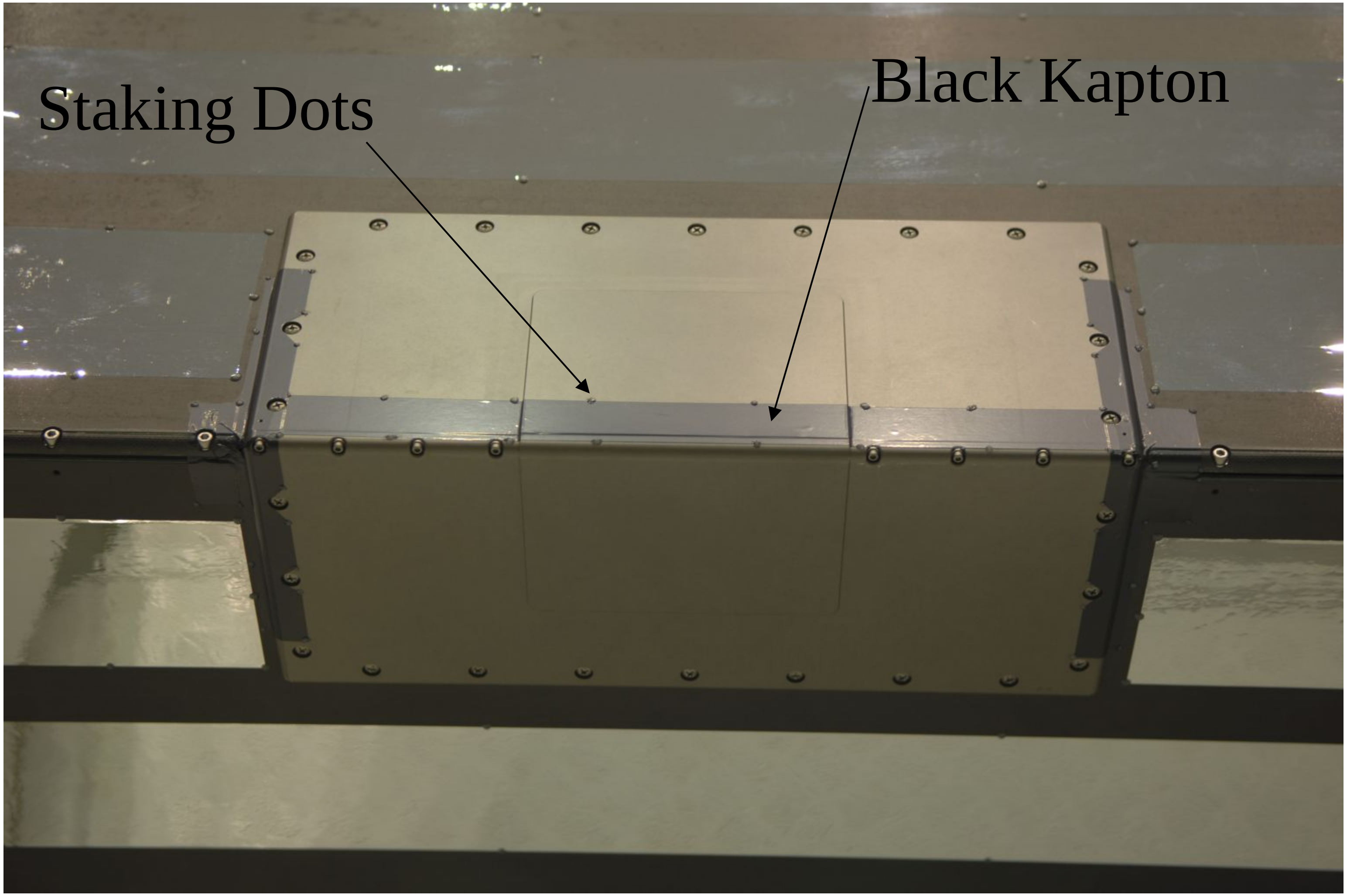
Cosmic Origins Spectrograph

Enclosure Light Leak Test

Enclosure Light Leak Test

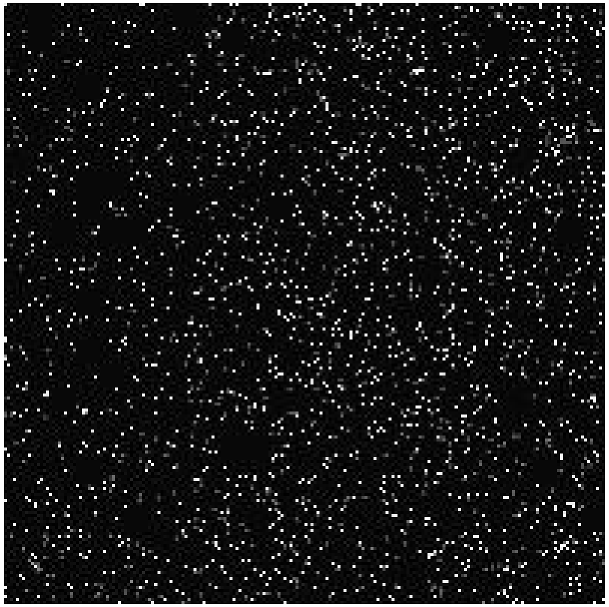
- NUV detector image during dark rate testing

Light Leak Fix



Before and After Images

Before Fix



After Fix

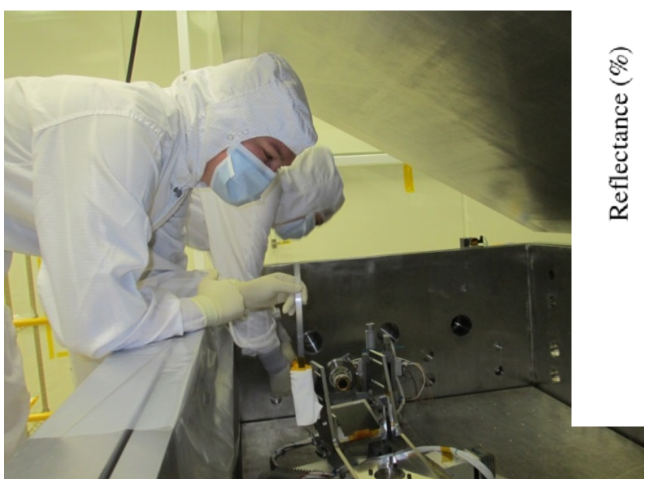
- Enclosure now light tight

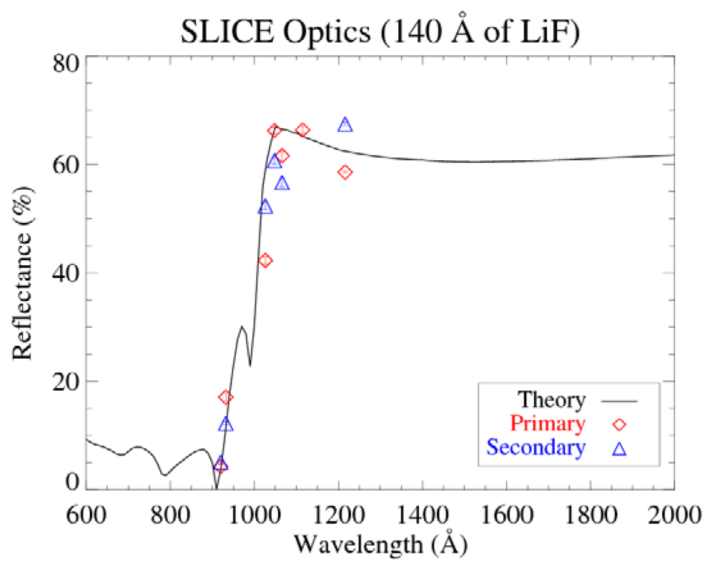
Cosmic Origins Spectrograph

Contamination

Surface Cleanliness

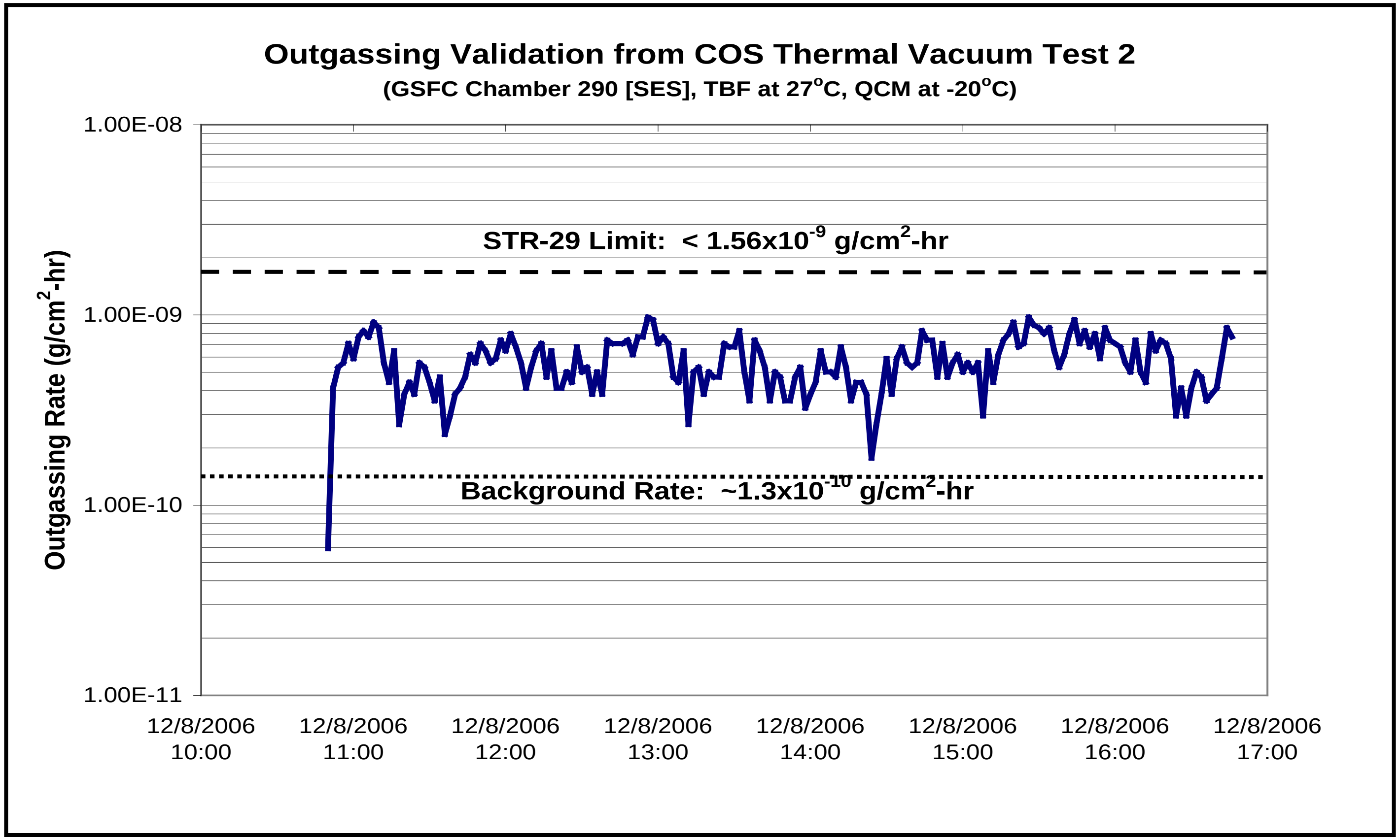
- Requirement: Level 400B per MIL-STD 1246B
- Measurement:
  - To be verified by tapelift and NVR swab sampling at KSC, just prior to ASIPE integration.
  - Preliminary tapelifts taken after Crew Fam #4 (5/4/08) indicate current cleanliness of Level 250
- Mitigation: **constant vigilance** to maintain VCHS





Outgassing Verification

- Requirement: $<1.56 \times 10^{-9}$ g/cm^2-hr condensable at -20°C
- Measured Rate: $\sim 5.8 \times 10^{-10}$ g/cm^2-hr condensable at -20°C
- Documentation: SAI-1145-COS/RLP-1 **"Validation of COS Outgassing Rate and T-Vac 2 Cleanliness Results"**



General Contamination Controls

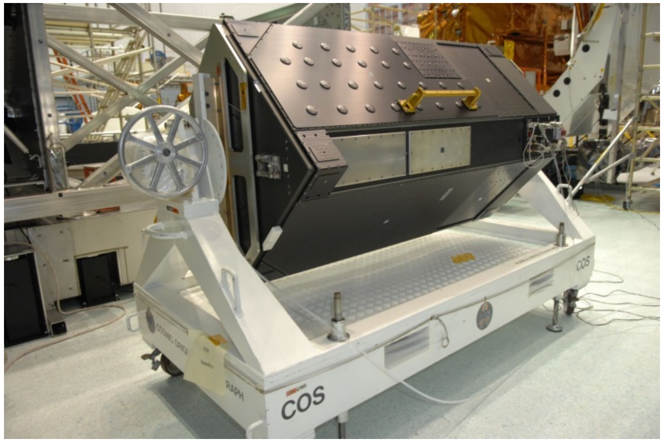
- COS may only be exposed in a Class 10,000 (FED-STD-209) or better environment

- COS remains purged whenever possible
  - GN_2 Purge disconnect not to exceed 60 minutes per 24 hours
  - Ion Pump GSE disconnect not to exceed 240 minutes per 24 hours

Transportation
(read – contamination II)

COS Shipping Configuration

- All activities controlled by GSFC Work Orders
  - Shipping and handling procedures
  - Contamination Control Plan
  - Hazardous shipping regulations
- Transportation configuration
  - COS will be double bagged
  - COS hard mounted to isolated mount in COS shipping container
  - Container strapped to floor of trailer
  - COS Grounded through shipping container to trailer chassis ground.
  - Nitrogen purge connected to COS through shipping container fittings
  - GSE padded and strapped to the wall or floor.

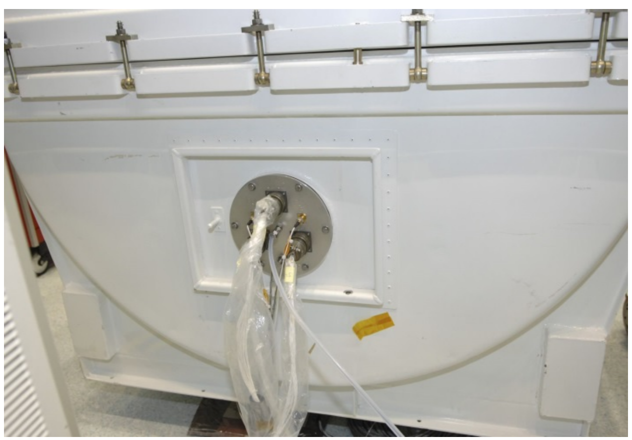


COS Double Bagged

Shipping Configuration

Instrument Closeout for shipment

COS Container Close up



COS Ion pump/Purge/Electrical Feed through

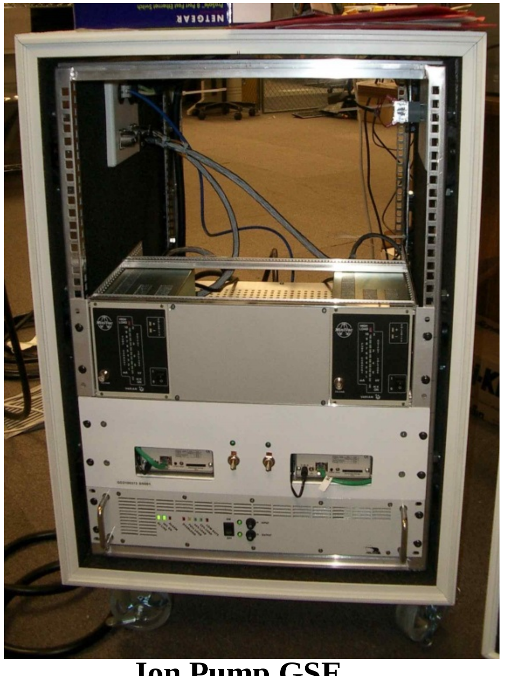
COS Ready to Ship

GN2 purge requirements for transportation

- Purge through fitting penetrating the container
- 10-15 cu ft per hour
- Supply: 8 “A” bottles manifolded together on purge cart
- Approximately an 8 day supply

- Ion pump GSE will be connected through the shipping container connector plate and connected to COS
- The GSE has a battery pack last between 8-10 hours
- The Ion Pump GSE will be checked at every stop
- The battery pack will be recharged at every fuel stop in route using a Honda 4000 generator (1 hour).

8-Bottle Purge Cart and Panel



Ion Pump GSE

Truck/Trailer

- Air ride rear suspension
- Radio communication with lead vehicle
- Two drivers, 24 hour service
  - English speaking, US citizens
- Fully enclosed
  - 12’ side doors
  - 102” wide w/ swing doors
  - Bullring tie downs in floor
  - tie down straps and dunnage supplied with trailer
- Air ride suspension
- Climatic control
- Temperature 65 to 75°F
- Humidity control: NTE 50% RH
- Honda Generator
- Van delivered one day prior to trip, instrumented, and qualified by driving preplanned course
- Trailer held after qualification at GSFC

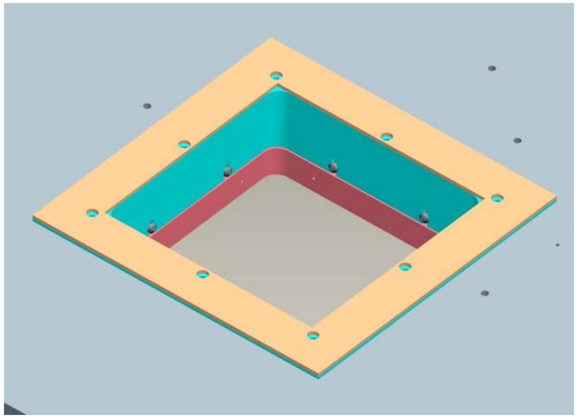
PHSF - COS Installation into ORUC ASIPE

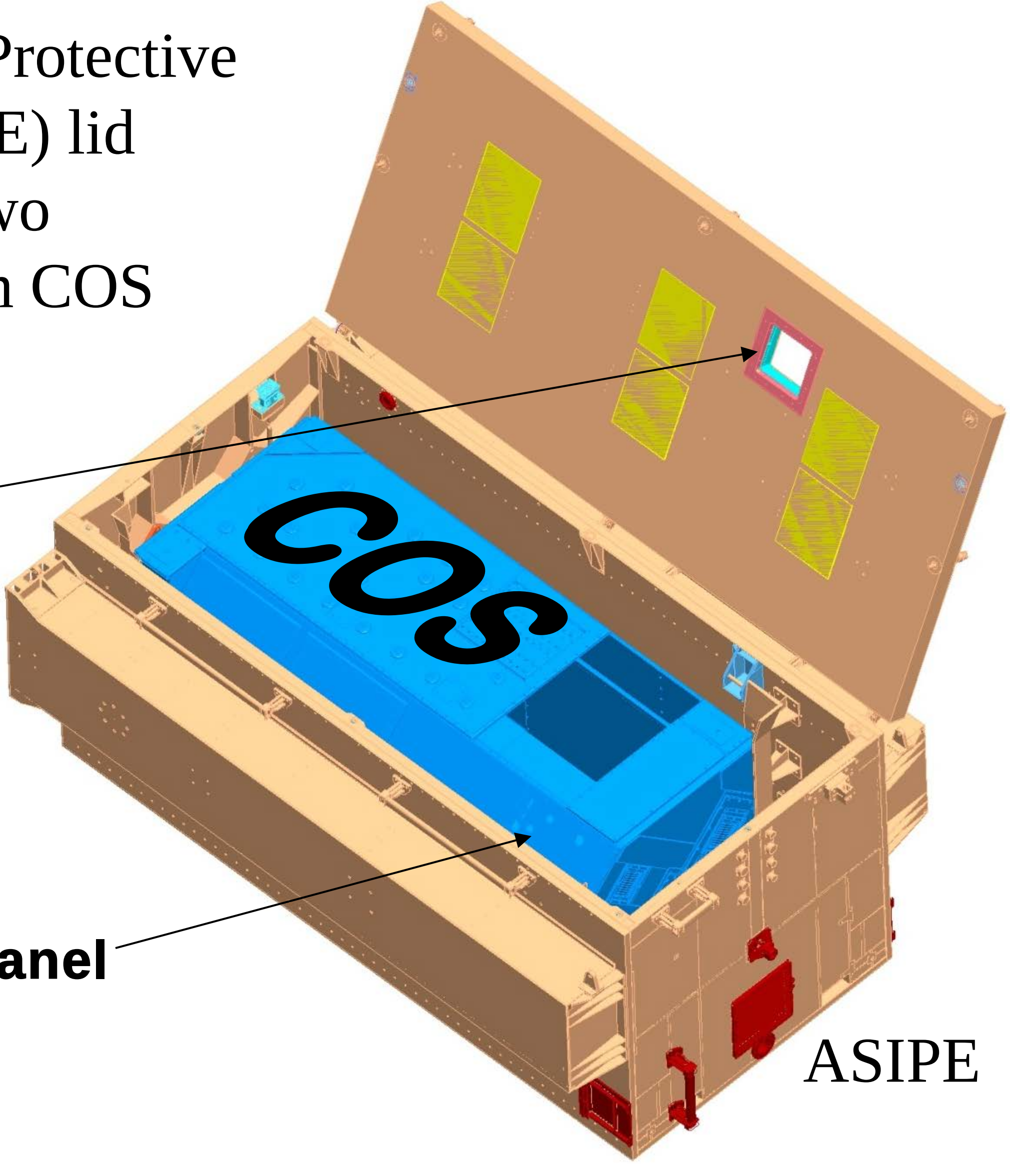
- COS Ion Pump remains powered during lift

COS Ion Pump Access

- Axial Scientific Protective Enclosure (ASIPE) lid accommodates two IPGSE lines from COS

8”x8” Access Hole

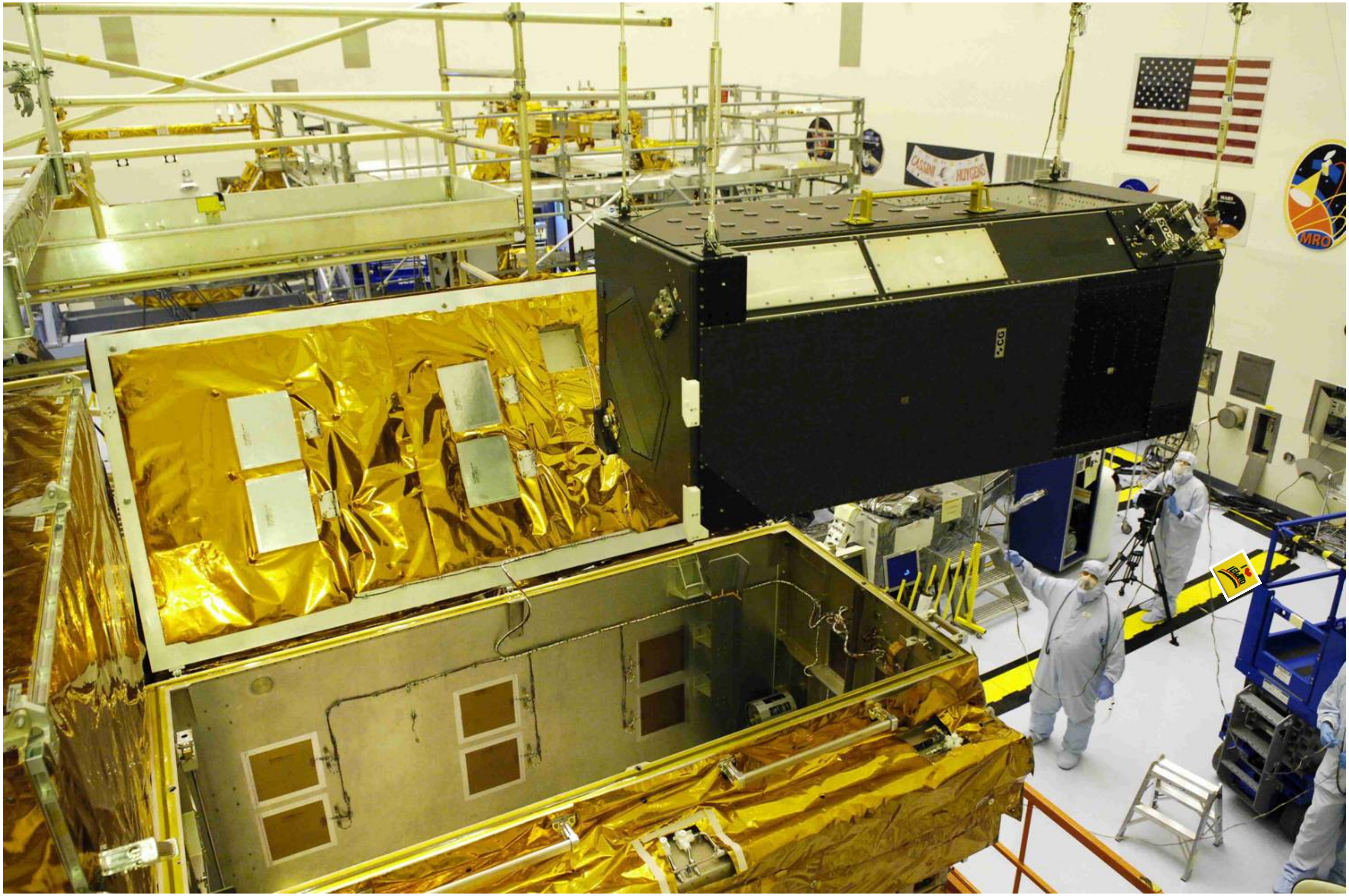




COS Connector Panel

ASIPE

COS Installation



Can IPGSE Logistics

Canister Rotation

Can IPGSE Logistics

Canister Rollout

Can IPGSE Logistics

Canister Rotation

Canister Hoist at Pad

COS Installation

Cosmic Origins Spectrograph

Cosmic Origins Spectrograph

COS Instrument and on-orbit performance:

Green et al. (2012) & Osterman et al. (2011)

The End