THE LUVOIR ULTRAVIOLET MULTI-OBJECT SPECTROGRAPH (LUMOS): INSTRUMENT OVERVIEW AND PERFORMANCE

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THE LUVOIR ULTRAVIOLET MULTI-OBJECT SPECTROGRAPH (LUMOS): INSTRUMENT OVERVIEW AND PERFORMANCE

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Jane Rigby (GSFC),
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Jason Tumlinson (STScI)

LUVOIR

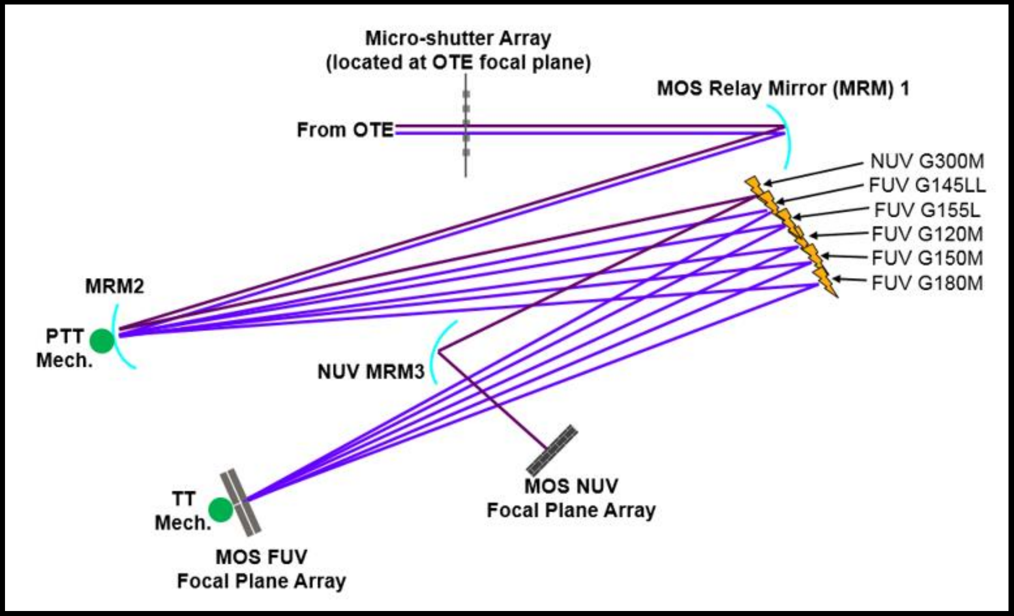
LUVOIR astrophysics science drivers

- Characterizing the gas phase of the cosmos:
  - IGM, CGM – H I, CIII, C IV, O VI, Ne VIII
  - ISM, Galaxies – Si II, Mg II, C II, C I, H, D, H_2, HD
  - PPDs – C IV, H_2, CO, H_2O, CO_2, OH, CH_4
  - Exoplanet atmospheric and exospheric markers - H I, O I, C II, Mg II, O_2, O_3, H_2
- All of these are well-traced (often best-traced) in the UV (100 – 400nm)
- CGM, galaxies, disks are often extended objects. (imaging, multi-object spec)
- QSO tomography and disks require high velocity resolution (med/high-res)
- Lyman Continuum and other low-brightness sources require large statistics (high throughput, multi-object spec)

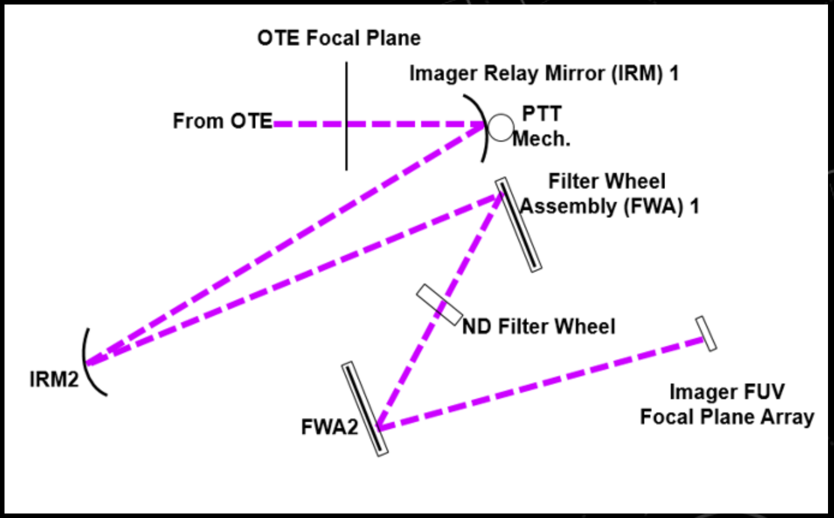
LUMOS requires multi-object, wide-field imaging spectroscopy capability with both high and low resolution modes, with sensitivity into the Lyman UV (at least to 100 nm).

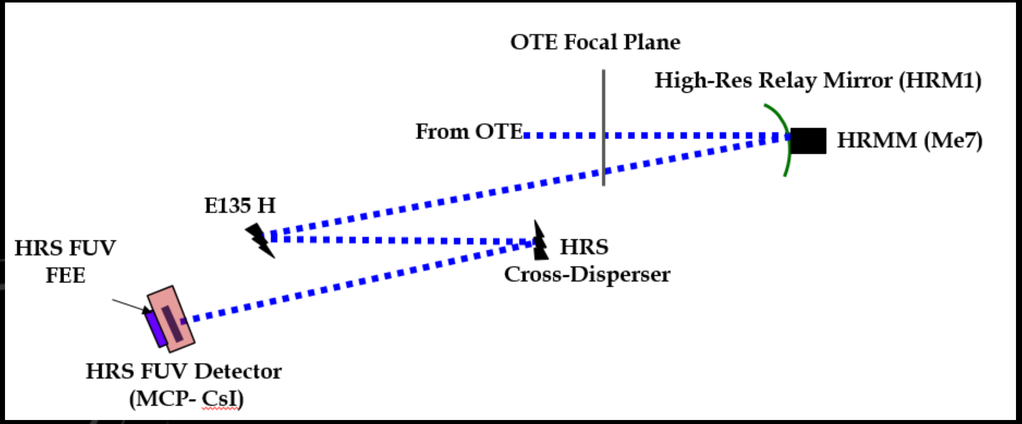
LUMOS: three channels (FUV and NUV)

- Low/Med-res (R =500 -> 60K), FUV and NUV MOS. FOV = 3' x 1.6'



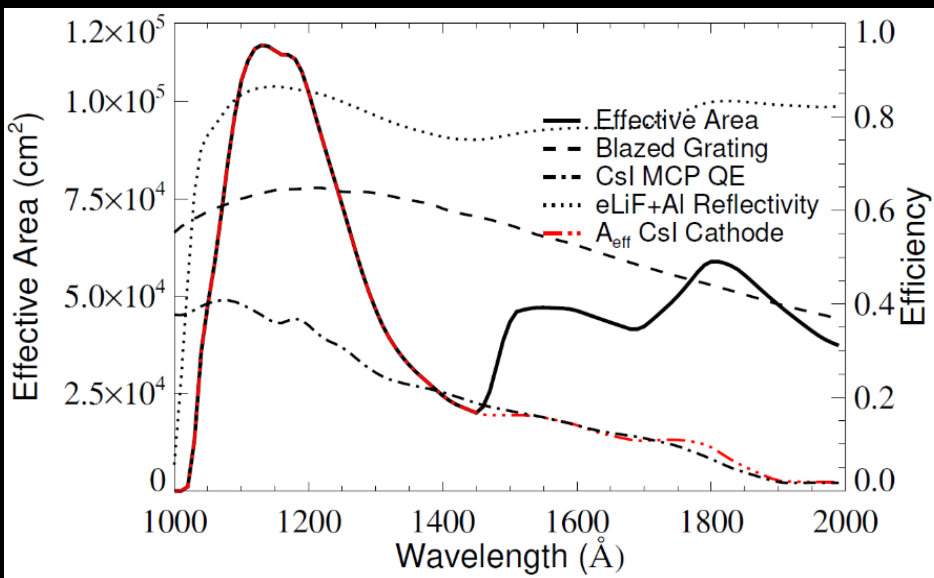
- FUV imager. FOV = 2' x 2'

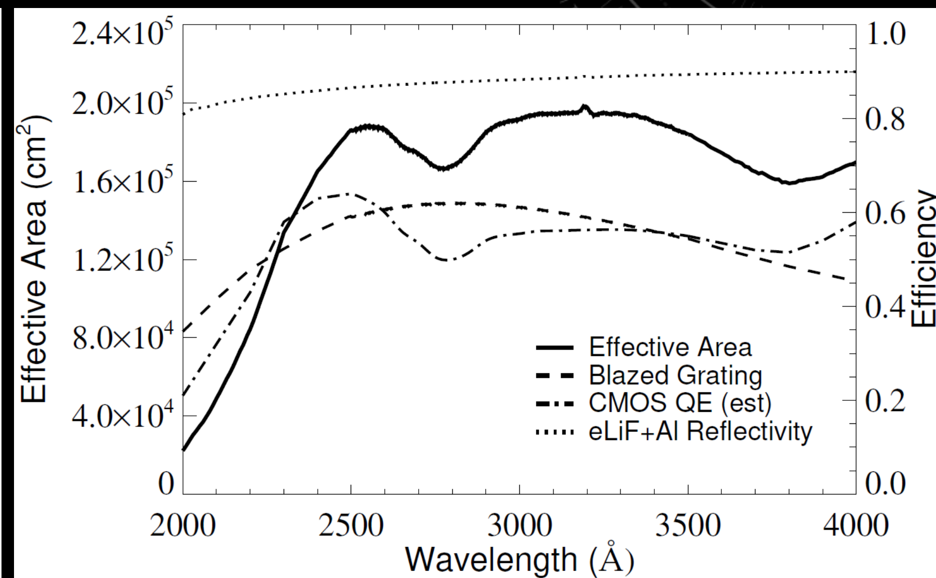




- High-res (R ≥ 100K) point source spectrograph (complements CNES POLLUX instrument)

LUMOS: Specs and Performance

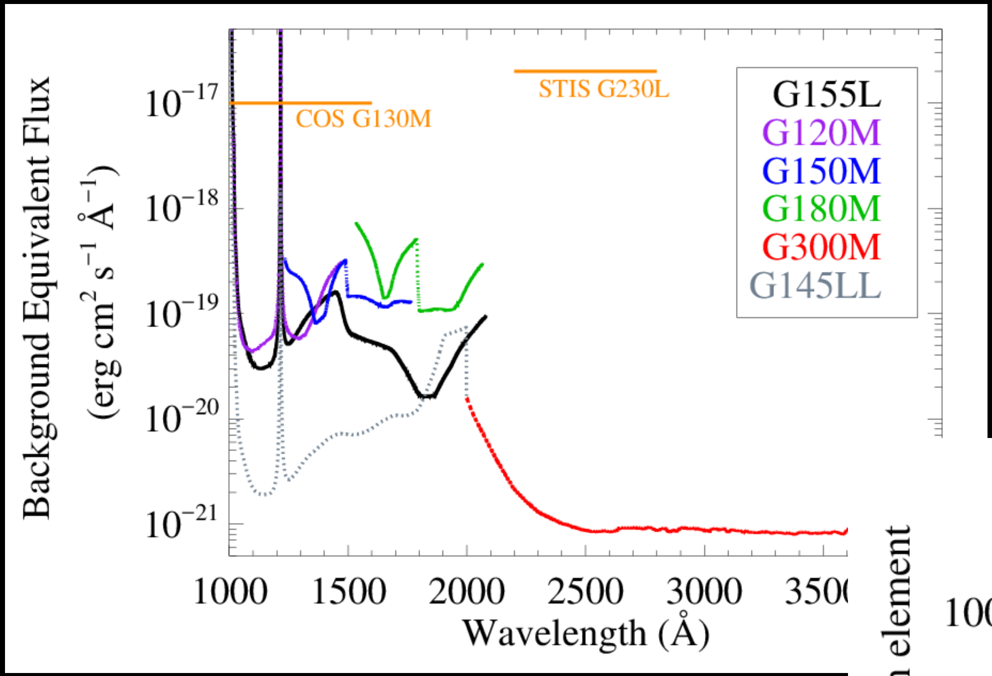


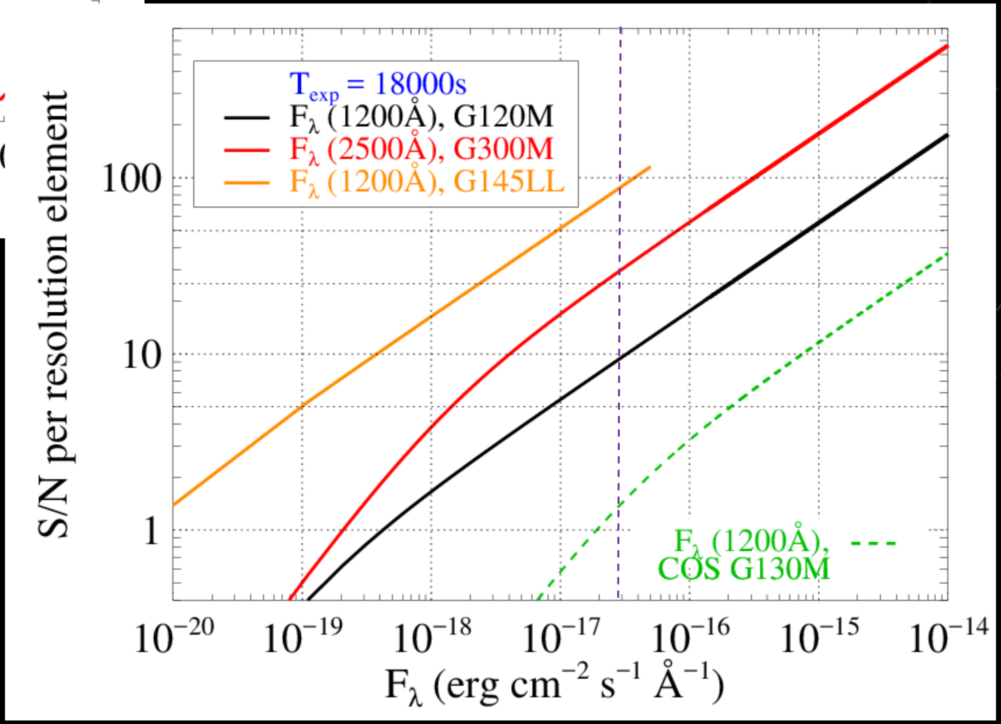


Sources:

- Gratings: HST COS (Heritage)
- MCP QE: HST COS, O. Siegmund
- CMOS QE: Nikzad et al. 2016
- eLiF Reflectivity: Fleming et al. 2016
- MSAA: JWST NIRSpec (Heritage)

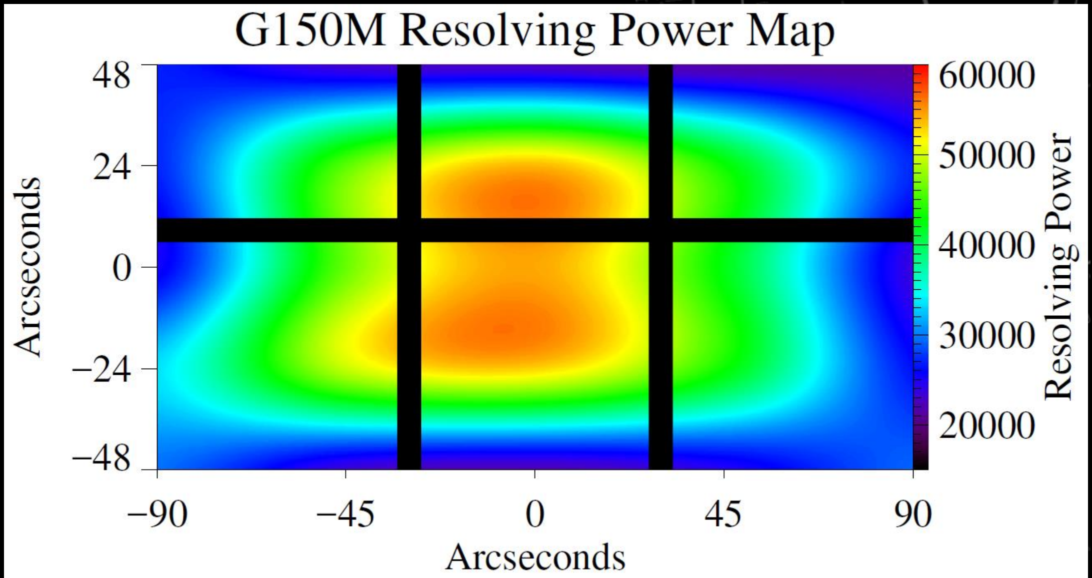
LUMOS Performance

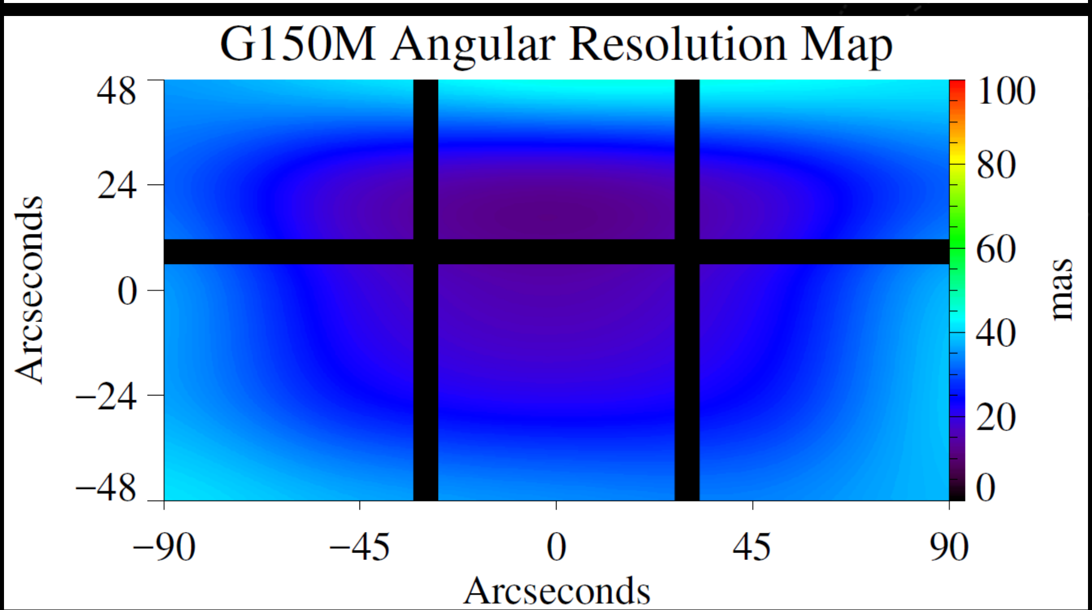




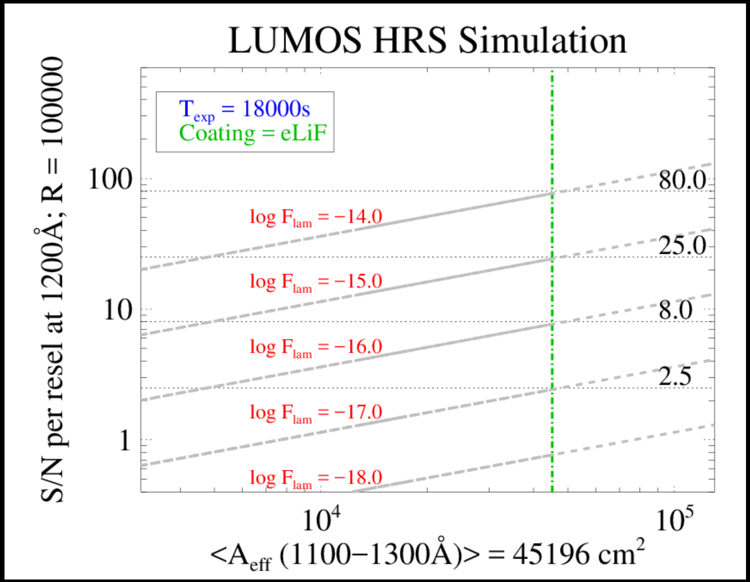
LUMOS Performance**

- $R \geq$ *HST*-COS everywhere in FOV
  - Extended source R ~ 1/6 point source R for filled slit
  - **~ 1200 shutters available per exposure in M & L modes**
    - **(~ 10,000 for G145LL)**
- Angular resolution < STDT spec for 95% of the FOV
- Each microshutter is ~110 mas (clear) in height, so each is a "long slit" aperture (~4-10 XD resols/shutter).
  - **(Figures represent the average over the bandpass, not the peak)





LUMOS Performance



Prototypical Observation:

$F_\lambda \approx 1 \times 10^{-15}$ erg cm^{-2} s^{-1} $Å^{-1}$
to S/N = 25/resel in 5 hours

HST Comparison:

1) HST-COS @ R = 17,000
T_{exp} = 76 ks

2) HST-STIS @ R = 114,000
T_{exp} = 150 Ms (~5 yr)

- High-res (R ≥ 100K) point source spectrograph

- FUV imager

Filter	Bandpass
F110M	102 – 118 nm
F140M	130 – 150 nm
F160M	150 – 170 nm
G180M	170 – 190 nm
F150W	135 – 175 nm
Open	100 – 200 nm
"GALEX FUV"	~ 135 – 200 nm

Detector-limited 12.6 mas imaging over the entire FOV. Multi-layer filters have ~ 85% peak reflection in band, ~ 1% out of band (Rodreguez-De Marcos et al. 2016)

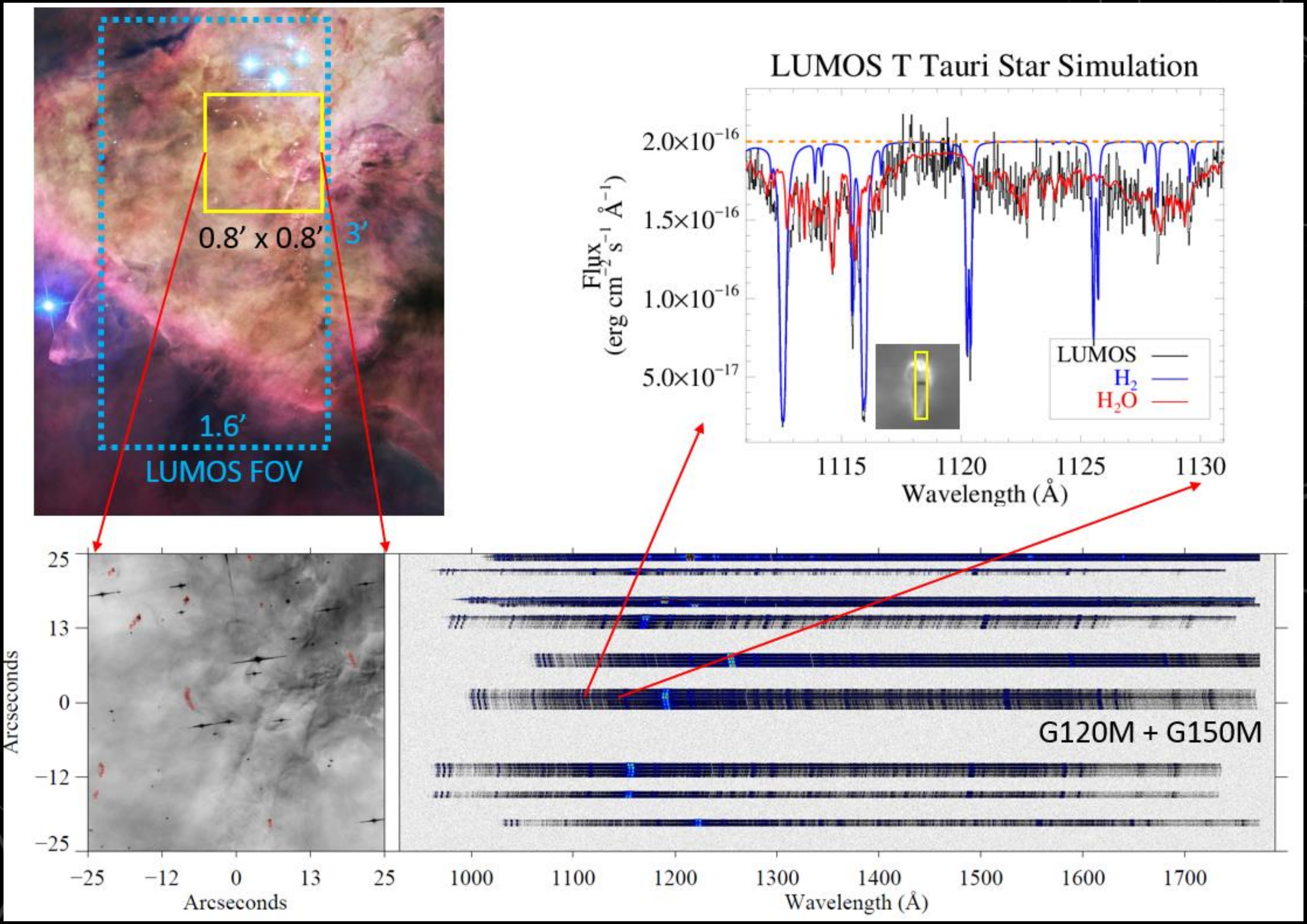
LUMOS Performance Summary: see France et al. 2017

LUVOIR

power, bandpass, and angular resolution boxes, the ***target value is on top***, the ***average value at the center of the field delivered by the LUMOS design is beneath in bold and parentheses***, and the ***average parameter value over 80% of the imaging field-of-view is beneath in bold, italics, and parentheses***. The lower number demonstrates that LUMOS achieves the spectral and spatial resolution goals across the majority of its spectral and spatial detector area.

Instrument Parameter	**G120M**	**G150M**	**G180M**	**G155L**	**G145LL**	**G300M**	**FUV Imaging**
Spectral Resolving Power	30,000 **(42,000)** ***(30,300)***	30,000 **(54,500)** ***(37,750)***	30,000 **(63,200)** ***(40,750)***	8,000 **(16,000)** ***(11,550)***	500 **(500)**	30,000 **(40,600)** ***(28,000)***	…Avg, cen of FOV Avg, 80% of FOV
Optimized Spectral Bandpass (Total)	100 – 140nm **(92.5 – 147.4 nm)**	130 – 170nm **(123.4 – 176.6 nm)**	160 – 200nm **(153.4 – 206.6 nm)**	100 – 200nm **(92.0 – 208.2 nm)**	100 – 200nm	200 – 400nm	100 – 200nm
Angular Resolution	50 mas **(11 mas)** ***(17 mas)***	50 mas **(15 mas)** ***(19.5 mas)***	50 mas **(17 mas)** ***(24 mas)***	50 mas **(15 mas)** ***(27.5 mas)***	100 mas **(32 mas)**	50 mas **(8 mas)** ***(26 mas)***	25 mas **(12.6 mas)** ***(12.6 mas)***
Temporal Resolution	1 msec	1 msec	1 msec	1 msec	1 msec	1 sec	1 msec
Peak Throughput	5% 7.5%	5% 7.5%	5% 7.5%	5% 7.5%	5% 7.5%	5% 12%	10% 11%
Field of View	2′ × 2′ **(3′ × 1.6′)**	2′ × 2′ **(3′ × 1.6′)**	2′ × 2′ **(3′ × 1.6′)**	2′ × 2′ **(3′ × 1.6′)**	2′ × 2′ **(3′ × 1.6′)**	2′ × 2′ **(1.3′ × 1.6′)**	2′ × 2′ **(2′ × 2′)**

LUMOS MOS Example Science Program: Surveying the Birthplace of Planets



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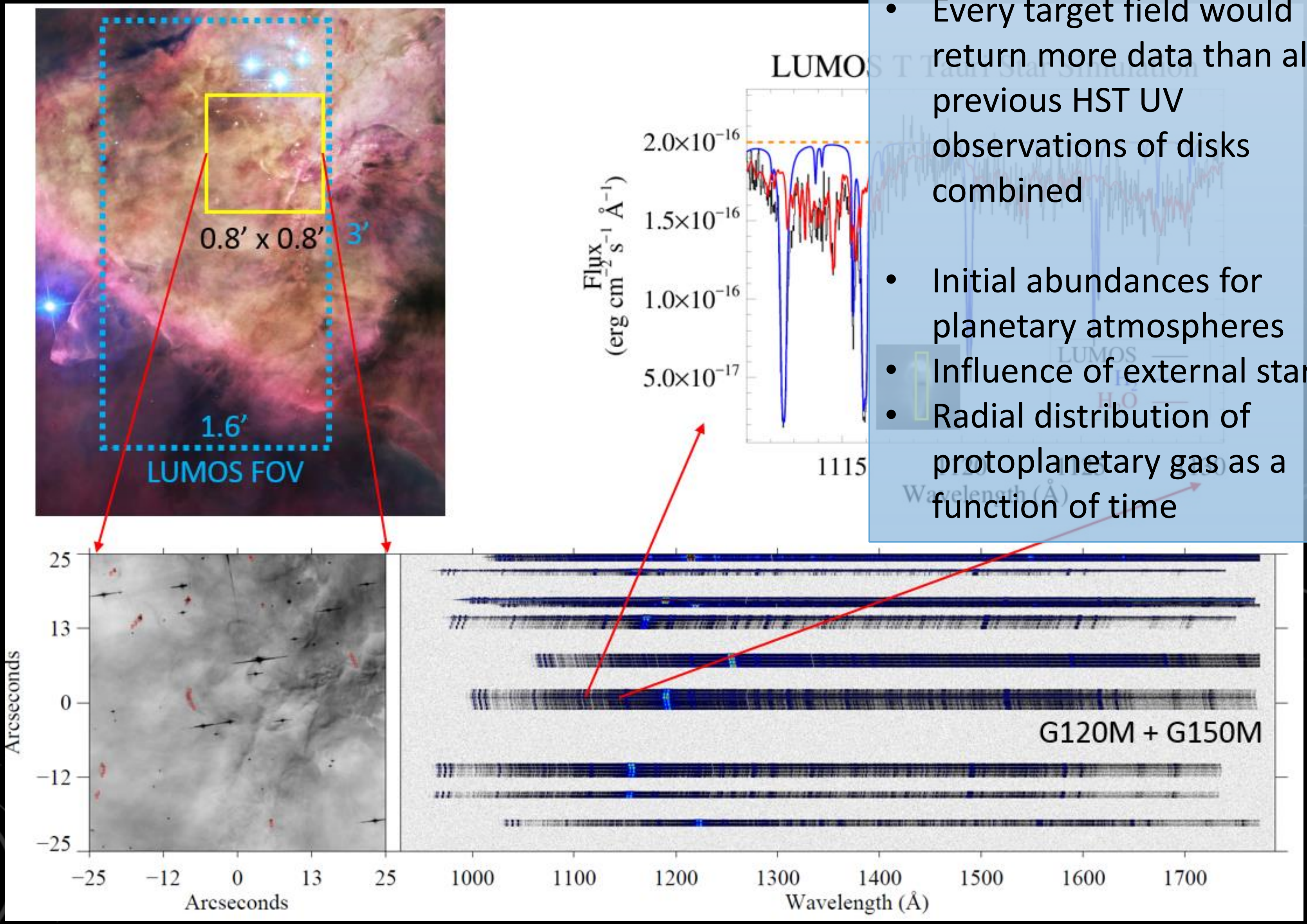

- Map 5 regions in Orion from 1 – 10 Myr, 10s – 100s protoplanetary disks in each
- Every target field would return more data than all previous HST UV observations of disks combined

- Initial abundances for planetary atmospheres
- Influence of external stars
- Radial distribution of protoplanetary gas as a function of time

LUVOIR online simulation tools

https://asd.gsfc.nasa.gov/luvoir/tools/

LUVOIR

Large UV/Optical/IR Surveyor

Science | Design | Team | Tools | Events | Participate | Resources | Technology | Press

Tools

This page links to performance simulation and visualization tools for the LUVOIR mission, a future ultraviolet / optical / near-infrared observatory concept.

These widgets are experimental. If they are not working, email Jason Tumlinson (STScI). For the Planetary Spectrum Generator, email Geronimo Villanueva (GSFC).

Coronagraphic Spectra of Exoplanets

Simulate optical/near-IR reflection spectra of various exoplanets with realistic noise.

Multiplanet Yield Tool

Tool for visualizing yields of observed exoplanets (of various types) as function of basic mission parameters.

Planetary Spectrum Generator

Advanced tool for simulating spectra of Solar System bodies (with LUVOIR and other telescopes).

HDI Photometric ETC

Basic exposure time calculator for optical photometry in multi-band images.

LUMOS Spectroscopic ETC

Simple exposure time calculator for UV spectroscopy.

UV MOS Visualizer

See the impact of UV multi-object spectroscopy on the study of stellar clusters and their feedback.

High-Resolution Imaging

Examples of astronomical objects viewed with different sized telescopes.

Goddard SPACE FLIGHT CENTER

Curator: J.D. Myers
NASA Official: Phil Newman

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Summary

LUVOIR has multiple primary science goals

1. Habitable exoplanets & biosignatures
2. Broad range of general astrophysics and Solar System observations

LUMOS meets the science requirements for COR and EXO

--Imaging and spectroscopy over ~4-5 arcmin^2, 100-400nm

--Peak A_{eff} > 10^5 cm^2 in FUV and > 1.8 x 10^5 cm^2 in NUV

--Imaging Spectroscopy $\theta < 30$mas at $R = 30{,}000$-$65{,}000$ across band

--BEF ≈ few x 10^{-21} erg cm^{-2} s^{-1} Å^{-1} in LowLow Mode

Wide range of capabilities to enable decades of future investigations and unexpected discoveries

FIN

LUMOS technology gaps

- Broadband mirror coatings for λ > 100 nm
  - Partial success already – work is moving in the right direction (also – ALD) – environmental tests and scalability
- Large format photon counting detectors (FUV and NUV)
  - Cross-strip borosilicate MCPs
  - sCMOS or CCDs
- Low scatter (holographic) aberration correcting gratings 👍
- Microshutter Arrays for spectral multiplexing
- High groove efficiency, low scatter echelle gratings

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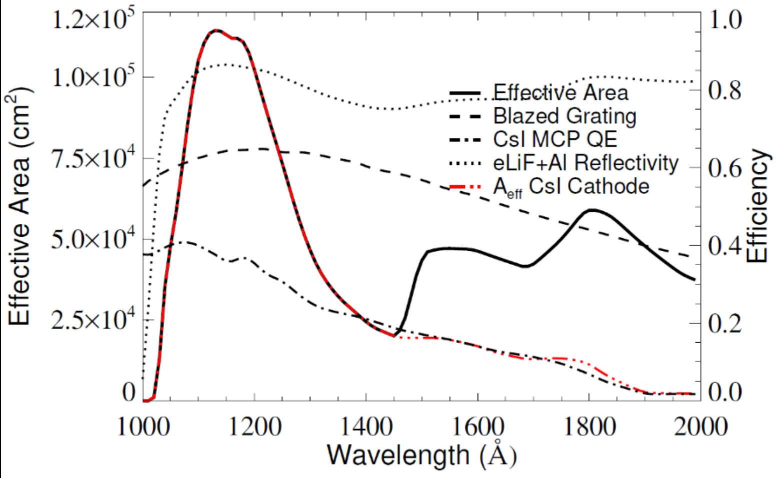
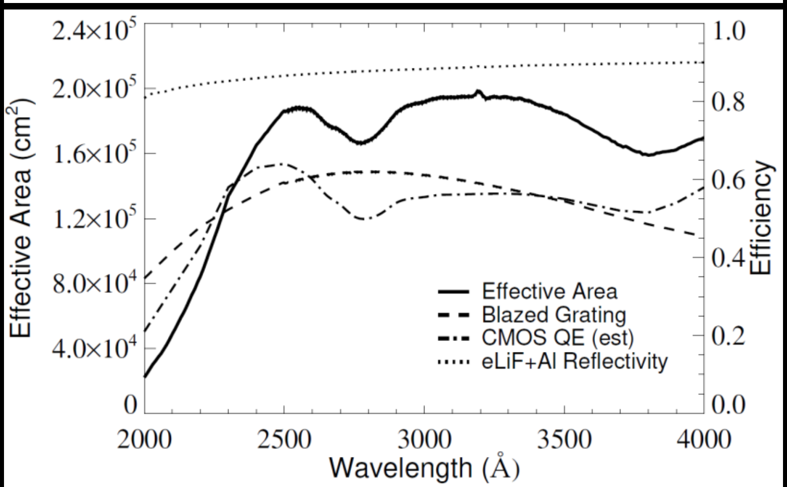
Broadband advanced coatings, large format detectors, and space-qualified MSAs all being developed and flight tested as part of NASA-supported Sounding Rocket missions, APRA programs, and Roman Technology Fellowships
(Pis – France, Green, McCandliss, Siegmund, Vallerga, Nikzad, Quijada, Fleming, and others)

LUMOS: Specs and Performance

	Microshutter Array Assembly (MSAA)	FUV MOS and Imager MCP	NUV MOS CMOS
FOV	1.6’ x 3.0’	1.6’ x 3.0’	1.6’ x 1.3’
Element Size/Resolution	100 x 200 um (pitch)	20 um (resel)	6.5 um (pixel)
Elements per Tile	840 x 420 shutters	10Kx10K resels	8192 x 8192
Tiles per Array	3 x 2	2 x 2 (Imager 1)	7 x 3
Detector Tile Dimensions	88.2mm x 85.7mm	200mm x 200mm	54mm x 55mm
Detector Package Dimensions	444mm x 316mm x 150mm	600mm x 600mm x 140mm	400mm x 200mm x 140mm





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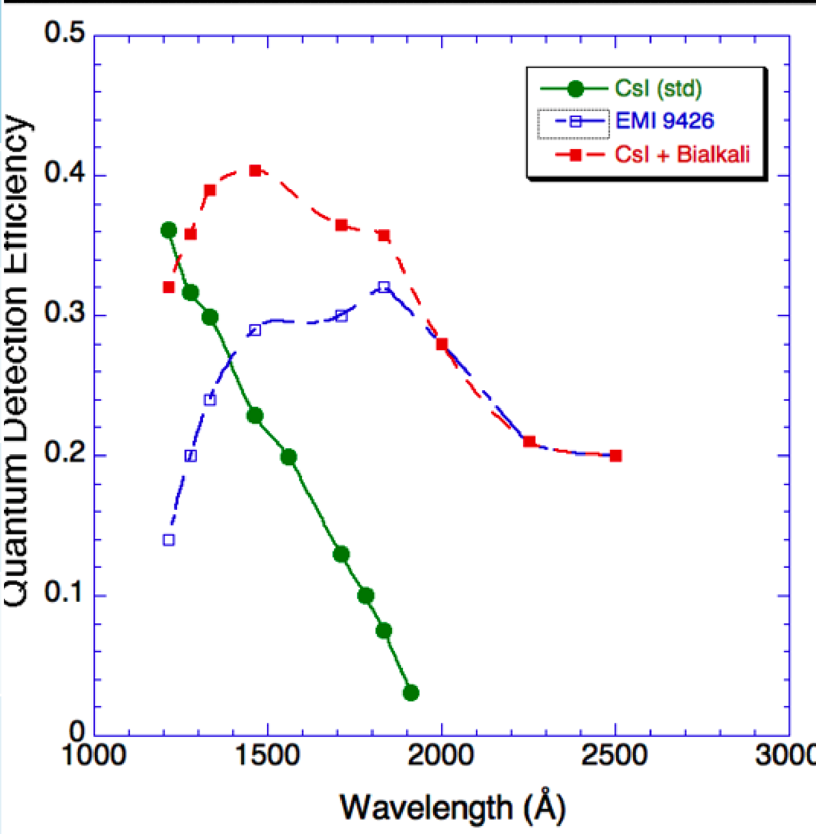

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Particle Background Reduction

The particle background at L2 is 3 – 5 times that in LEO. (!)
Measured by LRO-LAMP, interplanetary coast on ALICE spectrographs

This will dominate the Background Equivalent Flux (BEF) for the open-face MCPs and limit faint object spectroscopy, especially for extended objects.

We are adopting two strategies to mitigate the background:

ALD/Borosilicate glass plates, reduce sensitivity to MeV gamma-rays by ~2 – 3 (~5 – 10 times lower dark rates in lab total)

(Anti-) Coincident detection/rejection

Particle Background Reduction

Very low MCP background (~0.03 cm^{-2} sec^{-1}) is achievable with ALD MCPs. But having intrinsically low MCP background is not enough. It is often the case that the local high energy particle & gamma rates dominate.

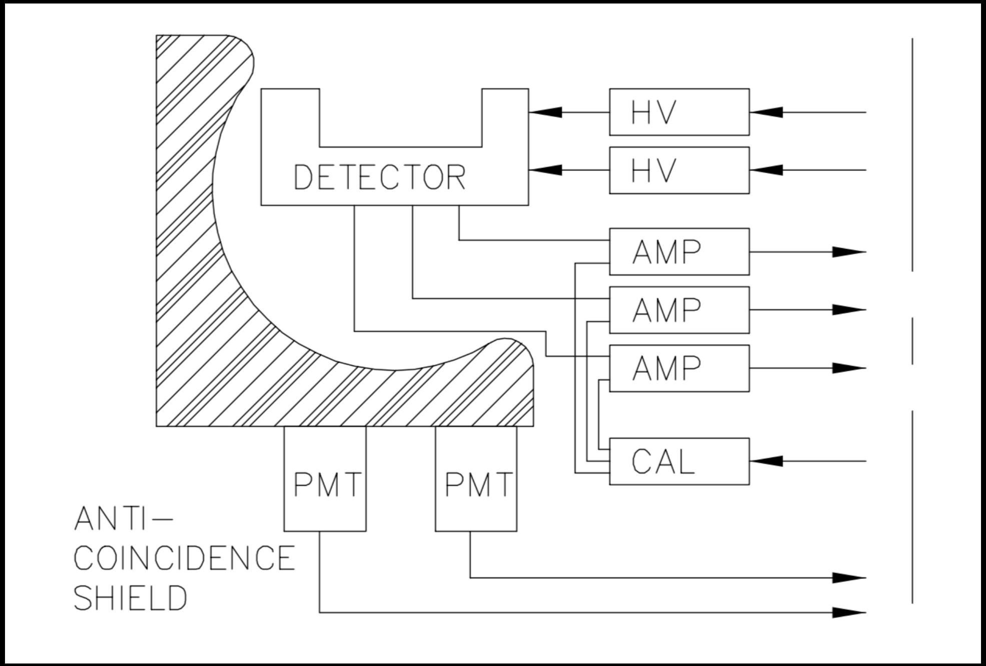
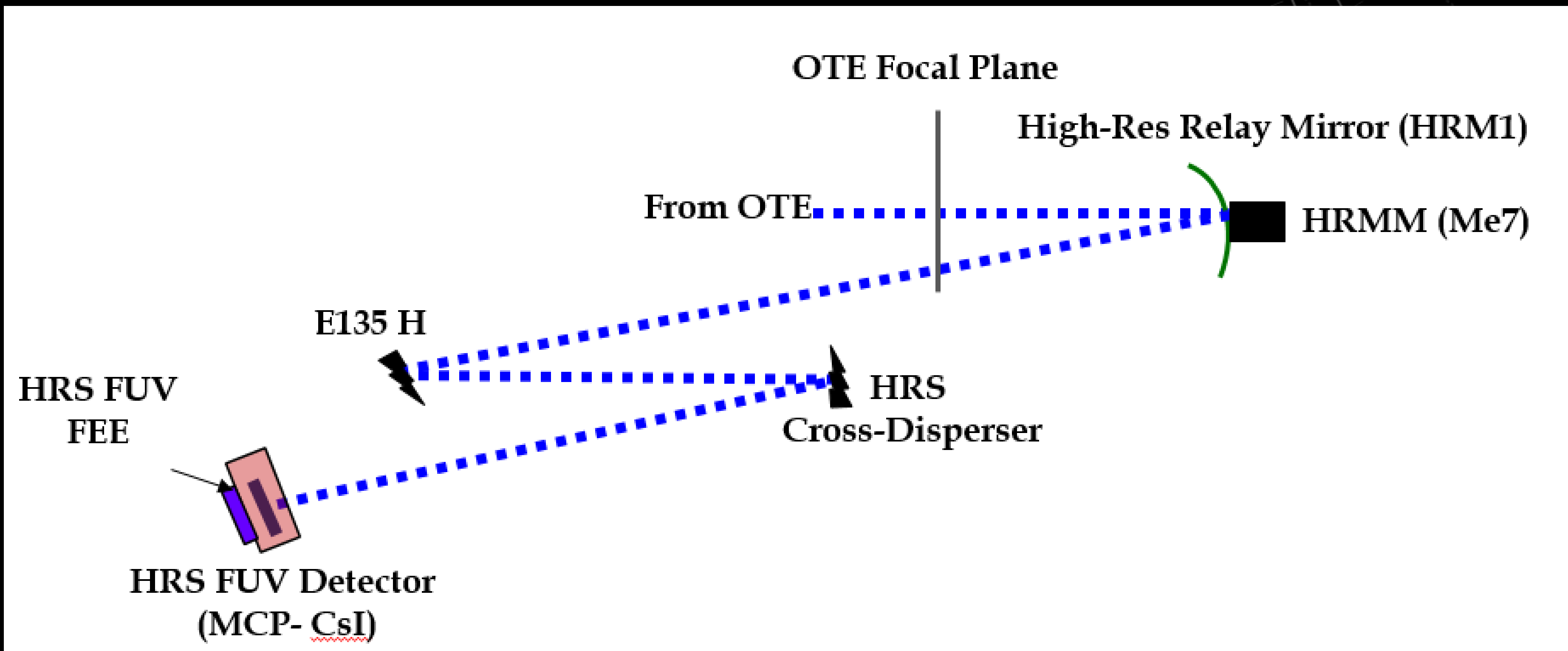


Illustration of the anti-coincidence shield flown on the EURD instrument in 1997. 85% rejection of muon events in ground tests, MCP background rate ~0.06 cm^{-2} sec^{-1} (Bowyer et al 1997).

The timing resolution with photon counting MCP detectors is at the 100ps level. High energy particle events look like single events and can be discriminated with high efficiency by amplitude rejection and by timing coincidence. A combination of radiation shielding, amplitude thresholding, coincidence timing rejection and intrinsically low background / gamma sensitivity could make background improvements of an order of magnitude.

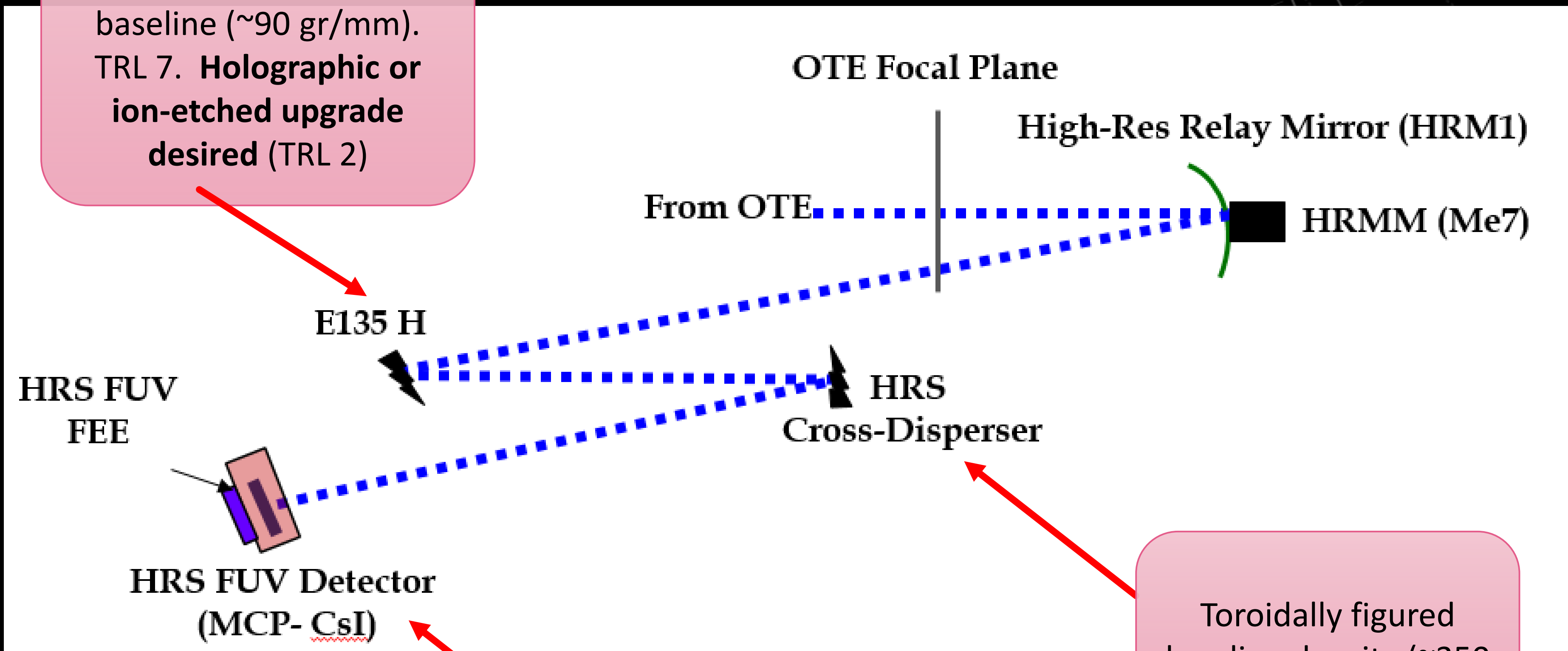
Slide from Ossy Siegmund – UC Berkele

LUMOS High-Resolution Channel: E135H



LUMOS High-Resolution Channel

Mechanically ruled baseline (~90 gr/mm). TRL 7. **Holographic or ion-etched upgrade desired** (TRL 2)

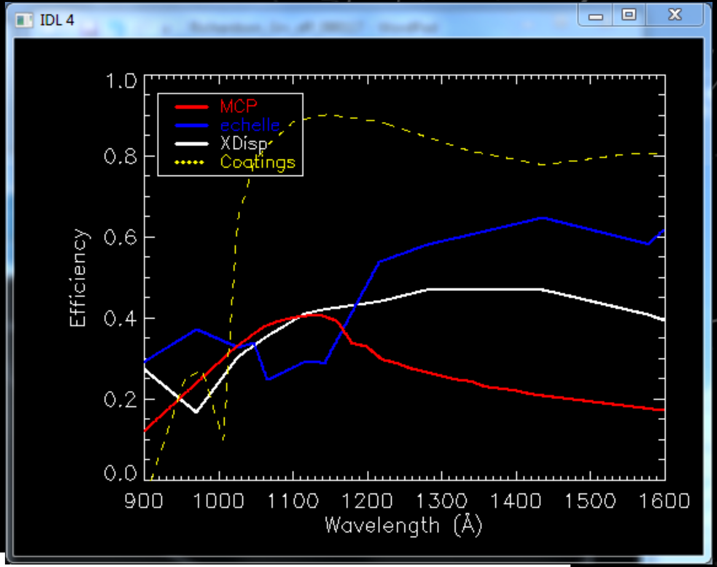


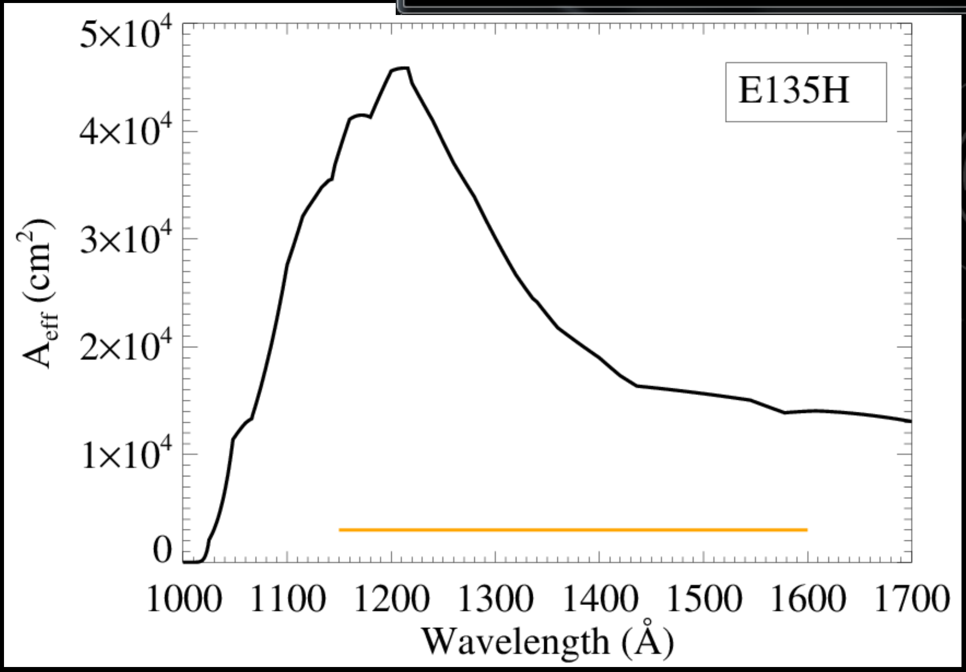
Toroidally figured low-line density (~350 gr/mm). J-Y. TRL 7

100mm x 100mm
Cross-strip anode
TRL 5

LUMOS High-Resolution Performance

- *R* > 100,000 over 1000 – 1600 Å bandpass
- Peak $A_{eff} \approx 45{,}000\ cm^2$ (throughput ~4.5 x STIS E140H)
- BEF ≈ 5×10^{-19} erg $cm^{-2}\ s^{-1}$ $Å^{-1}$ (ignoring echelle scatter)





LUMOS High-Resolution Performance

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to S/N = 25/resel in 5 hours

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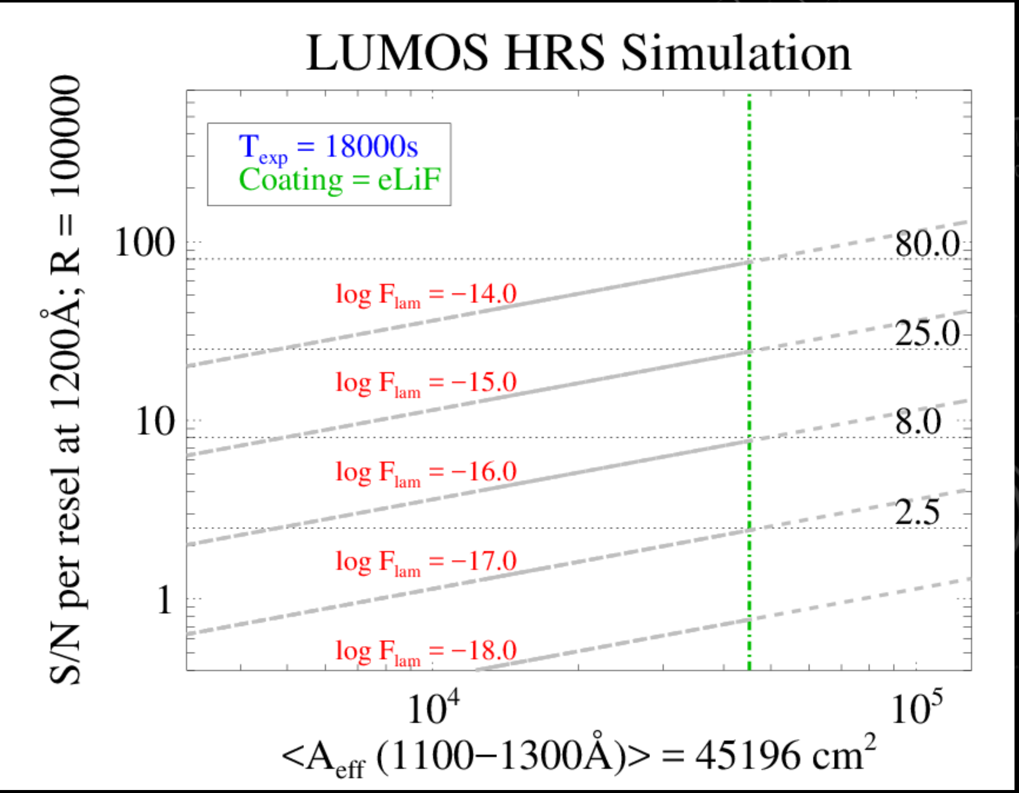
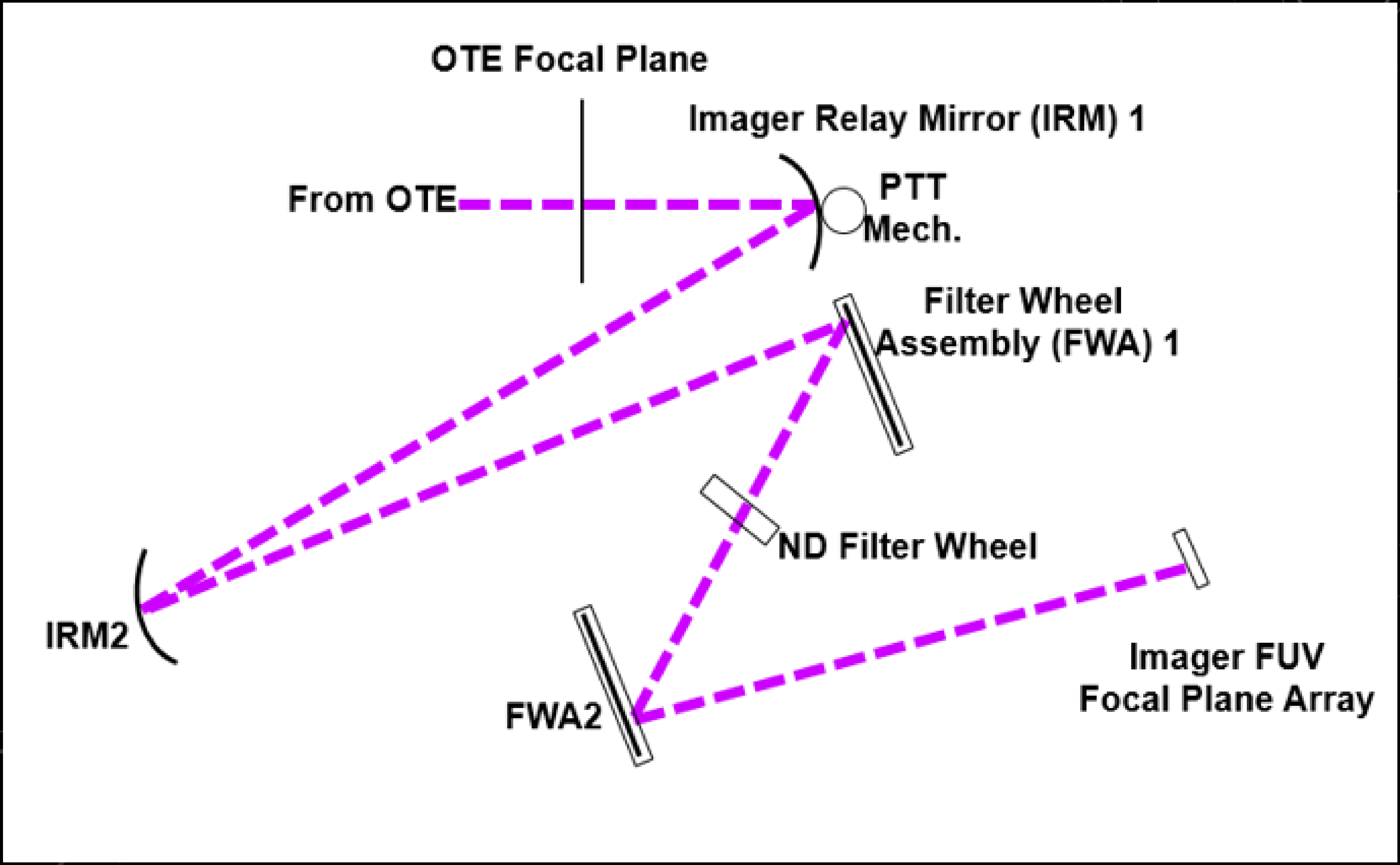
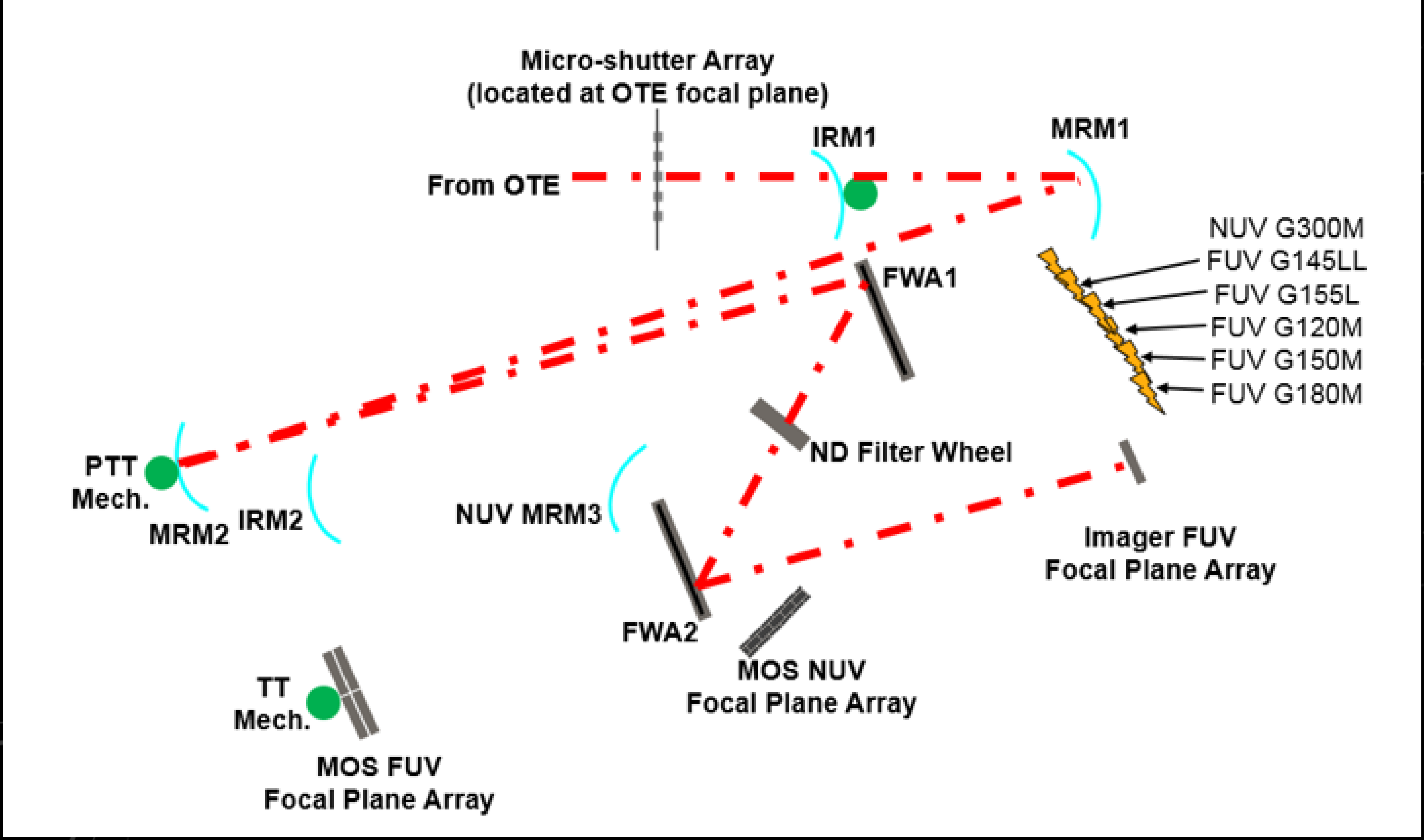


LUMOS FUV Imager



LUMOS Target Acquisition and BOP



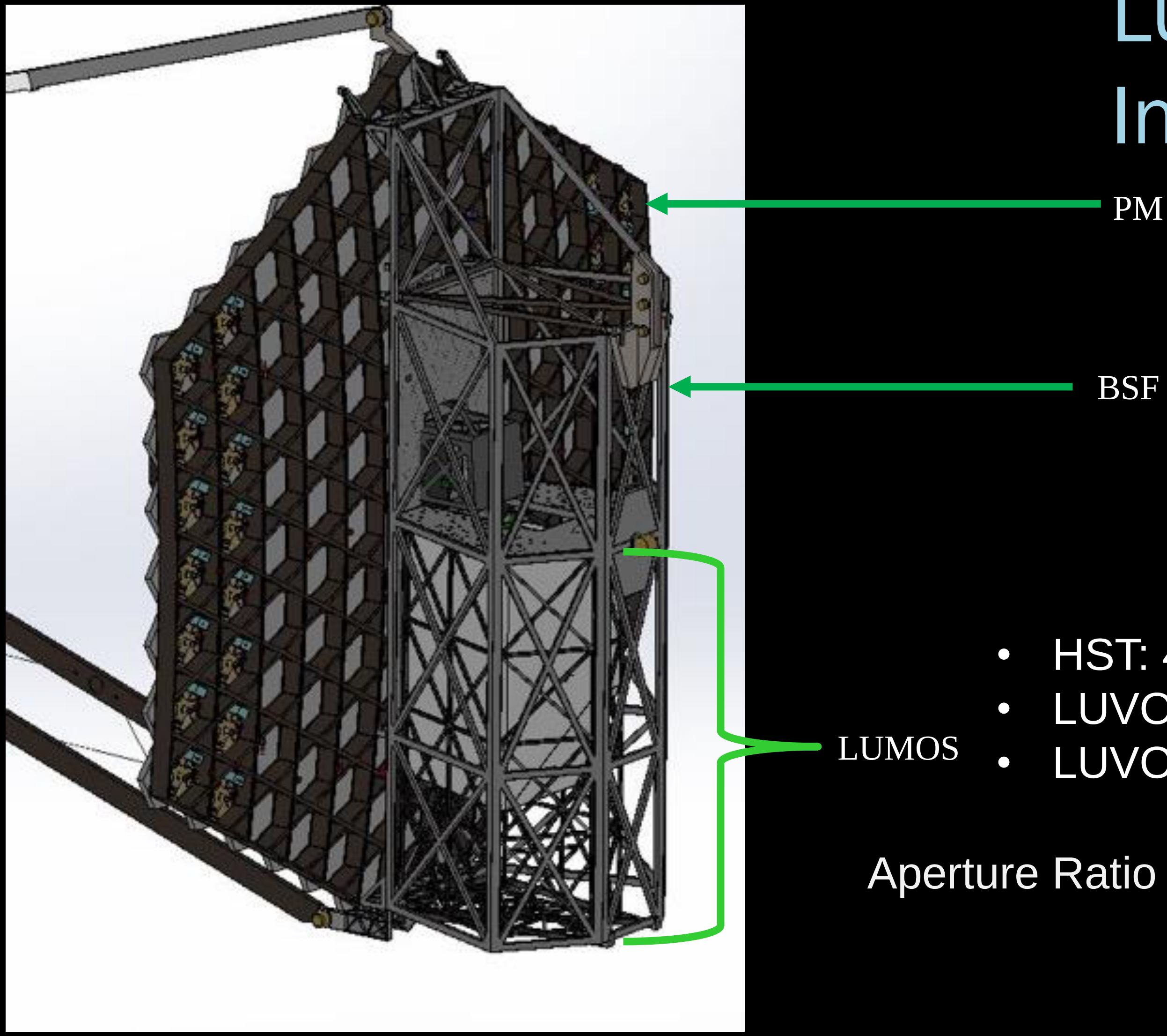
LUMOS (Design team – Colorado, Engineering team – GSFC)

One of the three primary instruments voted on by the STDT at the second face-to-face meeting at Goddard in Aug 2016 (w/ HDI, coronagraph)

- First design for Architecture A (15m) complete
- Instrument Design Lab run (GSFC), May 15-19 2017
- LUMOS team has its own technology gap list, collaboration on development programs

“LUMOS-B” for 9m Architecture B beginning

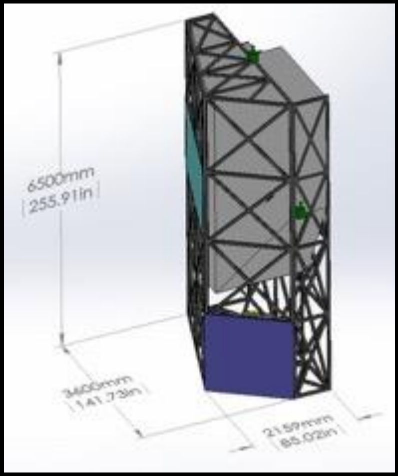
LUMOS Instrument Bay



- HST: 4.5 m^2
- LUVOIR (Arch A): 134.8 m^2
- LUVOIR (Arch B): ~54 m^2

Aperture Ratio = 134.8 m^2/4.5 m^2 ≈ 30x

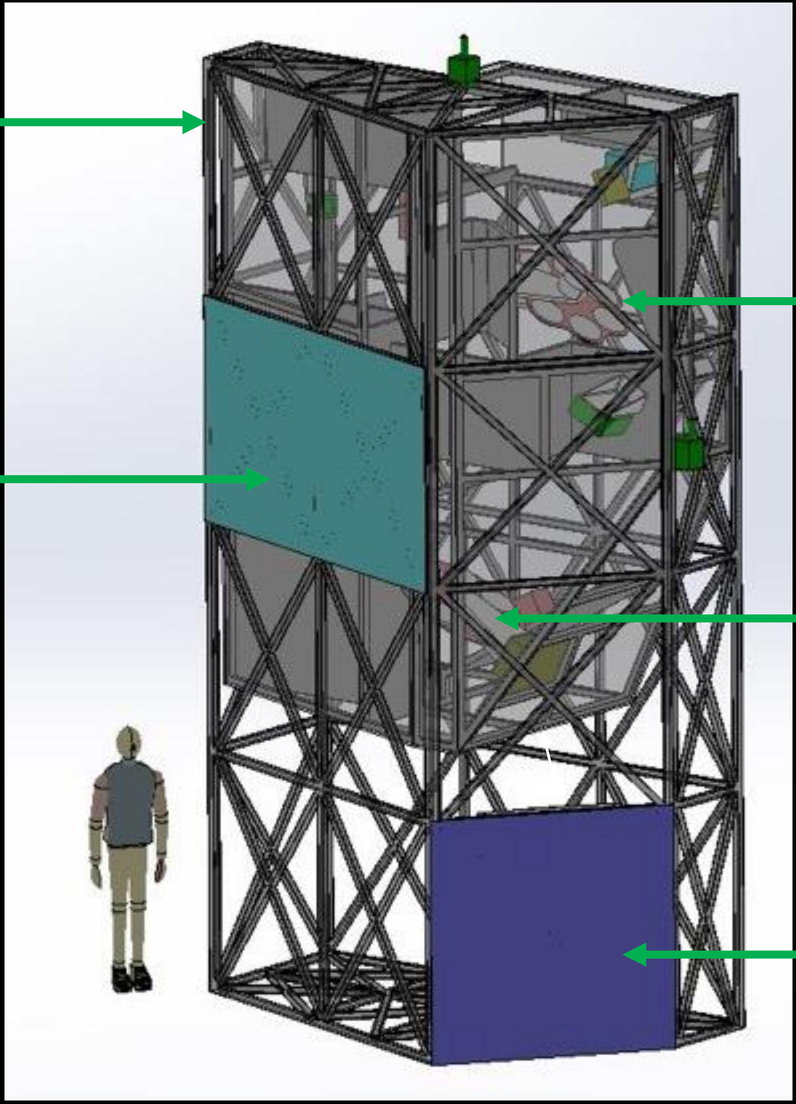
LUMOS Structure and Mechanical



LUMOS Truss Enclosure (LTE);
mounted with flexures to Optical Bench;
composed of two halves;
square tubes (carbon composite)

170 K Radiator;
mounted to LTE;
alum. HC and facesheets

Graduate research assistant storage area



FWA1

FWA2

Electronics Radiator;
mounted to LTE;
alum. HC and facesheets

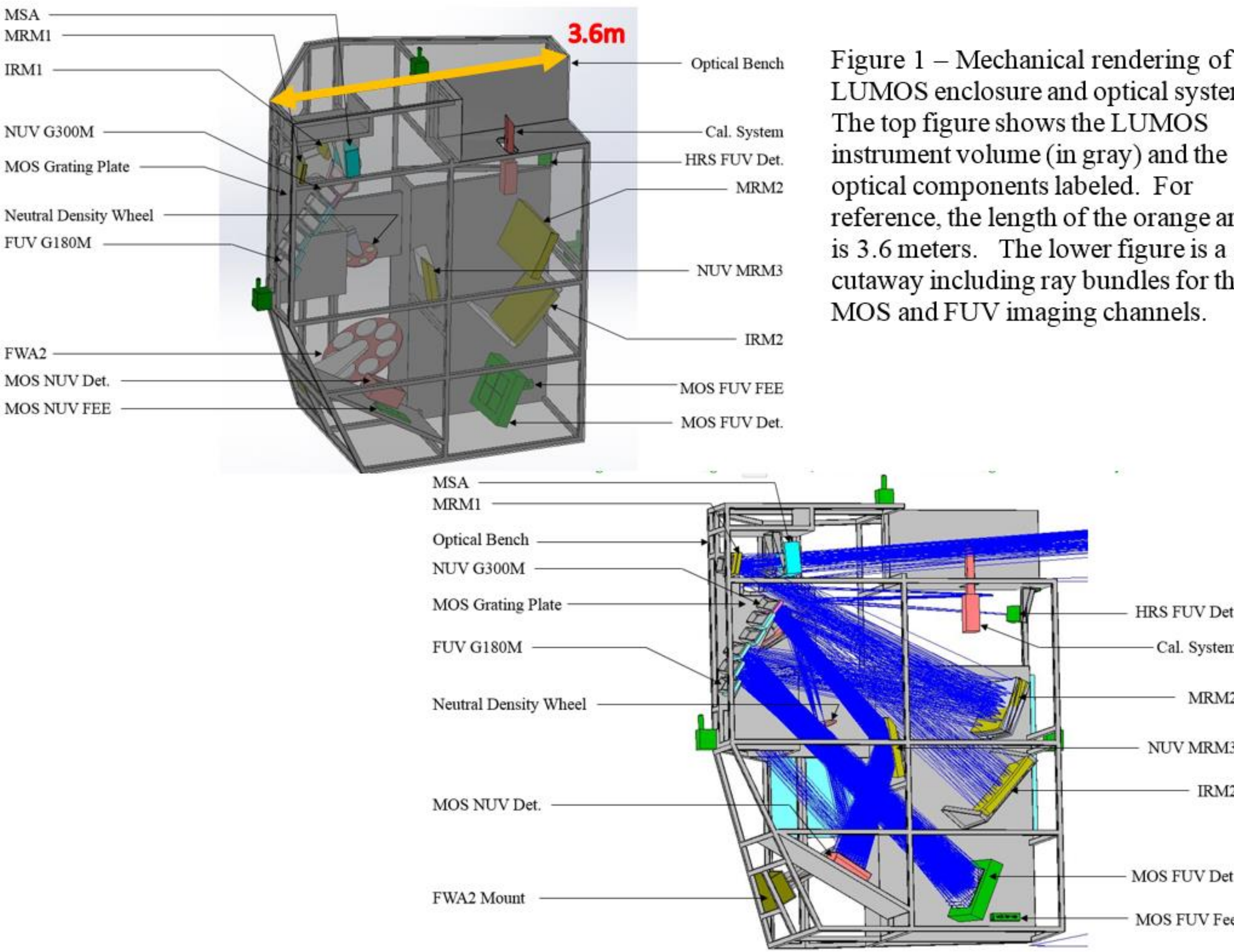


Figure 1 – Mechanical rendering of the LUMOS enclosure and optical system. The top figure shows the LUMOS instrument volume (in gray) and the optical components labeled. For reference, the length of the orange arrow is 3.6 meters. The lower figure is a side cutaway including ray bundles for the MOS and FUV imaging channels.

LUVOIR Overview

Large UV / Optical / Infrared Surveyor (LUVOIR)

A space telescope concept in tradition of Hubble

- Far-UV to Near-IR bandpass
- ~ 9 – 15 m aperture diameter
- Suite of imagers and spectrographs → broad program of exoplanet science and general astrophysics
- Serviceable and upgradable, largely GO observatory

"Space Observatory for the 21st Century"
Decades of science
Ability to answer questions we have not yet conceived

LUMOS: Specs and Performance