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

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University of Colorado
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POLLUX Team Meeting
Marseille - 9 October 2017

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Magazine

Why it's hard to be a Kevin in France

19 March 2017 | Magazine

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A movie star, oui... But still a Kevin

What happens when you have a name that seems perfectly reasonable in your home country, but raises a sympathetic smile when you're abroad? BBC Europe Correspondent Kevin Connolly has been finding out the hard way.

There is a theory called nominative determinism, much beloved of students of literature and other idlers. It holds that your character will come over time to match your name.

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

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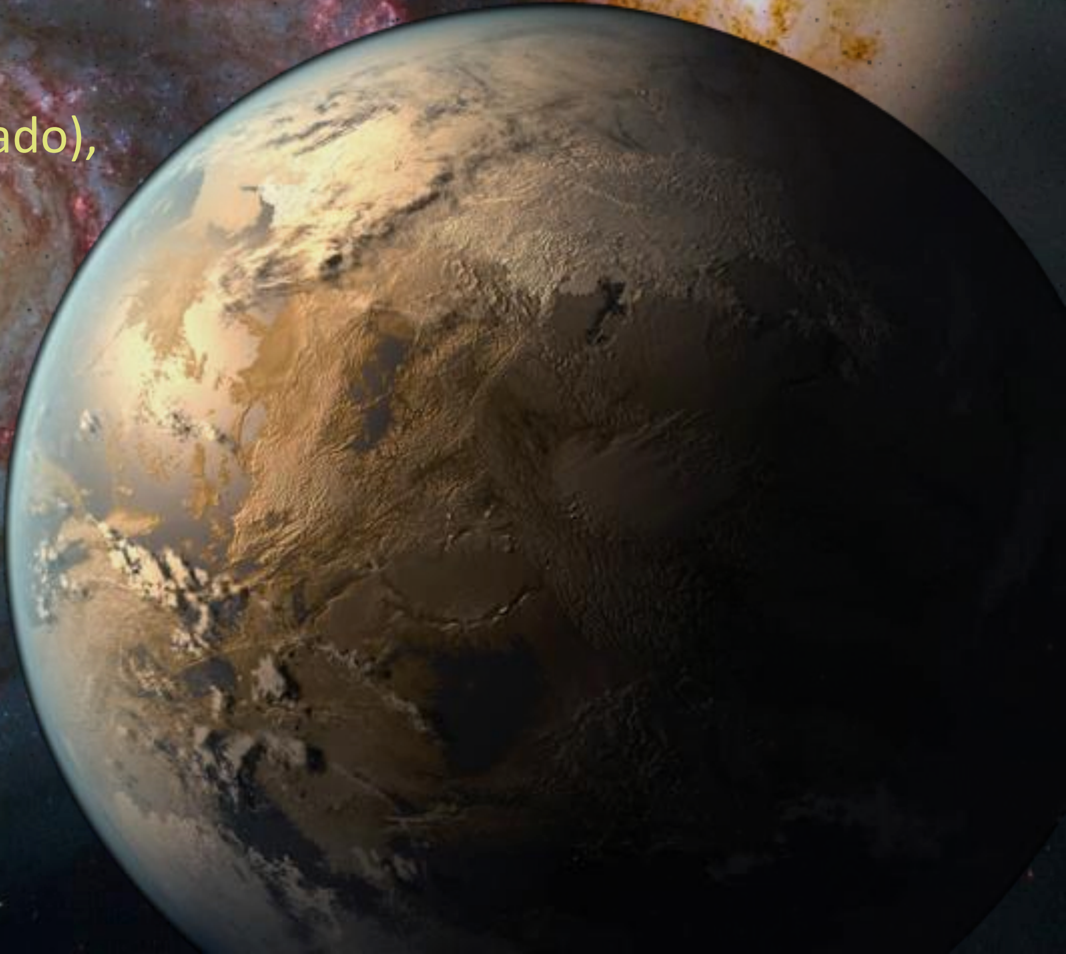
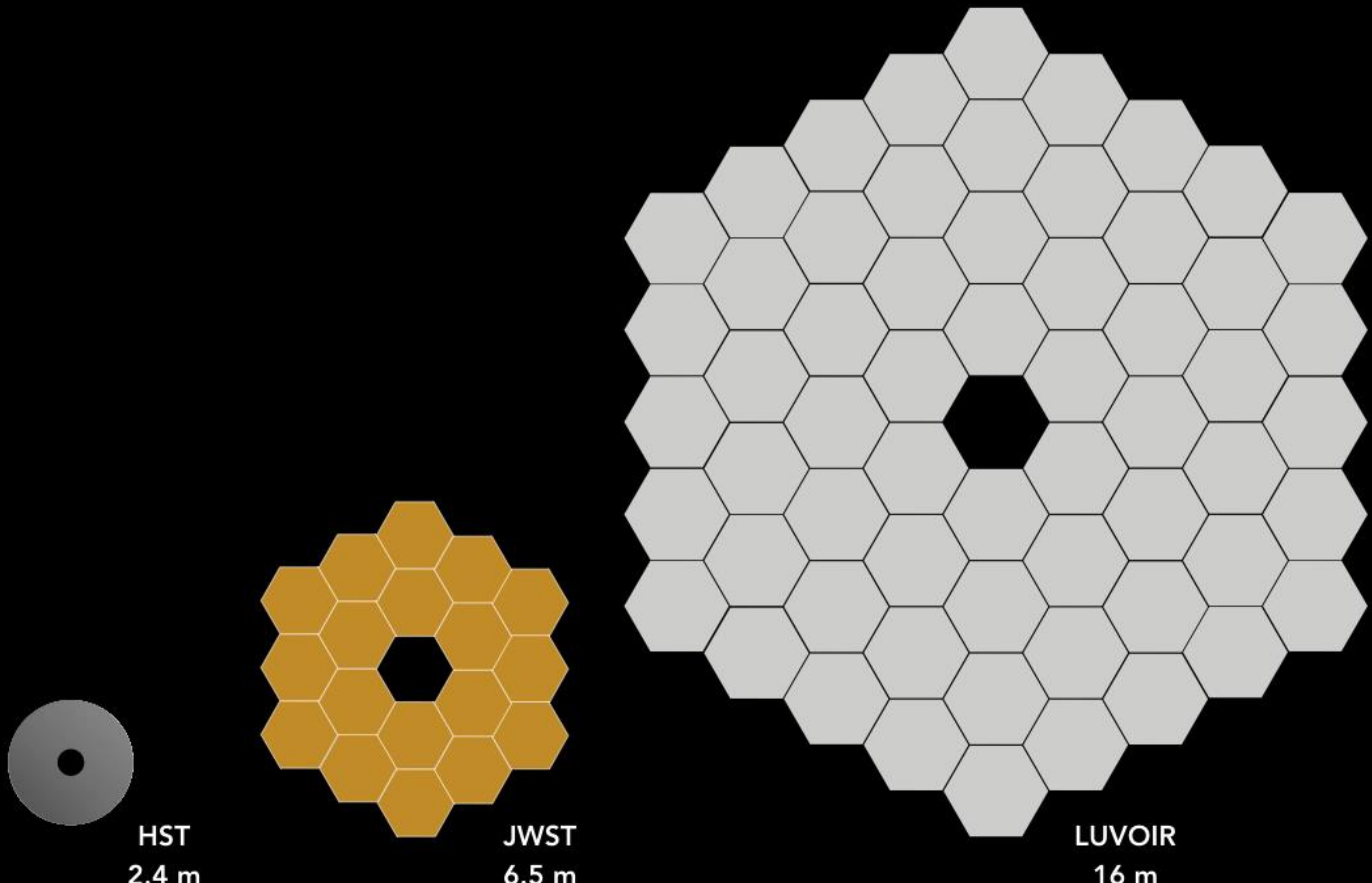
Jason Tumlinson (STScI)



Part 1: LUVOIR Update



The LUVOIR instruments: Oct 1st

HDI – 200 – 2400 nm imaging and grism spectroscopy

LUMOS – 100 – 400 nm imaging and spectroscopy

ONIRS – 400 – 2400 nm spectroscopy

coronagraph – vis/NIR (200-1800nm) high-contrast imaging and spectroscopy

POLLUX – UV high-resolution spectropolarimetry

LUVOIR UPDATES – Face-to-Face Meeting 6

The 6th LUVOIR STDT F2F Meeting was held in Boulder, CO last week (Oct 5 & 6)

- Telescope Update
- Instrument Update
- Programmatic Update

LUVOIR UPDATES – Face-to-Face Meeting 6

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Telescope update:

- Architecture B – 9.3m R-C
- 54 m^2 collecting area, 7.7m filled area
- Current size fits in 5m rocket fairing (Delta IV Heavy), but mass requirements* still above 10,000 kg spec
- Pursuing 12,500 kg launch capability
- Laser metrology for segment alignment/control

*preliminary

LUVOIR UPDATES – Face-to-Face Meeting 6

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Telescope update:

- Architecture A – 15.1m TMA
- Coronagraph + telescope throughput too low to achieve all exoplanet science goals
- Redesign of Architecture A as a 2-bounce R-C design with all instruments at Cassegrain focal surface
- Central obscuration will decrease, segments may be altered slightly, likely faster system ($f/20 \rightarrow f/12$)

LUVOIR UPDATES – Face-to-Face Meeting 6

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Instrument update:

- Coronagraph renamed Extreme Coronagraph for Living Planetary Systems (ECLIPS)
- ECLIPS-A will preserve 3 bands 200-1800nm, ECLIPS-B: 410-1800nm + R~150-200 IFS (each with a vis + NIR channel), and an R = 800 mode
- Both ECLIPS will consider vector vortex coronagraph
- Various efficiency enhancements over original coronagraph: beam-splitters → drop-in flip mirrors, Ag-coatings internal, fiber spectrograph → IFU

LUVOIR UPDATES – Face-to-Face Meeting 6

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Instrument update:

- LUMOS and HDI will change with new Arch.-A, but performance should be comparable (possibly better in some metrics)
- ONIRS study is discontinued, capabilities will be split into LUMOS (R ~15,000 vis MOS, 400-1000nm) and ECLIPS (R = TBD, NIR)
- New wavefront for all instruments (Including POLLUX)

LUVOIR UPDATES – Face-to-Face Meeting 6

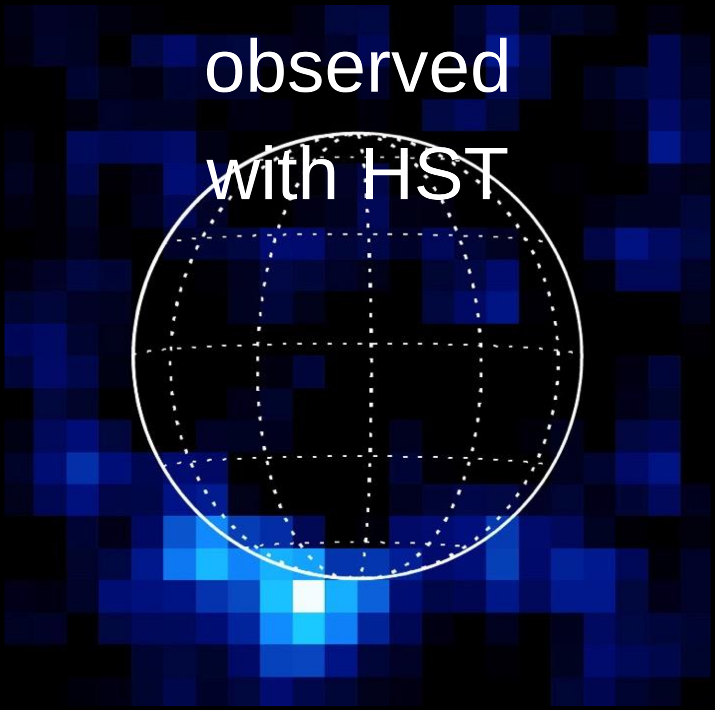
The 6th LUVOIR STDT F2F Meeting was held in Boulder, CO last week (Oct 5 & 6)

Programmatic update:

- All 4 mission studies have requested an extension on the interim report. NASA agrees, ~3 month extension tentatively approved
- Support for Ball Aerospace to carry out HDI redesign
- New Goddard IDL (Instrument design lab) runs for coronagraph, LUMOS, and HDI in late-2017 to mid-2018

The LUVOIR instruments

Europa jets observed with HST



Roth et al. (2014)

Z = 2 galaxy

The LUVOIR instruments: Oct 6th

HDI – 200 – 2400 nm imaging and grism spectroscopy

LUMOS – 100 – 400 nm imaging and spectroscopy

~~**ONIRS** – 400 – 2400 nm spectroscopy~~

ECLIPS – vis/NIR high-contrast imaging and spectroscopy

POLLUX – UV high-resolution spectropolarimetry

Europa jets observed with 15-m LUVOIR

Credit: G. Ballester (LPL)

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Europa jets observed with 15-m LUVOIR

Credit: G. Ballester (LPL)

Part 2: 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

- R-C telescope, longer instrument bay
- Mass constraints may require descope
- Plan is to make scalable from new 15m version

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, OH, O_2, O_3, H_2
- All of these are well-traced (often best-traced) in the UV
- CGM, galaxies, disks are often extended objects.
- QSO tomography and disks require high velocity resolution
- Lyman Continuum and other low-brightness sources require large statistics

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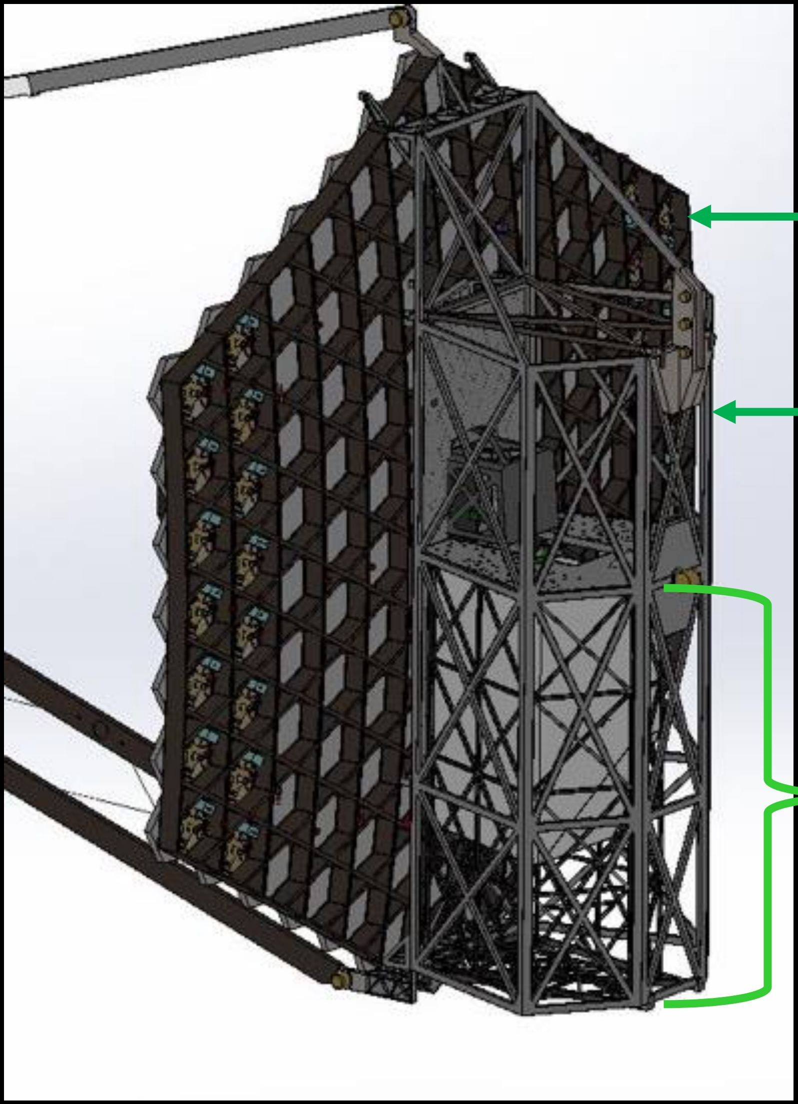
  - Exoplanet atmospheric and exospheric markers - H I, O I, C II, Mg II, O_2, O_3, H_2
- All of these are well-traced (often best-traced) in the UV (100 – 400nm)
- CGM, galaxies, disks are often extended objects. (imaging, multi-object spec)
- QSO tomography and disks require high velocity resolution (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).

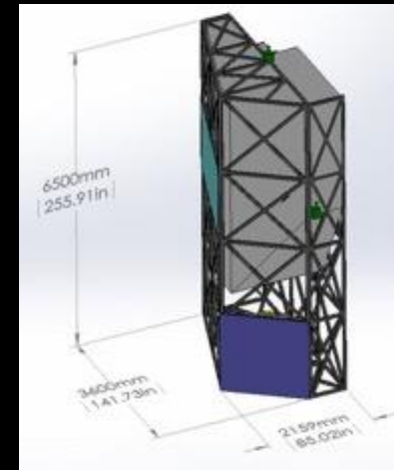
LUMOS Instrument Bay



- 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

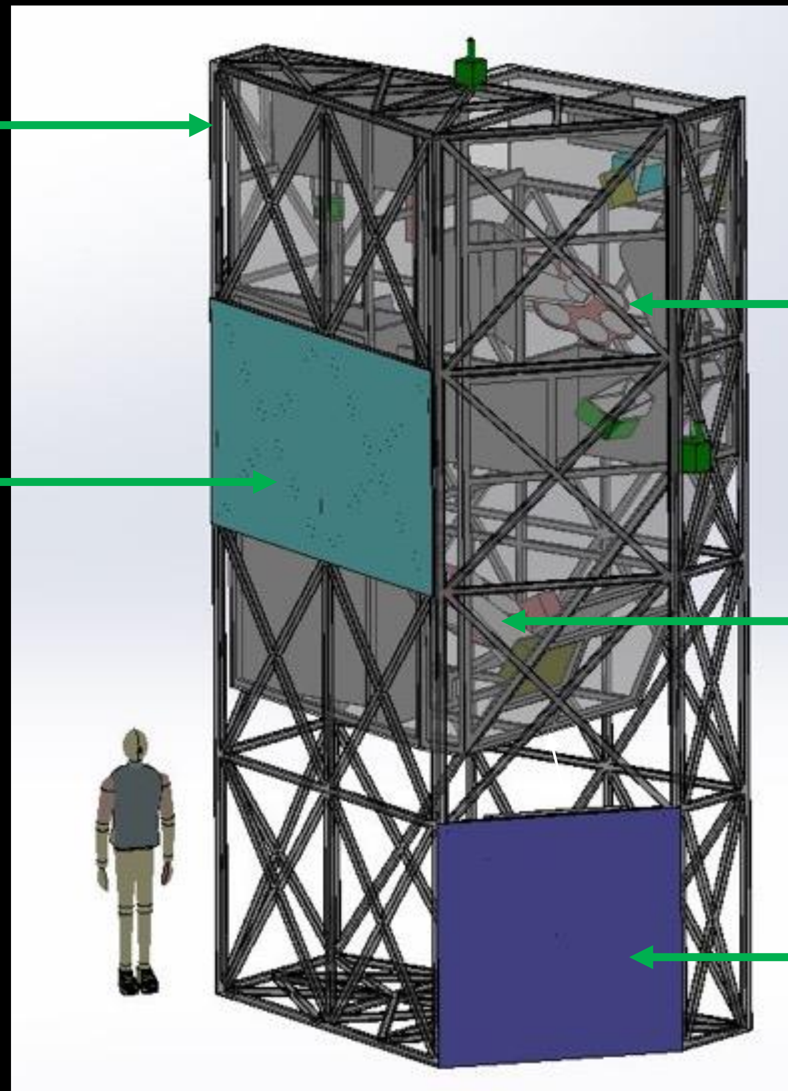
LUMOS Structure and Mechanical



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

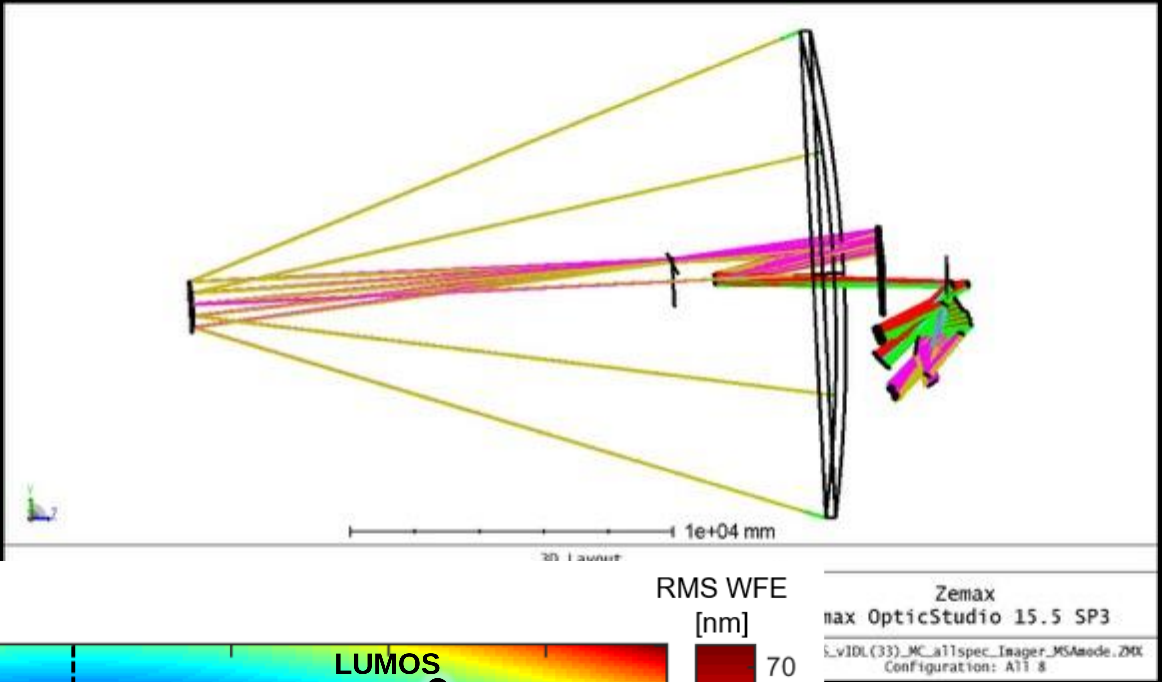


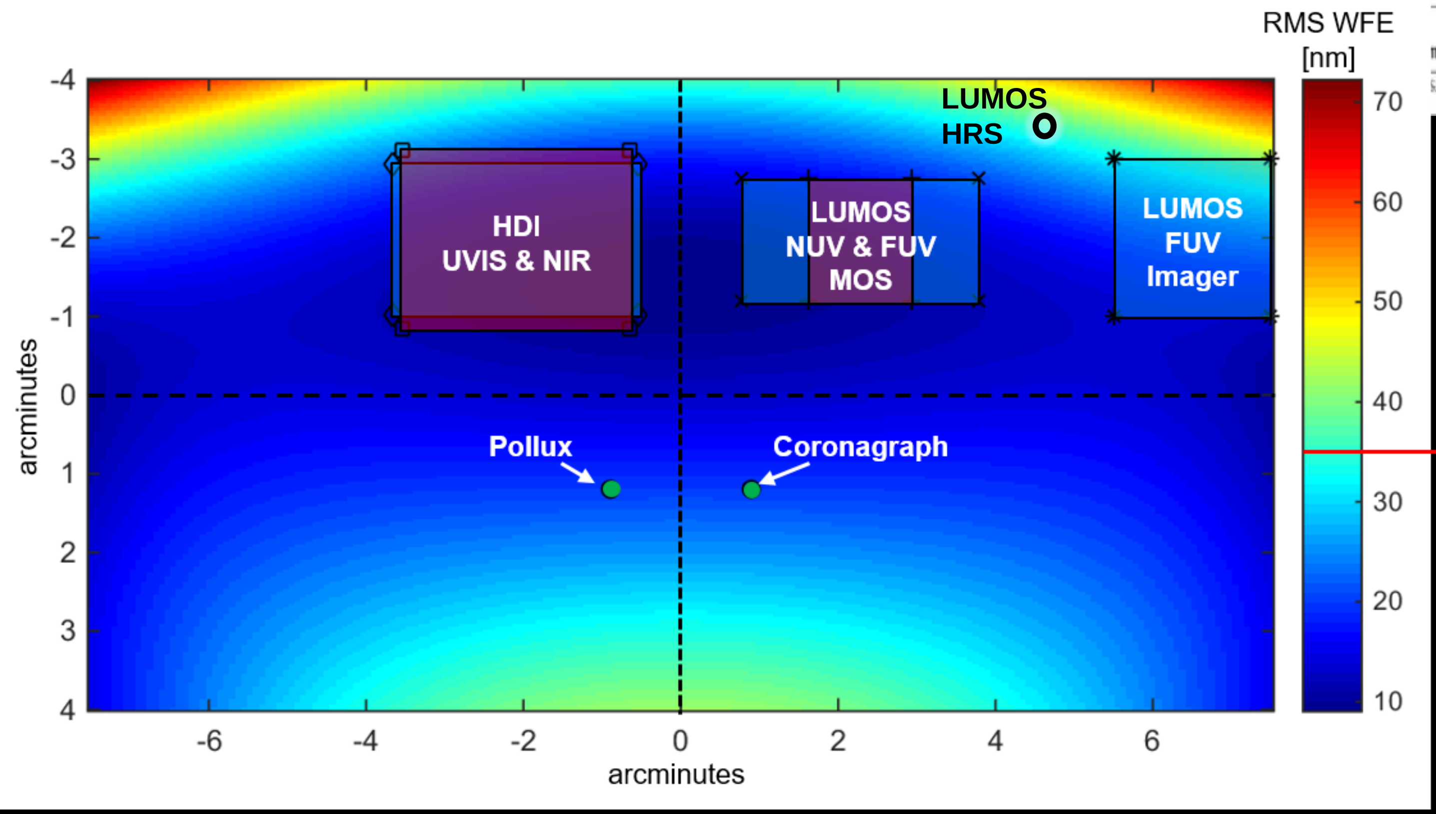
FWA1

FWA2

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

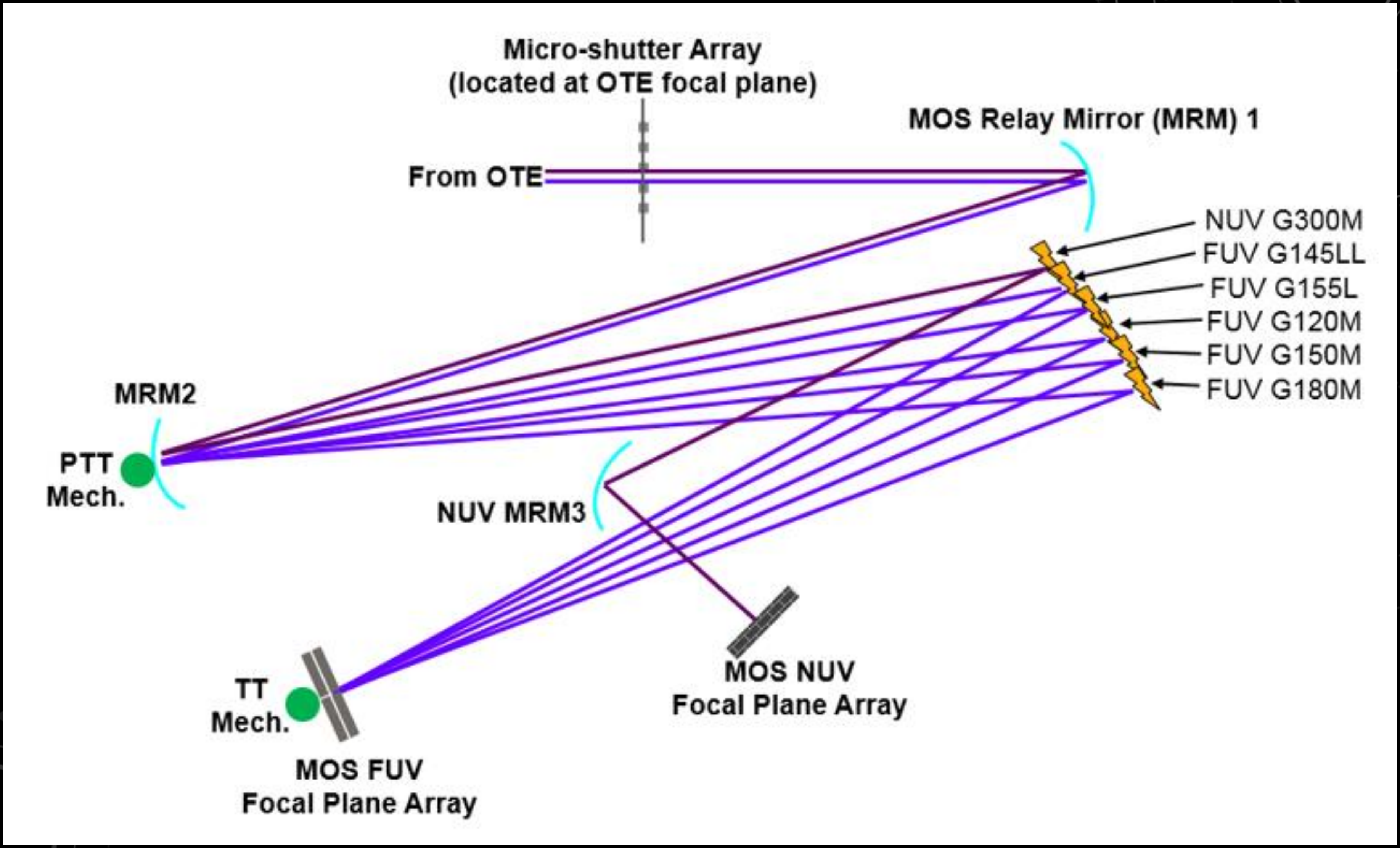
LUVOIR 15-m Focal Plane (will change)





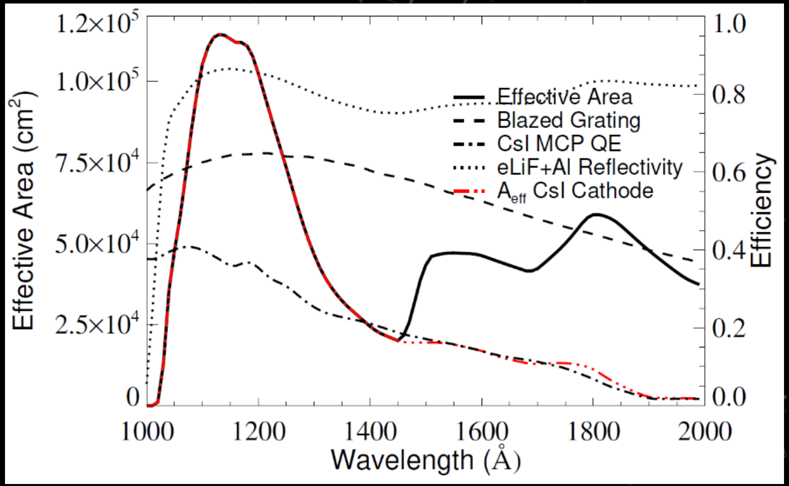
35 nm RMS (Diffraction Limit @ 500 nm)

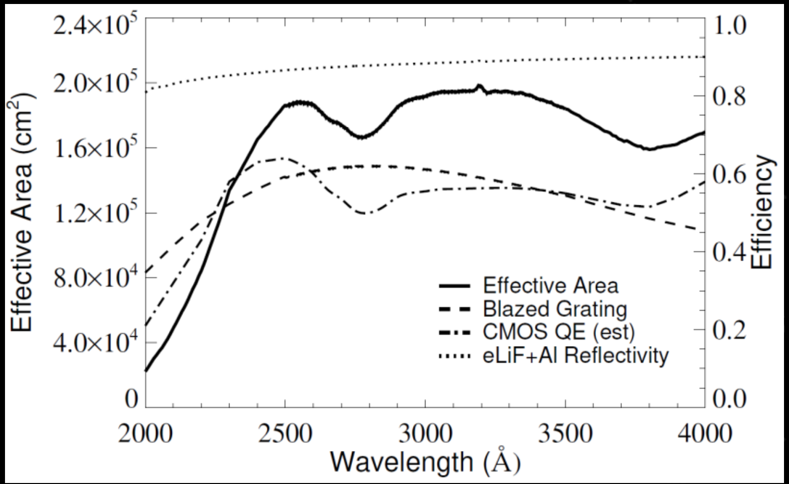
LUMOS: MOS channels (FUV and NUV)



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





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)

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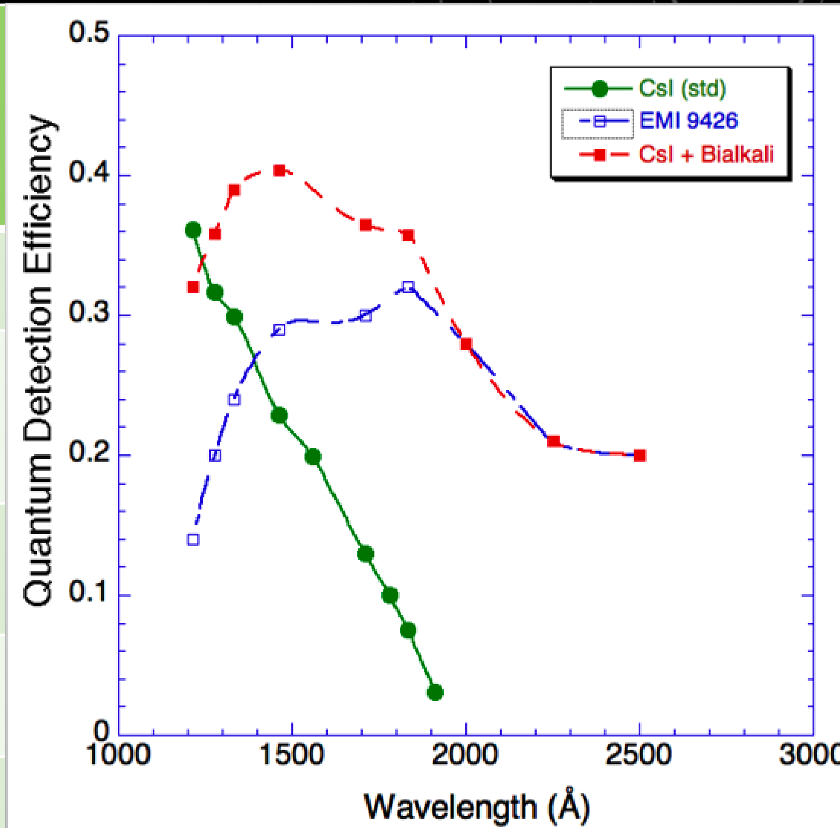

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Particle Background Reduction

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.

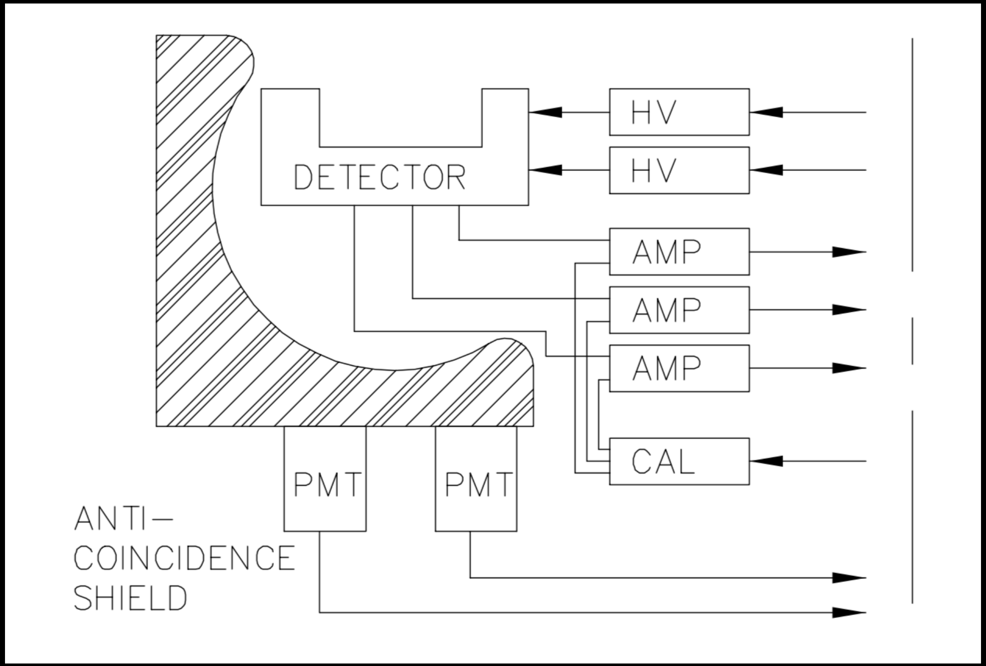
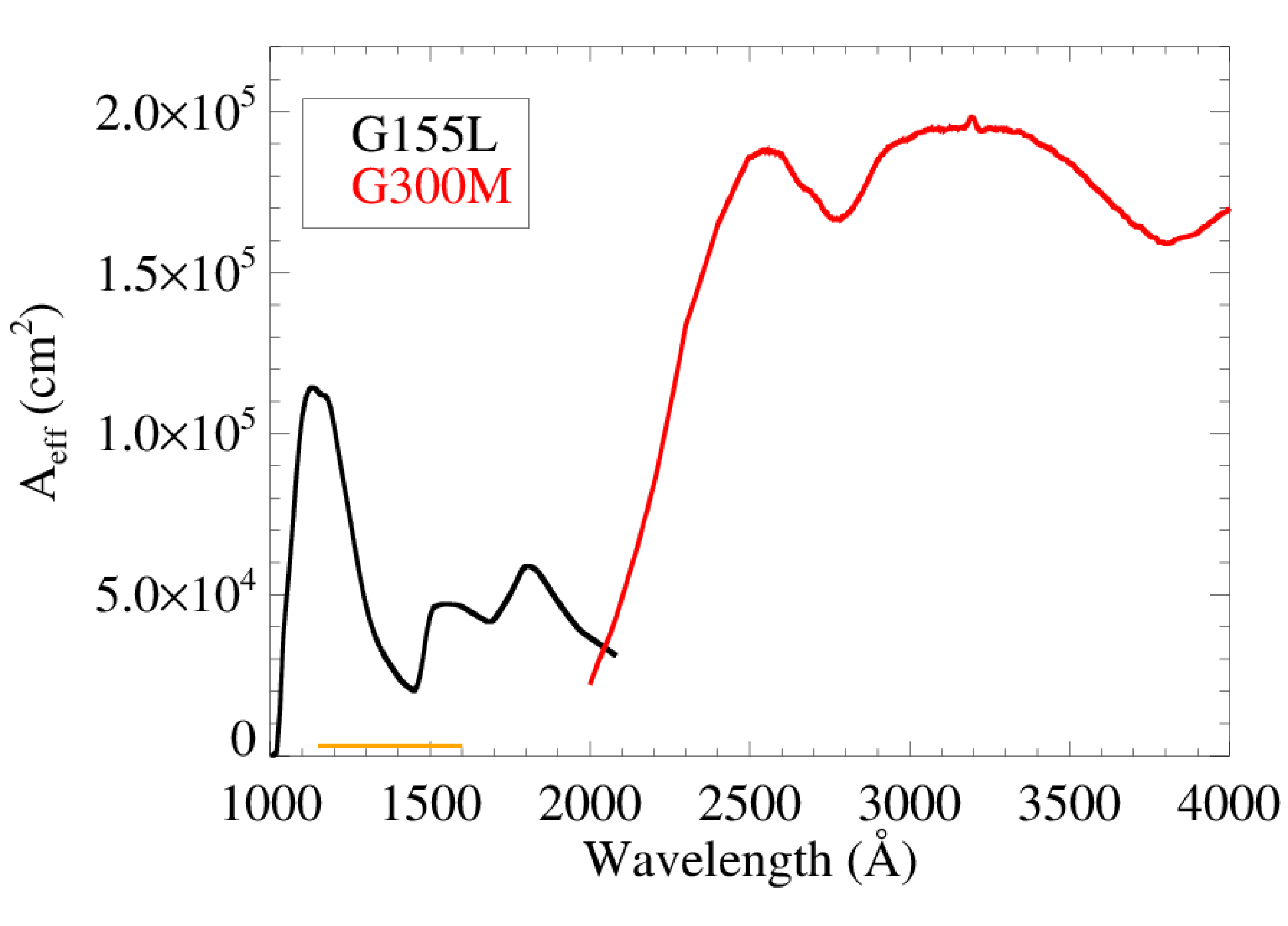


Illustration of the anti-coincidence shield flown on the EURD instrument in 1997. 85% rejection of muon events in ground tests, MCP background rate ~0.06 cm^{-2} sec^{-1} (Bowyer et al 1997).

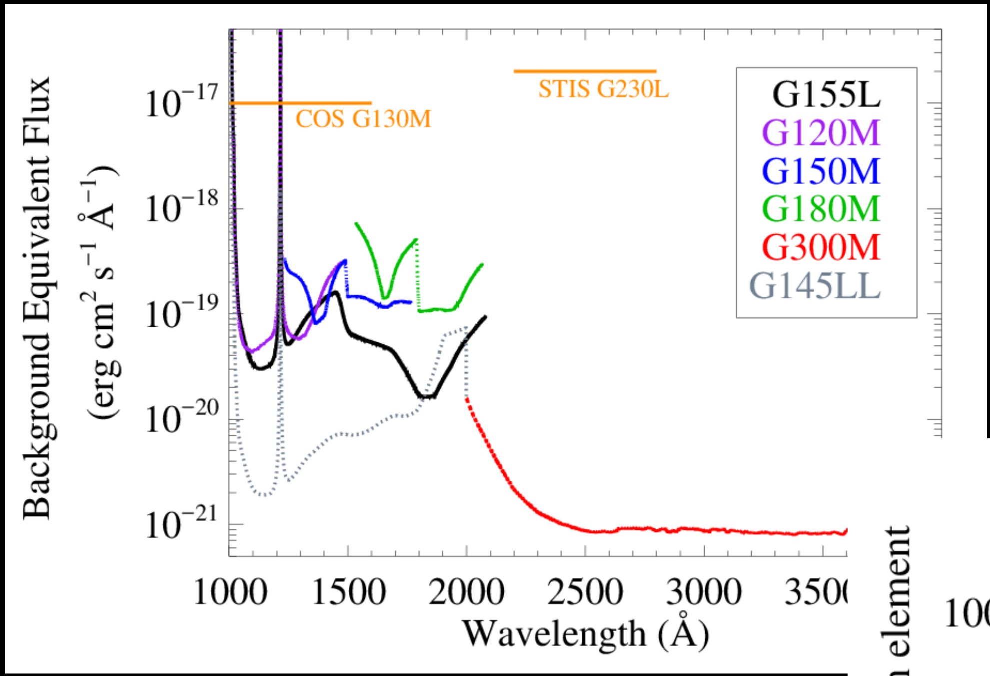
The timing resolution with photon counting MCP detectors is at the 100ps level. High energy particle events look like single events and can be discriminated with high efficiency by <u>amplitude rejection and by timing coincidence.</u> A combination of radiation shielding, amplitude thresholding, coincidence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

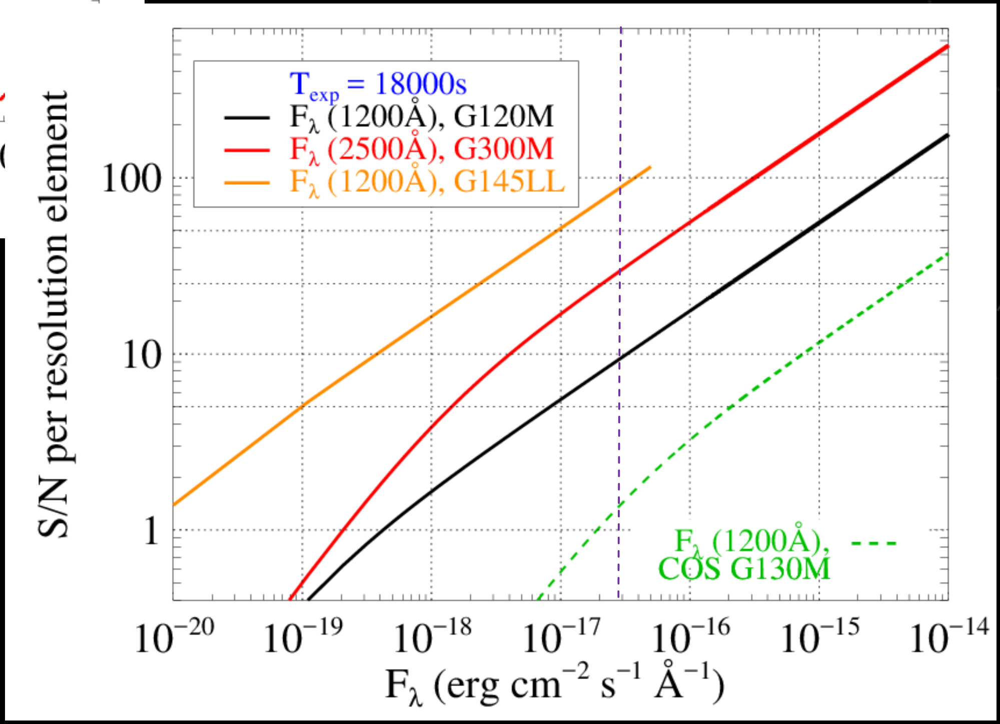
Slide from Ossy Siegmund – UC Berkeley

LUMOS Performance



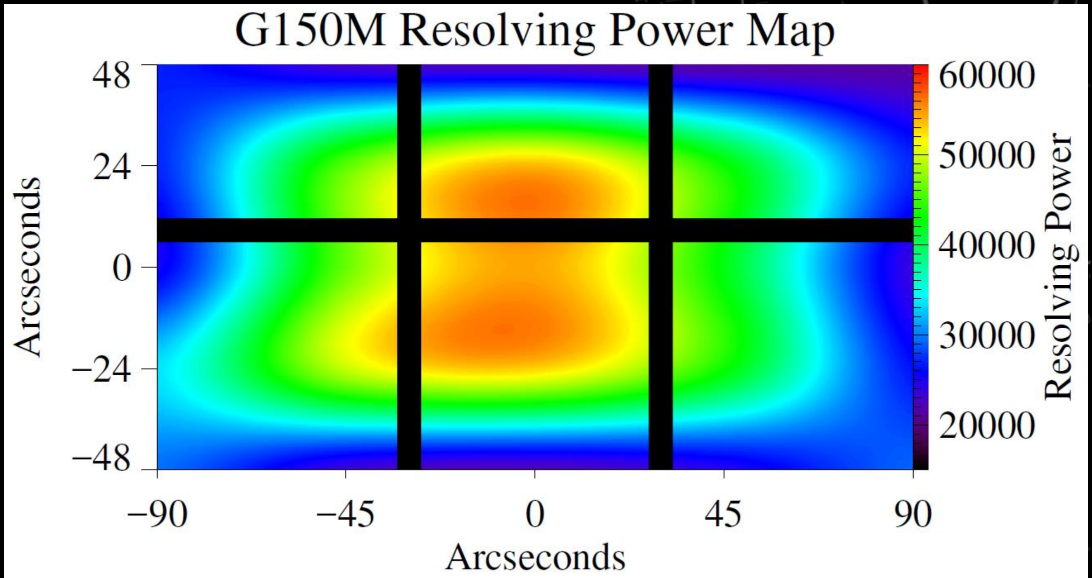
LUMOS Performance

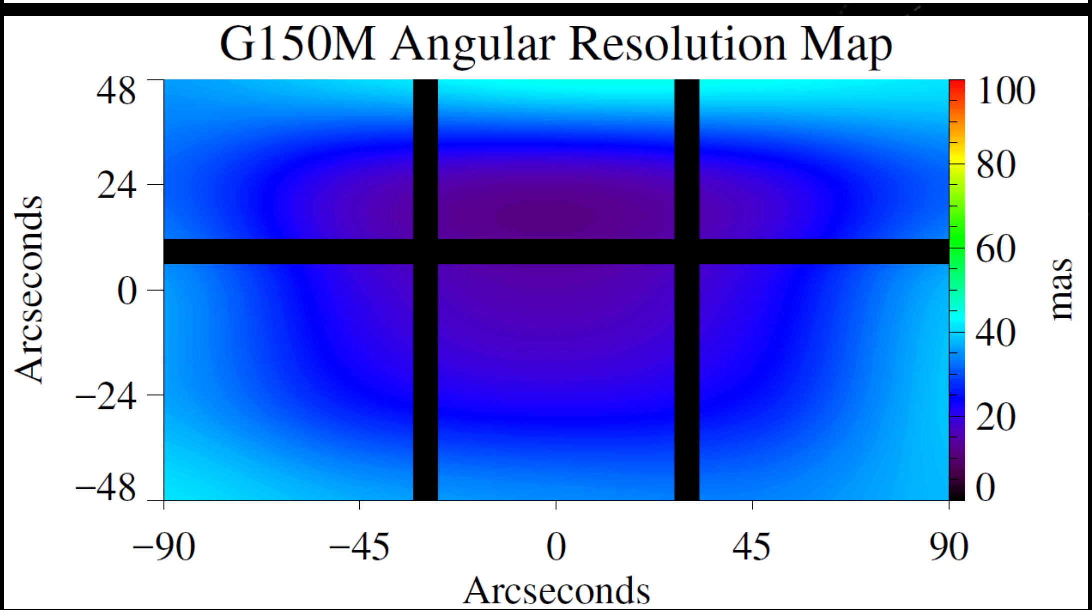




LUMOS Performance**

- $R \geq$ *HST*-COS everywhere in FOV
  - Meets STDT spectral resolution spec over > 80% of the 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)**

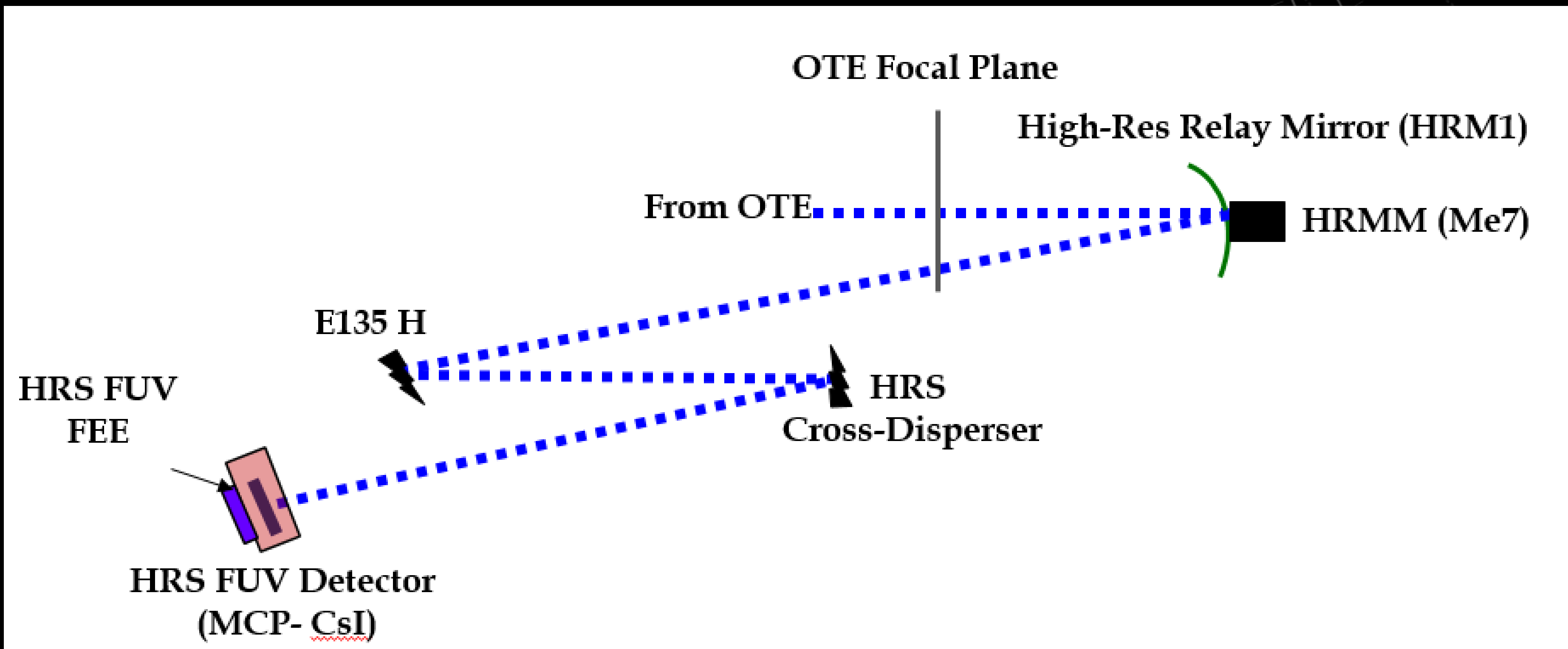




- Angular resolution < STDT spec for 95% of the FOV
- Each microshutter is ~110 mas (clear) in height, so each is a "long slit" aperture (~4-10 XD resols/shutter).

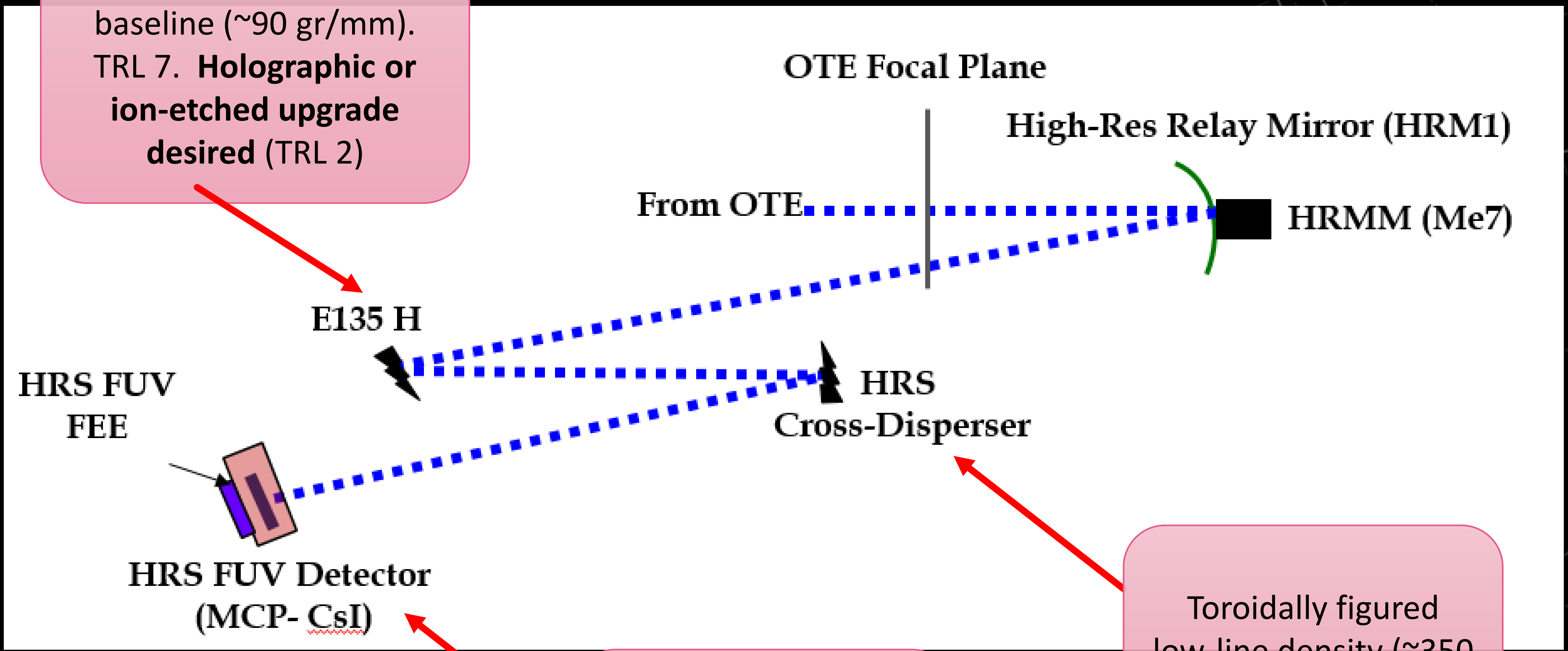
  - **(Figures represent the average over the bandpass, not the peak)

LUMOS High-Resolution Channel: E135H



LUMOS High-Resolution Channel

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

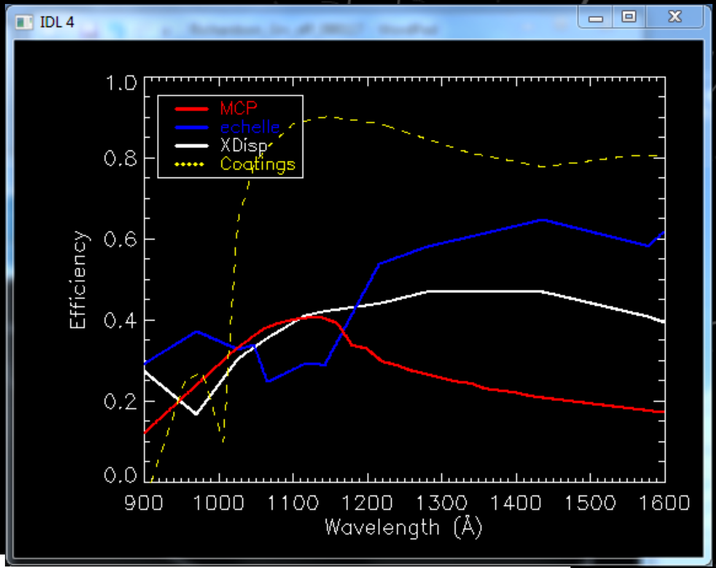


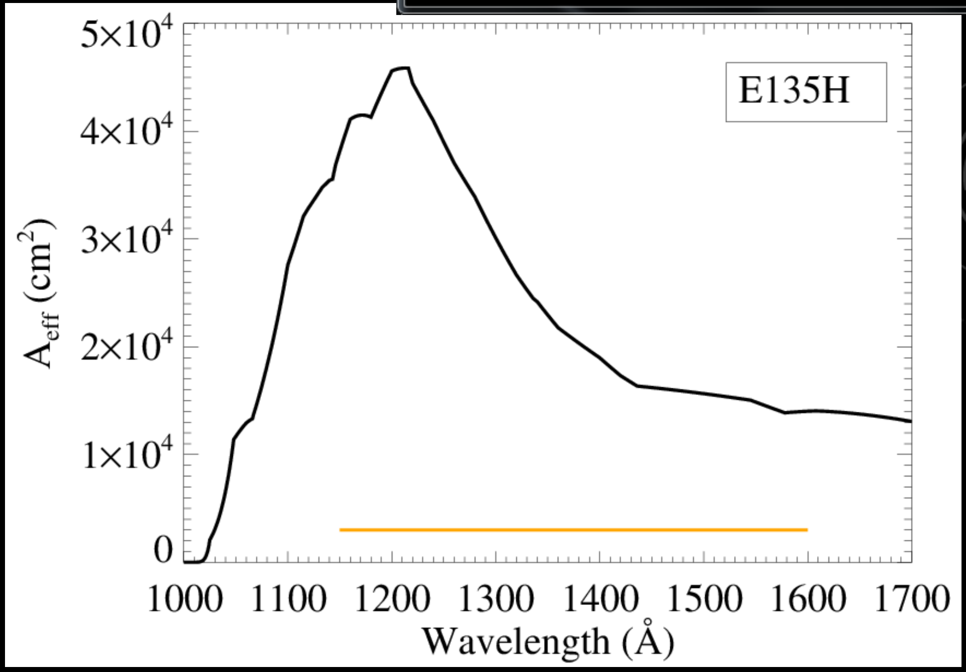
Toroidally figured low-line density (~350 gr/mm). J-Y. TRL 7

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 x 10^{-19} erg cm^{-2} s^{-1} $Å^{-1}$ (ignoring echelle scatter)





LUMOS High-Resolution Performance

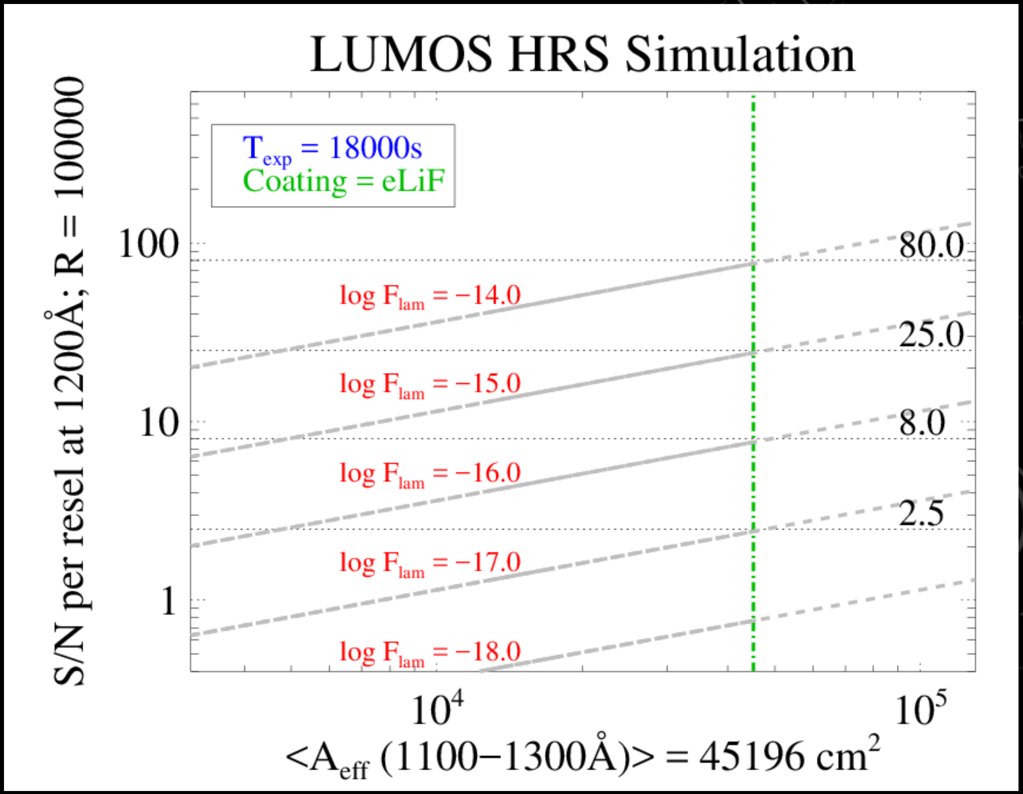
Prototypical Observation:

$F_\lambda \approx 1 \times 10^{-15}$ 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)



POLLUX Science Requirements

- SNR=10 for flux 1e-17 erg/s/cm2 in the NV line (124 nm) in a brown dwarf within 40 pc and dispersion 100,000 in 10,000 seconds

LUMOS HRS: SNR = 16.8 POLLUX FUV/FUV = 10.7

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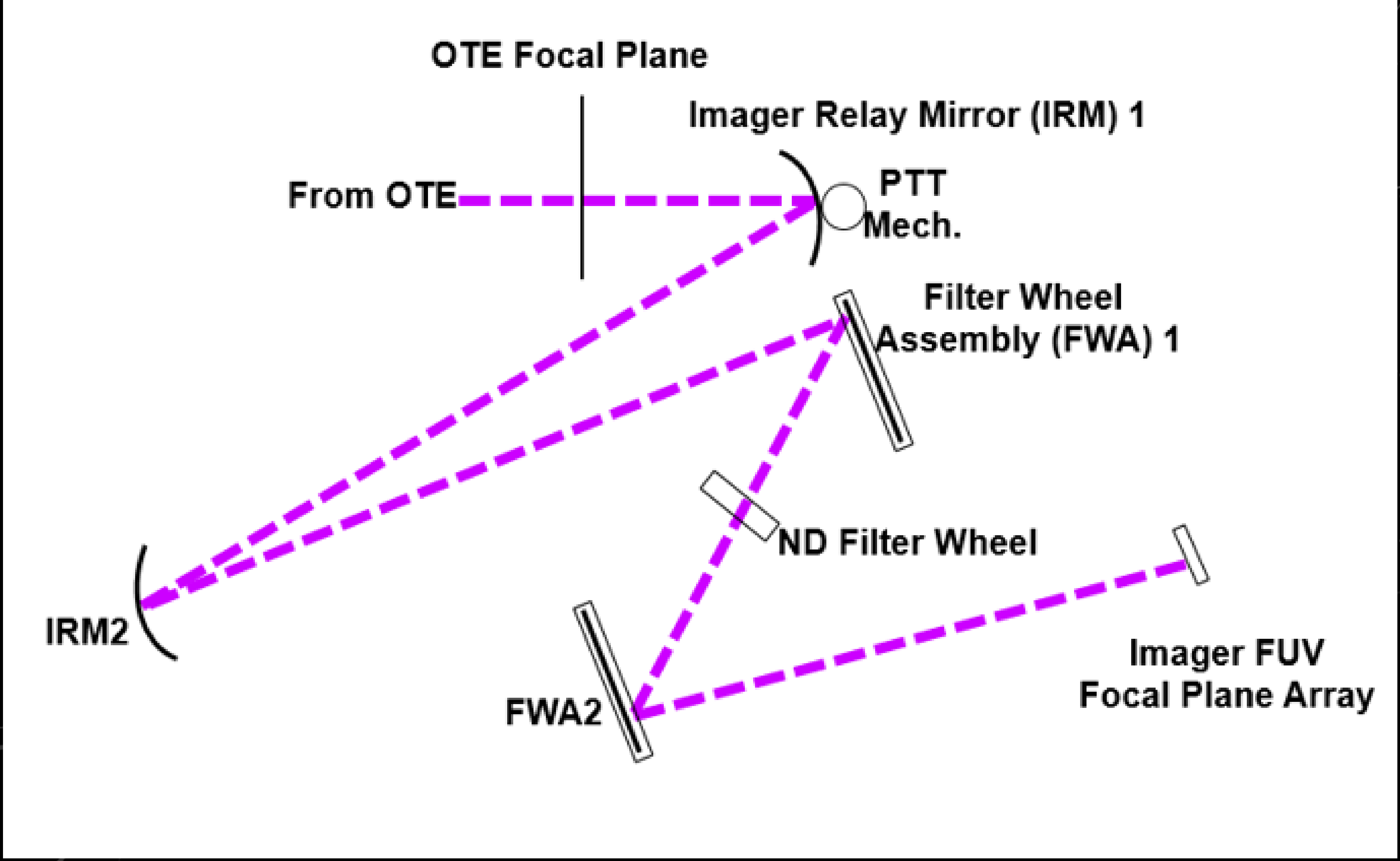
- S/N per resolution element of 100** integrating for 1 hour a flux of 10^-14 erg cm^-2 s^-1 A^-1 (**fixed pattern noise significant for S/N > 50 / resol)

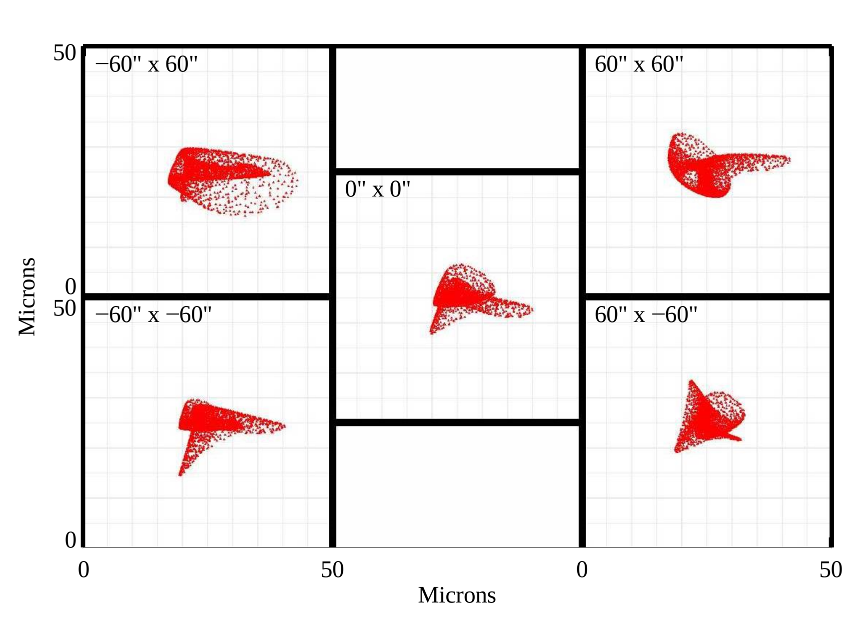
LUMOS HRS: SNR = 35 POLLUX EUV/FUV = 22

LUMOS FUV Imager



LUMOS Performance

FUV Imager Spot Sizes:



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)

Crossover mode images MSA through Imaging system for targeting and field screening (no band filters, but ND filters included for BOP)

LUMOS Performance Summary

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%	5%	5%	5%	5%	5%	10%
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′)**

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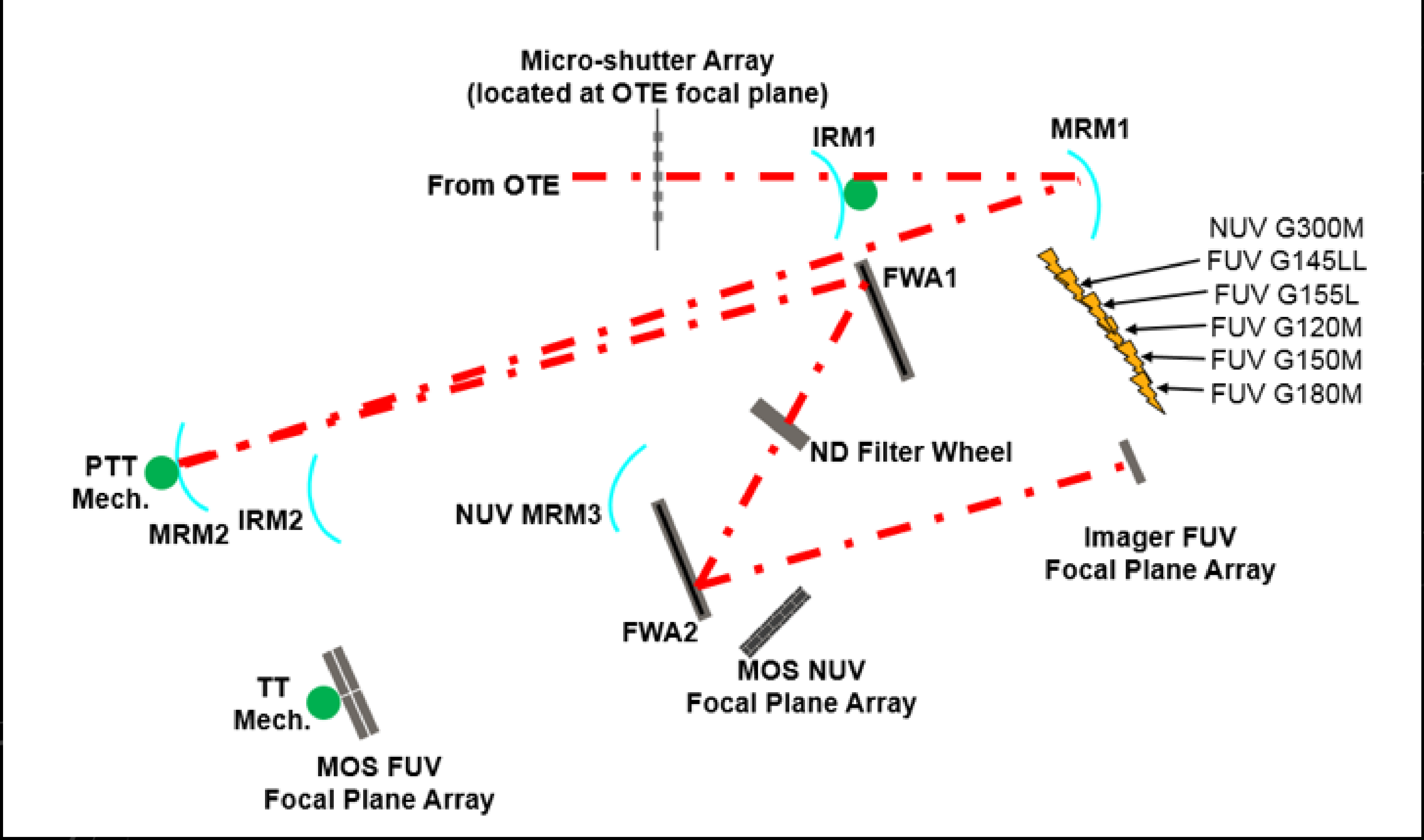
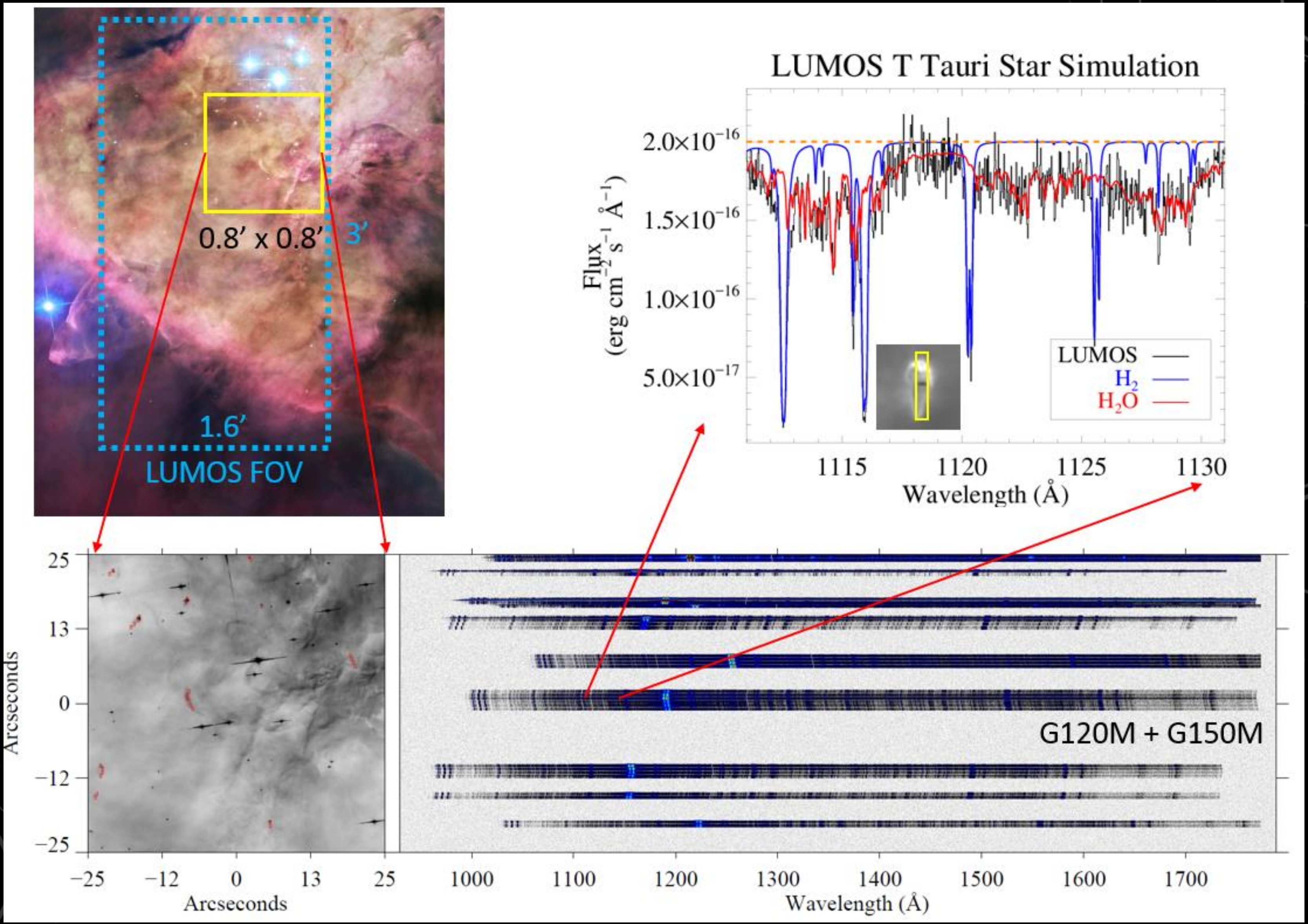
Peak Throughput	5% 7.5%	5% 7.5%	5% 7.5%	5% 7.5%	5% 7.5%	5% 12%	10% 11%
Field of View	2′ × 2′ **(3′ × 1.6′)**	2′ × 2′ **(3′ × 1.6′)**	2′ × 2′ **(3′ × 1.6′)**	2′ × 2′ **(3′ × 1.6′)**	2′ × 2′ **(3′ × 1.6′)**	2′ × 2′ **(1.3′ × 1.6′)**	2′ × 2′ **(2′ × 2′)**

LUMOS Target Acquisition and BOP



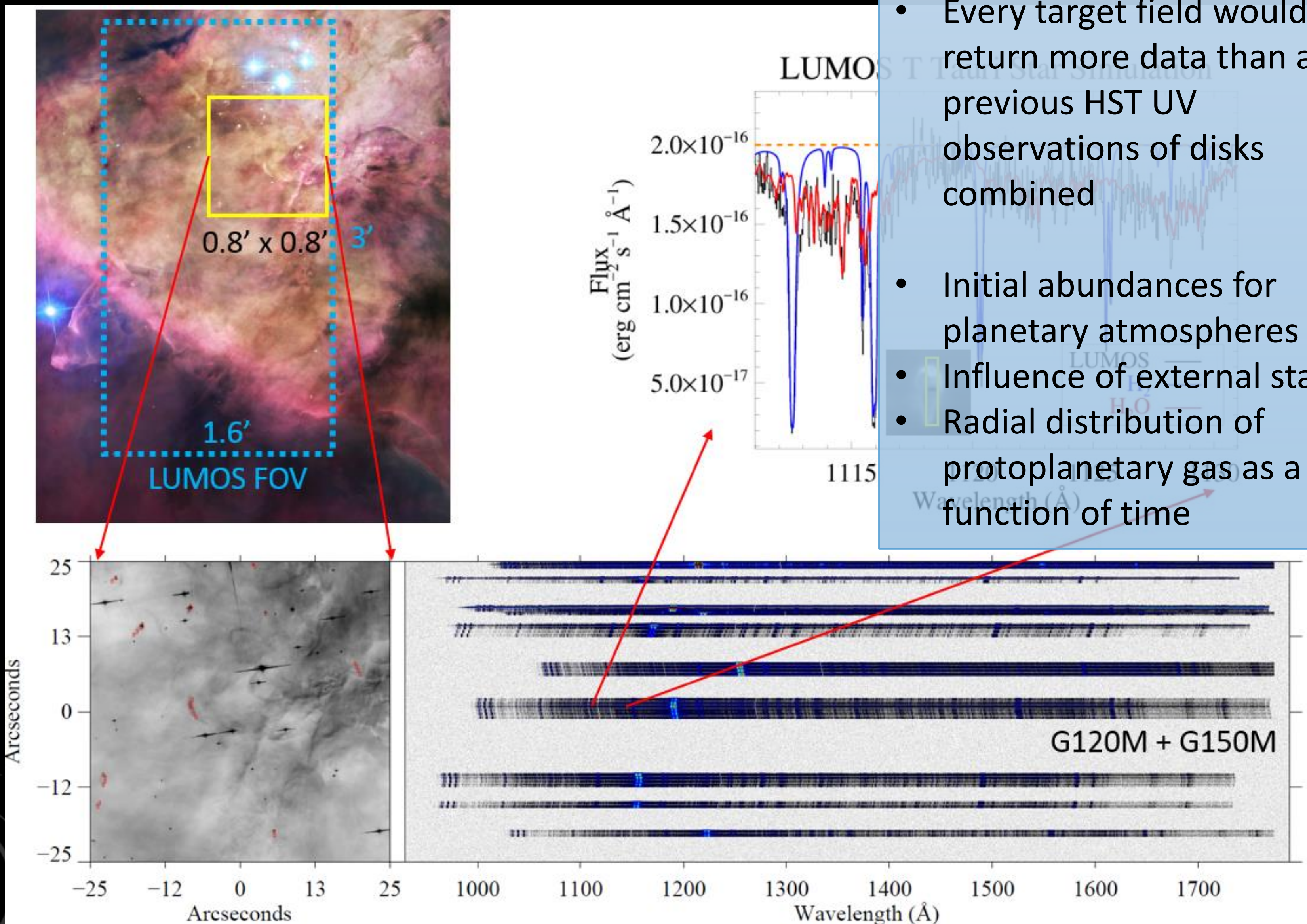
LUMOS MOS Example Science Program #1: Surveying the Birthplace of Planets



LUMOS MOS Example Science: Surveying the Birthplace of Planets

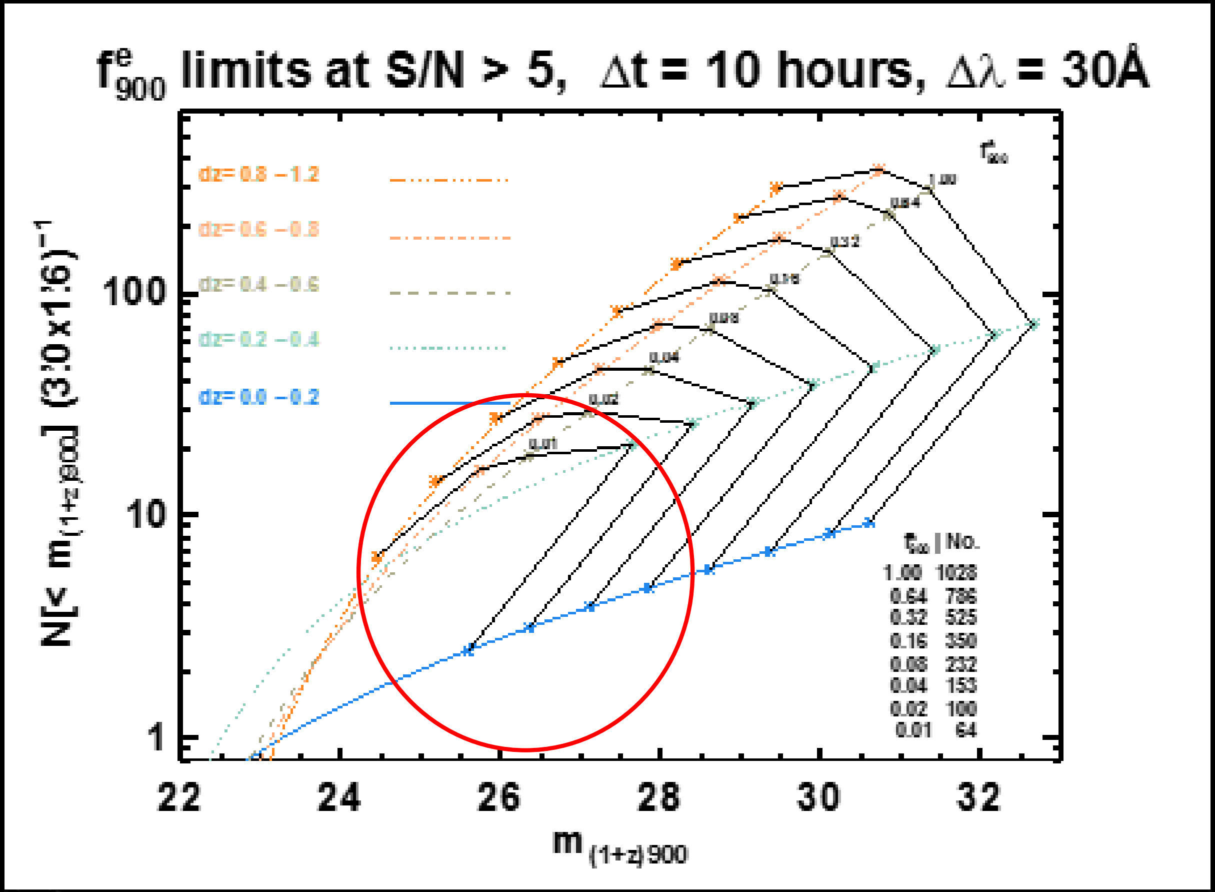
- Map 5 regions in Orion from 1 – 10 Myr, 10s – 100s protoplanetary disks in each
- Every target field would return more data than all previous HST UV observations of disks combined

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



LUMOS MOS Example Science Program #2:

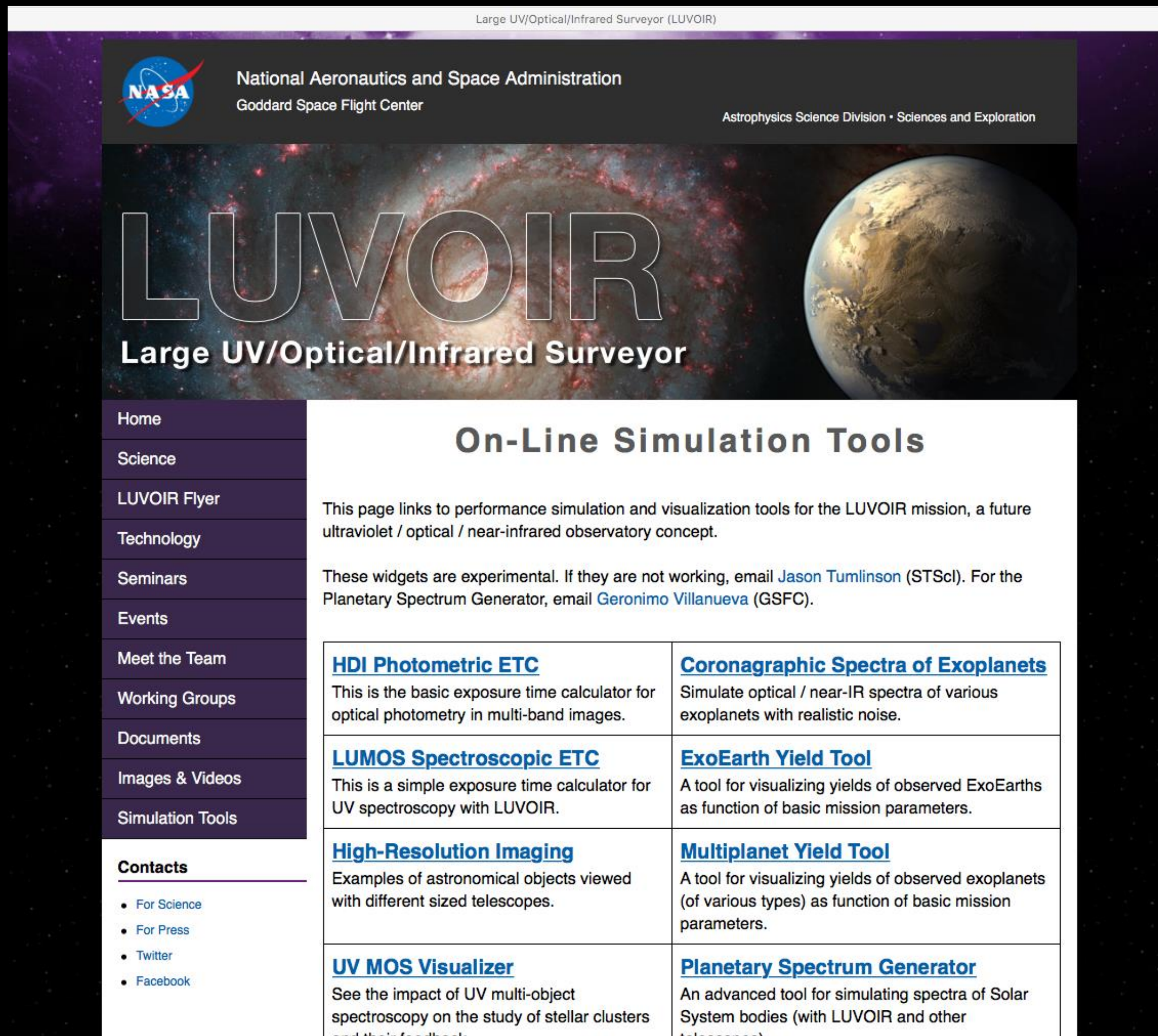
Lyman Continuum Luminosity Function Evolution 0.1 < z < 1.2



- ~600 ionizing radiation detections from 0 < z < 1.2 galaxies to f_{esc} = 1%
  - **> 100x current, contested sample**
  - **$f_{esc}(z)$**

LUVOIR online simulation tools

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



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)

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 $arcmin^2$, 100-400nm

--Peak $A_{eff} > 10^5$ cm^2 in FUV and $> 1.8 \times 10^5$ 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