SPIE.

LUVIS: Ultraviolet SMEX mission optimized for the Lyman UV

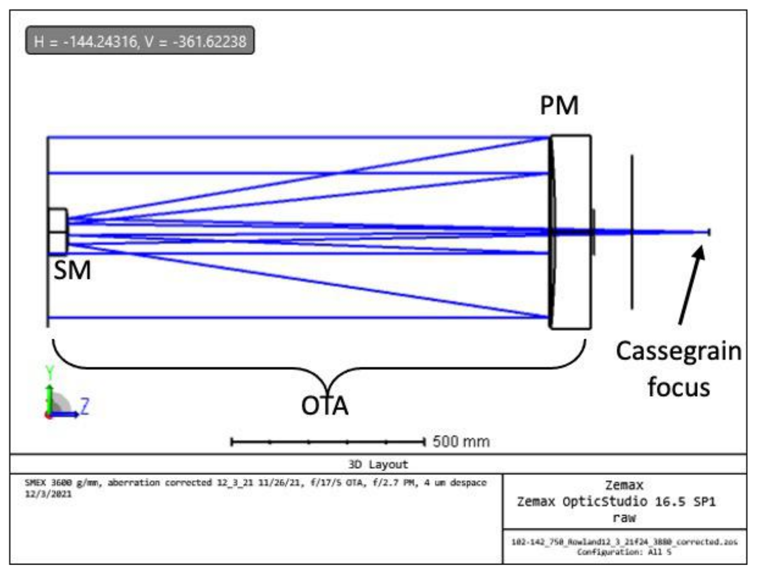
Stephen E. Kendrick[a]*, Robert A. Woodruff[b], Tony Hull[c],, Daewook Kim[d], Gopal Vasudevan[e], Sara R. Heap[f]
[a]Kendrick Aerospace Consulting, [b]Woodruff Consulting, [c]University of New Mexico, [d]University of Arizona, [e]Lockheed Martin, [f]University of Maryland

Overview of the LUVIS Mission

LUVIS is a SMEX-class mission consisting of a 0.5-m f/24 Cassegrain optical telescope assembly (OTA) feeding a Lyman UV/ far-UV spectrometer. Continued access to UV-enabled science beyond Hubble is critical with the IR/O/UV Great Observatory not slated for launch until the 2045 time period.

- ***Simple optical train*** *with a minimum of reflections and optics: PM, SM, Slit, Grating, Detector*
  - *OTA diffraction limited at ~ 0.8 micrometer*
  - *Minimum number of mechanisms: telescope door, SM 3-DOF (Degrees of Freedom) mechanism, and vacuum door for detector*
  - *Classical baffle design; sun avoidance > 95 degrees*
- ***Lyman UV spectrograph*** *(~102-140 nm) with a 6 arc min long slit*
  - *A long slit imaging spectrometer in a Rowland configuration*
  - *Single blazed holographic spherically concave grating*
  - *Resolving Power (RP) of 20,000*
  - *Micro-channel Plate (MCP) detector (CsI photocathode)*
  - *Photon counting with time-tagging*
- ***Orbit trades*** *are continuing but a TESS-like orbit is currently baselined*

Two-Mirror Cassegrain Telescope



0.5-m Optical Telescope Assembly (OTA) aperture provides the light-gathering power to reach galaxies with near-UV fluxes as low as 10^{-14} erg/s/cm^2/Å (and lower with long time exposures).

LUVIS Science Objectives[1-2] and Derived Requirements

- **The key LUVIS science objective is to study galaxies and the circumgalactic medium (CGM) thru far-UV spectroscopic observations such as of the O VI doublet (103.2, 103.8 nm).** **(see question 2 below)**
  - **LUVIS can help address 10 of the 24 key scientific questions posed by Astro2020:**

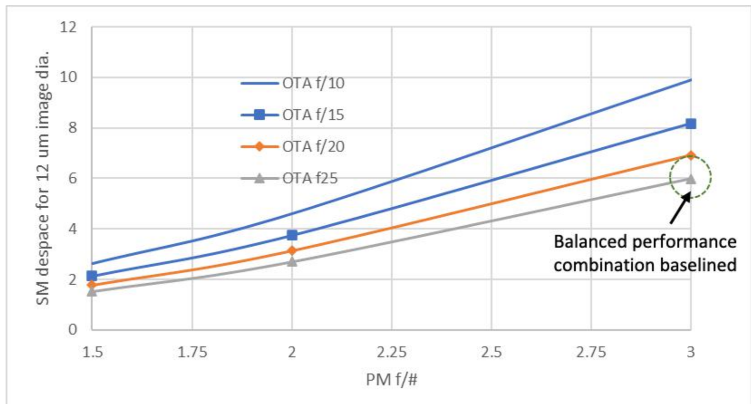
1. How did the intergalactic medium and the first sources of radiation evolve cosmic dawn through the epoch of reionization?
2. **How do gas, metals, and dust flow into, through, and out of galaxies?** ***(key LUVIS goal)***
3. How do supermassive black holes form and how is their growth coupled to the evolution of their host galaxies?
4. What are the properties of individual planets, and which processes lead to planetary diversity?
5. How do habitable environments arise and evolve within the context of their planetary systems?
6. How do star-forming structures arise from, and interact with, the diffuse ISM?
7. What are the most extreme stars and stellar populations?
8. How does multiplicity affect the way a star lives and dies?
9. What would stars look like if we view them like we do the Sun?
10. How do the Sun and other stars create space weather?

- The derived requirements and implementation approach:
  - Requires observing in the Far and Lyman-UV (102-140 nm)
  - FOV of 6 arc minutes length for mapping CGM interaction with galaxies, etc.
  - 0.5-m aperture telescope with minimum reflections (3) for the necessary sensitivity
  - RP of 20,000 over a 115 mm detector implies a grating with 3000 lines/mm
  - MCP detector with CsI photocathode for the desired spectral range, efficiency, and red-light rejection (solar blind); time-tagging of data for post correction of position
  - Fine Guidance Sensor to aid spacecraft body pointing line of sight; 15 arc min FOV
  - Line-of-sight control of spacecraft (S/C) – bus jitter, etc.

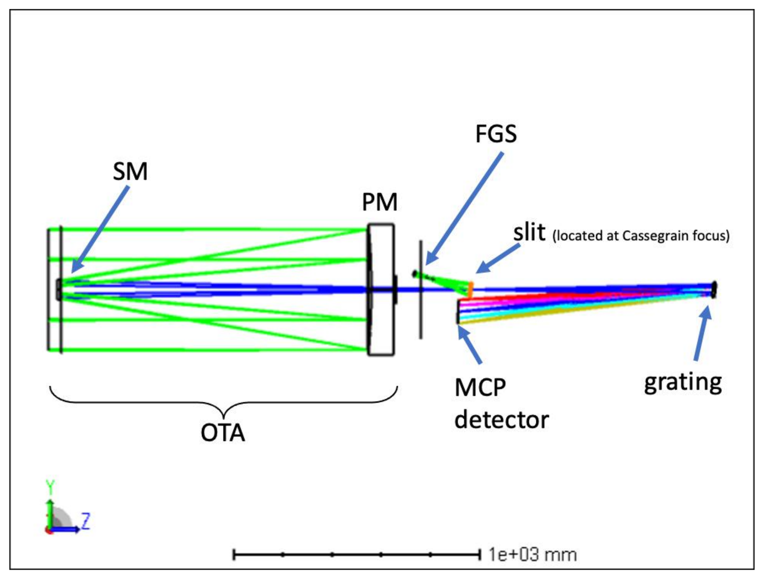
Lyman UV Imaging Spectrograph (LUVIS) instrument design approach and performance

LUVIS Optical Design with ray trace[3]

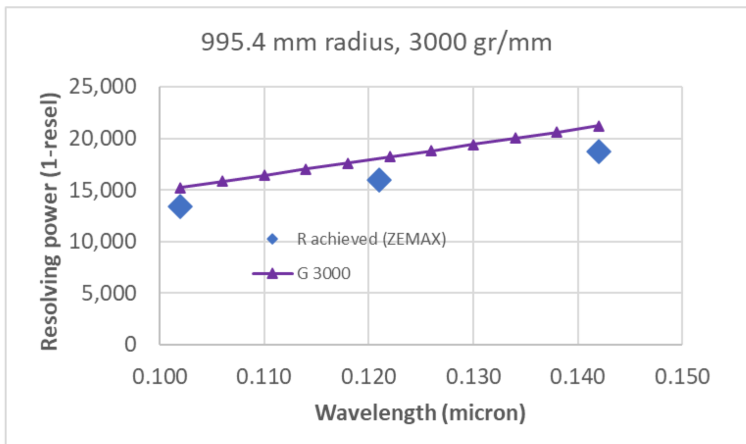
The f/24 0.5-m aperture telescope images through a slit onto a concave grating with Resolving Power of 20,000 and detected with a micro-channel plate.



OTA focus stability key to practical design. Trades were performed to determine the OTA f/# and the PM f/# that increases despace tolerance > 5-microns. f/24 was selected for the OTA and f/3.0 for the PM based on performance and manufacturability and packaging



2-mirror Cassegrain OTA with 6 arcmin slit and Rowland grating imaging on a Micro-channel Plate



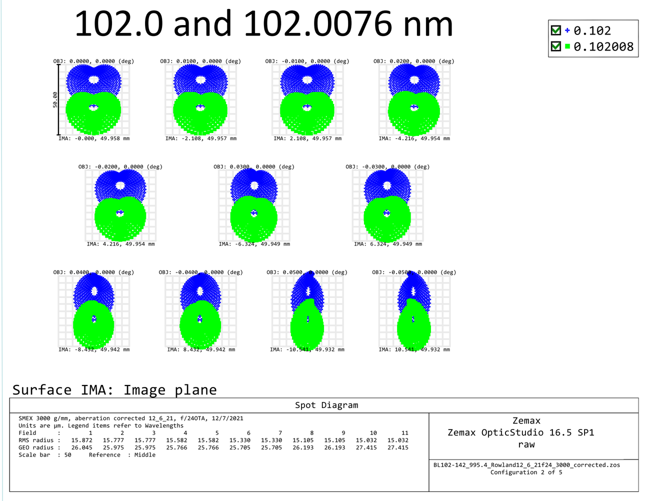
Rowland grating designed for Resolving Power of 20,000 at ~140 nm

		CTE (/K)	dT (K)	d_focus (um)		despace
Defocus	BFL	4.52E-07	0.0	0.00	97% M55J, 3% Ti6A14V	
320.3 um	PM to SM	2.33E-07	-17.0	324.98	97% M55J, 3% Invar	5.00
waves rms	PM	7.00E-09	-10.0	-6.59	ZERODUR	
0.0200	SM	7.00E-09	-24.0	1.95	ZERODUR	
20 nm rms	Overall WFE with increase T level					

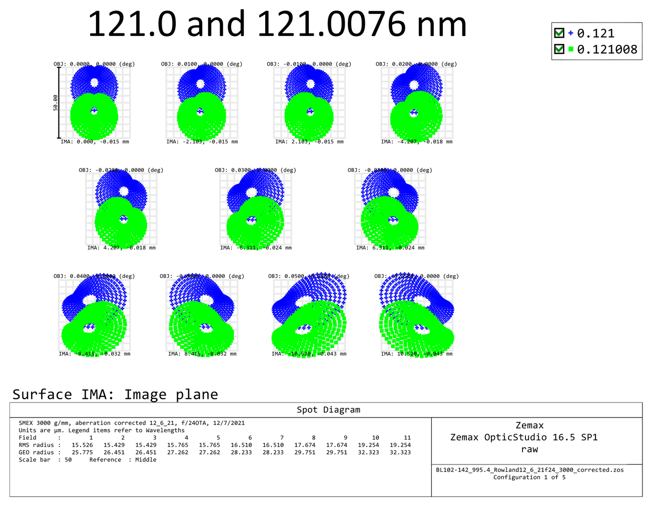
Specification of 5 µm SM despace allows ~ 20K axial temperature change from aligned condition

LUV Spectrometer Image Quality meets requirements over the full Field of View (FOV) and spectral band

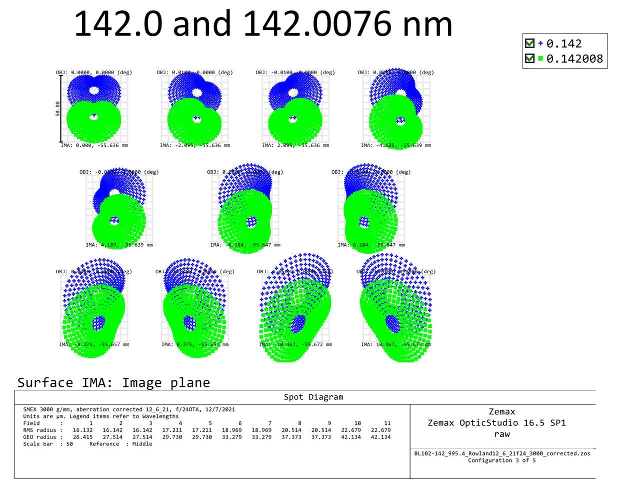
102.0 and 102.0076 nm



121.0 and 121.0076 nm

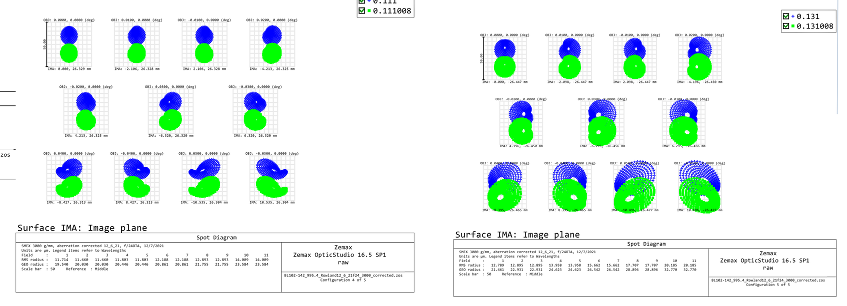


142.0 and 142.0076 nm



- Image at MCP: Two wavelengths separated by 0.076 Å
- Over 360 arc sec FOV (X-dispersion)
- Box = 50 microns = 0.88 arc sec

N.B. Improved correction @ 111.0 and 131.0 nm



High-TRL Technologies are available for the implementation

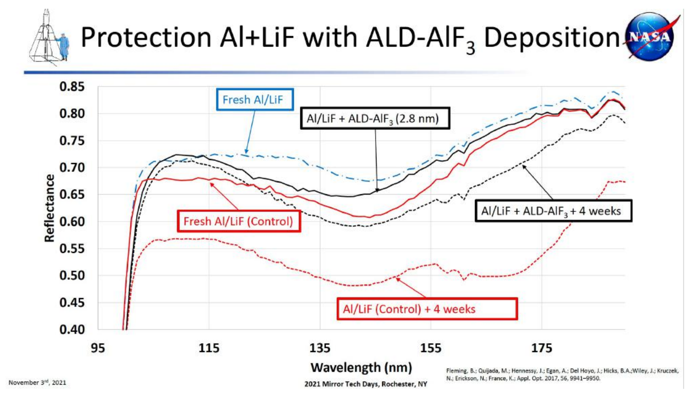
All of the component technologies are TRL 5 or higher

Spherical Concave Holographic Grating – provides high efficiency

- Concave grating with 3,000 lines/ mm chosen for the required Resolving Power of 20,000
- Blazed to enhance signal (tentatively at 120 nm wavelength)

Optical Coatings[4-8] are selected for the desired FUV bandpass

- Mirror optical coatings highly reflective in LUV/FUV
- Reflective coating is protected with a stable overcoating to prevent aluminum oxidation
- Aluminum coating plus LiF with Atomic Layer Deposition (ALD) protective overcoat is the baseline which has been demonstrated for 0.5-m class optics



Protected aluminum mirror coatings with LiF and an ALD-deposited AlF_3 overcoat offer high reflectivity (down to the O VI doublet and below) and are environmentally stable. The dotted black curve shows > 60% at 103 nm is a conservative assumption for our baseline reflectivity predictions.[6,7] Recent unpublished measurements show improved reflectivity.

A 50 mm x 115 (effective) mm curved MCP[9-11] is baselined as the detector

- Door in front of MCP maintains vacuum until opened on-orbit
- Place door in front of Cassegrain focus with whole spectrometer in vacuum housing -- allows small door
- MCP photocathode is solar blind which eliminates "red leak" concern
- Cesium Iodide photocathode
- 20 μm resolution element
- Cross-strip readout for faster data readout

Summary

LUVIS will accomplish priority UV science contained in the budget of a SMEX-class mission. LUVIS consists of a 0.5-m f/24 Cassegrain optical telescope assembly feeding a UV/ far-UV spectrometer using existing technologies.

REFERENCES

1. Heap, S., et al., "LUVIS: a small telescope to provide a UV pathway to discovery," SPIE Astronomical Telescopes & Instrumentation, (July 17, 2022).
2. Heap, S., et al., "LUVIS: a small telescope to provide a UV pathway to discovery," AAS 240th Meeting, (June 13, 2022).
3. Woodruff, R.A., et al., "Optical design of LUVIS for SMEX," SPIE Astronomical Telescopes & Instrumentation, 12181-5, (July 2022).
4. Hinton, P.C., Hennessy, J., et al., "New far-ultraviolet reflectivity measurements from ALD-deposited mirror coatings," Proc. SPIE 11821, (August 24, 2021).
5. Fleming, B., Quijada, M., et al., "New UV instrumentation enabled by enhanced broadband reflectivity lithium fluoride coatings," Proc. SPIE 9601, (August 24, 2015).
6. Fleming, B., Quijada, M., Hennessy, J., et al., "Advanced environmentally resistant lithium fluoride mirror coatings for the next generation of broadband space observatories," Applied Optics, Vol. 56, No. 36, pp 9941-9950, (December 20, 2017).
7. Quijada, Manuel, "Advances in developing mirror coating technologies for enhancing the FUV reflectance of protected aluminum coatings," 2021 Mirror Tech Days, (November 3, 2021).
8. Rodriguez de Marcos, L., Boris, D., et al., "Room temperature plasma-etching and surface passivation of far-ultraviolet Al mirrors using electron beam generated plasmas,", Optical Materials Express, pp. 740-756, (2021).
9. Cremer, T., Aviles, M., et al., "Large-area, high-resolution atomic layer deposited microchannel plates for UV imaging and particle identification in space science applications," Proc. SPIE 11821, (August 30, 2021).
10. Siegmund, O.H.W., Curtis, T., et al., "Development of sealed cross strip readout UV detectors," Proc. SPIE 11821, (August 24, 2021).
11. Davis, M., Siegmund, O.H., et al., "TRL6 testing of a curved borosilicate glass microchannel plate far-UV detector assembly for spaceflight," Proc. SPIE 11821, (August 24, 2021).

*skconsulting@comcast.net