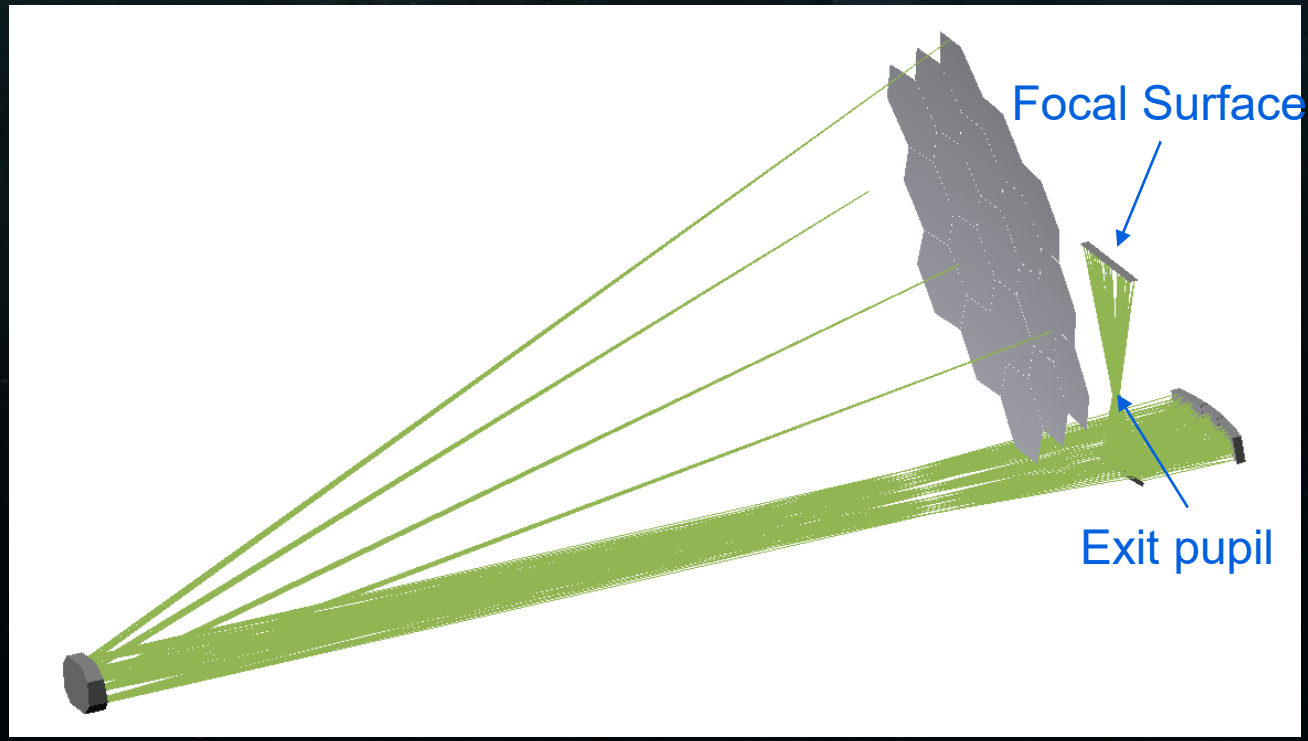
HWO Optical Design (telescope, UVI, HRI)

Breann Sitarski, Joe Howard, Jon Papa, and James Corsetti (GSFC)
Michael Rodgers (Synopsys/JPL)

HABITABLE WORLDS OBSERVATORY

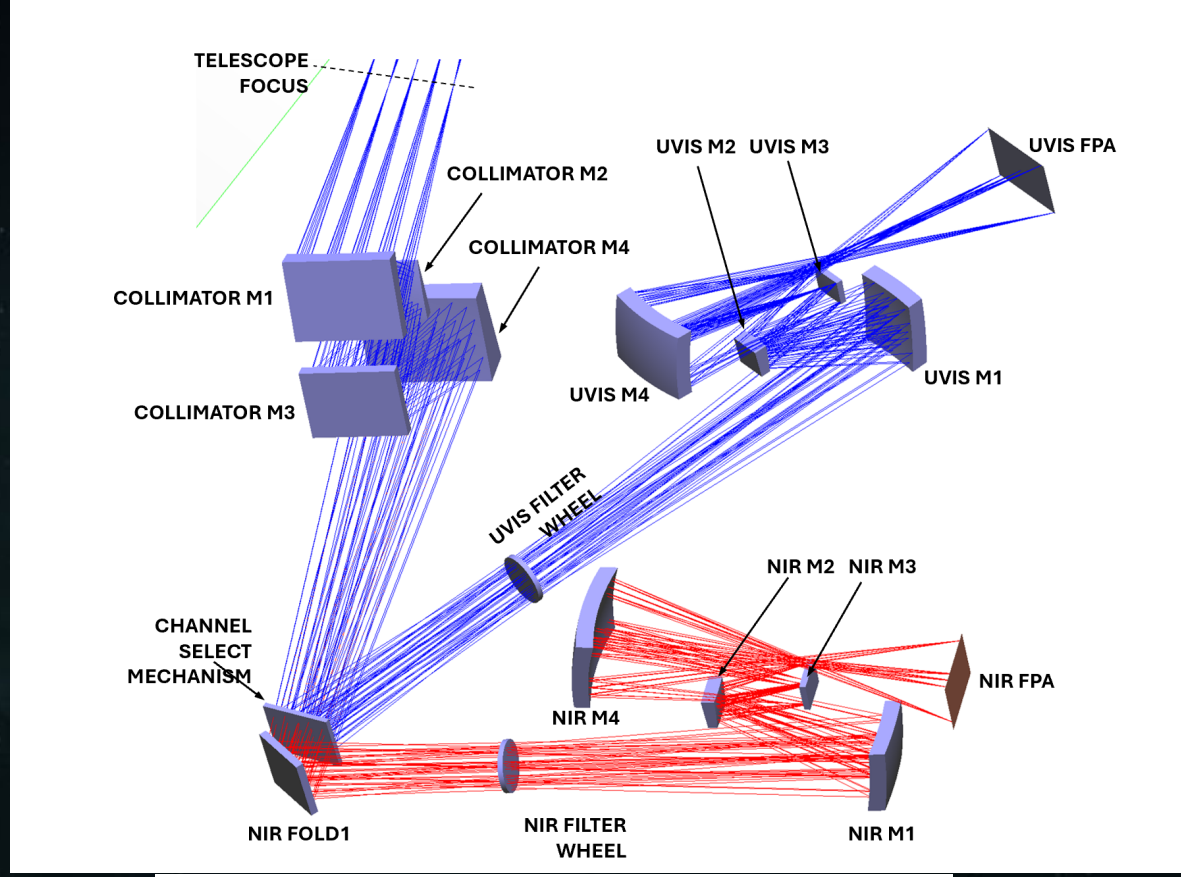
Telescope Design

- Off-axis, F/20 telescope with four optics to the telescope focal plane
  - 6 m inscribed diameter; 7.2 m circumscribed diameter
  - 19 hexagonal segments, 1.65 m point-to-point
  - 6 mm optical gap
- Leverages JWST and heritage
- Flat focal image



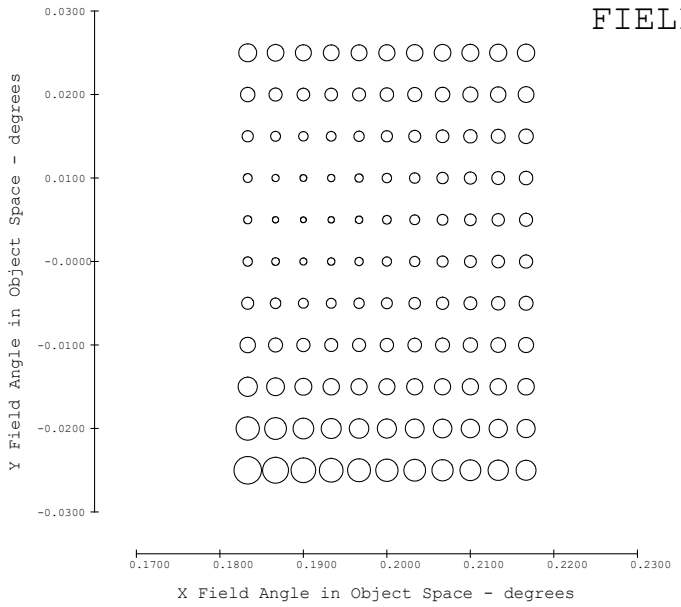
High-Resolution Imager (HRI)

- Design heritage from LUVOIR-B High Definition Imager (HDI) design
- 3’ x 2’ Field of View
- Channel select mechanism to give five operational modes:
  - NIR Transmissive
  - UVIS Reflective
  - 50/50 beamsplitter for simultaneous obs. over full wavelength range
  - Dichroic beamsplitter: simultaneous UVIS (400 – 800 nm) and NIR (800 nm – 1.6 µm)
  - Optimized UV reflective: Improved UV throughput



SPOT SIZE VARIATION OVER FOV

UVIS

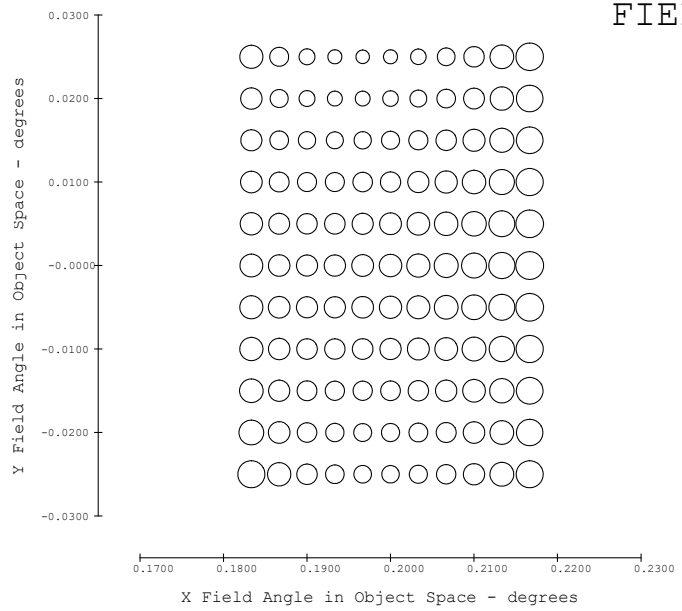


RMS SPOT DIAMETER
vs
FIELD ANGLE IN OBJECT SPACE
(mm)
Minimum = 0.0029483
Maximum = 0.014023
Average = 0.0072177
Std Dev = 0.0023042

RMS spot variation
= 2.53 mas

HRI_Mar28_EAC1_Mar24 _UVIS.len	RMS SPOT DIAMETER vs FIELD ANGLE IN OBJECT SPACE Minimum = 0.0029483 Maximum = 0.014023 Average = 0.0072177 Std Dev = 0.0023042
ORA 13-May-24	0.053mm

NIR



RMS SPOT DIAMETER
vs
FIELD ANGLE IN OBJECT SPACE
(mm)
Minimum = 0.0081638
Maximum = 0.016856
Average = 0.012954
Std Dev = 0.0019787

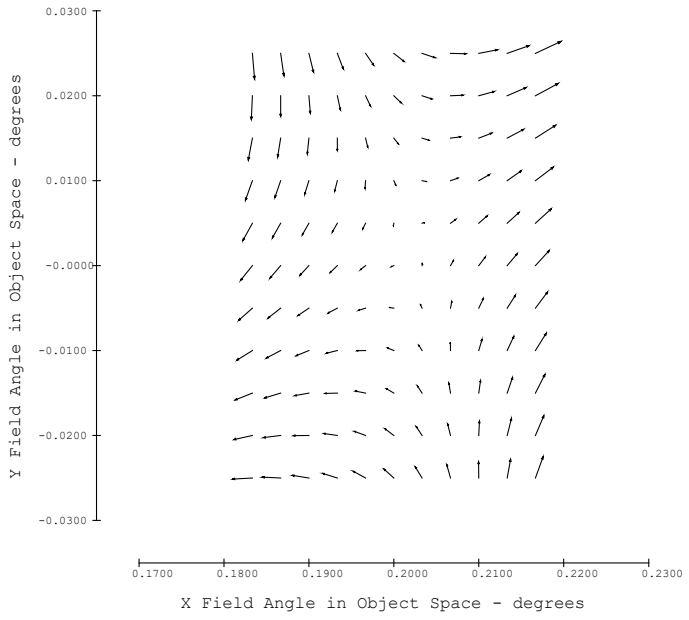
RMS spot variation
= 2.83 mas

HRI_Mar28_EAC1_Mar24 _NIR.len	RMS SPOT DIAMETER vs FIELD ANGLE IN OBJECT SPACE Minimum = 0.0081638 Maximum = 0.016856 Average = 0.012954 Std Dev = 0.0019787
ORA 13-May-24	0.063mm

HRI Grid Distortion

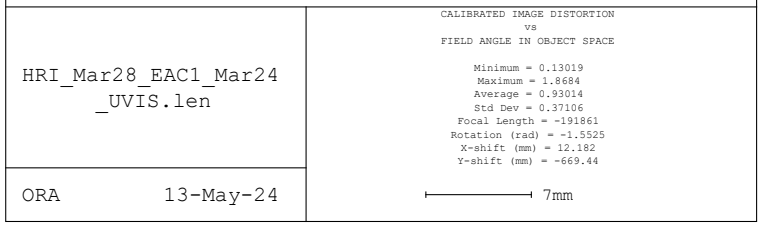
Arrows indicate the magnitude and direction of displacement with respect to nominal grid; values indicate magnitude of offset

UVIS

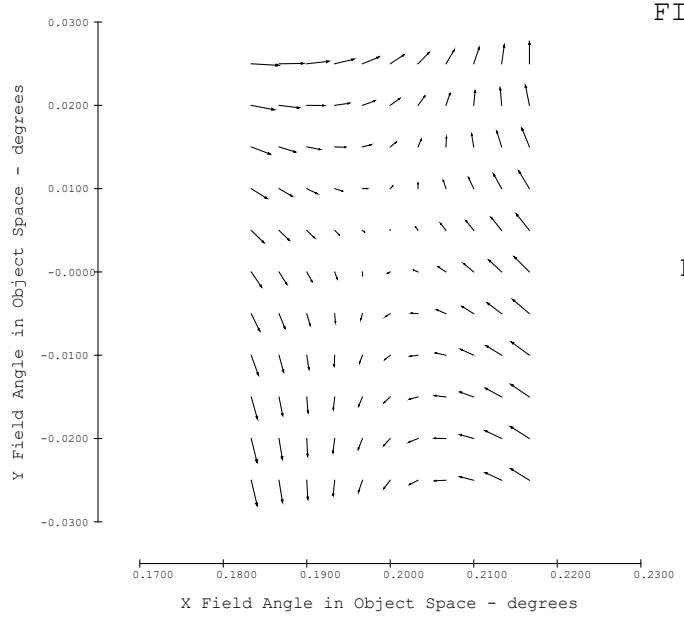


CALIBRATED IMAGE DISTORTION
vs
FIELD ANGLE IN OBJECT SPACE
(mm)
Minimum = 0.13019
Maximum = 1.8684
Average = 0.93014
Std Dev = 0.37106
Focal Length = -191861
Rotation (rad) = -1.5525
X-shift (mm) = 12.182
Y-shift (mm) = -669.44

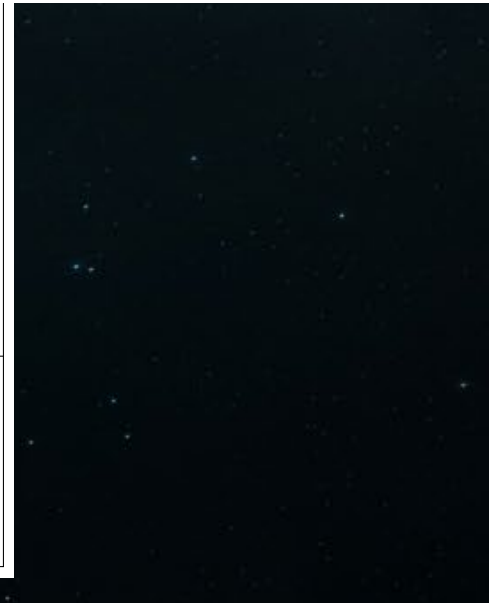


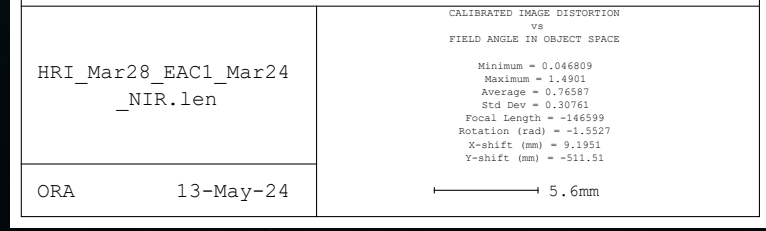


NIR



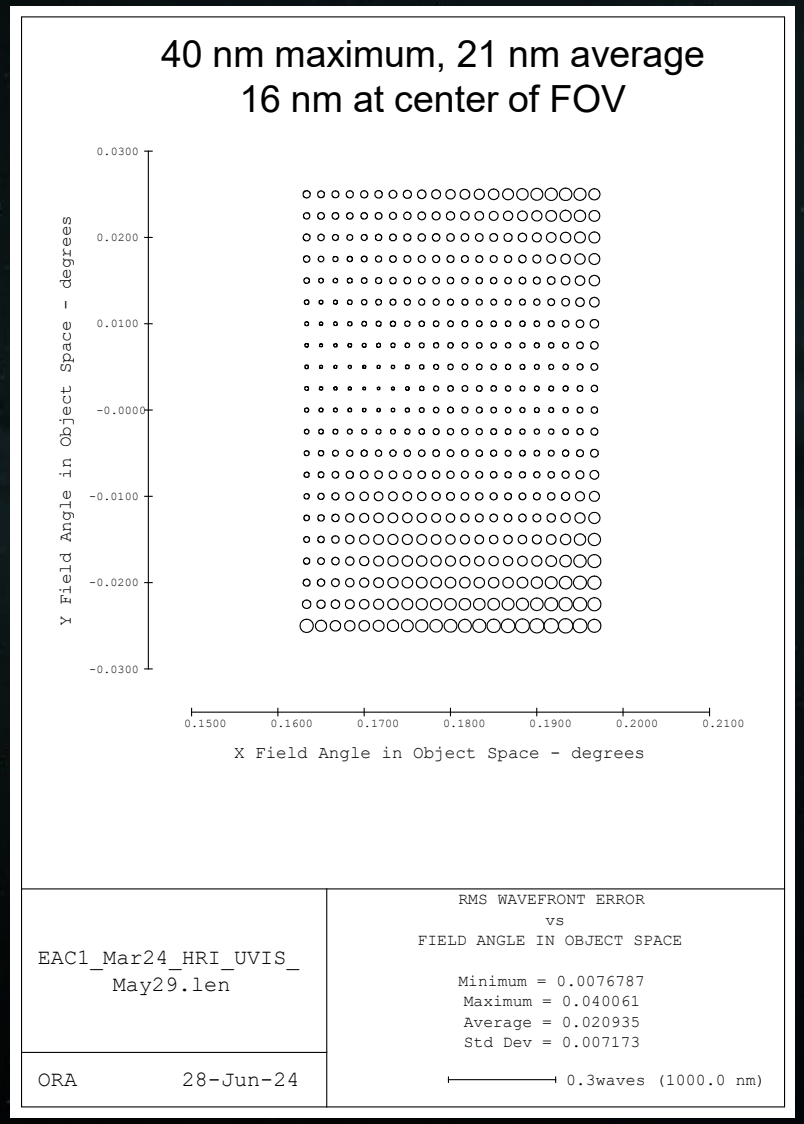
CALIBRATED IMAGE DISTORTION
vs
FIELD ANGLE IN OBJECT SPACE
(mm)
Minimum = 0.046809
Maximum = 1.4901
Average = 0.76587
Std Dev = 0.30761
Focal Length = -146599
Rotation (rad) = -1.5527
X-shift (mm) = 9.1951
Y-shift (mm) = -511.51



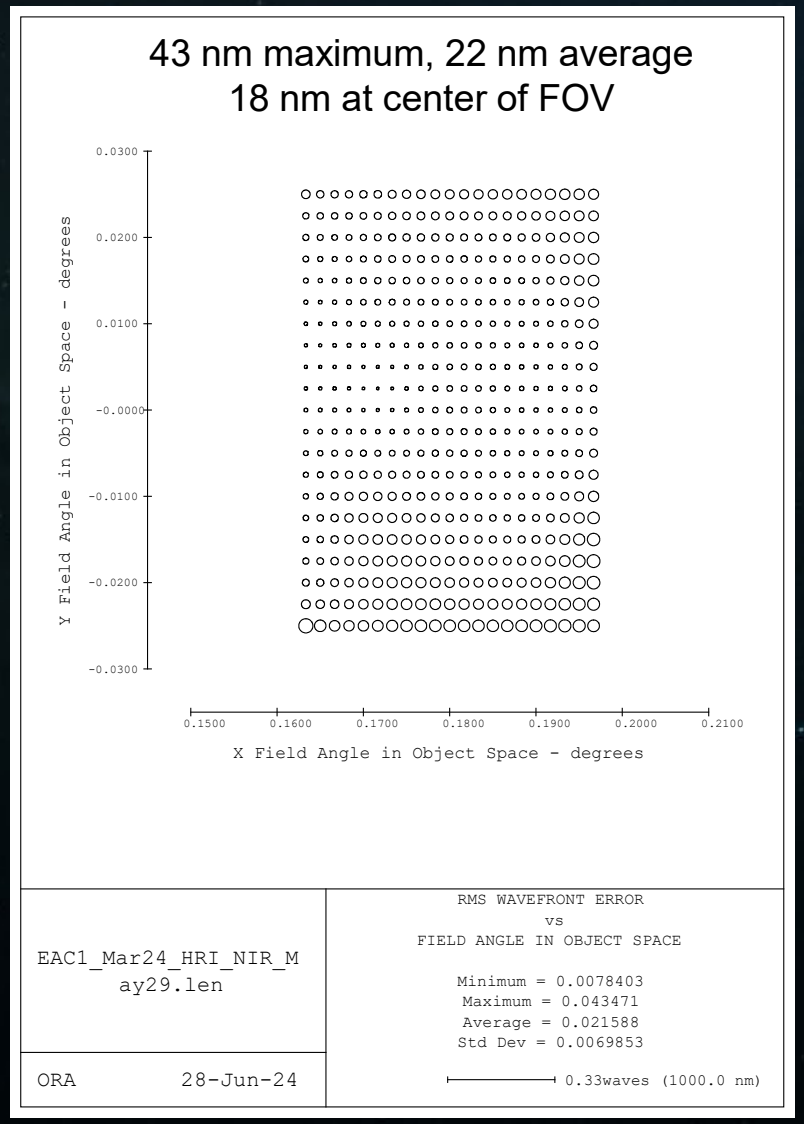


HRI RMS Wavefront Error

UVIS

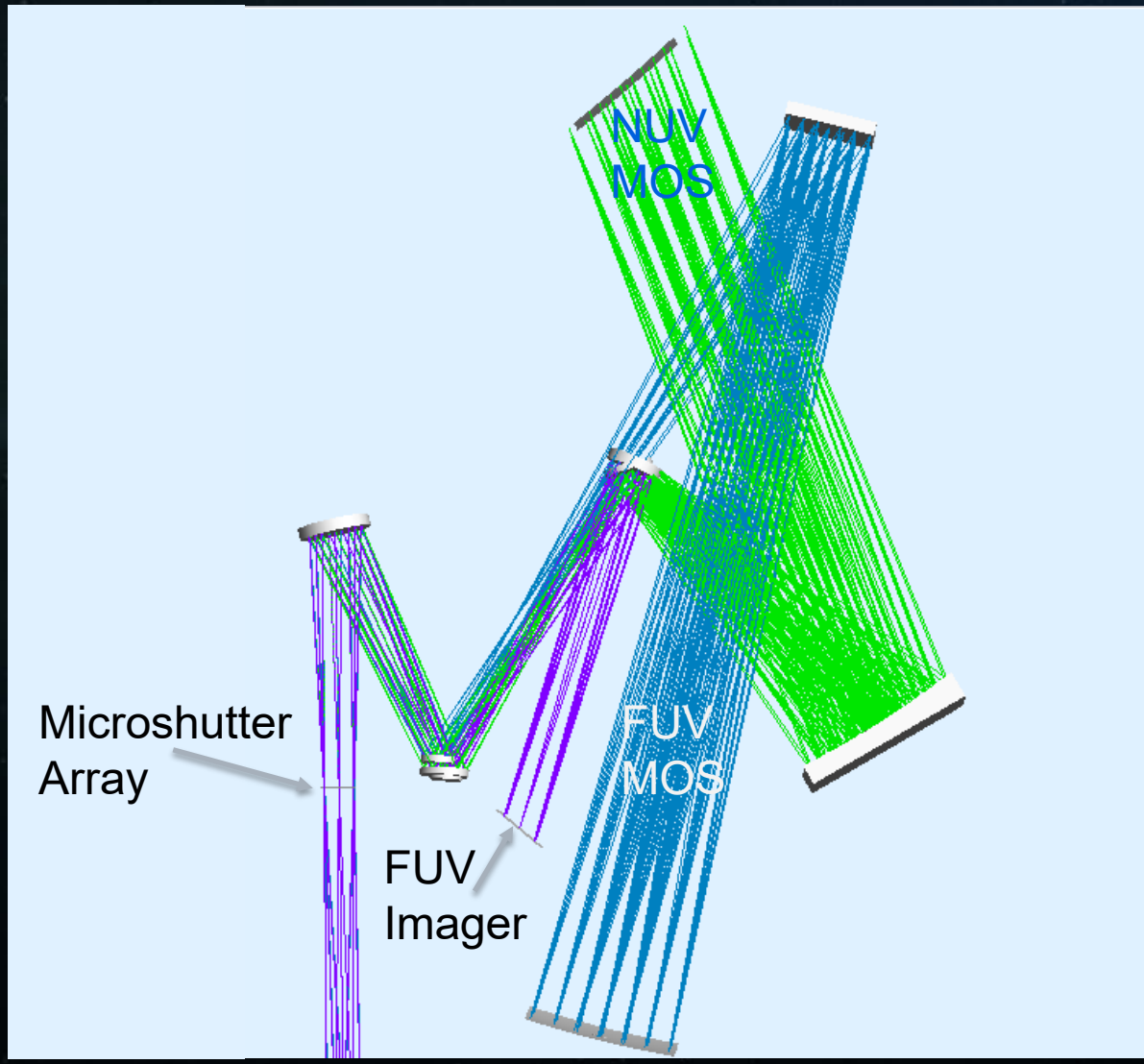


NIR



Ultraviolet Instrument (UVI)

- Design heritage from LUVOIR-B LUMOS
- 2’ x 2’ FOV
- Multiple arms
  - FUV Imager
  - Multi-Object Spectrographs in FUV and NUV
- Design was incomplete for EAC1
  - Completed one FUV MOS channel (G120M), one NUV MOS channel (G300M), and the FUV imager design
- Individual microshutters are 100 x 200 µm and formed into an 84 x 84 mm array
- Microchannel plates are consistent with the LUVOIR study (170 x 110 mm)



OPTICAL SPECIFICATIONS

Instrument Parameter	Units	G120M	G150M	G180M	G155L	G145LL	G165LL	G300M	G700L	FUV Imager
Optimized Spectral Bandpass	nm	100-140	130-170	160-200	100-200	100-200	110-200	200-400	400-1000	100-200
Field of View	arcmin	2 x 2	2 x 2	2 x 2	2 x 2	2 x 2	2 x 2	1.5 x 2 (A) 2 x 2 (B)	1.5 x 2 (A) 2 x 2 (B)	1.2 x 2 (A) 2 x 2 (B)
Spectral Resolving Power (λ/Δλ) [Required]	-	3.0×10^4	3.0×10^4	3.0×10^4	8000	500	500	2.0×10^4	1.5×10^4	-
Imaging Resolution [Required]	mas	50	50	50	50	50	50	50	50	50
LUMOS-B										
Effective Area, Peak	cm^2	8.6×10^4	3.8×10^4	4.4×10^4	8.4×10^4	5.1×10^4	-	9.0×10^4	8.4×10^4	$\sim 2.8 \times 10^4$
Effective Area, Central Wavelength	cm^2	8.1×10^4	2.8×10^4	4.4×10^4	2.5×10^4	8700	-	6.8×10^4	7.4×10^4	$\sim 2.8 \times 10^4$
Grating Ruling Density	lines/mm	2555	2630	2610	1060	50	-	865	349	-
Average Resolving Power (Full Field-of-View)	-	2.9×10^4	3.7×10^4	5.0×10^4	1.4×10^4	455	-	2.0×10^4	1.8×10^4	-
Average Resolving Power (Best 1' x 1')	-	4.0×10^4	5.2×10^4	5.9×10^4	1.7×10^4	537	-	3.3×10^4	2.8×10^4	-
Average Angular Resolution (Full Field-of-View)	mas	41	42	43	48	28	-	25	48	48
Average Angular Resolution (Best 1' x 1')	mas	31	32	33	39	23	-	23	41	40

Data: LUVOIR final report

- High-to-mid spectral resolution
- Various channels cover FUV and NUV

FUV MOS

- G120M design completed (100 – 140 nm bandpass, R = 30000 spectral resolving power)
  - Spot size < 50 mas requirement not met for EAC-1 design
  - Spectral resolving power > 3 x 10^4 as required
- 2 x 1 microchannel plate detector array

Instrument Parameter	Units	G120M	G150M	G180M	G155L	G145LL	G165LL
Optimized Spectral Bandpass	nm	100-140	130-170	160-200	100-200	100-200	110-200
Actual Spectral Bandpass	nm	93-159	111-189	141-219	93-267	93-210	110-270
Field of View	arcmin	2 x 2	2 x 2	2 x 2	2 x 2	2 x 2	2 x 2
Spectral Resolving Power (λ/Δλ) [Required]	-	3.0 x 10^4	3.0 x 10^4	3.0 x 10^4	8000	500	500
Imaging Resolution [Required]	mas	50	50	50	50	50	50
			LUMOS-B				
Effective Area, Peak	cm^2	8.6 x 10^4	3.8 x 10^4	4.4 x 10^4	8.4 x 10^4	5.1 x 10^4	-
Effective Area, Central Wavelength	cm^2	8.1 x 10^4	2.8 x 10^4	4.4 x 10^4	2.5 x 10^4	8700	-
Grating Ruling Density	lines/mm	2555	2630	2610	1060	50	-
Average Resolving Power (Full Field-of-View)	-	2.9 x 10^4	3.7 x 10^4	5.0 x 10^4	1.4 x 10^4	455	-
Average Resolving Power (Best 1' x 1')	-	4.0 x 10^4	5.2 x 10^4	5.9 x 10^4	1.7 x 10^4	537	-
Average Angular Resolution (Full Field-of-View)	mas	41	42	43	48	28	-
Average Angular Resolution (Best 1' x 1')	mas	31	32	33	39	23	-

NUV MOS

- G300M design (200 – 400 nm bandpass, R = 20000 spectral resolution)
- 8K x 8K CMOS detectors at 6.5 µm pixel pitch in a 2 x 7 tiled formation
- Spot size < 50 mas requirement met
- Spectral resolution > 20000 at all wavelengths

Instrument Parameter	Units	G300M	G700L
Optimized Spectral Bandpass	nm	200-400	400-1000
Actual Spectral Bandpass	nm	193-460	340-1000
Field of View	arcmin	1.5 x 2 (A) 2 x 2 (B)	1.5 x 2 (A) 2 x 2 (B)
Spectral Resolving Power (λ/Δλ) [Required]	-	2.0×10^4	1.5×10^4
Imaging Resolution [Required]	mas	50	50
Effective Area, Peak	cm^2	9.0×10^4	8.4×10^4
Effective Area, Central Wavelength	cm^2	6.8×10^4	7.4×10^4
Grating Ruling Density	lines/mm	865	349
Average Resolving Power (Full Field-of-View)	-	2.0×10^4	1.8×10^4
Average Resolving Power (Best 1' x 1')	-	3.3×10^4	2.8×10^4
Average Angular Resolution (Full Field-of-View)	mas	25	48
Average Angular Resolution (Best 1' x 1')	mas	23	41

FUV Imager

- 2’ x 2’ FOV
- Spot sizes < 50 mas requirement met

Instrument Parameter	Units	FUV Imager
Optimized Spectral Bandpass	nm	100-200
Actual Spectral Bandpass	nm	100-200
Field of View	arcmin	1.2 x 2 (A) 2 x 2 (B)
Spectral Resolving Power (λ/Δλ) [Required]	-	-
Imaging Resolution [Required]	mas	50
Effective Area, Peak	cm^2	~2.8×10^4
Effective Area, Central Wavelength	cm^2	~2.8×10^4
Grating Ruling Density	lines/mm	-
Average Resolving Power (Full Field-of-View)	-	-
Average Resolving Power (Best 1' x 1')	-	-
Average Angular Resolution (Full Field-of-View)	mas	48
Average Angular Resolution (Best 1' x 1')	mas	40