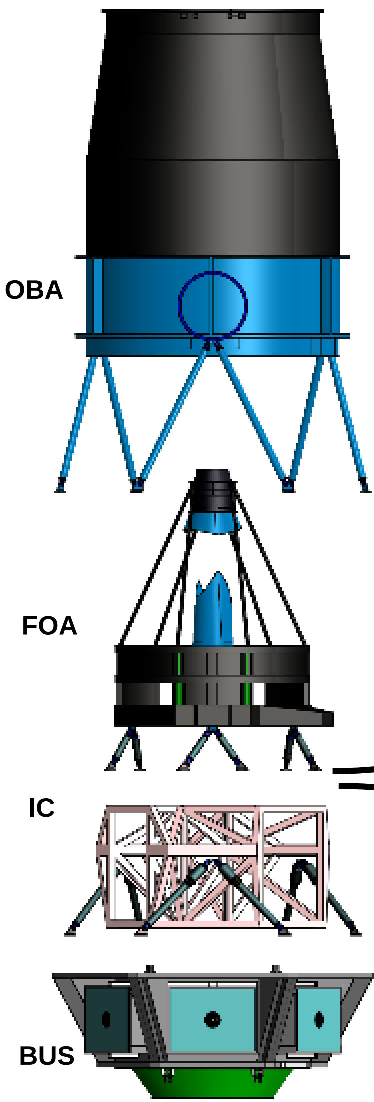
Wide Field Instrument Overview
Design, performance, risk reduction status

D. Content

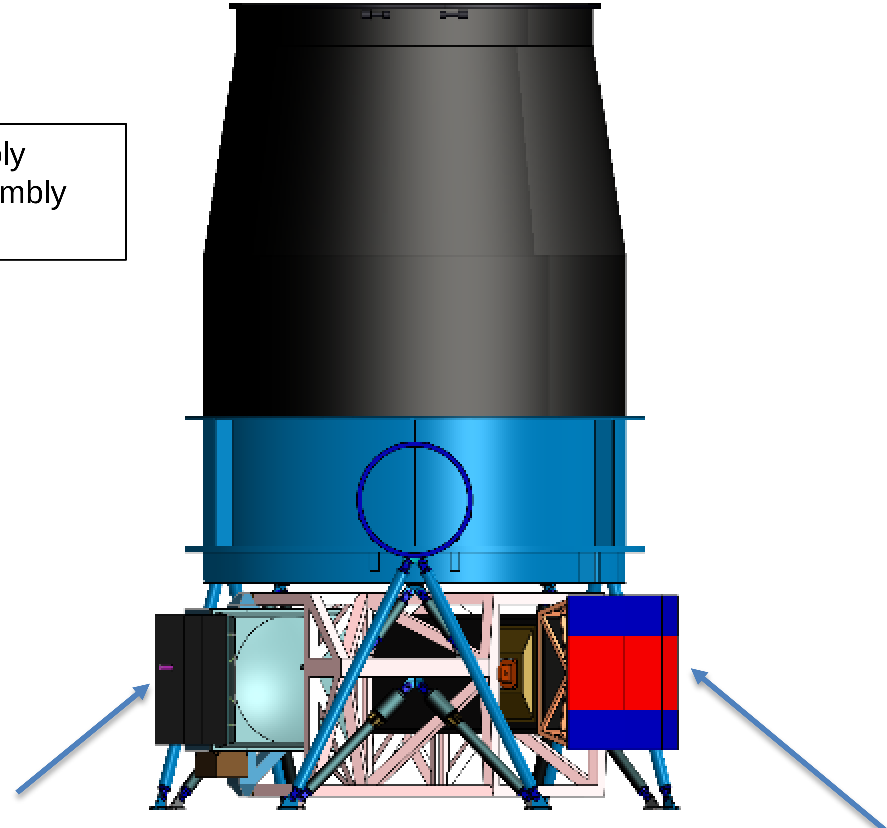
Observatory Hardware Groupings

OBA = Outer Barrel Assembly
FOA = Forward Optics Assembly
IC = Instrument Carrier



Telescope

Spacecraft (Solar Array not shown)

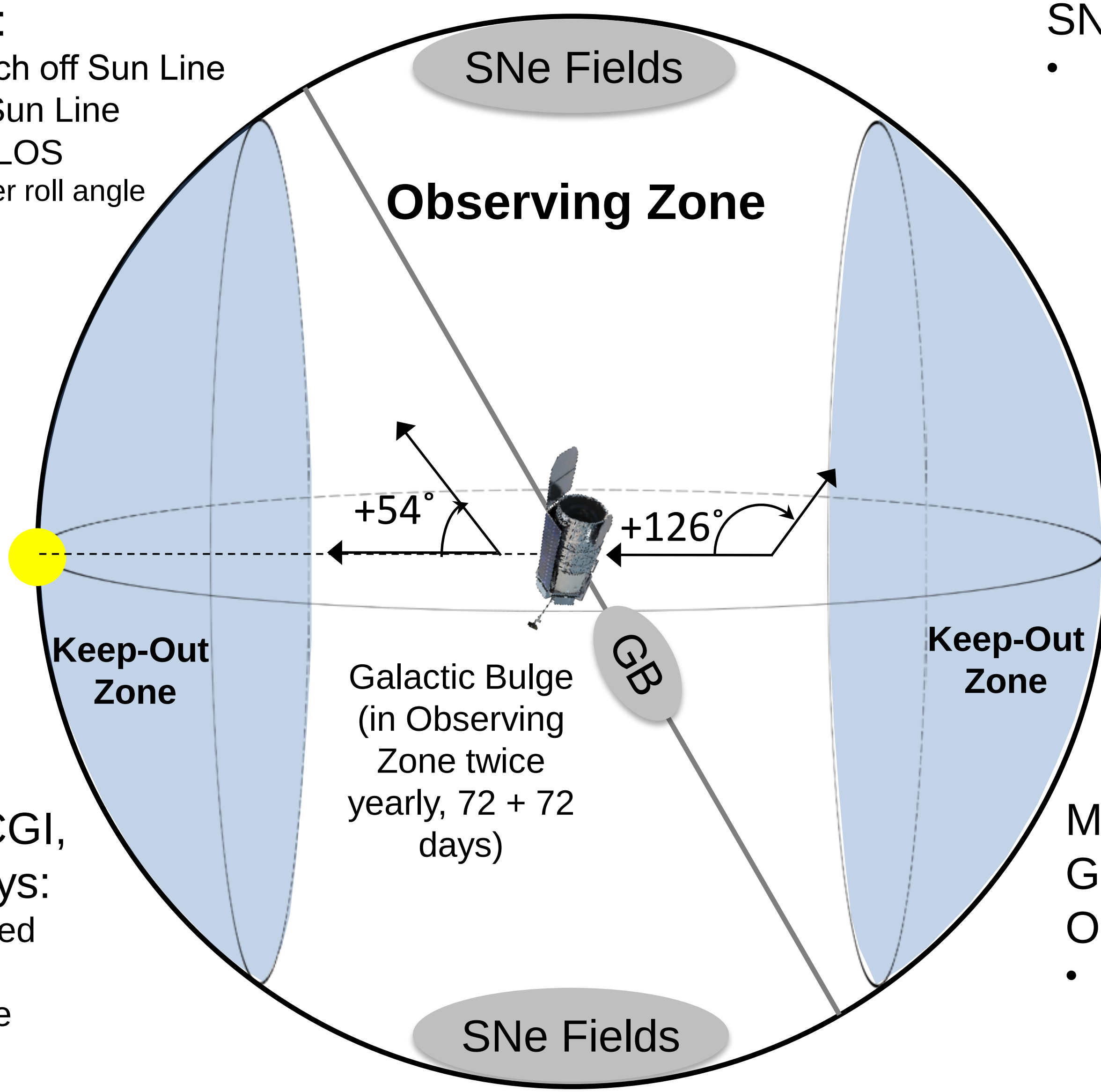


- CoronaGraph Instrument (CGI)
- Wide Field Instrument (WFI)

Payload Central Line of Sight (LOS) Field of Regard (FOR)

Observing Zone:
- 54˚-126˚ LOS Pitch off Sun Line
- 360˚ Yaw about Sun Line
- ±15˚ Roll about LOS
  - Off max power roll angle

SNe Fixed Fields:
- ±20˚ off one of the Ecliptic Poles

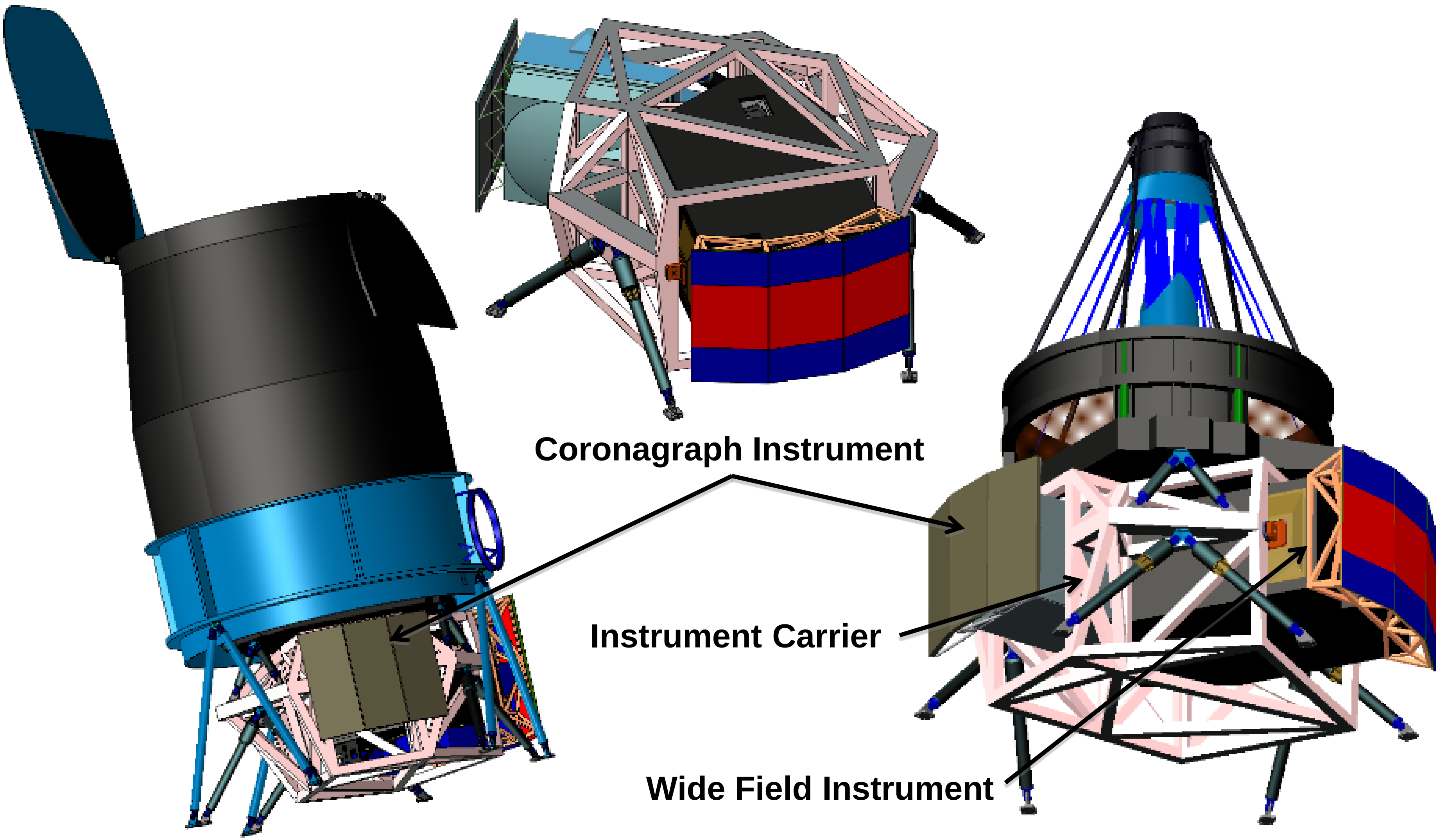


The Central LOS cannot point within ~35˚ of the limb of the Earth or ~35˚ of the Moon and meet WFI stray light rqts (values used by C. Hirata in 2015 SDT Final Report)

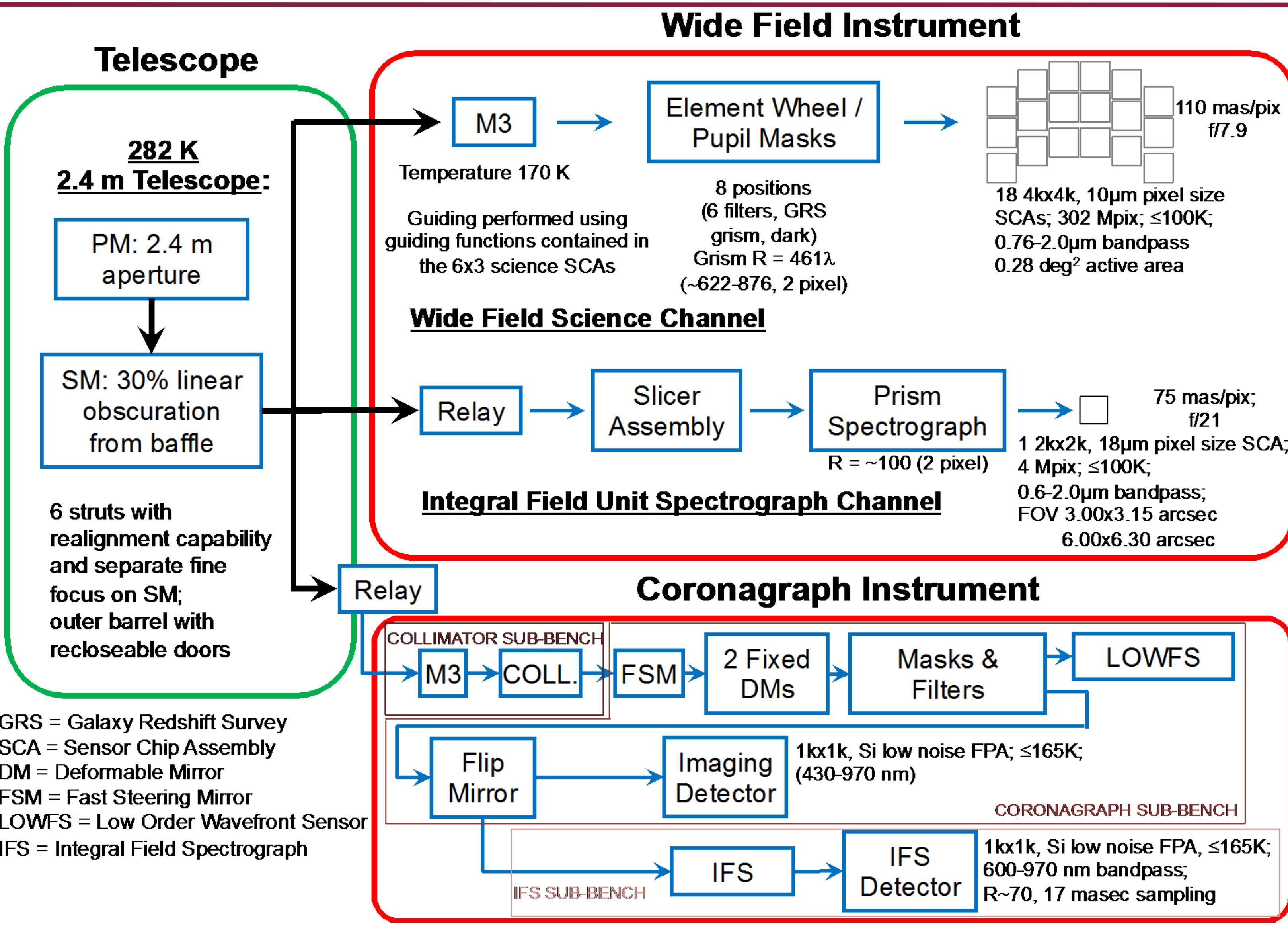
HLIS, HLSS, CGI, and GO Surveys:
- Can be optimized within the full Observing Zone

Microlensing Galactic Bulge (GB) Observations:
- 72 days available twice a year

WFIRST-AFTA Payload Layout



WFIRST-AFTA
Payload Optical Block Diagram

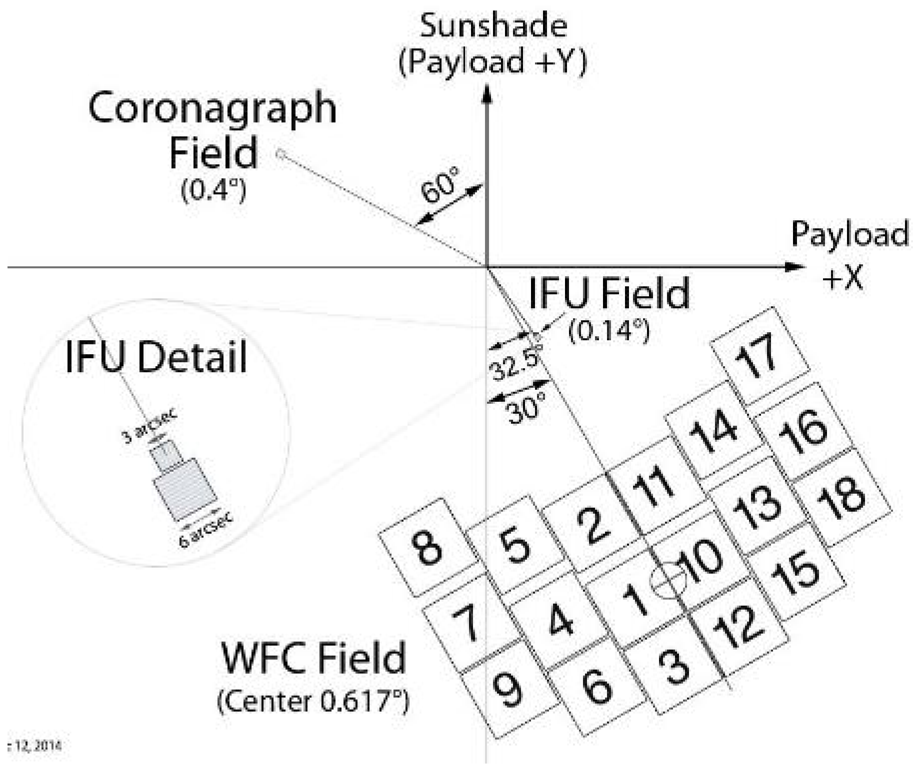


GRS = Galaxy Redshift Survey
SCA = Sensor Chip Assembly
DM = Deformable Mirror
FSM = Fast Steering Mirror
LOWFS = Low Order Wavefront Sensor
IFS = Integral Field Spectrograph

Optical Field Layout

- The Wide Field Instrument (WFI) has two science channels
  - A Wide Field Channel (WFC) with two modes dependent on element wheel position
    - Wide Field Imaging Mode (WIM)
    - Wide Field Spectroscopy Mode (WSM)
  - An Integral Field Unit (IFU) channel viewing two fields
    - 3”x3.15” and 6x6.3” FOVs
- The Coronagraph Instrument (CGI) is a small field system in a separate field of view
  - Contains an imager and a Integral Field Spectrometer (IFS) viewing the same field

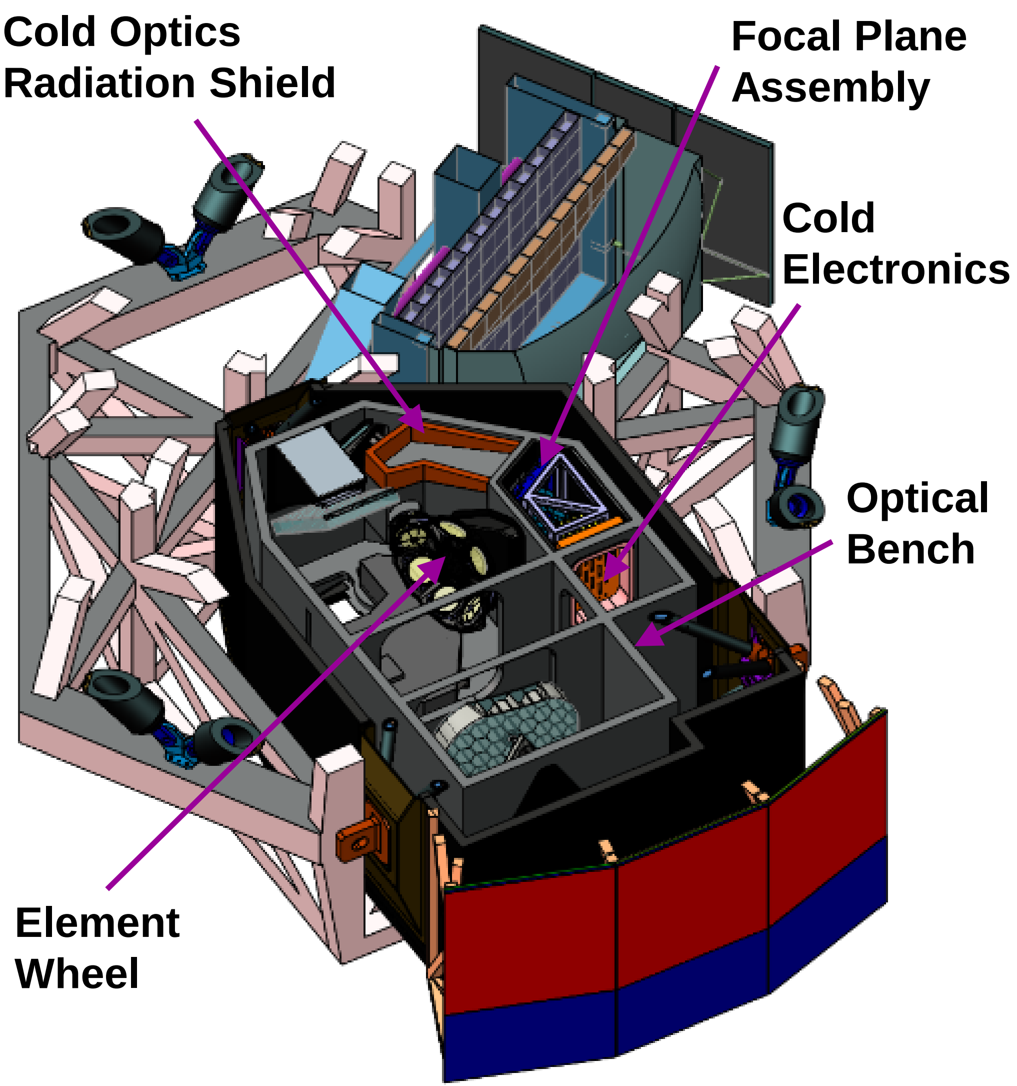
Channel Field Layout for WFIRST-AFTA Instruments



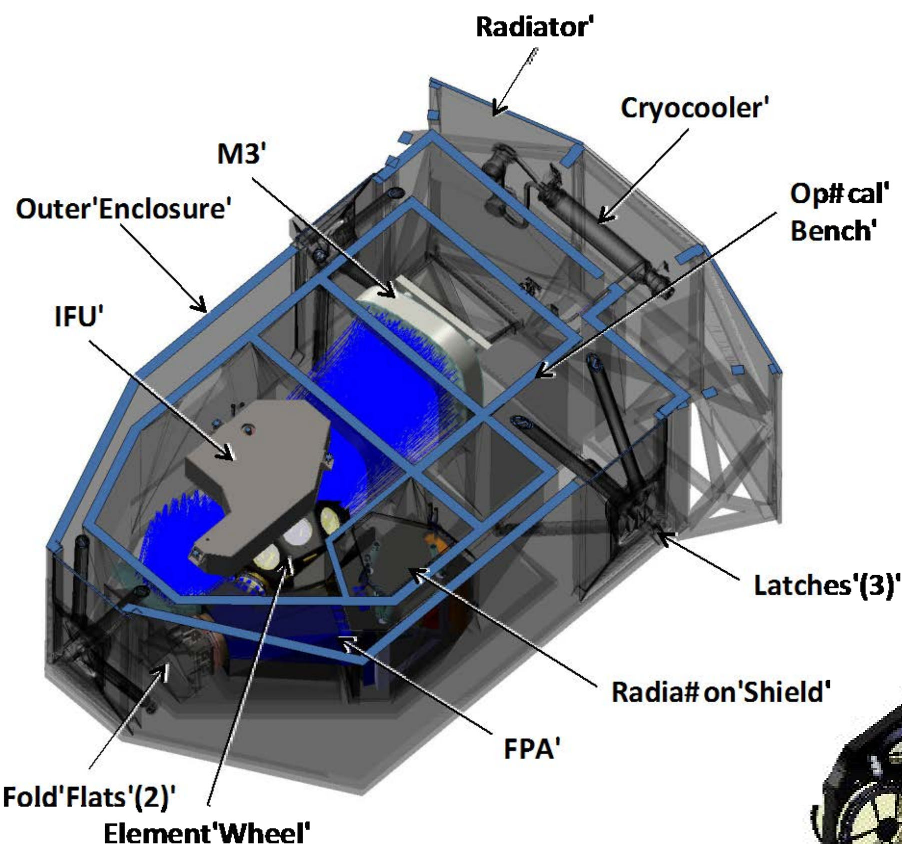
Wide Field Instrument Overview

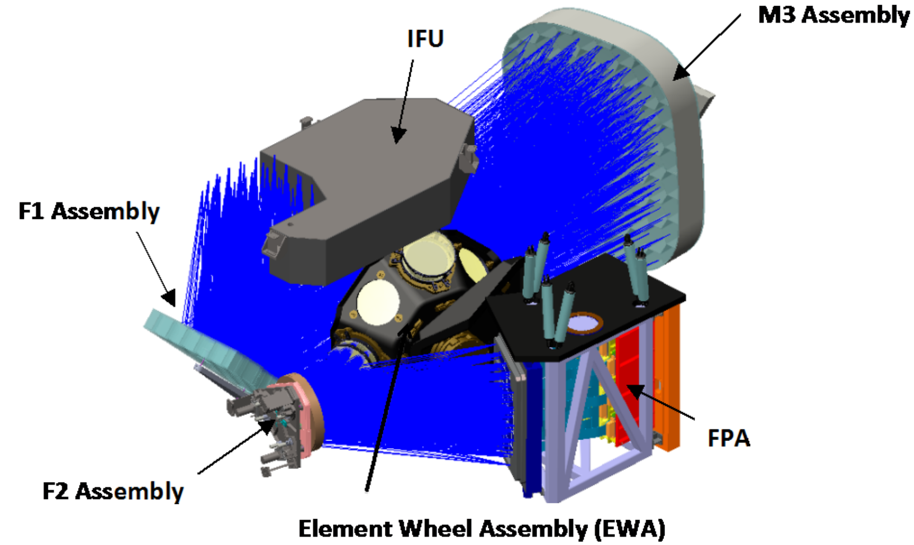
Key Features

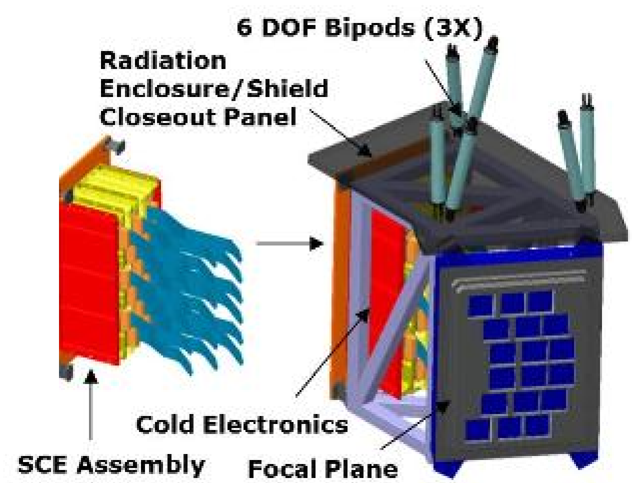
- Wide field channel instrument for both imaging and spectroscopy
  - 3 mirrors, 1 optically powered
  - 18 4k x 4k HgCdTe detectors cover 0.76 - 2.0 μm
  - 0.11 arc-sec plate scale
  - Single element wheel for filters and grism
  - Grism used for galaxy redshift spectroscopy (GRS) survey covers 1.35 – 1.89 μm with R = 461λ (~620 – 870)
- IFU channel for SNe spectra & Galaxy photo-z calibration spectroscopy
  - single HgCdTe detector covers 0.6 – 2.0 μm with R ~100



Wide Field Instrument Layout and Major Subassemblies





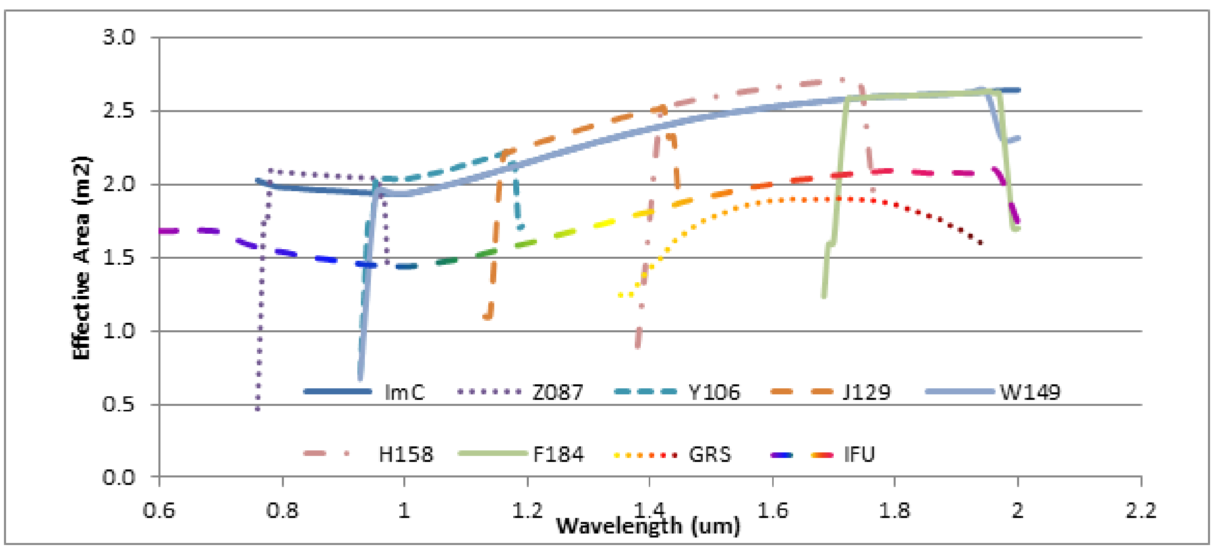


System Observing modes & Throughput

name	Mode	Element	min (um)	max	R	SN detect shallow	SN detect med/deep	SN spec	HLS Imaging	HLS Spec	uLensing monitor	uLensing color	available for GO?	FGS pointing quality
Z	WIM	Z087	0.760	0.977	4.0							freq 2x daily	all	fine
Y		Y106	0.927	1.192	4.0	x			Photo-z					
J		J129	1.131	1.454	4.0	x	x		Photo-z & shape					
H		H158	1.380	1.774	4.0		x							
F184		F184	1.683	2.000	5.81									
W		W149	0.927	2.000	1.442						15 min cadence			
GRS	WSM	GRS	1.35	1.95	461λ					x				coarse
IFU	IFU	IFU	0.600	2.000	75			x						n/a

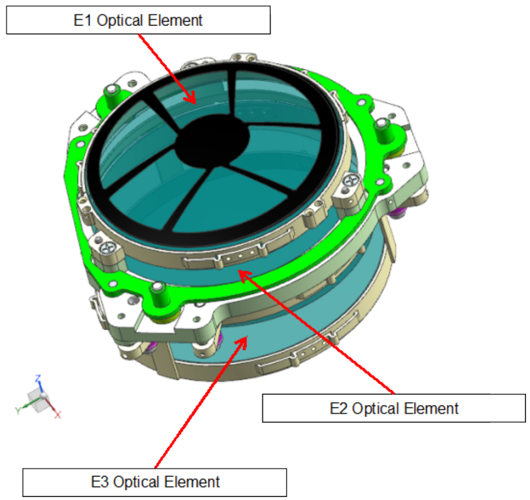
WIM == wide imaging mode
WSM == wide spectroscopy mode
IFU == integral field spectroscopy

Note: IFU or coronagraph (small field of view channels) science requires fine pointing, so parallel GRS mode is not possible

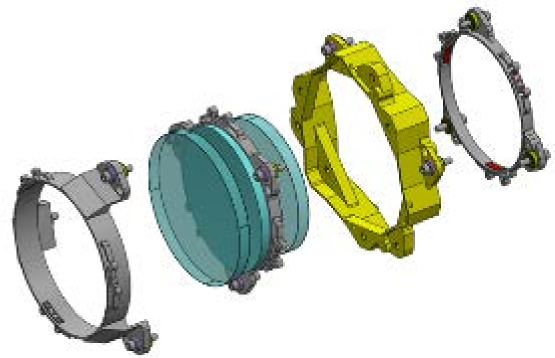


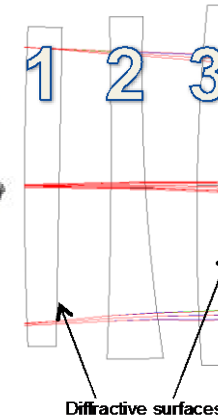
Other Wide Field Risk Reduction Activities

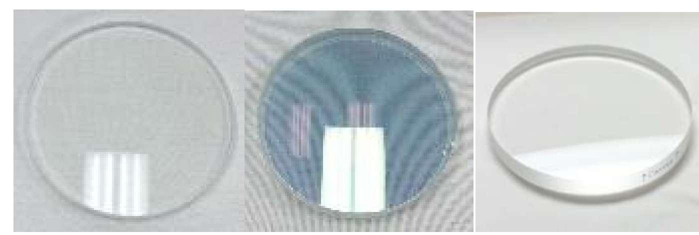
- The Wide Field element wheel presents unique challenges due to the large optical FOV of the instrument and the tight space that is available inside the instrument for the element wheel.
- The performance and manufacturability of the element wheel design are being examined in this engineering development hardware.
- The Wide Field grism presents some challenges due to its wide field of view, large dispersion, broad spectral range, relatively small F/#, and the high efficiency diffractive surfaces.



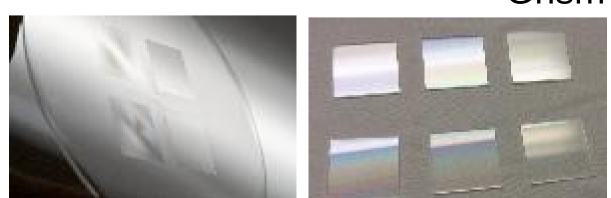
Grism mechanical design



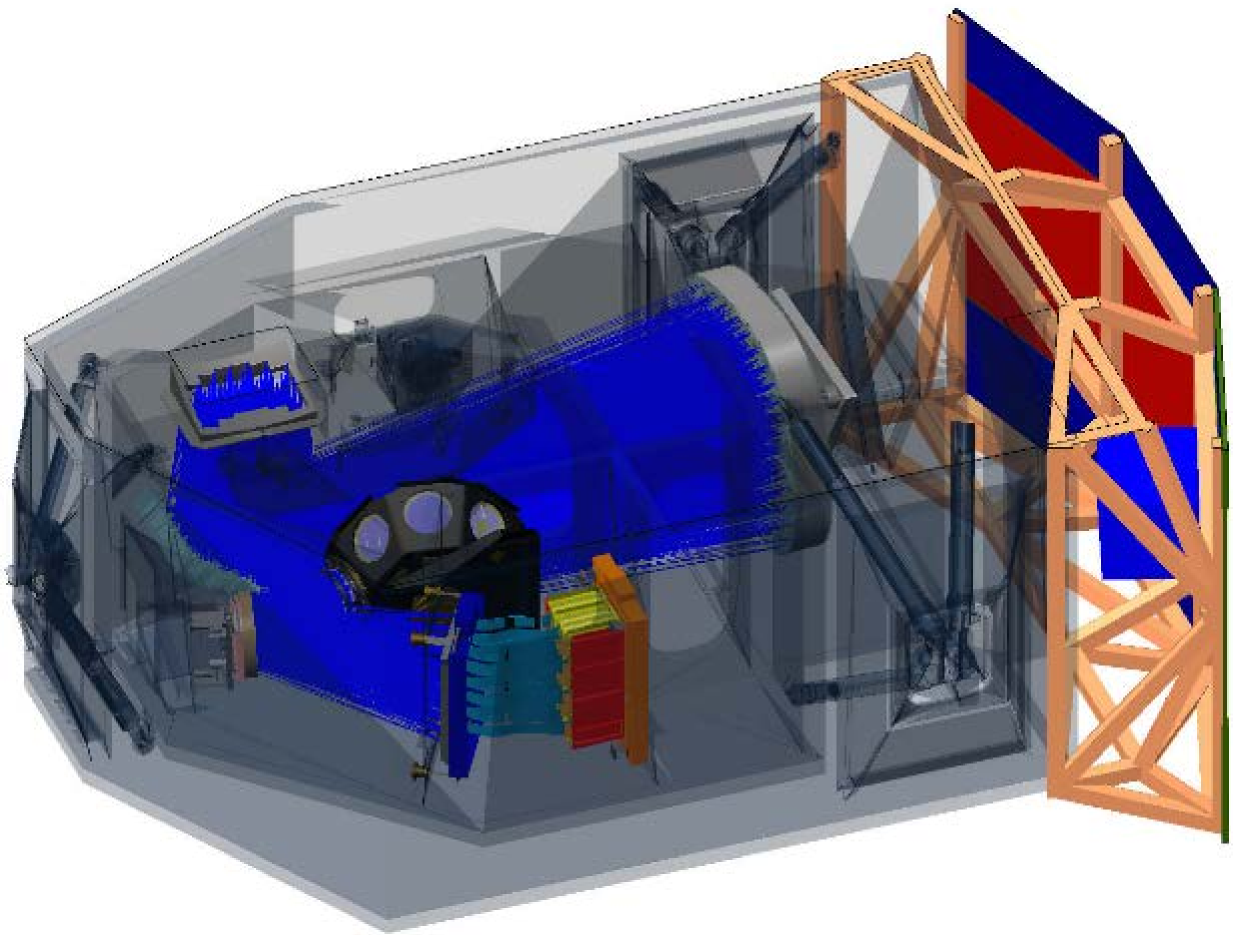



Grism procured substrates

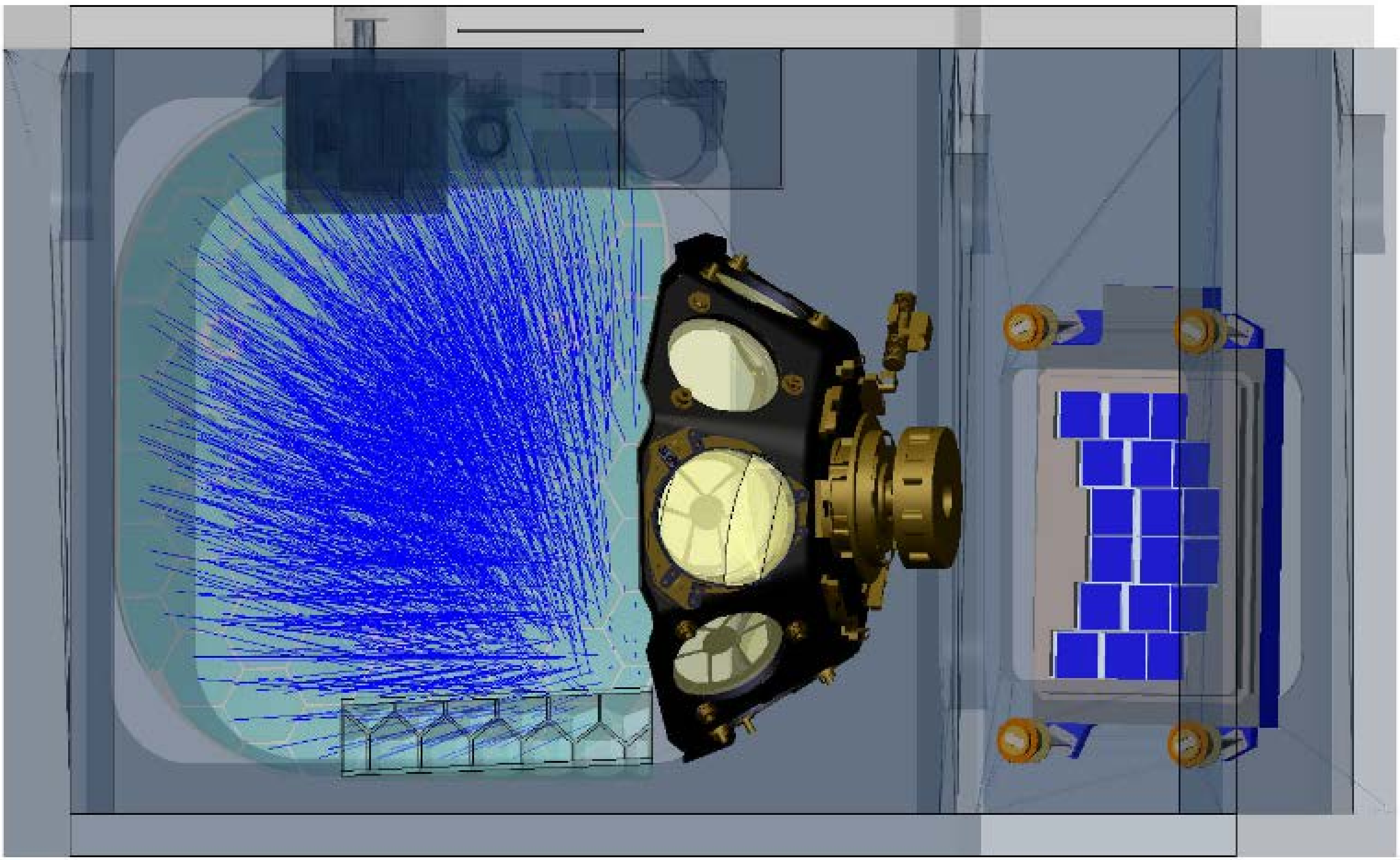

Grism mount


Grism grating samples

WFI Cycle 5 Optical Bench

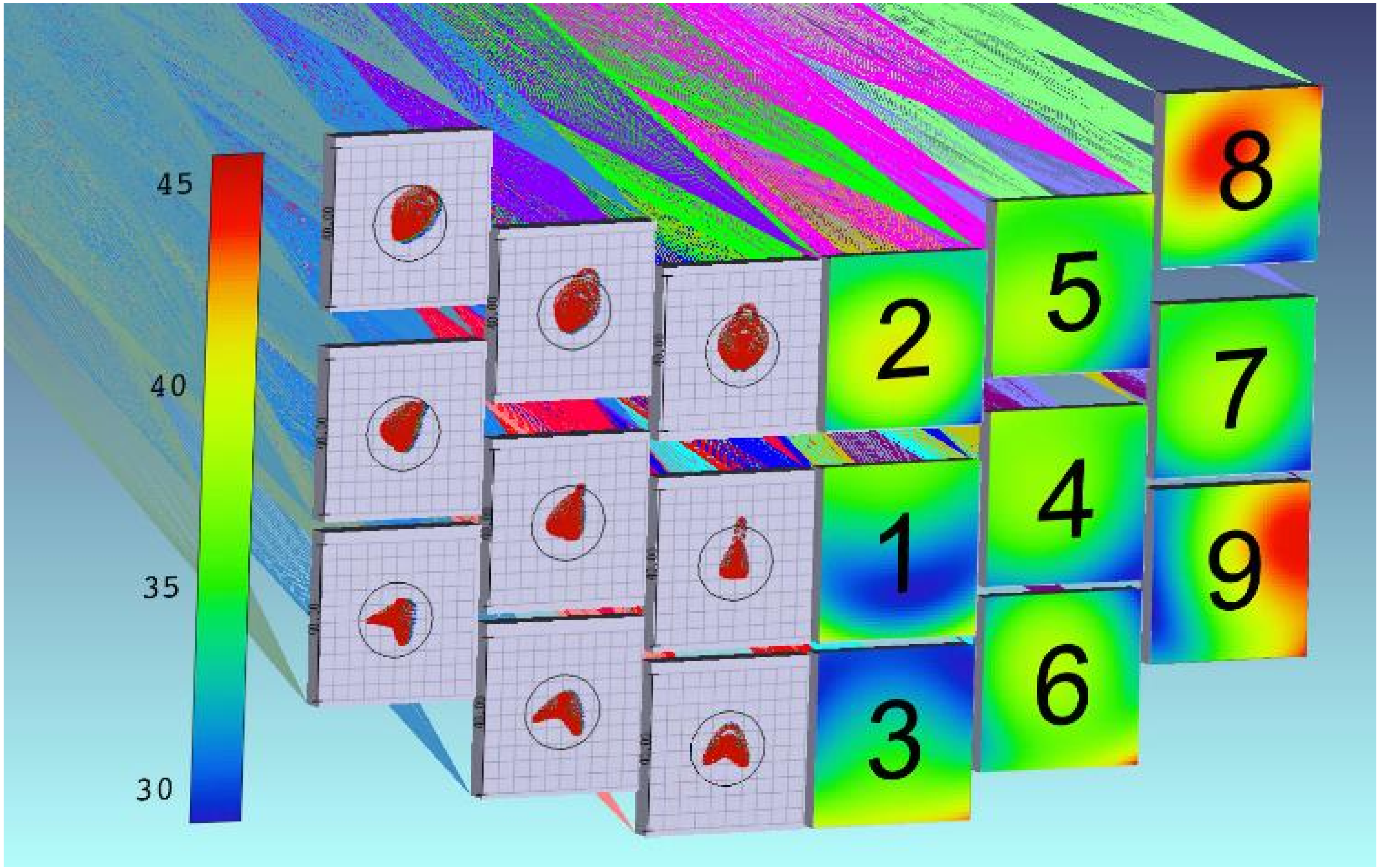


F1-M3 Rays: Very Tight Clearance to Element Wheel



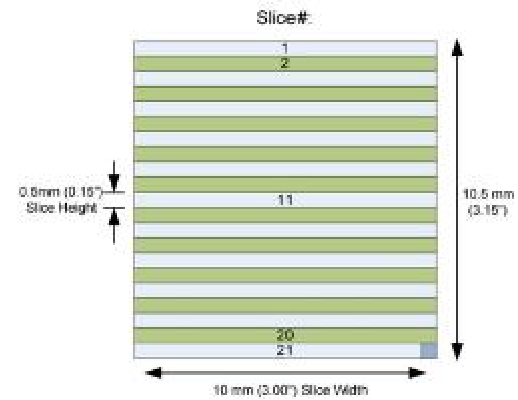
Cycle 5 Imager Performance

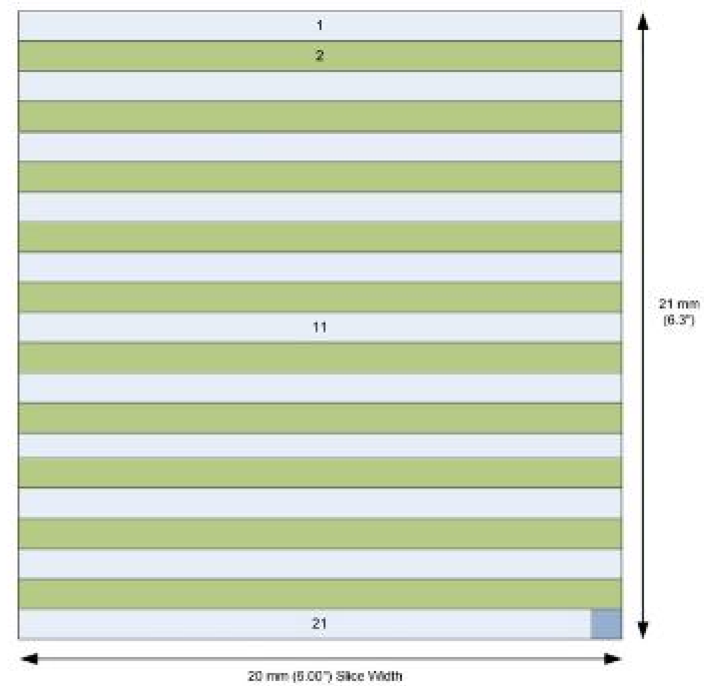
- Comparative Spot Sizes and RMS WFE



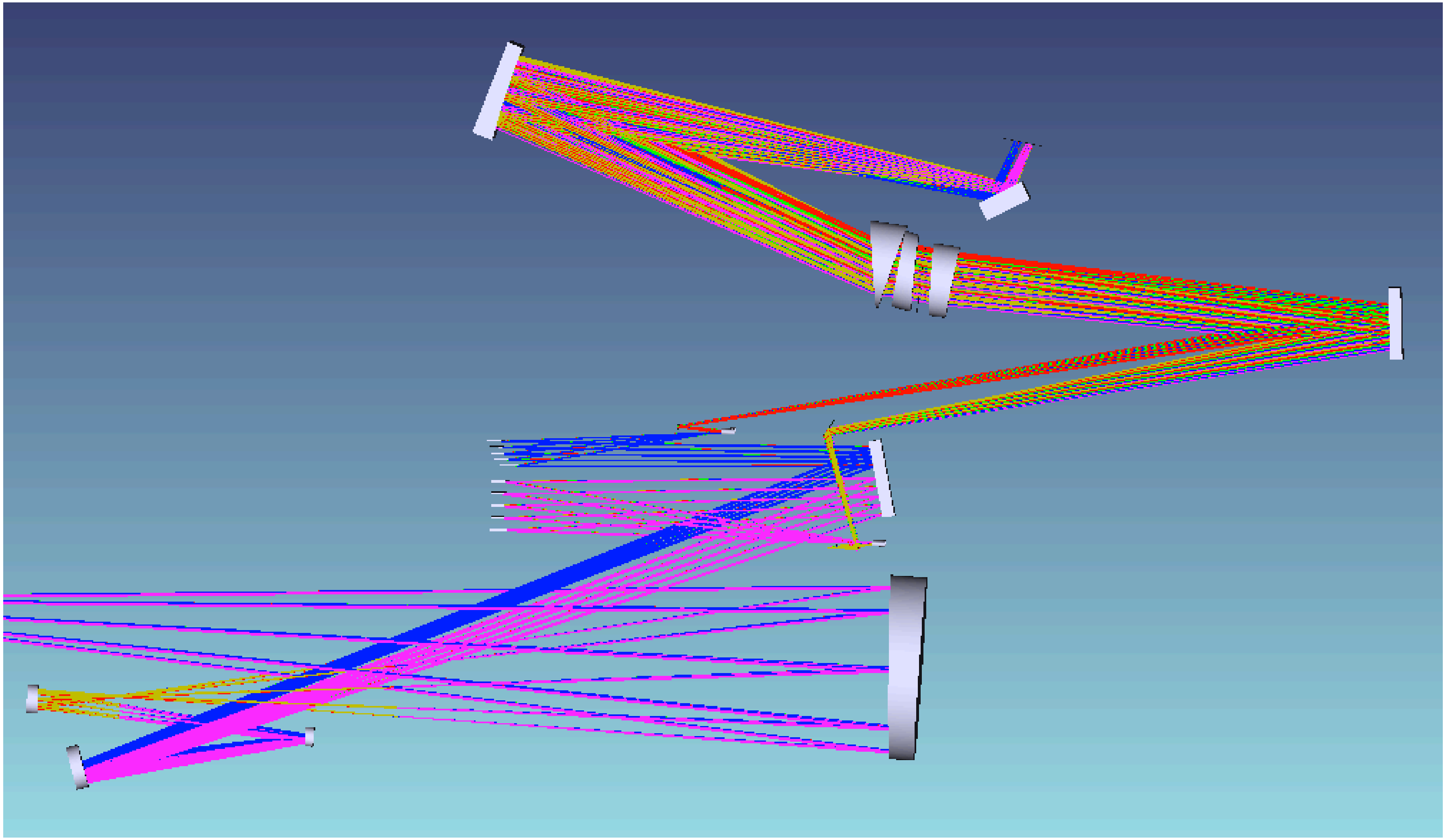
5.0.6 IFU Changes

- Addition of Second Image Slicer
  - 6” x 6”, 0.3” sampling
  - Combined with original slicer through spectrograph
- Non-vignetting Slicer layout
- Output mirrors used as field lenses
  - Form pupil at prism location
- Spectrograph improved
  - Reduced from 6 mirrors to 2
  - Anamorphic Asphere Focus Mirror
  - Same imaging performance on original slicer
  - Prism has flatter R-curve

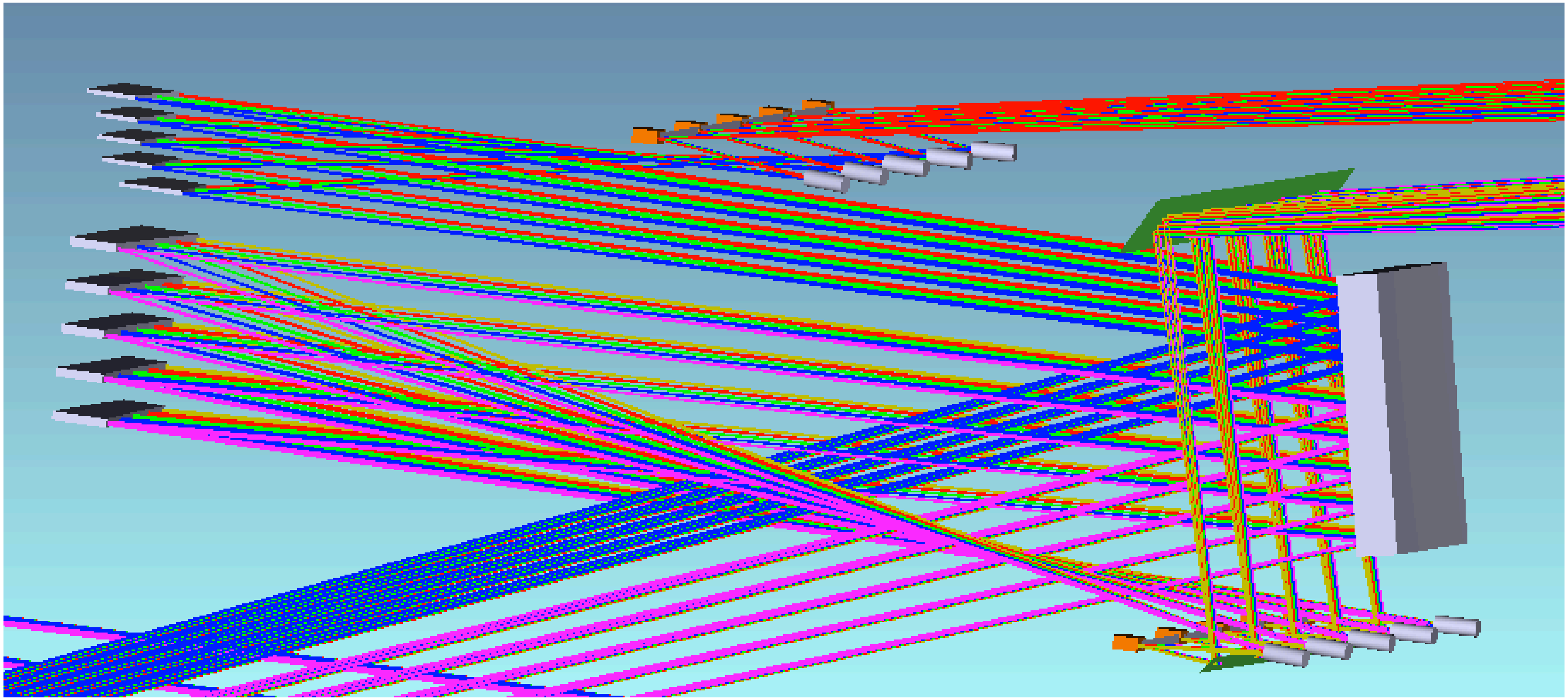




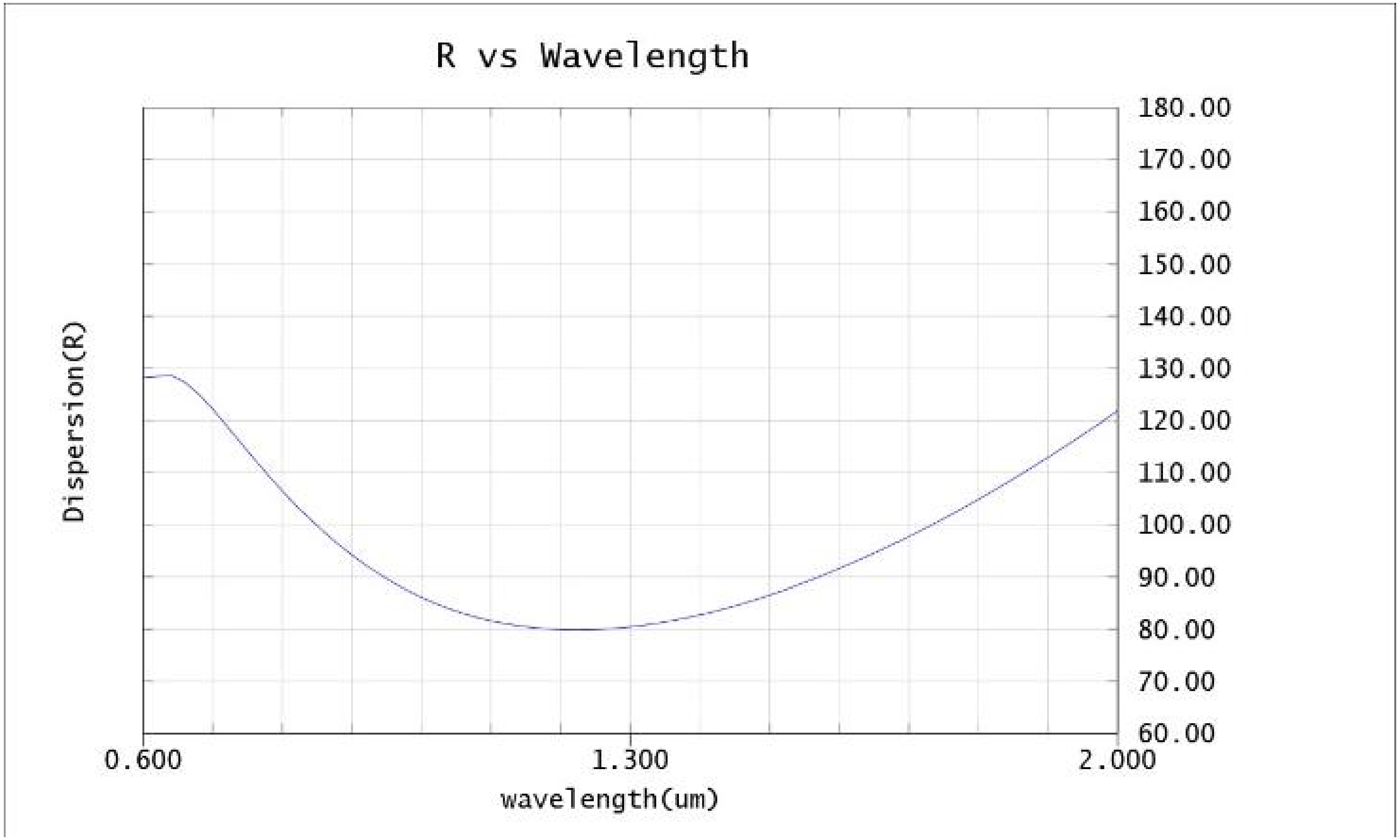
5.0.6 IFU Layout



5.0.6 IFU Layout



5.0.6 IFU Performance: R-Curve



Stray Light Modeling

- Model currently incorporates Telescope, Sculptured Baffles, WFI subassemblies and SCAs focal surface.
- Most surfaces were constructed using native FRED object types. New FRED version allows for CAD objects to be efficiently traced.
- Lyot Stop analysis of thermal emission and scattered light over various optical pass bands will be convolved with the system’s spectral and thermal responses.

WIM CBE stability margin results

Metric	Discipline	Source		Predict w/MUF	Requirement	Margin
WFE	STOP	Cooldown		14.2 nm	20.2 nm RMS	By design
WFE Stability	STOP	WFI Worst Case Slew		0.041 nm / 184 sec	0.707 nm RMS / 184 sec	**17.2x**
	Jitter	RWA	0.515 nm	0.538 nm (RSS)	0.707 nm RMS	**1.31x**
		HGA	0.153 nm			
		Cooler	0.016 nm			
		Thruster	0.0065 nm			
LOS Stability	STOP	WFI Worst Case Slew		See ACS package	14 masec RMS	**~x**
	Jitter	RWA	9.63 masec	10.48 masec (RSS)	14 masec RMS	**1.34x**
		HGA	4.13 masec			
		Cooler	0.22 masec			
		Thruster	0.0155 masec			
Ellipticity Stability	STOP	WFI Worst Case Slew		4.5e-5 / 184 sec	4.7e-4 / 184 sec	**10.4x**

Notes: 1) 18 SCAs considered in WFI STOP and RWA/Cooler Jitter performance assessment; one central FPA field point for HGA Jitter assessment; 2) STOP LOS stability per Observatory ACS estimate; 3) Jitter results from rigid body mirror motions, but STOP results include mirror motions/deformations; 4) Cooldown per budget allocation of 36.2 nm out of ~90 nm total WFE … achieved w/77% correction of cooldown shifts. 5) Thruster results scaled down by 100x based on LTR measurements.

Wide Field Instrument Detector Development Update

D. Content (for the detector development team)

Updated 5/1/2015

Summary

- Recent progress is very encouraging:
  - √ 8/6/14, 12/1/14: 1st 2 detector technology milestone reviews (passed)
  - √ 9/14: All testing completed for three lots of (banded array) development H4RGs – details below
  - √ 10/14-4/15: 1st full array lot (PV2a) fabricated & processed
  - √ 4/28/15: 2nd (PV3) full array lot done growth, started processing
  - √ Cryostat completed for testing 4 H4RGs in parallel
- Expectations for near term :
  - Summer 2015: Initial deliveries to DCL of first SCAs from full array lot
  - Infrastructure development for rapid testing and characterization is proceeding
    - Cold metrology gantry (FPA

WFIRST-AFTA Detector Technology Milestones

MS #	Milestone	Milestone Date
√ 1	Produce, test, and analyze **2 candidate passivation techniques** (PV1 and PV2) in **banded arrays** to document baseline performance, inter-pixel capacitance, and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, and QE greater than 60% (over the bandpass of the WFI channel) at nominal operating temperature.	7/31/14 **Passed 8/7/14**
√ 2	Produce, test, and analyze **1 additional candidate passivation technique** (PV3) in **banded arrays** to document baseline performance, inter-pixel capacitance, and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, and QE greater than 60% (over the bandpass of the WFI channel) at nominal operating temperature.	12/30/14 **Passed 12/1/14**
3	Produce, test, and analyze **full arrays with operability > 95%** and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, QE greater than 60% (over the bandpass of the WFI channel) , inter-pixel capacitance ≤3% in nearest-neighbor pixels at nominal operating temperature.	9/15/15
4	Produce, test, and analyze final selected recipe in **full arrays demonstrating a yield of > 20%** with operability > 95% and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, QE greater than 60% (over the bandpass of the WFI channel) , inter-pixel capacitance ≤3% in nearest-neighbor pixels, persistence less than 0.1% of full well illumination after 150 sec at nominal operating temperature.	9/15/16
5	Complete environmental testing (vibration, radiation, thermal cycling) of one SCA sample part, as per NASA test standards.	12/1/16

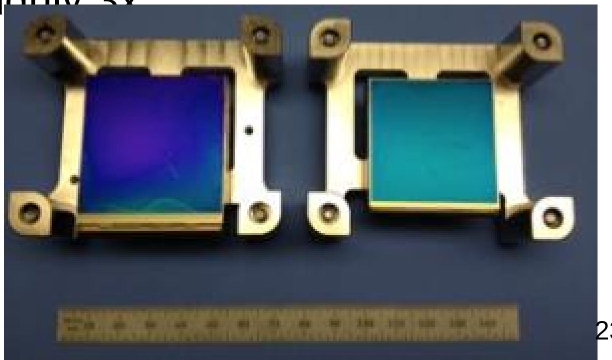
Milestone 2 Performance Requirements Have Been Met

MS #	Milestone	Milestone Date
1	Produce, test, and analyze **2 candidate passivation techniques** (PV1 and PV2) in **banded arrays** to document baseline performance, inter-pixel capacitance, and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, and QE greater than 60% (over the bandpass of the WFI channel) at nominal operating temperature.	7/31/14

- The Band 1 pixel design exhibits the best performance across the 8 SCAs tested in the DCL and exceeds the milestone requirements by a significant margin.
  - Other bands (3, 4) also show good performance; preliminary recommendation of band 1 folds in yield considerations as well as performance
  - PV3 showing significant improvement in persistence (roughly 3x better than PV1/2)

	Milestone Requirement	PV1/2 Band 1 Average	PV3 Band 1 Average
Median Dark Current (e-/pix/sec)	<0.1	0.0023	0.0066
Median CDS Noise (e- rms)	<20	12	17
Median QE (%)	>60	95%	101 (>90) %

Comparison of the size of an H4RG (4k x 4k pixels, 10 µm pixel size) on left to an H2RG (2k x 2k pixels, 18 µm pixel size) on the right.



Dark Current is low for banded arrays

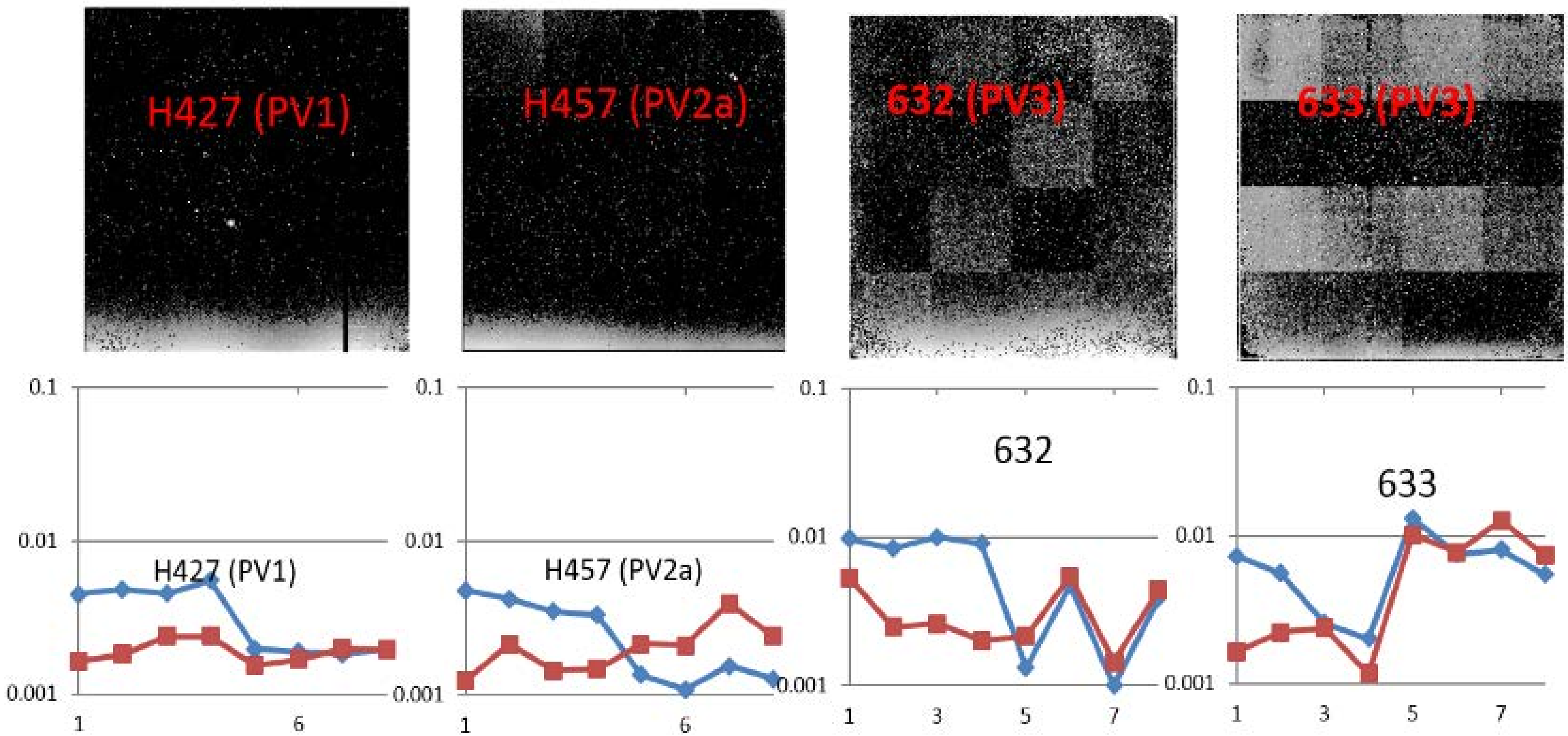
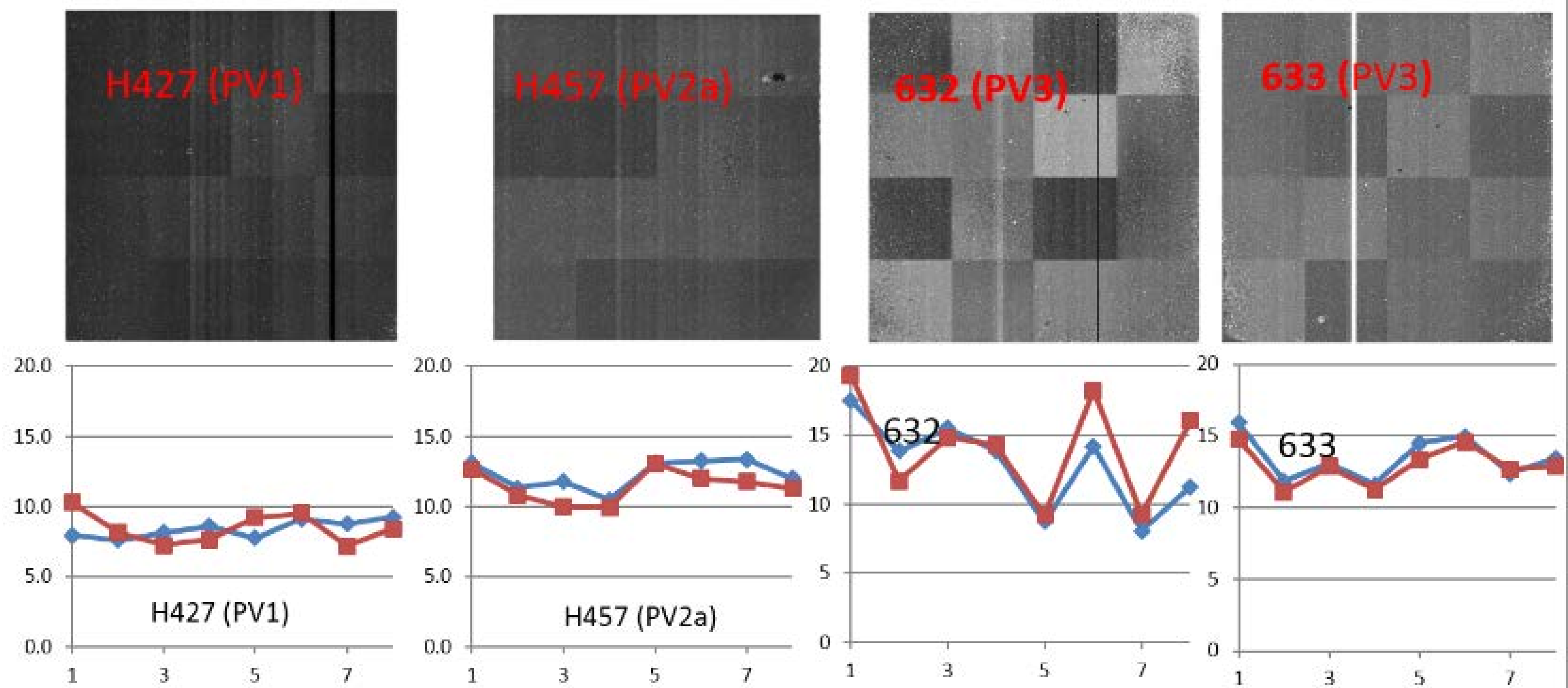


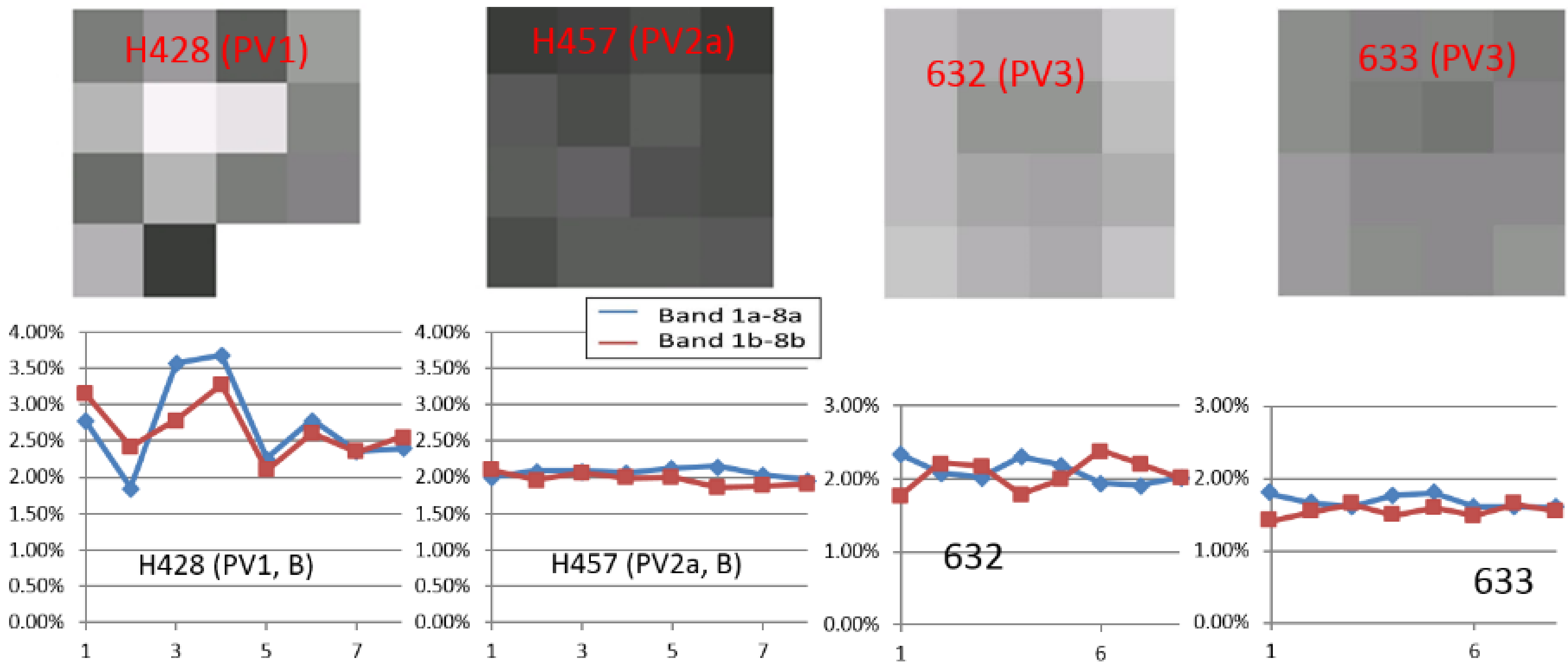
Figure 3: Fig 3-XX. Dark Current maps of the same example devices shown above. Uncertainty: 0.003 e-/s/pixel; i.e. any values below 0.001 e-/s or negative are set to be 0.001 in the plots. All plotted dark current numbers are median values. Images are in log scale [black = 0.005 e-/s, white = 0.1 e-/s]. While a low level glow along readout register (bottom of SCA) is evident, this is within the draft requirement. However, this will be addressed in a redesign/remake of the H4RG readout integrated circuit (ROIC).

Short term noise is very promising



Correlated double sample or short term noise for the same devices as shown above. All plotted CDS noise numbers are median values. Images are in linear scale: Black=0, White=30e. Horizontal and vertical axes on plots on bottom row are band # and CDS rms noise averaged per band, respectively.

Cross talk results for banded arrays



Example cross talk for each of two repeats of 8 band designs over four example H4RG test devices. The x axis in the bottom row is band #, with two sets of curves for the 1st and 2nd occurrence of each band design. The selected band (band1) is the bottom left, with a repeat being the bottom left of the upper right quadrant, in each array. The upper row shows band-averaged cross talk with black to white range of 1-4%.

H4RG-10 Development Upcoming Work

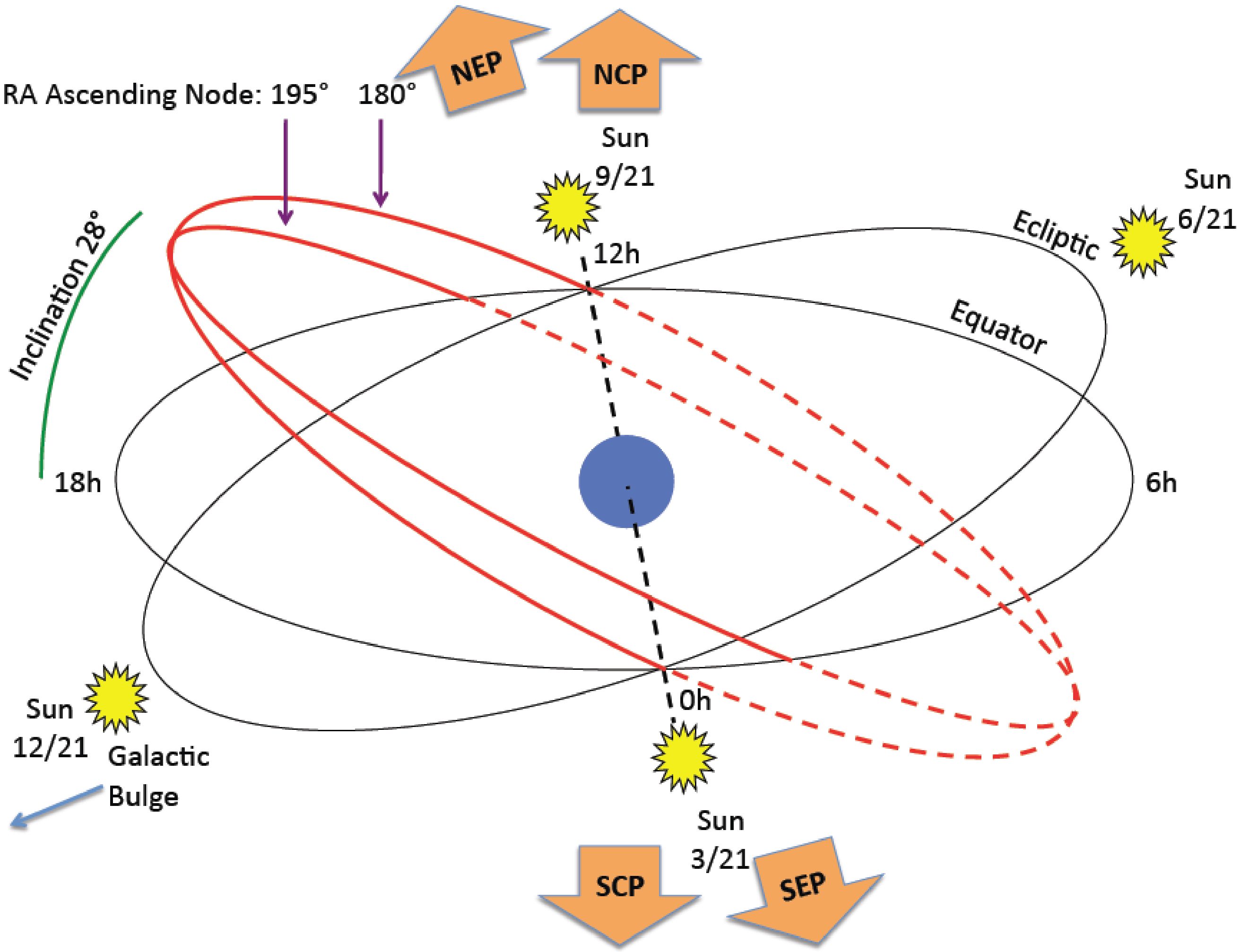
- The final pre-flight lot will be the Yield Demonstration Lot.
  - Anticipated start by early FY16, possibly late FY15.
  - A single flight candidate recipe will be used.
  - These detectors are expected to be of fairly high quality, and will be using during instrument development as engineering devices, for qualification testing, and for detailed performance characterization. Thus, detectors for flight instrument build-up will be available quite early.
  - Completion of the Yield Demonstration Lot is planned to be late in FY16, after which the flight build can be started.
- We are also funding detailed characterization testing at GSFC DCL

backup

Cycle-3 RAAN Orbit Parameters Shown in Picture …
See text box for Cycle-5 Updates

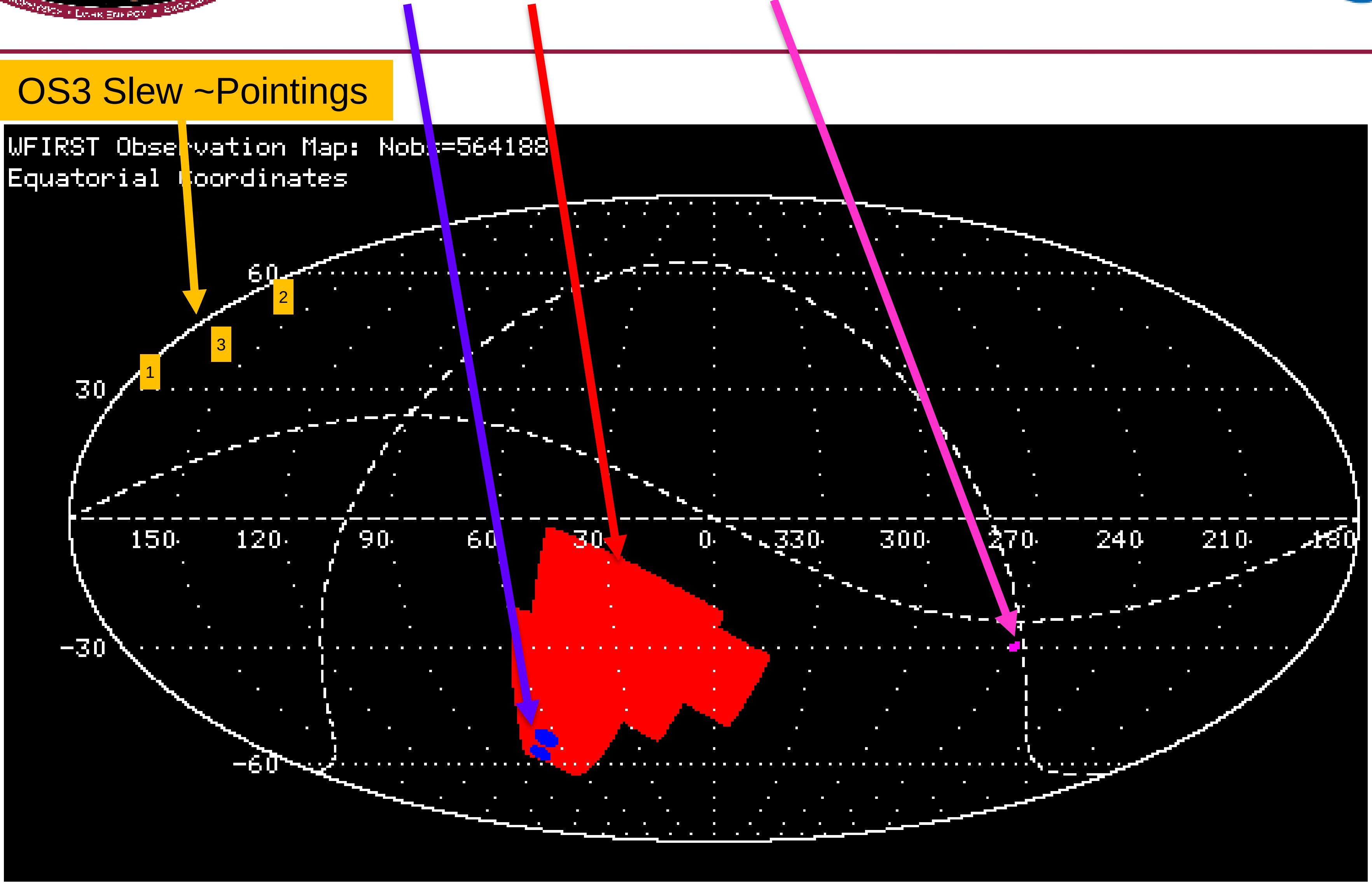
For Cycle 5:

- RAAN = 228° at mission start, ~188° after 5 years
- Launch date in SDT 2015 report ops summary was 10/31/2024

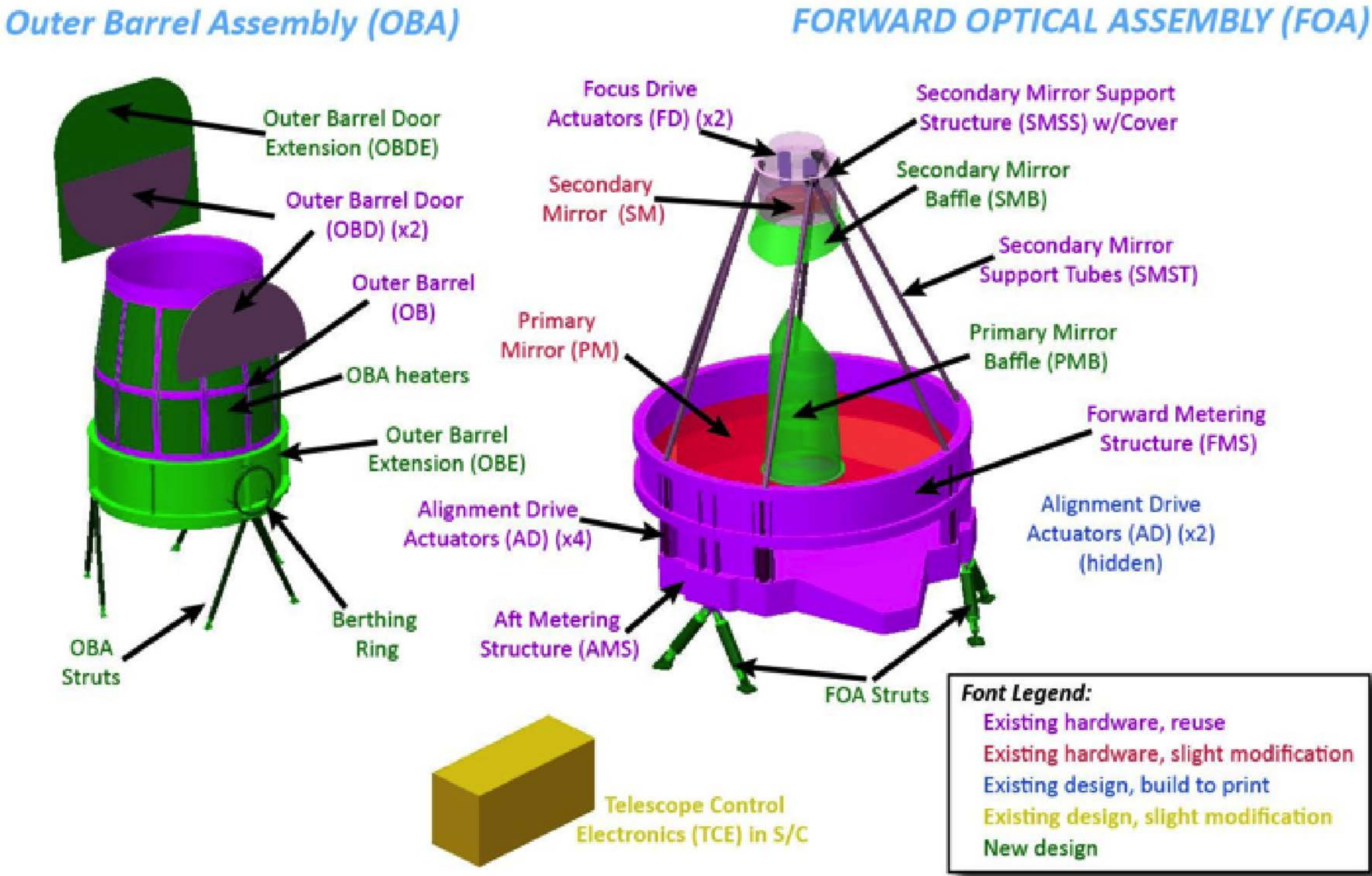


SNe, HLS, and uL Survey Fields

OS3 Slew ~Pointings



Telescope Reuse



Path Forward

- Optimization of the Reference Design
  - Study L2 mission concept and perform science/cost trade vs. GEO configuration
  - Study non-exoplanet uses for the coronagraph
  - Perform analysis to improve microlensing event rate predictions
  - Refine wide field IFU design to optimize wavelength range and resolution, and slice scale and sampling of the slices
- Systematic Error Control
  - Develop a calibration strategy
  - Characterize astrometric performance of the WFI
- Synergies with Other Observatories
  - Survey the need for precursor observations for microlensing, low z SNe and RV studies of coronagraph targets
  - Study opportunities for joint observations and requirements for joint analyses with Euclid, LSST and other ground telescopes
- Coronagraph
  - Develop more detailed coronagraph DRM
  - Perform deeper investigation of effects of coronagraph polarization and PSF subtraction
  - Assist with development of wavefront control technology
- Policy Issues
  - Consider possibilities for foreign involvement
- Observatory
  - Further refine servicing architecture and ops concept

Integrated modeling - WSM CBE

Metric	Discipline	Source		Predict w/MUF
WFE	STOP	Cooldown		26.3 nm
WFE Stability	STOP	WFI Worst Case Slew		4.47 nm
	Jitter	RWA	0.506 nm	0.529 nm (RSS)
		HGA	0.153 nm	
		Cooler	0.016 nm	
		Thruster	0.0065 nm	
LOS Stability	STOP	WFI Worst Case Slew		See ACS package
	Jitter	RWA	9.60 masec	10.45 masec (RSS)
		HGA	4.13 masec	
		Cooler	0.21 masec	
		Thruster	0.0155 masec	

Notes: 1) 18 SCAs, 3 wavelengths considered in WFI STOP and RWA/Cooler Jitter performance assessment; one central FPA field point , 1.65um, for HGA Jitter assessment; 2) STOP LOS stability per Observatory ACS estimate; 3) Jitter results from rigid body mirror motions, but STOP results include mirror motions/deformations; 4) Cooldown per budget allocation of 36.2 nm out of ~90 nm total WFE … achieved w/77% correction of cooldown shifts. 5) Thruster results scaled down by 100x based on LTR measurements. 6) WSM HGA, thruster jitter not analyzed; estimated from WIM results. 7) Cooldown is after correction with WIM T2 PTT.

Integrated modeling: IFU CBE

Metric	Discipline	Source		Predict w/MUF
WFE	STOP	Cooldown		16.75 nm
WFE Stability	STOP	WFI Worst Case Slew		9.56 nm
	Jitter	RWA	0.515 nm	0. 997nm (RSS)
		HGA	0.854 nm	
		Cooler	0.015 nm	
		Thruster	0.0064 Nm	
LOS Stability	STOP	WFI Worst Case Slew		See ACS package
	Jitter	RWA	9.29 masec	14.07 masec (RSS)
		HGA	10.56 masec	
		Cooler	0.21 masec	
		Thruster	0.00155 masec	

Notes: 1) 5 wavelengths considered in WFI STOP, RWA/Cooler Jitter performance assessment; one central FPA field point for HGA Jitter assessment; 2) STOP LOS stability per Observatory ACS estimate; 3) Jitter results from rigid body mirror motions, but STOP results include mirror motions/deformations; 4) Cooldown per budget allocation of 36.2 nm out of ~90 nm total WFE … achieved w/77% correction of cooldown shifts. 5) Thruster results scaled down by 100x based on LTR measurements. 6) Cooldown is after WIM T2 PTT correction.