OPTICAL DESIGN OF WFIRST-AFTA WIDE-FIELD INSTRUMENT

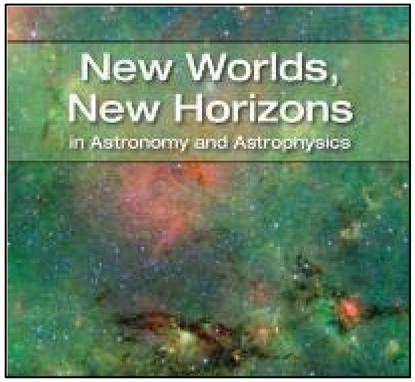
Bert Pasquale
NASA Goddard Space Flight Center

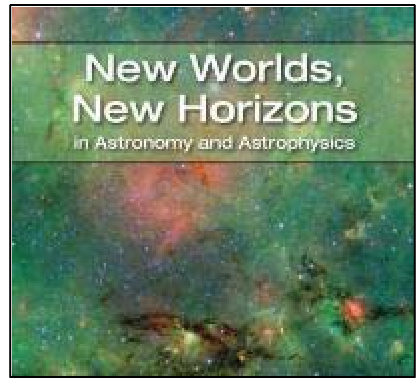
David Content, Jeffrey Kruk, David Vaughn,
Qian Gong, Joseph Howard, Alden Jurling,
Eric Mentzell, Nerses Armani;
NASA Goddard Space Flight Center
Gary Kuan, Jet Propulsion Laboratory

WFIST-AFTA Optical Design

- Wide-Field Infra-Red Survey Telescope - Astrophysics Focused Telescope Assets
- Makes use of unused telescope components from the intelligence community, repurposed to NASA for scientific use.
- Optical Design: 2.36-meter aperture Three Mirror Anastigmat (TMA)
- Constrained and influenced by a combination of existing hardware, design heritage, science interests and volume constraints

Hits 5 of 6 NASA Strategic Goals	**#1 Large Mission Priority** WFIRST science	**#1 Medium Scale Priority** Exoplanet Imaging	Nobel Prize science

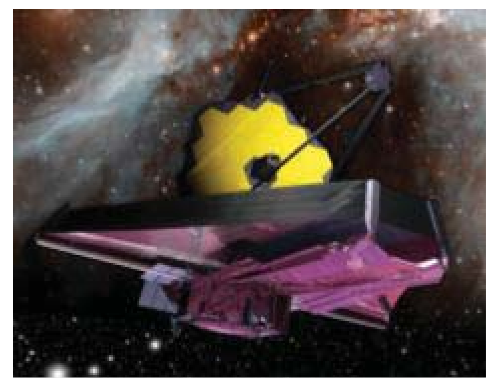




COST EFFECTIVE – LOW RISK – MATURE TECHNOLOGIES

Brings Universe to STEM
Next generation citizen science

Foundation for discovering Earth-like planets



Complements and enhances JWST science

WFIST-AFTA Optical Design

- Wide-Field Instrument composed of two channels:
- Wide-Field Channel (WFC) provides ~1/3-square degree of instantaneous field coverage at 0.11 arcsecond pixel scale.
- WFC Focal plane of 300 million pixels
- Diffraction-limited imaging mode (WFI), operating in six panchromatic bands between 0.6 – 2.0μm, or spectrographic mode (WFS) from 1.3-2.0μm.
- Separate Integral Field Channel (IFC) - Discrete spectral analysis over a ~3″x3″ field with 0.15″ sampling and R=100 spectral resolution.

Wide-Field Channel Optical Design

- The WFIRST-AFTA TMA optical design is anchored to the repurposed assets' size and figures
- Allows for small changes in the conic figure of the Primary Mirror (T1) and minor changes in the curvature and position of the Secondary Mirror (T2)
- Entrance Aperture Plate (EAP) at the intermediate focus passes the WFC's field into the instrument enclosure.

Wide-Field Channel Optical Design

- Powered mirror within the instrument (M3) works in concert with T1 & T2 to produce a corrected field
- All three powered mirrors are optically co-axial and simple conics
- Two fold mirrors are use for packaging
- Maximum root mean square (RMS) polychromatic wavefront error of 45nm across entire field
  - Half of the 90nm budget (based on 1/13 λ @ 1.2μm)
- Currently in "Cycle 4" design iteration

Focal Plane Array Layout

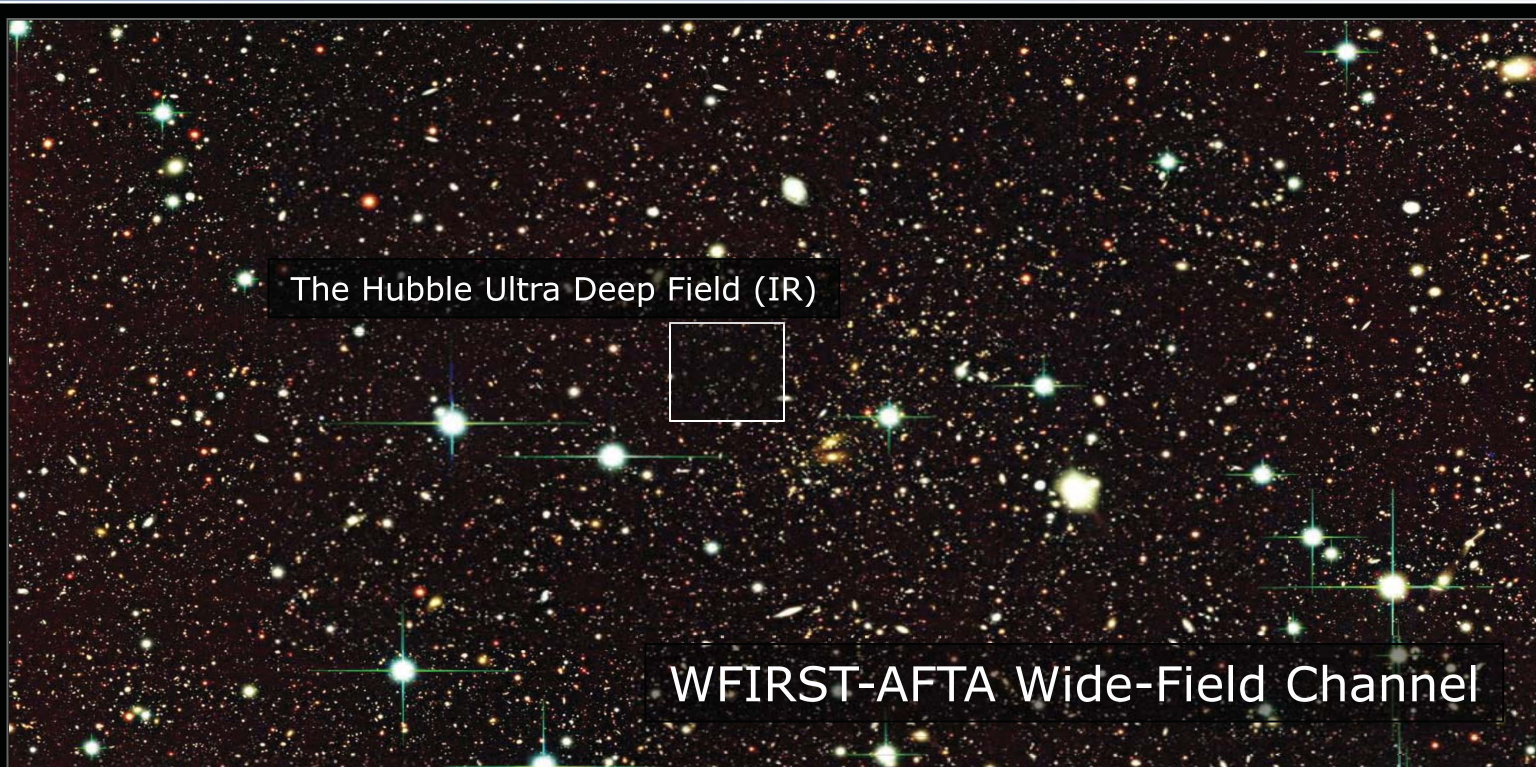
- 18 individual H4RG-10 detectors, each with 4,088x4,088 10μm active pixels.
- Each sensor is custom shimmed in the array with a tilt and piston to match a field curvature of about 16 meters, allowing a 10% performance gain over a perfectly flat field.
- 6 columns of 3 sensors w/ offset columns
- Columns follow the natural annular curve of an off-axis TMA optimized field.

Pupil / Element Wheel

- At the pupil, located approximately midway between M3 and the FPA, is the cold/Lyot stop and the element wheel.
- Blocks the scatter and emissions form the telescope struts and baffles.
- 8-position Element Wheel: 6 bandpass filters, 1 spectrograph grism assembly, 1 null position.
- All wheel modes are par-focal to no filter.
- The filters are very weak meniscus lenses.
- The grism consists of 3 optical elements; only spherical surfaces on fused silica and two diffracting surfaces on flats. (See presentation by Qian Gong)

Optical Design Considerations

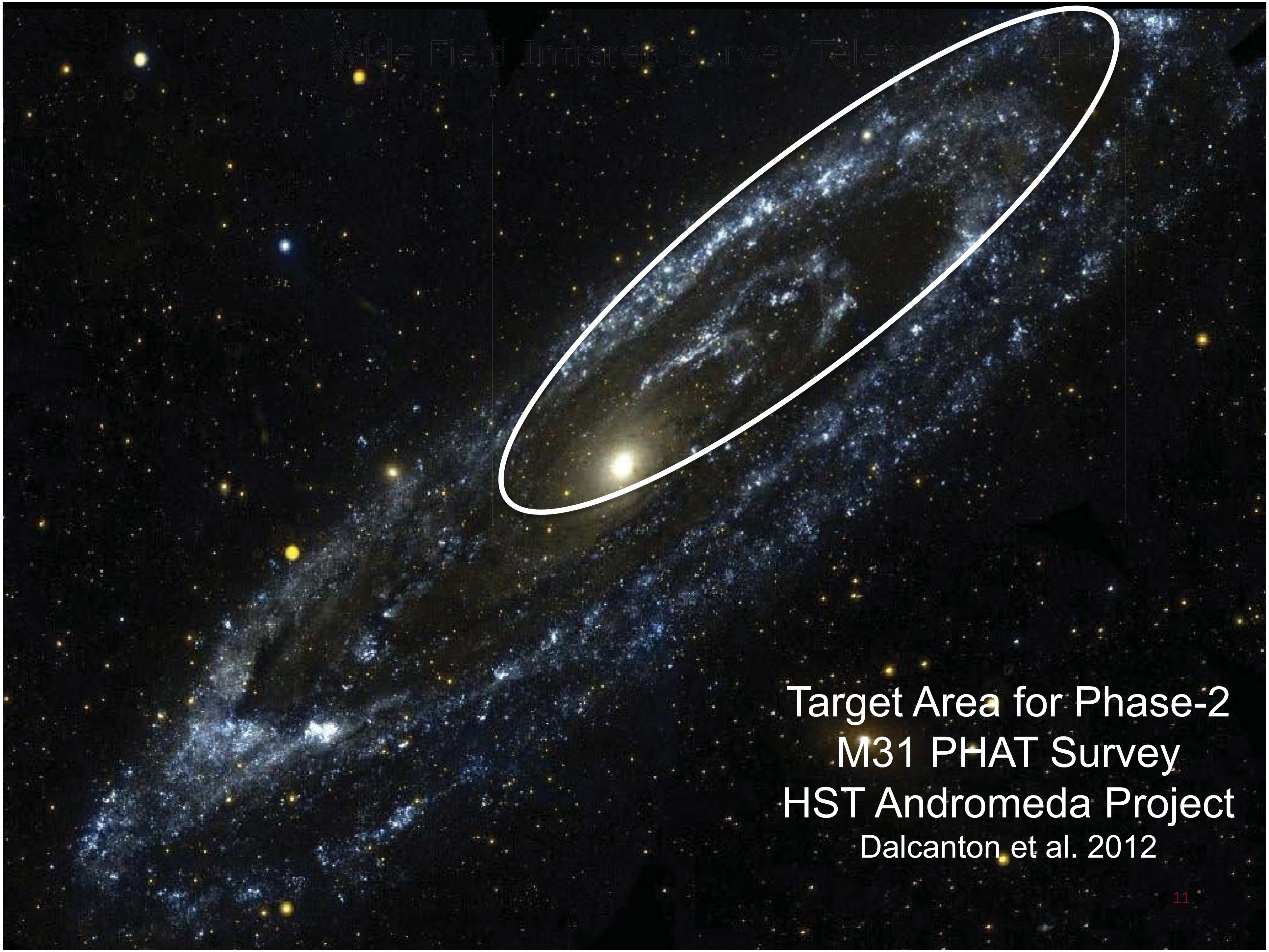
- Constraints of existing hardware (Use “as-is”)
- Hold volume while maintaining large field.
- Pupil clearance to allow for the large element wheel
- M3 distance to allow for mounting
- EAP location which allows for clean baffling of the intermediate focus
- Minimum central obscuration

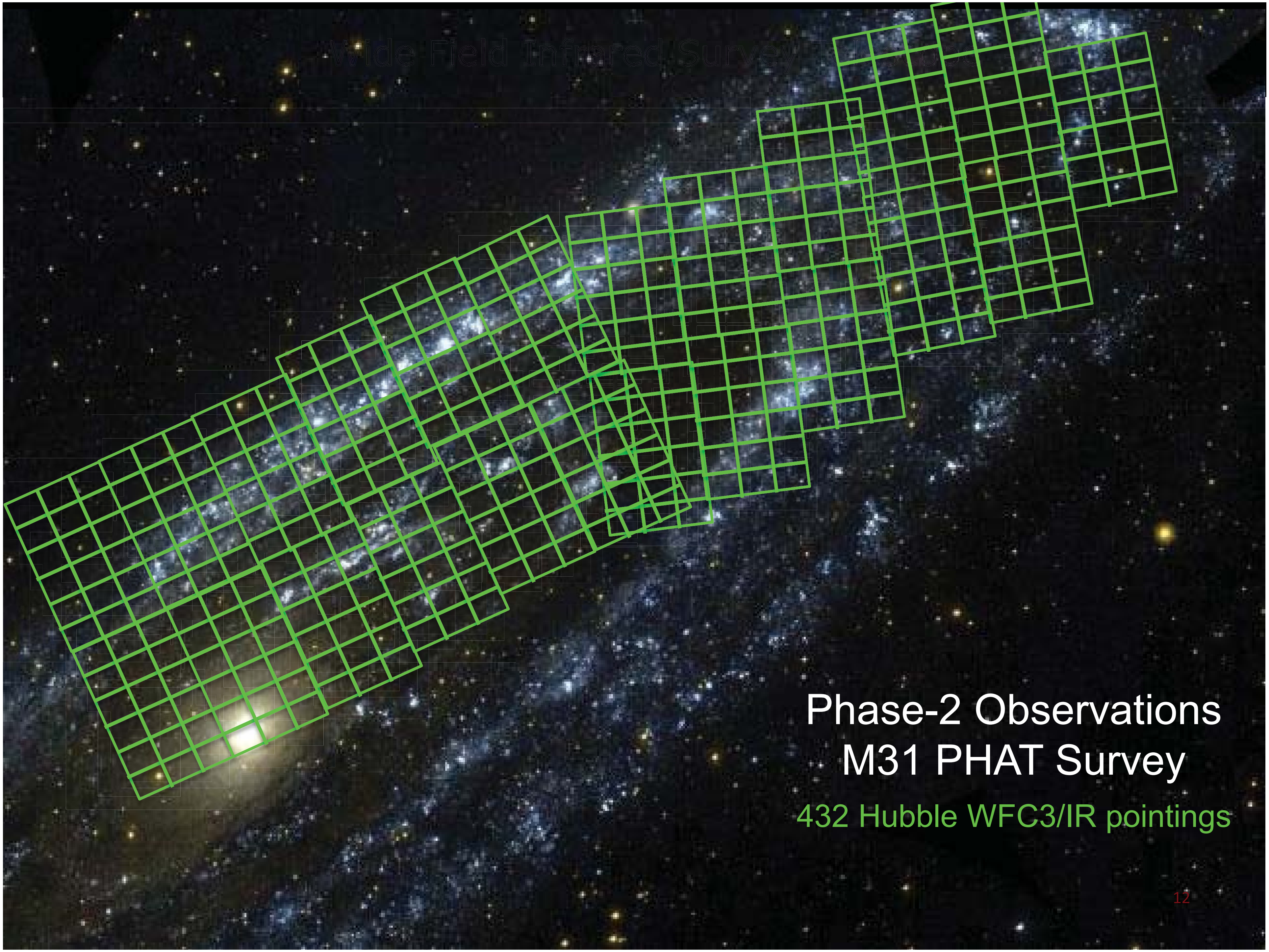


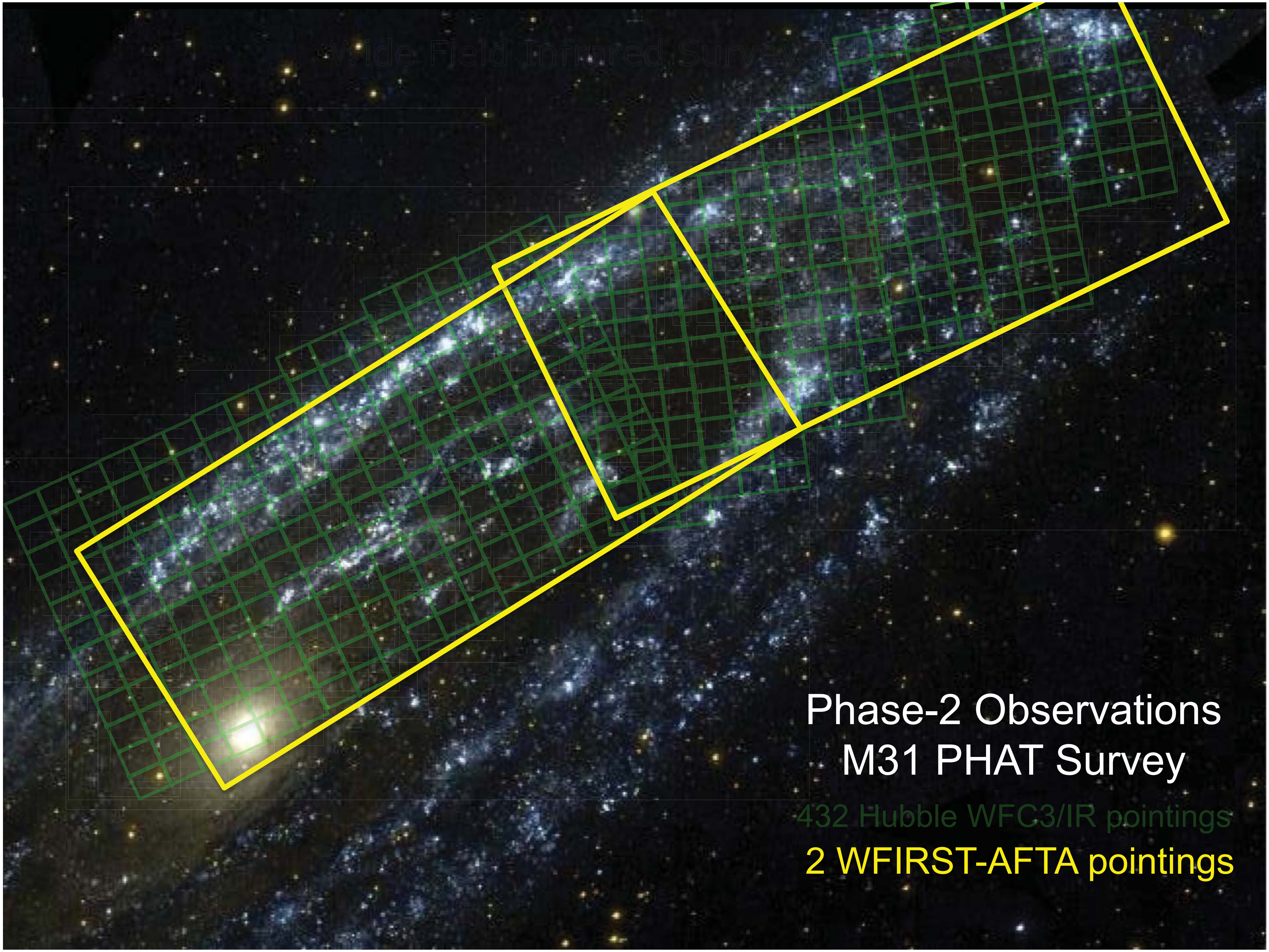
Imagine 200x more, with >1,000,000 galaxies

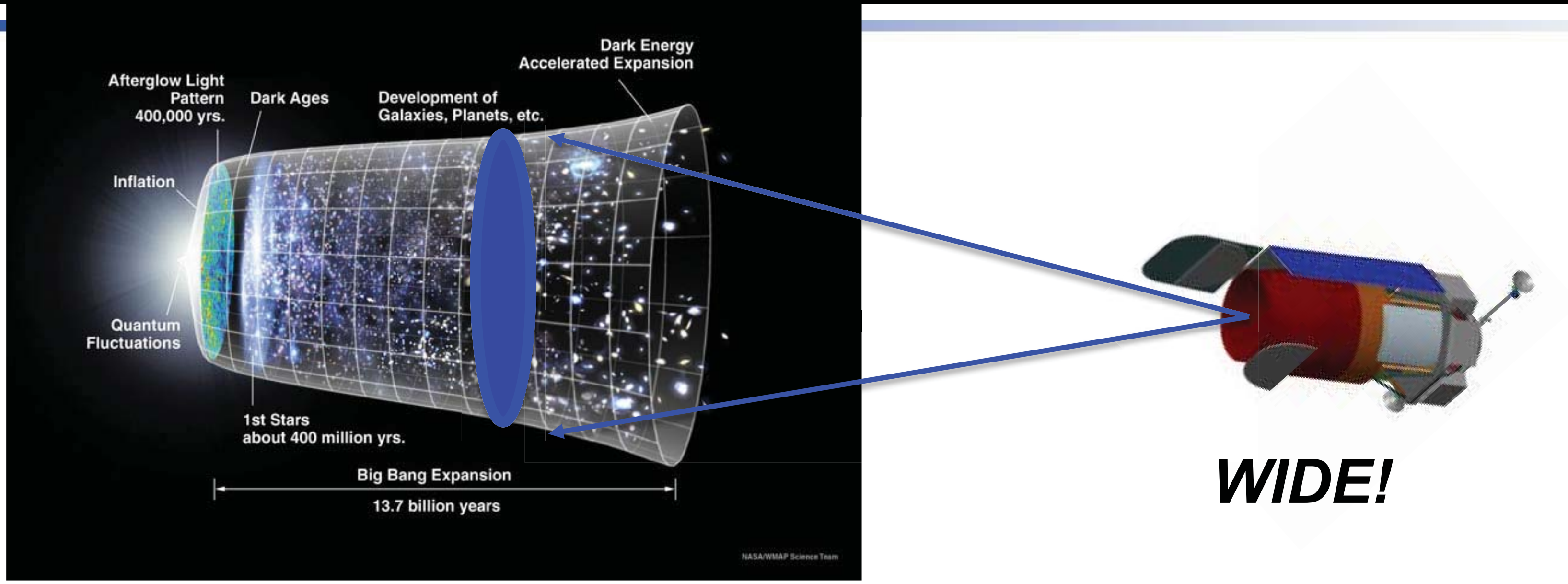
(a 20'x10' wall of "retina" displays!)

Imagine this wall of a million galaxies – a 300 megapixel image from a single WFIRST-AFTA pointing -- filling walls of schools and museums and providing a wealth of citizen science.

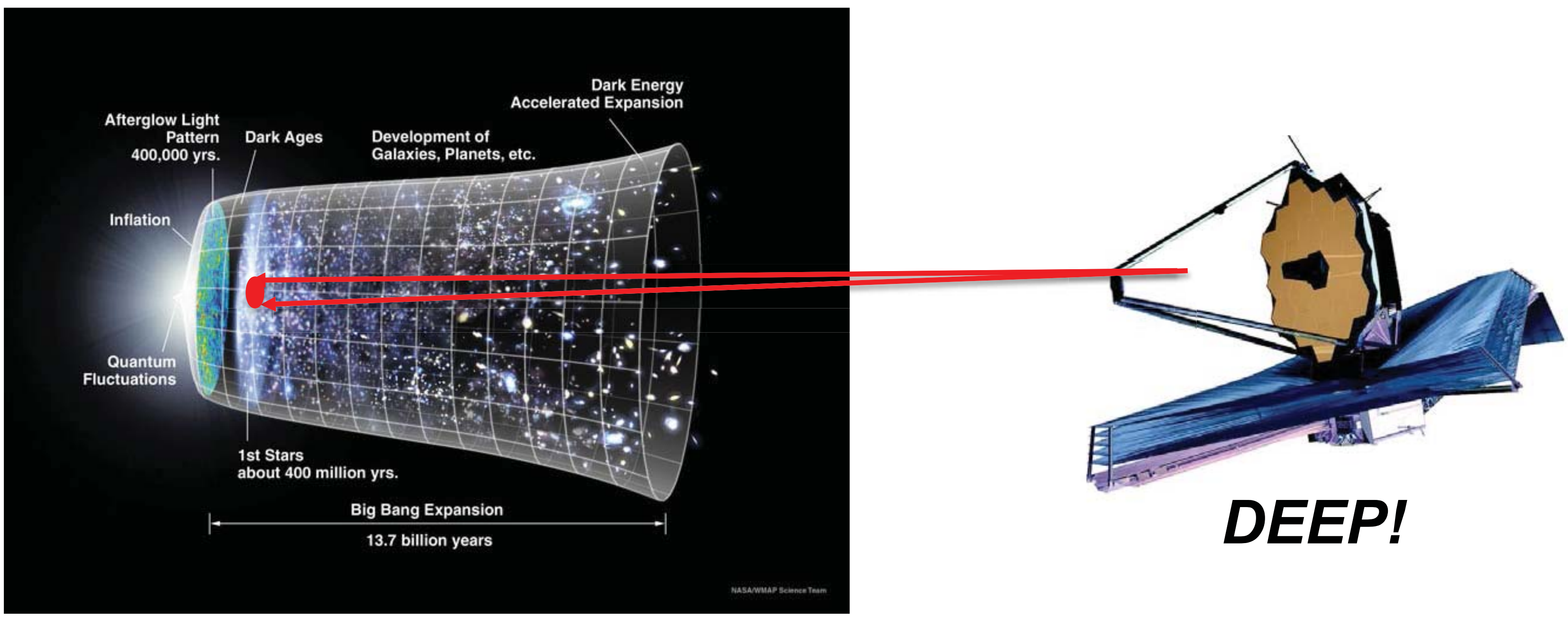

Target Area for Phase-2
M31 PHAT Survey
HST Andromeda Project
Dalcanton et al. 2012


Wide Field Infrared Survey
Phase-2 Observations
M31 PHAT Survey
432 Hubble WFC3/IR pointings


Phase-2 Observations
M31 PHAT Survey
432 Hubble WFC3/IR pointings
2 WFIRST-AFTA pointings


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years
NASA/WMAP Science Team

WIDE!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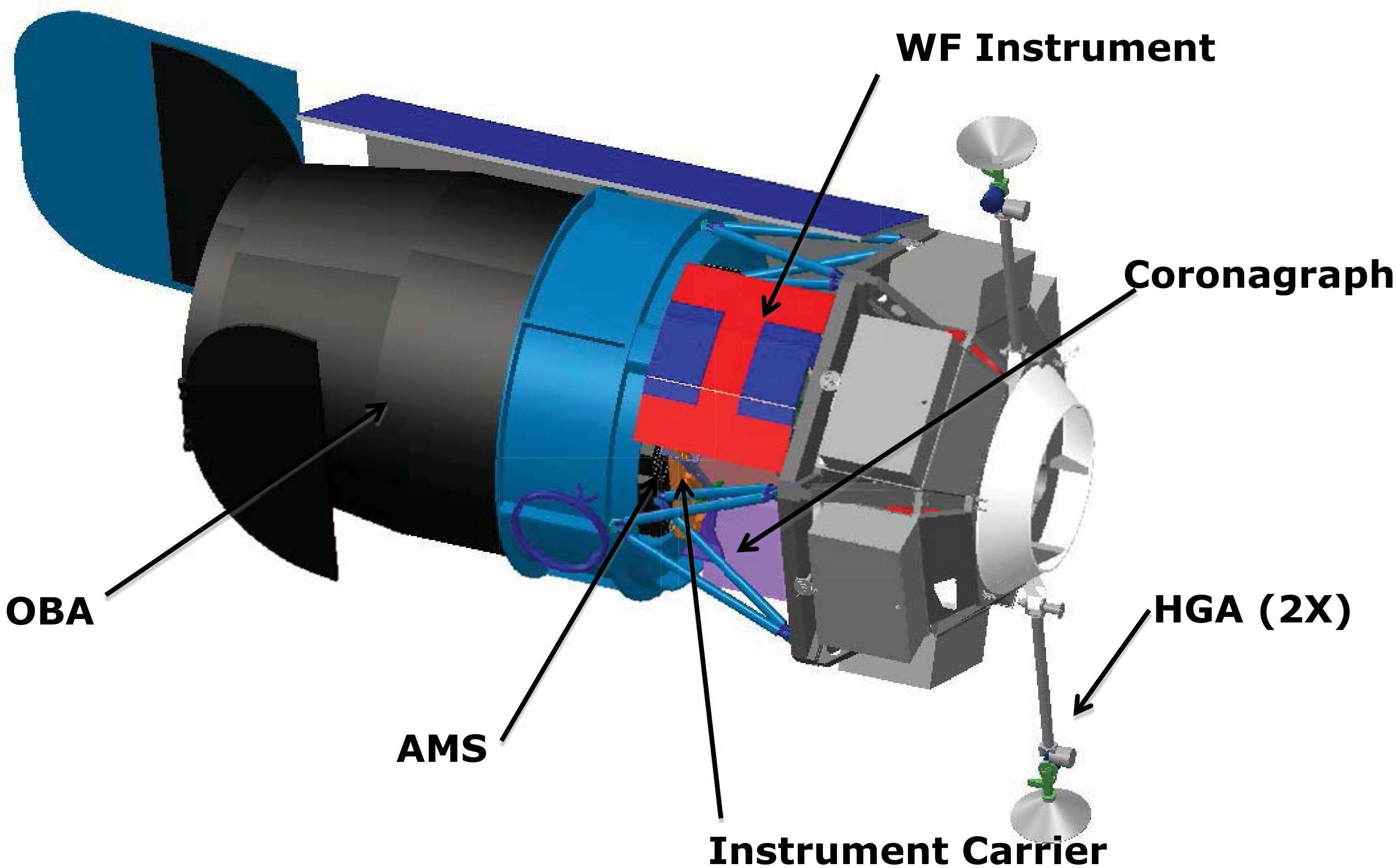
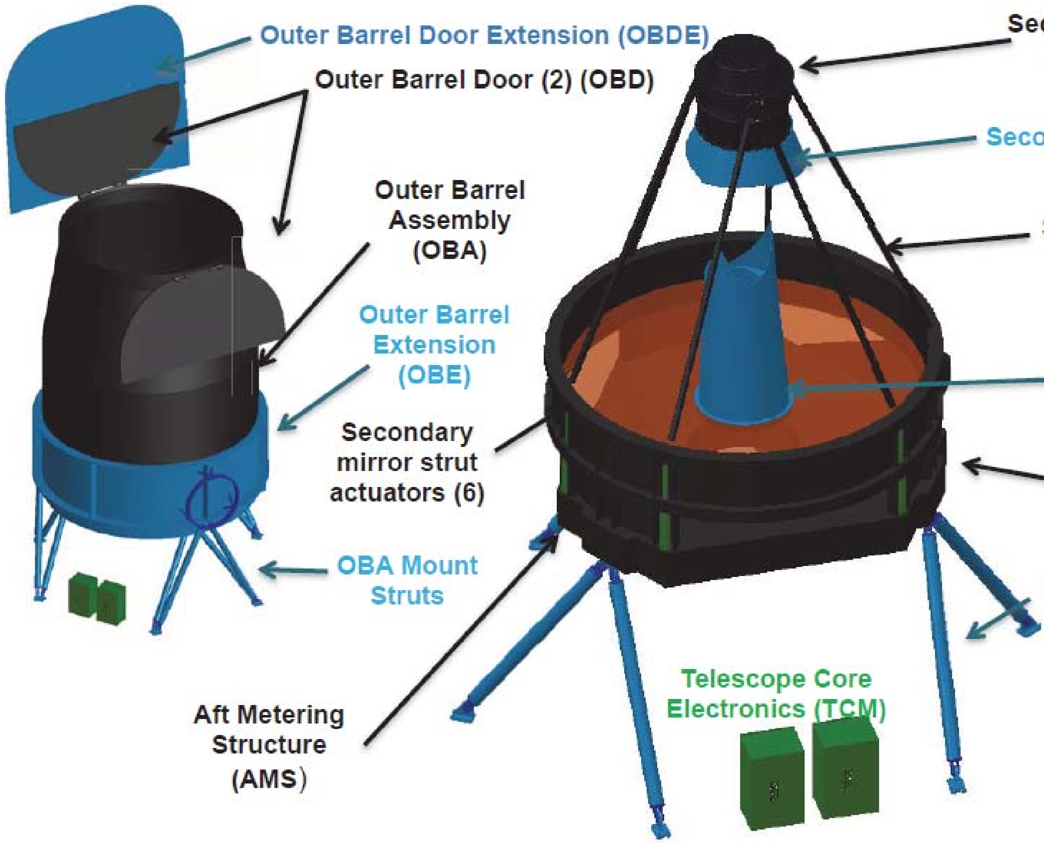
DEEP!

WFIRST Observatory Layout



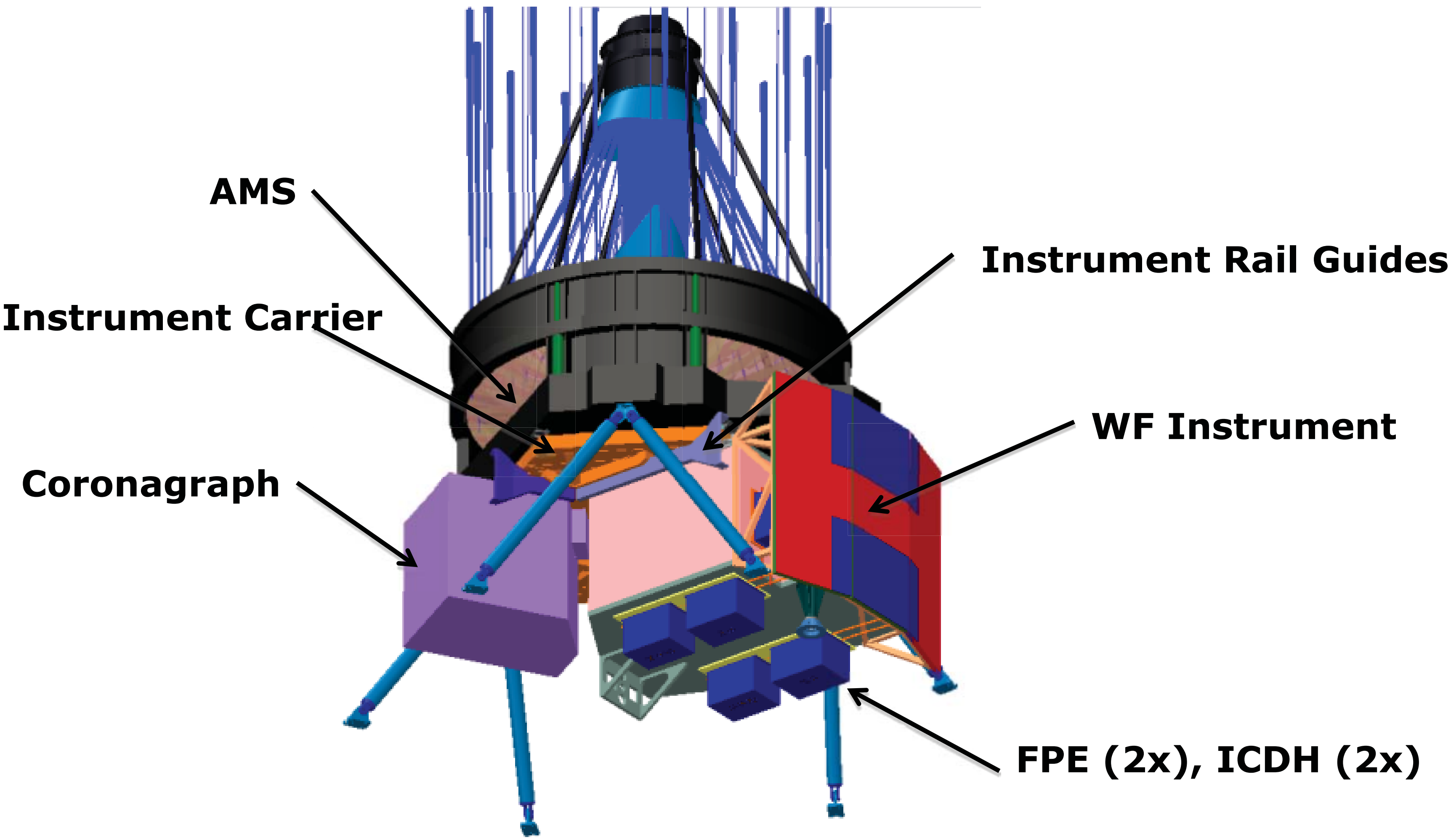
Telescope Reuse



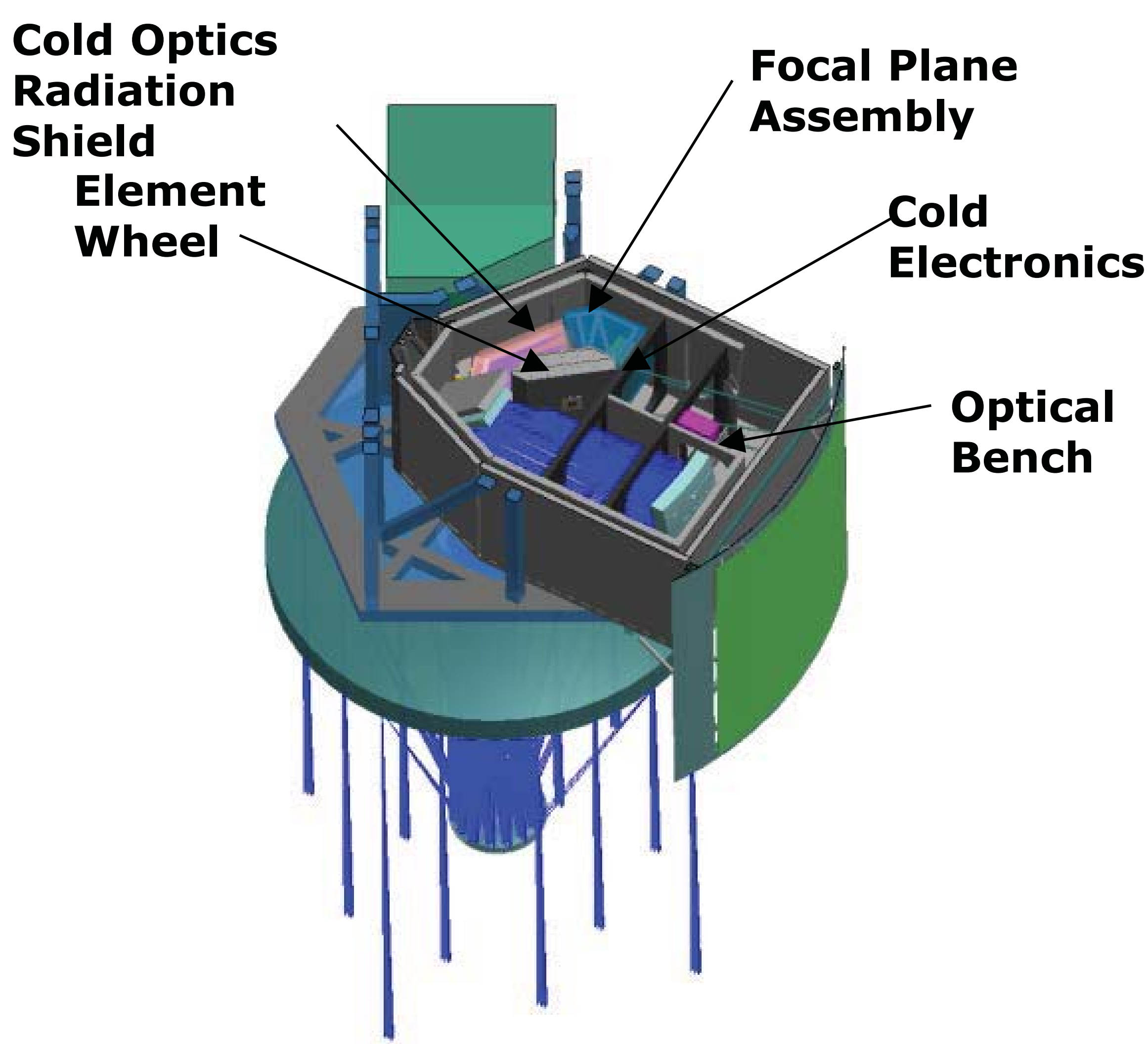
Existing H/W, reuse	1188 kg
Existing design, remake	153 kg
New design	254 kg
TOTAL:	1595 kg

100% of the existing telescope hardware is being re-used.
Electronics and baffles not available and must be replaced.

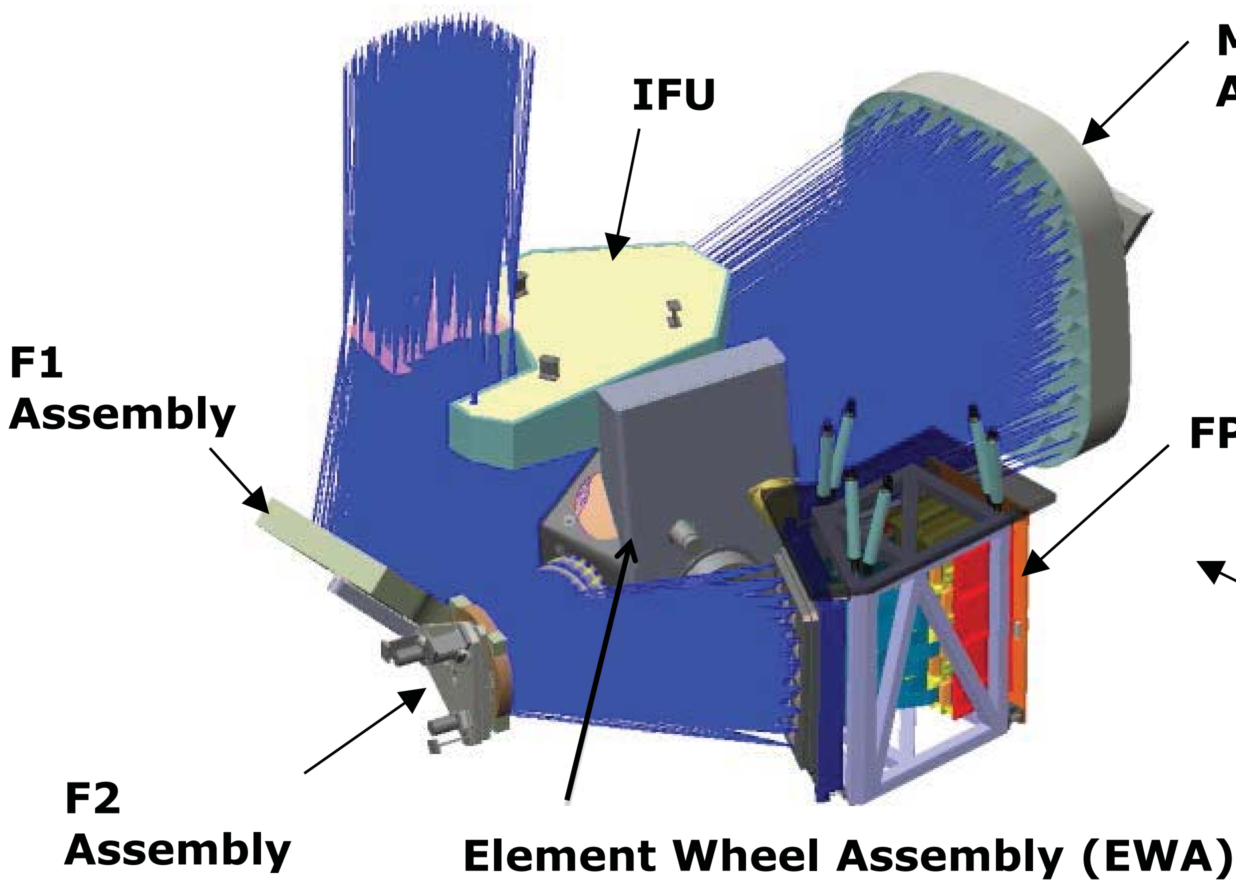
WFIRST IC/WFI/CGI Layout – Cycle 4



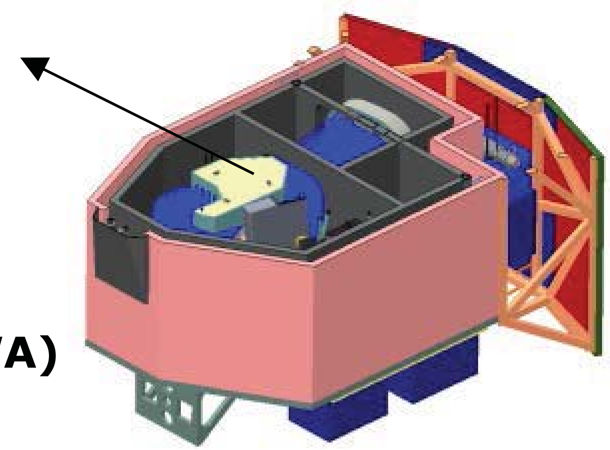
- Single wide field channel instrument
- 3 mirrors, 1 powered
- 18 4K x 4K HgCdTe detectors
- 0.11 arc-sec plate scale
- IFU for SNe spectra, single HgCdTe detector
- Single filter wheel
- Grism used for GRS survey
- Thermal control – passive radiator



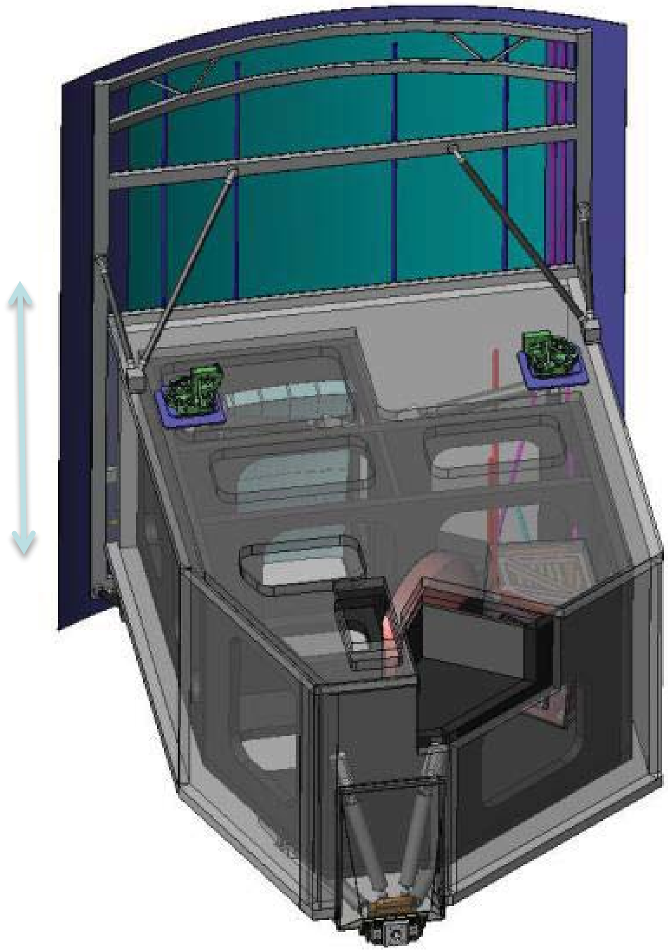
WFIRST WFI Layout – Cycle 4



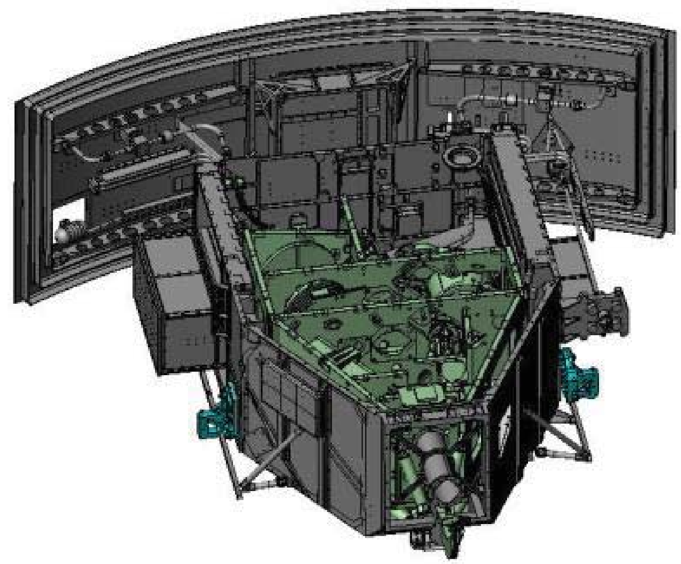
Optical Layout v4-2-0



Wide field Instrument Shares Architecture and Heritage with HST/WFC3

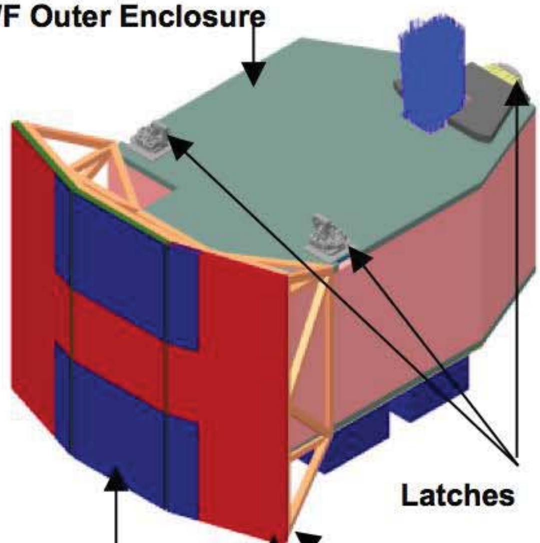


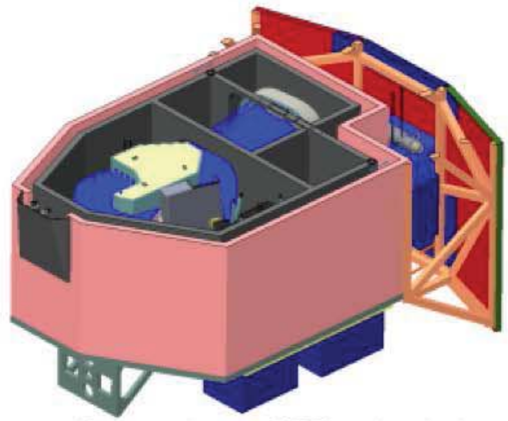
WFIRST wide field



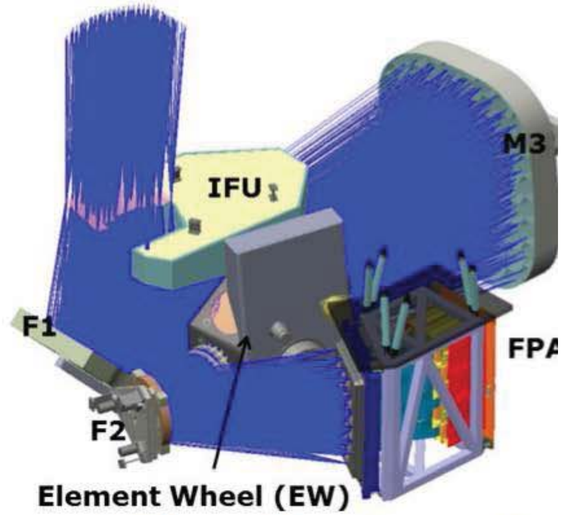
HST/WFC3

Wide-Field Major Subassemblies



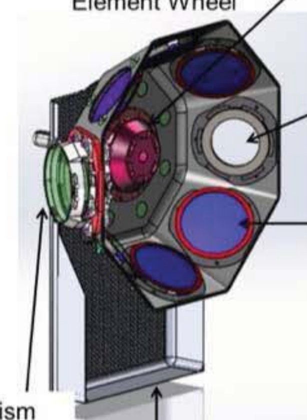


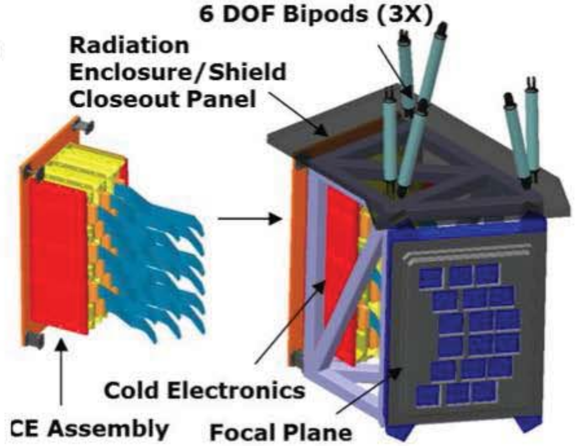
Outer enclosure (OE) and optical bench (OB) top panels removed



Element Wheel (EW)

Wide field mirrors; Focal plane assembly (FPA); Integral field unit (IFU)

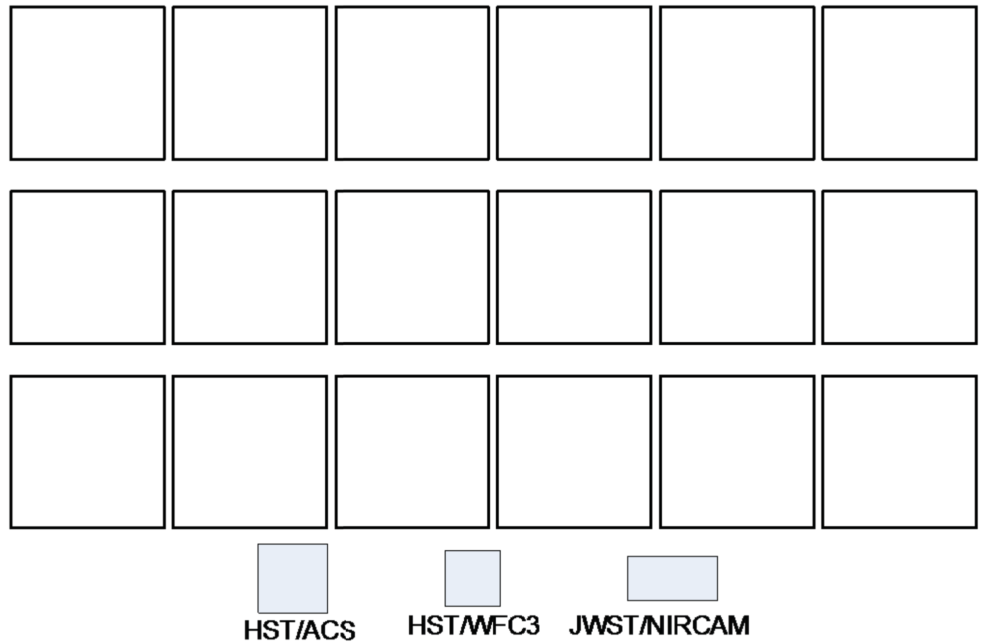




18 NIR detectors

0.11 arcsec/pixel   0.28 deg^2

Moon (average size seen from Earth)



Each square is a H4RG-10
4k x 4k, 10 micron pitch
288 Mpixels total

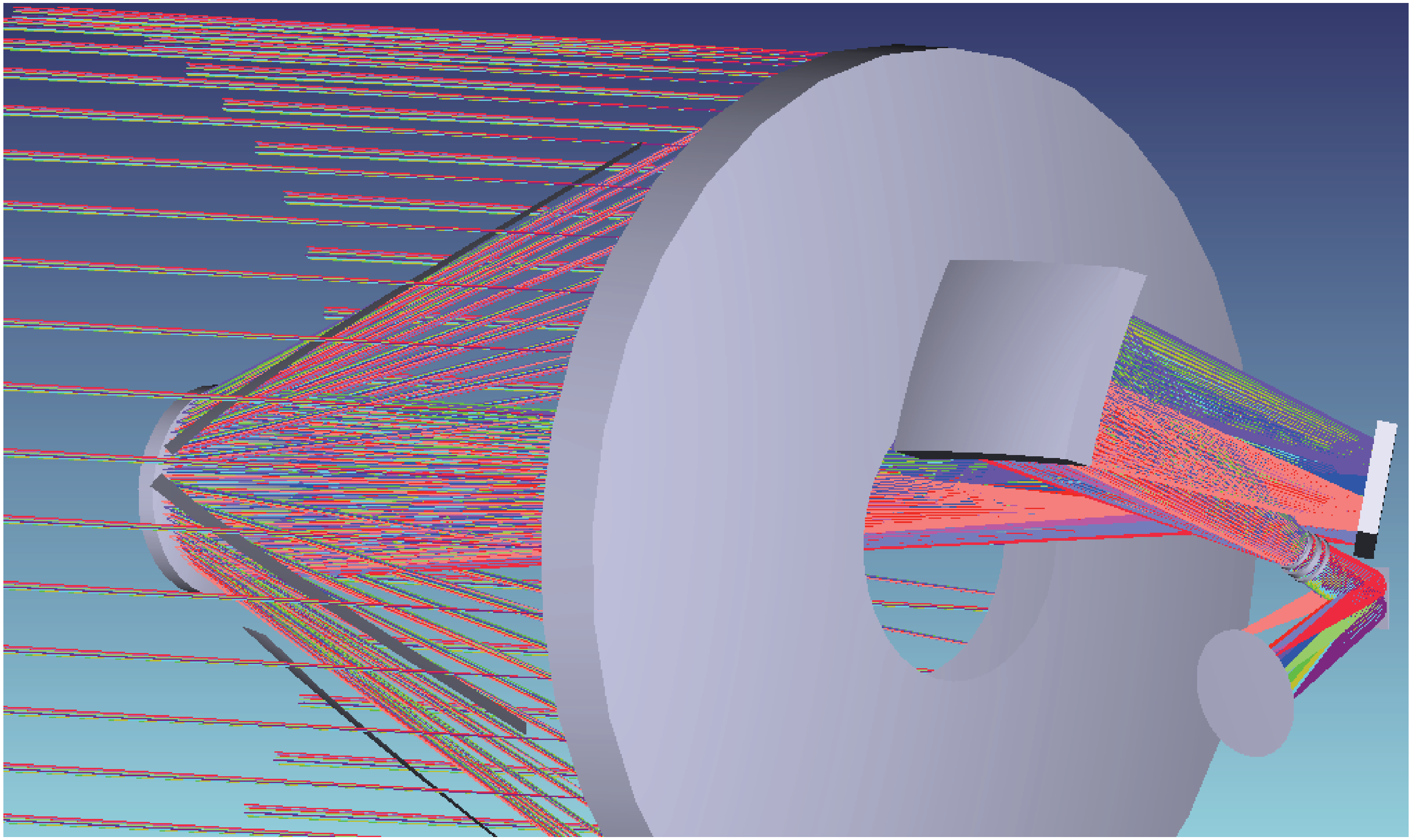
Slitless spectroscopy with grism in filter wheel
$R_\theta \sim 100$ arcsec/micron

OPTICAL DESIGN OF WFIRST-AFTA WIDE-FIELD INSTRUMENT

Bert Pasquale
NASA Goddard Space Flight Center

CONTINUED
PART 2

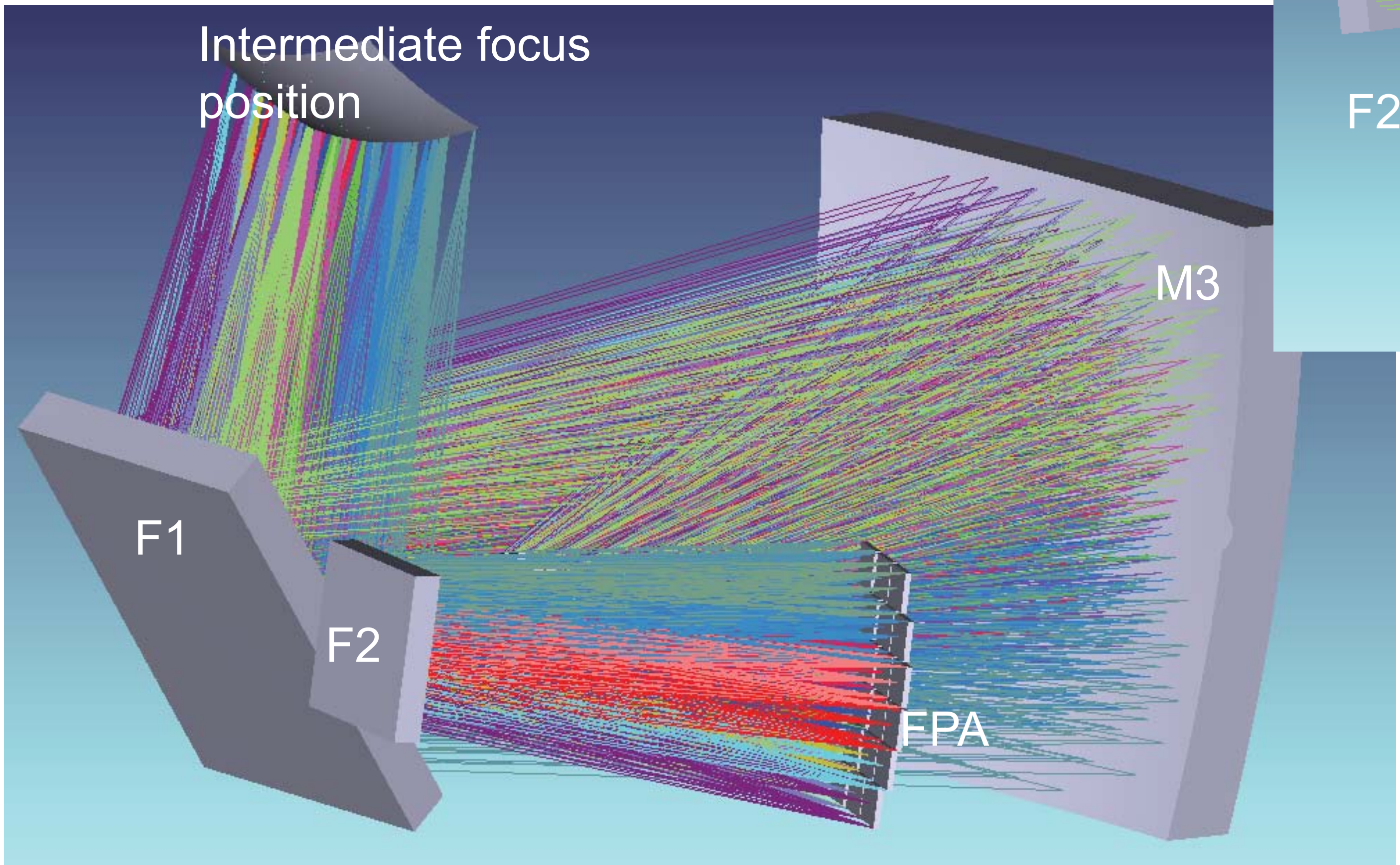
Design overview

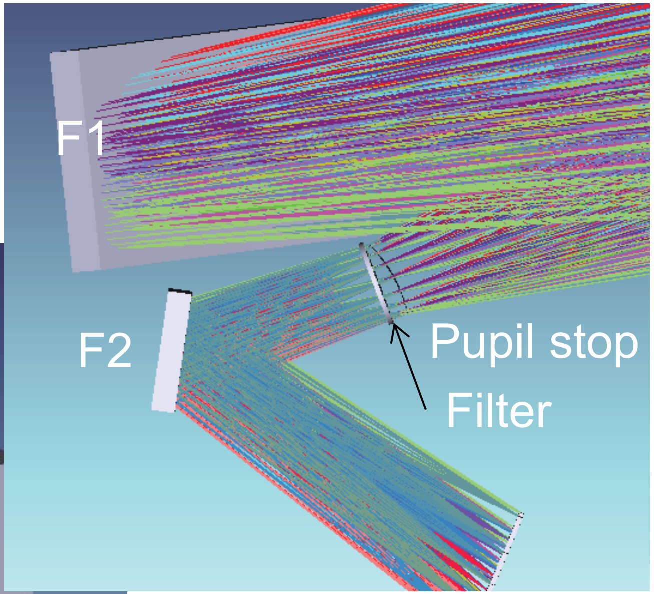


ATLAST (v4.2.5) Optical Components

	Radius (mm)	Conic	Aperture (mm) Circular: Diameter Rectangular: Width x Height	Other
PM (T1)	5,670.69	-0.97198	C 2,362	Concave
SM (T2)	1,294.73	-1.69502	C 536	Convex
Fold 1	Flat	0	R 504 x 280	
Mirror 3	1,729.732	-0.56660	R 620 x 500 240 Off-Axis	Concave
Filter	S1: 1,594.07 S2: 1,593.09	0	C 110	Meniscus
Fold 2	Flat	0	C180	

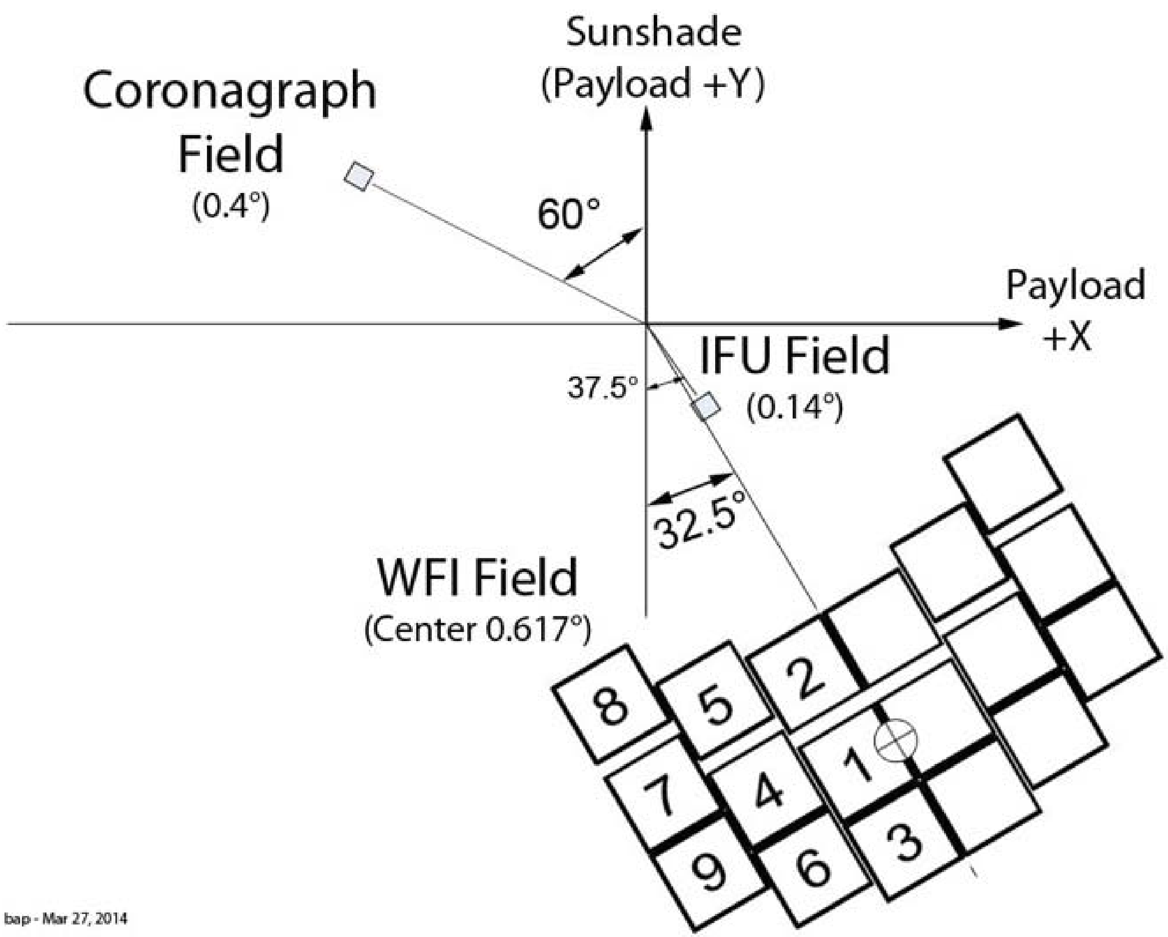
Instrument ray trace views





Channel Field Layout for AFTA-WFIRST Instruments

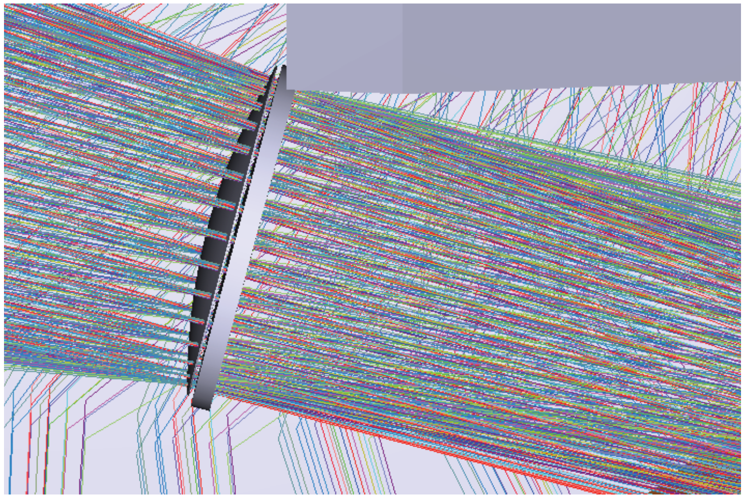
As Projected on Sky
[Cycle 4, v4.2.5]



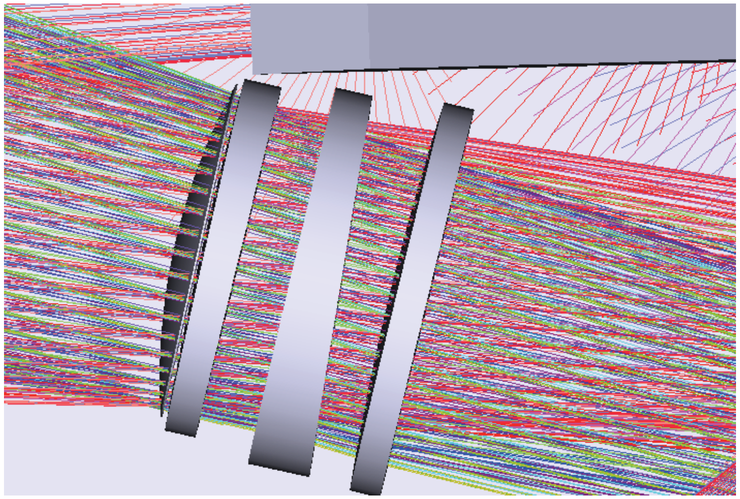
bap - Mar 27, 2014

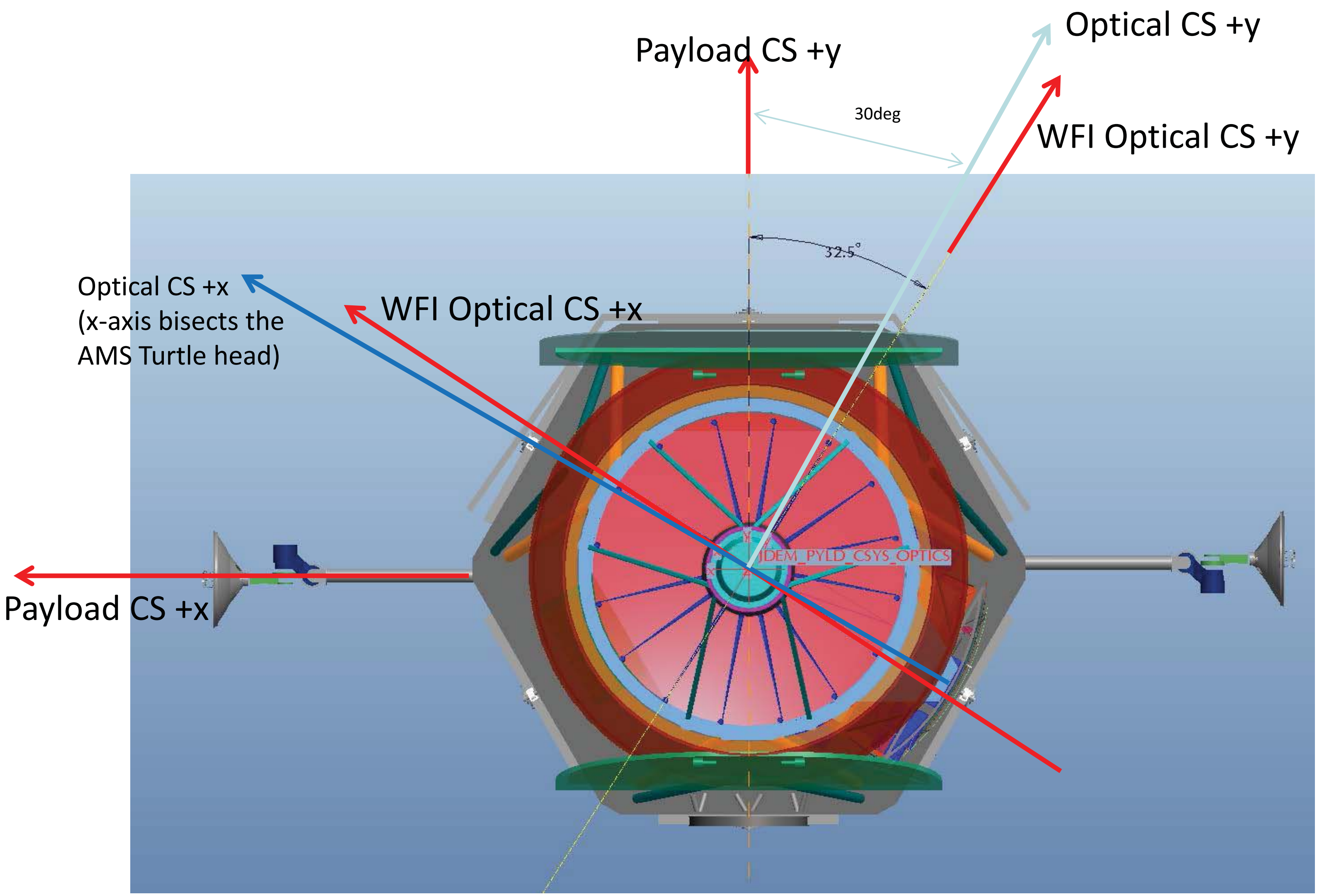
Element Wheel Modes

Wide-Field Imaging Mode
Bandpass Filter
(6 positions)

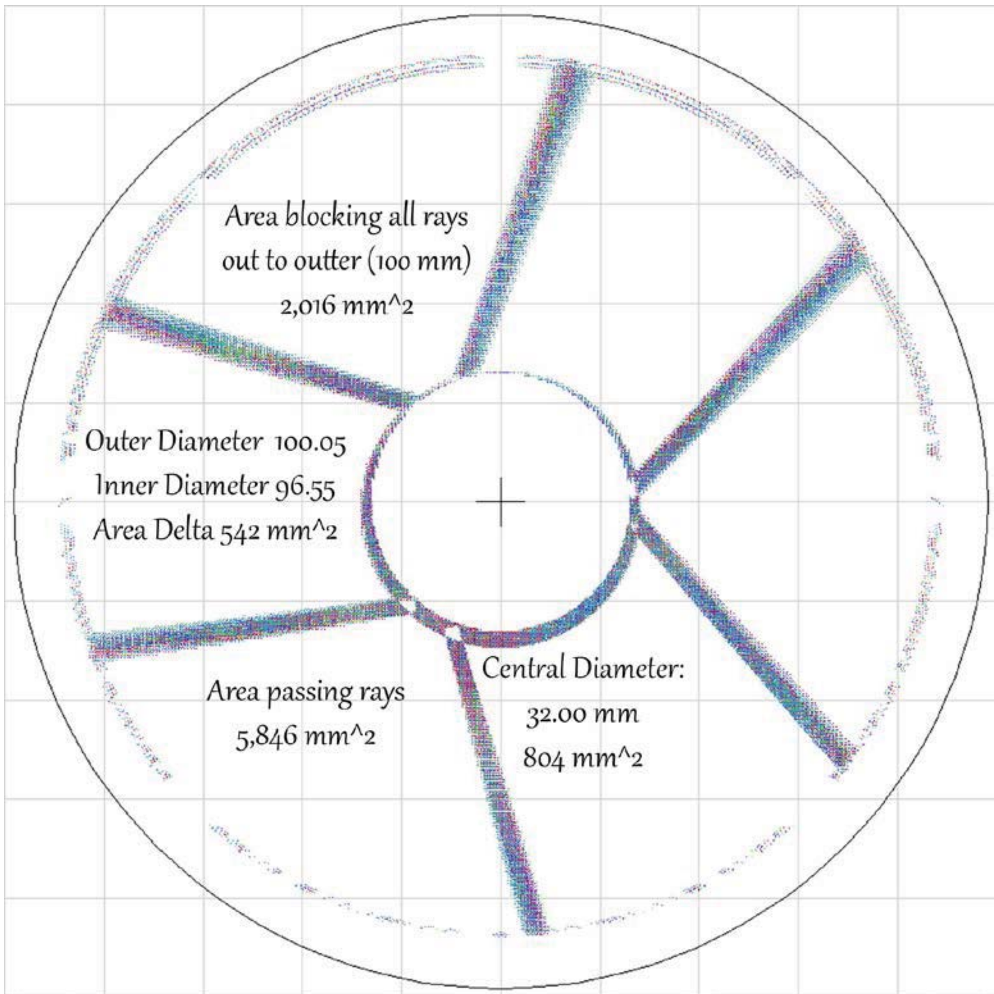


Wide-Field Spectrograph Mode
Bandpass Filter
(1 position)




Payload CS +y
Optical CS +y
30deg
WFI Optical CS +y
32.5°
Optical CS +x
(x-axis bisects the
AMS Turtle head)
WFI Optical CS +x
JDEM_PYLD_CSYS_OPTICS
Payload CS +x

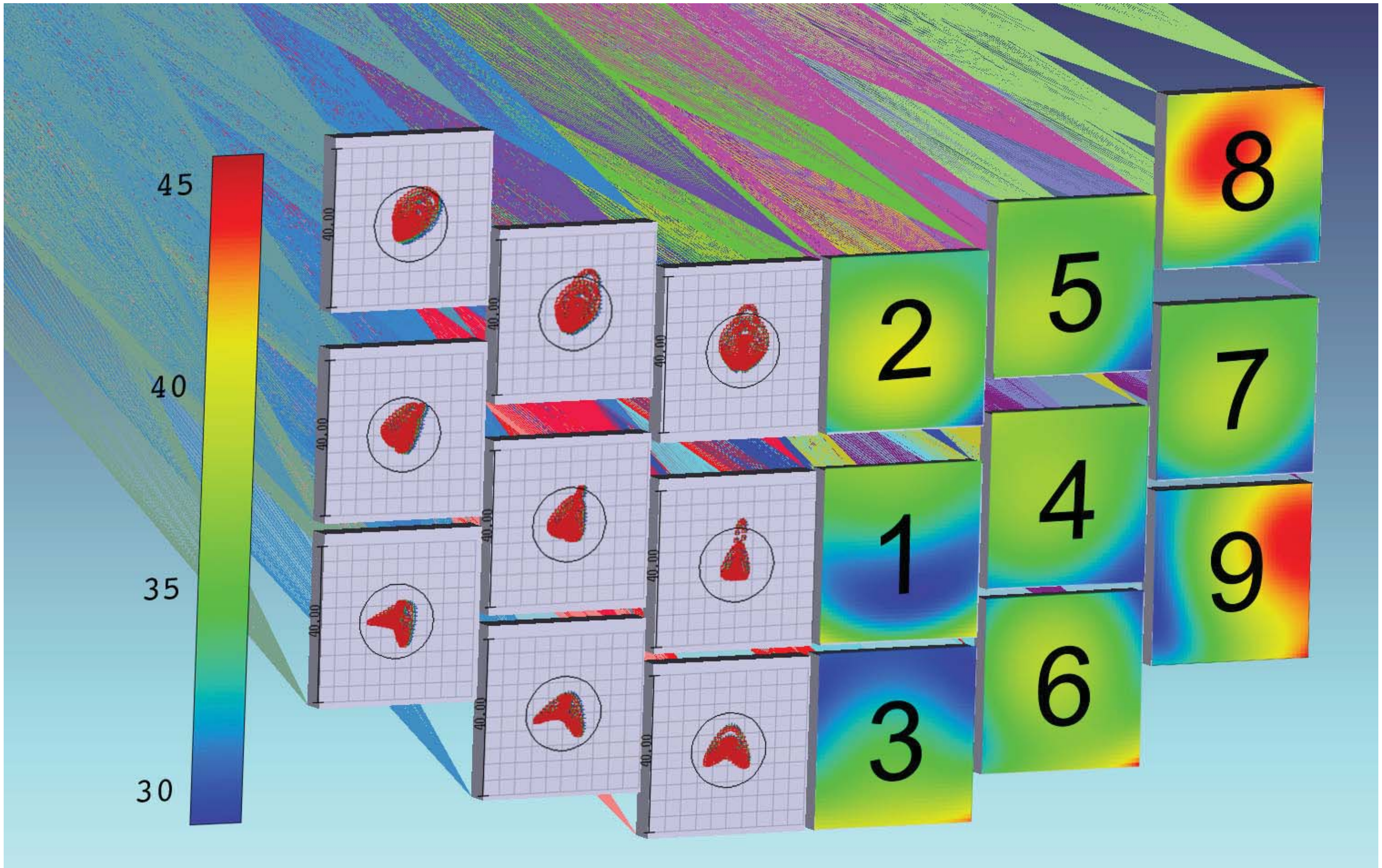
Lyot Cold Stop Layout



- Average blockage over field:
- Telescope Only:
  15%
- Tel plus Lyot Stop:
  23%
  - Mask blocks additional 5.1% to 10.6%)

Imager Performance

- Comparative Polychromatic Spot Sizes



WFI Error Budget

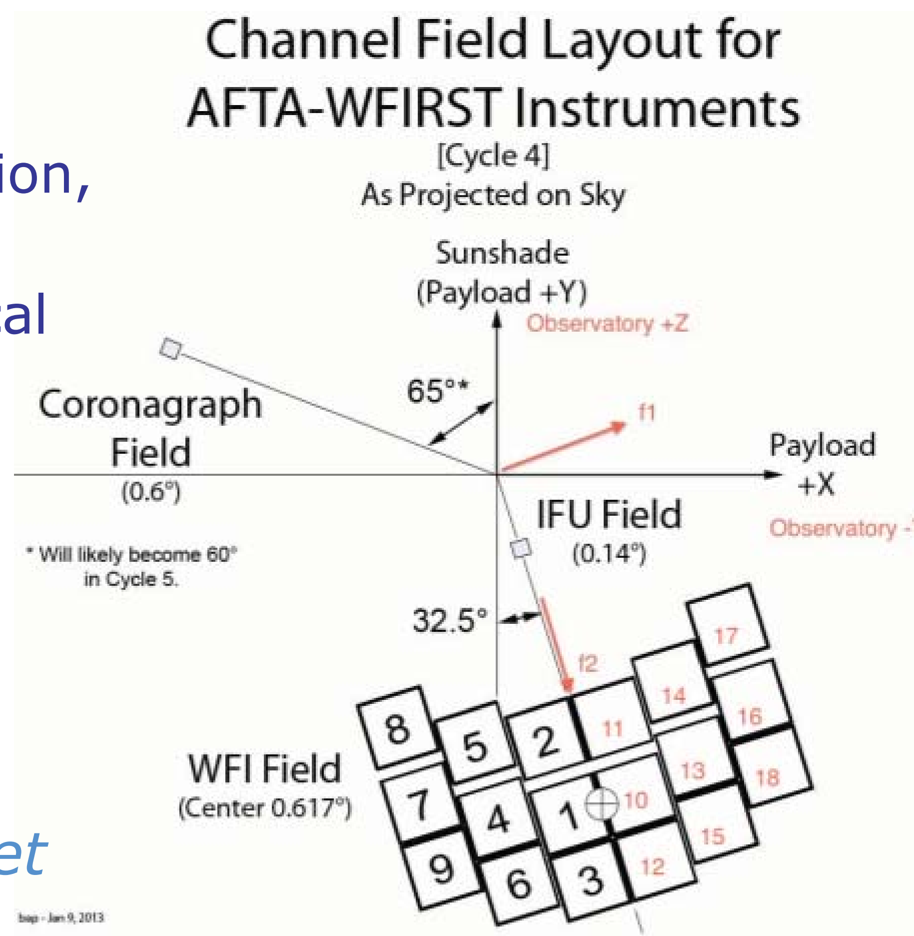
- Pre-Launch Phase:
  - Each parameter is budgeted for degrees of freedom in both fabrication and alignment
  - Predictions in cooldown and gravity release are accounted for
  - These form compensated/uncompensated totals
  - All I&T methods (alignment tools, Wavefront sensing, etc…) and all adjustable (mechanisms, shims, etc.. Are brought to bear for compensation.
- Post-Commissioning
  - Errors in analysis and stabilities form new compensated/uncompensated totals
  - Only adjustable mechanisms are available for compensators

WFI Error Budget (Sample Totals)

- Error Budget Totals are applied to the Linear Optical Model (LOM)
- Wavefront and boresight changes are calculated.
- Totals compared against system budgets.
- Iterative process, refined as I&T methods and tools are refined.

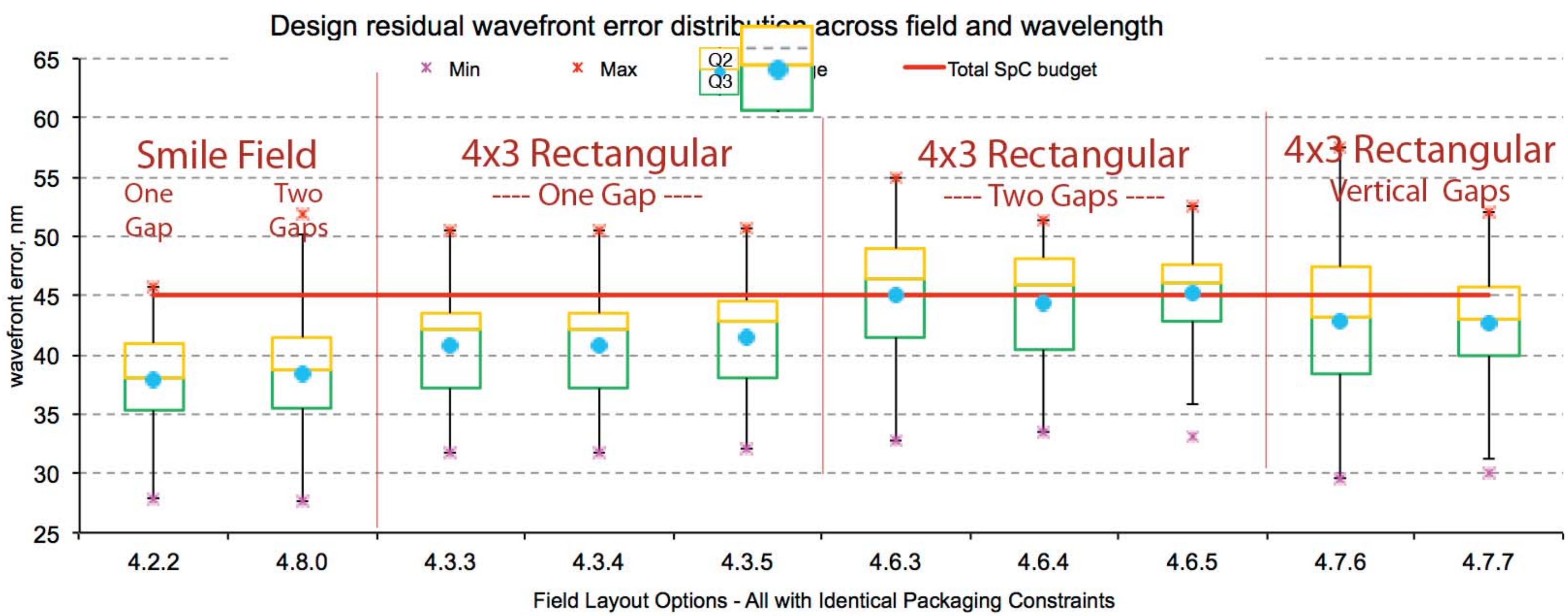
Cycle4 WFI design update

- Outline
- WFI design progress
  - Optics performance: distortion, dispersion
  - Mechanical, thermal, electrical progress examples
  - Error budgeting
  - Risk reduction activities
- Cycle5 trade space
- Update on detector development
- *Reminder – details of filter set are pending the telescope temperature vs risk assessment, ongoing*



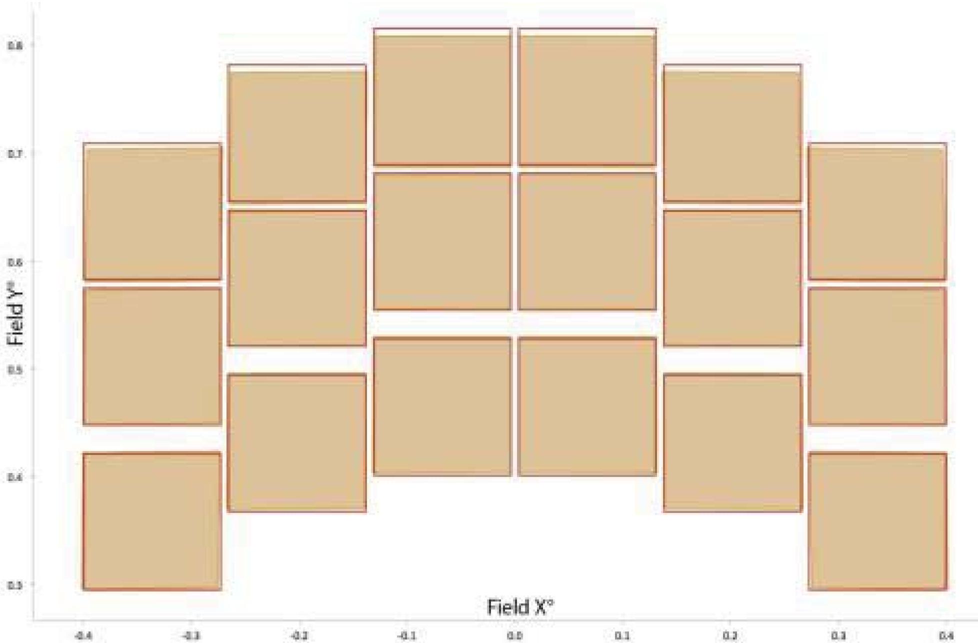
Statistical Results4088x4088-p

- 41x41 sampling of across each sensor
- Each group showed distinct trending:

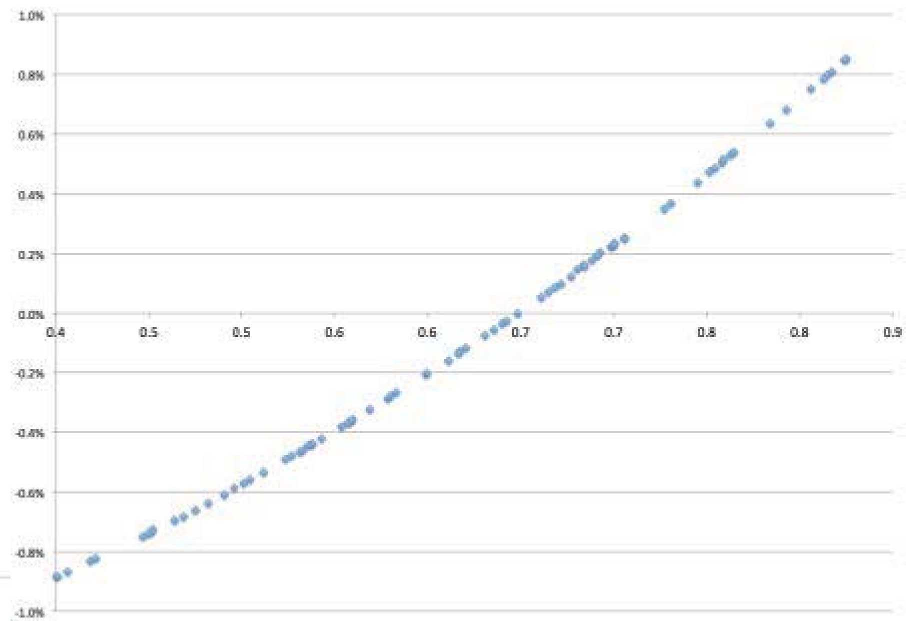


Optical distortion

- Optical distortion assessed
  - ‘Feature’ of TMA optical designs used off field axis
  - Independent of the small field configuration tweaks under consideration for Cycle5, see below
  - Simple function of radial field angle

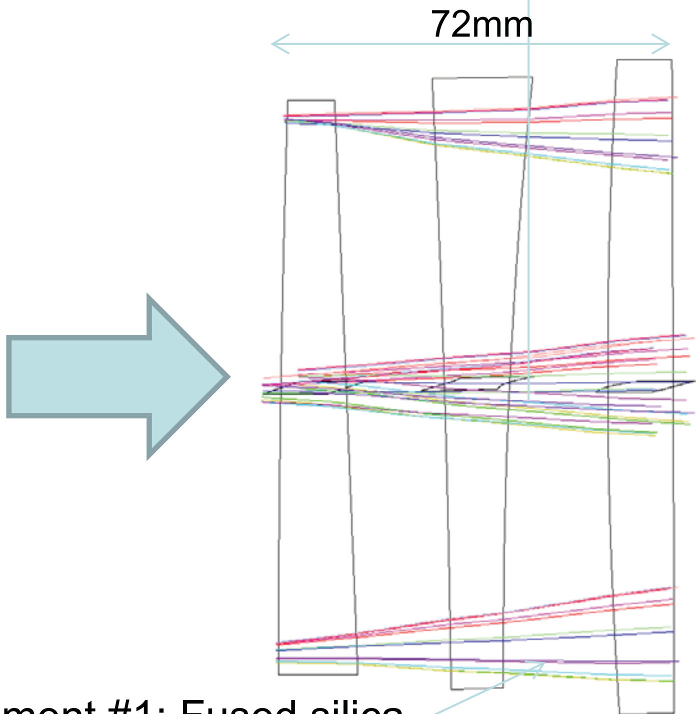


Square outline: zero distortion;
Filled trapezoids: actual SCA field positions



X: field angle, degrees; Y: Distortion, %

Grism Layout



Element #1: Fused silica
Surface #1: Filter (spherical)
Surface #2: Diffractive lens (flat)

Element #2: Fused silica
Surface #1: spherical
Surface #2: Spherical

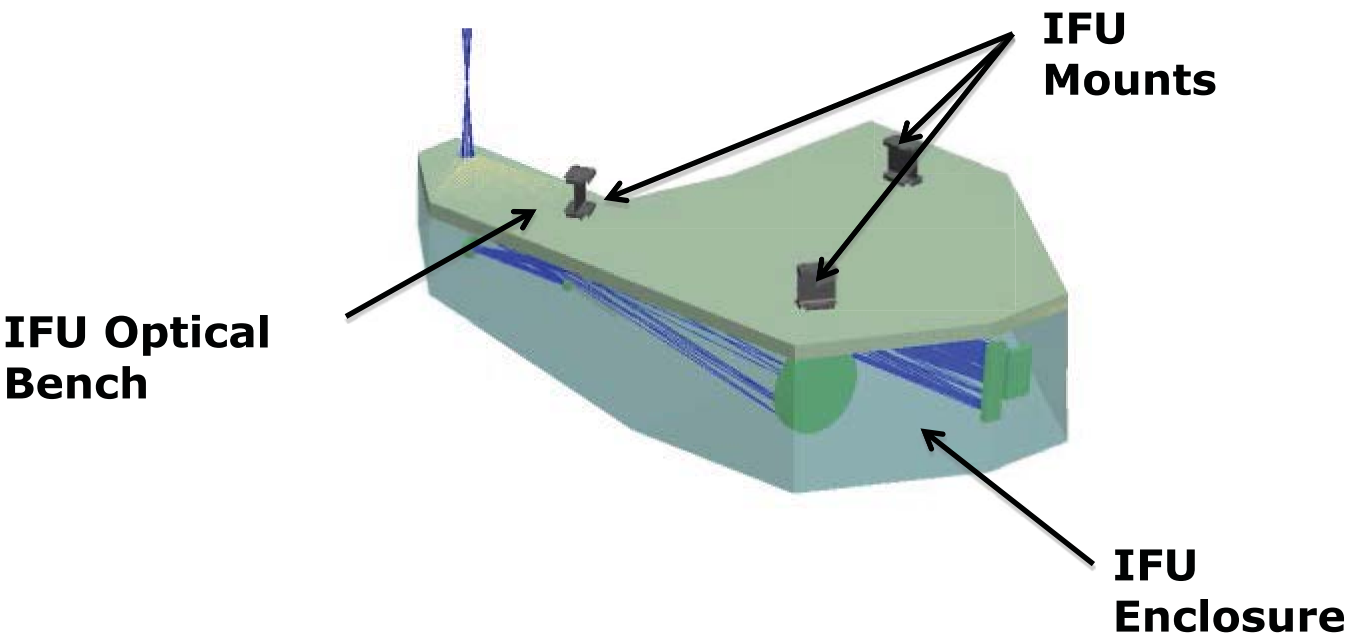
Element #3: Fused silica
Surface #1: Spherical
Surface #2: Grating (flat)

The filter can be on any spherical surface, but the first surface is smaller, also more perpendicular to the beam.

Integral Field Channel

- A separate channel within the Wide-Field instrument enclosure
- Using an assembly of 21 sets of 0.5 x 10 mm slicer mirrors, pupil mirrors, and output mirrors, a 3″x3.15″ field is sliced and re-arranged into a continuous slit.
- This slit is then relayed through a spectrograph (R~100), allowing for the multiplexing spectral analysis of each individual 0.15x0.15″ field

WFIRST IFU Design

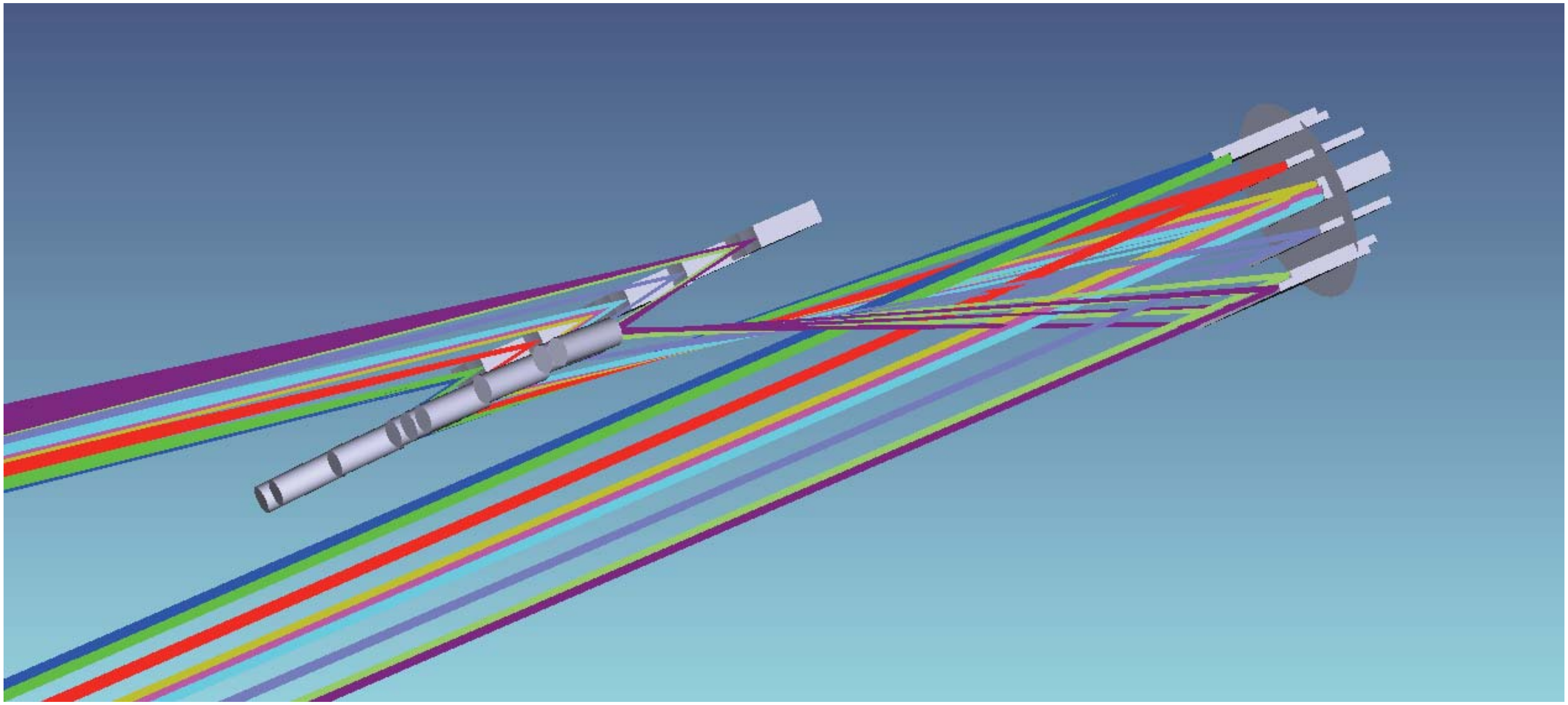


<u>IFU Assembly v4-2-5</u>

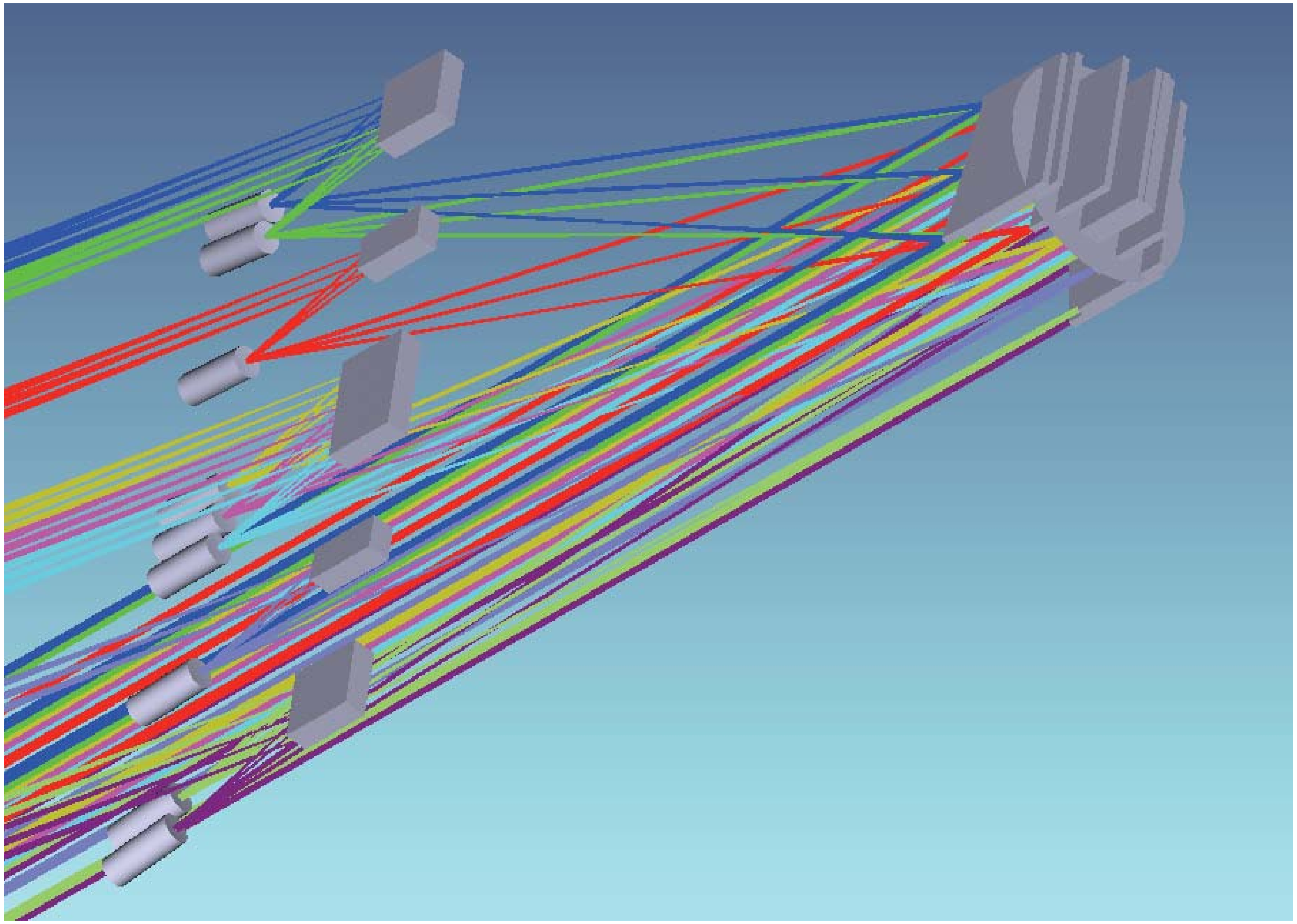
IFU Design Features

- Uses "current art" for image slicing method
- 21 10mm x 0.5mm slicer mirrors form pupils
- 21 pupil mirrors reimage slices to single 50mm output slit
- 21 slice output field mirrors create telecentric output
- Spectograph used tri-prism for more constant R
- Collimation and focus mirrors reduce to 18mm, fits on single H1RG.
- Telecentric input & output

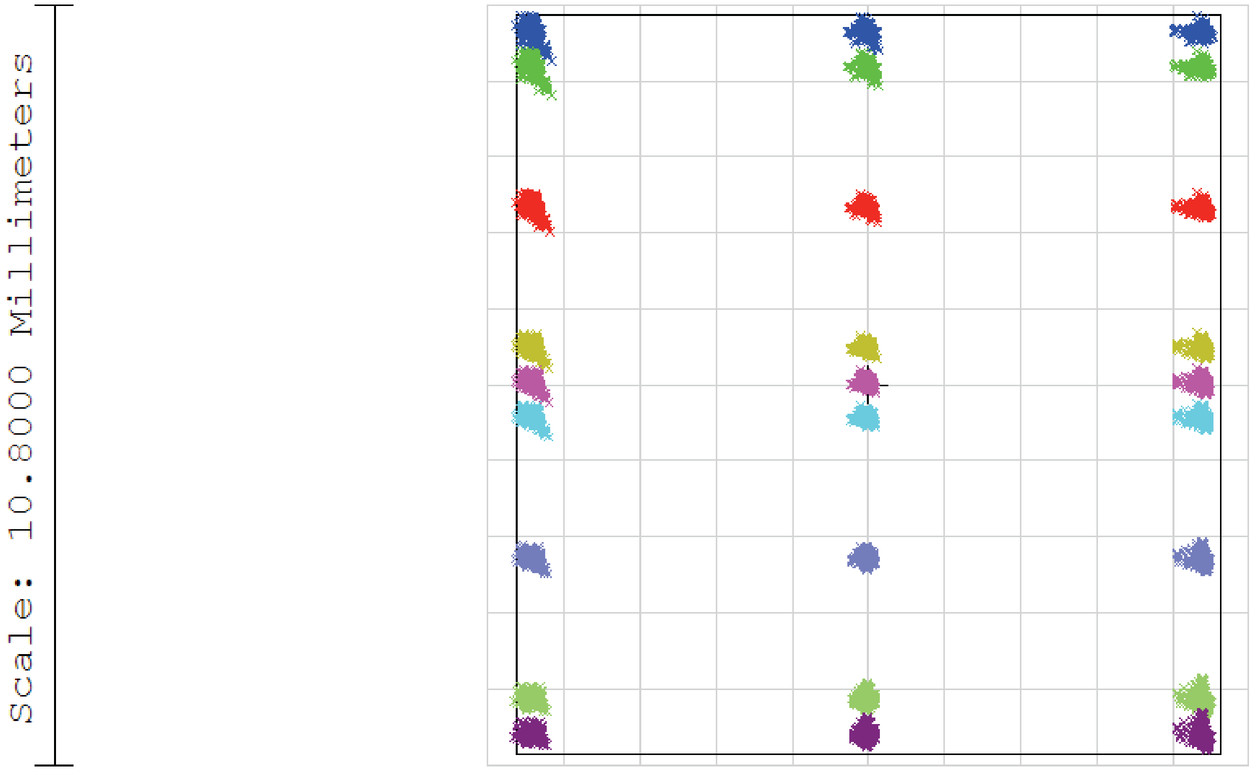
IFU Layout: Slicer with Relay Mirrors



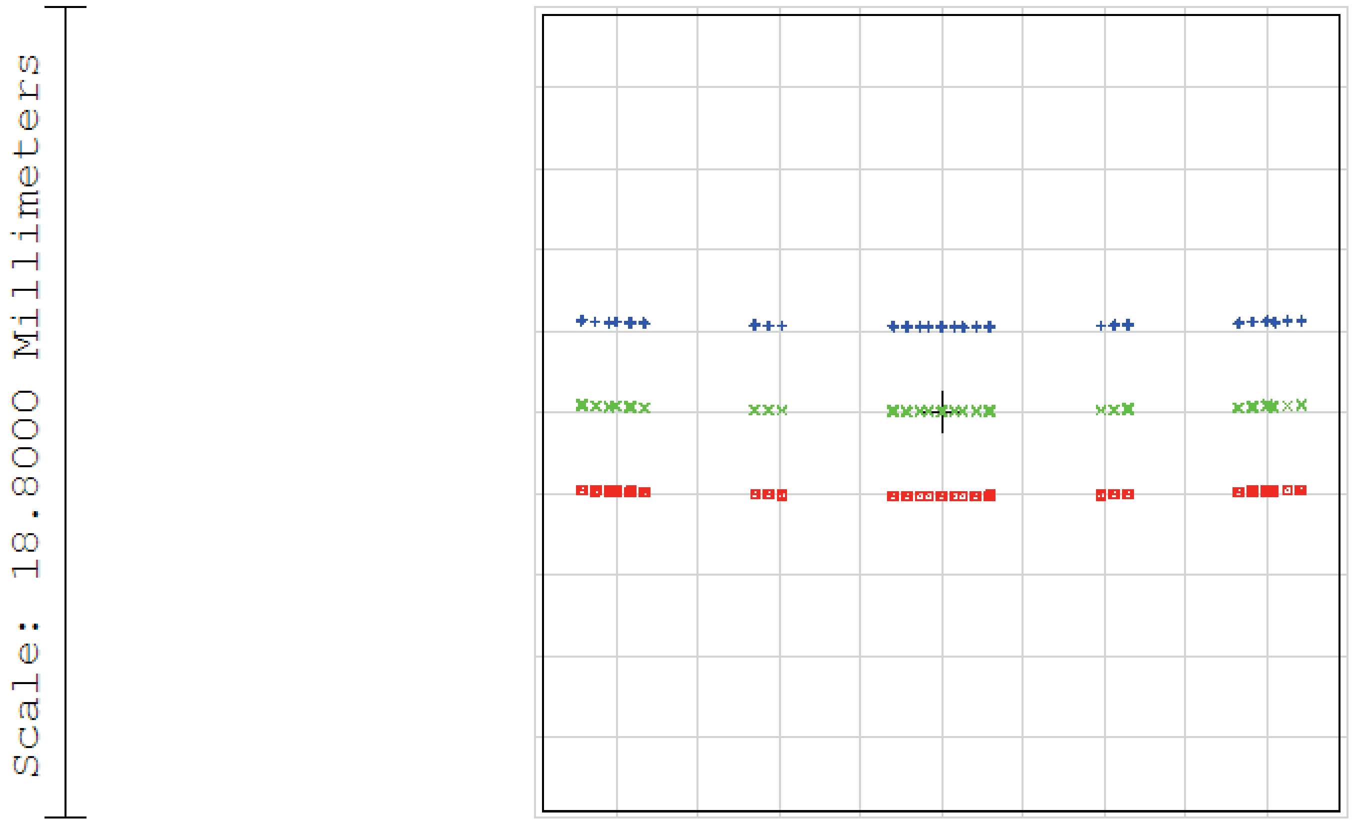
IFU Layout: Slicer with Relay Mirrors



3”x3.15” field cut into 21 0.5mm slices



Final Image Plane: 21 slices dispersed



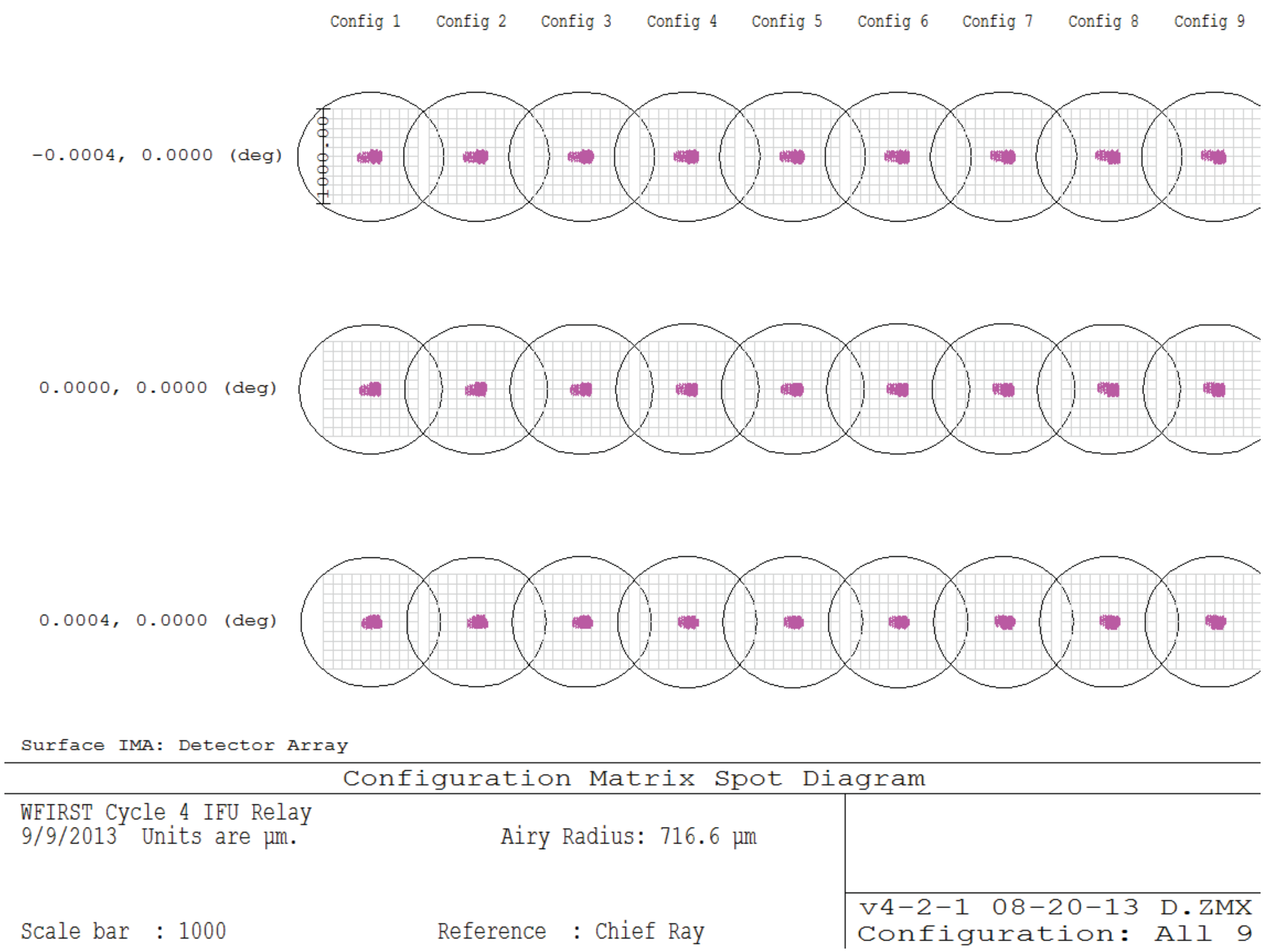
Final Images near diffraction-limited

IFU Performance

- Shortest Wavelength (0.6µm)

IFU Performance

- Longest Wavelength (2µm)



Stray Light Requirement (Cycle 2&3)

In simplistic terms, the requirement is for stray light to be <= 10% of Zodi min

$$\sum_{\lambda=1.3\,\mu m}^{\lambda=2.0\,\mu m} Zodi_{\min}(\lambda)\times Bandwidth(\lambda)$$

$\left(\textbf{Watts/m}^2\textbf{/arcsec}^2\right)$

Obscuration Factor

IFOV (arcsec^2)

$$P_{stray-light}^{WFIRST\text{-}SCA} = 0.1\times 2.269469^{-18}\times\pi\cdot(1.1811)^2\times(1-0.13)\times(0.98)^5\times(450)^2 = 1.58\times10^{-13}\ \frac{\textbf{Watts}}{\text{WFIRST-SCA}}$$

10%

Aperture Area (m^2)

Mirror Reflectivity (5 mirrors)

Stray-light / SCA at focus (10% of Zodi-min)

Based on “Cyc1_S-N_Sim_Parameter_Freeze_v5.xls” spreadsheet dated: 1/10/2007

Currently, there is no “official” stray-light requirement for the WFIRST/AFTA, so a tentative “Pass” or “Fail” threshold value of 1.58e-13 Watts/(WFIRST-SCA) is assumed

Description of PST Calculation (Sunshield)

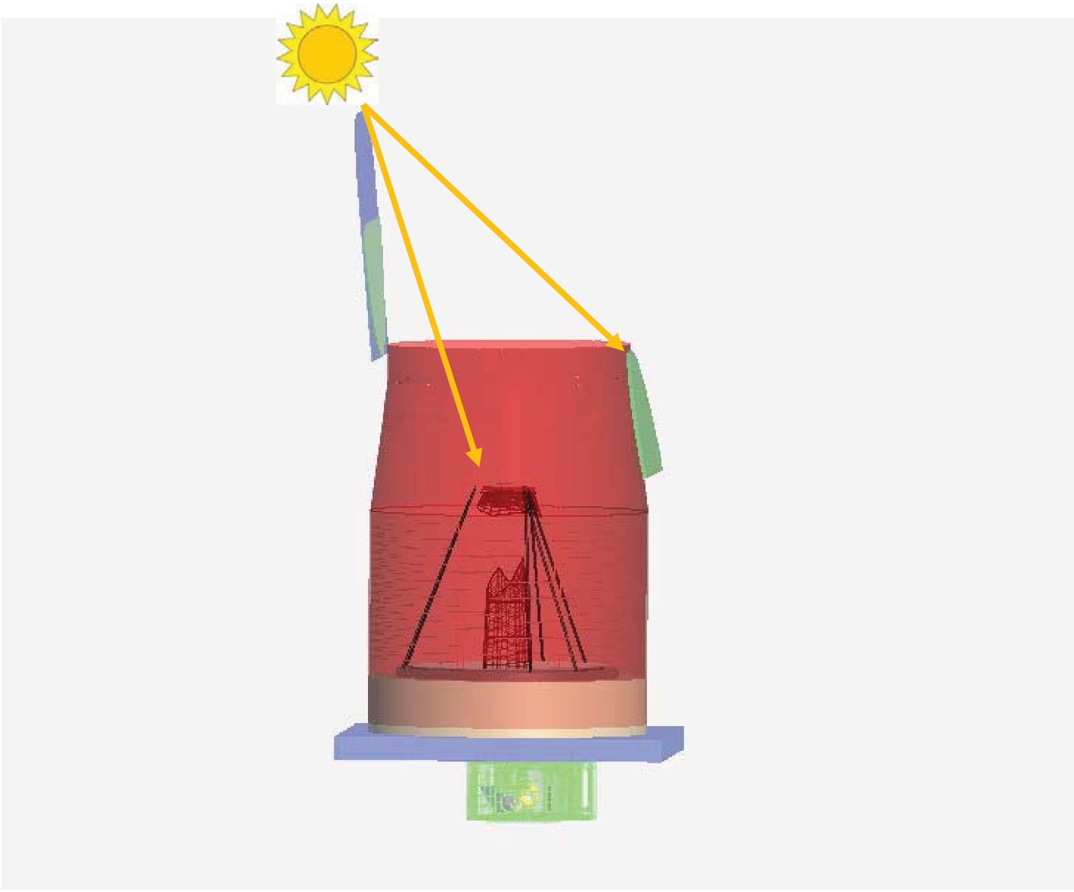
Sun, earth and moon are modeled as rising above the horizon of the Sunshield

The values of Irradiance (Power/Area) and Flux (Power) utilized in the irradiance calculations are model and are listed in the appendix

The source is assumed uniform and collimated (far away)

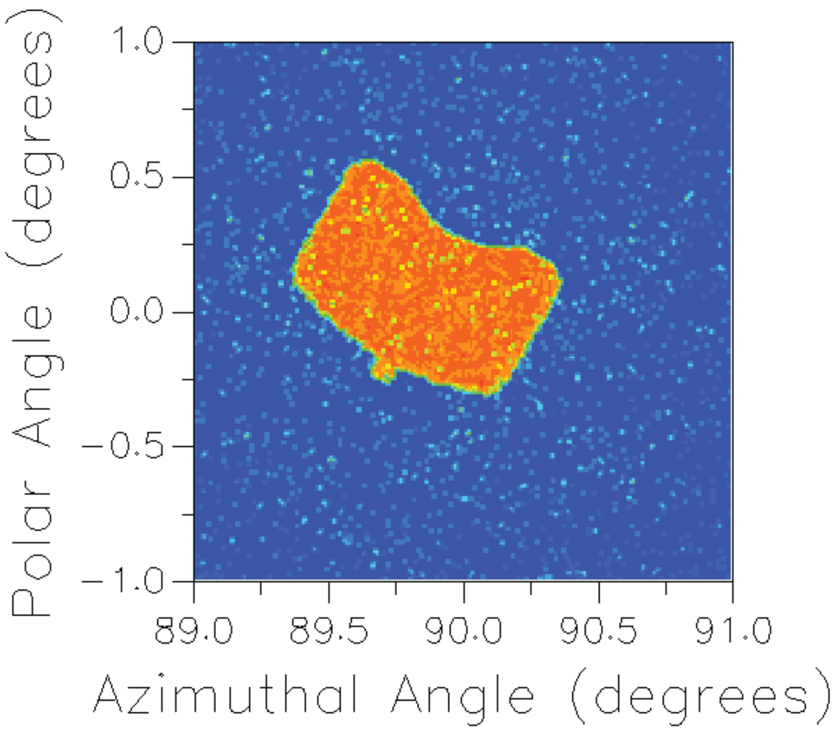
To produce the proceeding graphs the PM aperture is illuminated at various angles

The results are read as detector Irradiance vs. Requirement

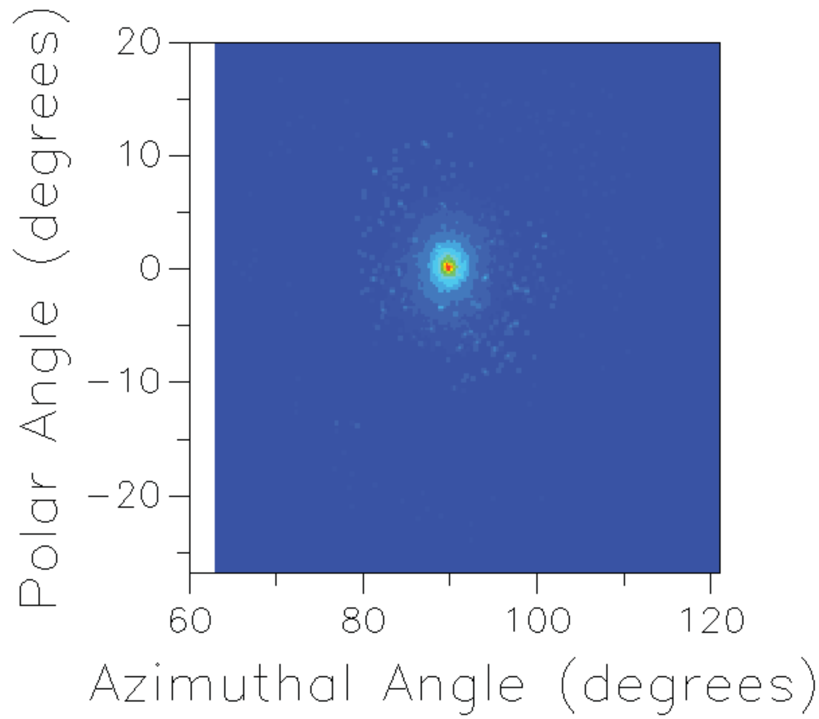


Field of View as Seen from Detector (31% Obscuration)

Footprint of Beam on Sky

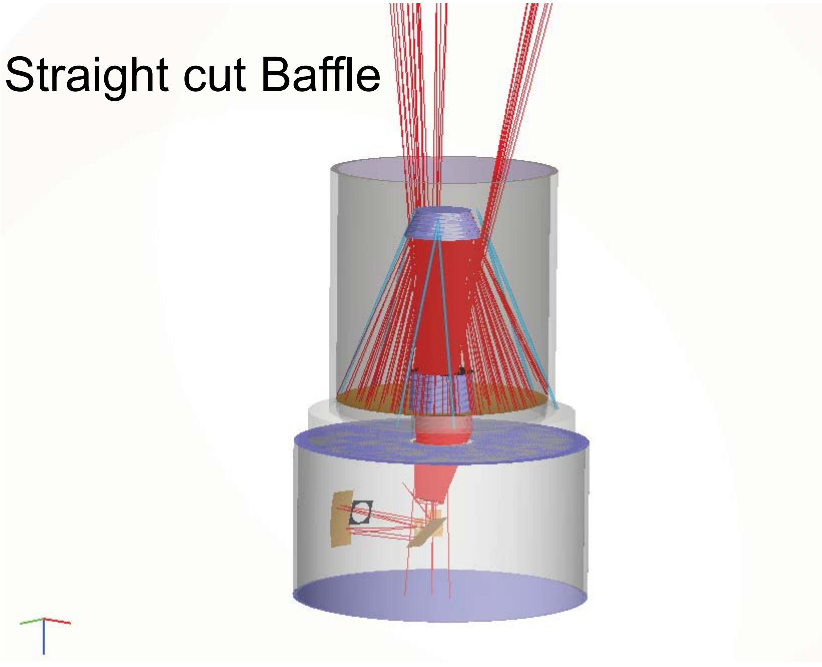


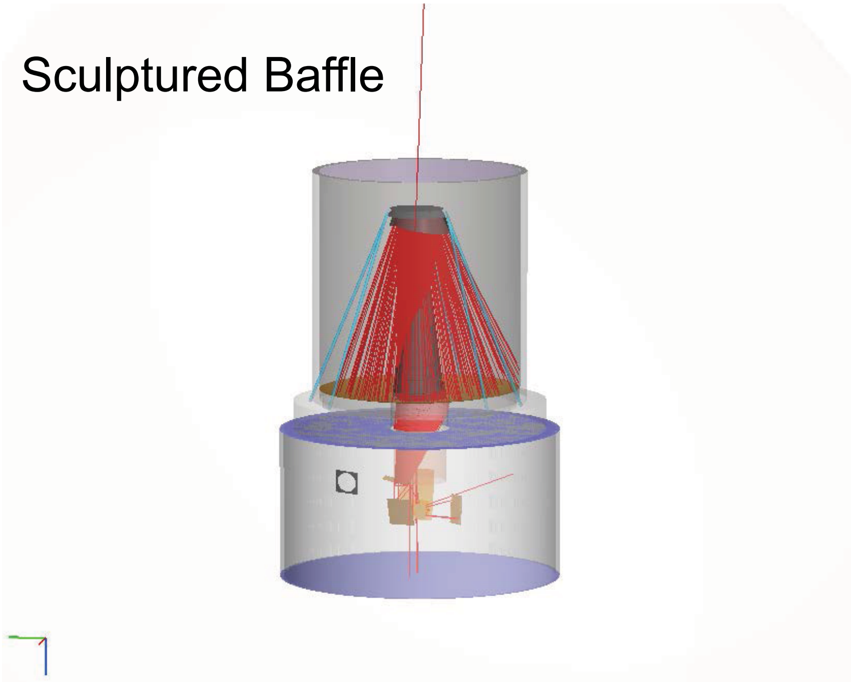
Full Sky View



Central Obstruction: Standard Cut vs. Sculptured Baffle (30% Central Obscuration)

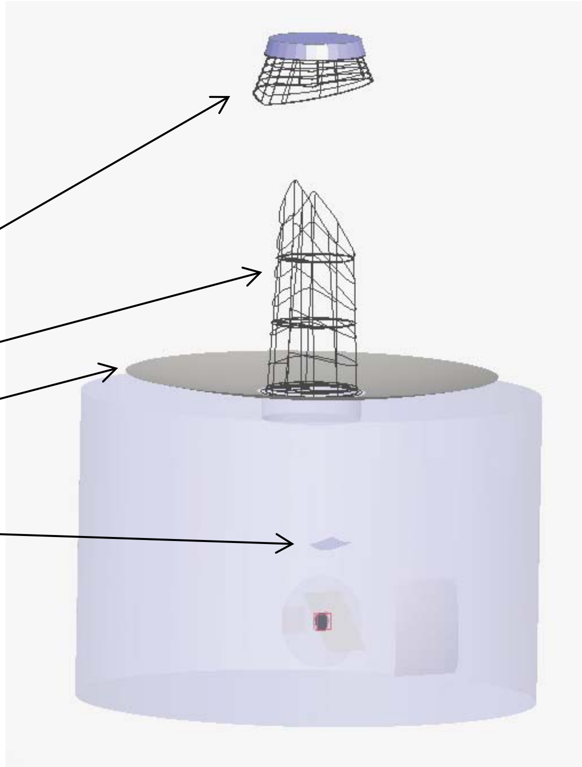
- Rogue (Out-of-field) rays greatly reduced with Sculpted Baffles



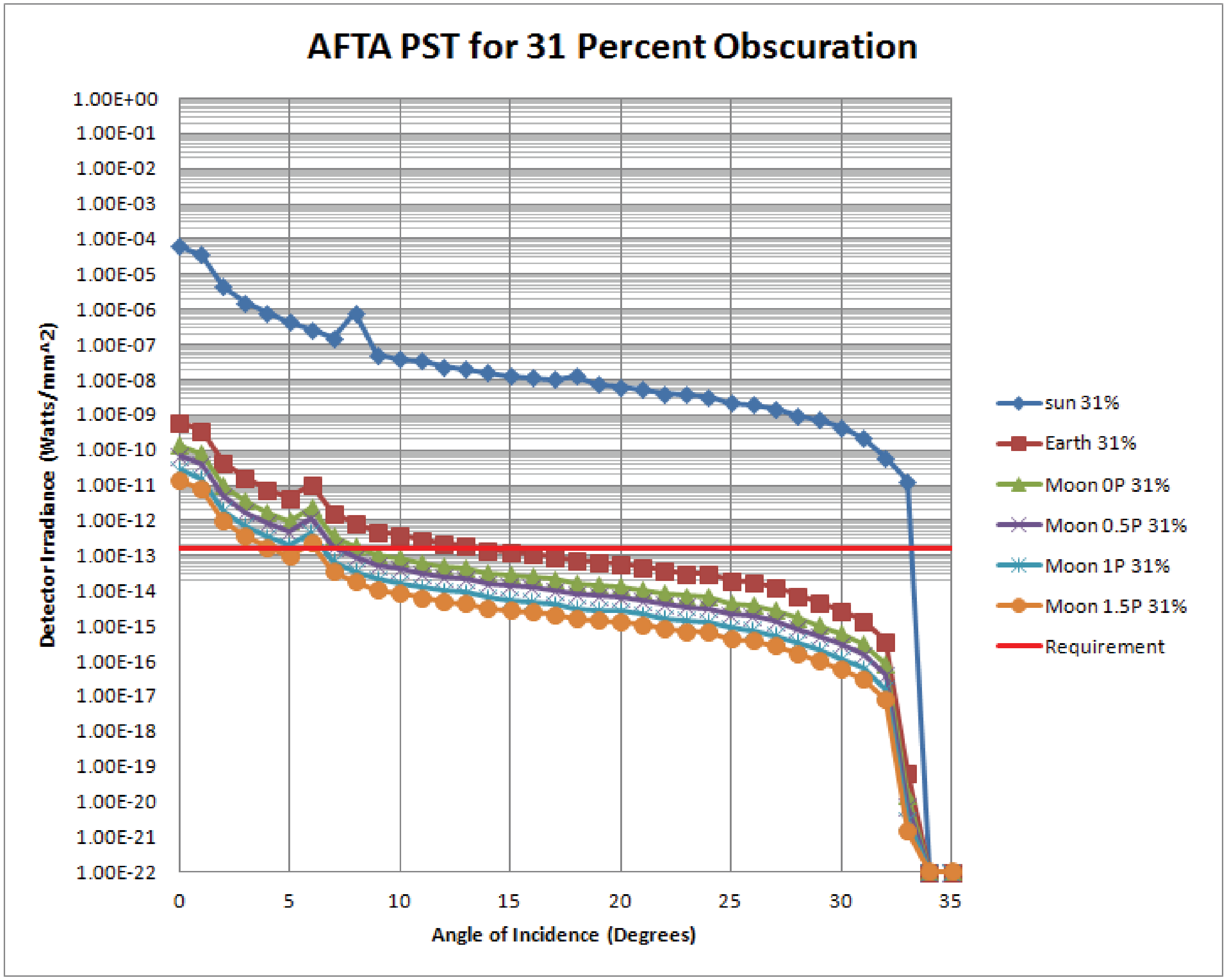


Telescope Baffles

- WFIRST-AFTA's Telescope baffles will be custom sculpted to match the instrument fields
  - Secondary Mirror Shade
  - Inner Telescope Baffle
  - Primary Mirror edge
  - Entrance Aperture Plate
  - Reduce Rogue Rays



WFIRST-AFTA Stray Light model example


AFTA PST for 31 Percent Obscuration
Detector Irradiance (Watts/mm^2)
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
1.00E-16
1.00E-17
1.00E-18
1.00E-19
1.00E-20
1.00E-21
1.00E-22
0
5
10
15
20
25
30
35
Angle of Incidence (Degrees)
sun 31%
Earth 31%
Moon 0P 31%
Moon 0.5P 31%
Moon 1P 31%
Moon 1.5P 31%
Requirement

CURRENT EFFORTS

- Full Bottom-up I&T error allocation for predicted performance
- Expansion of IFU Field to include 6”x6” ‘coarse’ 0.3” sampling field, adjacent to current field
- … All this in PRE-PHASE-A!
- Launch Date: 2021 - 2024

For More WFIRST Information:

- http://wfirst.gsfc.nasa.gov

(or just search "WFIRST" in any search engine)

- Science Definition Team Presentations
- Project Reports
- Contact Project Team Members