

WFIRST-AFTA

Presentation to the NRC Mid-Decadal Panel

Neil Gehrels (NASA-GSFC)
Kevin Grady (NASA-GSFC)
John Ruffa (NASA-GSFC)
Mark Melton (NASA-GSFC)
Dave Content (NASA-GSFC)
Feng Zhao (JPL/Caltech)

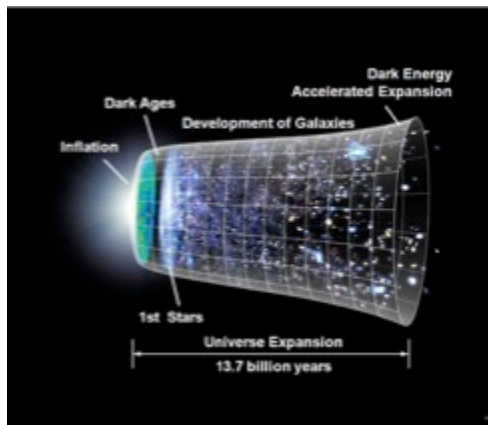
October 9, 2015

NRC Questions

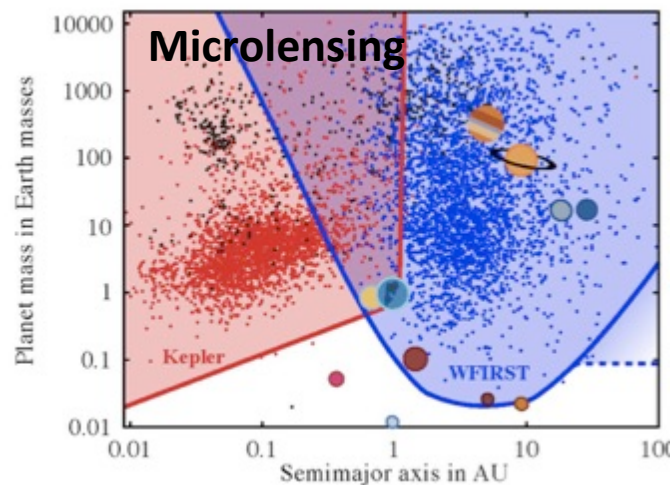
- 1) Please describe the status of your project and agency support in the context of the recommendations of NWNH.
 - This presentation addresses the project status and Paul Hertz's presentation yesterday addresses the agency support.
- 2) What is the current cost and schedule estimate for WFIRST/AFTA and how was it determined?
 - Paul Hertz's presentation yesterday addressed cost and schedule and this presentation addresses it on pages 43-45
- 3) The recent NAS report on WFIRST/AFTA concluded that the use of inherited hardware comes at increased risk. What is the plan to manage this risk?
 - This question is addressed on slide 25.

- WFIRST was highest ranked large space mission in 2010 Decadal Survey
- Use of 2.4m telescope enables
 - Hubble quality imaging over 100x more sky
 - Imaging of exoplanets with 10^{-9} contrast with coronagraph

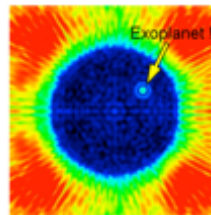
Dark Energy



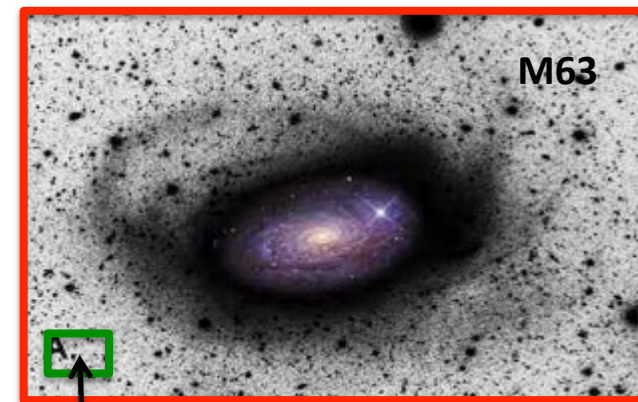
Exoplanets



Coronagraph



Astrophysics



HST

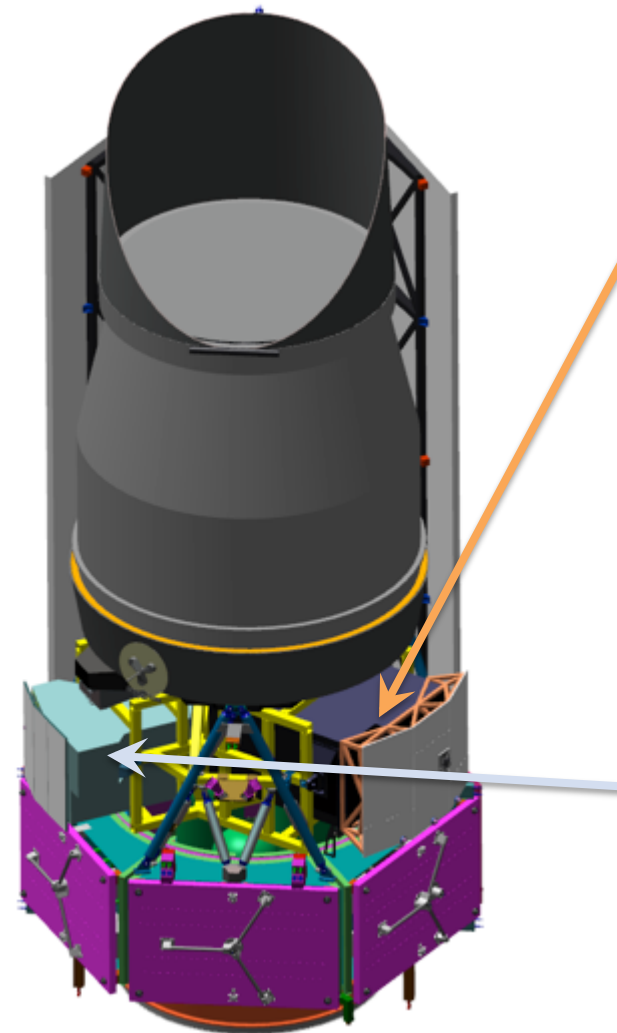
WFIRST

Wide-Field Instrument

- *Imaging & spectroscopy over 1000s of sq. deg.*
- *Monitoring of SN and microlensing fields*
- 0.7-2.0 μm (imaging), 1.35-1.89 μm (spec.), 0.6-2.0 μm (IFU)
- 0.28 deg^2 FoV (100x JWST FoV), 9 asec^2 & 36 asec^2 (IFU)
- 18 H4RG detectors (288 Mpixels), 2 H1RG detectors (IFU)
- 6 filter imaging, grism + IFU spectroscopy

Coronagraph

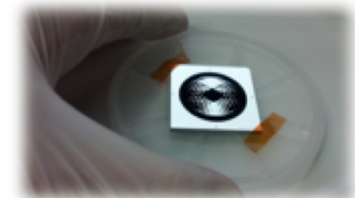
- *Image and spectra of exoplanets from super-Earths to giants*
- *Images of debris disks*
- 430 – 970 nm (imaging) & 600 – 970 nm (spec.)
- Final contrast of 10^{-9} or better
- Exoplanet images from 0.1 to 0.9 arcsec



Executive Summary

- Huge progress on WFIRST over the past two years
- SDT studies & NRC Harrison committee report confirm that WFIRST-AFTA exceeds NWNH requirements in all areas.
- \$107M in FY14 & 15 has enabled major steps forward and NRC-Harrison committee recommendations have been addressed (H4RGs, coronagraph, mission design). Planning against \$56M in FY16, exact amount depends on appropriations.
- Coronagraph on track, technology development on schedule. Wide Field detector technology development on schedule
- MCR scheduled for Dec 8-9. Prepared for start of formulation (KDP-A) as early as January 2016.
- SDT 2014 & 15 studies completed
- Preparatory Science teams selected
- Pasadena conferences held
- Special session at AAS's & IAU
- Science team NRA released
- Industry study RFIs received
- Significant international interest (Canada, ESA, Japan, Korea)

WFIRST H4RG-10

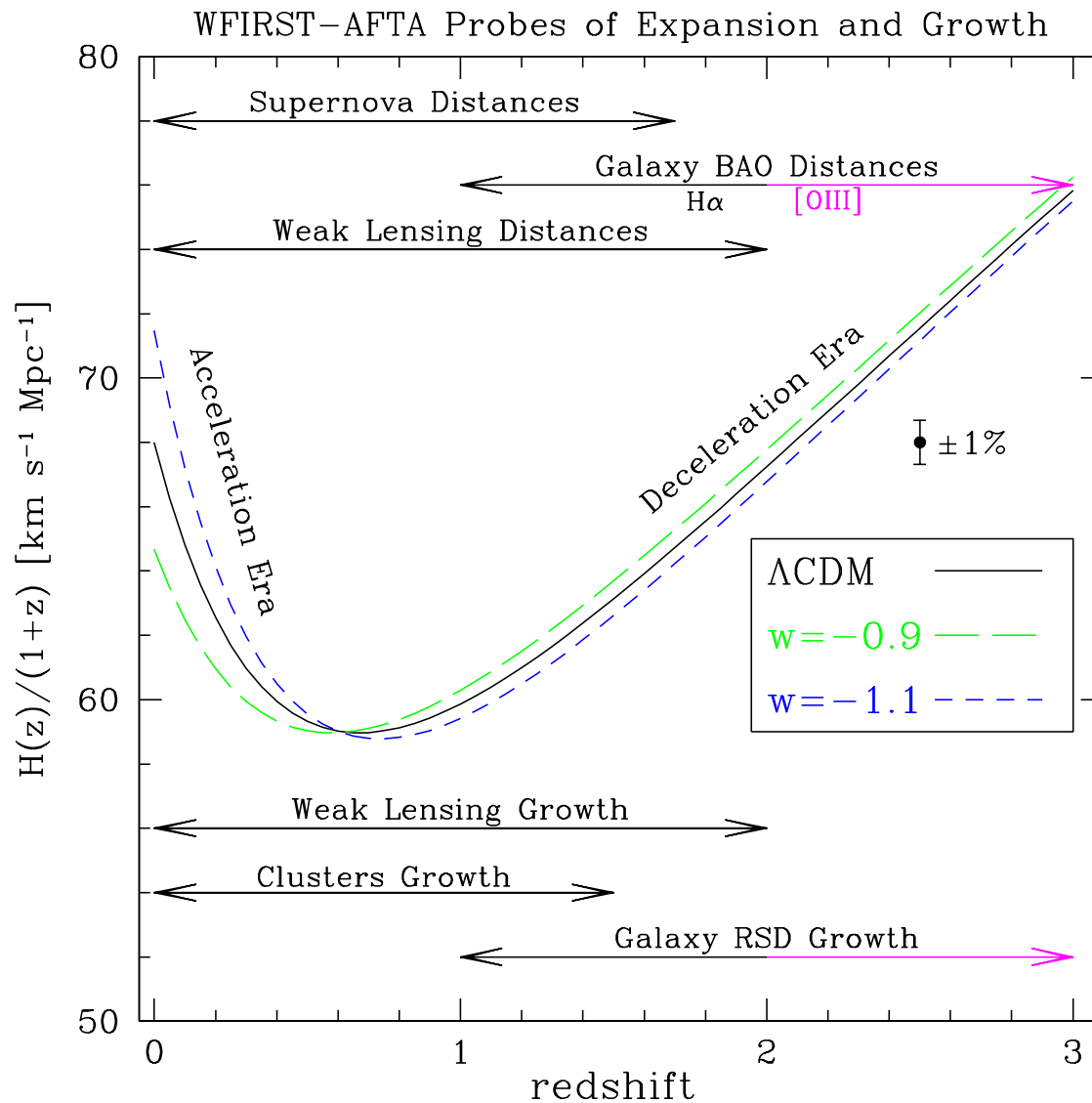


Shaped-Pupil Coronagraph Mask

Scientific Objectives

- 1) Produce NIR sky images and spectra over 1000's of sq deg ($J = 27AB$ imaging, $F_{\text{line}} = 10^{-16} \text{ erg cm}^{-2} \text{ sec}^{-1}$)
- 2) Determine the expansion history of the Universe and the growth history of its largest structures in order to test possible explanations of its apparent accelerating expansion including Dark Energy and modifications to Einstein's gravity.
- 3) Complete the statistical census of planetary systems in the Galaxy, from the outer habitable zone to free floating planets
- 4) Directly image giant planets and debris disks from habitable zones to beyond the ice lines and characterize their physical properties.
- 5) Provide a robust guest observer program utilizing a minimum of 25% of the time over the 6 year baseline mission and 100% in following years.

WFIRST Dark Energy Program



WFIRST & Euclid Complementary for Dark Energy

WFIRST

Deep Infrared Survey (2,200 deg²)

Lensing

- High Resolution (50 gal/arcmin²)
- Galaxy shapes in IR
- 5 lensing power spectra

Supernovae:

- High quality IFU spectra of ~2700 SNe

Redshift survey

- High number density of galaxies
- Redshift range extends to $z = 3$

Euclid

Wide Optical and Shallow Infrared Survey (15,000 deg²)

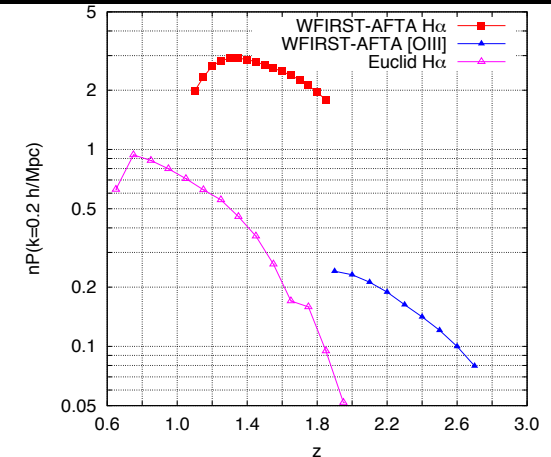
Lensing:

- Lower Resolution (30 gal/arcmin²)
- Galaxy shapes in optical
- 1 lensing power spectrum

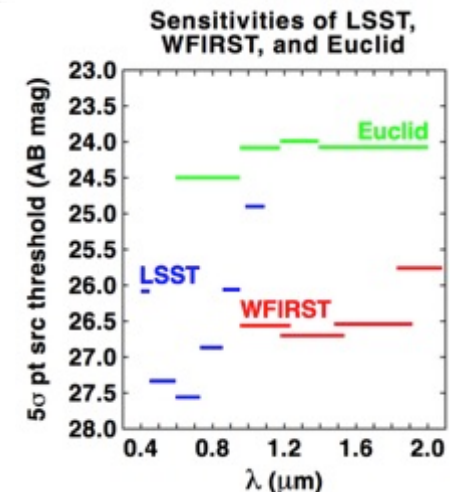
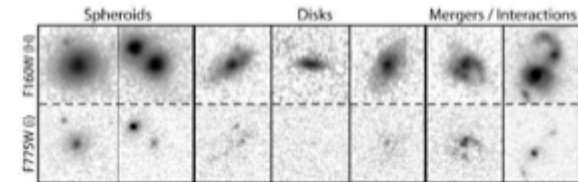
No supernova program

Redshift survey:

- Low number density of galaxies
- Significant number of low redshift galaxies
- Redshift range extends to $z \sim 2$

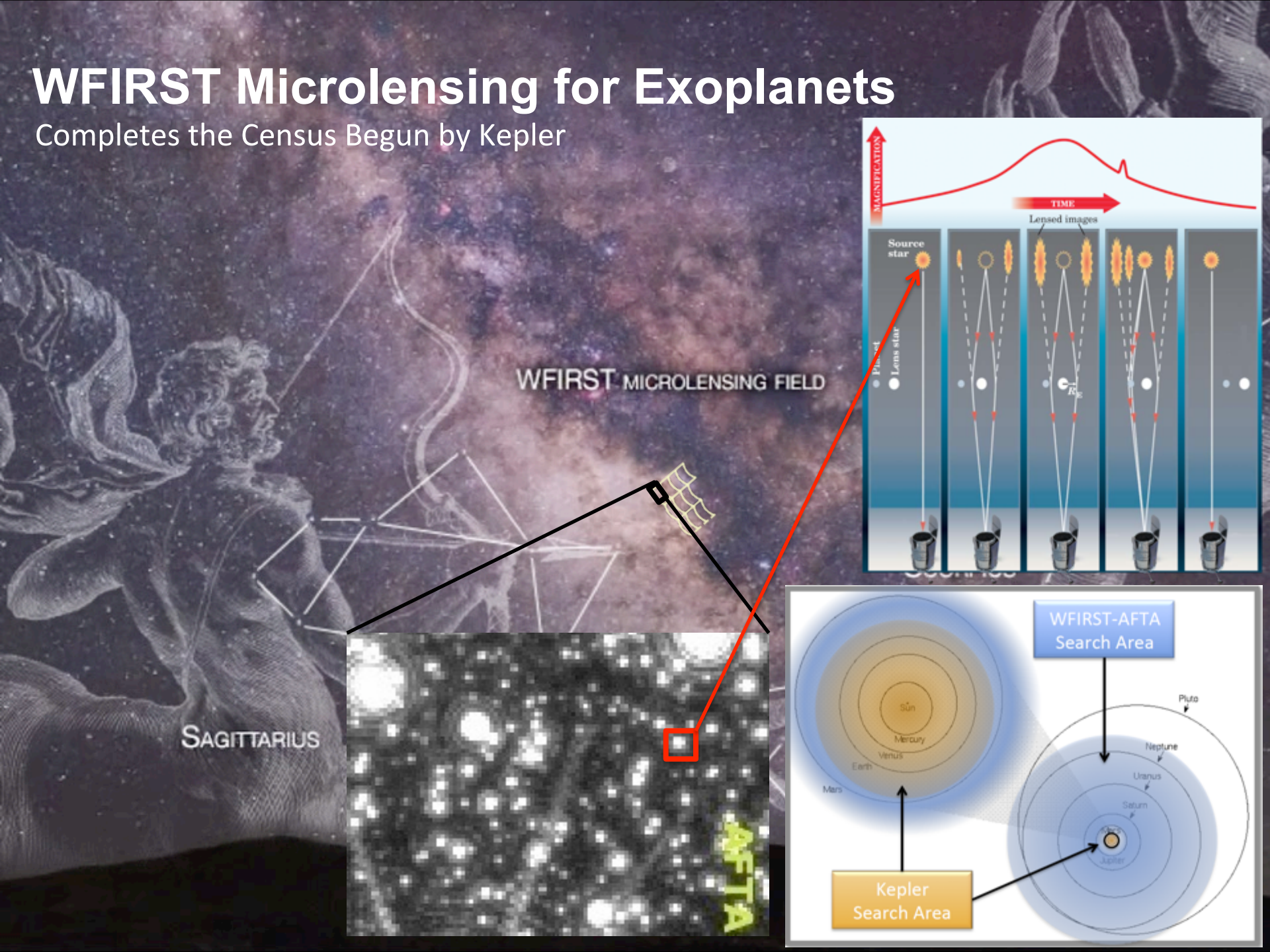


IR
Optical



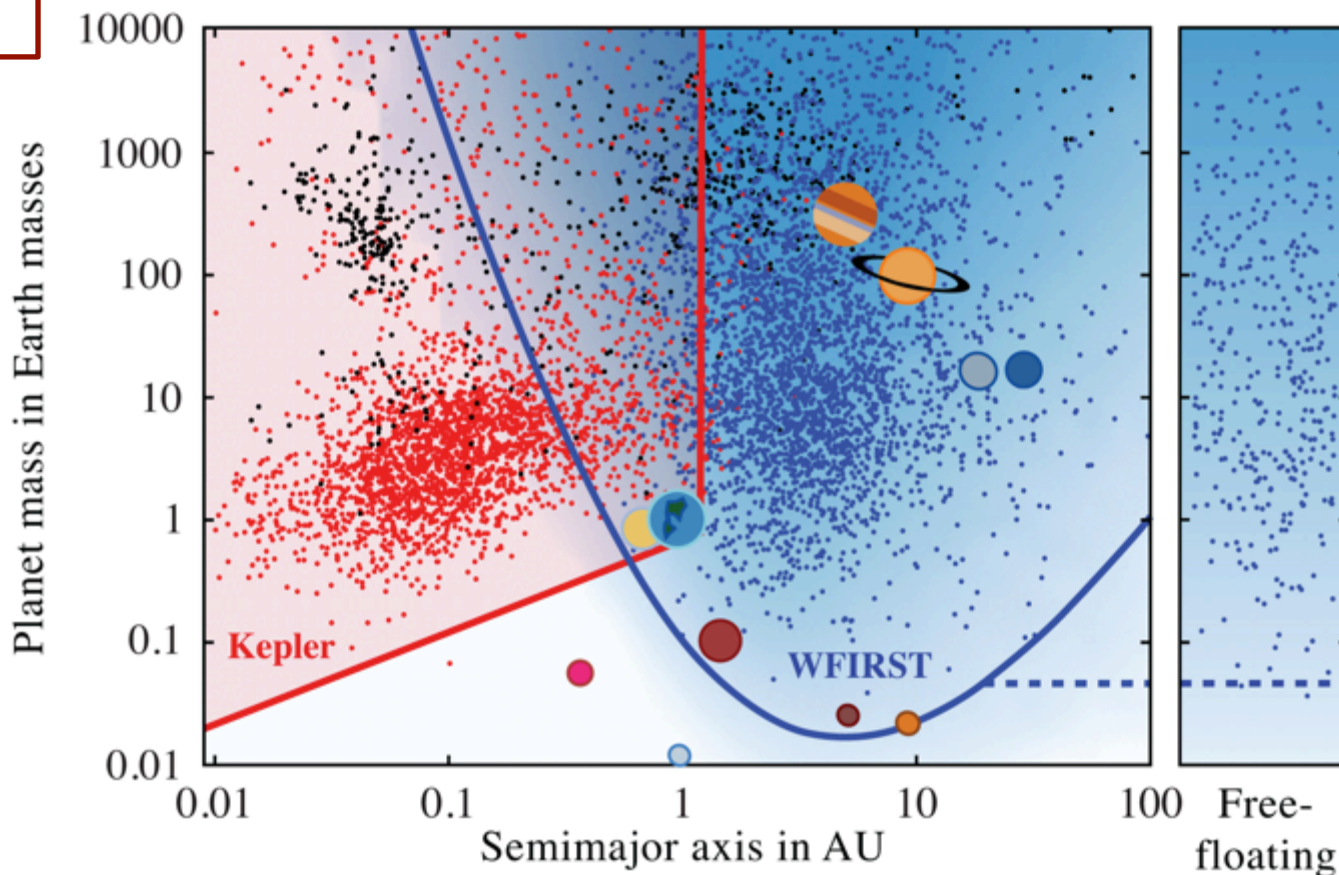
WFIRST Microlensing for Exoplanets

Completes the Census Begun by Kepler



Completing the Statistical Census of Exoplanets

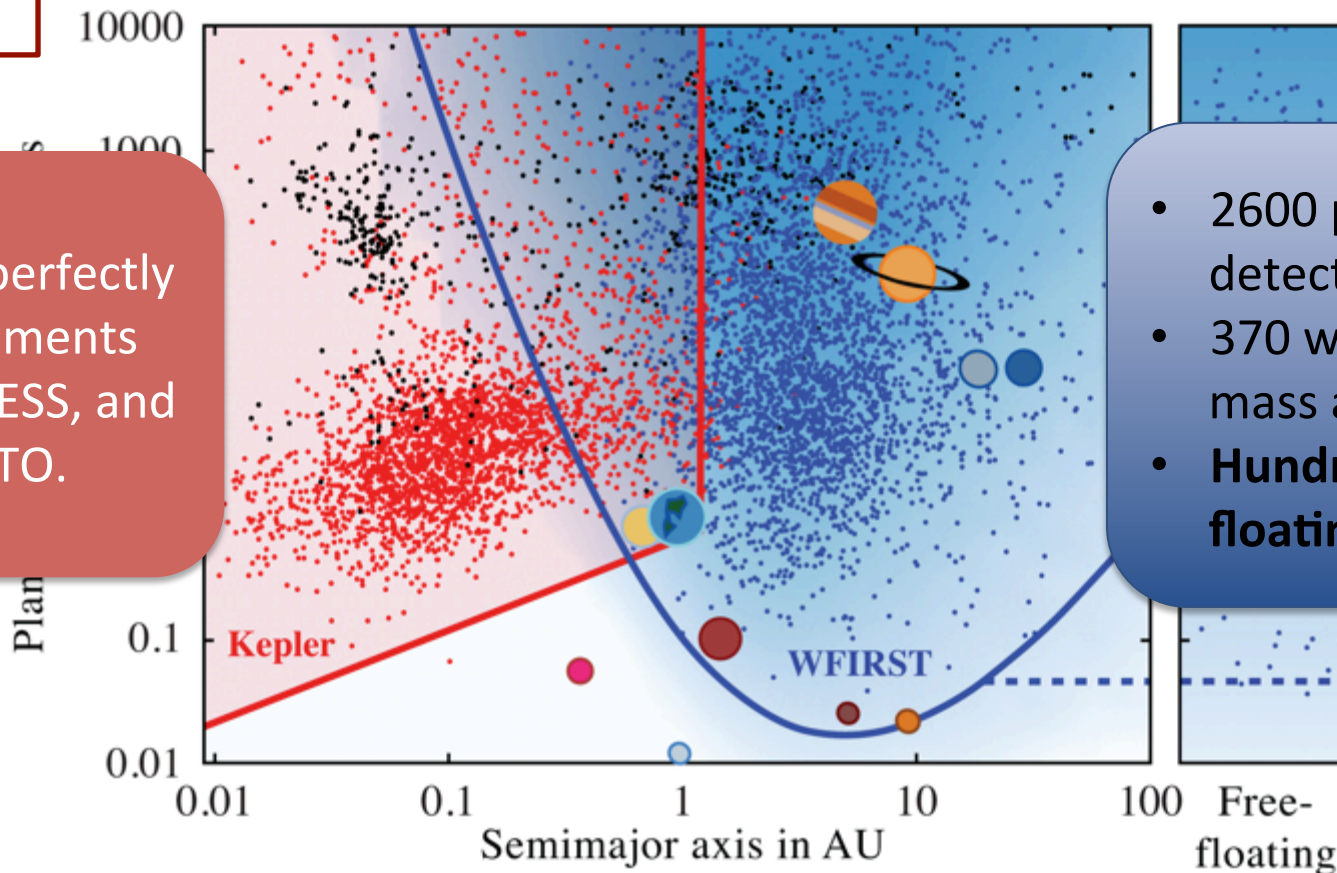
Combined with space-based transit surveys, WFIRST-AFTA completes the statistical census of planetary systems in the Galaxy.



Completing the Statistical Census of Exoplanets

Combined with space-based transit surveys, WFIRST-AFTA completes the statistical census of planetary systems in the Galaxy.

WFIRST perfectly complements Kepler, TESS, and PLATO.

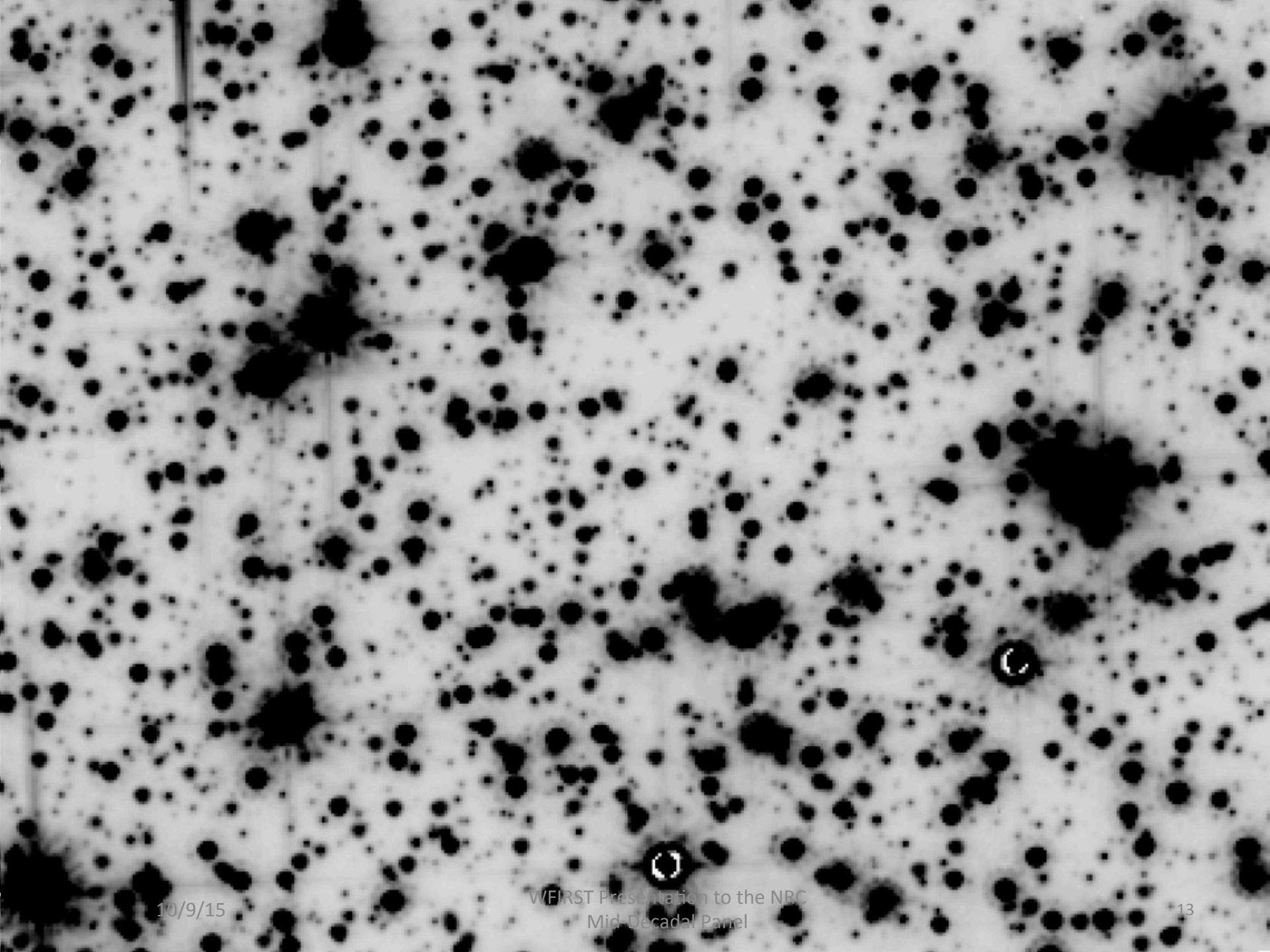


- 2600 planet detections.
- 370 with Earth mass and below.
- **Hundreds of free-floating planets.**

**SWEEPS 2012/4
F814W STACK**

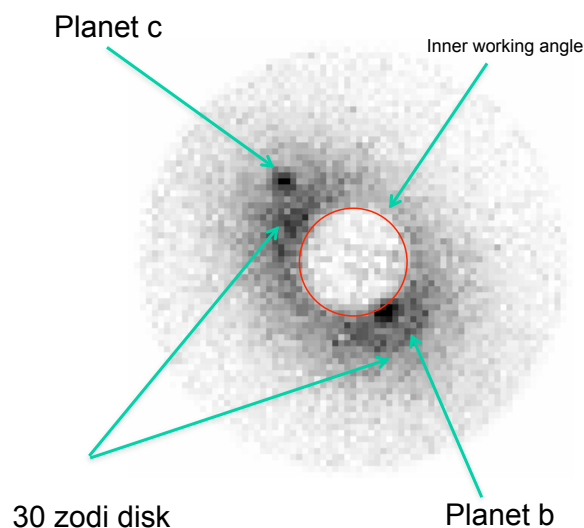
Jay Anderson

WMST Presentation to the NRC
Mid-Decadal Panel

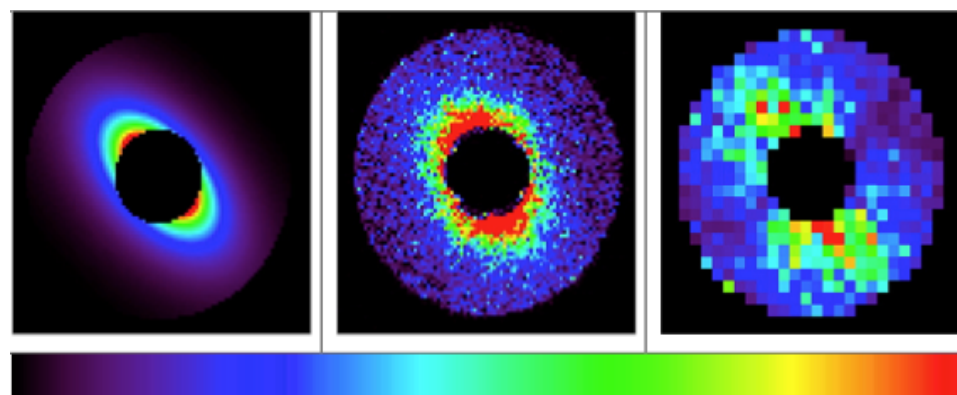


Coronagraphy

- Multi-band imaging at high contrast provides for direct detection and preliminary characterization of exoplanets



Simulated WFIRST-AFTA coronagraph image of the star 47 Ursa Majoris, showing two directly detected planets.

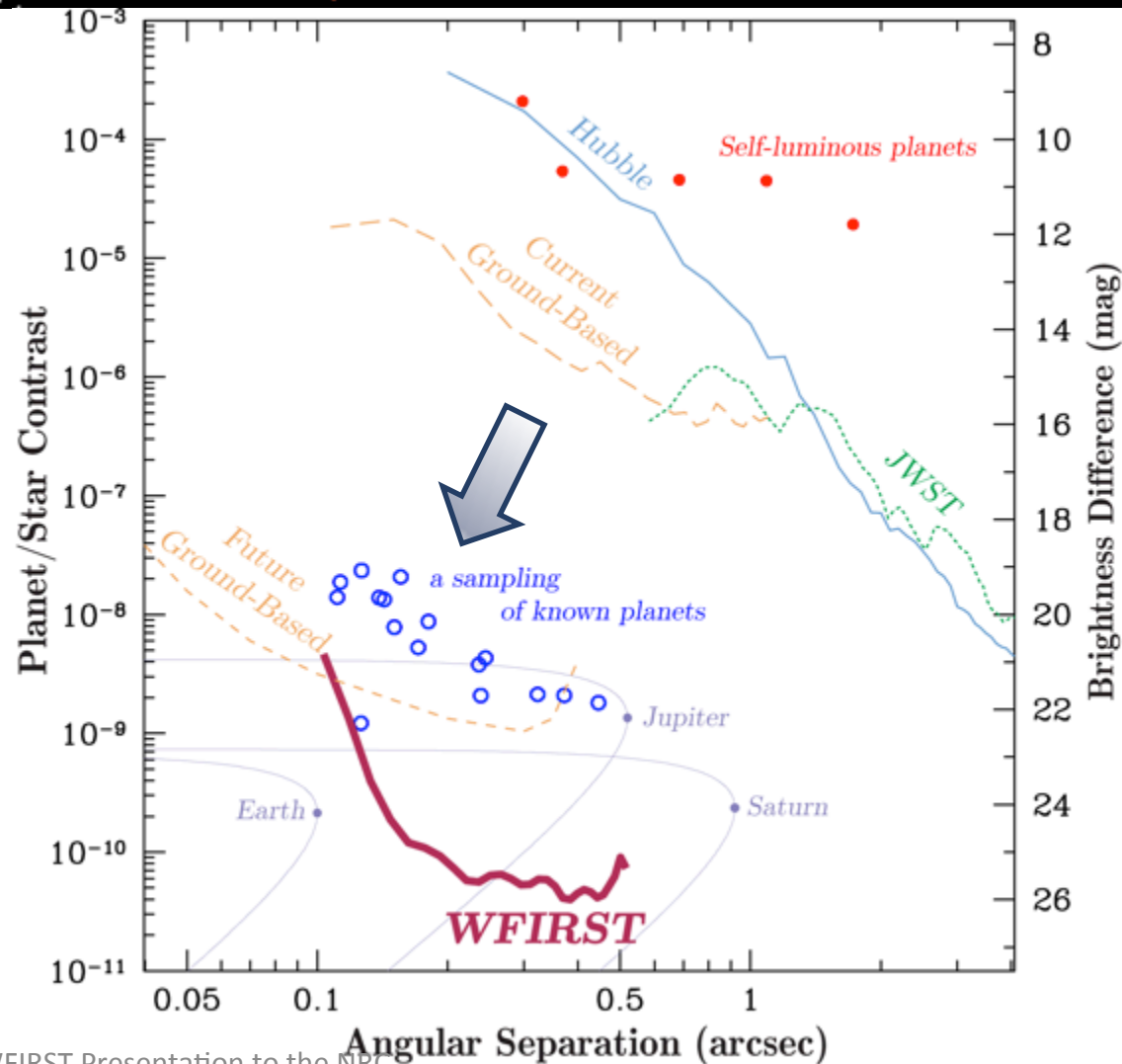


Simulated WFIRST-AFTA CGI images of a 30 zodi disk around 47 UMa.

WFIRST Brings Humanity Closer to Characterizing exo-Earths

➤ WFIRST-AFTA advances many of the key elements needed for a coronagraph to image an exo-Earth

- ✓ Coronagraph
- ✓ Wavefront sensing & control
- ✓ Detectors
- ✓ Algorithms



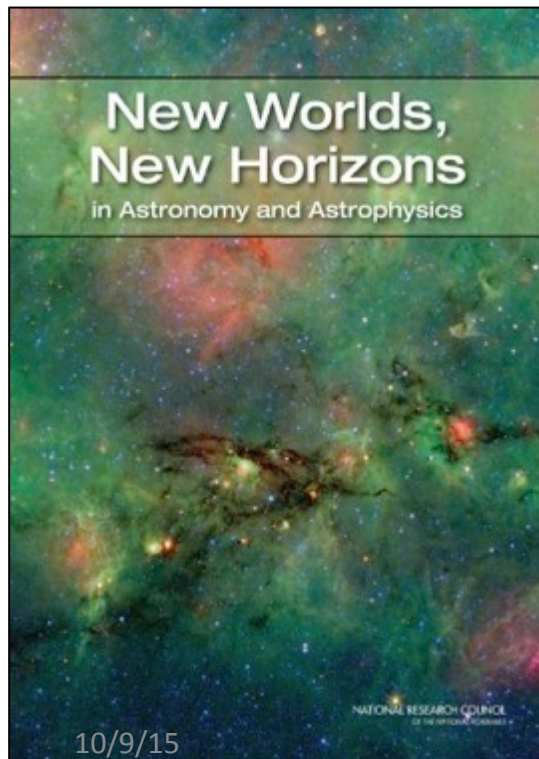
25% of WFIRST is GO Time

Frequently discussed

#1 Large-Scale Priority - Dark Energy, Exoplanets

#1 Medium-Scale Priority - New Worlds Tech. Development
(prepare for 2020s planet imaging mission)

WFIRST covers many other NWNH science goals



5 Discovery Science Areas

ID & Characterize Nearby Habitable Exoplanets ✓

Time-Domain Astronomy ✓

Astrometry ✓

Epoch of Reionization ✓

Gravitational Wave Astrometry

20 Key Science Questions

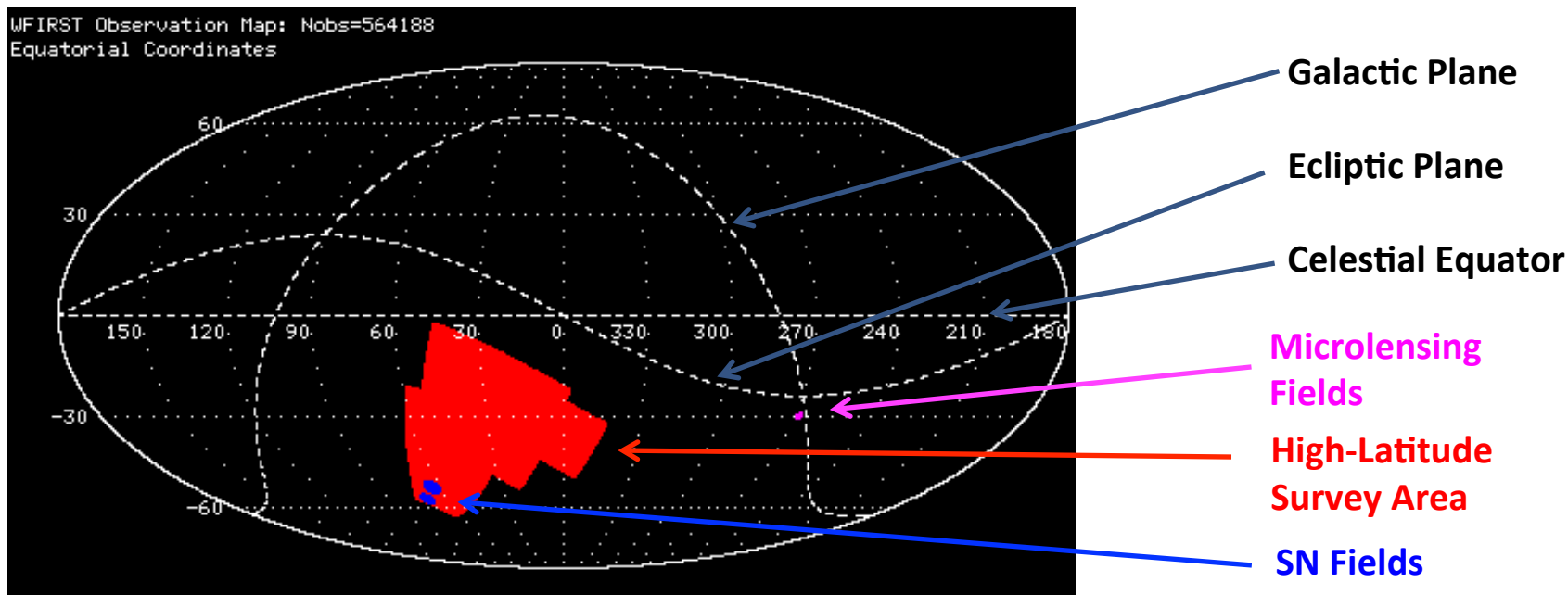
Origins (**7/7 key areas**)

Understanding the Cosmic Order (**6/10 key areas**)

Frontiers of Knowledge (**3/4 key areas**)

Example Observing Schedule

- High-latitude survey (HLS: imaging + spectroscopy): 2.0 years
 - 2227 deg² @ ≥3 exposures in all filters (2279 deg² bounding box)
- 6 microlensing seasons (1.15 years)
- SN survey in 0.6 years, field embedded in HLS footprint
- 0.75 years for the coronagraph, interspersed throughout the mission
- GO program 1.5 years (1.25 years + 0.25 years coronagraph GO)

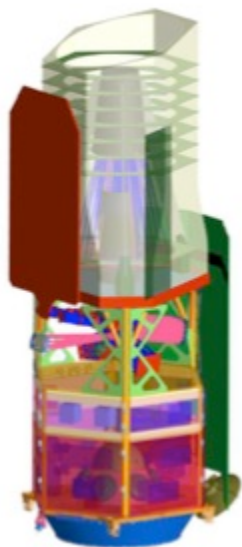


Comparison to IDRM

- WFIRST-AFTA gives HST imaging over 1000's of sq deg in the NIR
- 2.5x deeper and 1.6x better PSF than IDRM*
- More complementary to Euclid & LSST than IDRM. More synergistic with JWST.
- Enables coronagraphy of giant planets and debris disks to address "new worlds" science of NWNH
- Fine angular resolution and high sensitivity open new discovery areas to the community. More GO science time (25%) than IDRM.
- WFIRST-AFTA addresses changes in landscape since NWNH: Euclid selection & Kepler discovery that 1-4 Earth radii planets are common.
- Use of 2.4-m telescope and addition of coronagraph have greatly increased the interest in WFIRST in government, scientific community and the public.

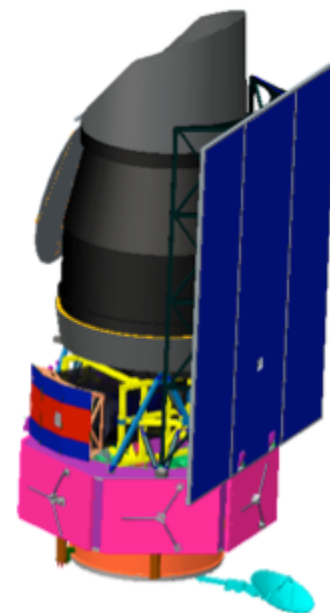
* IDRM = 2011 WFIRST mission design to match NWNH

Comparison of JDEM-Omega to WFIRST-AFTA



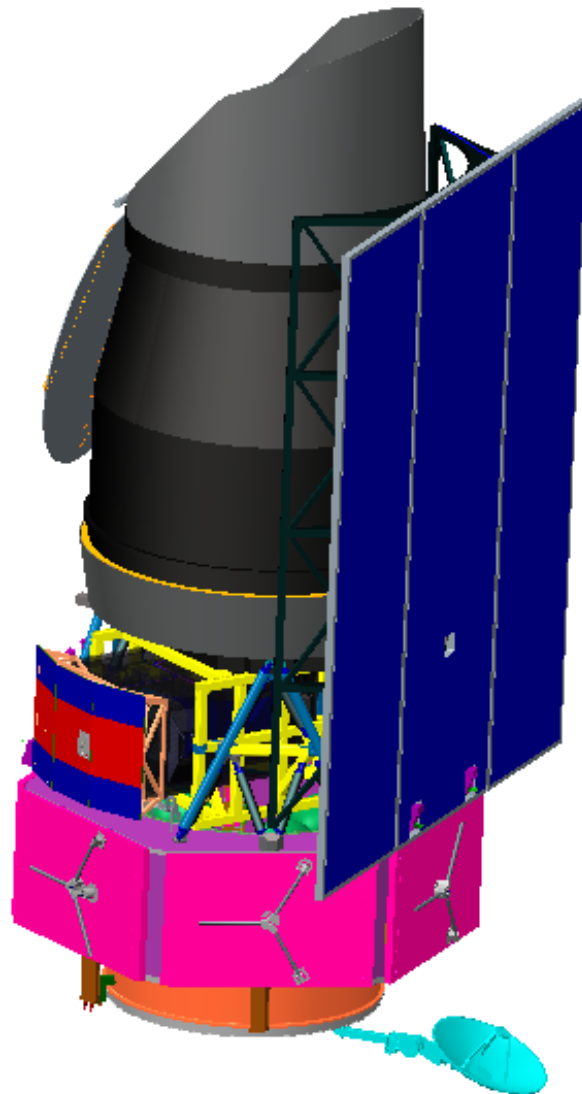
JDEM-Omega
Astro 2010 WFIRST

Parameter	JDEM-Omega	WFIRST-AFTA
Imaging bandpass	TBD-2.0 μ	0.76-2.0 μ
Depth in reddest filter (AB)	25.5	25.8
BAO Spectral bandpass	1.1-2.0 μ	1.35-1.89
BAO Spectral FoV (sq deg)	0.264 x 2	0.281
GRS line sensitivity 7 σ	1.6x10 ⁻¹⁶ erg/cm ² /s	1.2x10 ⁻¹⁶ erg/cm ² /s
SN redshift	0.2-1.3	0.2-1.7
SN bandpass	0.4-2.0 μ	0.6-2.0 μ
Telescope temperature	243K	282K
Imaging FoV (sq deg)	0.25	0.281
Imaging Plate Scale	0.18"	0.11"
Primary Mirror Diameter (m)	1.5	2.4
# of Science Detectors	36 H2RG-18	18 H4RG-10 2 H1RG-18



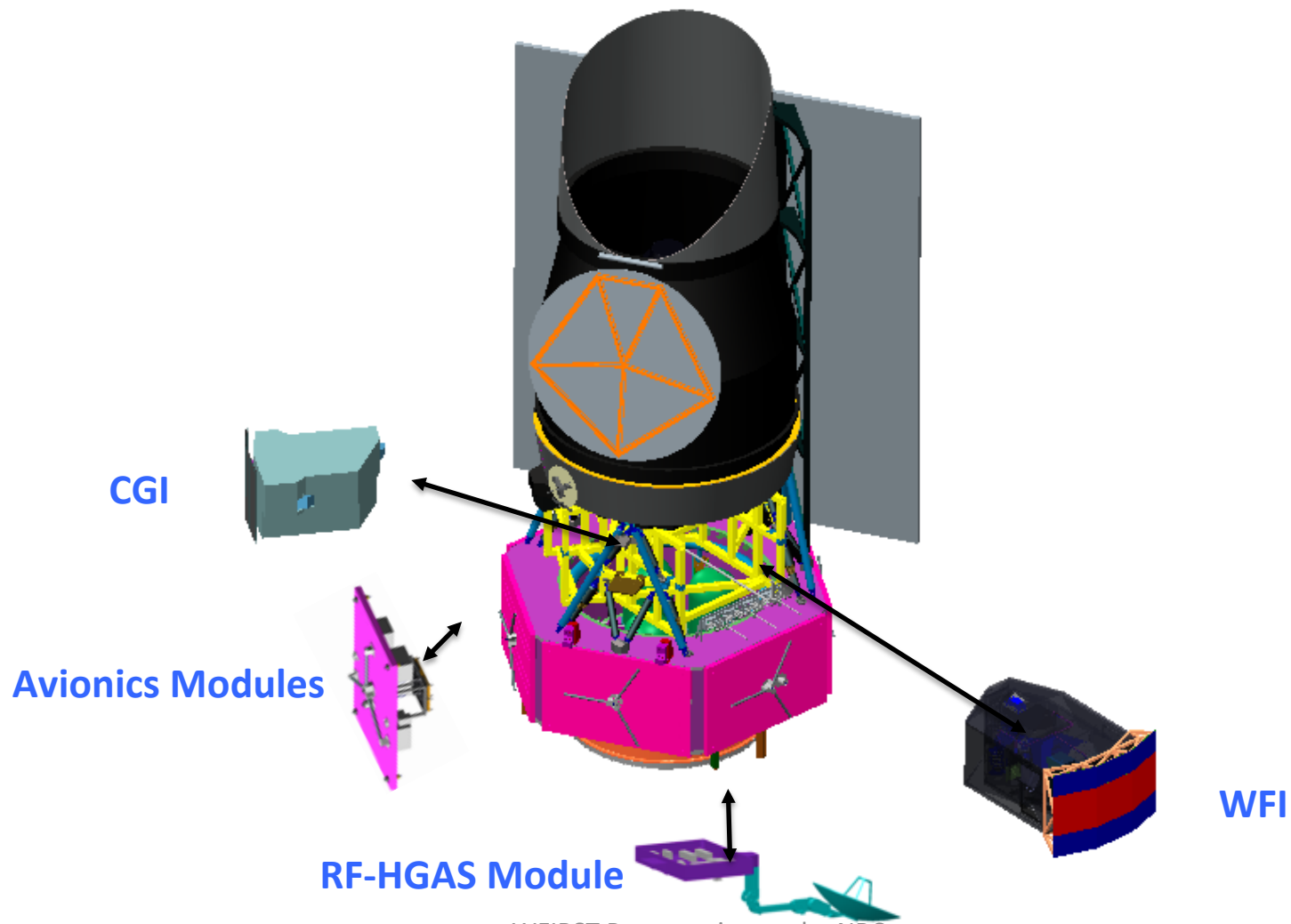
WFIRST-AFTA

WFIRST-AFTA Observatory Concept



Key Features

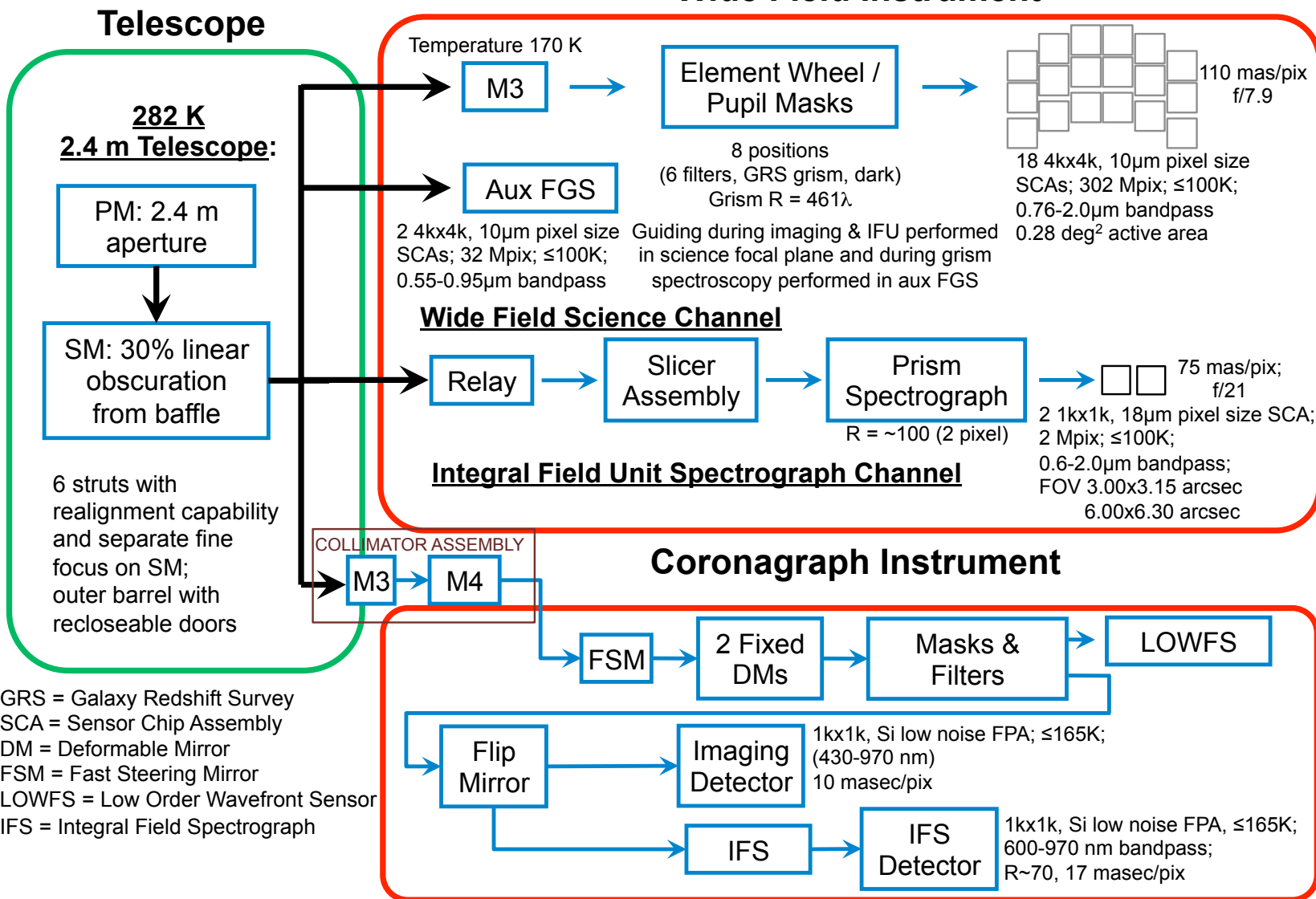
- **Telescope:** 2.4m aperture primary
- **Instruments**
 - Wide Field Imager/Spectrometer & Integral Field Unit
 - Internal Coronagraph with Integral Field Spectrometer
- **Max Data Downlink Rate:** 275 Mbps downlink
- **Data Volume:** 11 Tb/day
- **Orbit:** Sun-Earth L2
- **Launch Vehicle:** Delta IV Heavy
- **Serviceability:** Observatory designed to be robotically serviceable
- **GSFC:** leads mission and I&T, wide field instrument, spacecraft
- **JPL:** leads telescope, coronagraph



WFIRST-AFTA

Payload Optical Block Diagram

Wide Field Instrument



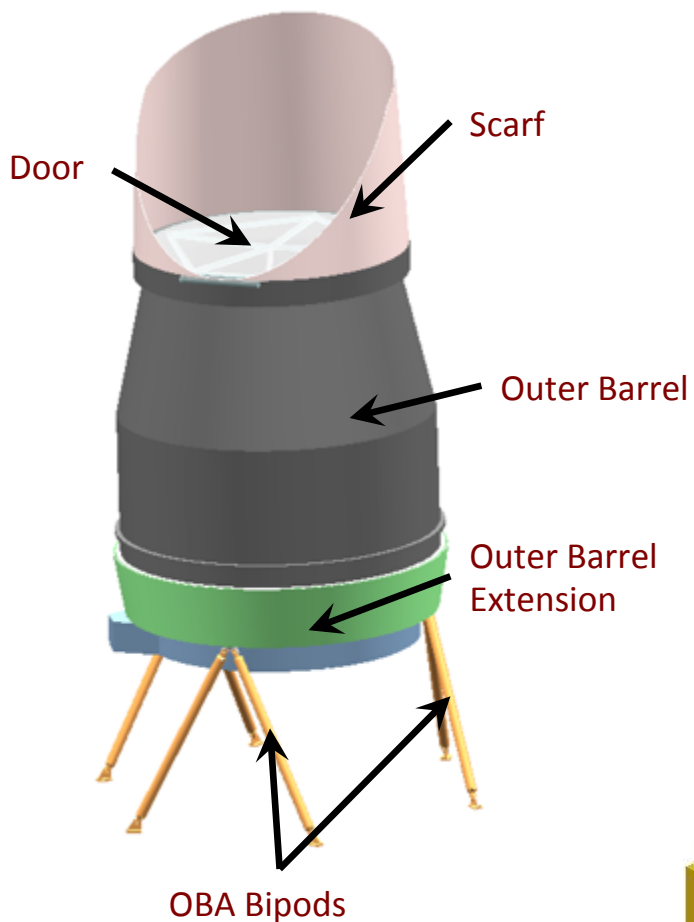
GRS = Galaxy Redshift Survey
SCA = Sensor Chip Assembly
DM = Deformable Mirror
FSM = Fast Steering Mirror
LOWFS = Low Order Wavefront Sensor
IFS = Integral Field Spectrograph

Telescope Overview

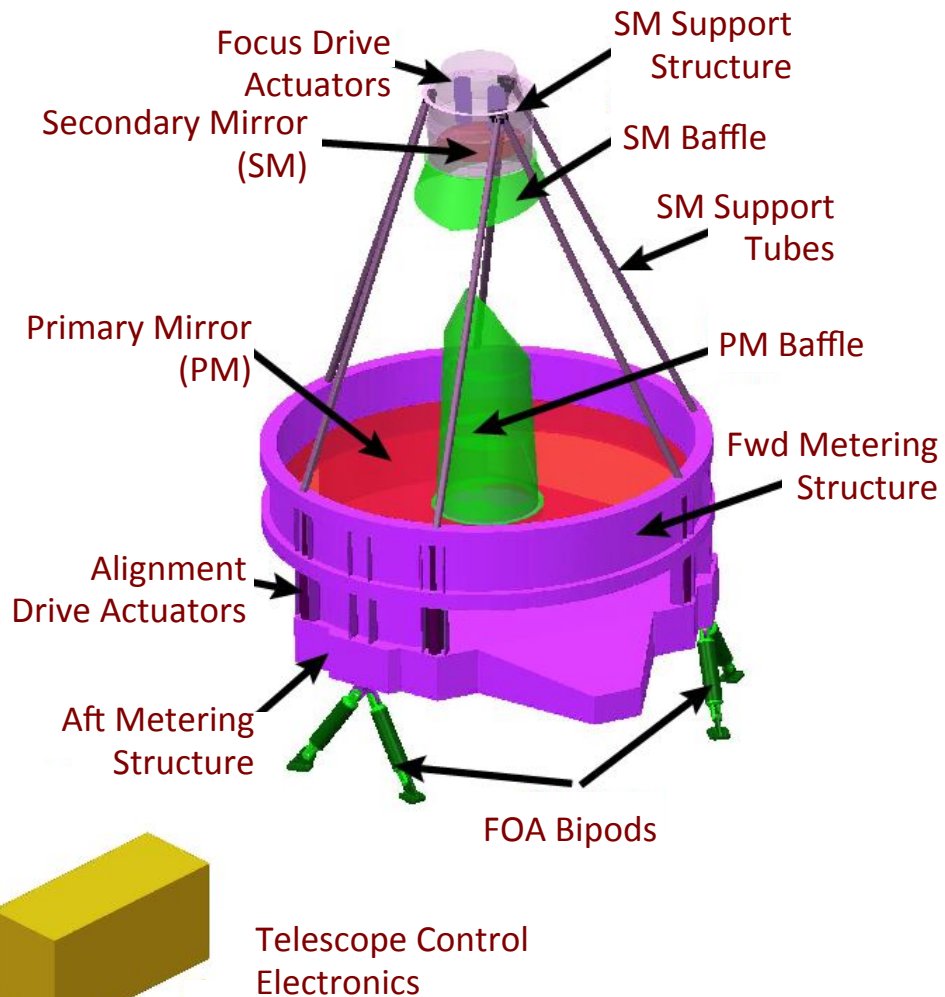
- 2.4 m, two-mirror telescope provided to NASA. Built by Harris (Kodak/ITT/Exelis).
 - Ultra Low Expansion (ULE[®]) glass mirrors
 - All composite structure
 - Secondary mirror actuators provide 6 degree of freedom control
 - Additional secondary mirror fine focus actuator
 - Active thermal control of structure
 - Designed for operation at room temperature (293 K) with design minimum temperature of 277 K, OBA design minimum temperature of 216 K
 - Outer barrel includes recloseable doors
 - Passive damping via D-struts at the spacecraft interface

Telescope Assembly

Outer Barrel Assembly (OBA)



Forward Optics Assembly (FOA)





Telescope Reuse Approach

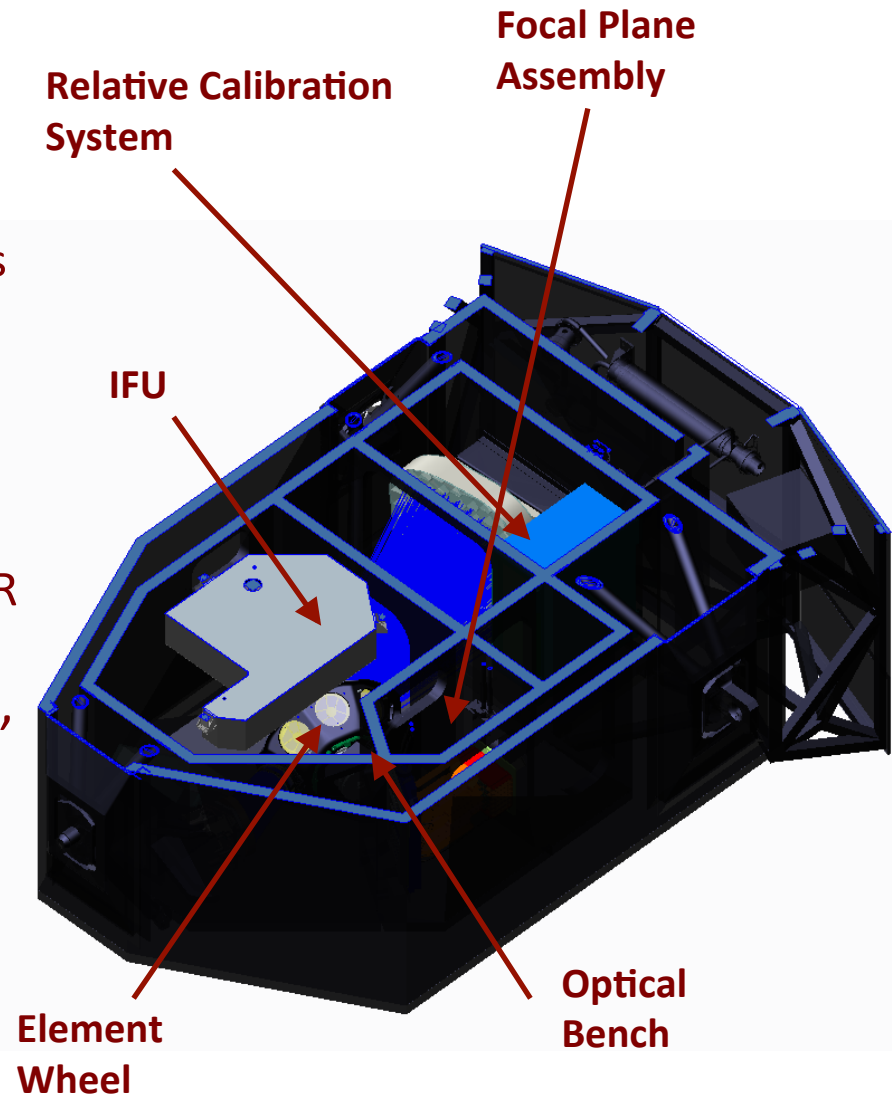


- JPL and the Study Office have worked closely with Harris to understand the telescope hardware.
 - The Observatory design provides an instrument carrier as the prime optical bench for the payload, supporting both the telescope and the instruments, providing substantial structural margin.
 - Set operating temperature at 282K, within heritage hardware design specifications.
 - Continuing to evaluate the feasibility of taking the telescope slightly colder to optimize system design (minimize heater power & improve science performance/margin).
 - Instituted a thorough inheritance audit process to ensure hardware is consistent with the WFIRST application.
 - Includes reviews of original hardware build books and analyses along with new assessments for aging and WFIRST environments.
 - No major issues with planned reuse have emerged to date
 - Detailed build plan, schedule, and cost estimate prepared and reviewed as part of Aerospace CATE.

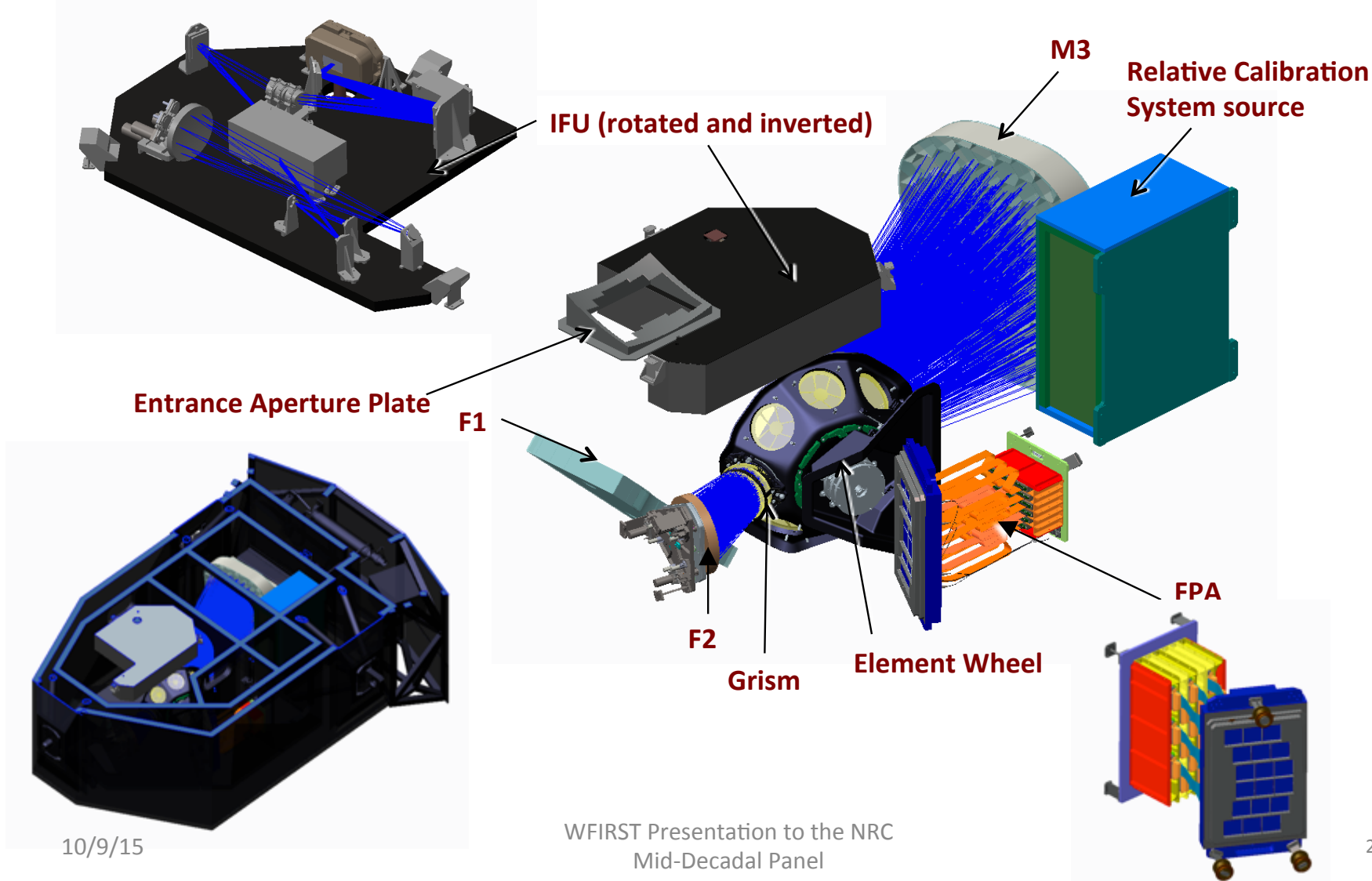
Wide Field Instrument

Key Features

- Wide field channel for both imaging and spectroscopy
 - 3 mirrors, 1 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 GRS survey covers 1.35 – 1.89 μm with $R = 461\lambda$ (~620 – 870)
- IFU channel for SNe spectra, single HgCdTe detector covers 0.6 – 2.0 μm with R between 80-120
- Auxiliary guider for guiding during grism spectroscopy mode



Wide Field Instrument Layout and Major Subassemblies



Detector Progress Has Been Steady Since 2014

MS#	Short Milestone	Date	Status
1	Banded Array Performance, PV2	7/31/2014	passed 8/7/14
2	Banded Array Performance, PV3	12/30/2014	passed 12/1/14
3	Full Array Performance	9/15/2015	review 10/28/15
4	Yield & Persistence	9/15/2016	Yield lot started recently
5	Environmental test to TRL6	12/1/2016	Test plan in hand

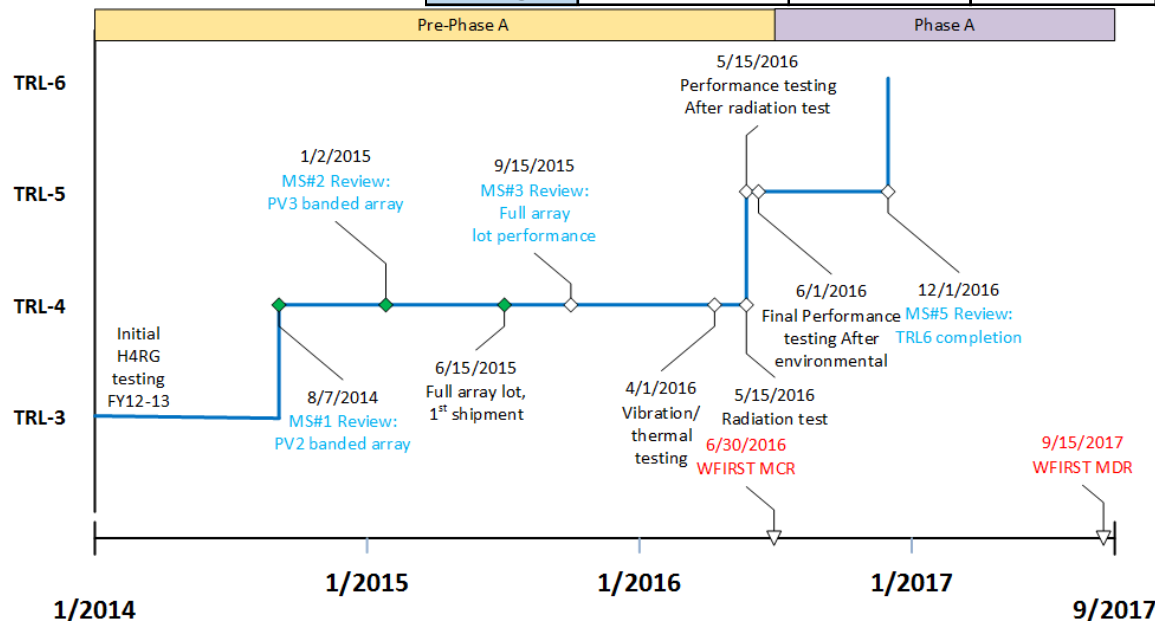
Performance testing of Full Array lot for MS#3 is in progress, with full data on 4 detectors, and partial data on several more.

- FY2014 - Completed pixel design trade, using detectors with 1M pixel banded arrays
- FY2015 - Scaled up to full arrays (MS 9/15/15, review 10/28/2015)
- FY2015 - Increased staffing and test facilities to allow for detailed characterization phase
- FY2016 - Full arrays in process now will be used for environmental qualification in CY16
- Yield lot recently started for MS#4
- Early persistence testing on full array lot in progress (MS#4)

WFIRST Detector Technology Milestone Progress

Table below shows range of results for the first 4 full arrays; all are within MS#3 specifications.

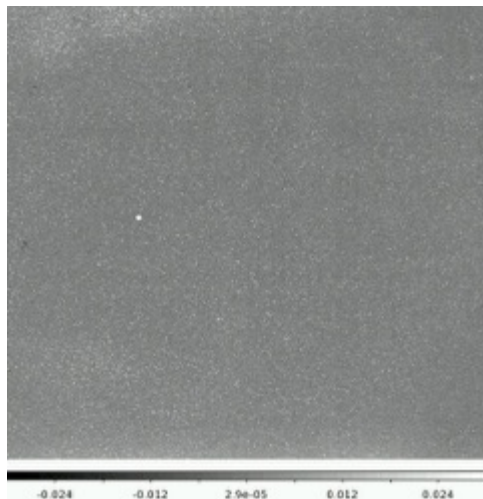
Detector	Median Dark Current (e/s)	CDS	QE (%)	Crosstalk (%) (nearest neighbor)	Pixels with Nominal Photo Response
		Noise (electrons)	(av. 800-2350nm)		
MS3 req't	<0.1	<20	>60	<3.0	>95
Range	0.001-0.007	14.5-16.6	89-94	1.8%-2%	96-99%



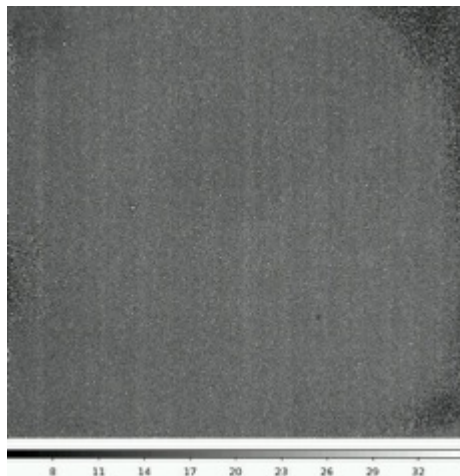
Test timeline uses full arrays to allow early environmental testing for TRL-6 over 2 years before mission PDR.

Performance is Successfully Scaling to Full Arrays

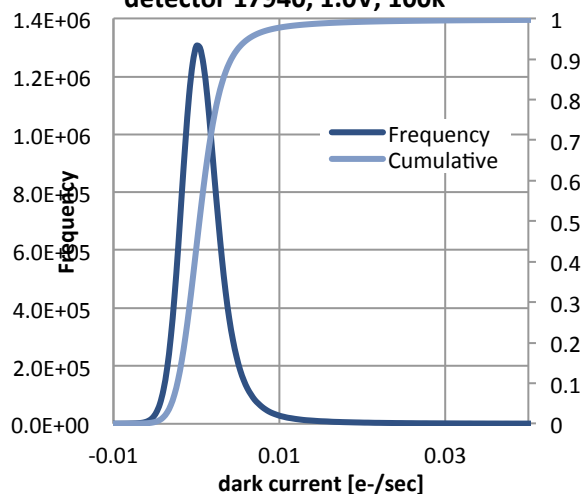
Dark Current



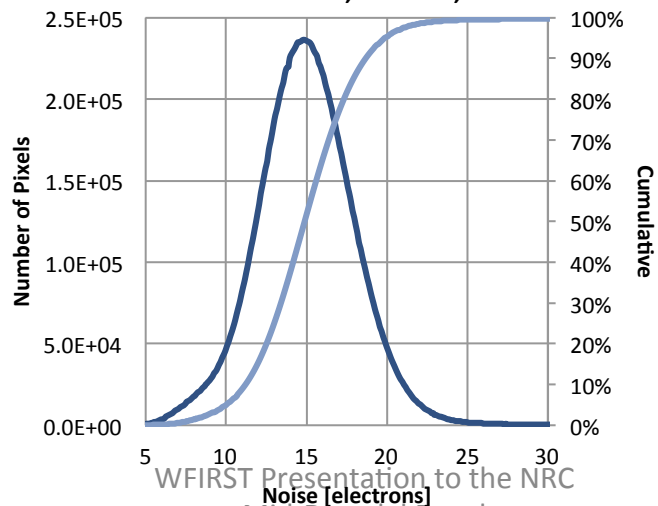
CDS Noise



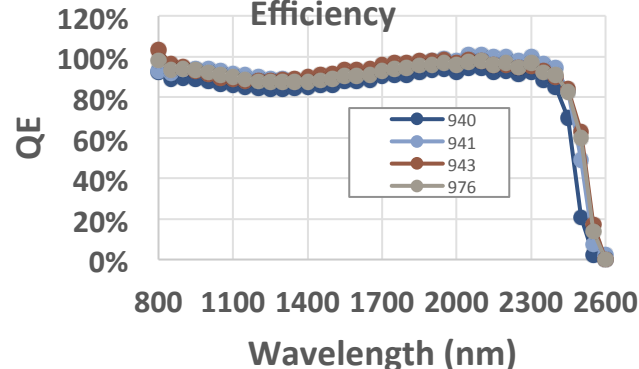
dark current
detector 17940, 1.0V, 100k



CDS Noise 940, T=100 K, 1 V



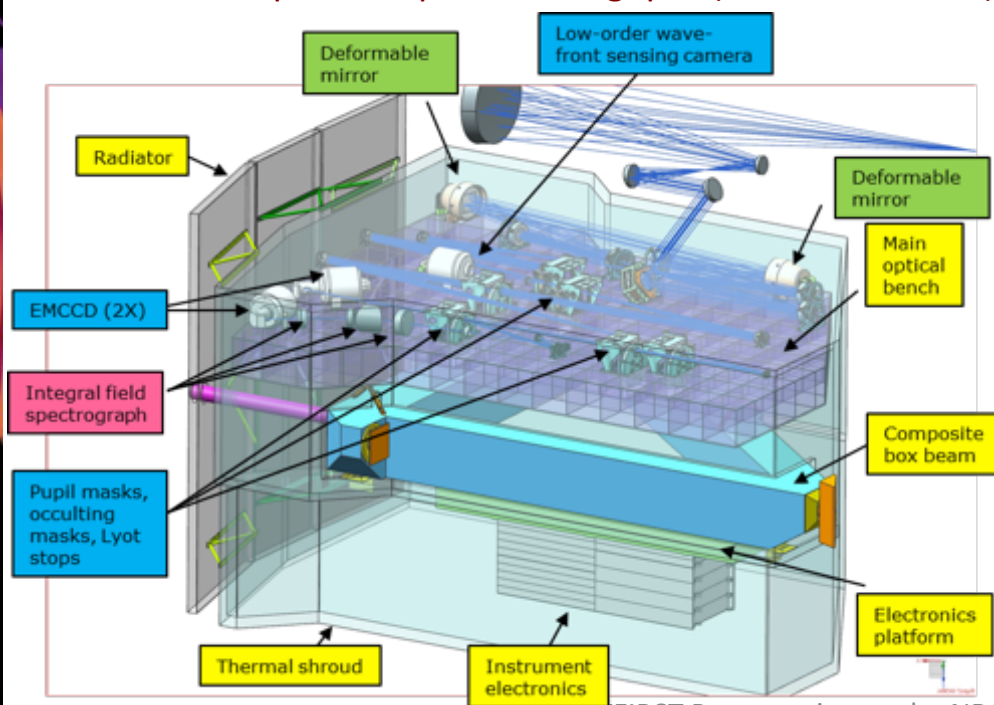
PV2a Full Array Quantum Efficiency



Left column shows image;
Middle column shows (log)
histogram;
QE for 1st several detectors
in the full array lot is shown
at upper right.

Coronagraph Instrument

- Completed design for 2015 SDT Report
 - Coronagraph met all WFIRST interface constraints
 - Initial end-end simulations indicate that the coronagraph is likely to achieve all performance goals with the current, unmodified telescope
- Coronagraph cost estimate within expectations
 - NICMs
 - CATE by Aerospace
- Currently working on refining design
 - Improved I&T flow
 - Improved optical throughput (less fold mirrors)



Bandpass	430 – 970 nm	Measured sequentially in 10% and 18% bands
Inner Working Angle [radial]	100 mas	at 550nm, $2\lambda/D$ driven by WFIRST-AFTA pupil occultations
	270 mas	at $1\mu\text{m}$
Outer Working Angle [radial]	0.5 as	at 550nm, $10\lambda/D$, driven by 48×48 format DM
	0.9 as	at $1\mu\text{m}$ (imaging camera)
Detection Limit (Contrast)	10^{-9}	Cold Jupiters; deeper contrast unlikely due to pupil shape & extreme stability requirements.
Spectral Resolution	70	$R = \lambda/\delta\lambda$ (IFS)
IFS Spatial Sampling	17 mas	3 lenslets per λ/D , better than Nyquist

Coronagraph Development Summary

- Team is making good progress on coronagraph technology program to achieve appropriate TRL by Phase A/B
- Coronagraph design is advanced and detailed, not driving mission complexity
- WFIRST coronagraph addresses key 2010 NWNH technology and science goals
 - WFIRST coronagraph brings wavefront-controlled coronagraphy to flight levels on the path to future Earth finding missions, not just hardware, but algorithms
 - As Kepler and microlensing complete the exoplanet census, the WFIRST coronagraph moves into the era of characterization

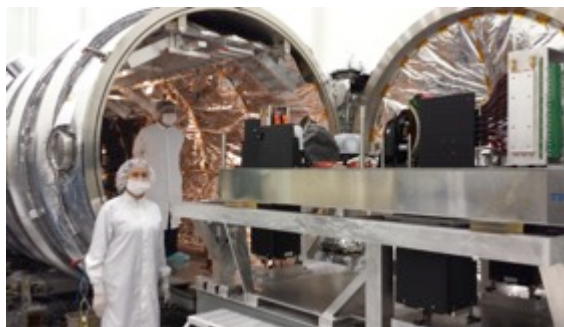
MS #	Milestone	Date
1 	First-generation reflective Shaped-Pupil apodizing mask has been fabricated with black silicon specular reflectivity of less than 10^{-4} and $20\ \mu\text{m}$ pixel size.	7/21/14
2 	Shaped Pupil Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with narrowband light at 550 nm in a static environment.	9/30/14
3 	First-generation PIAACMC focal plane phase mask with at least 12 concentric rings has been fabricated and characterized; results are consistent with model predictions of 10^{-8} raw contrast with 10% broadband light centered at 550 nm.	12/15/14
4 	Hybrid-Lyot Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with narrowband light at 550 nm in a static environment.	2/28/15
5 	Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a static environment.	9/15/15
6 	Low Order Wavefront Sensing and Control subsystem provides pointing jitter sensing better than 0.4 mas and meets pointing and low order wavefront drift control requirements.	9/30/15
7	Spectrograph detector and read-out electronics are demonstrated to have dark current less than 0.001 e/pix/s and read noise less than 1 e/pix/frame.	8/25/16
8	PIAACMC coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a static environment; contrast sensitivity to pointing and focus is characterized.	9/30/16
9	Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a simulated dynamic environment.	9/30/16

Excellent progress on technology development

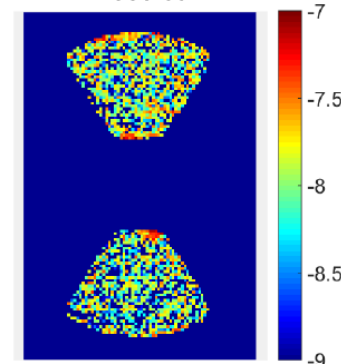
WFIRST Coronagraph Technology Systems Testbed



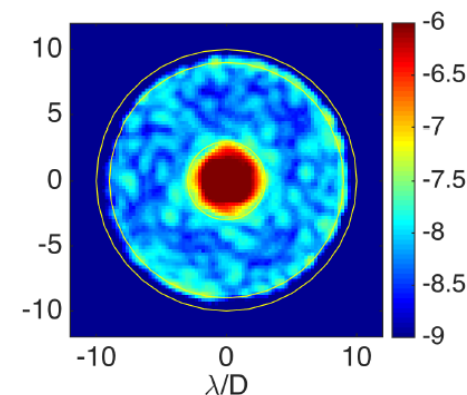
- Primary coronagraph architecture (Occulting Mask Coronagraph – OMC) consists of two occulting techniques.
 - HLC (Hybrid-Lyot Coronagraph)
 - SPC (Shaped-Pupil coronagraph)
- Demonstrated broadband (10% at 550nm) high contrast ($<1 \times 10^{-8}$) for both designs
- Milestone #5 passed TAC (Technology Assessment Committee) review on 9/29/2015



Contrast, all bands
7.98e-09



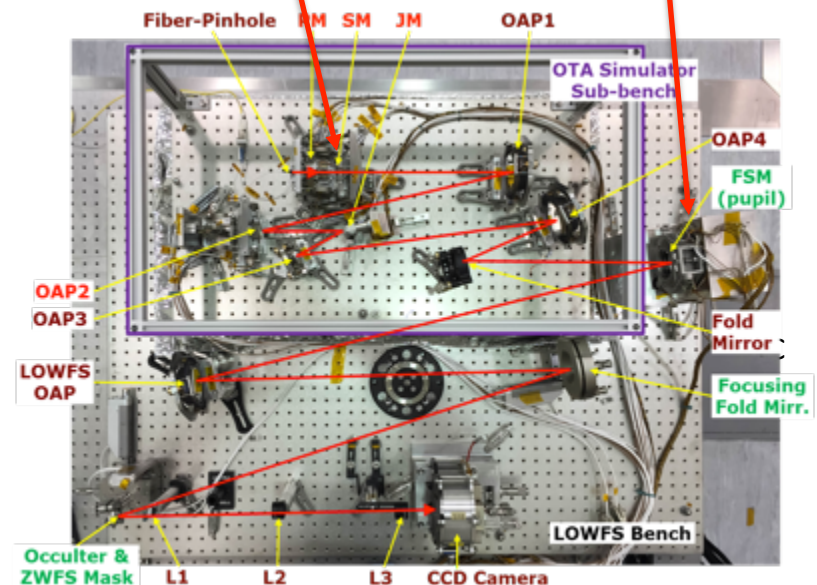
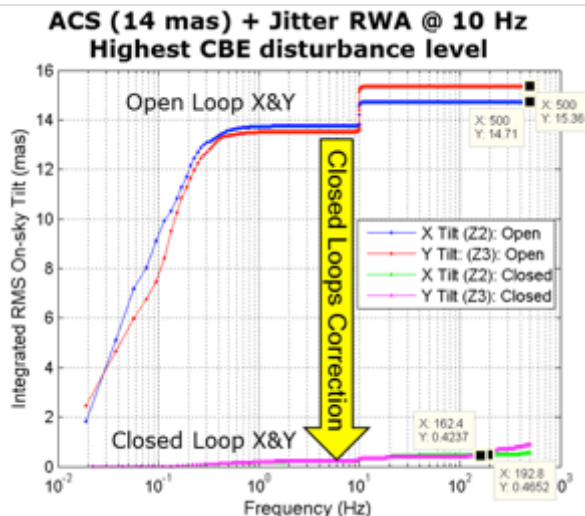
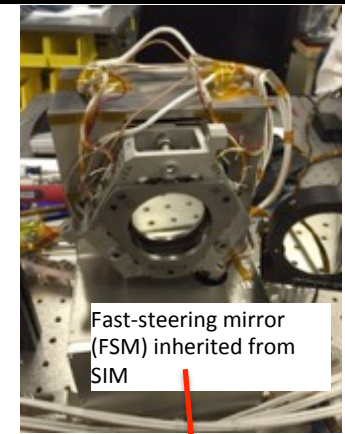
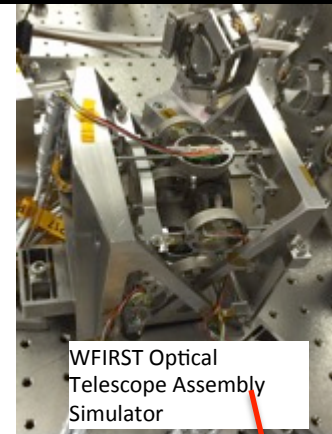
HLC: 10% bandwidth 550nm
Contrast: 8.54e-09



High contrast & broadband demonstration with WFIRST-AFTA pupil!

WFIRST Coronagraph Technology Low-Order Wavefront Sensing and Control (LOWFS/C)

- A key enabling technology for coronagraph working with as-built telescope
- Based on Zernike phase contrast microscope
 - Uses rejected star-light and measure observatory pointing jitter and telescope thermal drift.
 - Close-loop with a fast-steering mirror (pointing) and a deformable mirror (telescope thermal drift)
- Milestone #6 passed TAC (Technology Assessment Committee) review on 9/29/2015
 - Low order wavefront error sensing
 - Closed loop tip/tilt correction

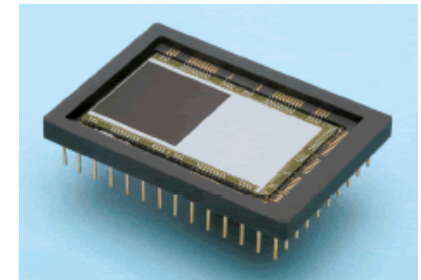


**Closed loop residual LoS error ~0.3 mas rms per axis (good case),
~0.5 mas rms per axis (worst case)**

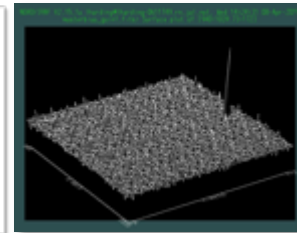
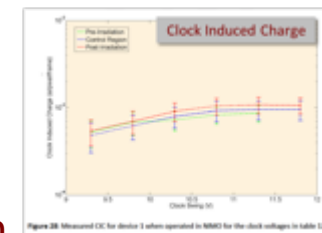
Low Noise Detector (EMCCD)

- Electron Multiplying (EM) CCD by e2v (model CCD201-20)
- Laboratory tests show Beginning of Life (BOL) performance requirements are met

AFTA-C Detector Performance Requirements						
Specification	Goal	Requirement	Measurement	Unit	Notes	Requirement met?
Active pixels	N/A	1024×1024	1024×1024	---	---	✓
Pixel pitch	N/A	13×13	13×13	microns	Effective area: 177.2mm ²	✓
Effective read noise w/gain	0.2	0.2	<0.2	e ⁻	EM amp w/EM gain	✓
Dark current	1×10 ⁻⁴	5×10 ⁻⁴	1.01×10 ⁻⁴ *	e ⁻ /pix/sec	*Measured at Temp 188K, IMO	✓
Clock induced charge (CIC) @ 5σ threshold	0.0010	0.0018	0.0017	e ⁻ /pix/fr	Measured using 10 MHz horiz. Rate, gain x1000	✓



e2v CCD201-20
Electron Multiplying CCD
(1K×1K format)



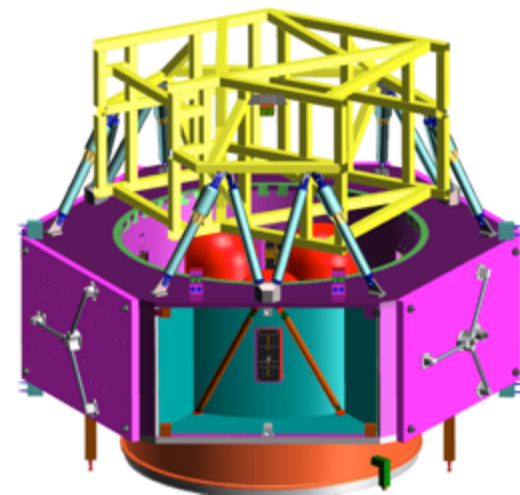
- Radiation tests on going:
 - Centre of Electronic Imaging at Open University, London
 - Radiation Test #1 at ambient temperature completed on 2015-04-08
 - Radiation Test #2 at low temperatures in 2015-06, data reduction under way

- ❖ Initial results indicate detector performs well after 6 years equivalent radiation in L2
- ❖ Negligible change in CIC
- ❖ Post-irradiation Dark Current meets WFIRST requirement
- ❖ Effect on CTE is being assessed → will be integrated into WFIRST-Coronagraph detector model



Spacecraft Overview

- Design relies on recent GSFC in-house spacecraft electronics designs
- Spacecraft module design enables serviceability and leverages designs from the Multimission Modular Spacecraft (MMS).
- Uses a distributed avionics architecture to facilitate modular approach
- Structures/Mechanisms
 - Spacecraft bus structure is aluminum honeycomb with composite facesheets, instrument carrier is a composite truss structure, qualified as an assembly
 - High Gain Antenna (HGA) system contains 2-axis gimbal
- Thermal
 - Passive cooling with coatings, MLI, heatpipes, and heater control
- Power (SDO & GPM heritage)
 - Internally redundant PSE, supplies power, controls array, battery
 - Fixed, body mounted arrays
 - Li-ion batteries for off-pointing during burns to L2

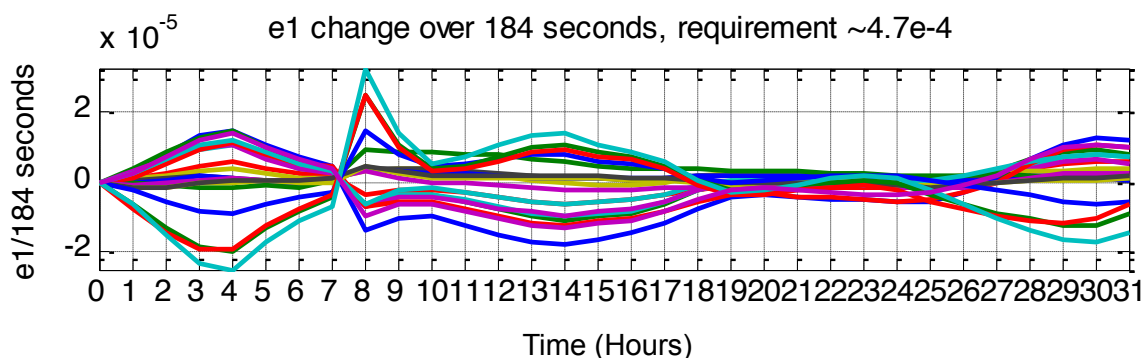


Spacecraft Overview

- C&DH (SDO & GPM heritage)
 - Platform for FSW: gathers TLM, sends commands, FDC
 - Low rate bus for housekeeping and spacecraft control
 - High speed science data interface between instruments and Ka downlink
 - End-to-end high speed test bed demonstration by end of 2015.
- Comm
 - S-band omni antennas for uplink and housekeeping data downlink
 - Ka-band for science data rate up to 275 Mbps (trading between DSN and dedicated ground stations)
 - GSFC developed transmitter (update of SDO design) with a capability of 1.2 Gbps (prototype on schedule for completion in early 2015)
- Attitude Control/Prop
 - 3-axis stabilized using 4 reaction wheels with thruster unloading
 - 14 mas drift & 14 mas jitter, RMS/axis
 - FGS uses guide window data from Wide Field Instrument
 - Mono-prop system for mid-course correction, station-keeping, momentum unloading and end of life disposal

Observatory Integrated Modeling

- A key focus of pre-Phase A Observatory analysis has been on integrated modeling (STOP and Jitter).
- Model fidelity is high for this phase of the mission.
 - Benefit of using the existing telescope
 - Required to optimize coronagraph mask designs
 - Critical for assessing PSF ellipticity for WL
- Analysis is on-going now for current configuration. Results below are from the configuration as documented in the 2015 report.
- WFI STOP stability specs met with margin (10x) even for an extreme WFI Worst Slew Case w/MUFs applied
- WFI Jitter stability specs met with margin (1.3x) for all disturbance sources even with MUFs applied
 - Modeled 4 RWAs, cryocooler and HGA jitter disturbances



Plot of delta ellipticity over a weak lensing observation with time steps of 3600 seconds after a slew at hour 7. $\Delta e1 \leq 3.3 \times 10^{-5} / 184 \text{ sec}$ provides 14.2x margin on 4.7×10^{-4} and $\Delta e2 \leq 4.1 \times 10^{-5} / 184 \text{ sec}$ provides 11.5x margin on 4.7×10^{-4} (not shown). The lines represent the center field point of each of the 18 detectors and a point for the FoV center.

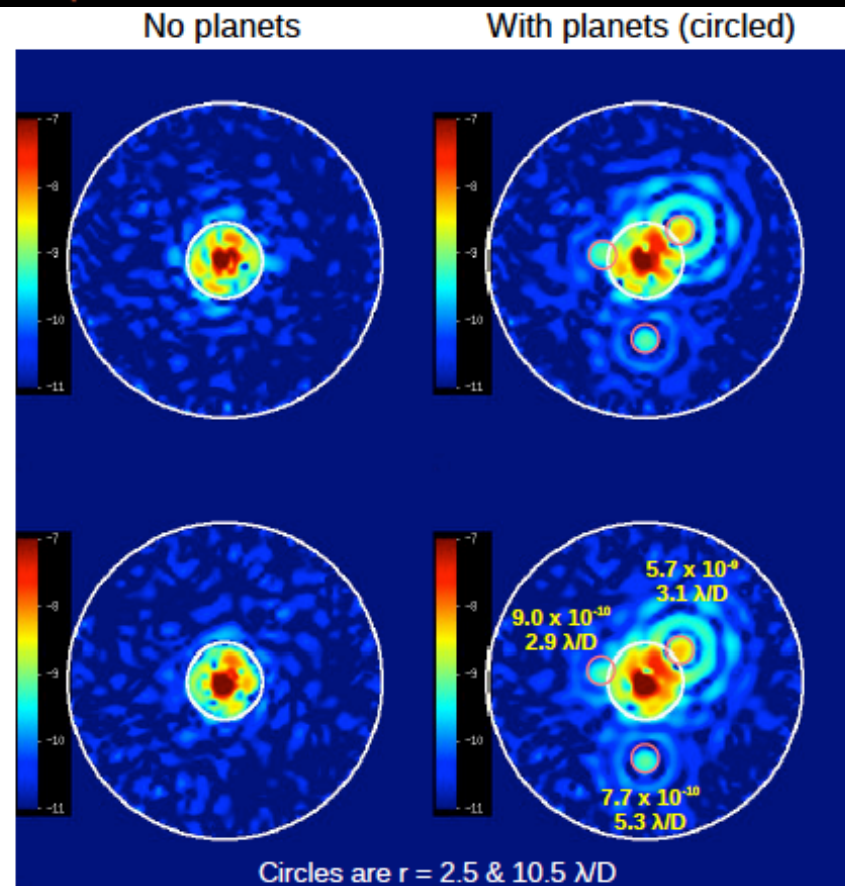
Coronagraph STOP Results from 2015 SDT Report Configuration

Initial simulations of Coronagraph performance in WFIRST-AFTA environment indicate that the Coronagraph is likely to achieve all performance goals with the current, unmodified telescope.

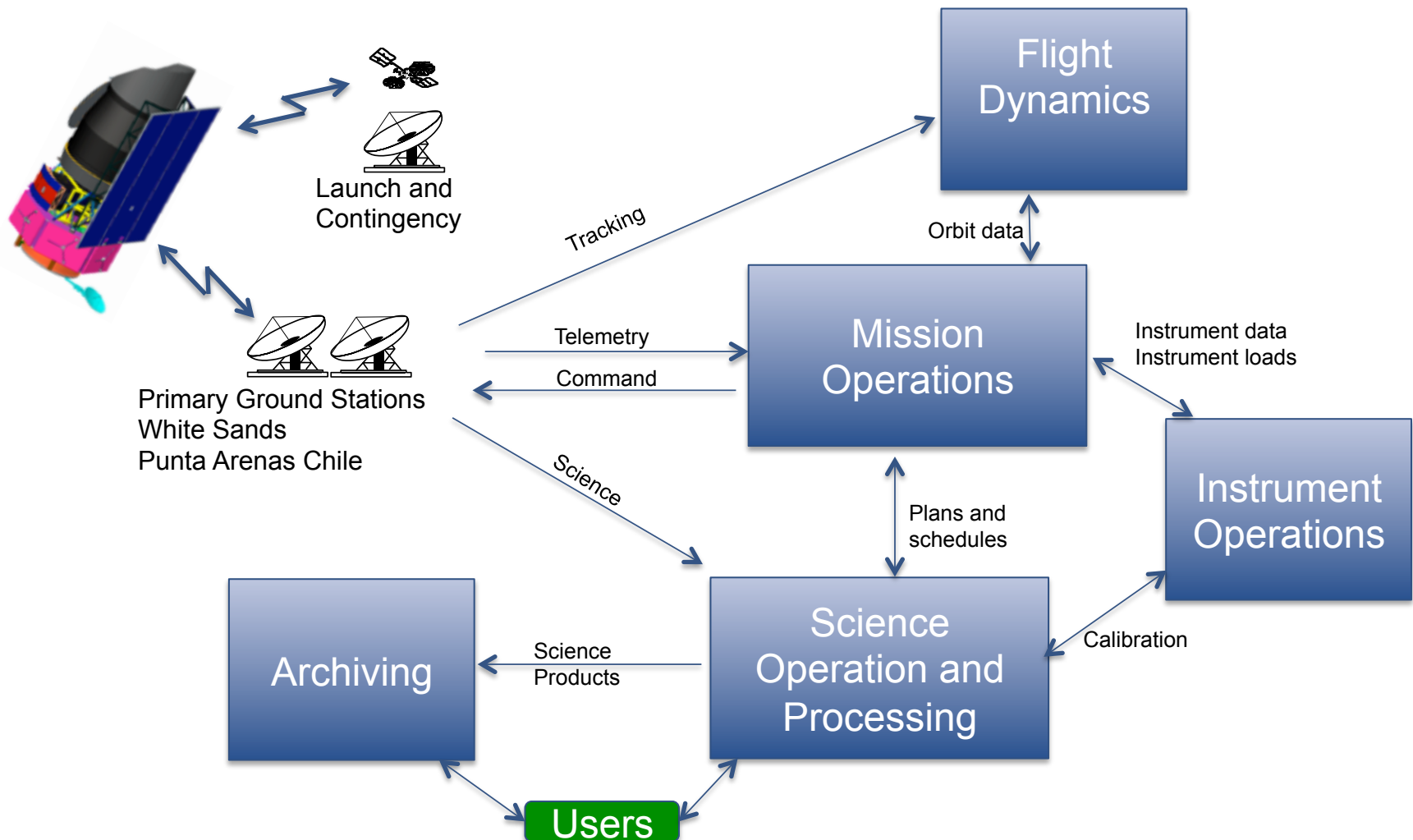
As part of the recent design refinement process, the Coronagraph collimator was moved from inside the instrument to the telescope aft metering structure. This change makes the Coronagraph >1000x less contrast sensitive to Coronagraph misalignments to the telescope.

| 47 Uma - β Uma |

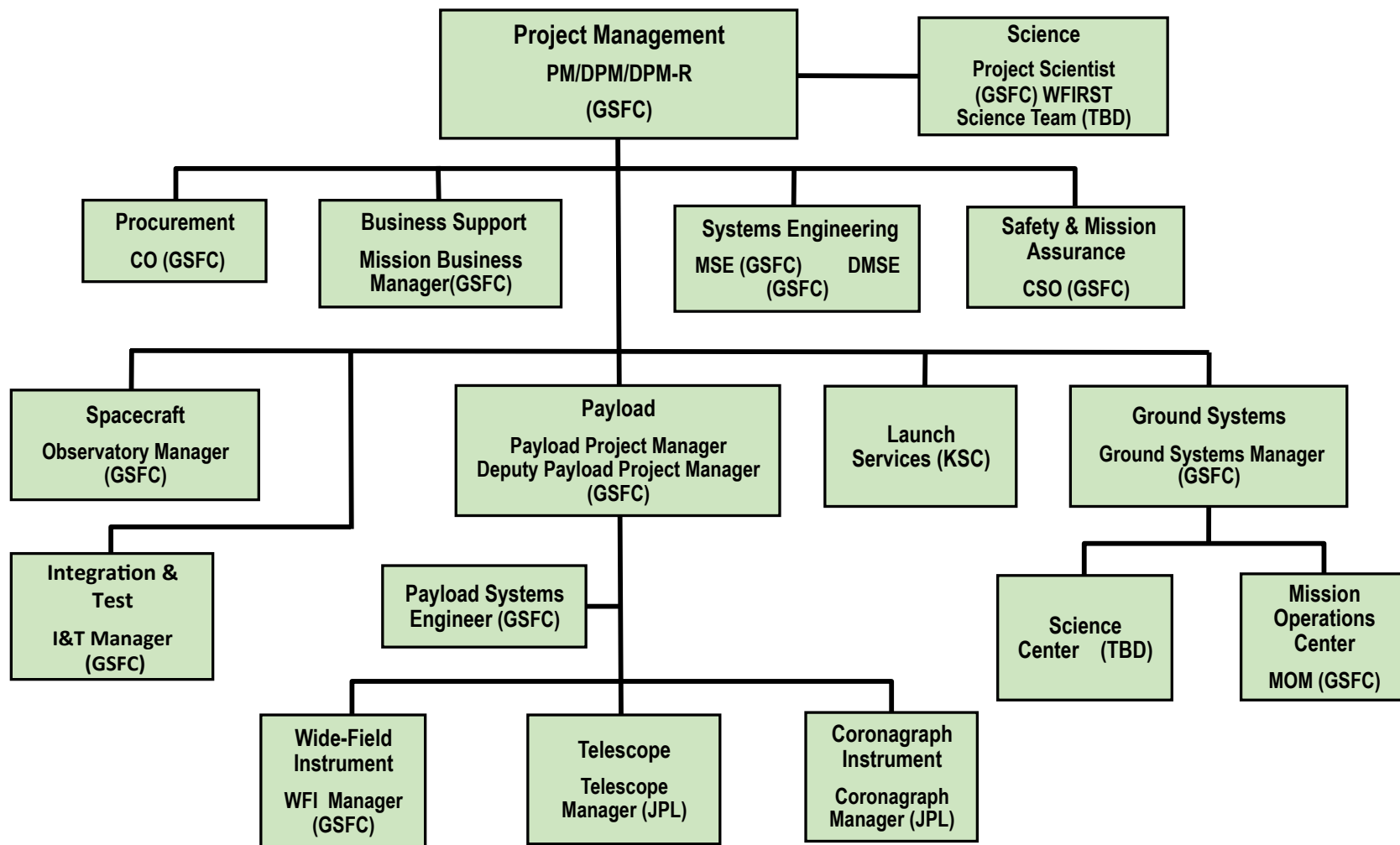
| 47 Uma - 61 Uma |



Baseline Ground System Architecture



WFIRST Project Organization





Recent Activities



- Completed design report with SDT – March '15.
- Developed life cycle mission cost (combination of parametric, grassroots, and analogy)
- Validated by independent cost assessment (Aerospace CATE).
- MCR design cycle progressing to completion in December.
- Milestones for Coronagraph and IR detectors continue to make excellent progress.
 - Technology Assessment Committee provides for external review of technology milestones.
- Risk management process being actively utilized.
- Industry RFI for potential participation in WFIRST development recently conducted; study solicitation this fall.
- Solicitation for WFIRST science team released July 17th.

NASA Cost Estimate	FY10\$B	FY15\$B	RY\$B
Mission Cost w/coronagraph	1.8-2.1	2.0-2.3	2.5-2.8
Cost of adding coronagraph	0.32	0.35	-
NWNH Mission Estimate*	1.6	1.8	-

* NWNH cost estimate did not include the GI/GO program

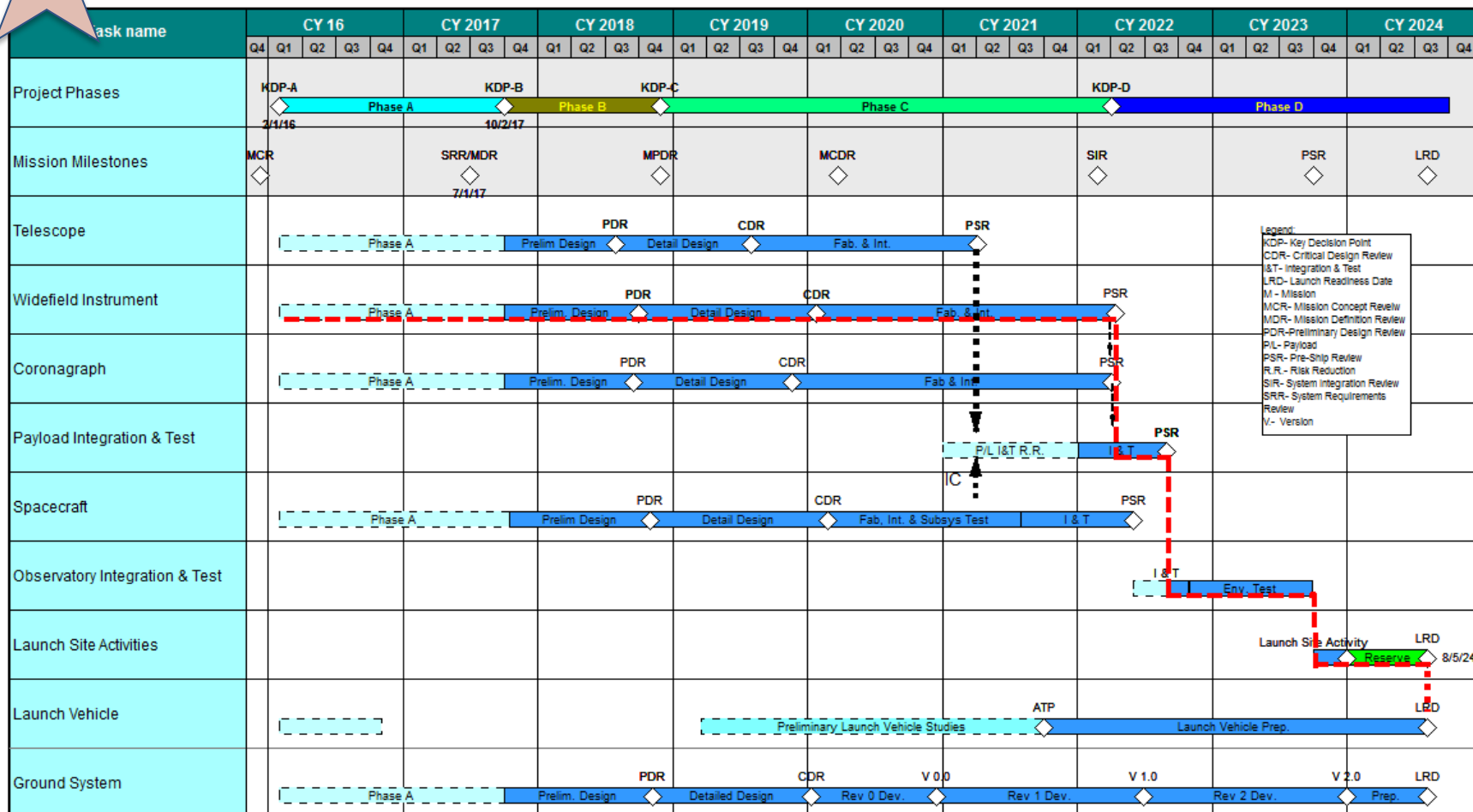
Path Forward

- Mission Concept Review schedule for Dec 8-9.
- Industry study solicitation to be released.
- Developing KDP-A documentation and products per NPR 7120.5E (control plans, descope plan, design reference, Formulation Agreement, etc.)
- Proposals for WFIRST Science Team due October 15; selection around Dec 1.
- Science Investigation Team kick-off planned for the first week of February.
- Award of industry studies in early 2016.
- Prepared for the start of formulation (KDP-A) as early as January 2016.
- Acquisition Strategy Meeting (ASM) in spring; finalizes acquisition approach.
- Systems Requirements Review/Mission Design Review (SRR/MDR) to be held prior to end of Formulation Phase.
- At the conclusion of the Formulation Phase, KDP-B and transition to development.

Preliminary Development Schedule

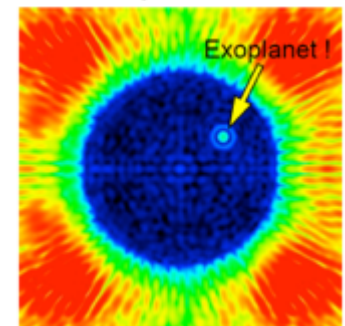
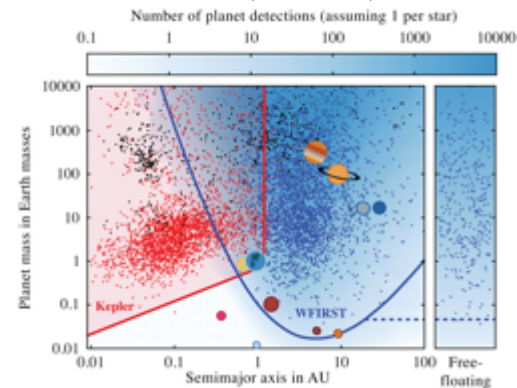
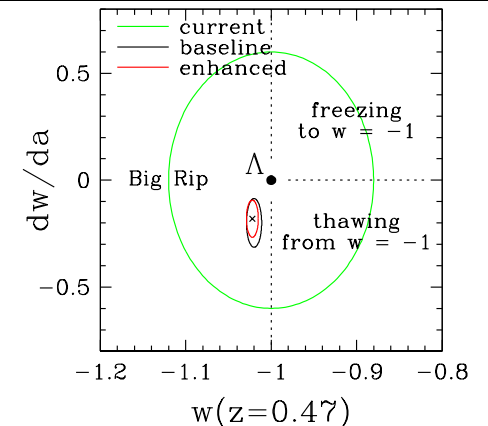
#2

Preliminary WFIRST Development Schedule (CR)



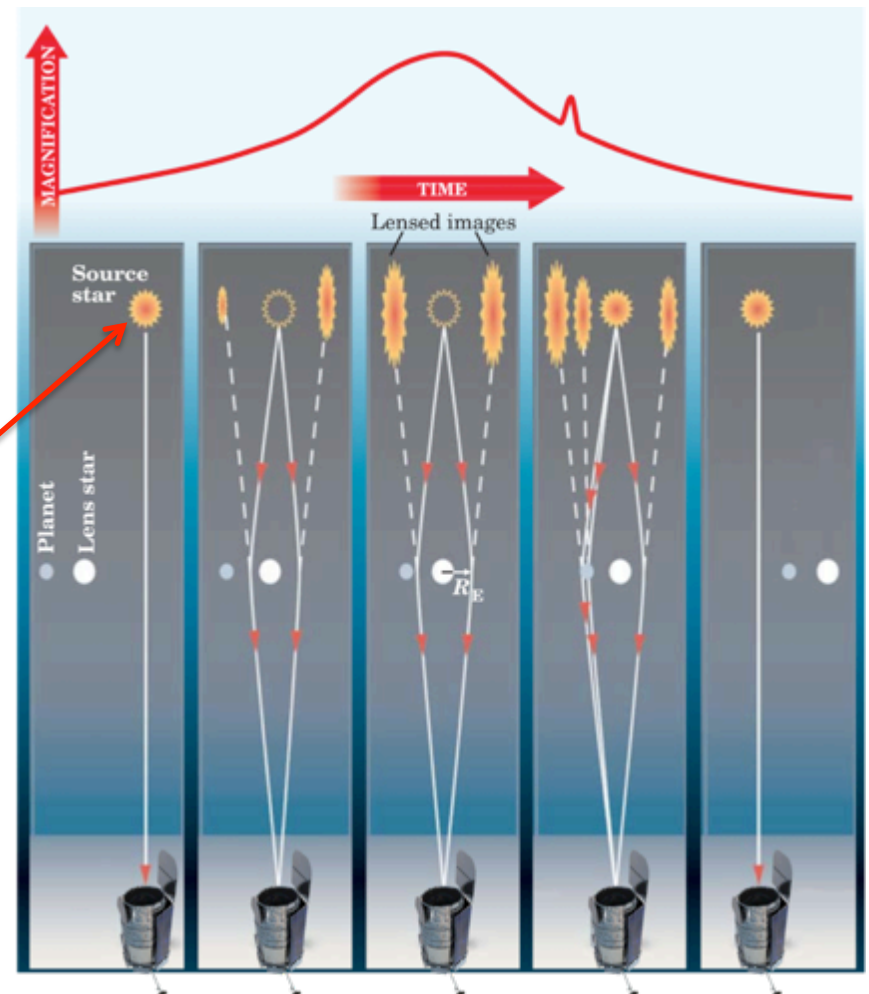
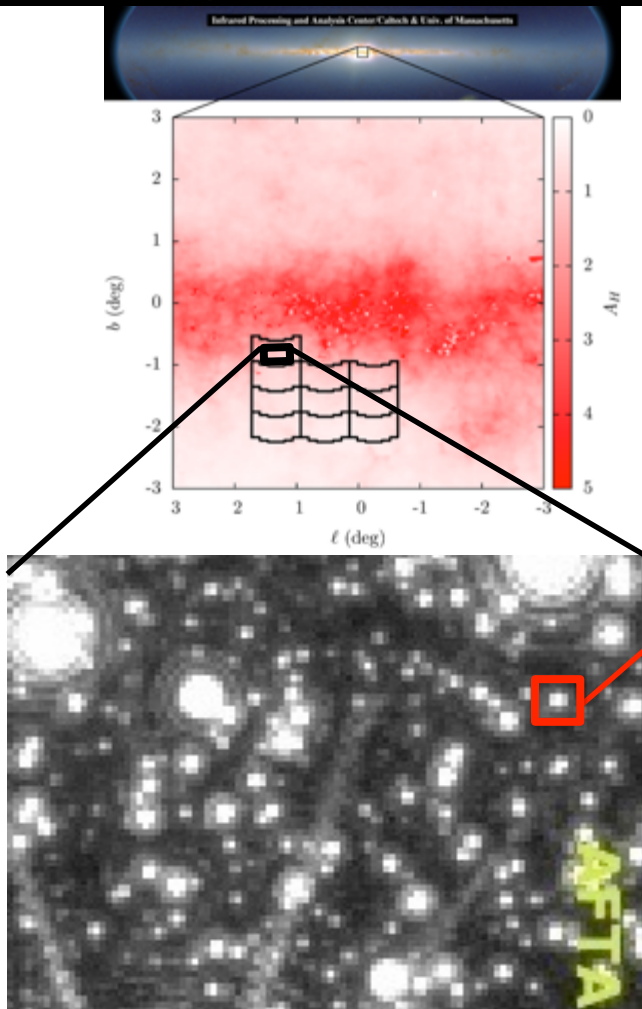
Summary

- Over the past two years, increased funding has enabled significant progress in technology maturation as well as additional fidelity in the design reference mission.
- WFIRST with the 2.4-m telescope and coronagraph provides an exciting science program, superior to that recommended by NWNH and also advances exoplanet imaging technology (the highest ranked medium-class NWNH recommendation).
- Great opportunity for astronomy and astrophysics discoveries. Broad community support for WFIRST.
- Key development areas are anchored in a decade of investments in JPL's HCIT and GSFC's DCL.
- Great progress made in pre-formulation, ready for KDP-A and launch in mid-2020s.



BACKUP SLIDES

Microlensing Technique



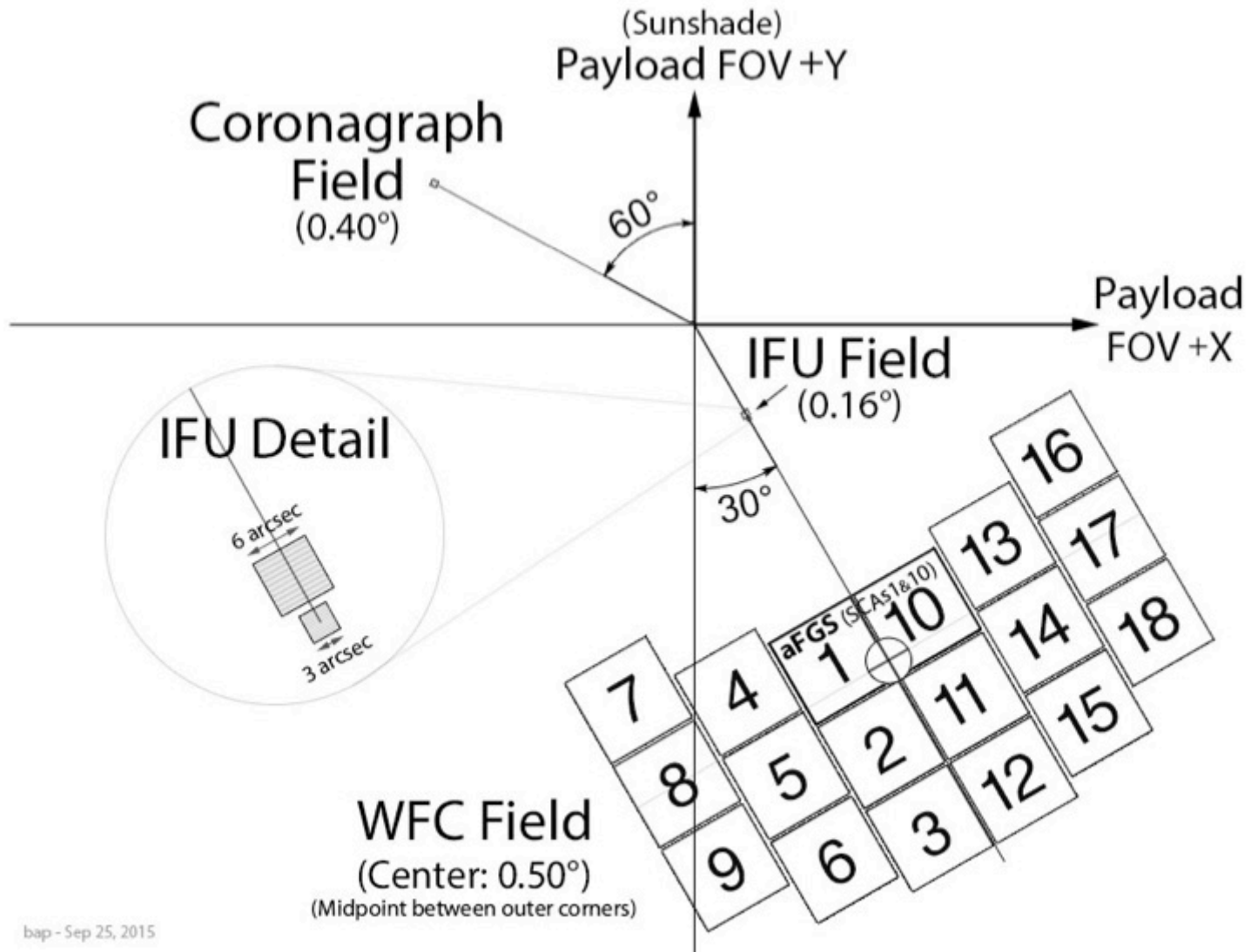
Great benefit of space observations in the crowded galactic bulge field

Telescope Temperature

- The telescope operating temperature was changed from 270K to 282K for the 2015 report to maintain the heritage hardware within its minimum design temperature with margin.
- Impact of change from 270K to 282K
 - HLIS:
 - F184: loss of 0.28 mag in depth, resulting in 18% reduction in galaxy density for WL
 - GRS:
 - bandpass reduced from 1.95μ to 1.89μ
 - H α redshift range reduced from $z=1.97$ to 1.87
 - 11% reduction in H α galaxies/sq deg at all redshifts
 - SNIa:
 - IFU sensitivity reduced 2X beyond $\sim 1.85\mu$
 - Microlensing:
 - No significant impact

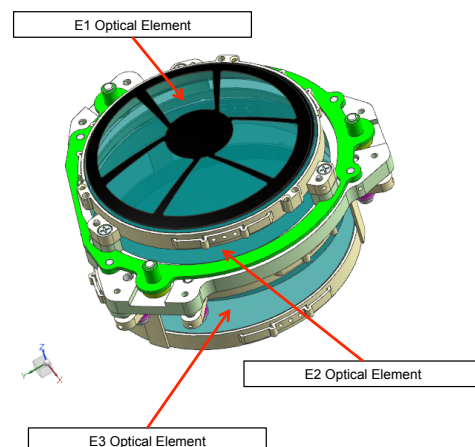
See SDT report App. A for details (arXiv:1503.03757)

Field of View Layout



Early Wide Field Development Activities

- With the availability of additional resources in FY14 and FY15, the Study Office began some early prototyping activities on the Wide Field grism to assess design and manufacturability of the grism with its wide field of view, large dispersion, broad spectral range, relatively small F/#, and high efficiency diffractive surfaces.



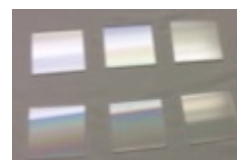
Grism mechanical design



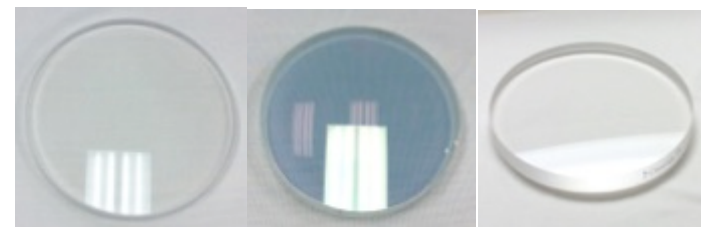
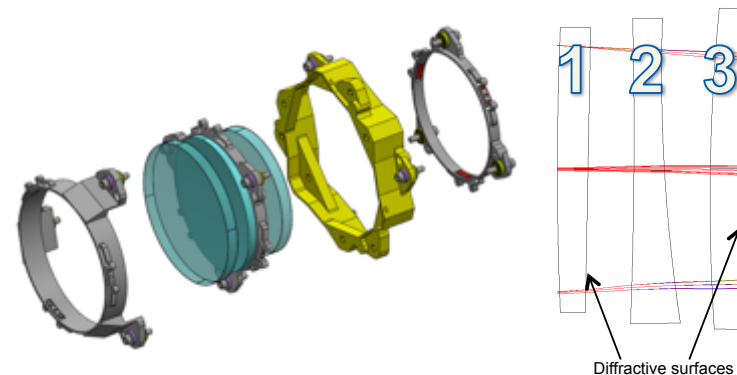
Grism mount



WFIRST Presentation to the NRC
Mid-Decadal Panel

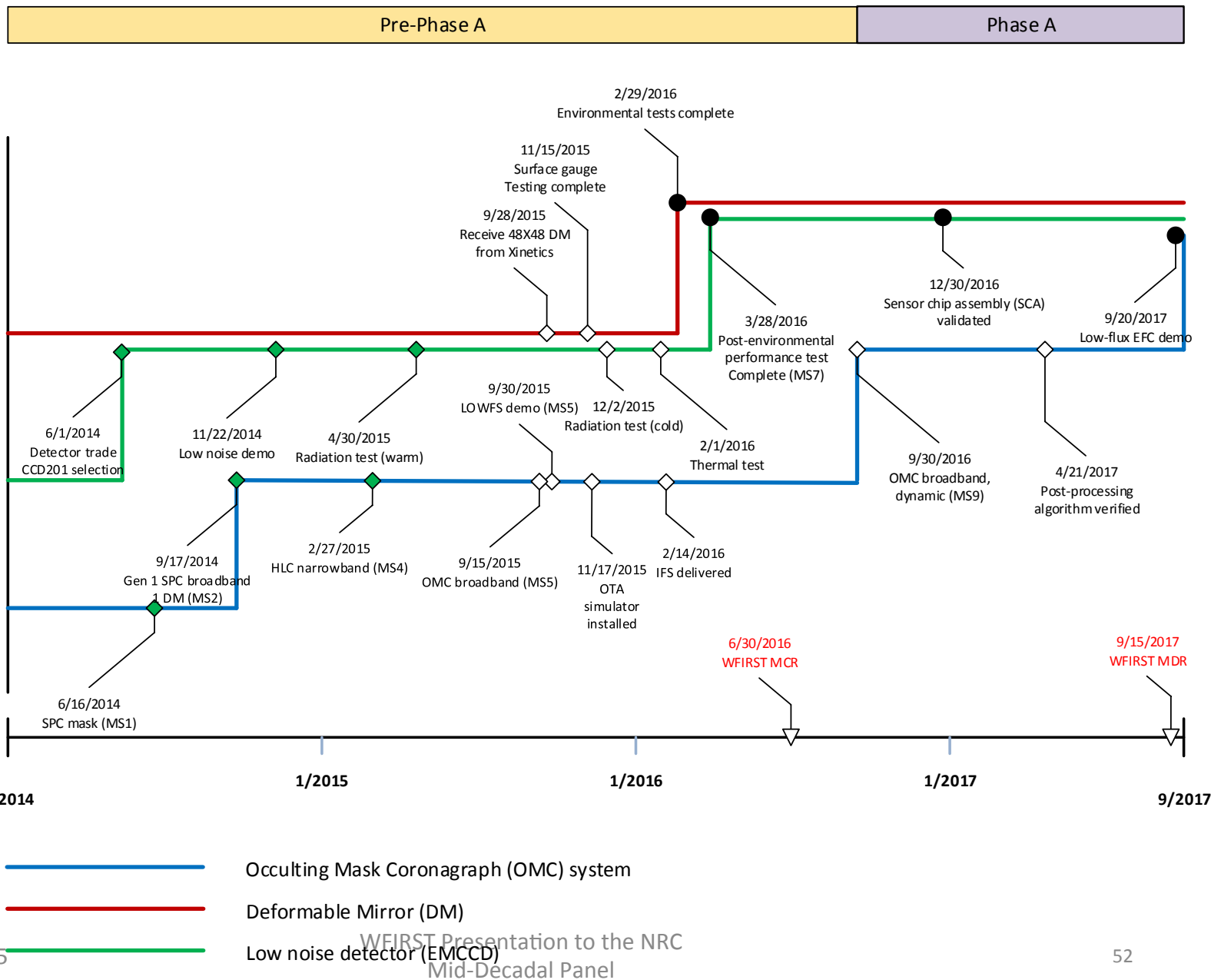


Grism grating samples



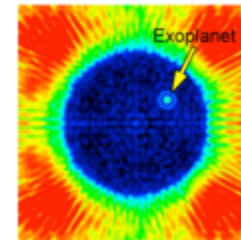
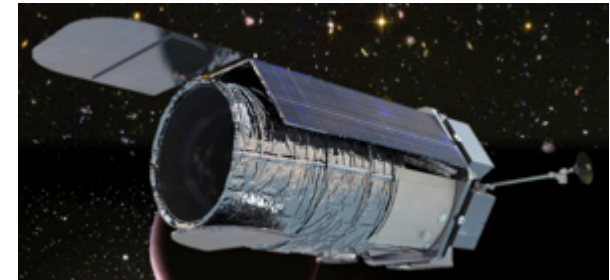
Grism procured substrates

Coronagraph Technology Path to TRL-6

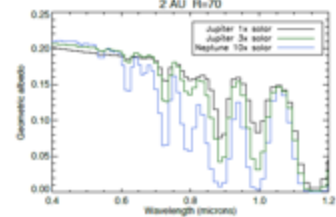


Coronagraph Instrument Summary

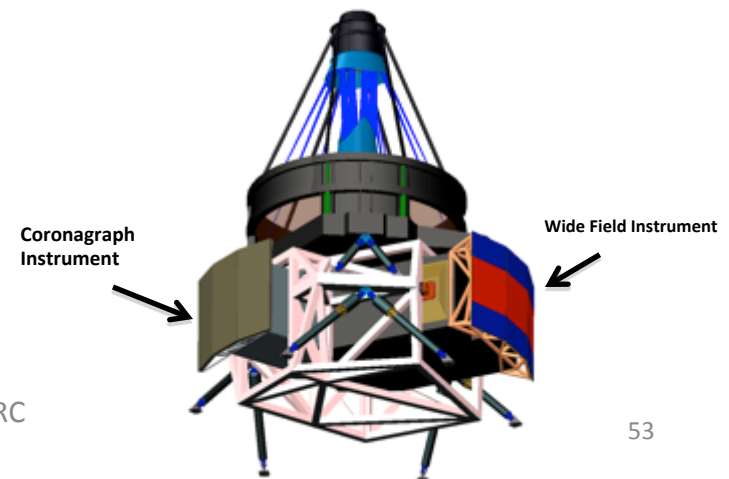
- **Occulting Mask Coronagraph (OMC):**
 - Shaped-Pupil and Hybrid-Lyot coronagraph masks
 - High contrast imaging using precision wavefront sensing and control
 - 2 Deformable mirrors (Xinetics)
 - 2nd instrument on WFIRST-AFTA
 - Exoplanet direct imaging technology demonstration
 - Pre-cursor science for future exo-earth missions
- **Team:**
 - JPL led technology team, with participations from many US institutions:
 - Princeton University
 - University of Arizona
 - GSFC
 - ARC
 - Caltech/IPAC
 - STScI
 - Northrop-Grumman Xinetics
- **Near-term Key Deliverables:**
 - ✓ ▪ SDT final report 1/2015
 - ✓ ▪ CATE 2/1015
 - Mission Concept Review (MCR) 12/2015
 - Technology demonstration by 10/2016:
 - TRL-5 at system level



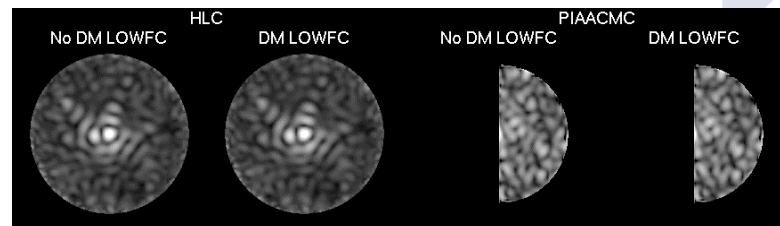
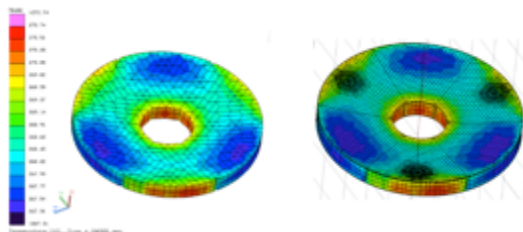
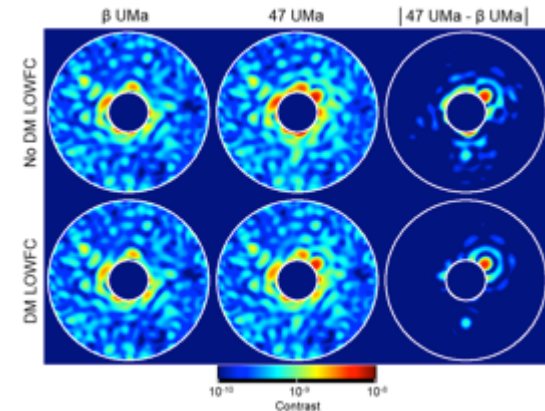
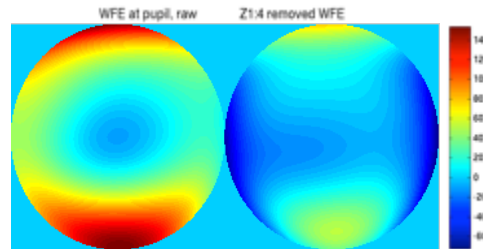
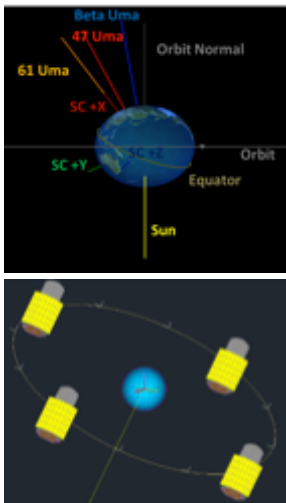
Exoplanet
Direct imaging



Exoplanet
Spectroscopy



Detailed Full-Physics Simulations to Validate Coronagraph with WFIRST

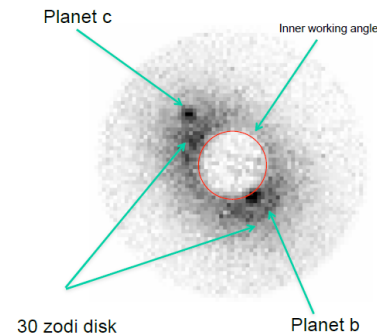
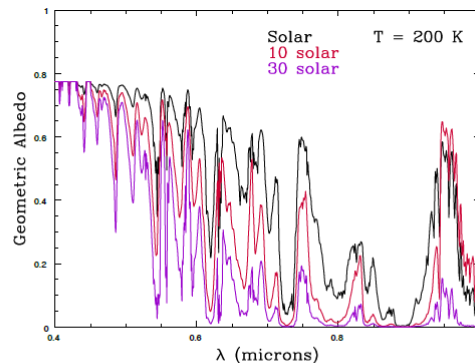


Initial simulations indicate that the coronagraph is likely to achieve all performance goals with the current, unmodified telescope.

Coronagraph Performance

Output channel	Coron. name	Spectral resolution	Polarization	Primary science	Wavelength (nm)	Number of RV planets detectable	Requirement
imager	HLC	R = 10	X & Y pol., separately	RV exoplanets & disks	blue: 465	18	>12
					green: 565	19	
					red: 835	10	
spectrometer (IFS)	SPC	R = 70	unpolarized	RV exoplanets	near-red: 670	10	>6
					mid-red: 770	8	
					far-red: 890	5	

1. Detections assume a best case of small pointing jitter (0.4 mas) and excellent post-processing speckle reduction factor (30x).
2. We expect that the actual case will be close to the best case, by using (a) feedback to control jitter, (b) advanced processing to reduce speckles, and (c) continued RV observations (WIYN) to discover more RV planets.
3. Most planets can be imaged in much less than 1 day; spectra will often take a few days. The totals are for a month-long campaign for imaging, and another month for spectroscopy.
- 4. The coronagraph is expected to exceed its requirements, with margin.**

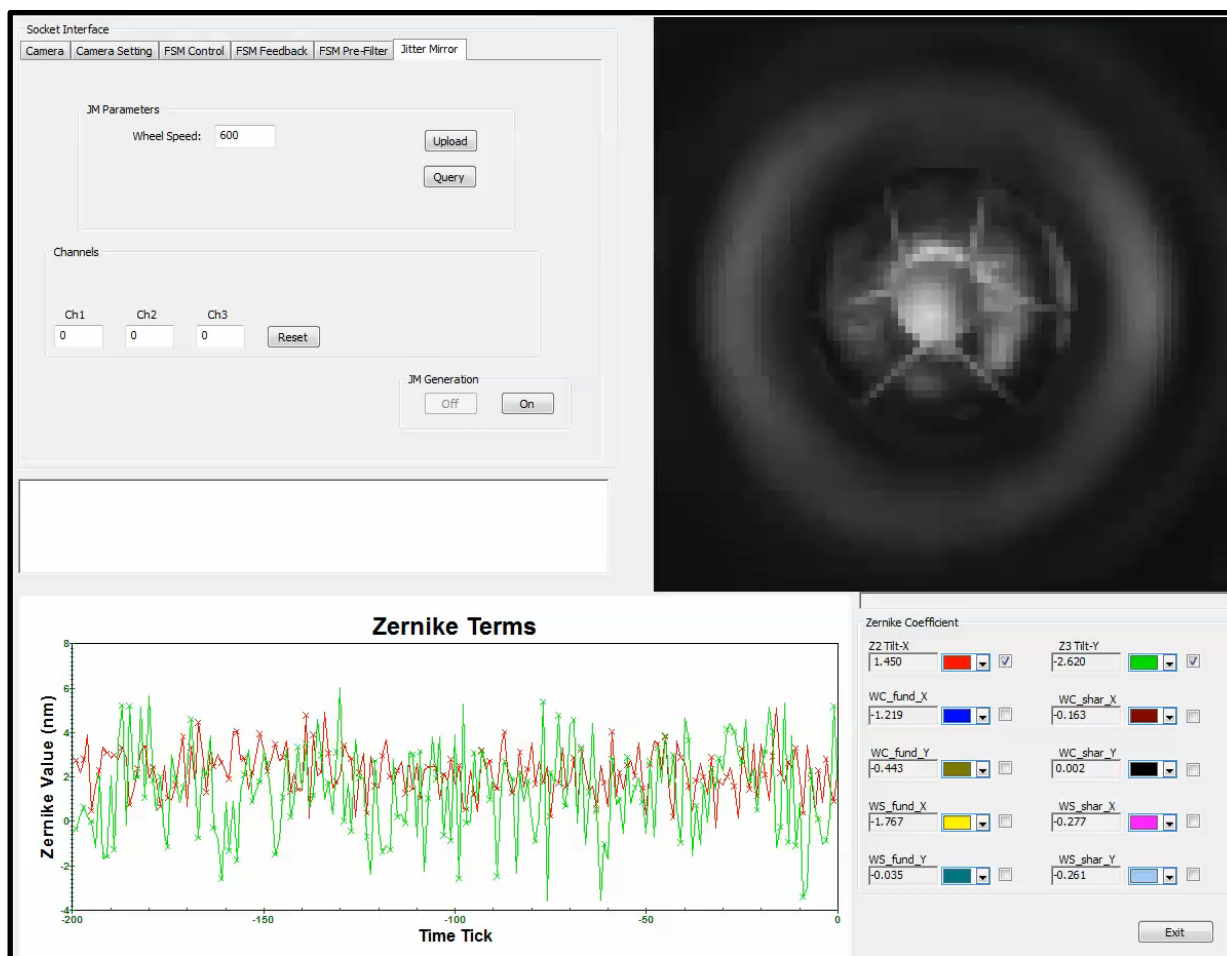


Compelling science from WFIRST coronagraph

LoS Control Loops Demo Video

Start: Lab ambient, ACS on (0:10), Jitter on (0:29), FB on (0:50), FF on (1:09)

ZWFS
measured X
and Y tilt



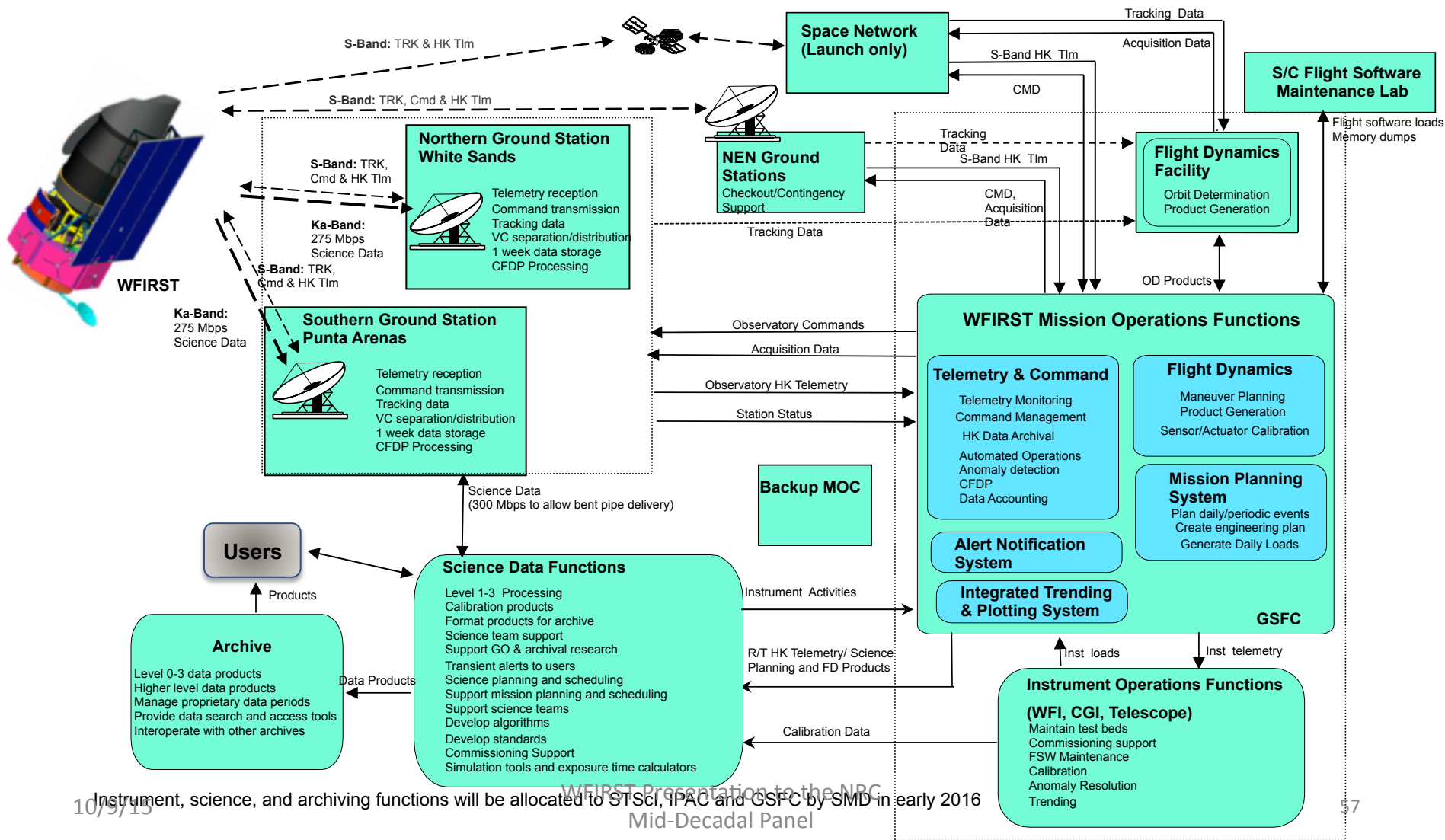
Closed loop residual LoS error ~ 0.3 mas rms per axis (good case),
 ~ 0.5 mas rms per axis (worst case)



WFIRST

WIDE-FIELD INFRARED SURVEY TELESCOPE
DARK ENERGY • EXOPLANETS • ASTROPHYSICS

Baseline Ground System Architecture



10/9/15

WFIRST Presentation to the NRC
Mid-Decadal Panel



WFIRST

WIDE-FIELD INFRARED SURVEY TELESCOPE

WFIRST Risk Summary

CONSEQUENCES

LIKELIHOOD

	1	2	3	4	5
5					
4					
3					
2		6 7	4 2 3 5	1	
1					

Rank/ Trend	ID	TITLE	APPROACH
1 ↓	WFIRST-RISK-WFI-0001	Detector Performance	Mitigate
2 ↓	WFIRST-RISK-WFI-0003	Detector Yield	Mitigate
3 ↓	WFIRST-RISK-WFI-0043	Focal Plan System Performance	Mitigate
4 ↓	WFIRST-RISK-WFI-0002	Detector Mfg Issues	Mitigate
5 ↓	WFIRST-RISK-TELE-0027	Telescope Pedigree & Capability	Mitigate
6 ↓	WFIRST-RISK-WFI-0015	Grim Optomechanical Performance	Research
7 ↓	WFIRST-RISK-CG-0044	Deformable Mirror Performance Risk	Mitigate

Criticality	L x C Trend	Approach
HIGH	↓ Decreasing (Improving)	M-Mitigate
MED	↑ Increasing (Worsening)	W-Watch
LOW	↔ Unchanged	A-Accept
	NEW New since last month	Ar-Archive

10/9/15

WFIRST Presentation to the NRC
Mid-Decadal Panel

Top Risks

Risk Summary	Proposed Mitigations	Status
<u>Detector Performance</u> Given that initial detector fabrication met some but not all performance requirements there is a possibility that future devices may also incur similar performance issues resulting in impacts to mission performance	a) Establish by modeling that the limitations experienced are the result of tunable manufacturing parameters and not due to fundamental device physics. b) Run early test lots to demonstrate detector performance c) Demonstrate detector performance on full 4kx4k detectors	- Received 14 of 15 SCAs - Completed testing of 8 full array parts in support of DTAC#3. Performance meets DTAC requirements.
<u>Detector Yield</u> Given HgCdTe devices using the H4RG-10 format have limited production experience there is the possibility that the device manufacturing yield will be low resulting in increased cost and schedule in order to produce the required number of devices	a) Perform preliminary assessment of yield during Process Optimization and Full Array Lots b) After proposed flight process is determined, run a yield demonstration lot to establish expected yields before committing to flight production.	- 1st Yield demo lot started 9/2/2015 - On plan for yield demo lot milestone (12/2016)
<u>Focal Plane System Performance</u> Given that focal plane assembly (FPA) performance reqs are likely to be challenging there is a possibility that system level FPA issues may be discovered resulting in not meeting FPA system performance requirements	a) Develop a high fidelity engineering model FPA for early assessment of any system level performance issues b) Obtain equipment needed for testing a full-scale focal plane c) Perform early assessment of detector module crosstalk and noise performance	- On Plan for Phase A/B - Plan includes Round Mosaic Plate Performance and Environmental Testing - Cold metrology gantry near complete; automation software in progress. DCL team conducted preliminary testing at GLS week of Aug 25th

Top Risks (cont')

Risk Summary	Proposed Mitigations	Status
<u>Detector Manufacturing</u> Given that some initial test lot devices experienced channel cracking there is a possibility that some flight devices may incur similar reliability concerns resulting in detectors unusable for flight application	a) Examine alternate base material (CE6) that reduces stress on detector material, reducing potential for cracking. b) Perform environmental and performance testing on test devices with candidate base materials (SiC/CE6) to evaluate performance and select flight base material	- SiC testing completed; CE6 testing continues- no cracking. - SiC/CE6 trade will be presented to WFIRST technical team on 10/14/2015 for review
<u>Telescope Pedigree & Capability</u> Given that the telescope was designed for a different application with different standards there is the possibility that the as-built telescope may have design/pedigree issues resulting in unplanned rework and/or additional verification steps	a) Systematically review Telescope build and verification records and compare to NASA and JPL standards. b) Identify any gaps between Telescope status and WFIRST reqs c) Determine what actions needed to resolve any gaps (e.g. additional verification, refurbishment, replacement, waiver)	- Telescope assessment Audit #1 completed by JPL, GSFC, and Harris technical teams - Audit #1 report delivered and in review. No major issues with planned reuse have emerged to date
<u>Grism Optomechanical Performance</u> Given that the grism is a complex multi-element optical design there is a possibility that optical shifts, distortions, or misalignments may occur resulting in poor wavefront or throughput performance with degraded science return	a) Conduct a fabrication & alignment feasibility assessment, alignment analysis b) Develop an early EDU to confirm design performance	- Error budget established and being validated by integrated modeling - Grism EDU parts procured/received and unmounted cold testing has started

Top Risks (cont')

Risk Summary

Deformable Mirror Performance Risk

Given that the deformable mirror (DM) is the key component to control coronagraph wavefront errors there is a possibility that 1)DM correction in low-order causes mid to high-order wavefront errors and 2) insufficient stroke available to correct all wavefront errors under required derating, resulting in coronagraph contrast performance degradation.

Proposed Mitigations

- 1) Decrease coronagraph thermal sensitivity, placing less demand on DM requirement for LOWFS
- 2) Demonstrate coronagraph DM performance capability at system level testbed
- 3) Examine system level parameters to manage DM stroke margins

Status

- Collimator bench location trade leads to a down-selection of AMS mounting, improving wavefront thermal stability
- Completed draft DM stroke error budget
- Demonstrated a new DM solution with 30% less DM stroke needed at the HLC testbed. HLC DM solution is the largest contributor to DM stroke error budget.

- Study Office has begun identifying potential items for the Descope List.
- This is the initial draft for more detailed evaluation in Phase A, especially as we define the minimum mission success criteria with NASA HQ

Draft Descope List

Draft Descope	Impact
Wide Field Instrument	
Accept reduced grism performance.	Protect schedule, reduction in BAO/RSD survey science.
Delete GRS grism.	Eliminate BAO/RSD survey capability.
Eliminate auxiliary guiding channel.	Degraded pointing in BAO/RSD survey, reduction in BAO/RSD survey science.
Delete IFU.	Reduction in SNe science. Assess SNe capability using existing filters and GRS grism.
Delete wide filter for microlensing.	Reduction in microlensing survey science.
Accept degraded performance detectors.	Protects schedule, assess detector specifications vs. science impacts.
Reduce size of wide field focal plane by eliminating detectors and/or increase plate scale.	Saves resources and/or protects schedule, reduces wide field survey science.
Eliminate the relative calibration system.	Assess impact of only using astronomical sources.

Draft Descope

Impact

Coronagraph Instrument

Reduce or terminate PIAA-CMC technology investments.

Eliminates backup architecture path.

Reduce or eliminate Hybrid-Lyot coronagraph capability.

Single coronagraph capability. Loss of imaging science without redesign.

Reduce or eliminate Shaped-Pupil coronagraph capability.

Single coronagraph capability. Loss of spectroscopic science without redesign.

Delete IFS.

Eliminate spectroscopic science and only perform photometric science.

Accept degraded performance deformable mirrors.

Protect schedule, reduction in coronagraph science.

Accept degraded performance EMCCD.

Protect schedule, reduction in coronagraph IFS science.

Reduce LOWFS to local feedback only.

Simplifies interfaces to S/C and testing, reduces jitter performance.

Eliminate coronagraph.

Protects cost & schedule, no on-orbit demonstration of coronagraph technology.

Draft Descope List (cont'd)

Draft Descope		Impact
Telescope		
Eliminate effort to study colder telescope operating temperature.	Warm temperature consumes larger portion of noise budget, large heater power requirement.	
Accept existing telescope heater redundancy scheme.	No single fault tolerance in the survival heater string.	
Eliminate recloseable door.	No protection against contaminates during servicing, no protection available if loss of attitude control.	
Spacecraft		
Reduce downlink data rate.	Assess impact to science of fewer samples per exposure.	
Eliminate reaction wheel isolators.	Assess impact of higher jitter on science.	
Reduce thruster count.	Maintain propellant sizing, assess impact mission lifetime.	
Replace composite bus structure with aluminum structure.	Assess impact of lower pointing stability on science.	

Draft Descope List (cont'd)

Draft Descope

Impact

Ground System

Delete second ground station.

Assess impact of lower data volume and impact to orbit determination.

Perform all Science Center functions at a consolidated Science Center.

Assess loss of science expertise from the distributed Science Center.

Mission

Assess emerging launch vehicle opportunities and orbit options.

New launch vehicle at potentially lower cost.

Accept degraded pointing performance due to breakpoints in hardware/software

Assess impact of higher jitter on science.

Eliminate serviceability.

Eliminates option to extend mission life.

Limit components which are serviceable.

Eliminates option to extend mission life.

Eliminate "10-year goal" for consumables (propellant).

Eliminates option to extend mission life.