WFIRST-AFTA
Overview & Technology needs summary
Mirror Technology Conference 2015

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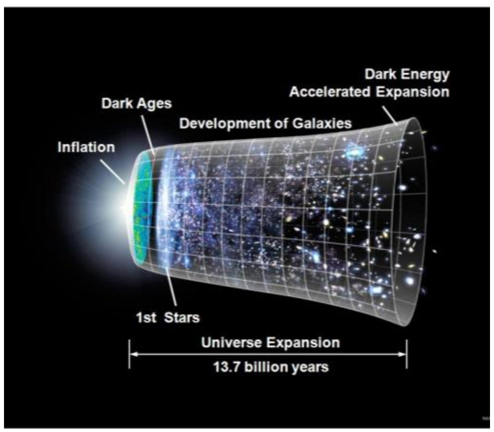
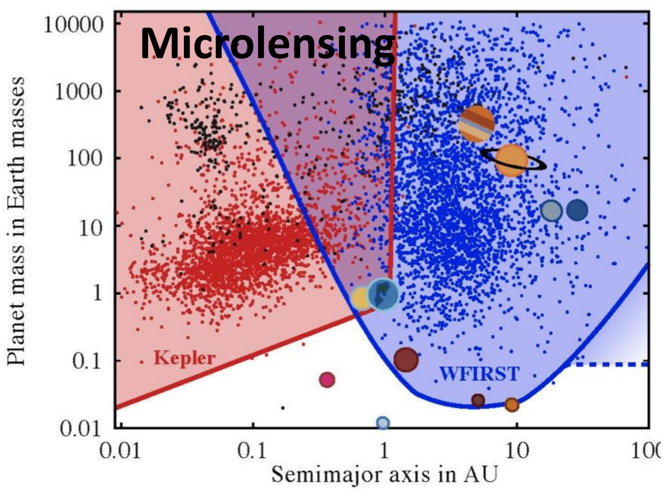
Discovery Science

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

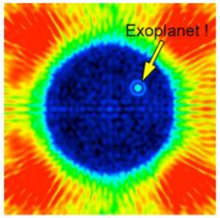
Dark Energy



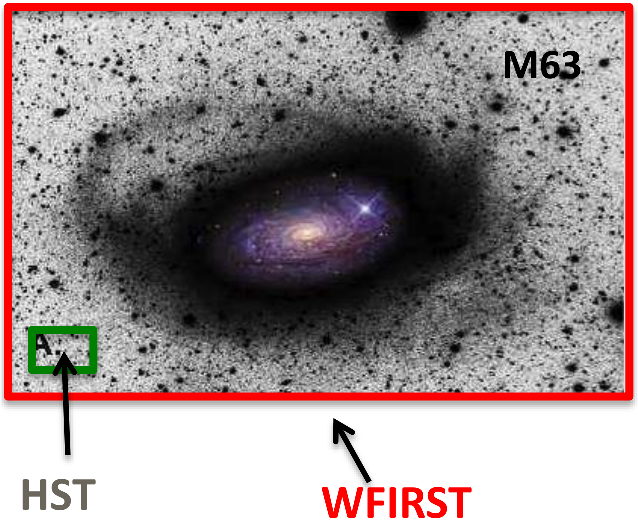
Exoplanets



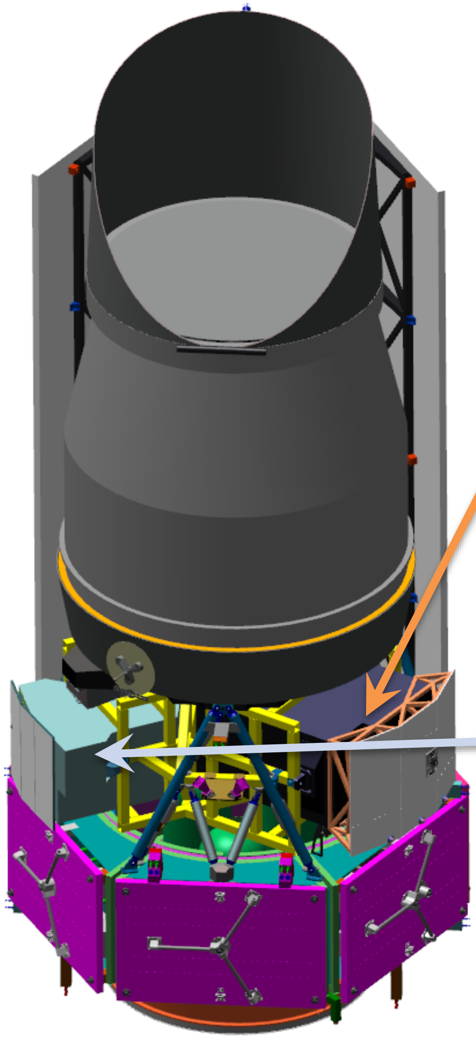
Coronagraph



Astrophysics



WFIRST Instruments



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.), 0.42-2.0 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

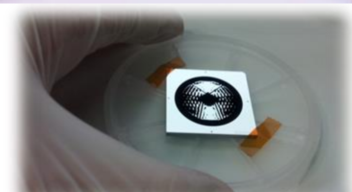
Coronagraph

- *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

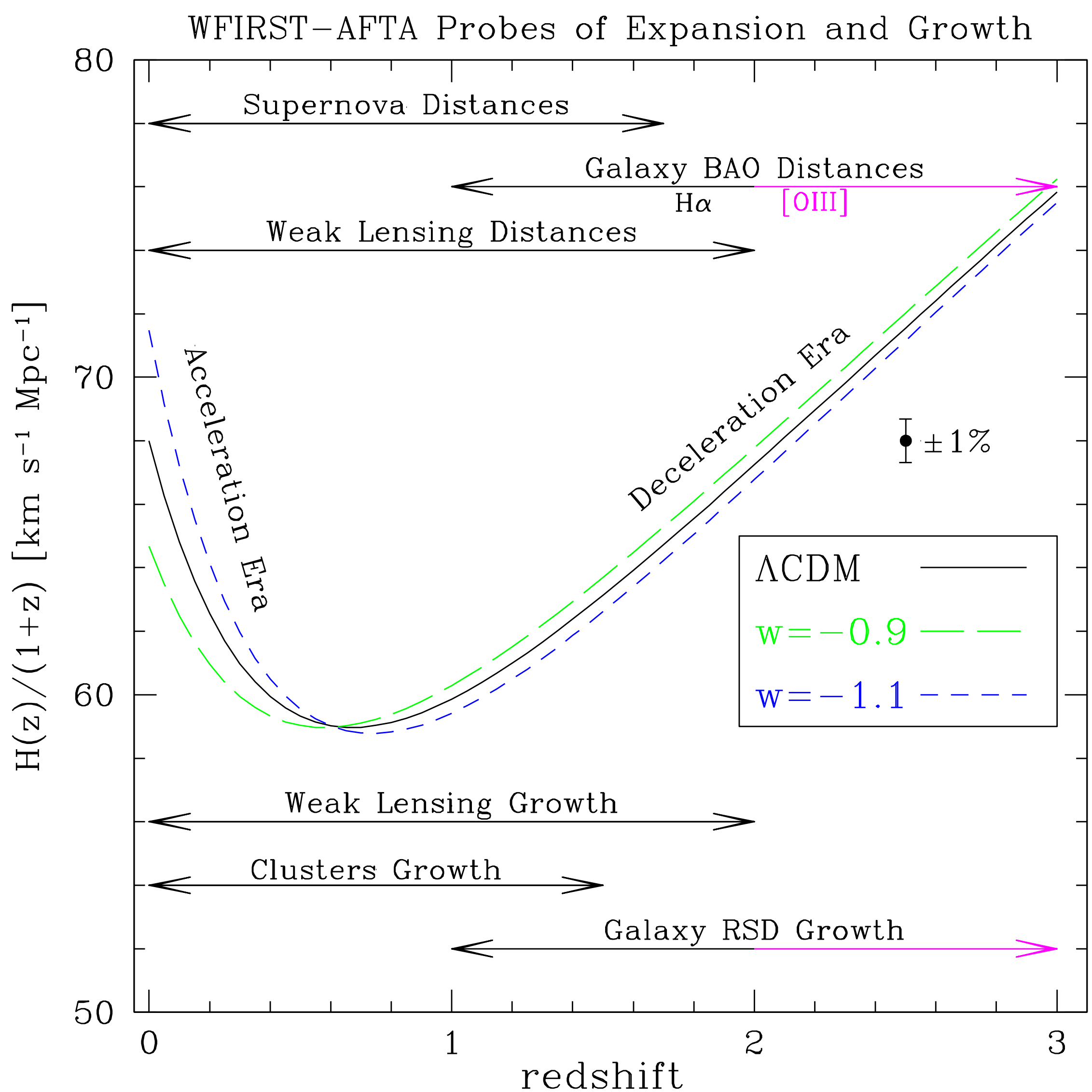
- Huge progress on WFIRST over the past two years
- SDT studies & NRC Harrison committee report confirm that WFIRST-AFTA exceeds NWNH requirements in all areas.
- $107M in FY14 & 15 has enabled major steps forward and NRC-Harrison committee recommendations have been addressed (H4RGs, coronagraph, mission 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



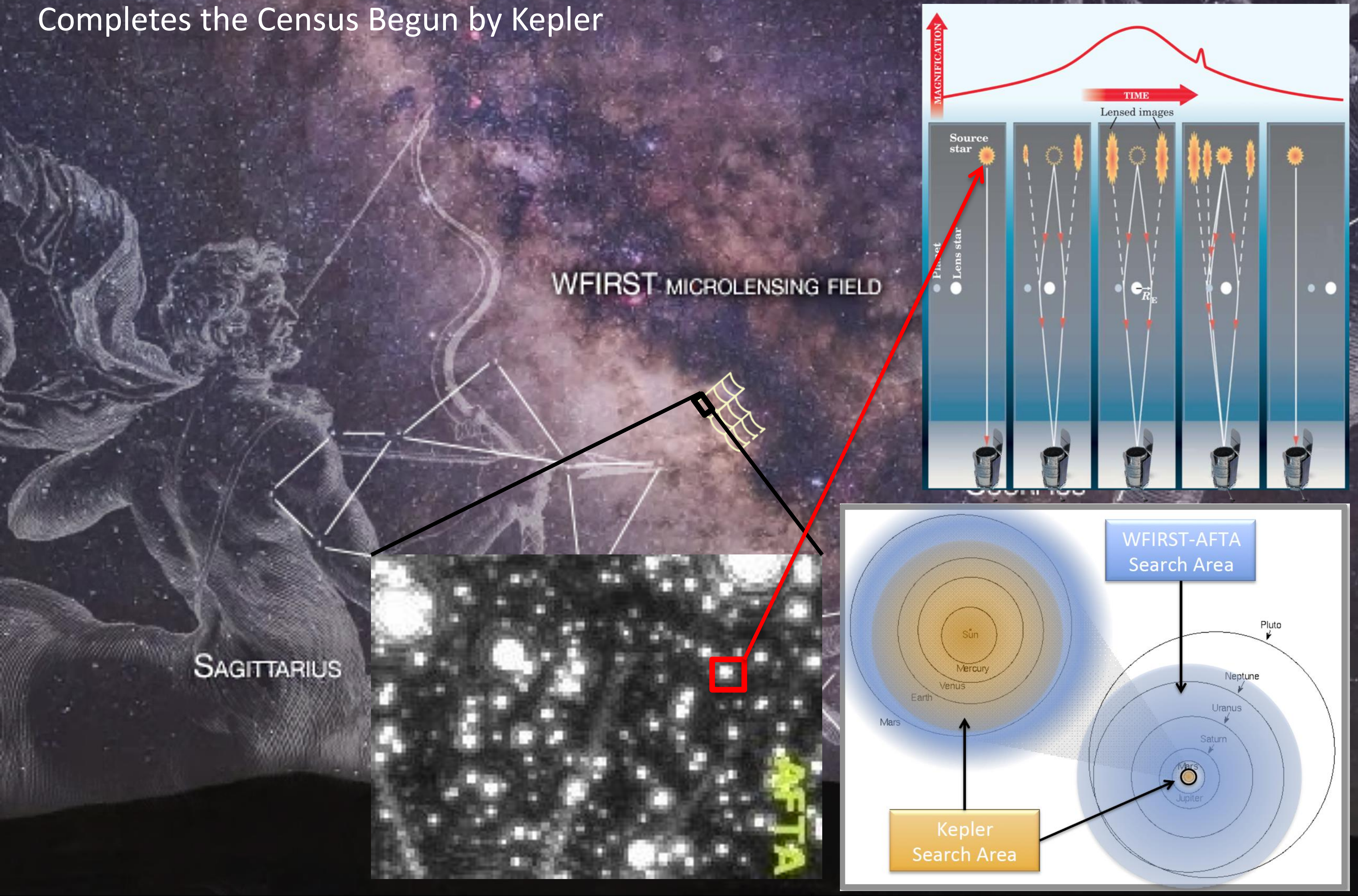
Shaped-Pupil Coronagraph Mask

WFIRST Dark Energy Program

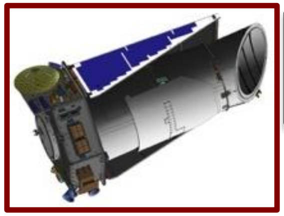


WFIRST Microlensing for Exoplanets

Completes the Census Begun by Kepler

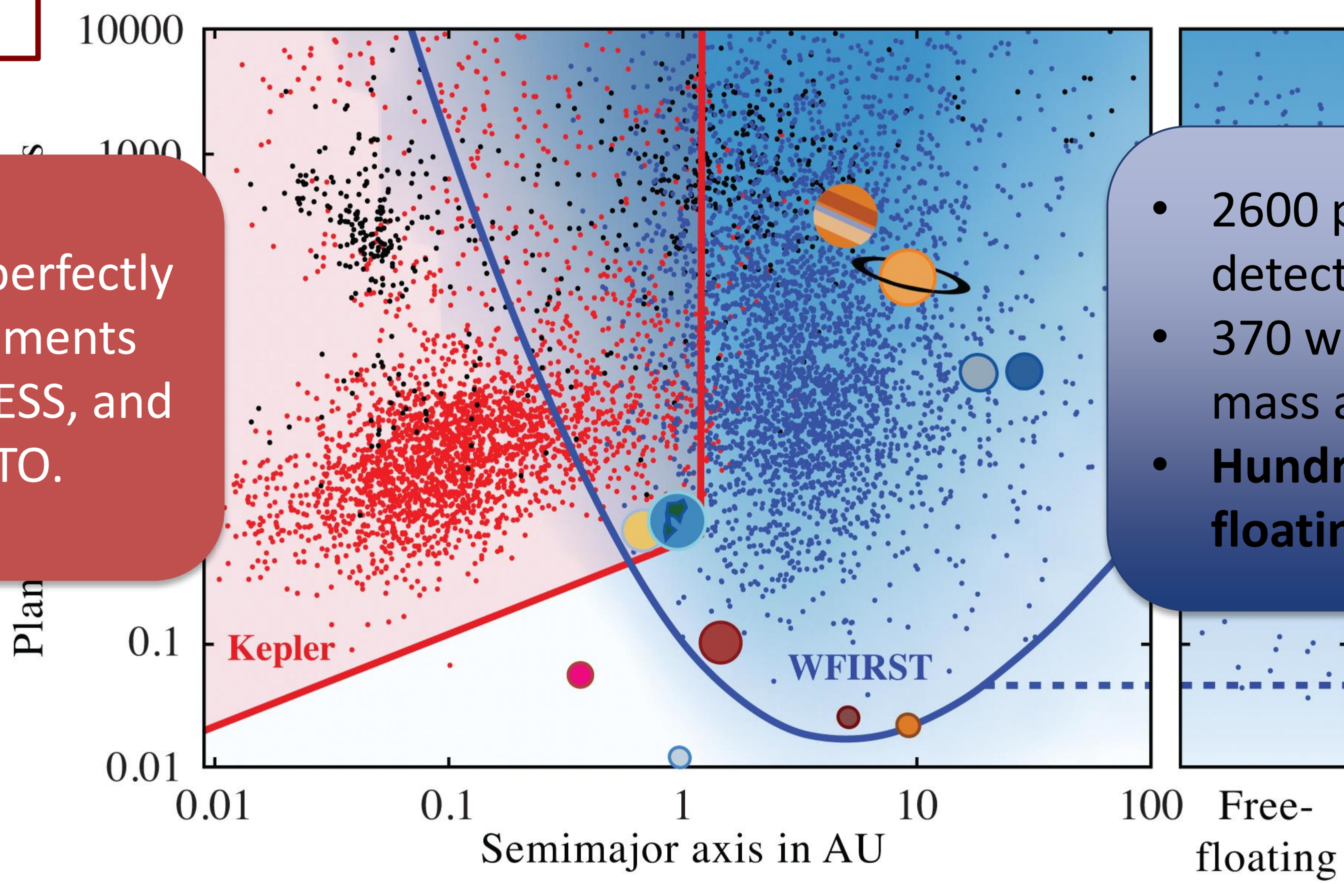


Completing the Statistical Census of Exoplanets



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

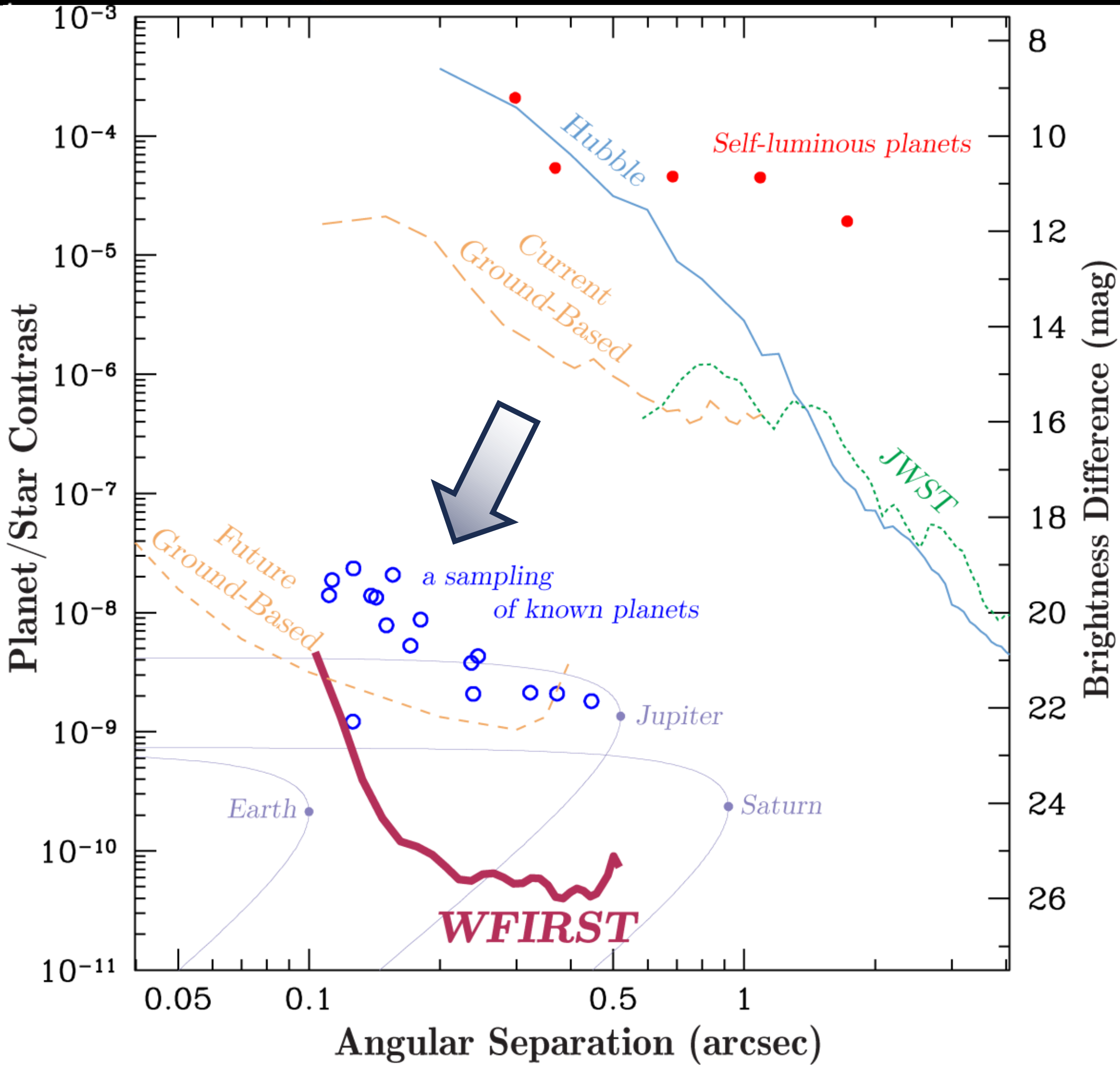
WFIRST perfectly complements Kepler, TESS, and PLATO.



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

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

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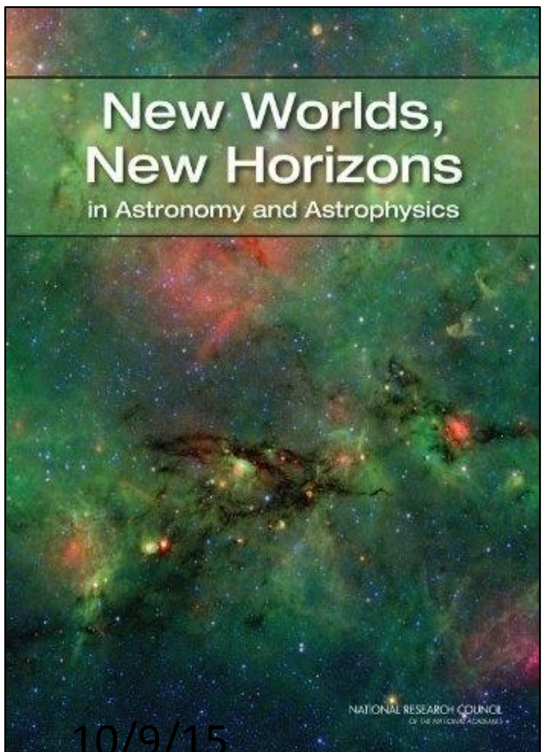
#1 Large-Scale Priority - Dark Energy, Exoplanets
#1 Medium-Scale Priority - New Worlds Tech. Development
(prepare for 2020s planet imaging mission)

WFIRST covers many other NWNH science goals



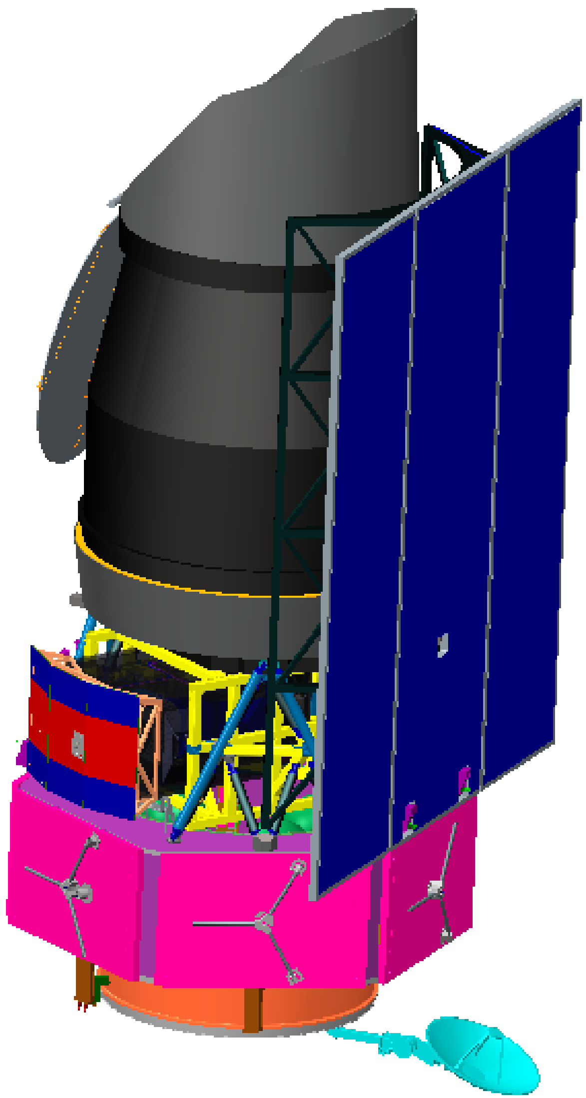
5 Discovery Science Areas

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)**

WFIRST-AFTA Observatory Concept



Key Features

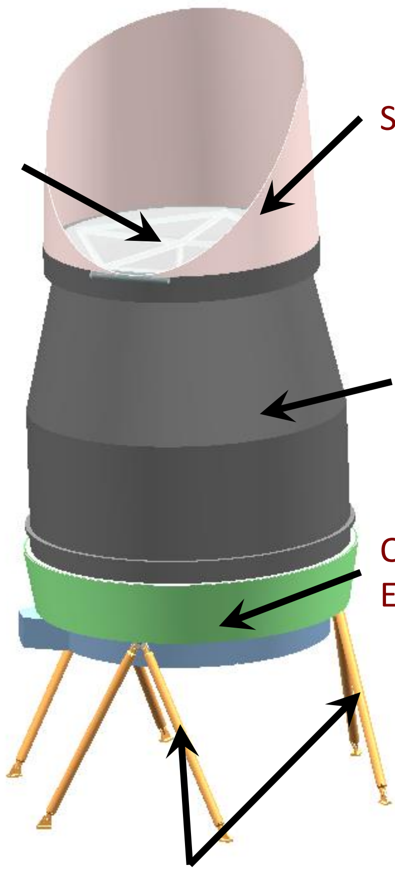
- **Telescope**: 2.4m aperture primary
- **Instruments**
  - Wide Field Imager/Spectrometer & Integral Field Unit
  - Internal Coronagraph with Integral Field Spectrometer
- **Max Data Downlink Rate**: 275 Mbps downlink
- **Data Volume**: 11 Tb/day
- **Orbit**: Sun-Earth L2
- **Launch Vehicle**: Delta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

Telescope Overview

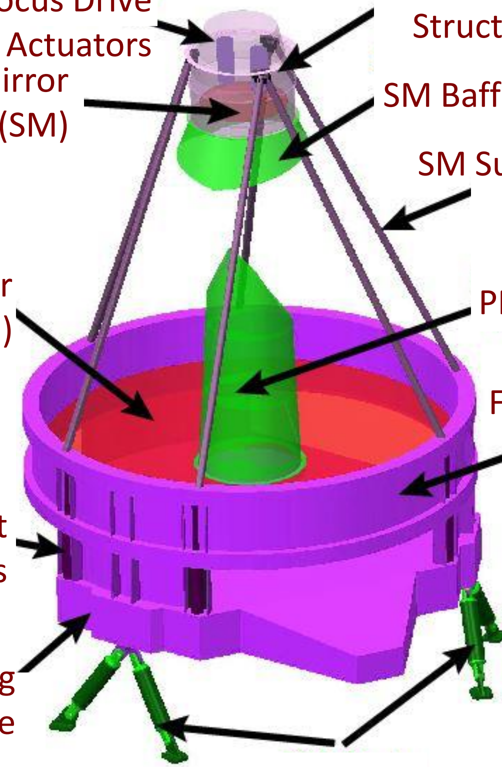
- 2.4 m, two-mirror telescope provided to NASA. Built by Harris (Kodak/ITT/Exelis).
  - Ultra Low Expansion (ULE®) glass mirrors
  - All composite structure
  - Secondary mirror actuators provide 6 degree of freedom control
  - Additional secondary mirror fine focus actuator
  - Active thermal control 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

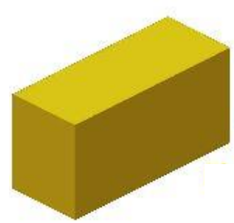
Telescope Assembly

Outer Barrel Assembly (OBA)



Forward Optics Assembly (FOA)

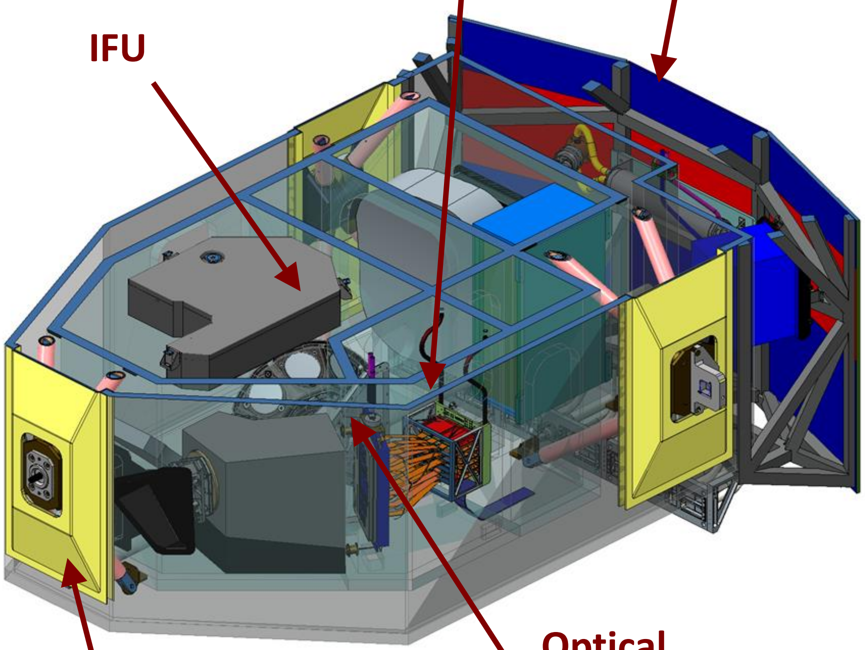




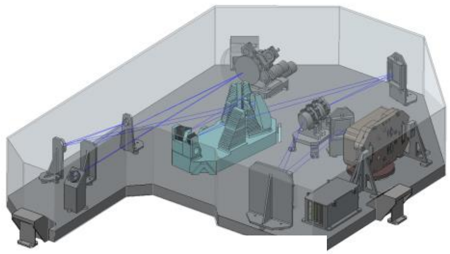
Wide Field Instrument

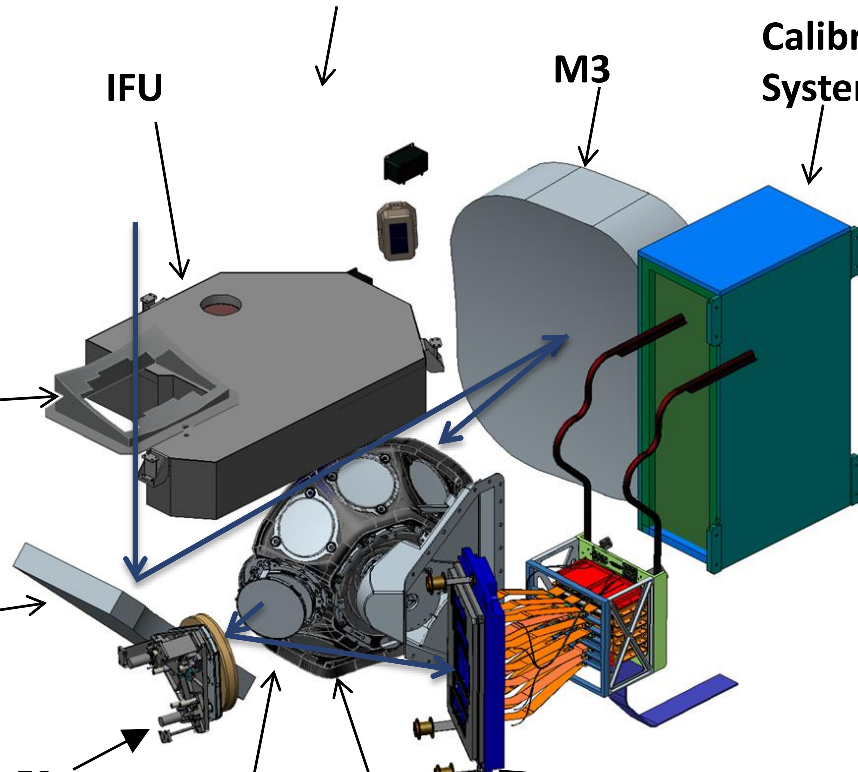
Key Features

- 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 = 461λ (~620 – 870)
- IFU channel for SNe spectra, split over two 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

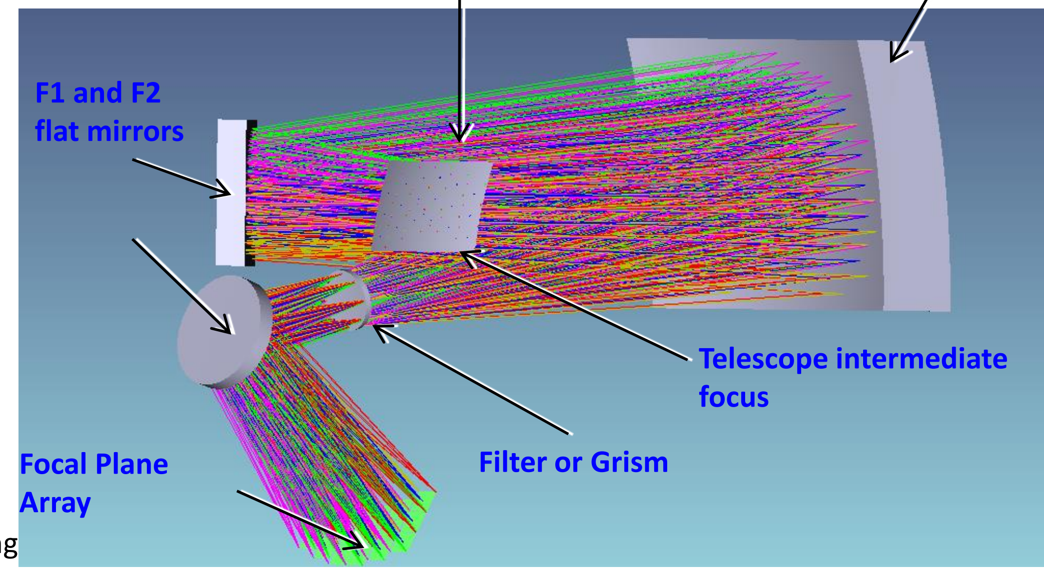


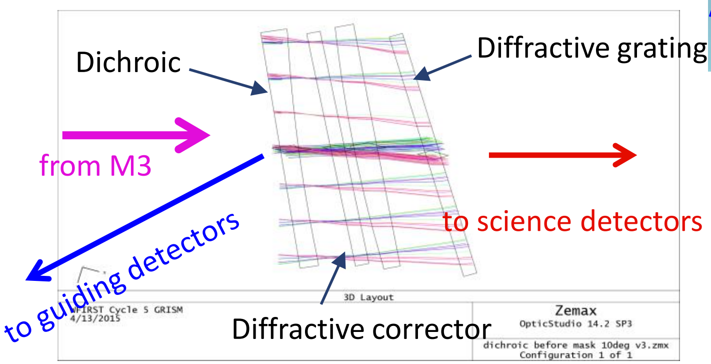


Element wheel includes bandpass filters and a wide field grism; see coatings talk by M. Quijada

Wide Field Channel

- **Driving Requirements**
  - Active field of view ≥0.25 deg2
  - Sampling ≤0.11 arcsec/(10 µm) pixel
  - 6 specified parfocal imaging filters from 0.7-2.0 µm
  - Slitless spectroscopy with spectral resolution between 645-900 over 1.35-1.89 µm
  - Illuminate auxiliary guide detector

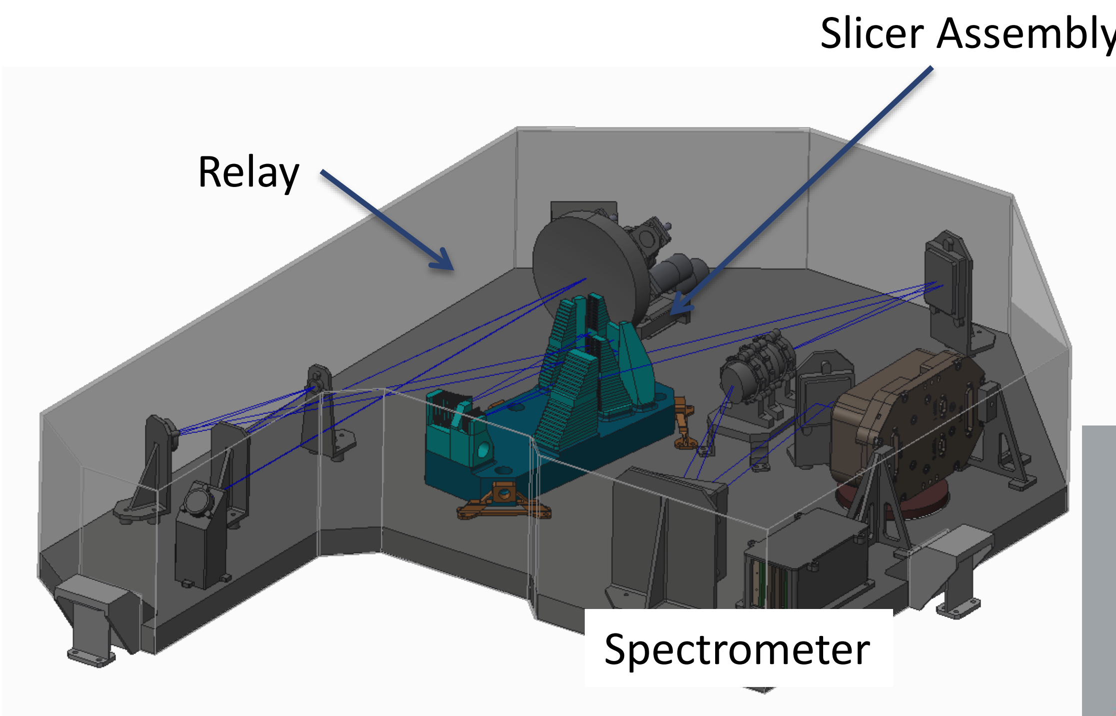


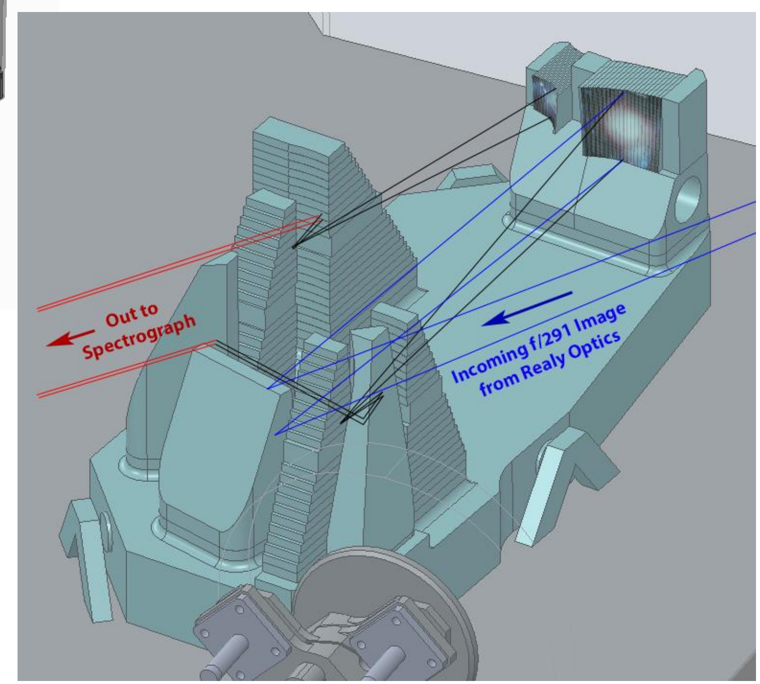


4-Element Grism with Cold Pupil Mask

Element 1: dichroic
Element 2: pupil mask
Element 3: diffractive aberration corrector
Element 4:prism to make grism zero deviation
Element 5: grating to provide dispersion

Integral Field Unit



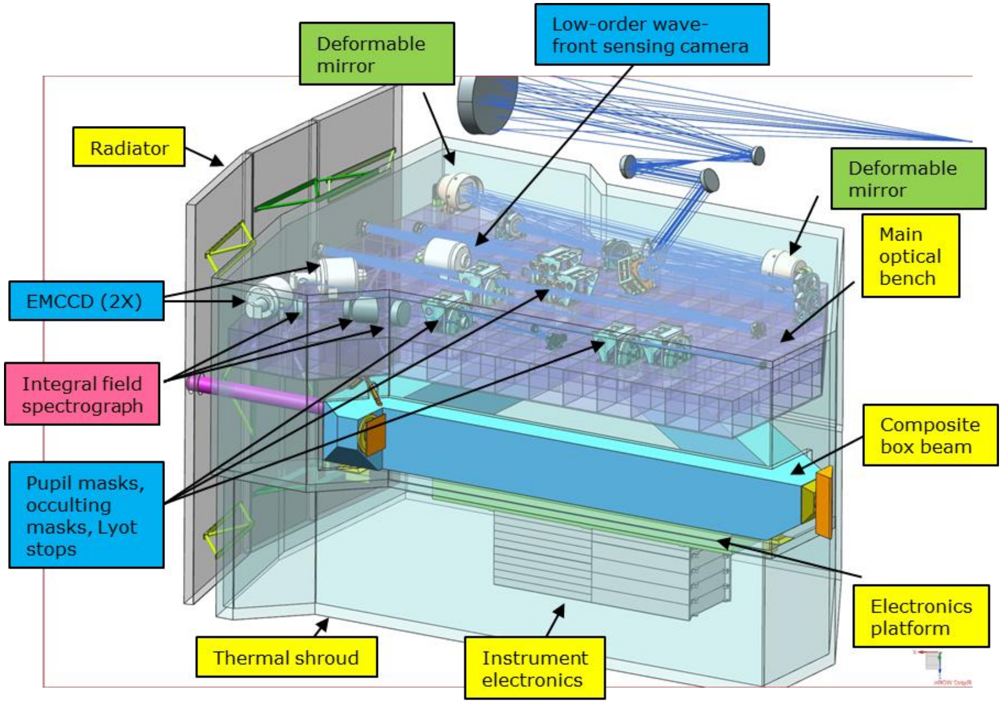


Slicer Assembly Close-Up

- **Driving Requirements**
  - Two fields of view (≥9 arcsec2, ≤0.075 arcsec/(18 µm) pixel; ≥36 arcsec2, ≤0.15 arcsec/(18 µm) pixel)
  - Spectral resolution of ~100 over 0.6-2.0 µm

Coronagraph Instrument – see also talk by R. Demers

- 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 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)



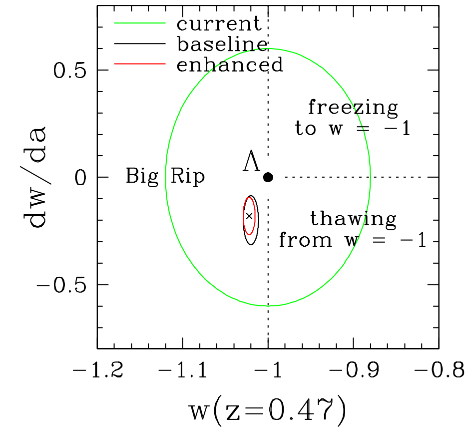
Bandpass	430 – 970 nm	Measured sequentially in 10% and 18% bands
Inner Working Angle [radial]	100 mas	at 550nm, 2λ/D driven by WFIRST-AFTA pupil obscurations
	270 mas	at 1µm
Outer Working Angle [radial]	0.5 as	at 550nm, 10λ/D, driven by 48×48 format DM
	0.9 as	at 1µm (imaging camera)
Detection Limit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

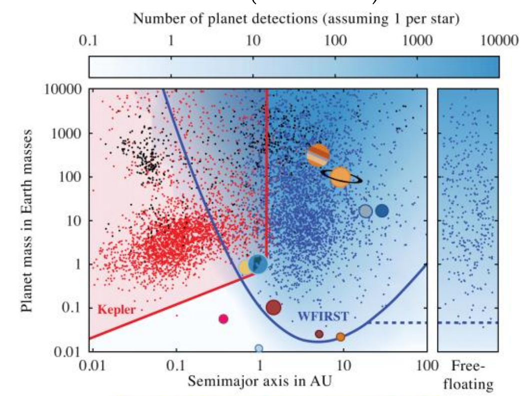
WFIRST technology overview

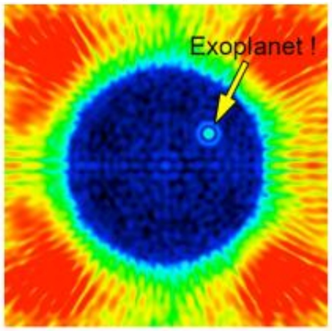
- Technology needs in 2 areas
  - Coronagraph technology: deformable mirrors, exquisite diffraction control using masks & stops, and very low noise Si detectors
    - See R. Demers talk for details
  - Wide field instrument, NIR detector technology
    - Progressing steadily towards TRL6
- WFI has significant engineering challenges also:
  - Lightweight cold M3 (tertiary mirror, 170K, ~0.6m)
  - Cold filters, grisms, large fold mirrors
  - Integral field unit – image slicer
  - Cold precision composite structures
- CGI has small but high precision optics also, few nm rms wavefront error class

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 High contrast imaging tested (HCIT) and GSFC's Detector characterization Lab (DCL).
- Great progress made in pre-formulation, ready for KDP-A and launch in mid-2020s.







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Backup slides

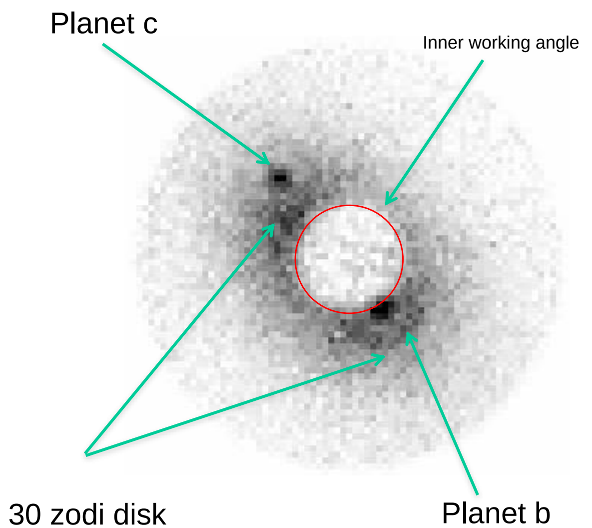
#3

Telescope Reuse Approach

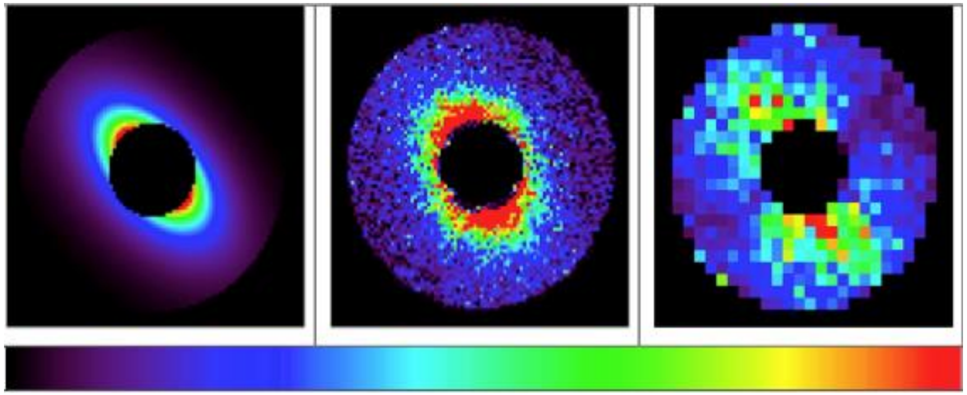
- JPL and the Study Office have worked closely with Harris to understand the telescope hardware.
  - The Observatory design provides an instrument carrier as the prime optical bench for the payload, supporting both the telescope and the instruments, providing substantial structural margin.
  - Set operating 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.

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.

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

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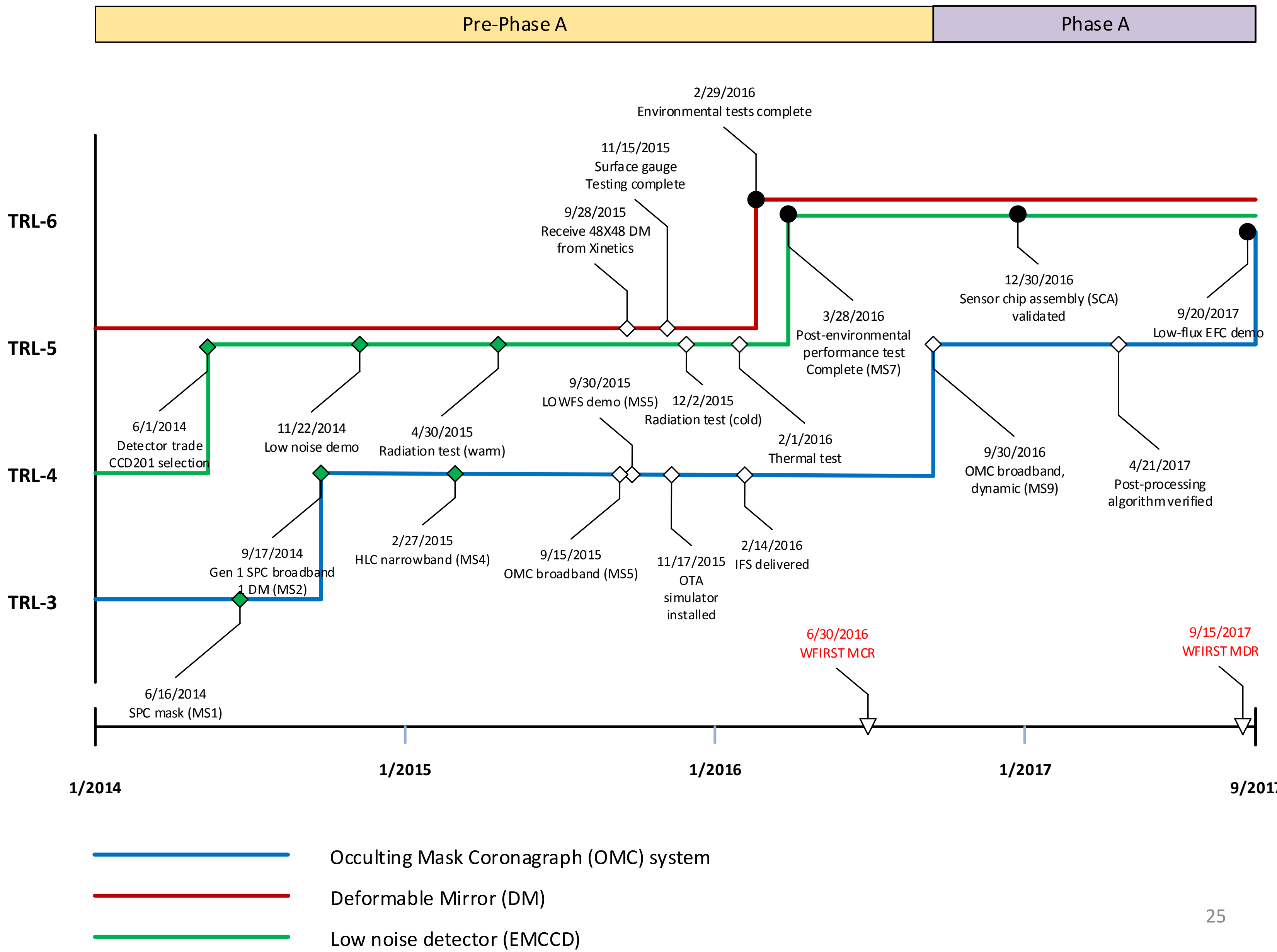
Coronagraph Technology Milestones

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 µm 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

Coronagraph TRL6 timeline



Scientific Objectives

1) Produce NIR sky images and spectra over 1000's of sq deg (J = 27AB imaging, F_line = 10^{-16} erg cm^{-2} 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.