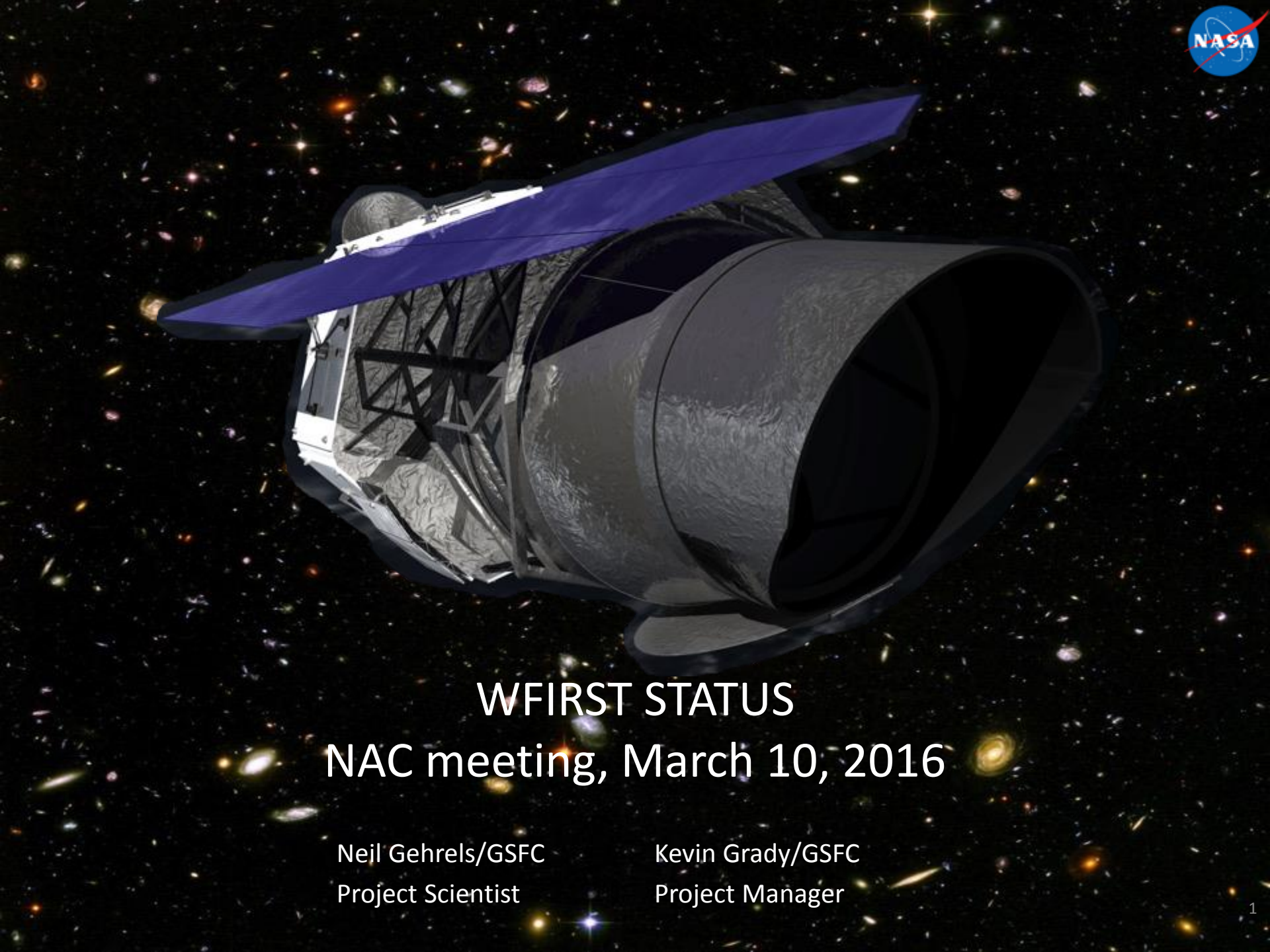


WFIRST STATUS
NAC meeting, March 10, 2016

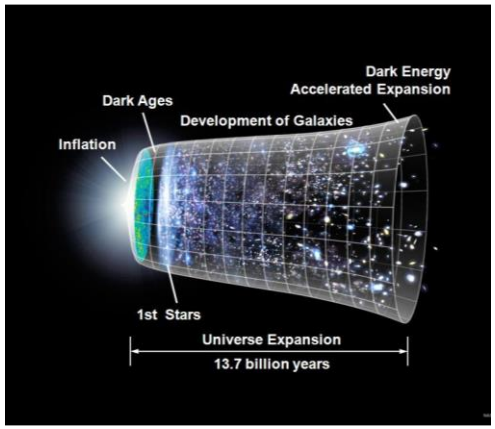
Neil Gehrels/GSFC
Project Scientist

Kevin Grady/GSFC
Project Manager

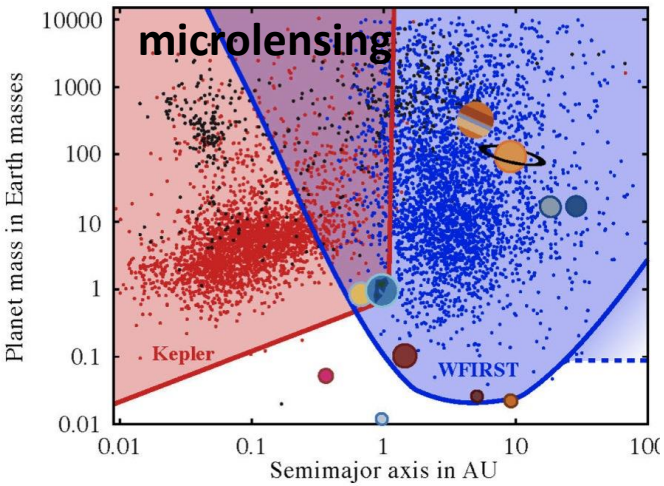
Discovery Science

- 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 a coronagraph

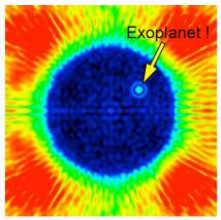
Dark Energy



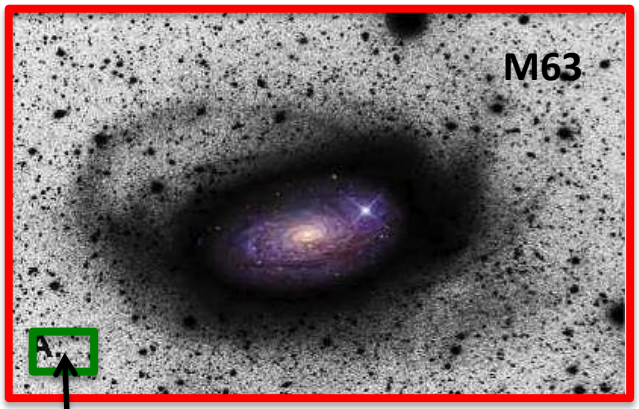
Exoplanets



coronagraph

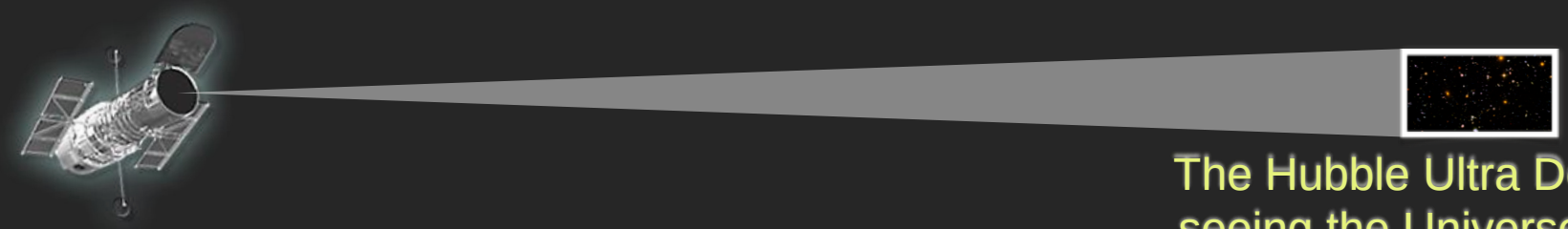


Astrophysics



HST **WFIRST**

Hubble - A Spectacular Start



The Hubble Ultra Deep Field seeing the Universe, 10,000 galaxies at a time

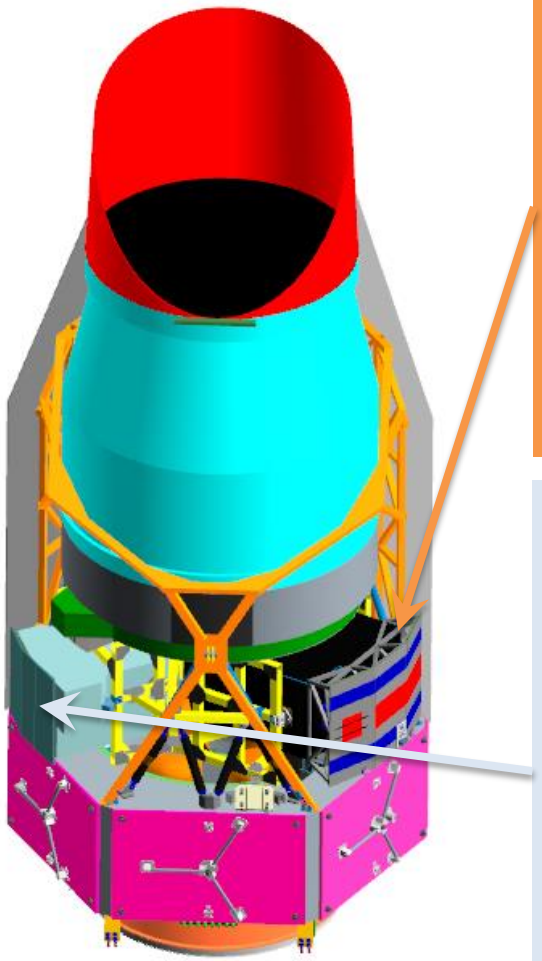
WFIRST-AFTA - Hubble X 100

An AFTA/WFIRST Deep Field
A New Window on the Universe - **1,000,000** galaxies at a time

Science Objectives

- Produce Hubble quality infrared sky images and spectra over 1000's of square degrees of sky
- 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.
- Complete the statistical census of planetary systems in the Galaxy, from the outer habitable zone to free floating planets
- Directly image giant planets and debris disks from habitable zones to beyond the ice lines and characterize their physical properties.
- 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 Instruments



Wide Field Instrument

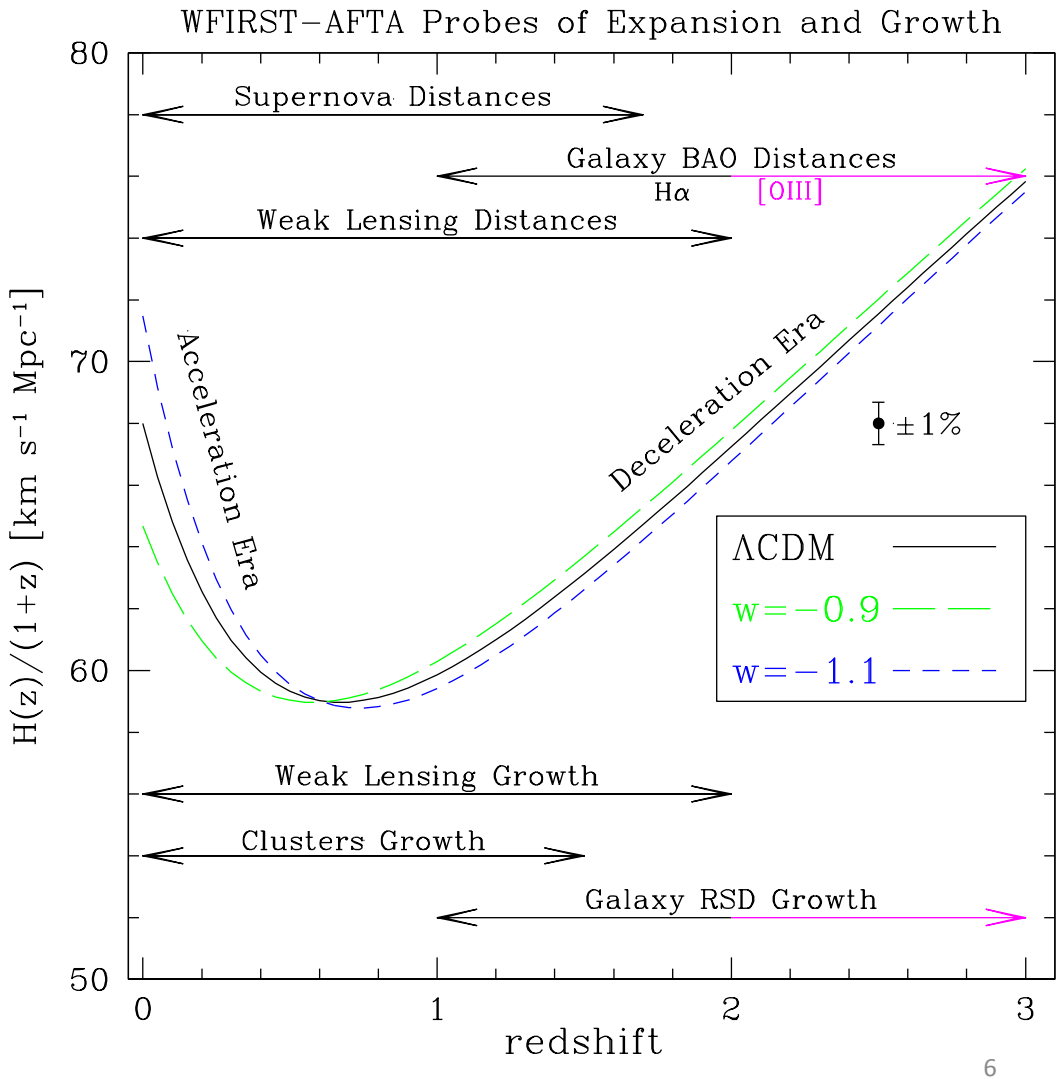
- *Imaging & spectroscopy over 1000s of sq. deg.*
- *Monitoring of SN and microlensing fields*
- Near infrared bandpass
- Field of view 100 x HST and JWST
- 18 H4RG detectors (288 Mpixels)

Coronagraph

- *Image and spectra of exoplanets from super-Earths to giants*
- *Images of debris disks*
- Visible bandpass
- Contrast of 10^{-9} or better
- Exoplanet images from 0.1 to 1.0 arcsec

Premier Dark Energy Observatory

- WFIRST combines all techniques to determine the nature of Dark Energy.
- Only observatory doing such comprehensive observations
- High precision measurements will be optimally combined for the best measurement

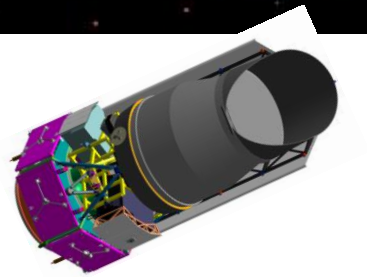


Weinberg & SDT 2015

Microlensing Exoplanet Survey

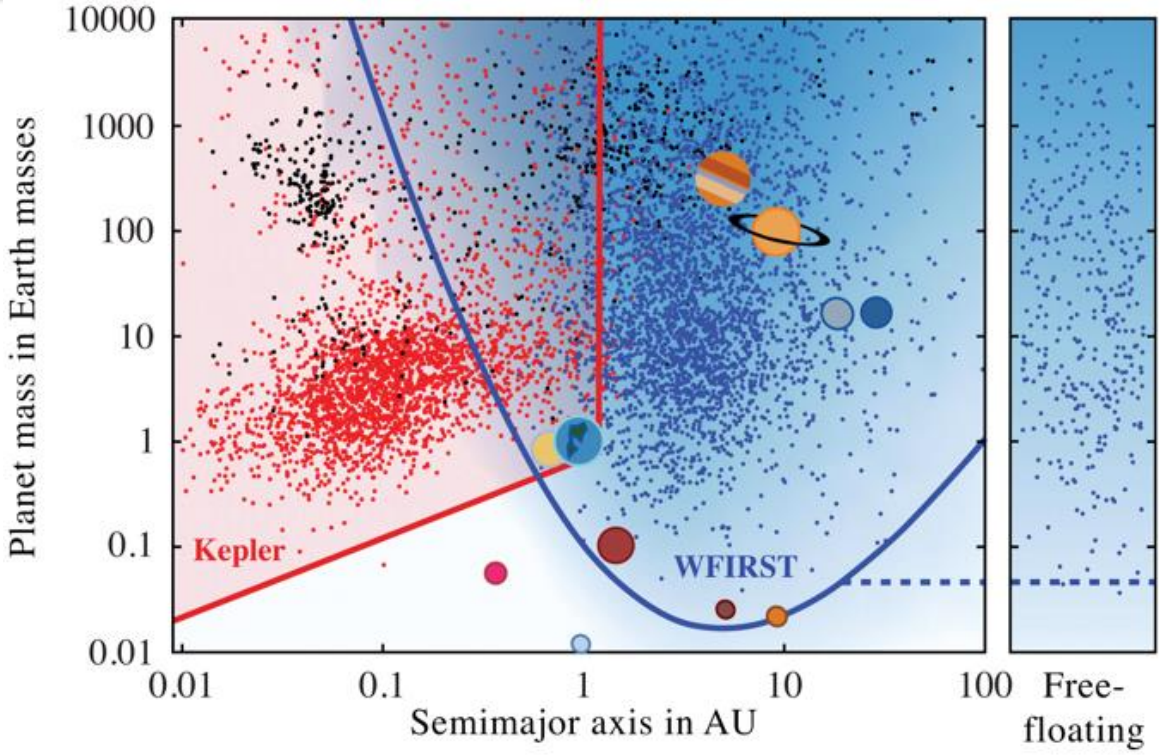
WFIRST complements Kepler, TESS, Pato

Kepler



WFIRST

- 2600 planets
- 370 Earth mass & less
- **100's free-floaters**

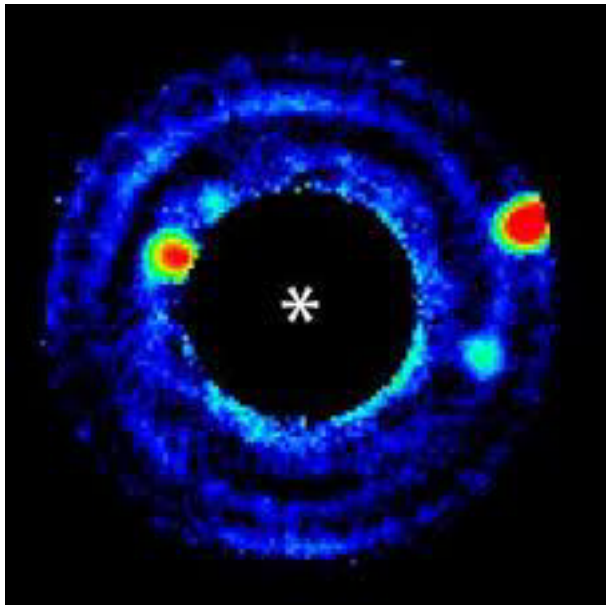


M. Perry

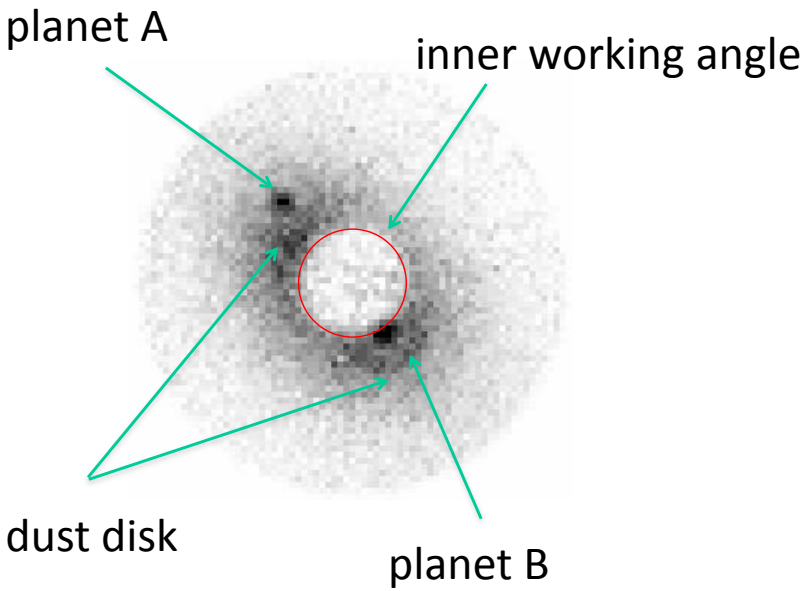
Pioneering High Contrast Exoplanet Coronagraph

- Imaging at high contrast provides for direct detection and spectroscopy (characterization) of exoplanets

Concept



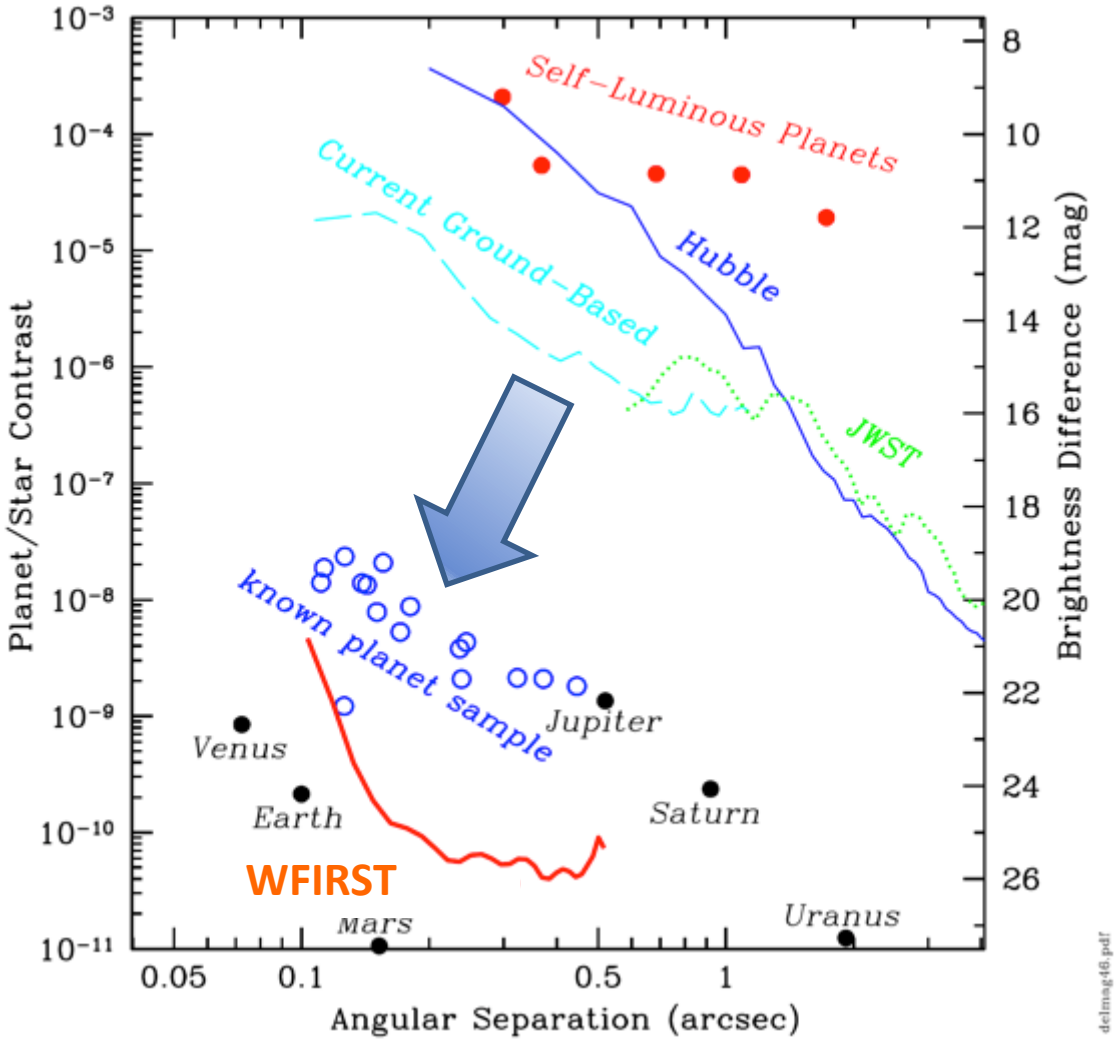
WFIRST Simulation



Greene 2015

WFIRST Brings Humanity Closer to Characterizing exo-Earths

- WFIRST advances key elements needed for a future coronagraph to image an exo-Earth
  - ✓ Coronagraph
  - ✓ Wavefront sensing & control
  - ✓ Detectors
  - ✓ Algorithms
- WFIRST performance predictions are exciting

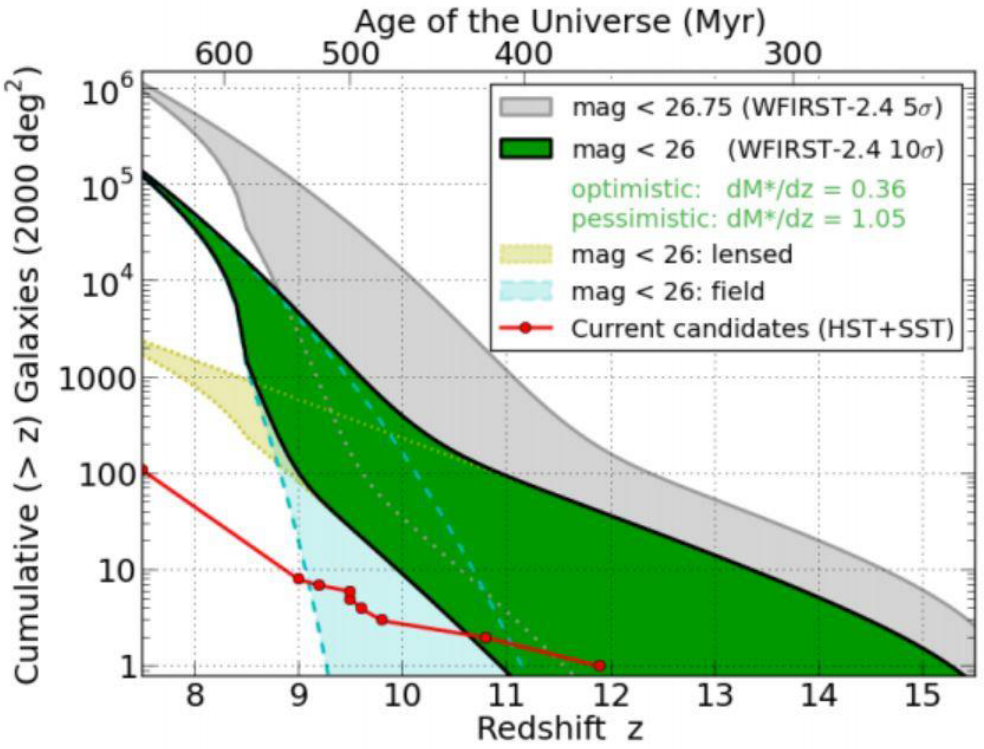


Traub & SDT 2015

Guest Observer Science

- GO Science: 25% of WFIRST observing time in first 6 years and 100% open competition in years 6+

- Example: WFIRST's HLS will yield up to 2 orders of magnitude more high redshift galaxies than currently known



Postman & Coe
SDT Report 2015

Recent Accomplishments

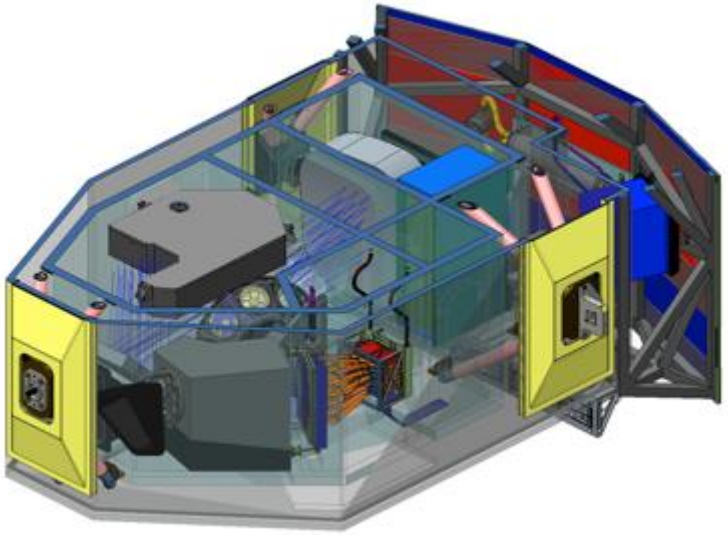
- Key Decision Point A (KDP-A) completed – February 17, 2016.
- Mission Concept Review (MCR) successfully completed in December.
- WFIRST technology (Coronagraph and IR detectors) continue to make excellent progress. All HQ milestones successfully completed.
  - A HQ chartered Technology Assessment Committee (TAC) provides for external review of technology milestones for coronagraph and IR detectors.
- President's Budget Request for FY17 has 90M from SMD and 10M from STMD. Recent augmented funding (FY14-16, 203M) has enabled significant mission progress.
  - Technology maturation.
  - Increased fidelity in the design reference.
- An industry Request For Information (RFI) was issued in July 2015 for potential participation in WFIRST. Inputs received and management briefed on results.
- Wide Field concept study RFP released January 4th. Recently awarded concept studies for the Wide Field Optical Mechanical Assembly (WOMA) to Ball and Lockheed.
- WFIRST Formulation Science Working Group and Science Investigation Teams selection made December 17, 2015. WFIRST Formulation Science Working Group (FSWG) kick-off with Project held February 2-4, 2016.

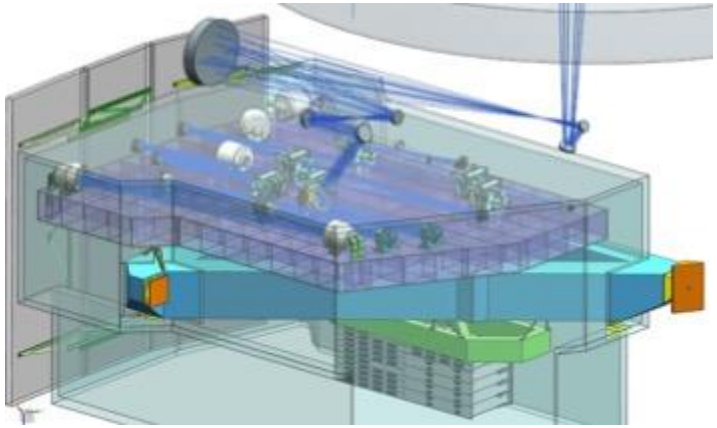
Key Programmatic Drivers
Program Level Requirements Appendix (PLRA)

- New Worlds New Horizons (NWNH) Science Objectives
  - Produce multi-band NIR sky survey: expansion history, growth of structure, planetary systems statistical census and robust Guest Observer program
- Mature exoplanet direct imaging technologies – demonstrate new internal starlight suppression techniques
  - Image and characterize giant planets and debris disks
- WFIRST is Category 1 project – Agency Program Management Council (APMC)
- Utilization of existing 2.4m aperture telescope.
- Two instruments: Wide Field and Coronagraph instruments.
- WFIRST designated Class B mission (NPR 8705.4); Coronagraph technology demonstration is designated as Class C.
- L2 orbit (current baseline) launched from Eastern Test Range (ETR).
- 6 ¼ year mission life.
- Modular spacecraft and instrument design to facilitate robotic servicing.
- Potential international partner contributions are under discussion.
- WFIRST part of Exoplanet Exploration Program (ExEP).

WFIRST Instruments

- Wide Field Instrument (WFI) - GSFC
  - Provides wide field imaging and spectroscopy in support of the dark energy surveys and the microlensing survey.
  - Provides integral field spectroscopy in support of the supernova survey and weak lensing photometric redshift calibrations.
  - Provides guide star data for observatory fine pointing.
- Coronagraph Instrument (CGI) - JPL
  - Provides high contrast imaging and integral field spectroscopy in support of exoplanet and debris disk science.





WFIRST KDP-A Budget Estimates

- WFIRST mission life-cycle cost was updated for MCR design configuration and the Key Decision Point A (KDP-A) milestone.
- The current WFIRST budget guidelines are constrained in FY18-20. As a result, the Project is working two development schedule profiles – an overguide 2024 launch date and an in-guide 2025 launch date.
- Mission cost was updated for the following:
  - increased launch vehicle costs,
  - increased science team funding (including number of teams selected),
  - design maturation (L2 changes & maturing design),
  - extended Phase A (KDP-A accelerated),
  - telescope outer barrel assembly configuration changes and
  - funding for Wide Field industry studies.
- The Project's life-cycle estimate over the range of launch vehicles and launch dates is 2.3–2.7B in FY15$. That equates to 2.7B to 3.2B in RY$.
- Budget includes STMD funding in FY16/17 for the coronagraph technology. STMD is considering funding portion of coronagraph flight development.
- International contributions – discussions in process for potential contributions from Europe/ESA, Canada and Japan. Contributions include elements of Wide Field instrument, Coronagraph and ground system.

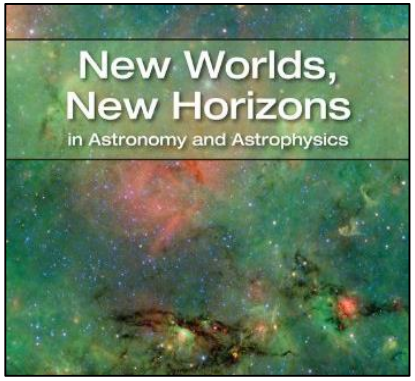
WFIRST Summary

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

Hits 5/6 NASA Strategic Goals

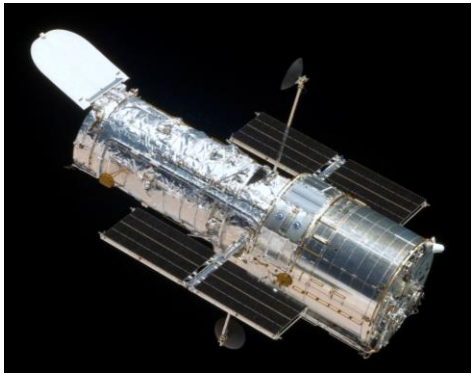
Addresses all 3 APS performance goals

#1 Priority of Astro Decadal Survey

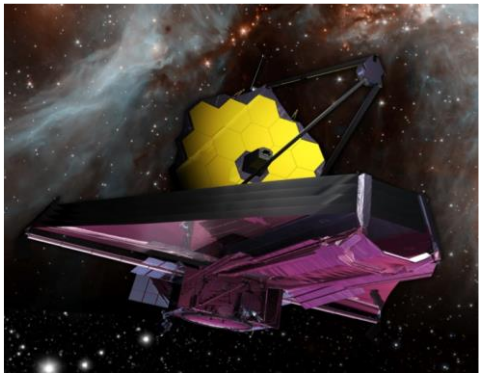


Brings the Universe to STEM education

Foundation for discovering Earth-like planets



Hubble's clarity over 10% of the sky



Complements and enhances JWST science

Questions from Jim Green

WFIRST Questions – NAC Science Committee Member Jim Green, U. Colorado

- 1: At what temperature will the primary mirror operate, and what effective long wavelength limit does this impose on the observations? (I am assuming that the NRO will be warmer than the DRM1 or DRM2 baseline.) What science is lost? If no science is lost, why were we cooling the original mirrors?

- 2: Can we get a presentation on the predicted PSF of the NRO telescope as will be seen in the weak lensing surveys? Presumably this is based on analysis, which I presume was performed by Chris Hirata. (Correct me if I am wrong.) How does it compare to the PSF of the pre-NRO telescope? Has the analysis of the PSF and its impact on weak lensing science been independently verified by anyone else's analysis? Is there a plan to verify the PSF through end-to-end testing on the ground?

- 3: I would like to see a real presentation of the coronagraph results: actual data and images rather than a simple quote of the contrast ratio. I would like to see a schematic of the test configuration and the current flight design to understand the validity of scaling the results. Has anyone measured the scattered light performance of the NRO telescope surfaces (and compared it to the optics used in the test setup).

- 4: Now that the ground based red-shift surveys and the EUCLID capabilities are reasonably well defined, can you summarize briefly the unique contributions that WFISRT will make to the dark energy science? We agonized over this on SDT1, but no one seems to talk about anymore. I assume that means there is a clean, simple answer.

Questions from Jim Green

- Comprehensive answers were provided separately to Dr. Green and discussed in a telecon with him. Here is a short summary
- 1: Temperature of mirrors. Science lost
  - Mirror temp = 284K, red limit = 2 microns
  - Modest loss of science compared to colder mirror and 2.4 micron limit in Green-Schechter SDT, mainly for GO science per Hirata report
  - NWNH science is fully accomplished with current baseline
- 2: PSF of the NRO telescope as seen for WL surveys compared to the PSF of the pre-NRO telescope.
  - PSF is more complex than for off-axis telescope in Green-Schechter SDT report
  - For weak lensing, the smaller size of the current PSF more than makes up for the complex shape
- 3: Coronagraph results: actual data and images. Schematic of the test configuration and the current flight. Scattered light performance of the NRO telescope surfaces.
  - Coronagraph testbed results and current schematic have been provided separately
  - Scattered list performance not yet measured. Modeled performance meets requirements with expected surface roughness and contamination
- 4: Unique contributions WFISRT dark energy science?
  - WFIRST will provide deep observations for dark energy science that are complementary to Euclid
  - WFIRST is the only observatory with a comprehensive SN Ia program
  - WFIRST multi-filter IR measurement of weak lensing shapes are expected to be superior to Euclid's single filter optical measurement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DARK ENERGY • EXOPLANETS • ASTROPHYSICS

Back-up

Formulation Science Working Group

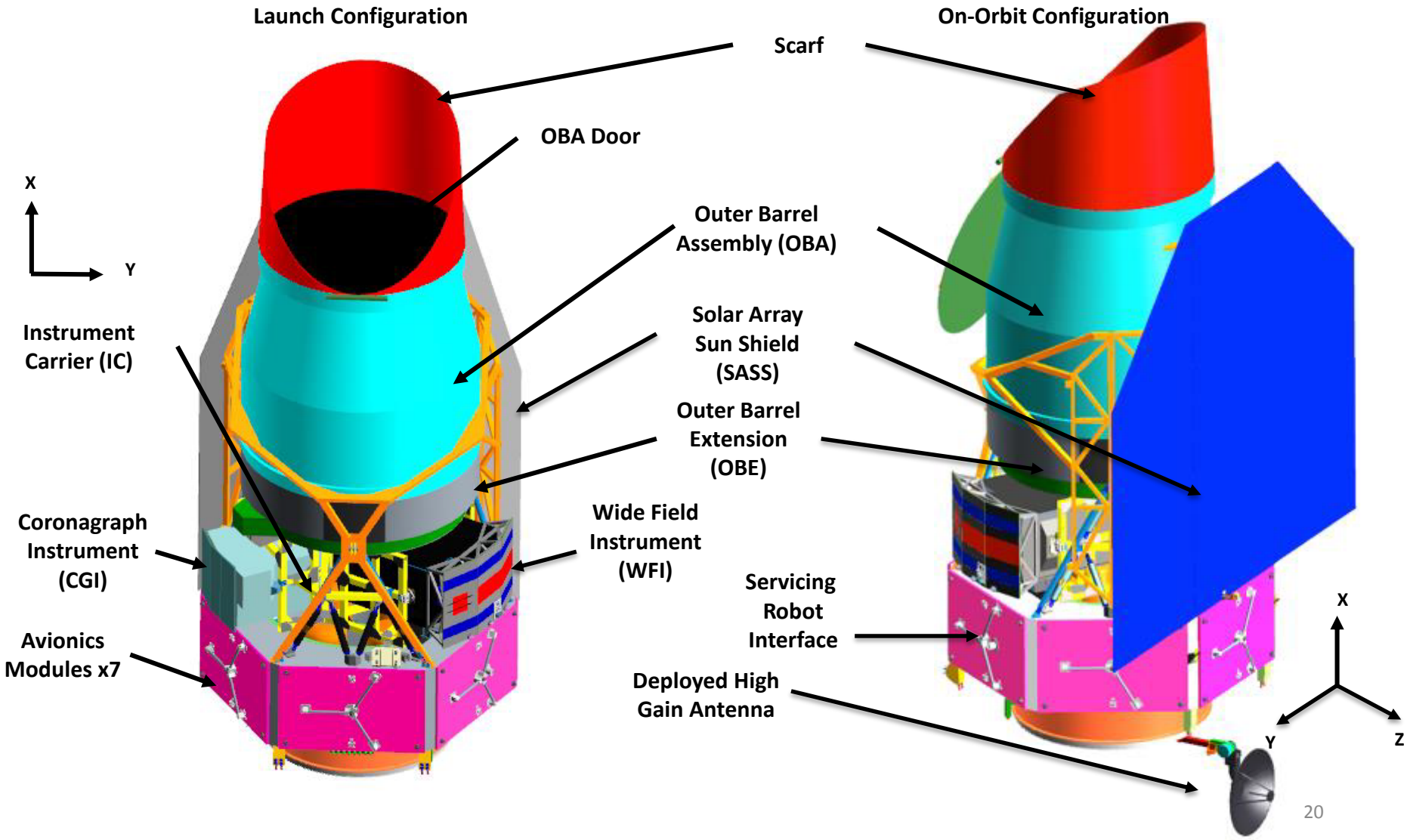
- Formulation Science Working Group (FSWG) is the science executive committee of WFIRST
- Membership (25 members)
- Project Scientist Chair, Adjutant Scientists Co-Chairs
- PIs and some Deputy PIs from Science Investigation Teams
- Program Scientist (ex-officio) Benford
- GSFC and JPL Deputy Project Scientists (ex-officio) Kruk, Rhodes, Traub
- Science Center Leads (ex-officio) Carpenter, Cutri, van der Marel

Science Investigation Team PIs

David Spergel	WFI Adjutant Scientist
Jeremy Kasdin	CGI Adjutant Scientist
Olivier Doré	Weak lensing and galaxy redshift survey
Saul Perlmutter	Supernovae
Ryan Foley	Supernovae
Scott Gaudi	Microlensing
Bruce Macintosh	Coronagraphy
Margaret Turnbull	Coronagraphy
Jason Kalirai	GO science, Milky Way
James Rhoads	GO science, cosmic dawn
Brant Robertson	GO science, galaxy formation & evolution
Alexander Szalay	GI science, archival research
Benjamin Williams	GO science, nearby galaxies

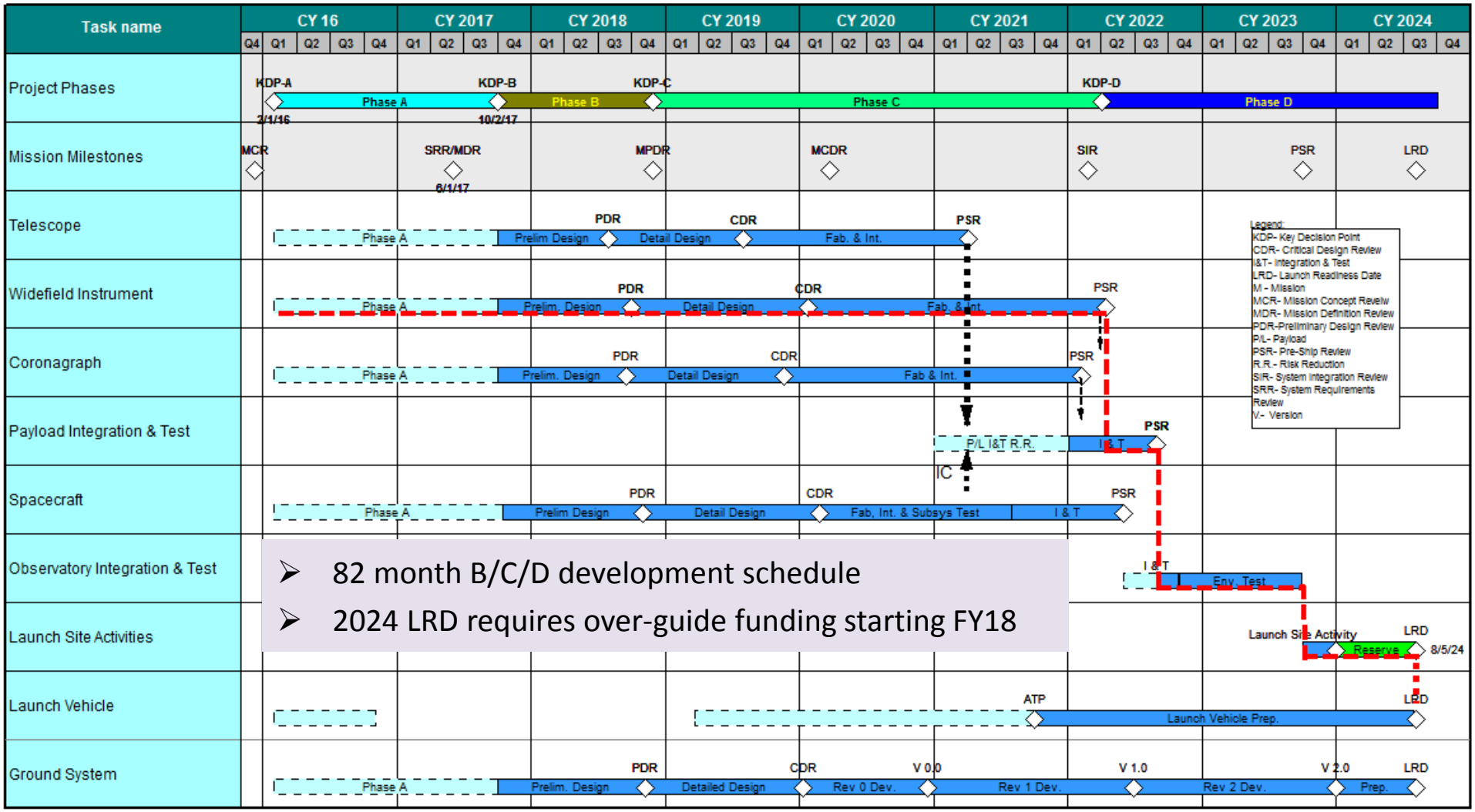
WFIRST
WIDE-FIELD INFRARED SURVEY TELESCOPE
DARK ENERGY • EXOPLANETS • ASTROPHYSICS

Observatory Configuration



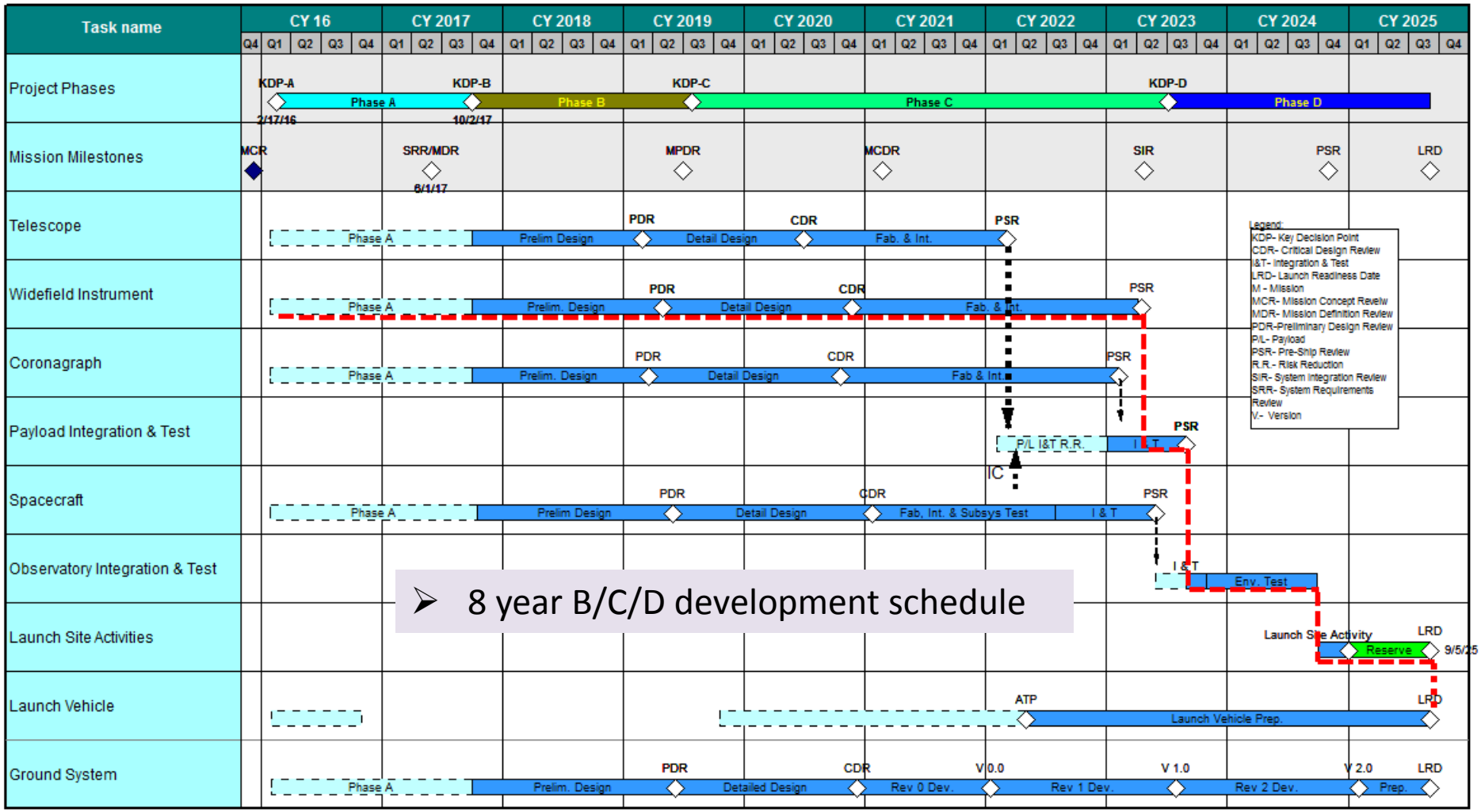
Mission Schedule – 2024 LRD Overguide Schedule

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



- 82 month B/C/D development schedule
- 2024 LRD requires over-guide funding starting FY18

Mission Schedule – 2025 LRD In-Guide Schedule



- 8 year B/C/D development schedule

WFIRST History (1 of 2)

- **Sept 2008 – August 2010:** Joint Dark Energy Mission (JDEM) Project established at GSFC. Multiple InfraRed (IR) survey configurations studied with interim science working groups appointed by HQ.
- **June 2009:** Omega configuration developed and white paper submitted to Decadal Survey.
- **August 2010:** New Worlds New Horizons (NWNH) identifies WFIRST as #1 large astrophysics mission priority for the decade. JDEM Omega configuration identified as reference.
  - Expansion history of Universe/growth of structure
  - Perform planetary systems statistical census
  - Survey of NIR sky
  - Guest observer program
- **Nov 2010 – Aug 2012:** Science Definition Team (SDT – Schechter & Green) and WFIRST Study Office developed Interim Design Reference Mission (IDRM), a 1.3m aperture off-axis design. Final Report Aug 2012. 2 Cost And Technical Evaluation (CATEs) performed.

WFIRST History (2 of 2)

- **Oct 2012 – Mar 2015:** A new Science Definition Team (SDT – Spergel & Gehrels) and the WFIRST Study Office developed a design reference mission utilizing the existing 2.4m telescope transferred to NASA. May 2013 and April 2014 Interim Report, March 2015 Final Report. 2 CATEs performed.
- **July 2013 – Dec 2013:** AFTA (WFIRST) Coronagraph Working Group (ACWG) recommends a coronagraph architecture for the potential coronagraph that would fly on the WFIRST mission. Science community/ExEP/WFIRST Study Office.
- **March 2014:** NASA requested a review of the larger aperture WFIRST mission concept in late 2013 and the NRC Committee Report (Harrison Committee) concluded, *"2.4m mirror will significantly enhance the scientific power of the mission." "Responsive to all NWNH scientific goals."*

Multiple independent cost and technical assessments of IR survey Design Reference Missions have been performed by Aerospace Corp. over the past seven years, each time validating the Study Office's estimate (10-15%), development schedule and technical approach/risk.