

# WFIRST KDP-A/APMC Science Overview

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Project Scientist

January 26, 2016

# ASTROPHYSICS

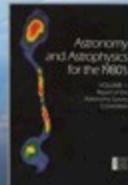
## Decadal Survey Missions

1990



**1972**  
Decadal  
Survey  
*Hubble*

1999



**1982**  
Decadal  
Survey  
*Chandra*

2003



**1991**  
Decadal  
Survey  
*Spitzer*

LRD: 2018



**2001**  
Decadal  
Survey  
*JWST, SOFIA*

LRD: 2020s

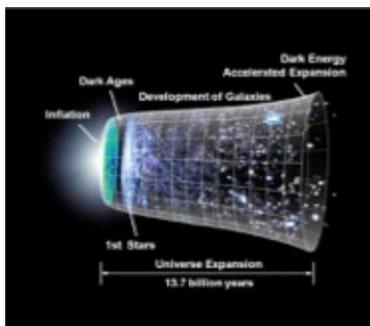


**2010**  
Decadal  
Survey  
*WFIRST*

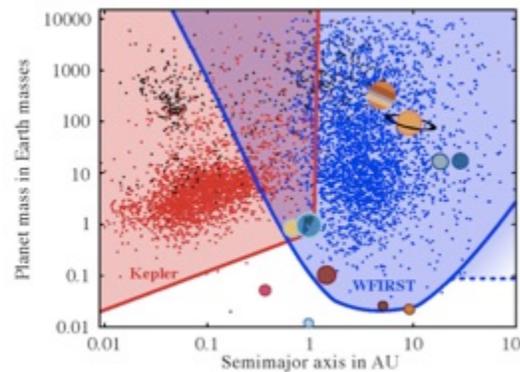


- WFIRST highest ranked large space mission in 2010 Decadal Survey
  - Study Dark Energy, Exoplanet Census, NIR Sky Survey
- Use of 2.4m telescope enables
  - Hubble quality imaging over 100x more sky
  - Imaging of exoplanets with  $10^{-9}$  contrast with a coronagraph

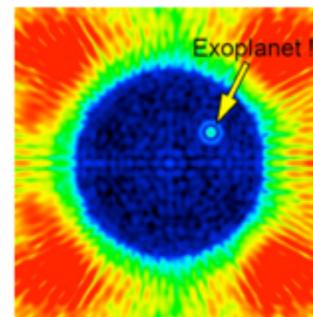
## Dark Energy



## Exoplanets

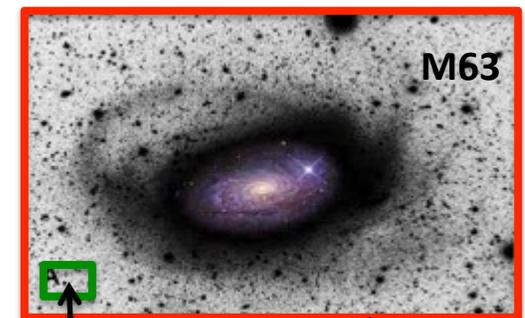


## Microlensing



## Coronagraph

## Astrophysics



HST

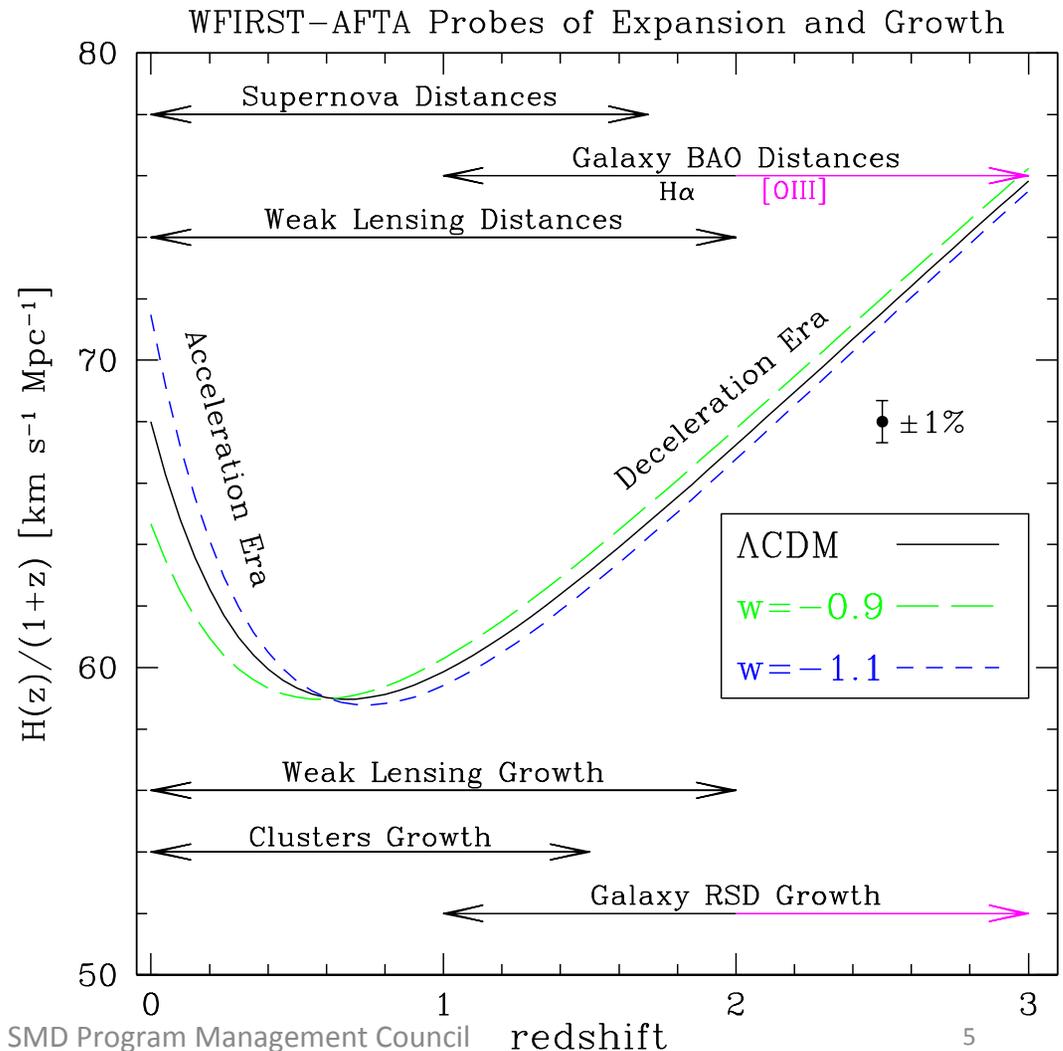
WFIRST

# HST Ultra Deep Field



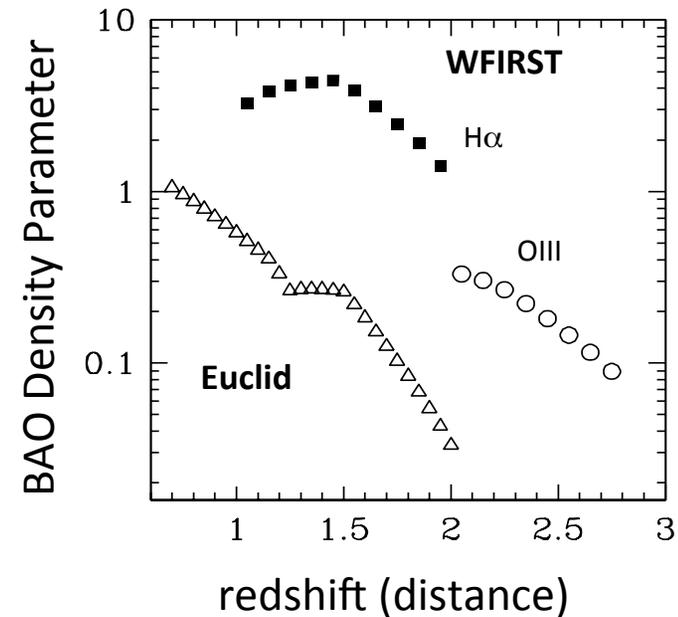
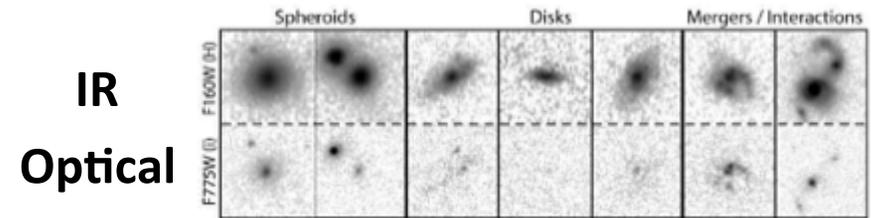


- WFIRST combines all techniques to determine the nature of Dark Energy.
- Only observatory doing such comprehensive observations.
- High precision measurements will be optimally combined for the best measurement.





- WFIRST will be the first mission to fully exploit the powerful IR band for dark energy measurements.
- It will be much more sensitive and have higher angular resolution than any other dark energy instrument.

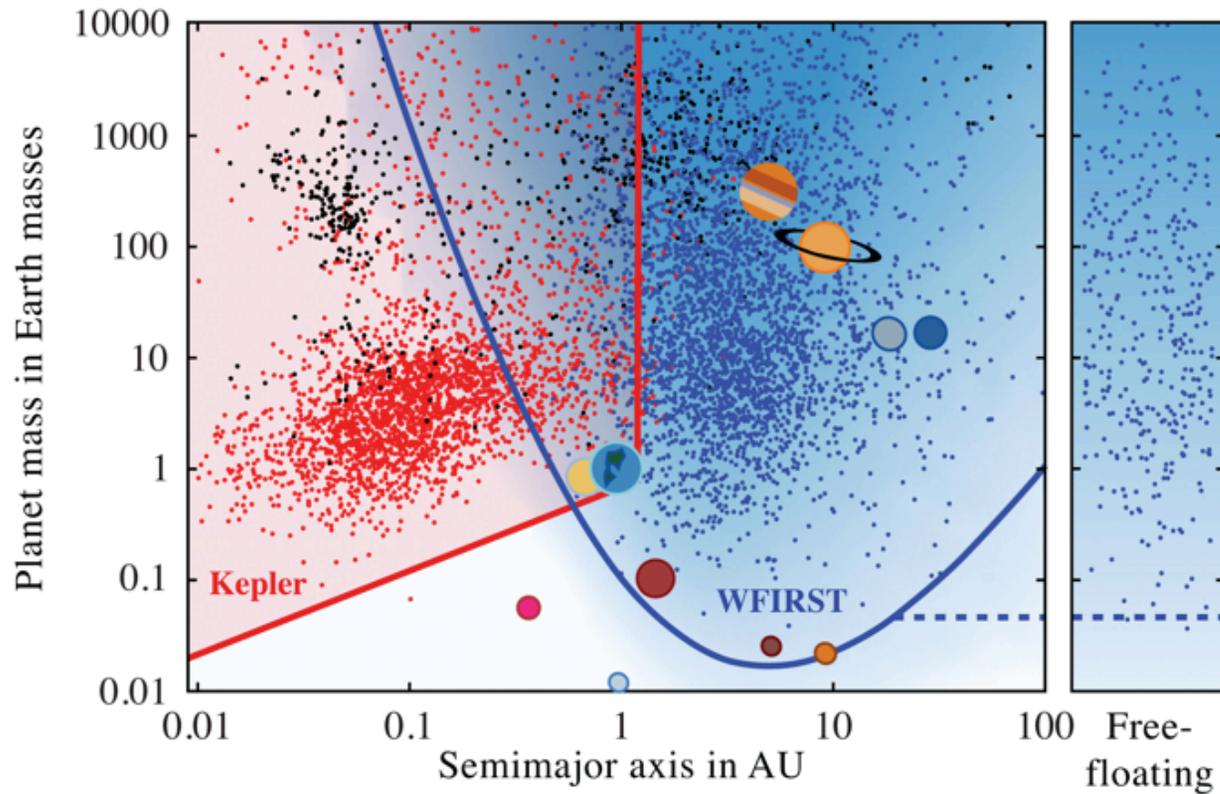




Kepler



WFIRST





# Complete the Census of Exoplanets - Microlensing

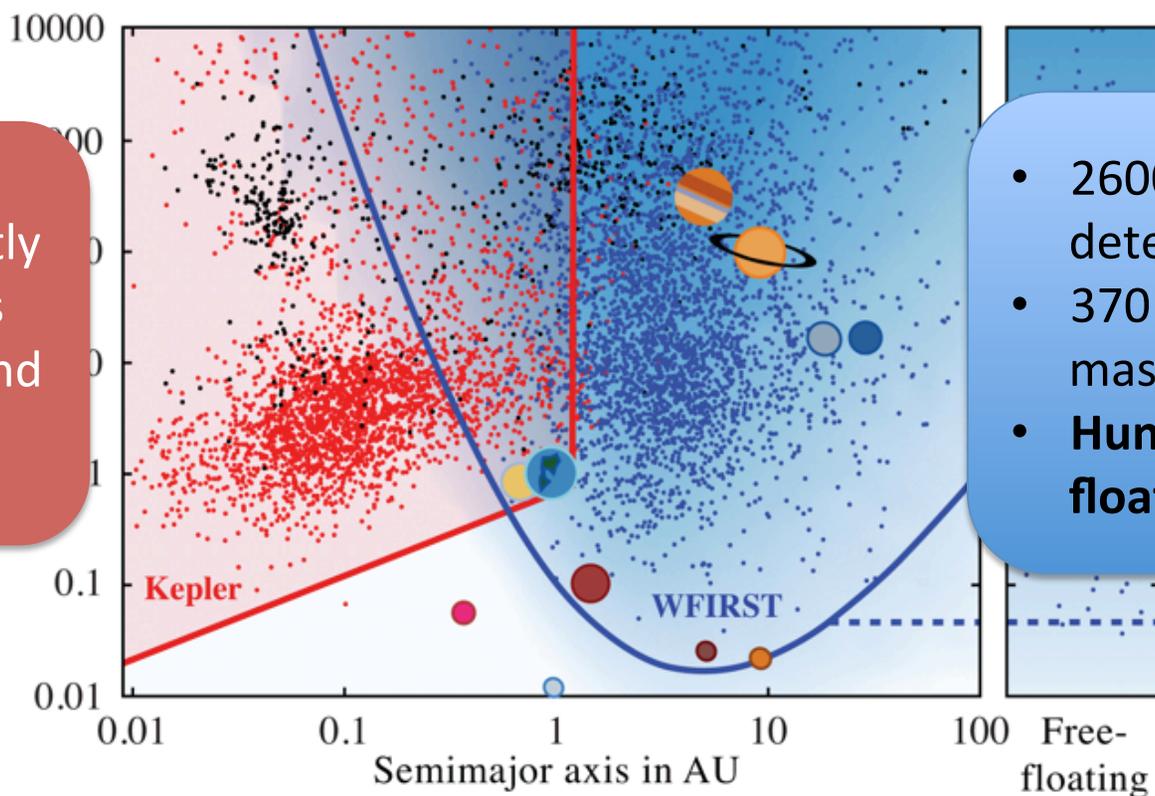


Kepler



WFIRST

WFIRST perfectly complements Kepler, TESS, and PLATO.

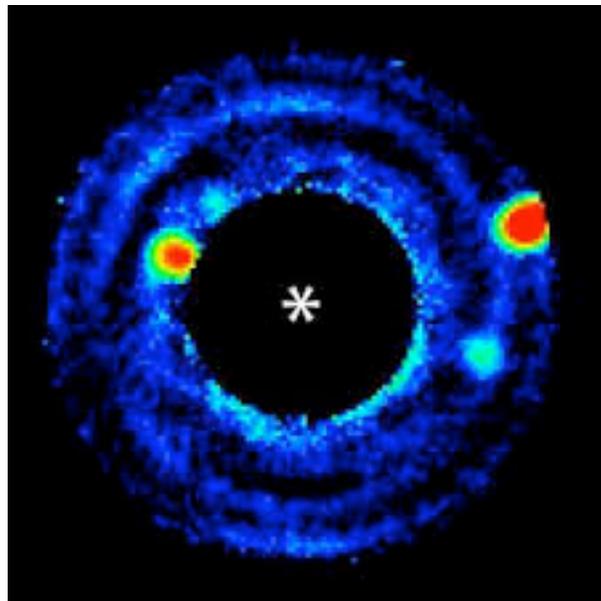


- 2600 planet detections.
- 370 with Earth mass and below.
- **Hundreds of free-floating planets.**

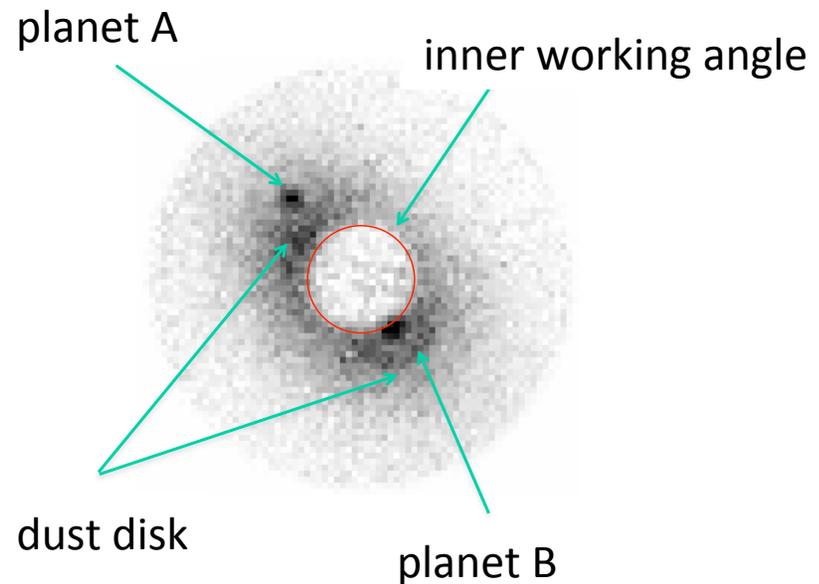


- Imaging at high contrast provides for direct detection and spectroscopy (characterization) of exoplanets

## Concept

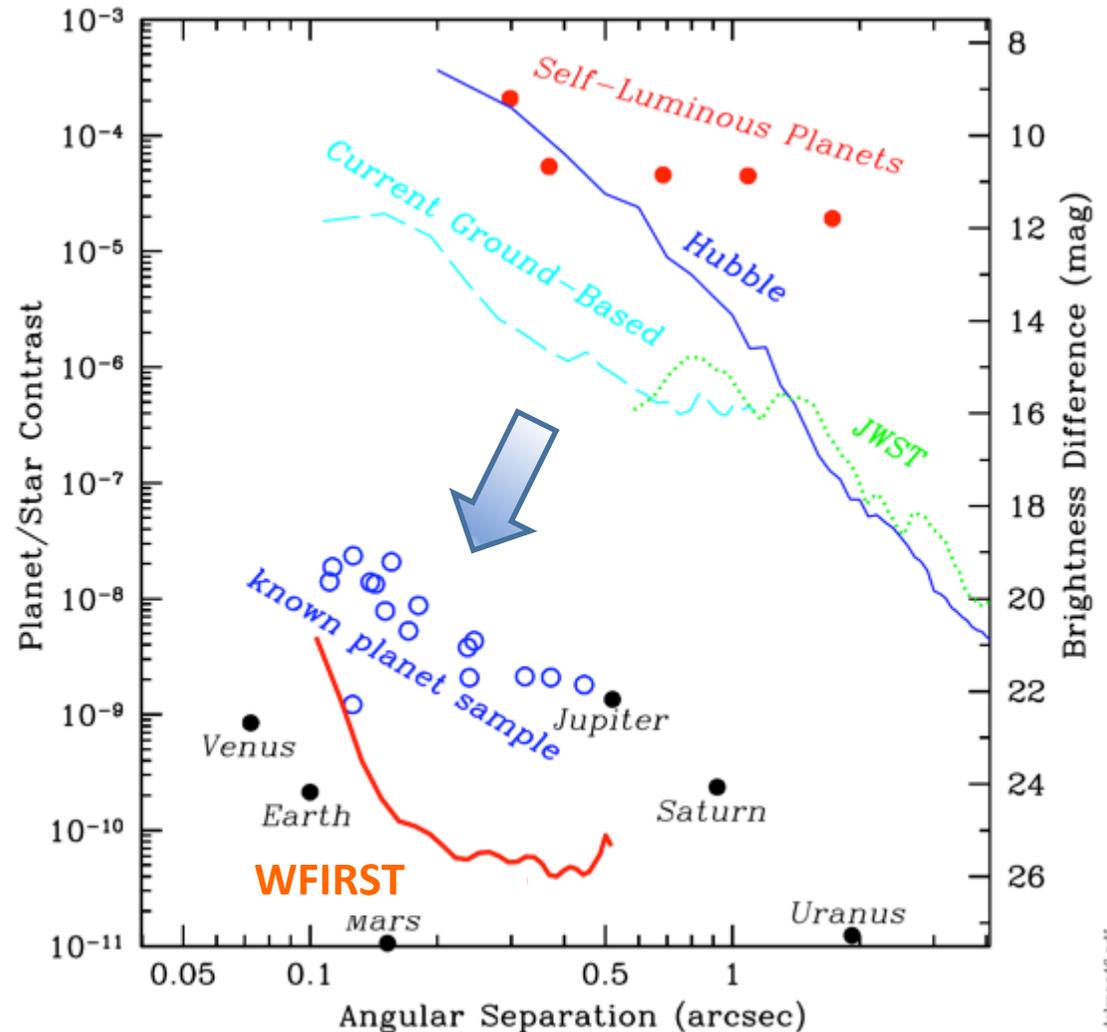


## WFIRST Simulation





- WFIRST advances many of the key elements needed for a coronagraph to image an exo-Earth
  - Coronagraph
  - Wavefront sensing & control
  - Detectors
  - Algorithms



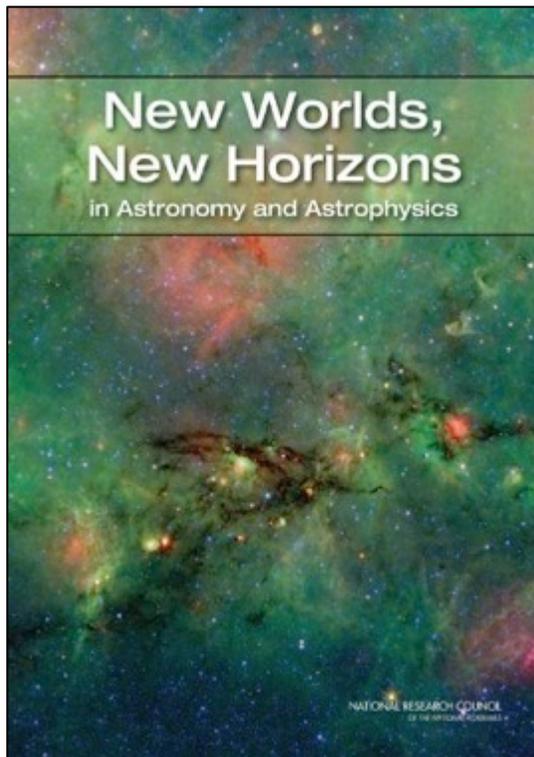


## WFIRST will address top NWNH goals

#1 Large-Scale Priority - Dark Energy, Exoplanets

#1 Medium-Scale Priority - New Worlds Tech. Development

## WFIRST Guest Observer program will covers many other NWNH goals



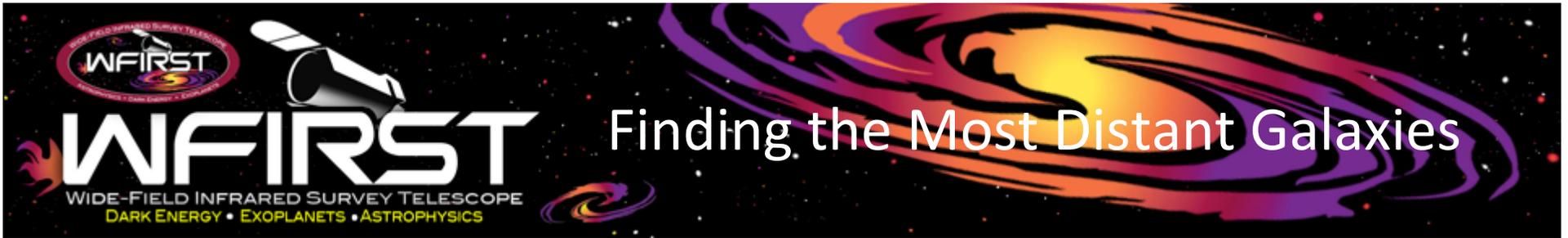
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### 5 Discovery Science Areas

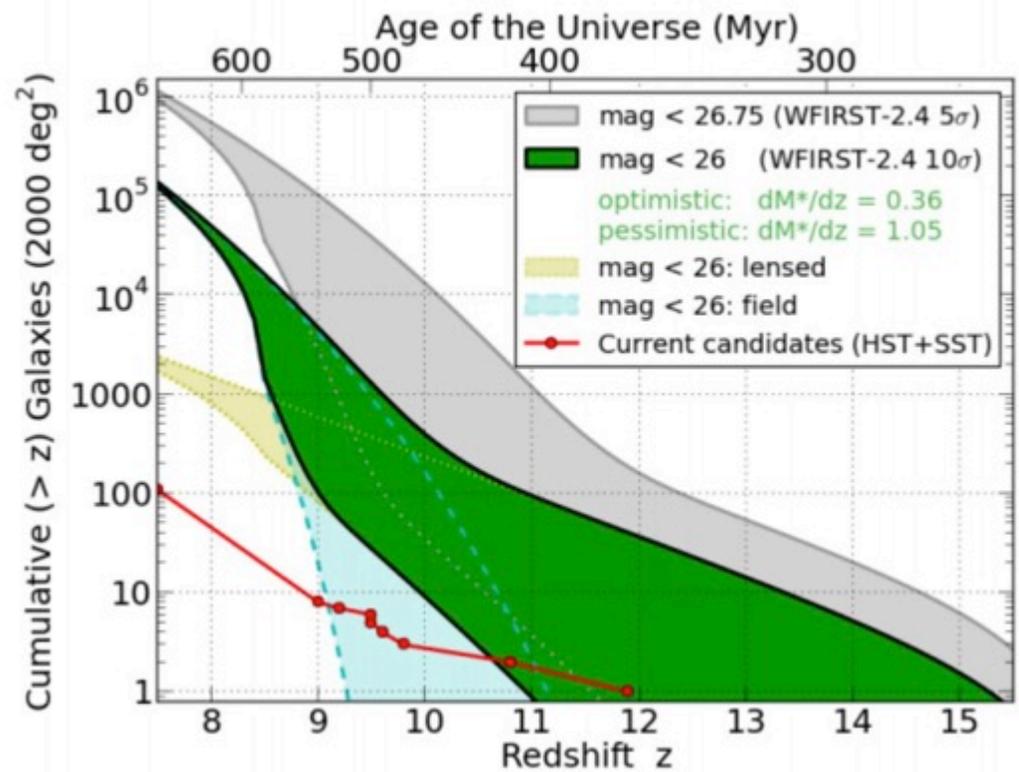
- ID & Characterize Nearby Habitable Exoplanets ✓
- Time-Domain Astronomy ✓
- Astrometry ✓
- Epoch of Reionization ✓
- Gravitational Wave Astrometry

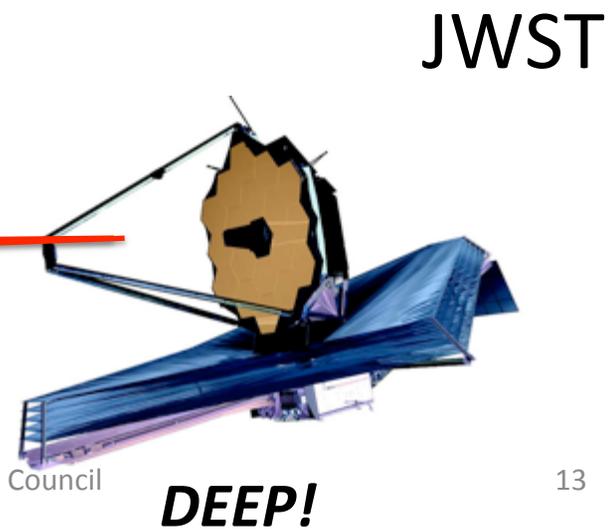
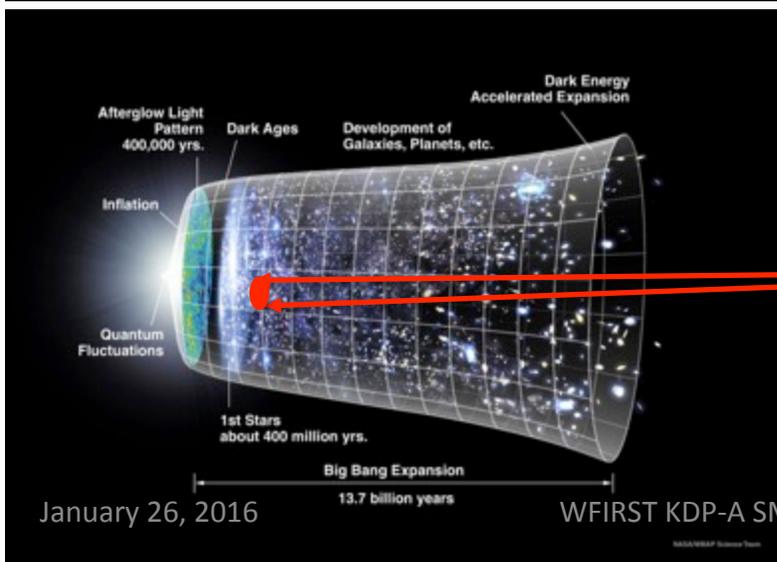
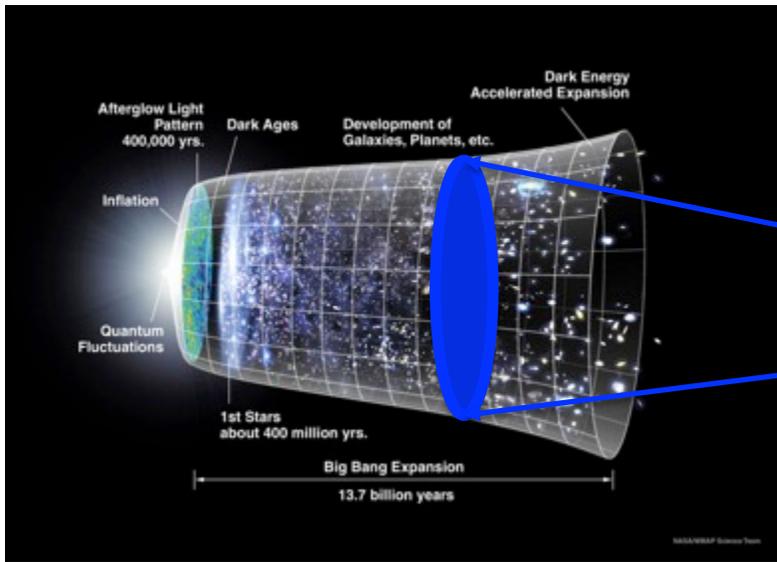
### 20 Key Science Questions

- Origins (7/7 key areas)
- Understanding the Cosmic Order (6/10 key areas)
- Frontiers of Knowledge (3/4 key areas)



- WFIRST's High-Latitude Survey will yield up to 2 orders of magnitude more high redshift galaxies than currently known.
- WFIRST will find interesting distant galaxies for JWST and future narrow-field telescopes to observe.



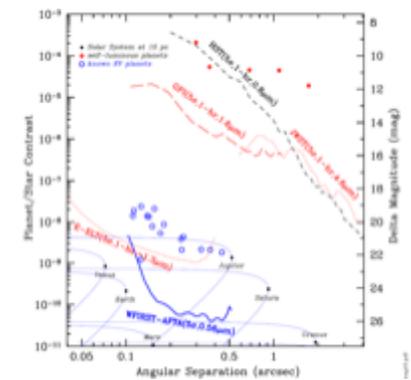
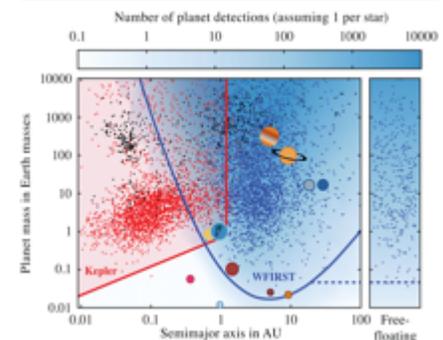
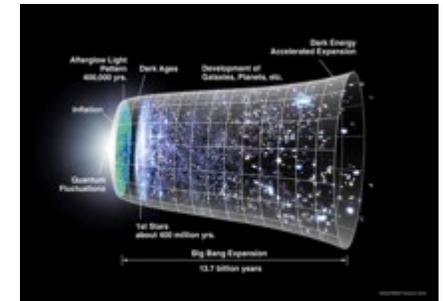


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WFIRST KDP-A SMD Program Management Council

# WFIRST Science Objectives

- Wide-Field Infrared Survey
  - Capable of producing NIR sky images in multiple-bands and spectra over thousands of square degrees with J = 27AB 5-sigma point-source imaging sensitivity and  $F_{\text{line}} = 10^{-16} \text{ erg cm}^{-2} \text{ s}^{-1}$  7-sigma line sensitivity.
- Expansion History of the Universe (Dark Energy)
  - Determine the expansion history of the Universe in order to test the possible explanations of its apparent accelerating expansion including Dark Energy and modification to Einstein's gravity using the supernova, weak lensing, and baryon acoustic oscillations techniques, providing in combination a sub-percent precision over the redshift range  $z = 0.2$  to 2 with high-precision cross-checks across the full redshift range.
- Growth of Structure in the Universe (Dark Energy)
  - Determine the growth history of the largest structures in the Universe in order to test the possible explanations of its apparent accelerating expansion including Dark Energy and modification to Einstein's gravity using weak lensing, redshift space distortions, and clustering surveys to produce a combined sub-percent precision over the redshift range  $z = 0$  to 2 with high-precision cross-checks across the full redshift range.
- Exoplanet Census (Microlensing)
  - Complete the statistical census of planetary systems in the Galaxy, from the outer habitable zone to free floating planets using the microlensing technique.
- Exoplanet Direct Imaging (Coronagraphy)
  - Directly image giant planets and debris disks from near the (TBR) habitable zones to beyond the ice lines and characterize their physical properties using the coronagraphy technique.
- Guest Observer Program
  - Provide a robust guest observer program utilizing a minimum of 25% of the observing time over the 6 year baseline mission.





- The WFIRST Design Reference Mission (DRM) consists of a five-part observing program in support of the WFIRST Science Objectives:
- Dark Energy Science/Infrared Survey
  - **High Latitude Survey (HLS):** Imaging and spectroscopic near infrared sky survey for Baryon Acoustic Oscillations/Redshift Space Distortions & Weak Lensing, and enables a variety of other infrared science by guest investigators
  - **Supernova (SN) Survey:** Multiple visits to SN fields at high ecliptic latitudes to discover and track SN light curves
- Exoplanet Science
  - **Microlensing Survey:** Multiple visits to microlensing fields near Galactic bulge to monitor planetary microlensing events
  - **Coronagraph Survey:** Observe nearby stars to find and characterize both previously known and new planets
- Guest Observer
  - **GO Program:** Allocated time for proposers to observe targets anywhere within the field of regard
    - GO program utilizes existing WFIRST capabilities and does not drive system reqs
    - The GO program by definition cannot be “allocated” at this stage in the project.



## WFIRST Payload Enables Top NWNH Priorities

- 2.4 m Telescope
  - Exquisite point spread function enhancing science beyond that envisioned by NWNH
- Wide Field Instrument
  - Provides near infrared wide field imaging and spectroscopy in support of the dark energy and exoplanet census objectives
  - Provides integral field spectroscopy in support of the dark energy objectives.
- Coronagraph Instrument
  - Provides high contrast imaging and integral field spectroscopy in support of exoplanet and debris disk direct imaging objectives.

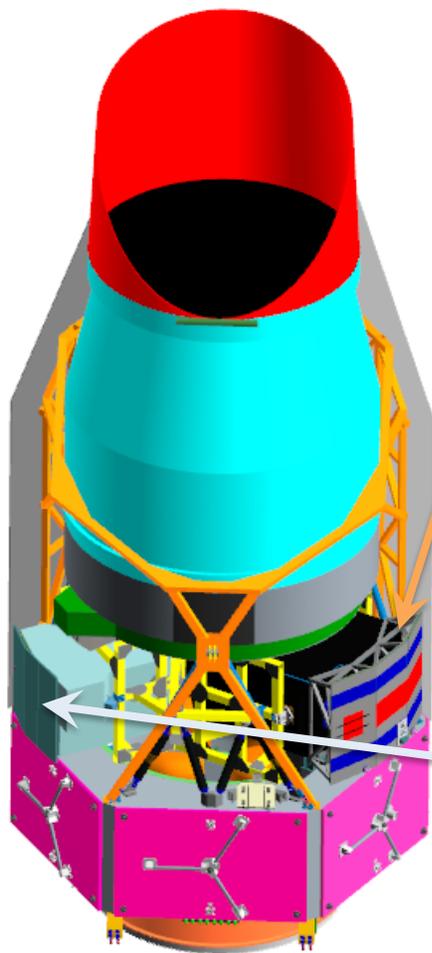


## Wide Field Instrument

- *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





Mission Success Criteria	Science Surveys
<p>Measure the history of cosmic expansion for redshifts 0.2 - 2 (TBR), by two or more methods and with aggregate precision and systematic uncertainty below 1%.</p>	<p>High Latitude Survey (BAO/RSD and WL), Supernova Survey</p>
<p>Measure the history of the growth of structure for redshifts &lt;2, by one or more methods and with aggregate precision and systematic uncertainty below 1%.</p>	<p>High Latitude Survey (BAO/RSD and WL)</p>
<p>Determine the statistical population of planets with the mass of Earth and above in the cold, outer regions of planetary systems to test theories of planetary formation and evolution, using microlensing observations of stars with 1% photometric precision at a depth of J=20 covering 2 square degrees.</p>	<p>Microlensing Survey</p>
<p>Provide a minimum of 15% of aggregated WFIRST operational lifetime to execution of a peer-reviewed Guest Observer (GO) program.</p>	<p>Guaranteed GO time</p>



Baseline Science Requirement	Science Survey	Instrument
<p>WFIRST WFI shall measure positions and redshifts of emission-line galaxies for redshift range <math>z=1-2</math> with a position accuracy of TBD and a redshift accuracy of 1 part in 1000 and a minimum detectable point-source line flux of <math>0.5 \times 10^{-16}</math> ergs/cm<sup>2</sup>/s at <math>7\sigma</math> significance in the high-latitude spectroscopic survey.</p>	<p>High Latitude Survey (BAO/RSD)</p>	<p>Wide Field Imager and Grism</p>
<p>WFIRST WFI shall measure shapes of galaxies at <math>z=0-2</math> in at least 2 bands, and fluxes in at least 4 bands for photometric redshifts at a depth equivalent to a 5-sigma point source detection at AB magnitude <math>J &lt; 26.9</math> or <math>H &lt; 26.7</math>, with photometric accuracy of TBD and with rms uncertainties (in the shape measurement filters only) below <math>10^{-3}</math> in the PSF second moment and below <math>5 \times 10^{-4}</math> in the PSF ellipticity, in the high-latitude imaging survey.</p>	<p>High Latitude Survey (WL)</p>	<p>Wide Field Imager and Integral Field Unit</p>



Baseline Science Requirement	Science Survey	Instrument
<p>WFIRST WFI shall measure the spectra, light curves, fluxes, and redshifts of Type Ia supernovae with 5 day cadence over a redshift range of <math>z = 0.2</math> to <math>1.7</math> with rms measurement errors of <math>\leq 0.08</math> mag per supernova from IFU spectrophotometry in synthetic bandpasses and systematic calibration uncertainties of <math>\leq 0.01 \times (1+z)/1.8</math> mag for the mean flux in each <math>\Delta z = 0.1</math> redshift bin.</p>	Supernova Survey	Wide Field Imager and Integral Field Unit
<p>WFIRST WFI shall monitor microlensing events toward the Galactic Bulge in a primary filter with a cadence of <math>\leq 15</math> minutes, achieving a <math>S/N \geq 100</math> per exposure for a <math>J_{AB} = 21.3</math> star, and in a second filter with a cadence <math>\leq 12</math> hours over, seasons of no less than 60 days.</p>	Microlensing Survey	Wide Field Imager
<p>WFIRST WFI shall have an angular resolution <math>&lt; 0.4</math> arcsec.</p>	Microlensing Survey	Wide Field Imager

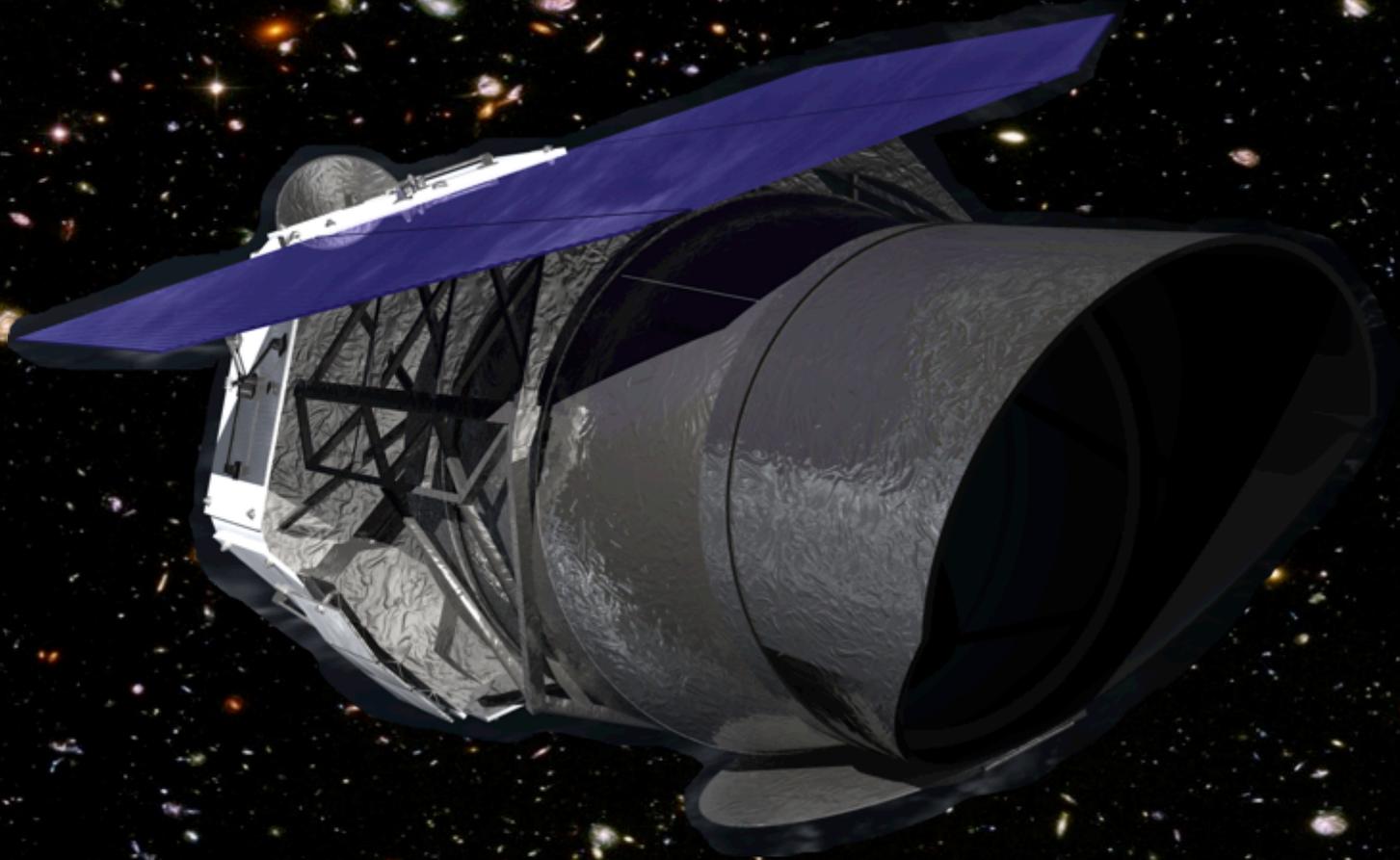


Baseline Science Requirement	Science Survey	Instrument
WFIRST Coronagraph shall directly image exoplanets around nearby stars, and carry out color photometry measurements in the spectral range about 400-1000 nm, with effective contrast of $3 \times 10^{-9}$ and an inner working angle of 200 milliarcsec after post-processing.	Coronagraph Survey	Coronagraph Imager
WFIRST Coronagraph shall spectroscopically characterize exoplanets by measuring continua and spectral absorption features over a wavelength range of 600 – 950 nm with mean spectral resolution of at least 70.	Coronagraph Survey	Coronagraph Integral Field Spectrograph
WFIRST shall be capable of making imaging observations of disks and planets in 2 orthogonal polarizations.	Coronagraph Survey	Coronagraph Imager



- 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)
  - GSFC and JPL Deputy Project Scientists (ex-officio)
  - Science Center Leads (ex-officio)
- Science Investigation Teams
 

▪ 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
▪ Benjamin Williams	GO science, nearby galaxies
▪ Alexander Szalay	GI science, archival research



# WFIRST KDP-A/APMC Project Overview

Kevin Grady/GSFC  
Project Manager

January 26, 2016

# Outline



- History
- Programmatic Requirements
- Mission Overview
- Implementation/Organization
- Schedule and Lifecycle Cost
- Near-Term Accomplishments & Phase A Plans





- **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.



- **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.*



- 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).



### Baseline Technical/Data Requirement

The WFIRST observatory and associated ground support equipment shall be designed and fabricated to sustain baseline science operations for at least 6 years.

The WFIRST observatory shall employ an existing telescope with a 2.36 m diameter primary mirror, on-axis secondary mirror, and associated metering structure.

The WFIRST observatory shall be diffraction limited at 1.2 micrometers, defined as having a Strehl Ratio greater than or equal to 0.8 across the wide field instrument field of view.

The observatory shall have the capability to respond to Target of Opportunity requests to point at a transient object in the sky within the Field of Regard of the observatory.

The WFIRST wide field instrument shall have a minimum field of view of 0.25 deg<sup>2</sup>.

The WFIRST flight system shall be implemented with mechanical features designed to facilitate a potential future robotic servicing mission.

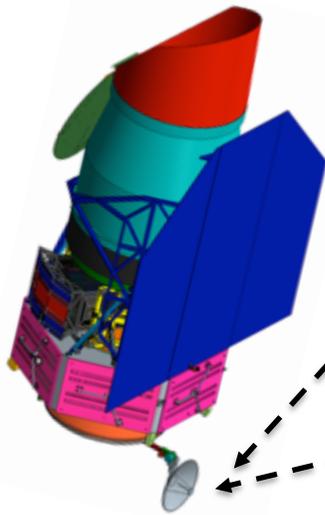
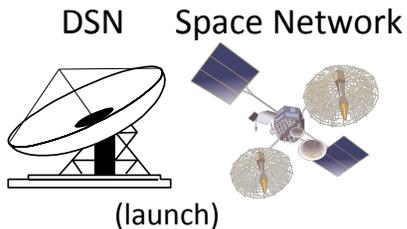
Provide a public release of imaging data from the WFI processed to the L1b standard within 72 (TBR) hours of acquisition, and provide a public release of all data processed to the L3 standard within 6 months (TBR) of acquisition.

WIDE-FIELD  
INFRARED  
SURVEY  
TELESCOPE

**WFIRST**  
DARK ENERGY • EXOPLANETS • ASTROPHYSICS



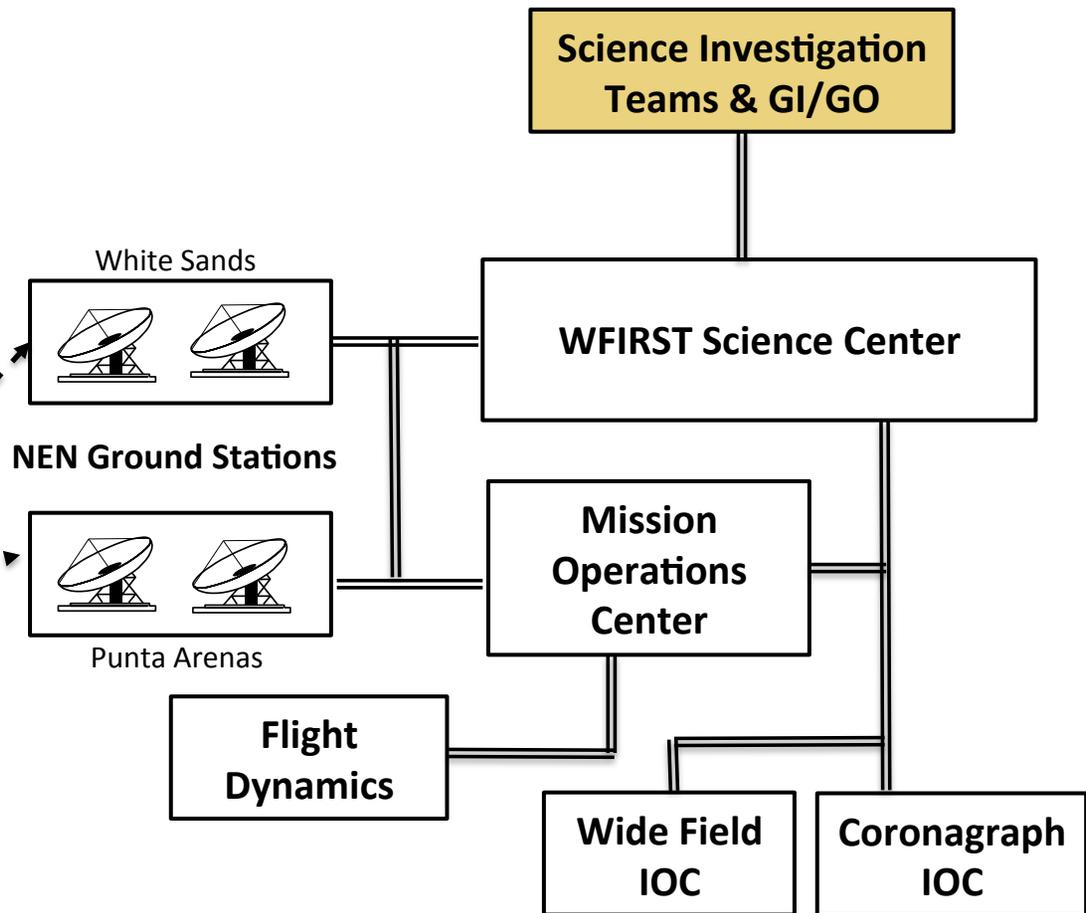
# WFIRST Mission Overview



Falcon Heavy Delta IV Heavy

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WFIRST KDP-A SMD Program Management Council

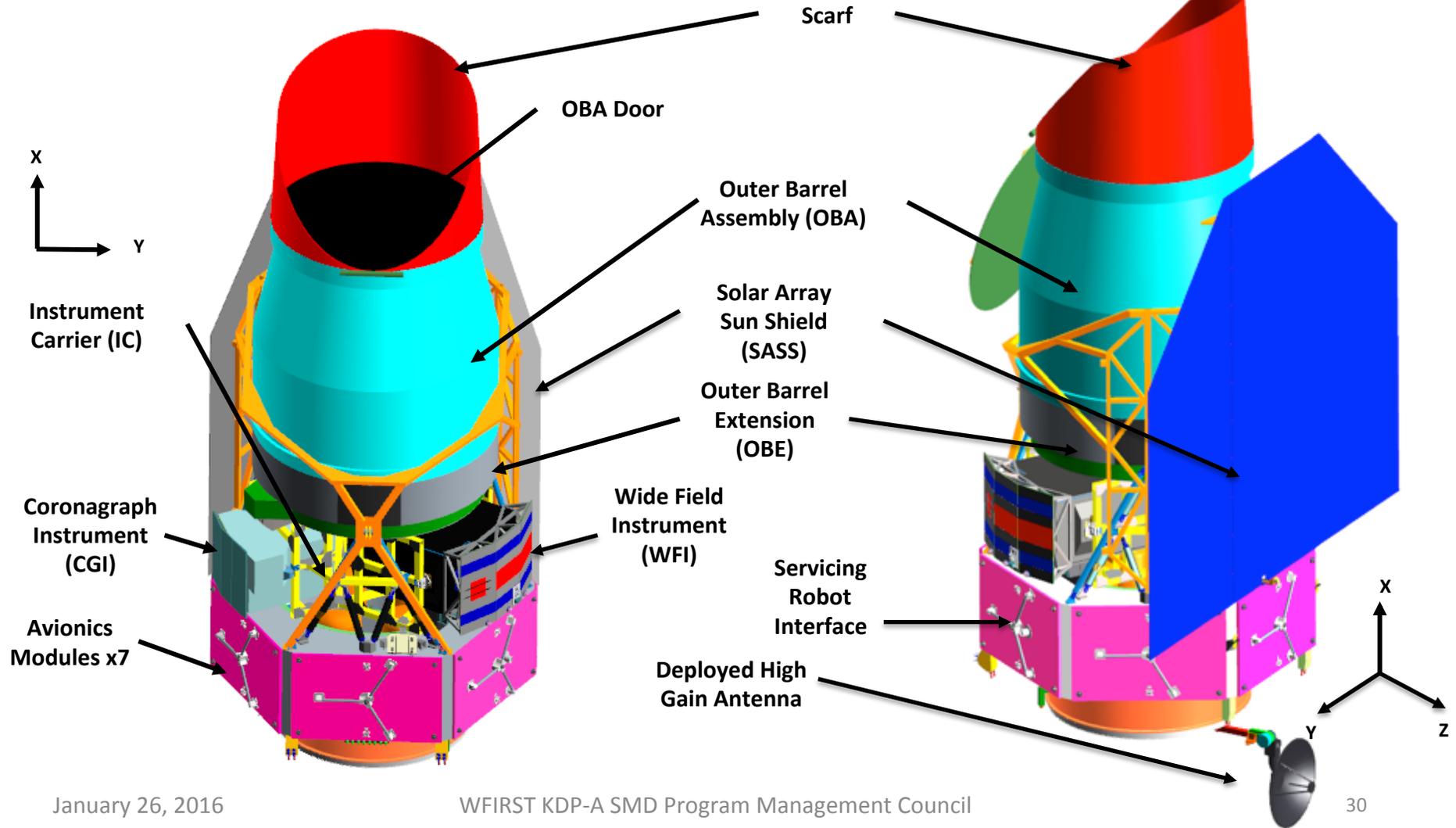


IOC – Instrument Operations Center



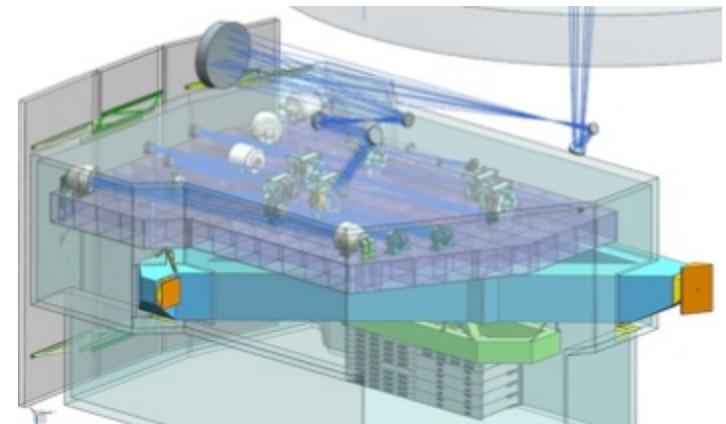
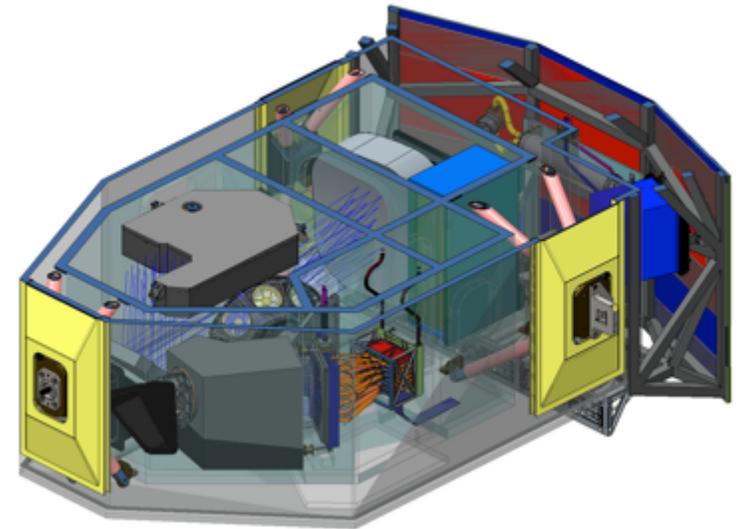
**Launch Configuration**

**On-Orbit Configuration**





- 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.



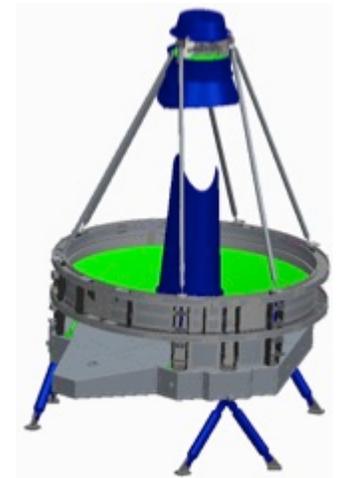


The WFIRST Observatory includes...

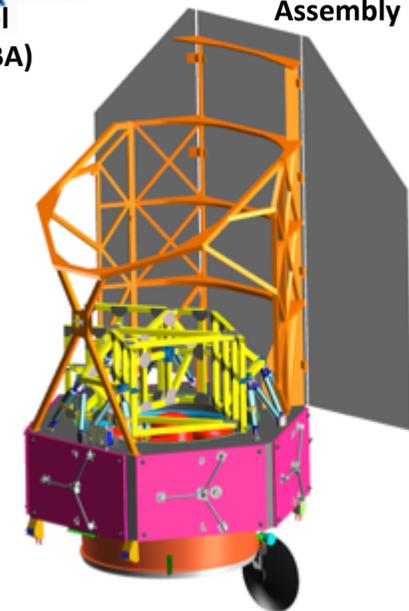
- Telescope – JPL/Harris
  - Provides the first two mirrors for both instruments, with the primary mirror sized at 2.4 m.
  
- Spacecraft (S/C) – GSFC
  - Provides power, command & data handling, attitude control and communications for the payload
  - Provides a modular design to enable serviceability.
  - Provides an optically stable structure to support the payload (telescope and instruments)



Outer Barrel Assembly (OBA)

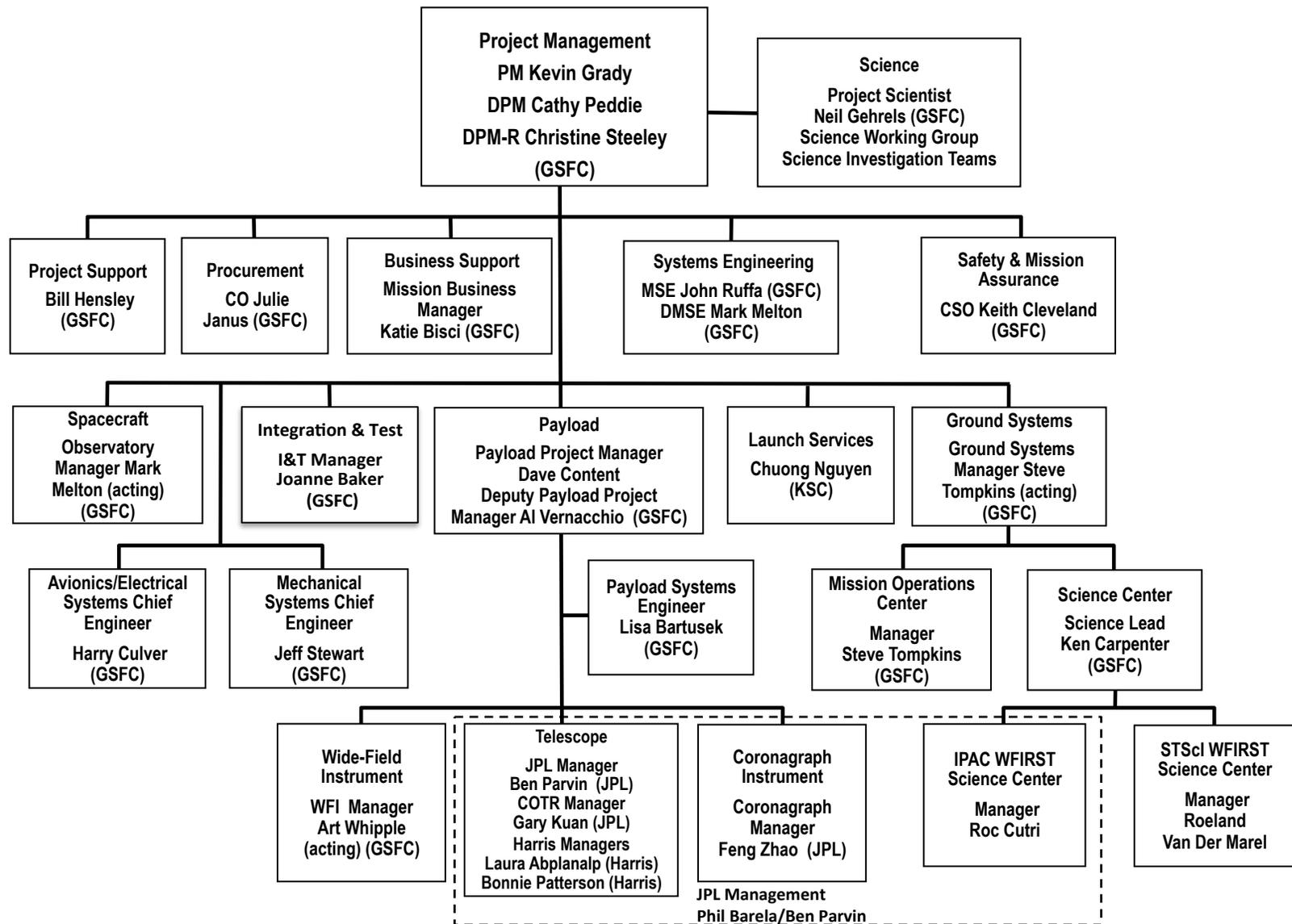


Forward Optical Assembly (FOA)



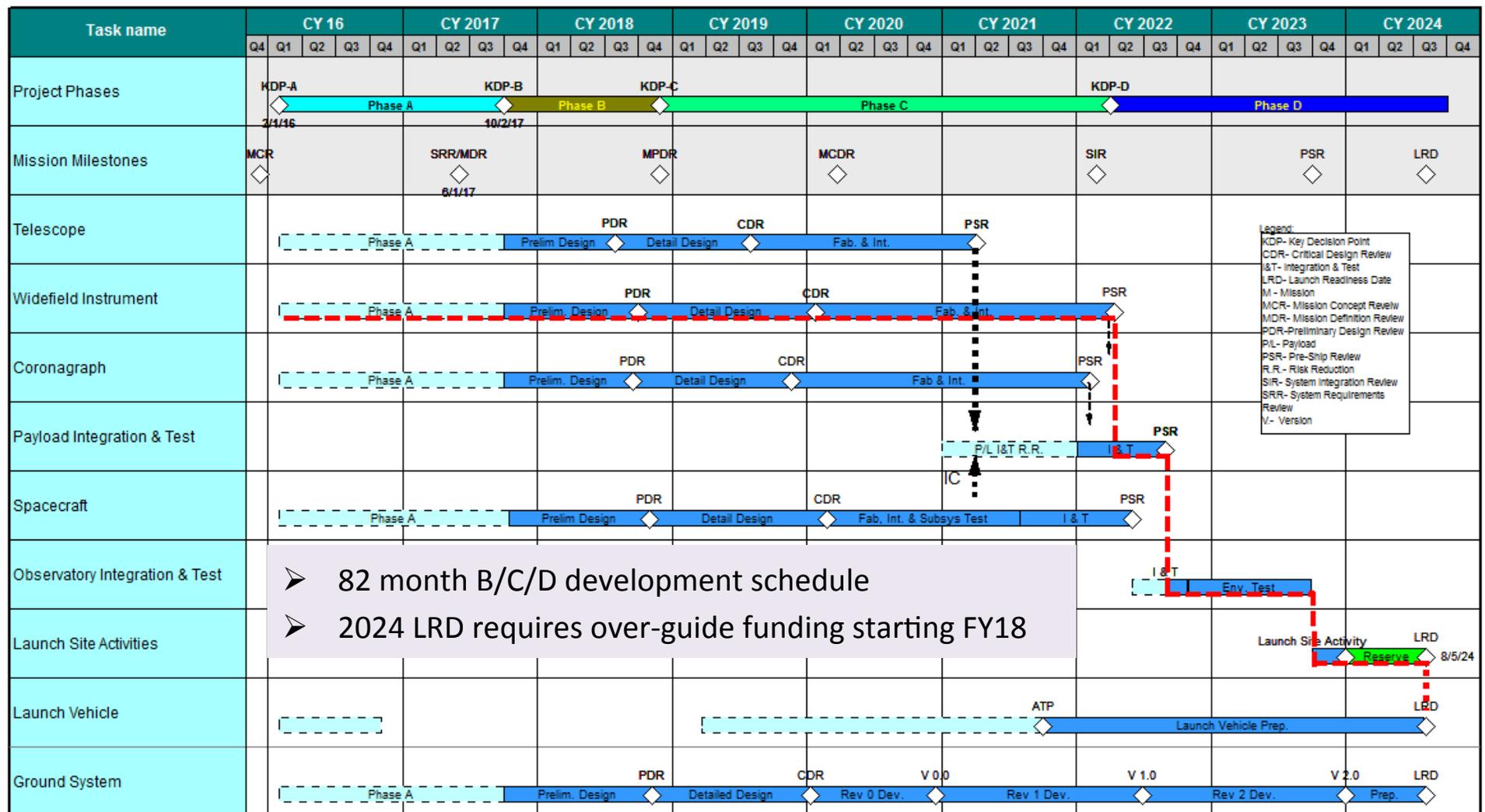


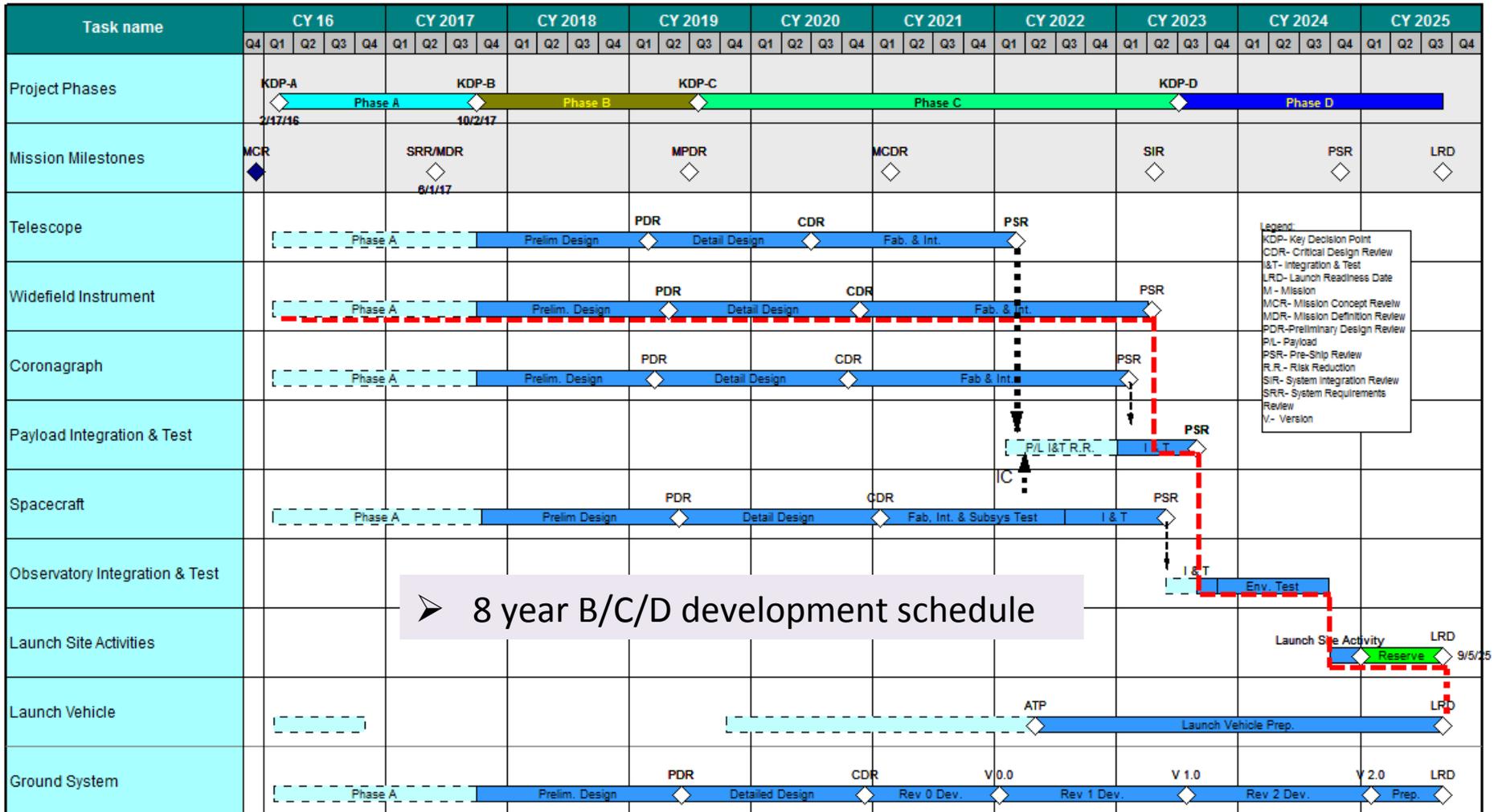
# Project Organization





# Mission Schedule – 2024 LRD







- Recent augmented funding (FY14-16, 203M) has enabled significant progress. Recent budget has 90M in FY17, and 10M from STMD.
  - Technology maturation.
  - Increased fidelity in the design reference.
- 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.
- Mission Concept Review (MCR) successfully completed in December.
- 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.
  - Proposals received February 3.
  - Anticipate awarding study contracts in March.
- Continued engaging the Science Community
  - WFIRST Preparatory Science (WPS) teams funded. 17 teams. \$2M/yr
  - Twice yearly special sessions at AAS's & IAU
  - WFIRST Formulation Science Working Group and Science Investigation Teams selection made December 17, 2015.
  - Planned: Feb 29 - March 2 "Community Astrophysics with WFIRST"
- WFIRST Formulation Science Working Group (FSWG) kick-off with Project held February 2-4, 2016.

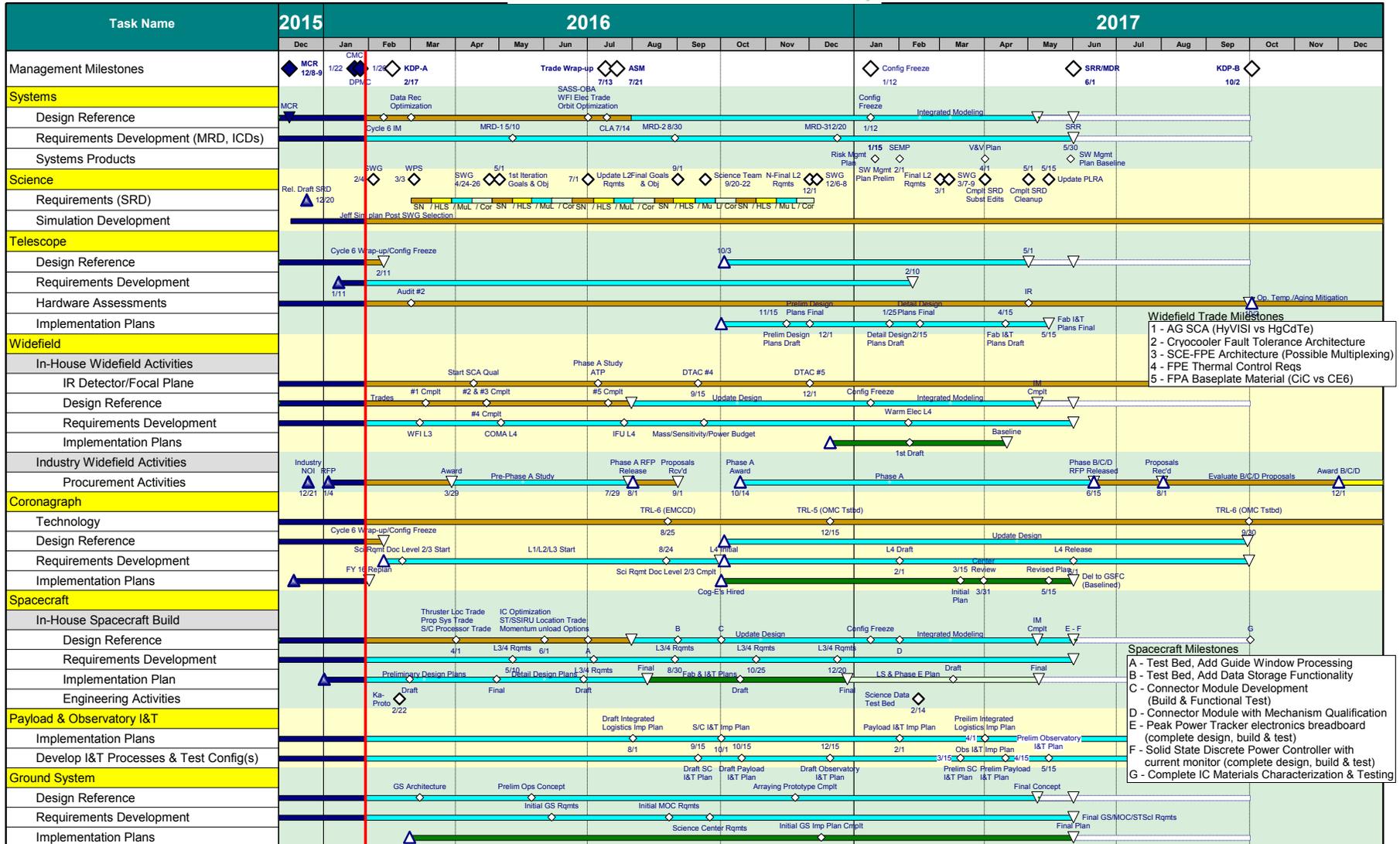


- Key Decision Point A (KDP-A) has arrived.
- Finalize Acquisition Strategy
  - Acquisition Strategy Meeting to occur in summer 2016.
  - Wide Field Industry concept study March – June 2016.
- SRR/MDR Preparation
  - Complete requirements development and flowdown from Science Objectives to Level 1, 2, 3 and driving Level 4 requirements
  - Complete open design trades and update the WFIRST design concept.
  - Complete IR detector and coronagraph technology milestones.
  - Develop grassroots implementation plans and schedules during Formulation.
  - Develop KDP-B documentation and products per NPR 7120.5E (control plans, descope plan, design reference, etc.)
    - Extensive descope list already generated, to be developed into full plan.

# Phase A Schedule

WFIRST Phase A Schedule - Preliminary

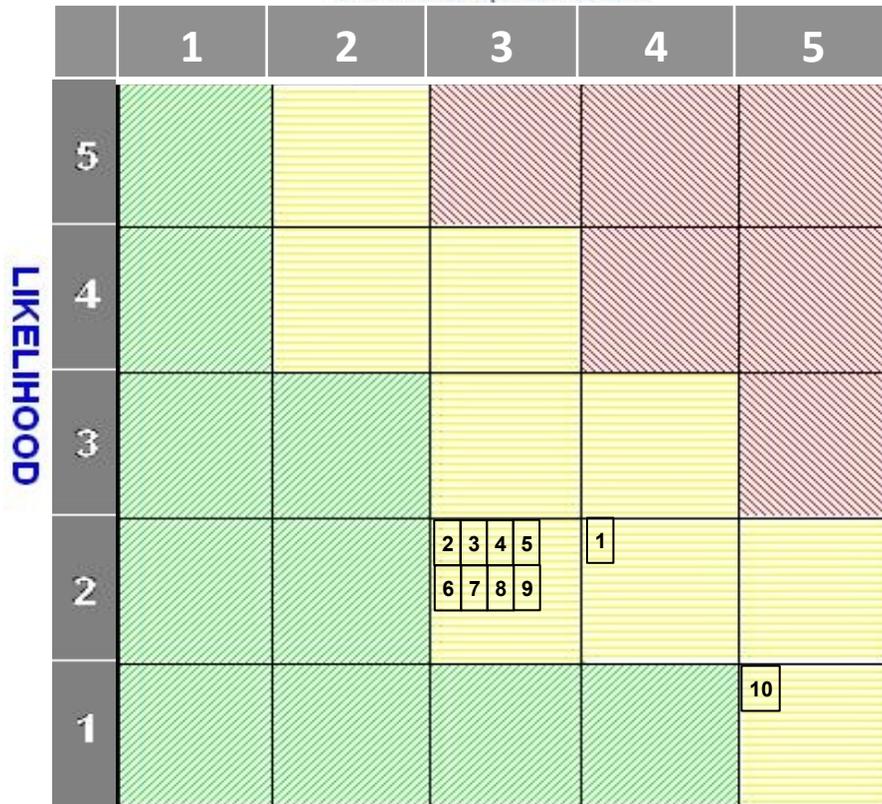
As of: February 2016





# WFIRST Risk Summary (Yellow and Red Ranking)

## CONSEQUENCES



Criticality	Approach
HIGH	M-Mitigate
MED	W-Watch
LOW	A-Accept
	Ar-Archive

Rank	ID	Title	Approach
1	RISK-WFI-0001	WFC FPA Detector Performance	Mitigate
2	RISK-WFI-0003	WFC FPA Detector Yield	Mitigate
3	RISK-WFI-0002	WFC FPA Detector Manufacturing Issues	Mitigate
4	RISK-WFI-0043	WFC Focal Plane System Performance	Mitigate
5	RISK-WFI-0042	WFC Focal Plane Integration	Mitigate
6	RISK-INST-0032	Instrument Carrier and WFI Optical Bench	Mitigate
7	RISK-WFI-0041	WFC Focal Plane Alignment Stability	Mitigate
8	RISK-WFI-0035	WFI IFU Image Slicer opto-mechanical manufacturing	Mitigate
9	RISK-TELE-0027	Telescope Pedigree and Capability	Mitigate
10	RISK-WFI-0039	WFI Cryocooler Turbine Lifetime	Mitigate



- ✓ The Study Team has explored IR survey instruments for the past 7 years; numerous concepts developed – **the trade space is well understood**.
- ✓ WFIRST with the 2.4-m telescope provides an exciting science program, **superior to that recommended by NWNH** with comparable cost and also advances exoplanet imaging technology (the highest ranked medium-class NWNH recommendation).
- ✓ Huge astronomy and astrophysics **discovery potential** – Guest Observer.
- ✓ Funding has allowed significant progress in **technology maturation**.
- ✓ Key development areas are anchored in **over a decade of investments** in JPL's high contrast testbed and GSFC's Detector Characterization Lab.

***Fate of the Universe  
Our Place in the Universe***

***WFIRST Team is ready for Phase A***