

# WFIRST STATUS

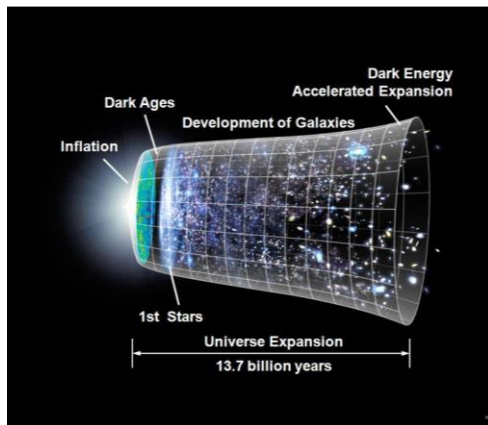
## APS meeting, March 15, 2016

Neil Gehrels/GSFC  
Project Scientist

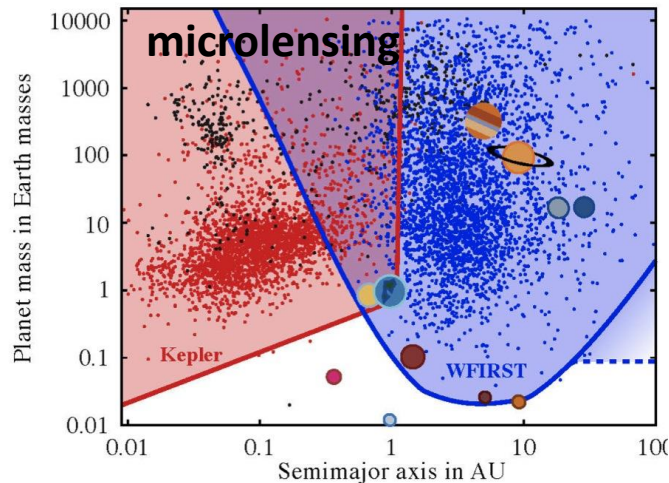
Kevin Grady/GSFC  
Project Manager

- 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

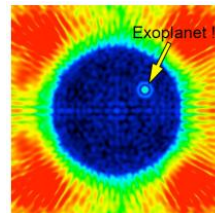
## Dark Energy



## Exoplanets



coronagraph



## Astrophysics

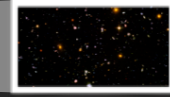


HST

WFIRST

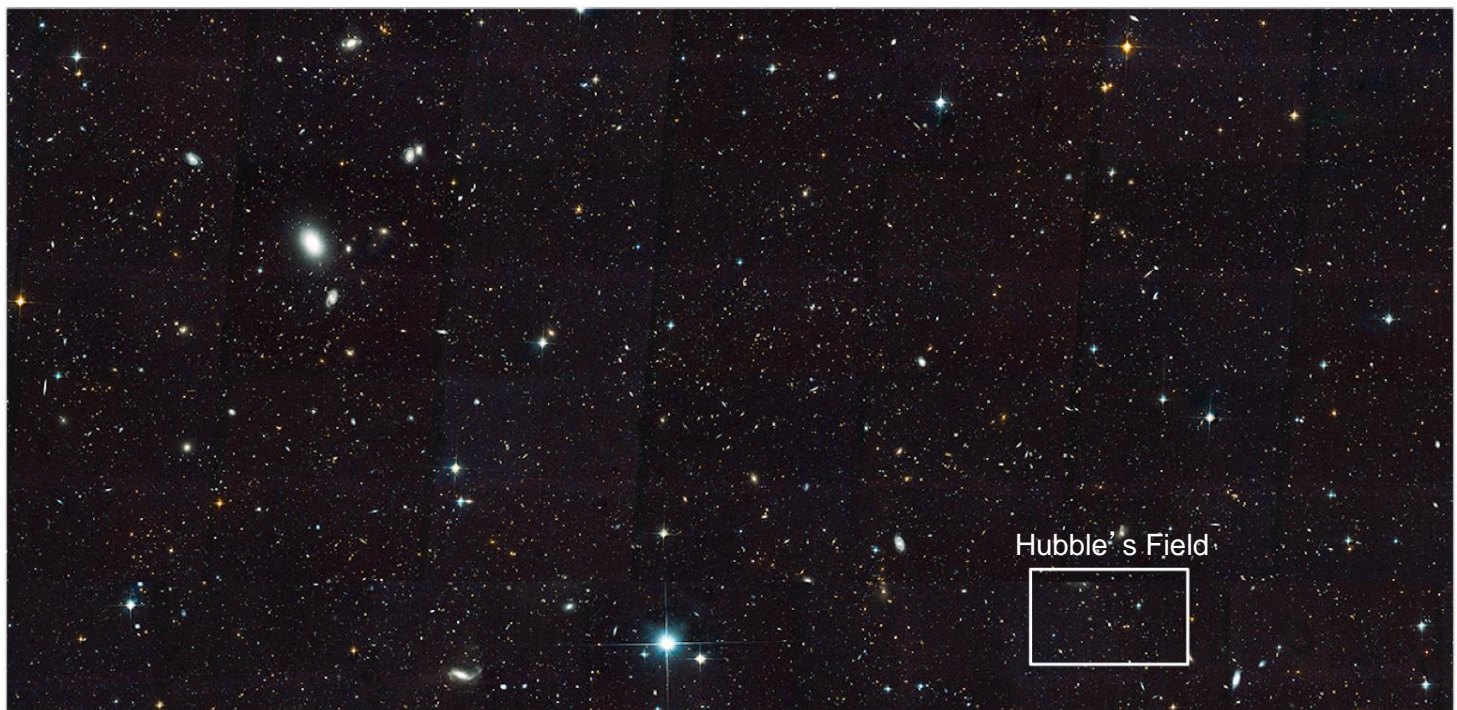
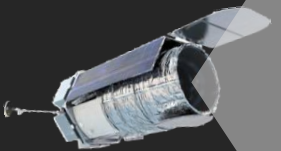


# Hubble - A Spectacular Start



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

## WFIRST - Hubble X 100



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

# Science Objectives

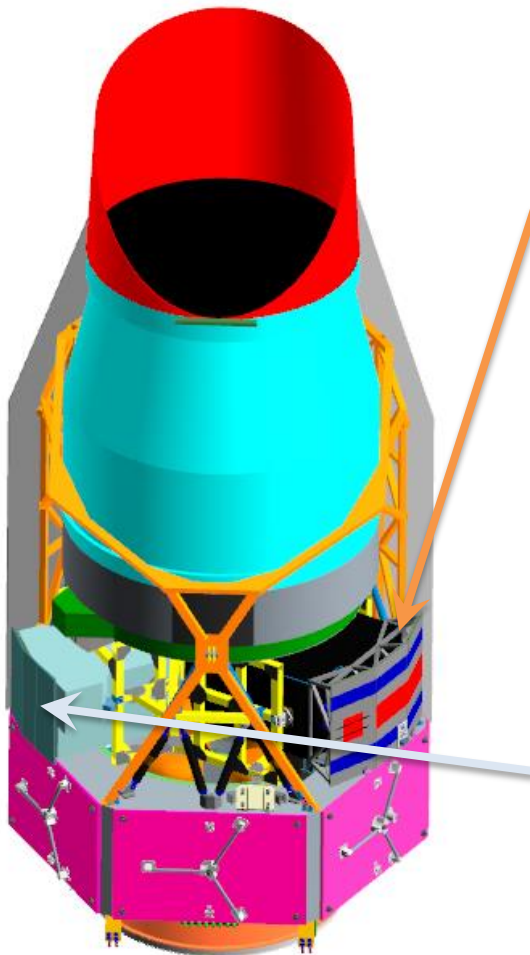
- Produce Hubble quality infrared sky images and spectra over 1000's of square degrees of sky
- Determine the expansion history of the Universe and the growth history of its largest structures in order to test possible explanations of its apparent accelerating expansion including Dark Energy and modifications 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% competed in following years.

## 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

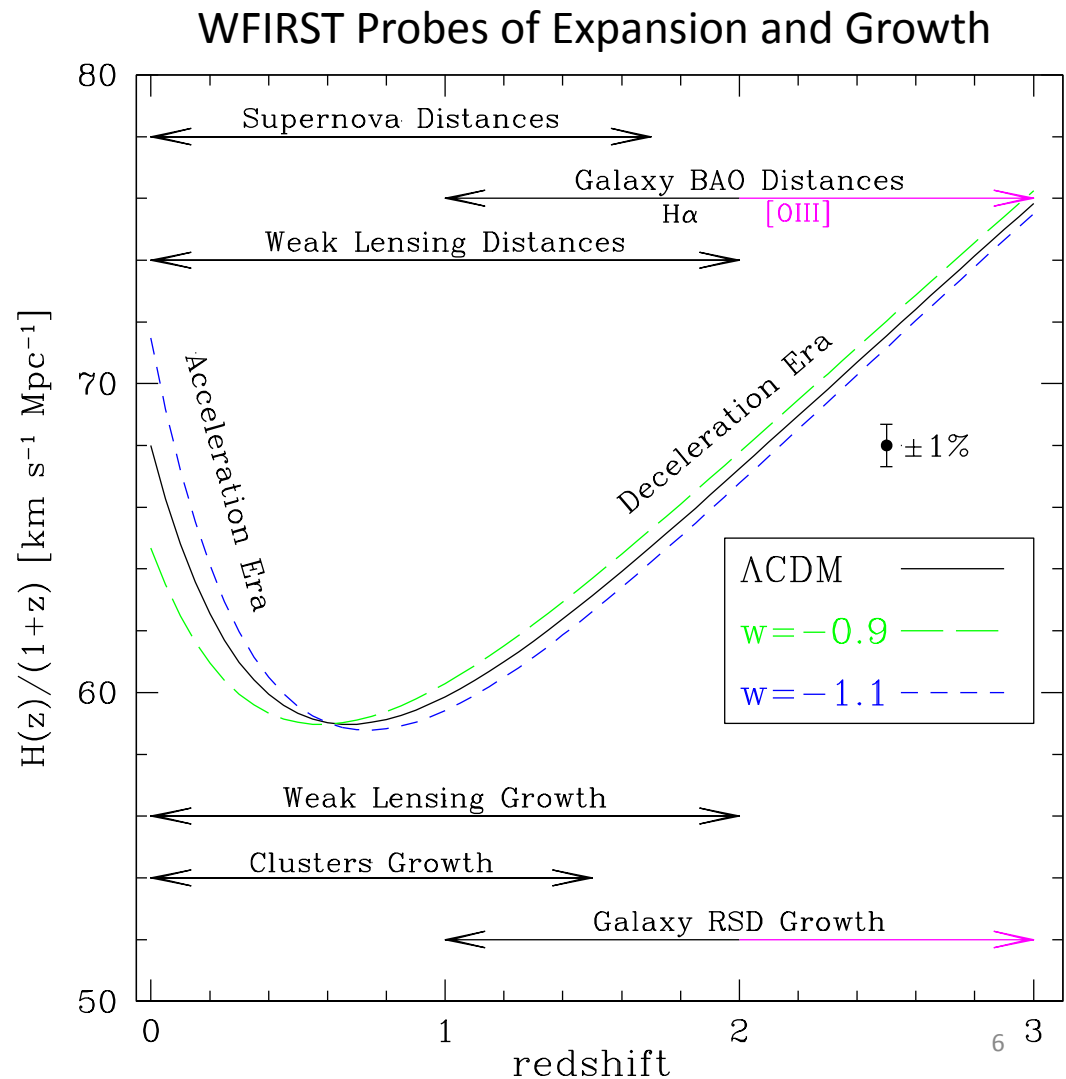




# Premier Dark Energy Observatory

- 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

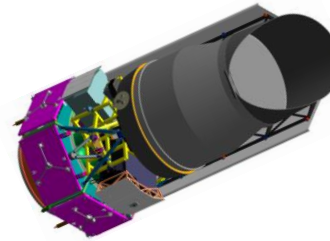


# Microlensing Exoplanet Survey

WFIRST  
complements  
Kepler, TESS,  
Plato

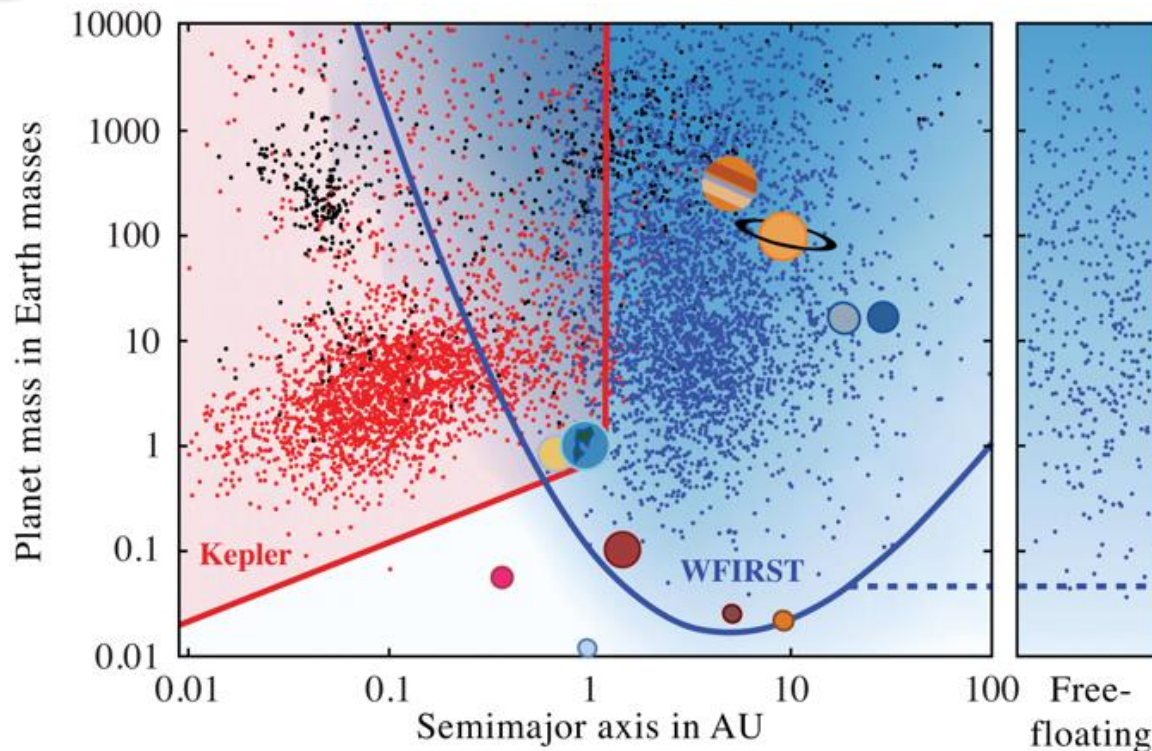


Kepler



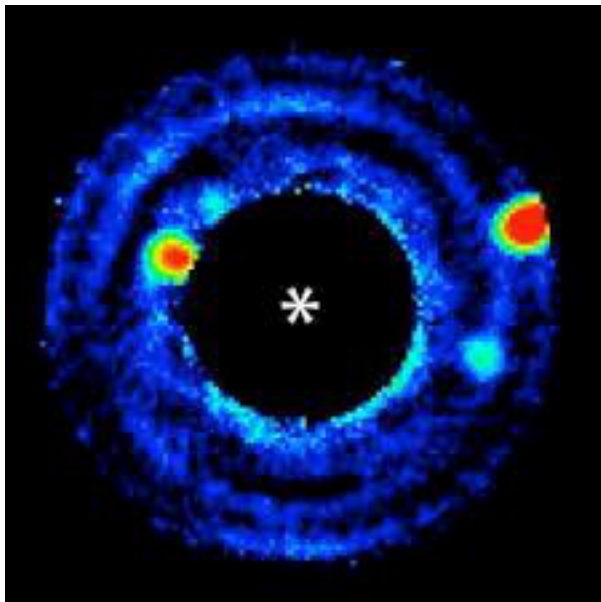
WFIRST

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

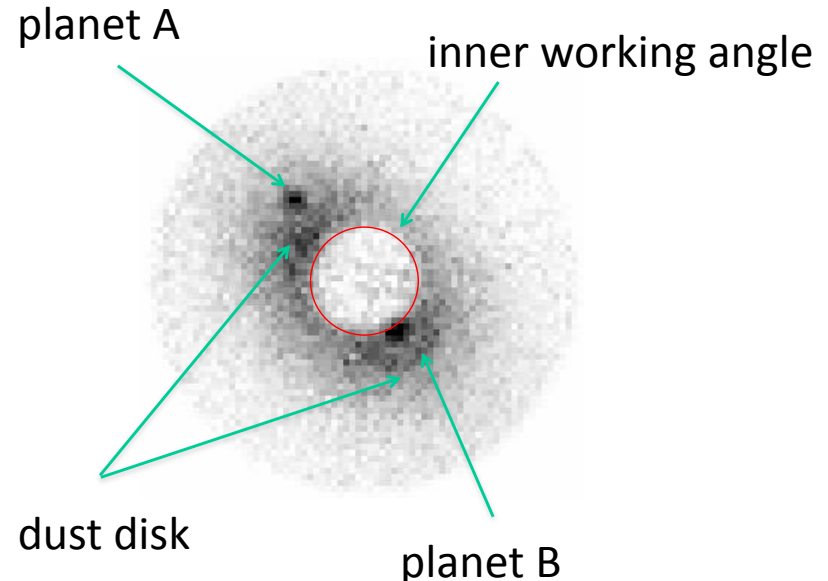


- Imaging at high contrast provides for direct detection and spectroscopy (characterization) of exoplanets

## Concept



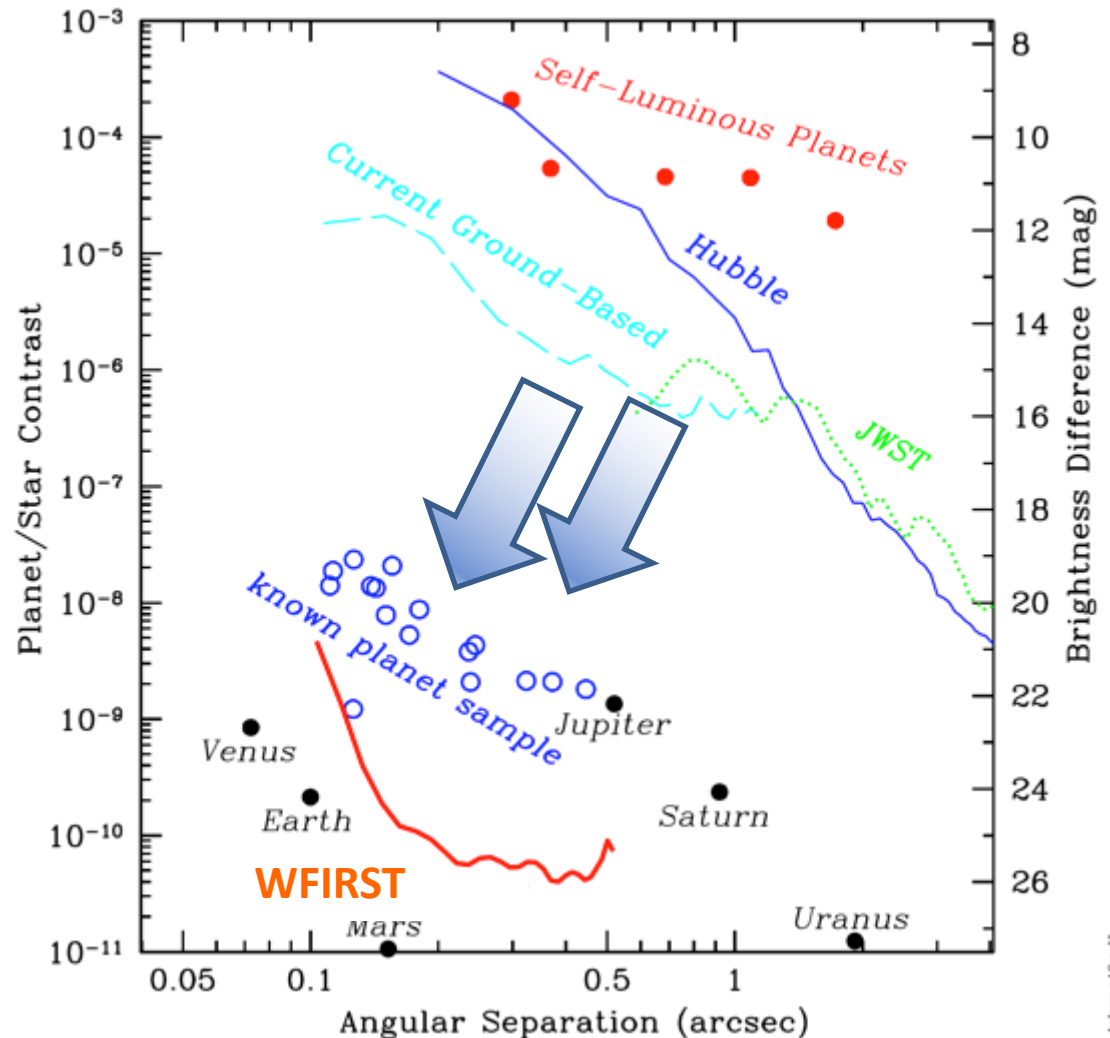
## WFIRST Simulation



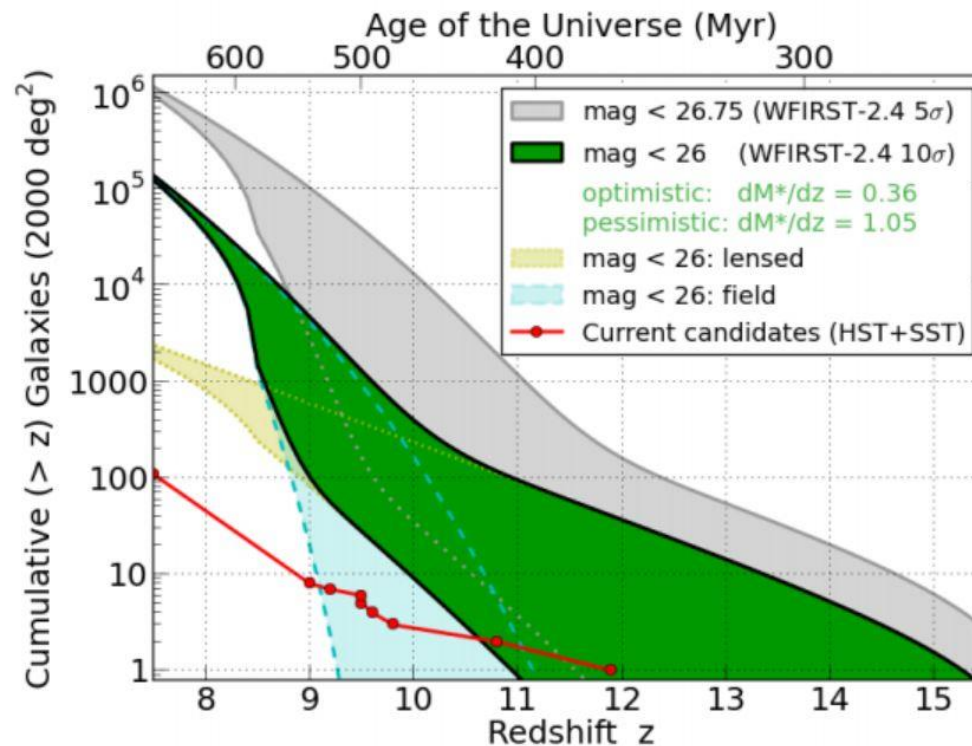


# WFIRST Brings Humanity Closer to Characterizing exo-Earths

- 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



- 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



Name	Affiliation	Role
Neil Gehrels, <b>Chair</b>	NASA/GSFC	Project Scientist
David Spergel, <b>Deputy Chair</b>	Princeton University	WFI Adjutant Scientist
Jeremy Kasdin, <b>Deputy Chair</b>	Princeton University	CGI Adjutant Scientist
Dominic Benford, <i>ex officio</i>	NASA/HQ	Program Scientist
Dave Bennett	UMBC & GSFC	Microlensing
Ken Carpenter, <i>ex officio</i>	NASA/GSFC	Project science
Roc Cutri, <i>ex officio</i>	IPAC	Science center
Olivier Doré	NASA/JPL	Cosmology: GRS+WL
Ryan Foley	UIUC	Supernova Cosmology
Scott Gaudi	Ohio State U.	Microlensing
Chris Hirata	Ohio State U.	Cosmology: WL
Jason Kalirai	JHU & STScI	GI/GO – Galactic science
Jeff Kruk, <i>ex officio</i>	NASA/GSFC	Project science
Nikole Lewis	STScI	Coronagraph
Bruce MacIntosh	Stanford	Coronagraph
Roeland van der Marel, <i>ex officio</i>	STScI	Science center
S. Perlmutter	UC Berkeley	Supernova Cosmology
James Rhoads	Arizona State	GI/GO – Cosmic Dawn
Jason Rhodes, <i>ex officio</i>	NASA/JPL	Project science
Aki Roberge	NASA/GSFC	Coronagraph
Brant Robertson	UC Santa Cruz	GI/GO – Galaxy evolution
Alexander Szalay	Johns Hopkins	GI/GO – Archival science
Wes Traub, <i>ex officio</i>	NASA/JPL	Project science
Maggie Turnbull	GSF & SETI	Coronagraph
Yun Wang	Caltech/IPAC	Cosmology: GRS
David Weinberg	Ohio State Univ.	Cosmology: Clusters
Benjamin Williams	U. Washington, Seattle	GI/GO – Nearby Galaxies



## *207 Members on selected WFIRST Science Investigation Teams!*

Aldering, Greg	Ciardi, David R	Freedman, Wendy L	Howell, Andy	Law, David R	Mellema, Garrelt	Ravindranath, Swara	Seth, Anil	Thomas, Rollin C
Anderson, Albert Jay	Connolly, Andrew	Frieman, Joshua	Hsiao, Eric Y	Lemson, Gerard	Menard, Brice	Rejkuba, Marina	Shaklan, Stuart B.	Trauger, John Terry
Baltay, Charles	Conroy, Charlie	Fruchter, Andrew S.	Hu, Renyu	Levesque, Emily M	Millan-Gabet, Rafael	Rest, Armin	Shapiro, Charles	Tumlinson, Jason
Barbary, Kyle	Crnojevic, Denija	Furlanetto, Steven R	Hudson, Michael J	Lewis, Nikole K	Miyatake, Hironao	Rhoads, James E	Shapley, Alice E	Turnbull, Margaret C
Batalha, Natalie	Dalcanton, Julianne	Gaudi, Scott	Jain, Bhuvnesh	Line, Michael Robert	Monachesi, Antonela	Riess, Adam	Shet Tilvi, Vithal	Van Dyk, Schuyler
Bean, Rachel	Dawson, Rebekah Ilene	Geha, Marla	Jang-Condell, Hannah	Lu, Jessica R	Morley, Caroline V	Roberge, Aki	Shvartzvald, Yossi	von der Linden, Anja
Beichman, Charles A.	Debes, John Henry	Girardi, Leo	Jansen, Rolf A.	Lupton, Robert	Nataf, David	Robertson, Brant	Simon, Amy A	Walker, Matthew
Bell, Eric F	Deustua, Susana E.	Goldblatt, Colin	Jarvis, Michael	Lupu, Roxana E	Newman, Jeffrey A	Robinson, Tyler D	Smith, Kendrick M	Wang, Lifan
Benson, Andrew J	Dickinson, Mark E.	Gordon, Karl D	Jensen, Hannes	Macintosh, Bruce	Nugent, Peter	Rodney, Steven A	Snyder, Gregory F	Wang, Yun
Bohlin, Ralph C	Dolphin, Andy	Gould, Andrew	Jha, Saurabh W	Madau, Piero	Padmanabhan, Nikhil	Rogers, Leslie A	Soummer, Remi	Wechsler, Risa
Bolatto, Alberto D	Dore, Olivier P	Greene, Jenny E	Johnson, L C	Madhusudhan, Nikku	Papovich, Casey J	Roman-Duval, Julia	Sparks, William B.	Weinberg, David H
Boyer, Martha L	Dressler, Alan	Greene, Thomas	Johnston, Kathryn V	Malhotra, Sangeeta	Peek, Joshua	Rosenfield, Philip	Spergel, David N	Wheeler, Coral Rose
Braganca, Vinicius M	Duchene, Gaspard	Groff, Tyler D	Juric, Mario	Mandel, Kaisey S	Penarrubia, Jorge	Rozo, Eduardo	Stark, Christopher C	Wheeler, J. Craig
Bryden, Geoffrey	Dvorkin, Cora	Guhathakurta, Puragra	Kalirai, Jason	Mandelbaum, Rachel	Penny, Matthew T	Rubin, David	Stark, Daniel	White, Richard L.
Budavari, Tamas	Eifler, Tim Frederik	Heap, Sally	Kane, Stephen R	Mandell, Avi M	Perlmutter, Saul	Sako, Masao	Stassun, Keivan	Williams, Benjamin F
Bullock, James	Fall, Michael	Heitmann, Katrin	Kasdin, Jeremy	Marley, Mark S	Perrin, Marshall D	Sales, Laura V	Strader, Jay	Willman, Beth
Burns, Christopher	Fan, Xiaohui	Helou, George	Kelly, Patrick	Marois, Christian	Phillips, Mark M	Samushia, Lado	Strolger, Louis-Gregory	Windhorst, Rogier A.
Burrows, Adam Seth	Ferguson, Henry C.	Henderson, Calen B	Kessler, Richard	Marrone, Dan	Poleski, Radek	Sand, David	Stubbs, Christopher	Wold, Isak G
Cahoy, Kerri	Filippenko, Alexei	Hinz, Philip	Kiessling, Alina	Martin, Nicolas	Pontoppidan, Klaus	Sanderson, Robyn E	Suntzeff, Nicholas	Wood-Vasey, Michael
CalchiNovati, Sebastiano	Finkelstein, Steven L	Hirata, Christopher	Kim, Alex	McConnachie, Alan	Postman, Marc	Sandstrom, Karin M	Szalay, Alexander	Woosley, Stan
Capak, Peter	Foley, Ryan J	Ho, Shirley	Kirshner, Robert	McElwain, Michael	Price-Whelan, Adrian	Savransky, Dmitry	Takada, Masahiro	Yee, Jennifer C
Carey, Sean Joseph	Foreman-Mackey, Daniel	Hounsell, Rebekah	Krause, Elisabeth	McGlynn, Thomas	Pueyo, Laurent	Scolnic, Dan	Teplitz, Harry I	Yoshida, Naoki
Chaname, Julio	Fortney, Jonathan J	Howard, Andrew	Lang, Dustin	Meixner, Margaret	Rabinowitz, David	Seiffert, Michael	Thakar, Aniruddha R	Zackrisson, Erik

# 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.

- 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).

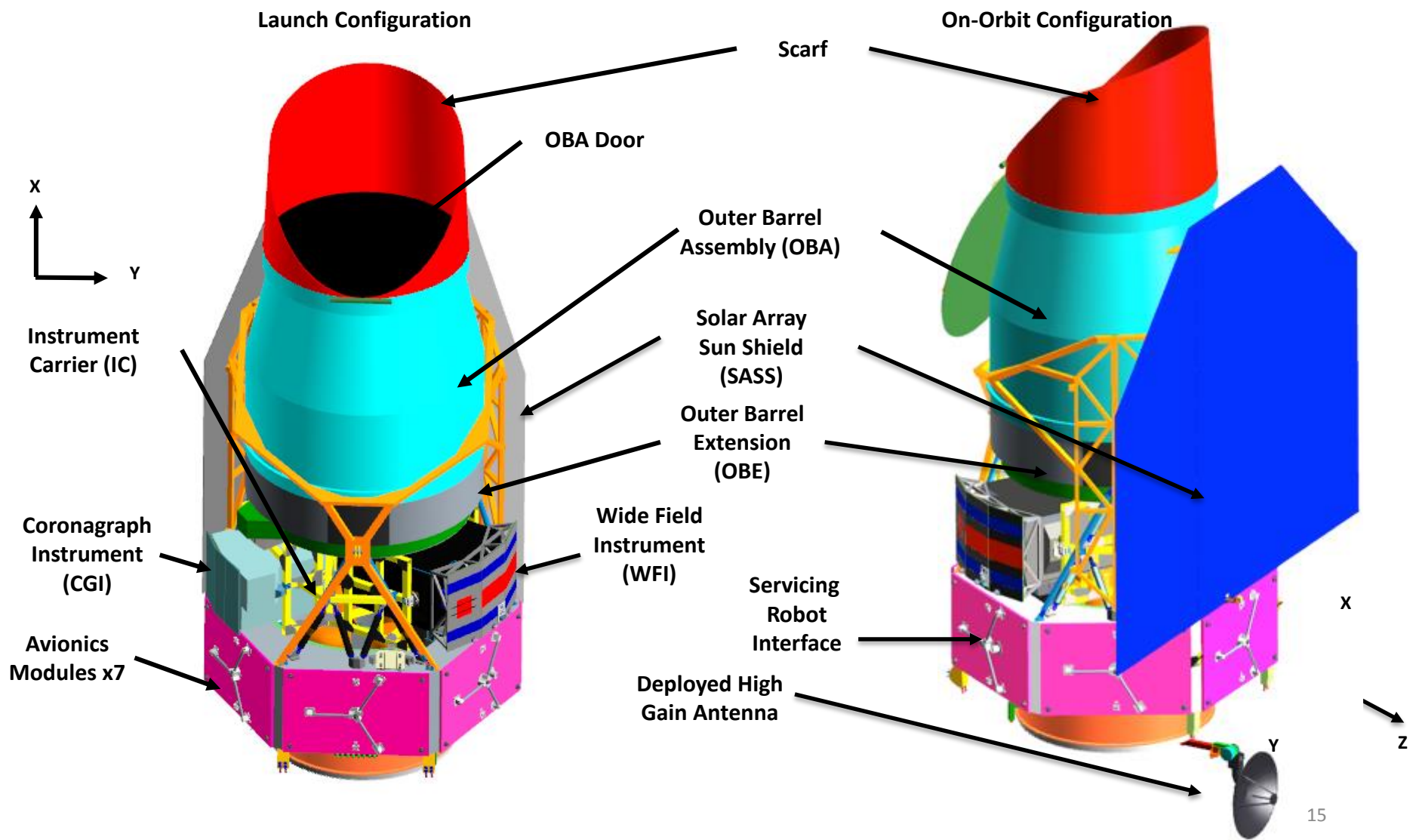




# WFIRST

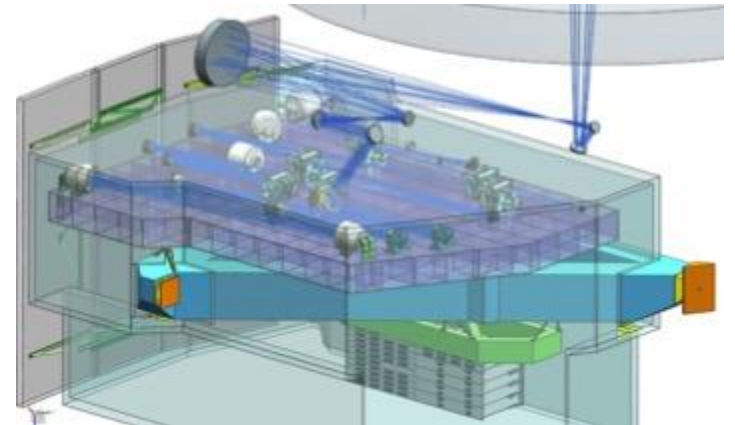
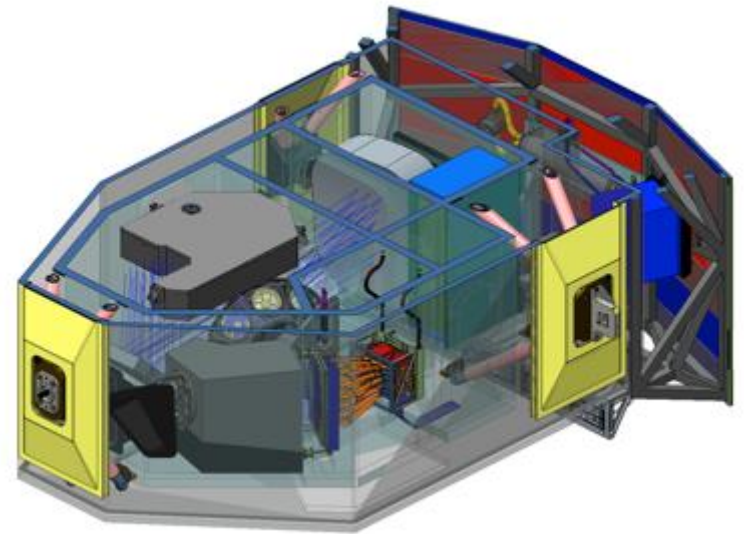
WIDE-FIELD INFRARED SURVEY TELESCOPE  
DARK ENERGY • EXOPLANETS • ASTROPHYSICS

## Observatory Configuration

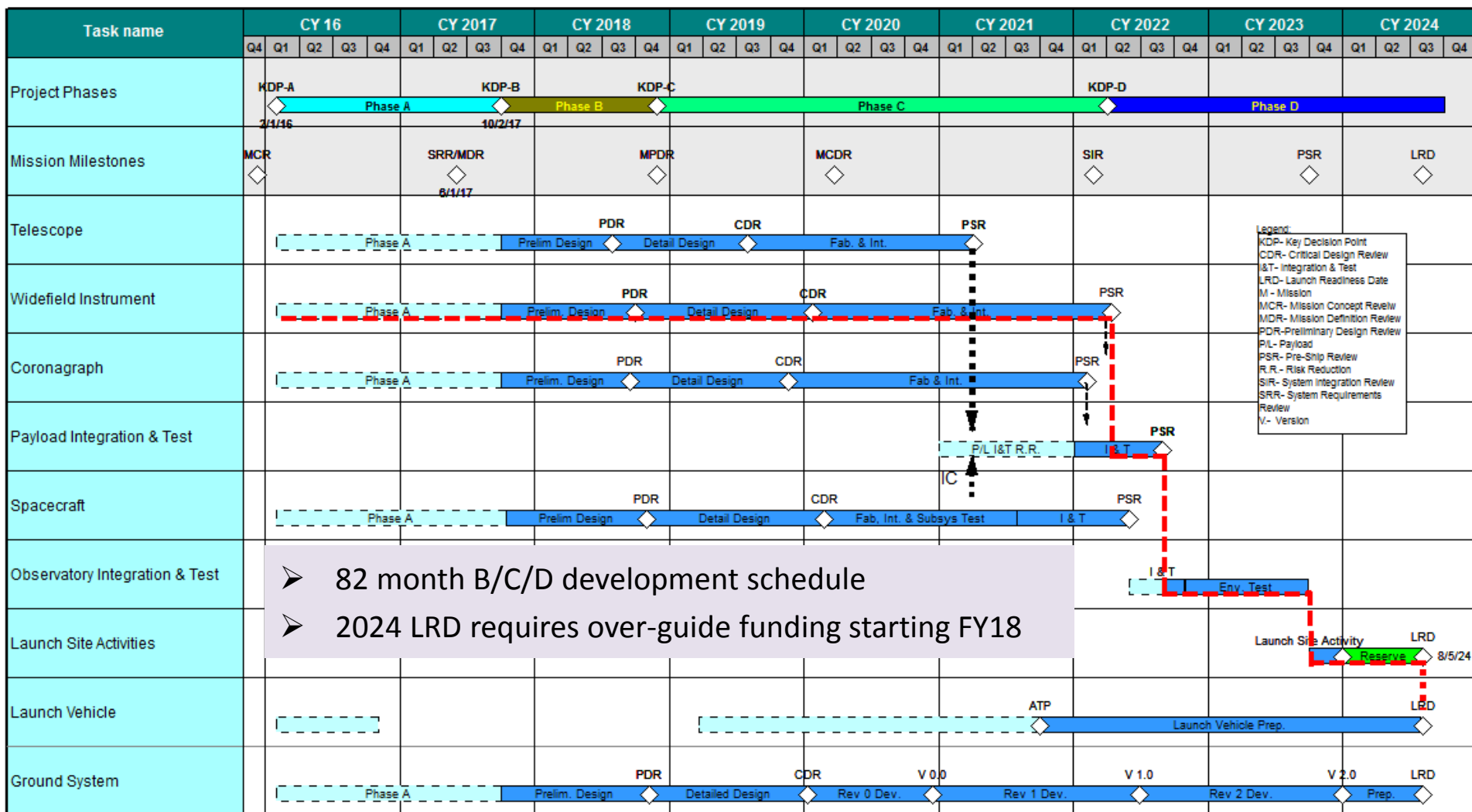


# WFIRST Instruments

- 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.

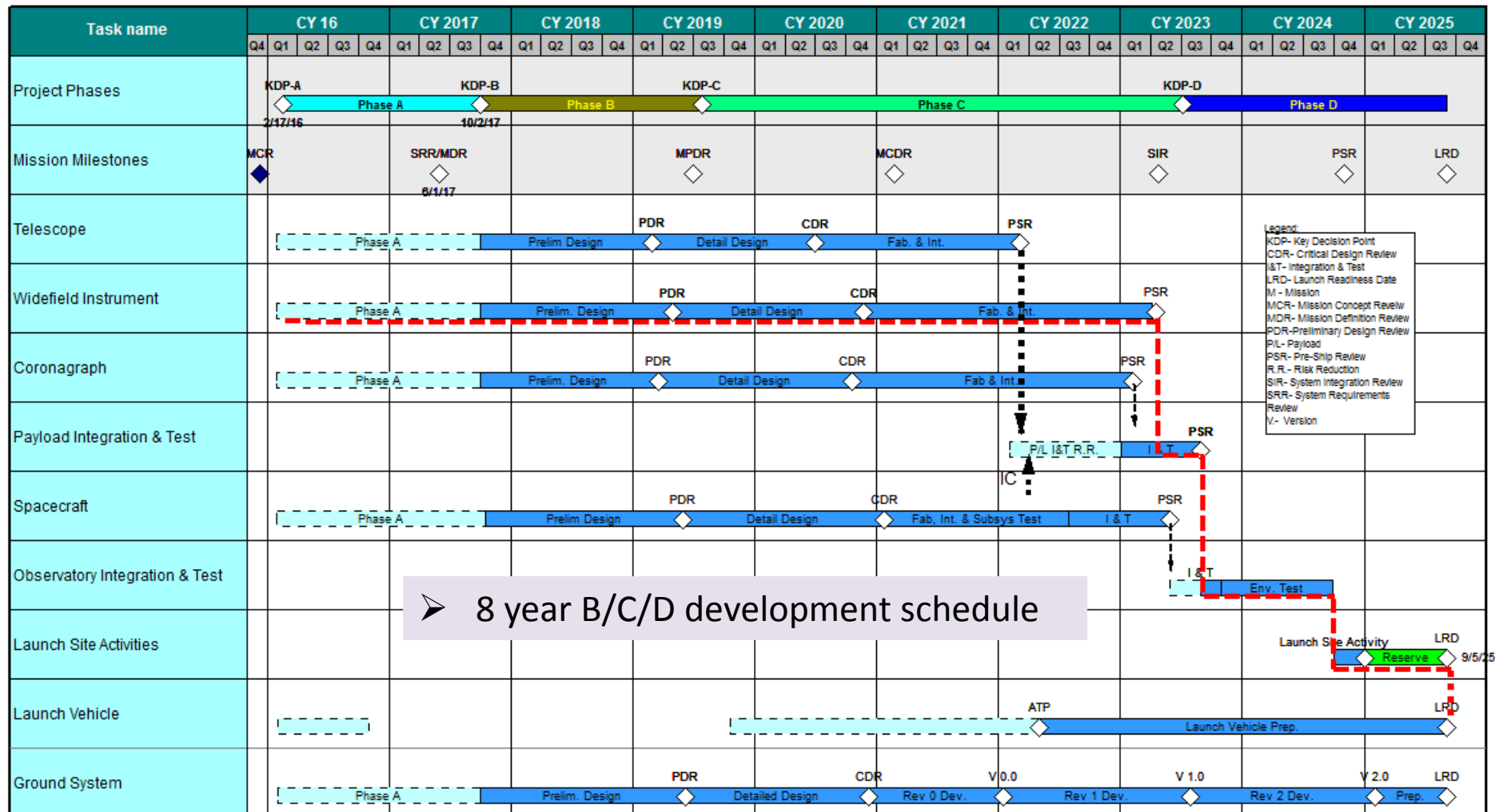


# Mission Schedule – 2024 LRD Overguide Schedule





# Mission Schedule – 2025 LRD In-Guide Schedule



# 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

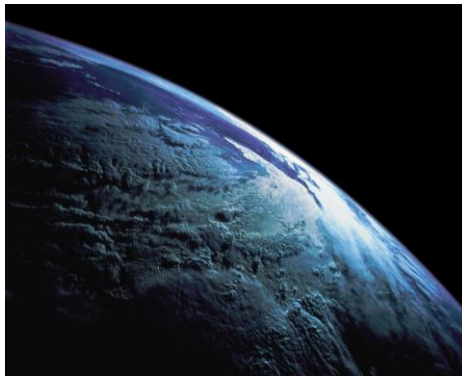
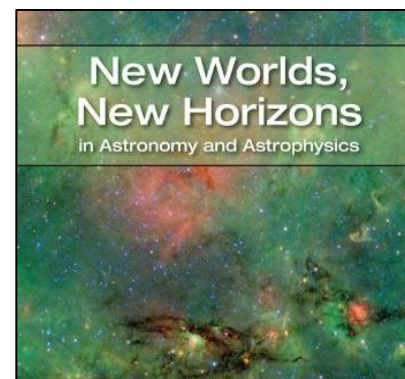


Hits 5/6 NASA Strategic Goals

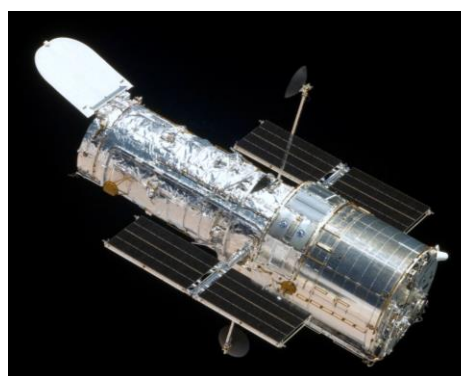
Addresses all 3 APS performance goals

#1 Priority of Astro Decadal Survey

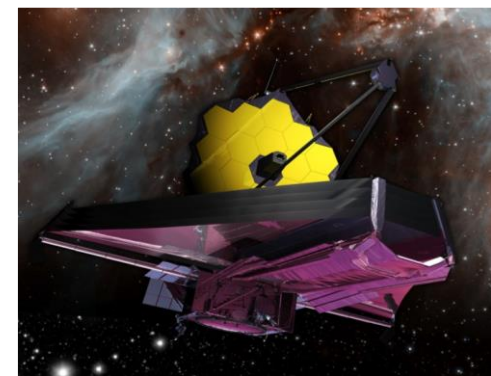
Brings the Universe to STEM education



Foundation for discovering Earth-like planets



Hubble's clarity over 10% of the sky



Complements and enhances JWST science





Back-up

- **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.*





# Formulation Science Working Group

## CHAIR & CO-CHAIRS

Neil Gehrels	GSFC
Jeremy Kasdin	Princeton
David Spergel	Princeton

## SCIENCE TEAM PIs

Olivier Doré	JPL
Ryan Foley	U. Illinois
Scott Gaudi	Ohio State
Jason Kalirai	Johns Hopkins
Bruce Macintosh	Stanford
Saul Perlmutter	LBNL
James Rhoads	Arizona State
Brant Robertson	UC Santa Cruz
Alexander Szalay	Johns Hopkins
Margaret Turnbull	SETI Institute
Benjamin Williams	U. Washington

## SELECTED SCIENCE TEAM DEPUTIES

Dave Bennett	GSFC
Chris Hirata	Ohio State
Nikole Lewis	STScI
Aki Roberge	GSFC
Yun Wang	Caltech / IPAC
David Weinberg	Ohio State

## EX-OFFICIO

Dominic Benford	NASA HQ Program Scientist
Ken Carpenter	GSFC Science Center
Roc Cutri	Caltech / IPAC Science Center
Jeff Kruk	GSFC
Jason Rhodes	JPL
Wes Traub	JPL
Roeland van der Marel	STScI Science Center