WFIRST Status

Spring 2019 Meeting of the Committee on Astronomy and Astrophysics

March 26, 2019

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WFIRST Project Manager

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• NASA GODDARD SPACE FLIGHT CENTER • JET PROPULSION LABORATORY •
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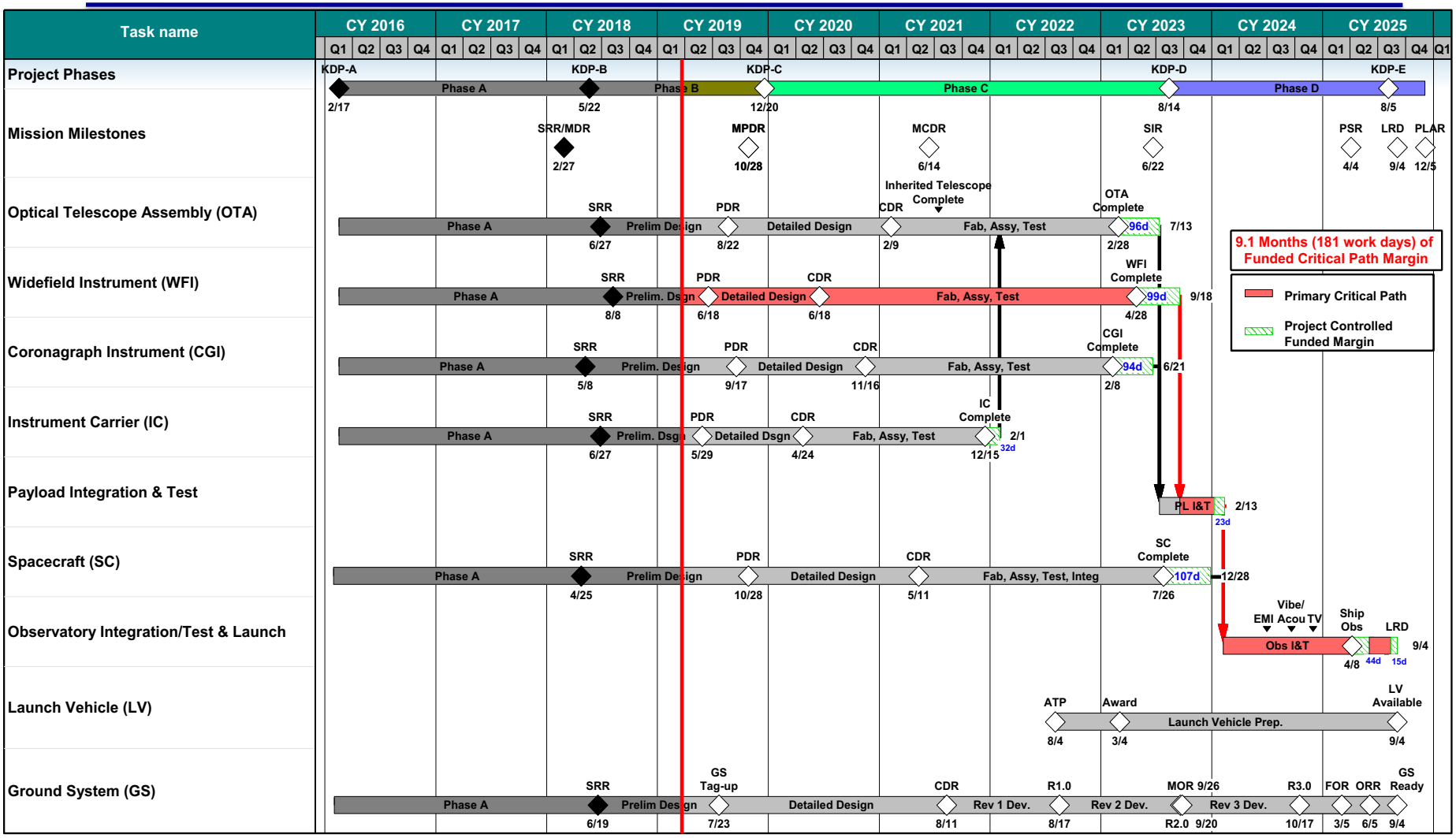
• SPACE TELESCOPE SCIENCE INSTITUTE • INFRARED PROCESSING AND ANALYSIS CENTER•

FY18 Technical Progress

- WFIRST made excellent technical progress during FY18
  - Successfully achieved KDP-B milestone and received approval to proceed to Phase B at the Agency Program Management Council on May 22, 2018
    - Project cost is $3.2B SMD Phases A-E, not including STMD contribution for coronagraph technology and HQ-held reserves; Launch Readiness Date of September 2025
  - Successfully replanned FY18 to updated budget ($150M) and ramped up to optimal funding profile as directed at the APMC
  - Selected Ball Aerospace as the Wide Field Opto-Mechanical Assembly WOMA vendor and executed contract
  - Awarded flight detector contract to Teledyne Imaging Systems and began production
  - Completed all element level System Requirements Reviews
    - Spacecraft, Instrument Carrier, Telescope, Ground System, Wide-Field Instrument and Coronagraph Instrument
    - All RFAs, Advisories closed except handful for CGI
  - Closed several key trades en route to defining overall mission architecture

WFIRST Project Master Schedule



Current Status

- Project remains on the development track established at KDP-B last year
  - Final approved FY19 budget allowed significant progress
- Successfully executed contract with Harris Corp for the Optical Telescope Assembly
  - Re-figuring of the telescope primary mirror is on track
    - Second run is in process
- Furlough impacted, but did not derail us
  - Delays were in detectors, instrument carrier and systems. These have been accounted for
- CGI phase B work is progressing in key areas, including controls, DM, emCCD detectors, electronics, active optics, processor
- Wide Field Instrument configuration is ”frozen” for Preliminary Design Review scheduled for June
- Launch Lock & Vibration Isolation System procurement released
- Reviews across the project have been scheduled for the remainder of the year
  - Over 130 planned for CY19 (component through system, peer level through Mission)
  - Mission PDR in October (was planned for December at this time last year)
- Mission systems architecture in great shape; have closed 16 of 21 key Phase B trades

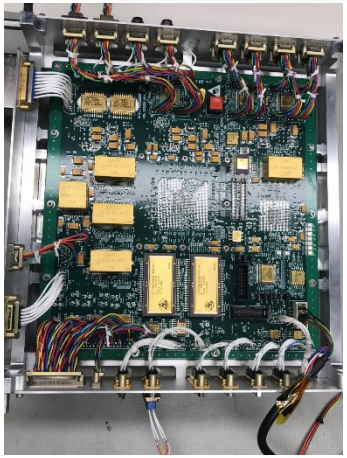
The Year Ahead

- Finalize contracts with STScI and IPAC
- Fabrication/testing of engineering development/test unit hardware ramping up; a few examples
  - Launch lock & vibration isolation system
  - Instrument latches
  - WFI focal plane electronics, grism
- Beginning/continuation of flight hardware fabrication
  - Detectors
  - Instrument latches
  - Instrument carrier structure
  - Completion of primary mirror figuring
  - Spacecraft components
- Beginning of flight hardware integration
  - OTA Tertiary Optical Mirror Assembly

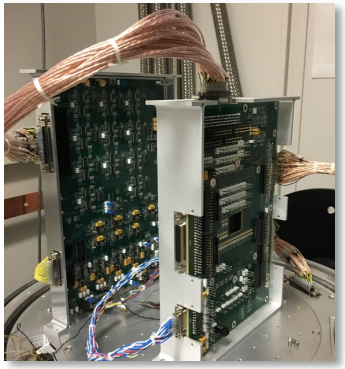
We are poised to make huge progress this year toward KDP-C/Confirmation in early CY20

Receipt of required funding will allow us to achieve it

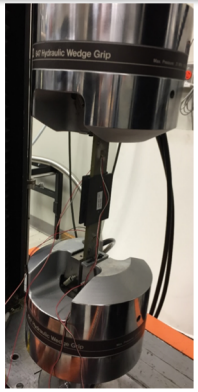
WFIRST Hardware Development



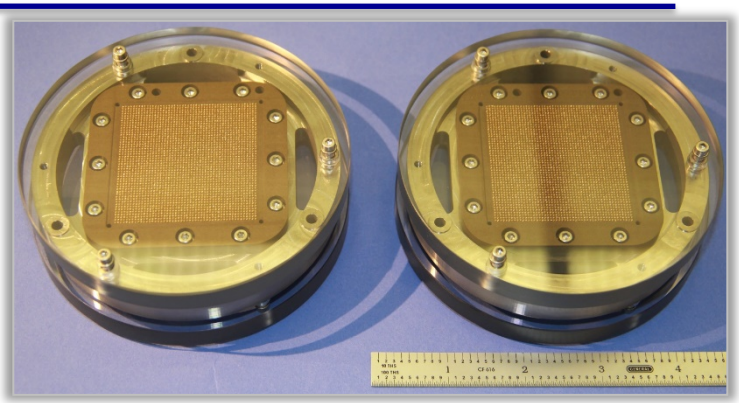
WFIRST processor card prototype



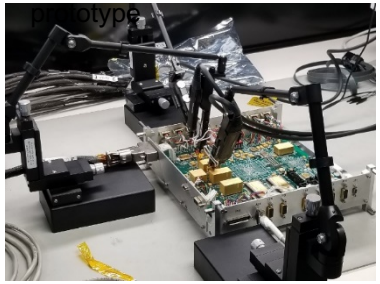
ACADIA cryogenic test setup in GSFC B11



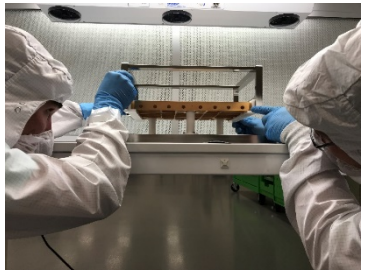
IC double lap shear testing at GSFC B30



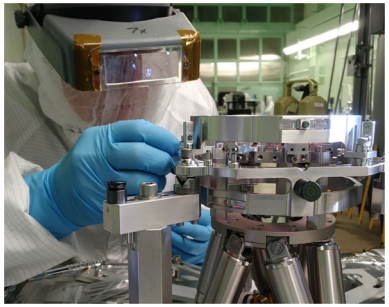
Fuzz button assembly complete and passed inspection



WPC Test Setup

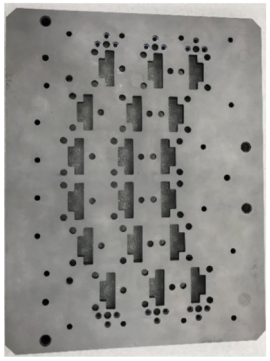


EDU Mosaic Plate Assembly

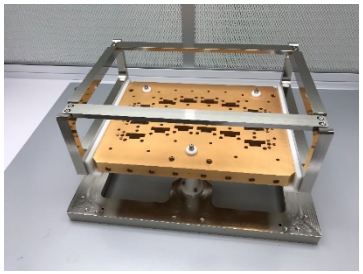


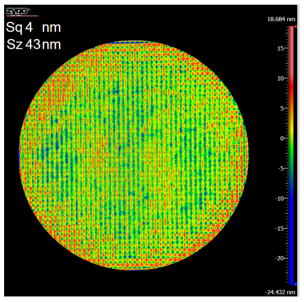
Grism E3 EDU cell bonding

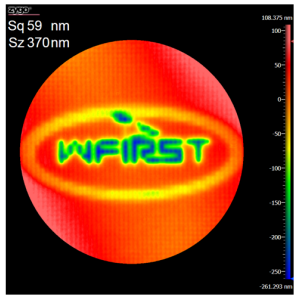
Flight SCA kits



CE6 EDU Mosaic Plate



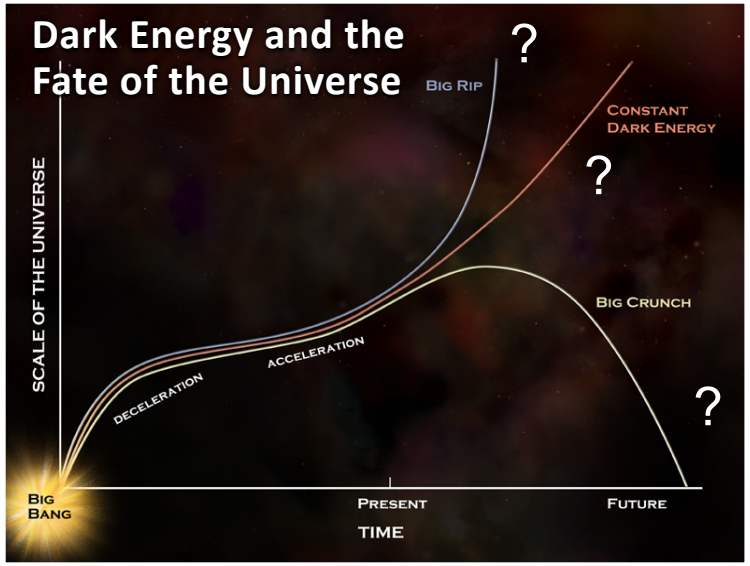


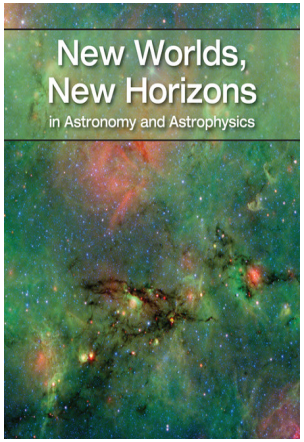


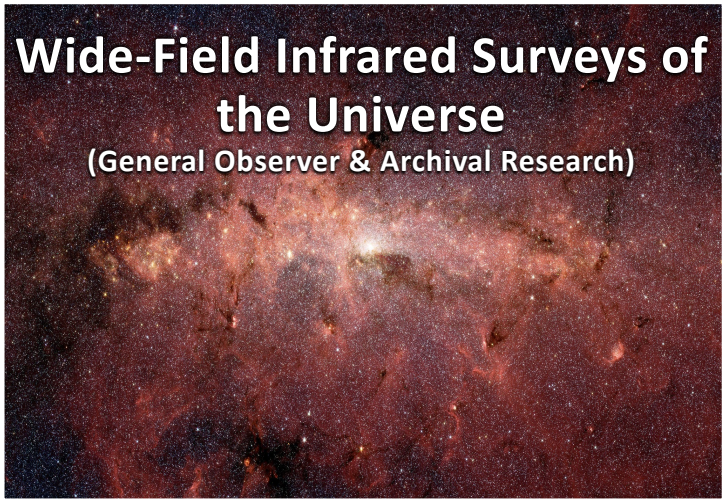
BMC DM test results
Left – flat; Right-logo

SCIENCE AND TECHNICAL UPDATE

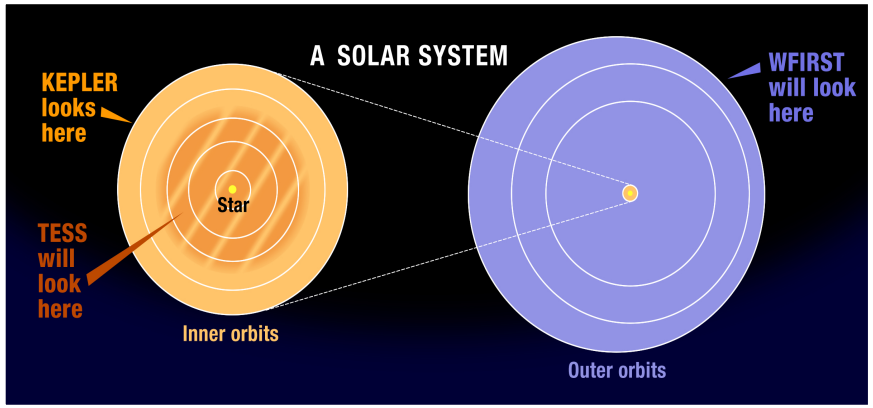
Science Program







The full distribution of planets around stars

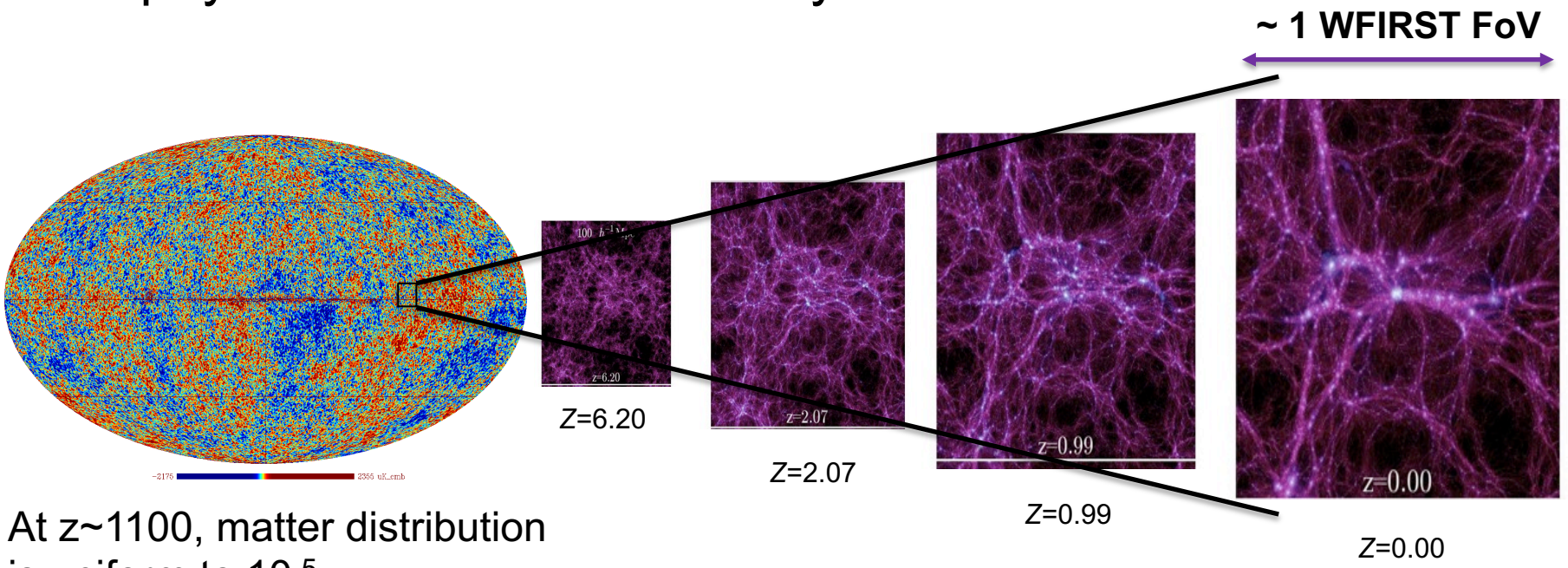


Wide FoV enables study of evolution of the Universe

WFIRST will measure expansion history *and* growth of structure

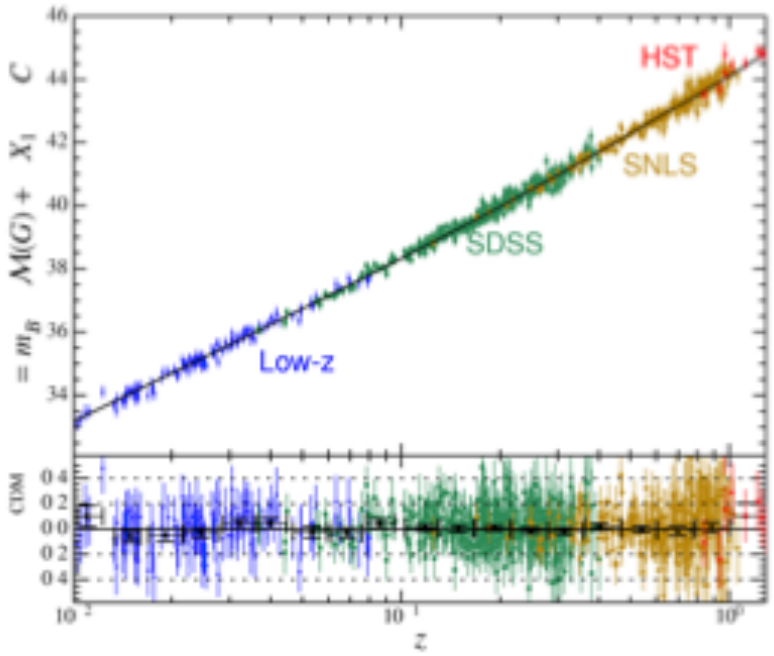
- If results discrepant -> breakdown of general relativity
- If results agree -> learn about nature of dark energy

WFIRST provides multiple probes, enabling cross-checks for astrophysical and instrumental systematics

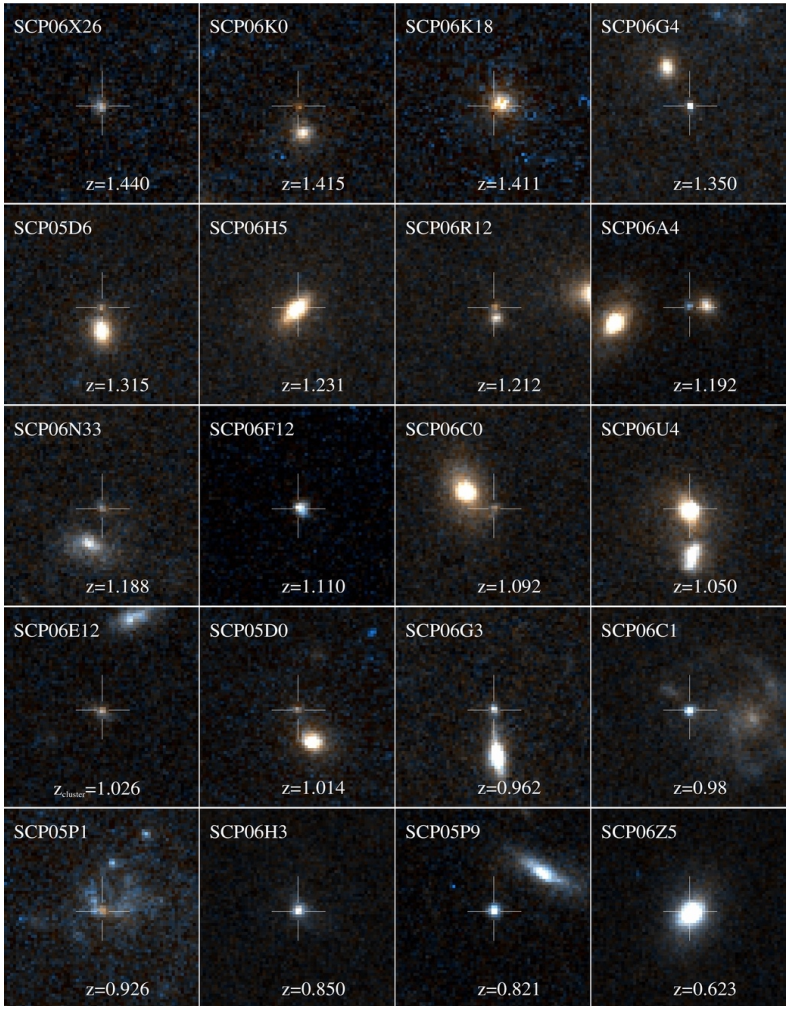


At z~1100, matter distribution is uniform to 10^{-5}

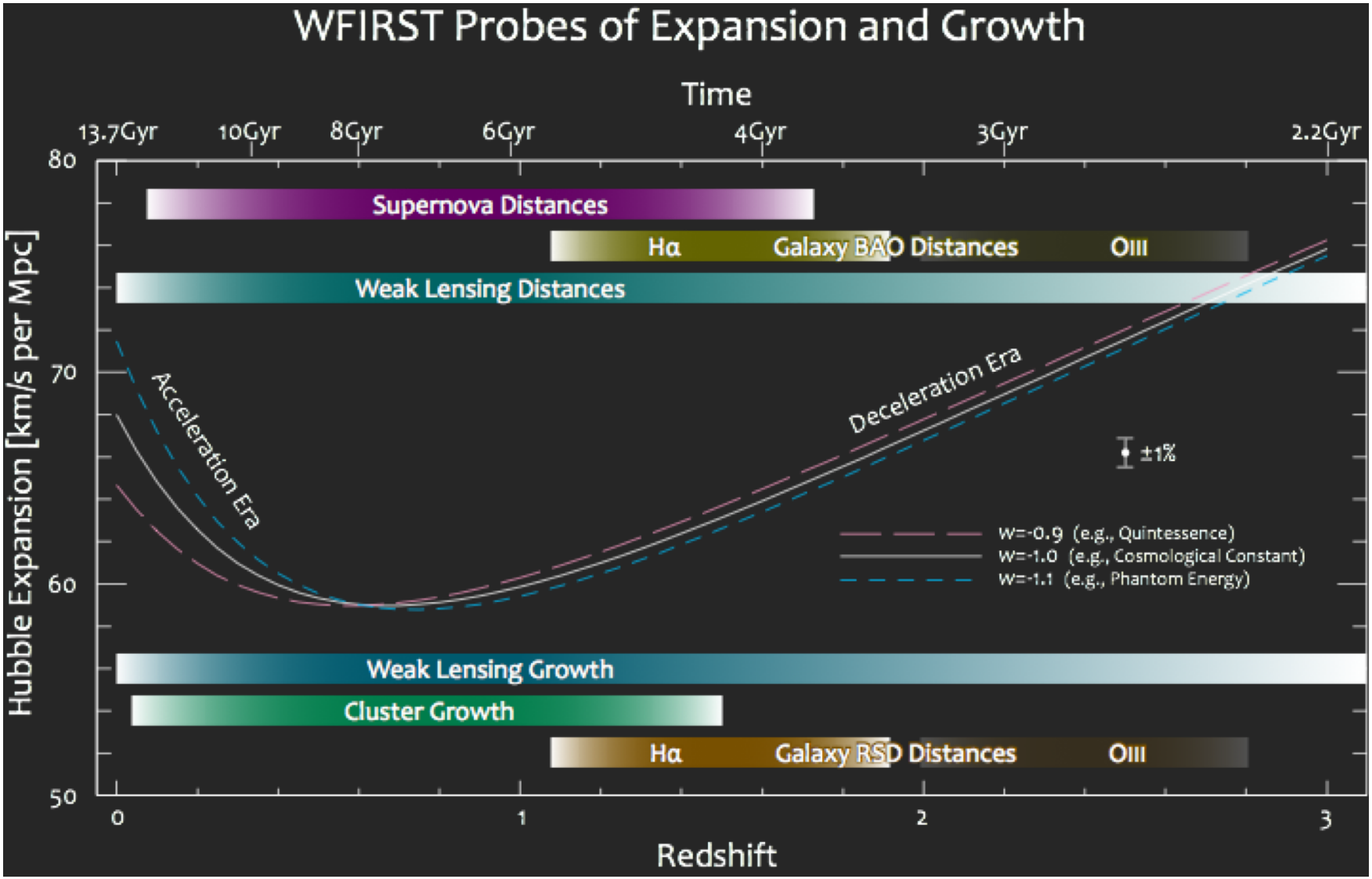
Luminosity distance from SNIa



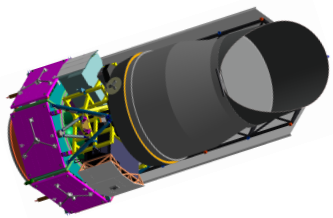
Hubble diagram from Betoule et al 2014, w/best-fit Λ-CDM model



Key next steps are to reduce systematic uncertainties, increase sample at redshift > 1

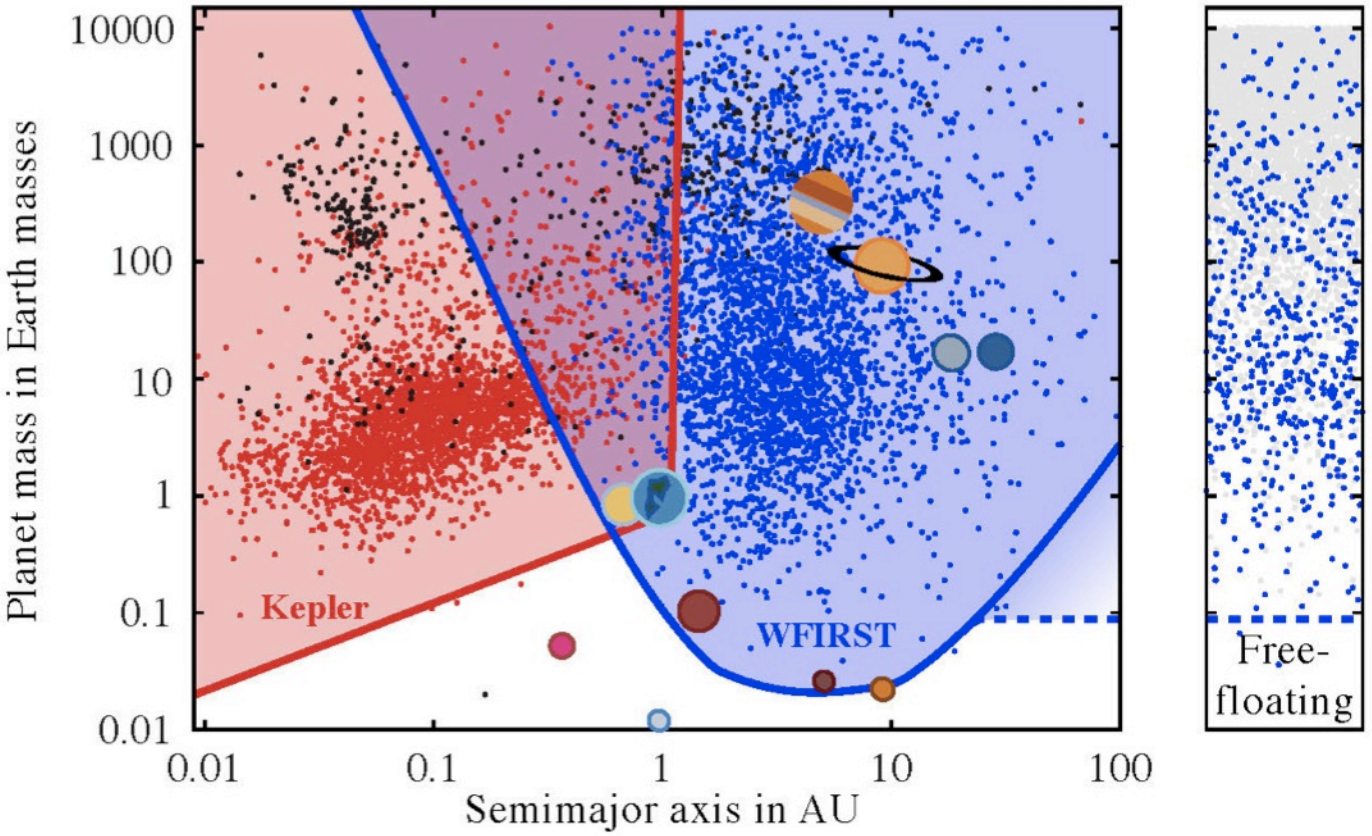

WFIRST Probes of Expansion and Growth
Time
13.7Gyr
10Gyr
8Gyr
6Gyr
4Gyr
3Gyr
2.2Gyr
Supernova Distances
Hα
Galaxy BAO Distances
OIII
Weak Lensing Distances
Acceleration Era
Deceleration Era
±1%
w=-0.9 (e.g., Quintessence)
w=-1.0 (e.g., Cosmological Constant)
w=-1.1 (e.g., Phantom Energy)
Weak Lensing Growth
Cluster Growth
Hα
Galaxy RSD Distances
OIII
Hubble Expansion [km/s per Mpc]
80
70
60
50
0
1
2
3
Redshift

Compete the Census of Exoplanets - Microlensing



Kepler

WFIRST



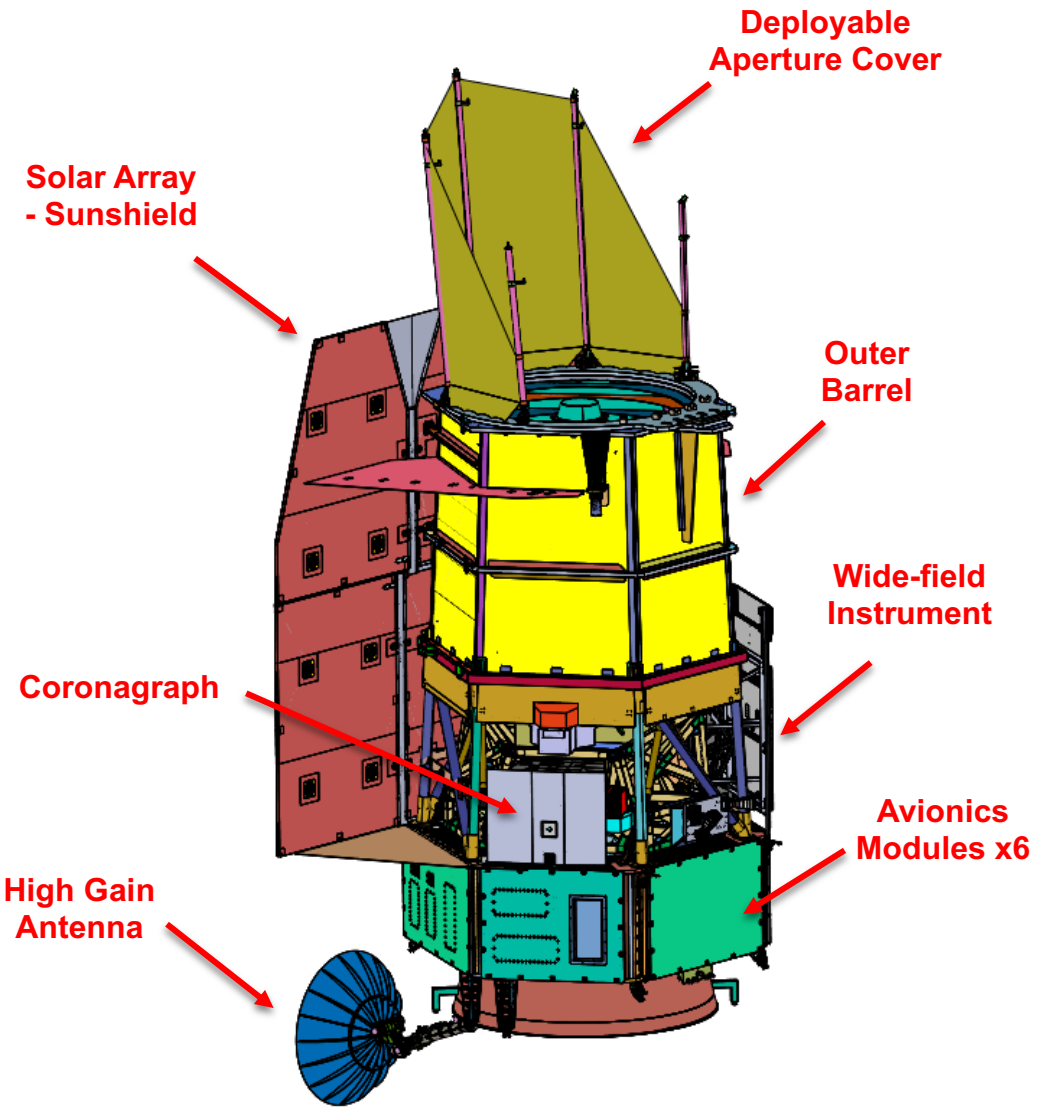
But that is just the beginning…

- Assembly and star-formation histories of galaxies
  - Nearby galaxies & globular clusters out to high redshift
  - Compare high & low density environments, including voids
- Probing the epoch of reionization
- Milky Way kinematics and formation history
- EM counterparts of GW events; multi-messenger astronomy
- Transiting planets in MW disk and bulge
- Astrometric planet detection around nearby stars
- Census of free-floating planets, neutron stars, black holes in MW disk
- Growth & evolution of galaxy clusters (+ X-ray, SZ, LSST, ELTs…)
- Cosmic infrared background
- Discovery of high-z quasars
- Stellar IMF in different environments

Technical Baseline

- Largely unchanged since SRR/MDR and last presentation to CAA
- Major exception is descope of the integral field channel
  - Had been baselined as an international contribution, which did not materialize
  - Replaced with low-dispersion prism in wide-field instrument
    - Slitless spectroscopy, with parameters optimized for Supernova program
    - Details on subsequent slides
- Ongoing design and analysis work has led to improved performance margins:
  - Reduced pupil obscuration & lower baffle temperatures
    - Improved WFI & CGI throughput, reduced WFI thermal background
  - Improved margins on wavefront stability
  - Improved margins on slew and settle time
  - Significant mass savings
  - CGI testbed performance continues to meet contrast goals

Observatory Concept



Key Features

Telescope: 2.4m aperture

Instruments:

- Wide Field Imager / Slitless Spectrometer
- Internal Coronagraph with Integral Field Spectrometer

Data Downlink: 275 Mbps

Data Volume: 11 Tb/day

Orbit: Sun-Earth L2

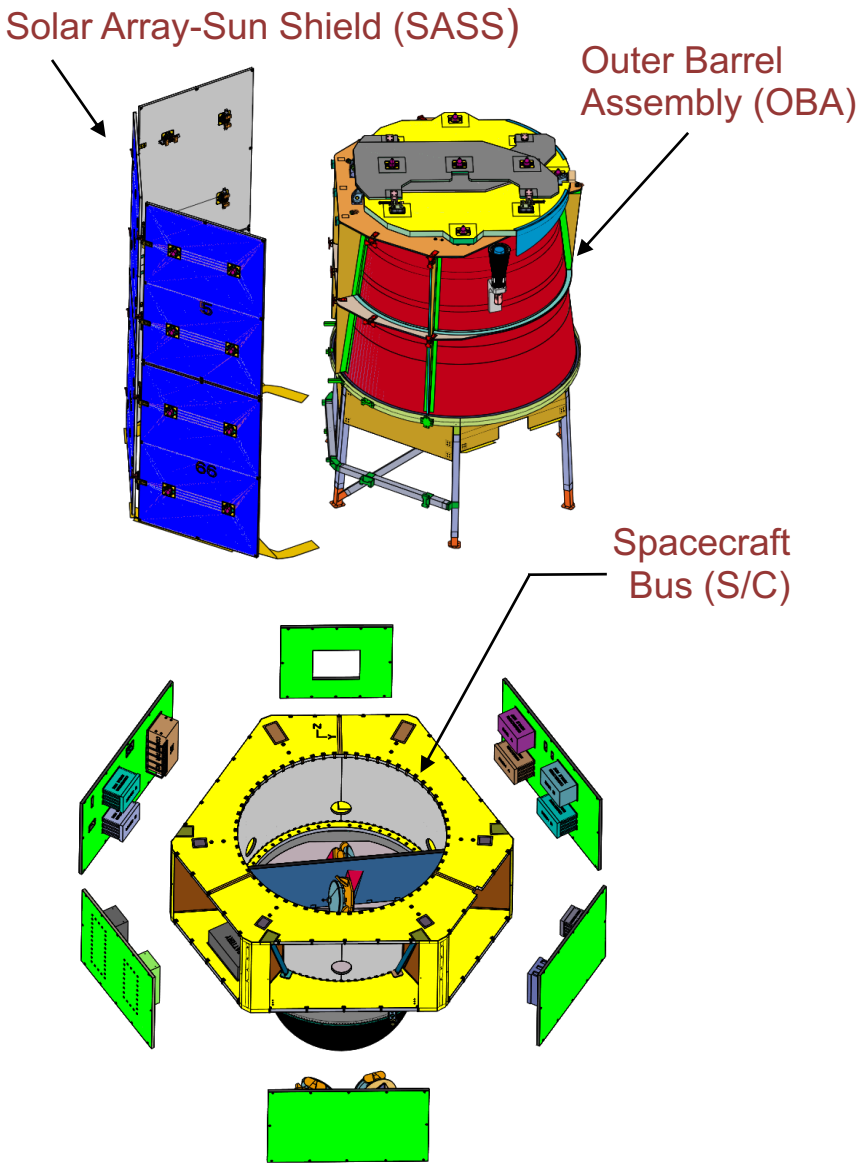
Launch Vehicle: 3 options

Mission Duration: 5 yr, 10yr goal

Serviceability: Observatory designed to be robotically serviceable

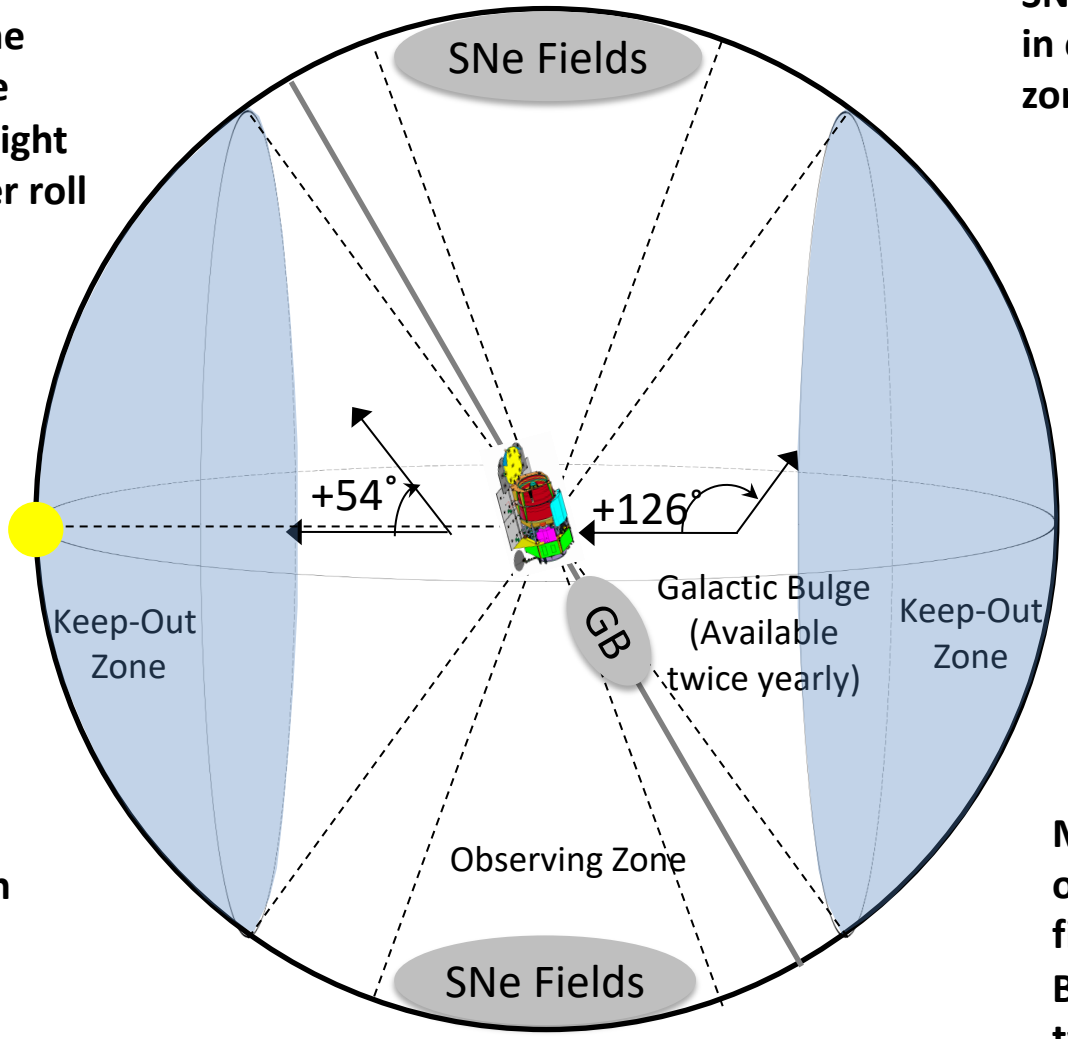
Starshade compatible

Payload expanded view



Field of Regard

Observing Zone:
- **54˚-126˚ off Sun Line**
- **360˚ about Sun Line**
- **±15˚ about line of sight (LOS) off max power roll angle**



SNe fixed fields located in continuous viewing zone

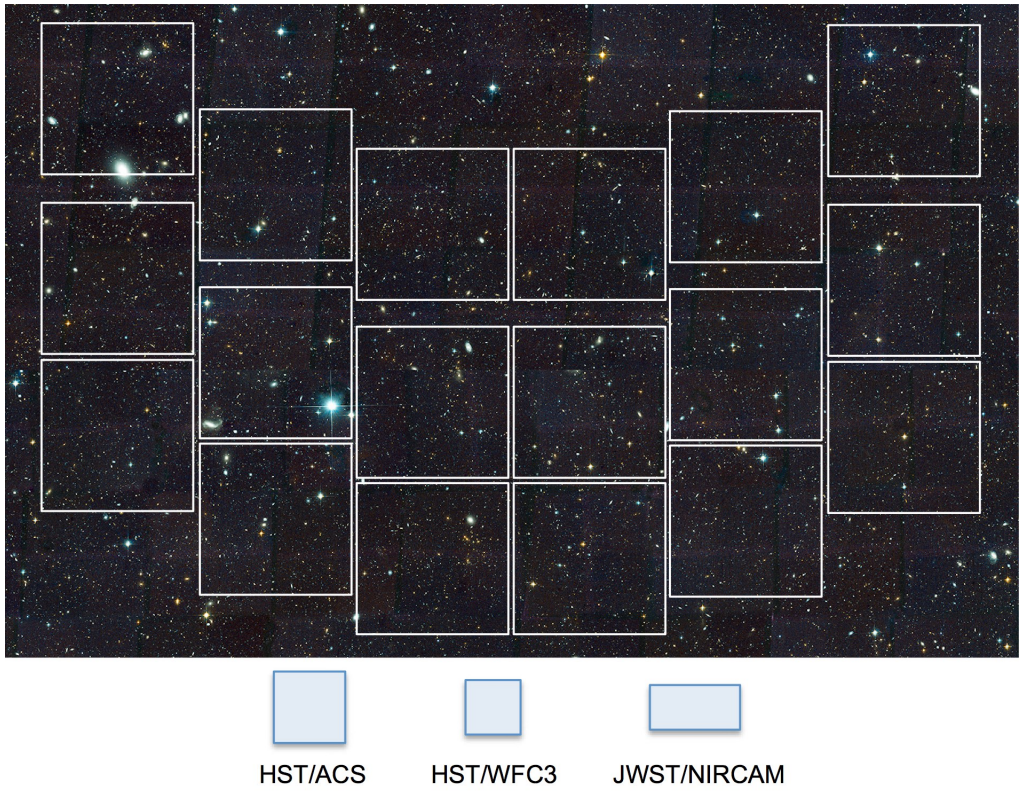
Earth/Moon LOS avoidance angles are a minor sporadic constraint

HLS/GO/Coronagraph observations can be optimized within the full Observing Zone

Microlensing can observe inertially fixed fields in the Galactic Bulge (GB) for 72 days twice a year

Wide-Field Instrument

WFIRST Field of View

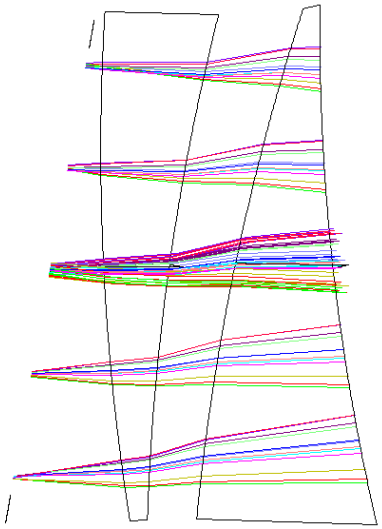


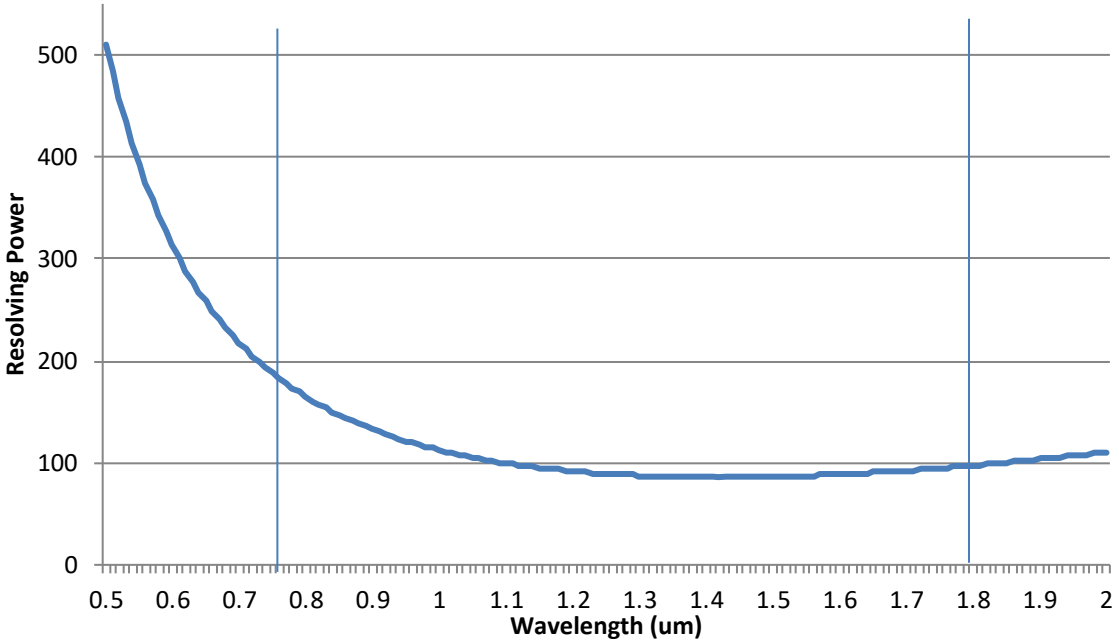
Diffraction-limited imaging
0.28 square degree FoV
0.11” pixels
18 4kx4k NIR detectors
R~4 filters spanning 0.48-2.0 μm
Sensitivity: 27.8 H(AB) @5σ in1hr

Slitless grism:
1.0-1.93 μm
R: 435-865

Slitless prism:
0.75-1.8 μm
R: 80-170

WFI – slitless prism





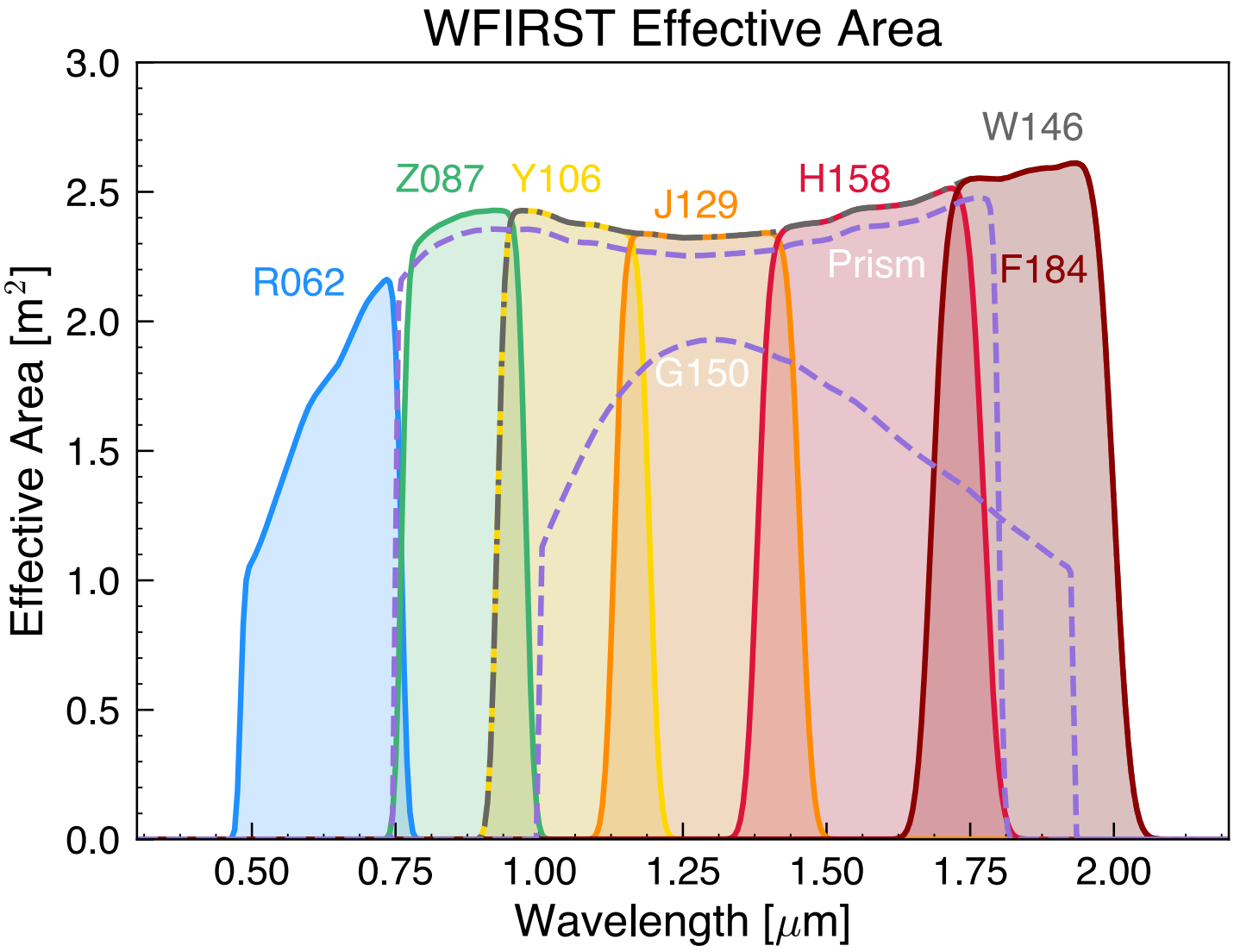
Exposure time/epoch	Max z to measure redshifts	Max z for SN Typing	Max z for SN Ia subtyping	Area surveyed using 1 month total, over 2 yrs, 5 day cadence
600 sec	1.3	1.1	0.8	8.4 deg^2
3600 sec	2.1	1.8	1.4	1.4 deg^2
9000 sec	2.2	2.1	1.8	0.56 deg^2

Observing program optimization ongoing; modeling to date shows acceptable performance over desired redshift range

WFI Filters & dispersers

Band	Element name	Min (μm)	Max (μm)	Center (μm)	Width (μm)	R
R	F062	0.48	0.76	0.620	0.280	2.2
Z	F087	0.76	0.977	0.869	0.217	4
Y	F106	0.927	1.192	1.060	0.265	4
J	F129	1.131	1.454	1.293	0.323	4
H	F158	1.380	1.774	1.577	0.394	4
	F184	1.683	2.000	1.842	0.317	5.81
Wide	F146	0.927	2.000	1.464	1.070	1.37
GRS	G150	1.0	1.93	1.465	0.930	461λ(2pix)
PRS	P127	0.75	1.80	1.275	1.05	80-170 (2pix)

WFI bandpass coverage



Representative Continuum Sensitivity

Limiting point-source sensitivity (AB mag) in 1 hour of exposure time, Zodiacal light set at twice minimum.

Imaging, 5σ						
R062	Z087	Y106	J129	H158	F184	W149
28.5	28.2	28.1	28.0	28.0	27.5	28.3

Spectroscopy, 10σ per pixel in continuum			
	0.8 μm	1.1 μm	1.5 μm
Grism	N/A	20.78	20.48
Prism	22.87	23.45	23.54

Representative Emission Line Sensitivity (grism)

Emission line flux detected at 6.5σ in one hour, with zodiacal light set at twice minimum.
Units are 10^{-17} ergs/cm^2/sec

Wavelength	Source half-light radius	
µm	0.0”	0.2”
1.05	7.8	17.0
1.15	5.6	12.25
1.25	5.0	10.5
1.35	4.8	9.7
1.45	4.8	9.6
1.55	5.0	9.8
1.65	5.5	10.5
1.75	5.9	11.3
1.85	6.7	12.3

WFIRST as a Survey Facility

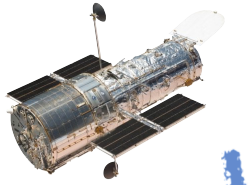
- The power of WFIRST is not *just* that it has a large field of view: it is also very efficient
  - Rapid slew & settle, no Earth occultations, no South Atlantic Anomaly
- Comparisons of total elapsed time for large HST surveys with WFIRST for equivalent area+depth:
  - 3-D HST: 1400 ksec grism spectroscopy over 0.17 sq deg
    - -> WFIRST: 1.9 ksec or 730x faster
  - COSMOS: 3300 ksec imaging over 2 sq deg
    - -> WFIRST: 26 ksec or 125x faster
  - CANDELS *Wide NIR*: 0.22 sq deg in 1790 ksec
    - -> WFIRST: 1.7ksec or 1050x faster
  - PHAT: 2360 ksec multi-band imaging over 0.5 sq deg
    - -> WFIRST: 1.6 ksec or 1475x faster

For details, see Akeson et al 2019 https://arxiv.org/abs/1902.05569

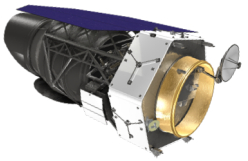
Sample GO Program
Assembly of Galaxies

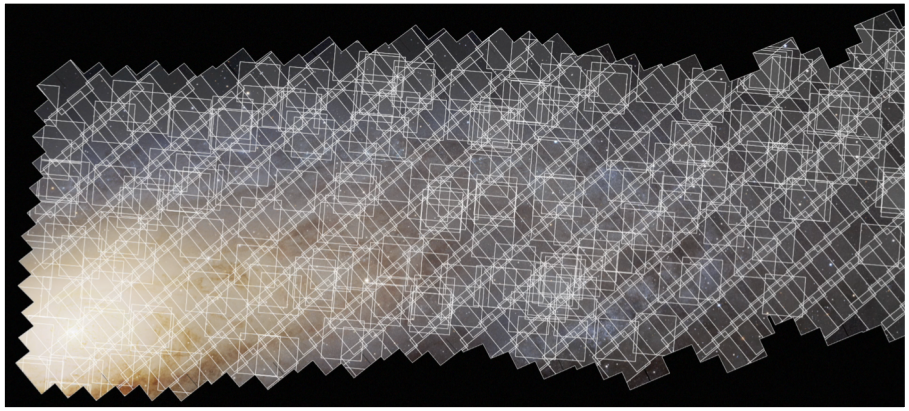
Andromeda - PHAT Survey

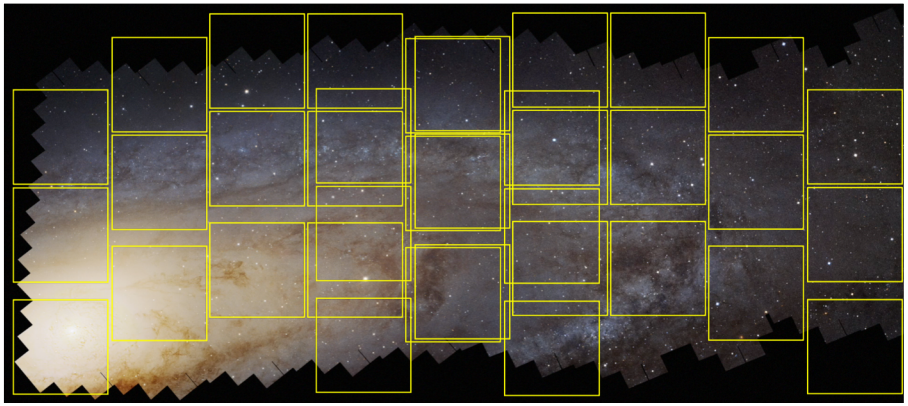
The Hubble Way
(400+ individual pointings)



The WFIRST Way
(2 pointings)

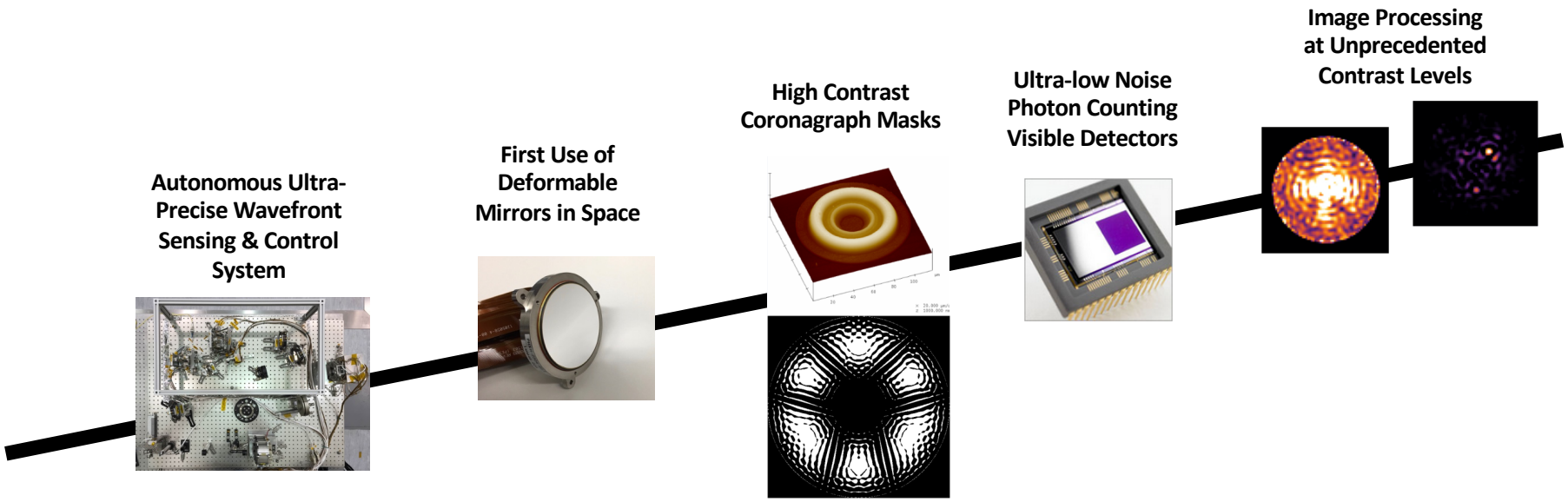






Coronagraph Technology Demonstration Instrument

Technology	• Low-order Wavefront Sensing and Control • Deformable Mirrors • Broad-band Coronagraphic Masks for Very High Contrast • Ultra-low Noise Photon Counting Detectors • High Contrast Imaging on Obscured / Discontinuous Aperture • Integral Field Spectrograph at Very High contrast



- CGI will premiere in space many key technologies required for the characterization of rocky planets in the Habitable Zone (HZ), significantly reducing the risk and cost of future possible mission concepts such as HabEx and LUVOIR
- CGI is a direct & necessary predecessor to these missions, and is a crucial step in the exploration of Sun-like planetary systems

Coronagraph Modes

- As a technology demonstration instrument, the supported modes are limited to those necessary to implement three basic observing scenarios:
  - Point-source imaging over a narrow field of view
    - Includes polarimetry of a bright source
  - Integral-field spectroscopy over a narrow field of view
  - Extended source imaging over a wide field of view
- These three "official" modes will be fully commissioned before launch.
  - the flight hardware will by fully tested with flight software before launch

CGI Filter	λ_{center} (nm)	BW	Channel	Mask Type	Working Angle	Can use w/ linear polarizers	Starlight Suppression Region
1	575	10%	Imager	HLC	3-9 λ/D	Y	360°
3*	730	15%	IFS	SPC bowtie	3-9 λ/D		130°
4	825	10%	Imager	SPC wide FOV	6.5-20 λ/D	Y	360°

* *Only change since last CAA presentation*: this filter had been at 760nm, w/18% BW

Coronagraph Modes

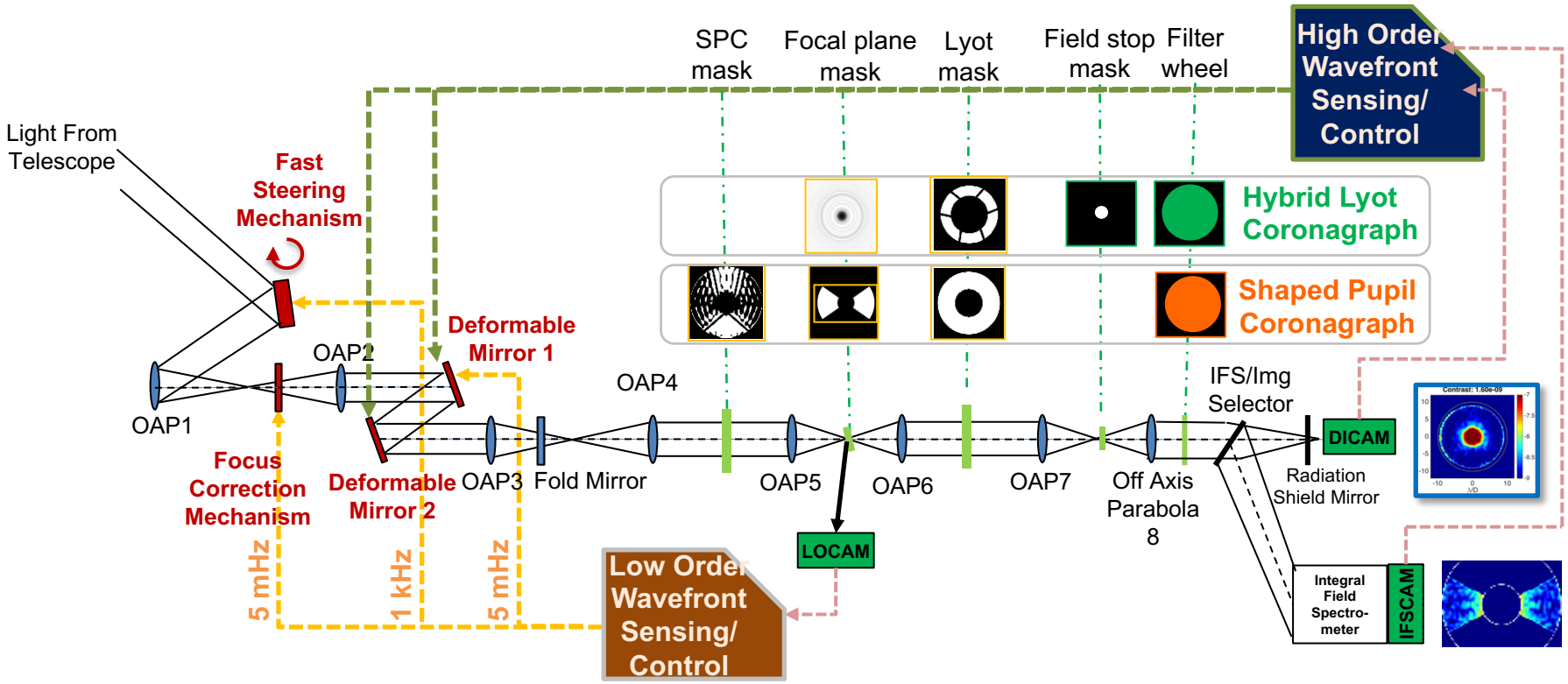
- Two additional unsupported modes are installed (highlighted rows)

CGI Filter	λ_{center} (nm)	BW	Mask Type	Working Angle	Starlight Suppression Region
1	575	10%	HLC	3-9 λ/D	360°
2	660	15%	SPC bowtie	3-9 λ/D	130°
3	730	15%	SPC bowtie	3-9 λ/D	130°
4	825	10%	SPC wide FOV	6.5-20 λ/D	360°
4	825	10%	HLC	3-9 λ/D	360°

These five masks will be installed in CGI. However, only those listed in the "official modes table" correspond to CGI requirements and will be officially supported for the tech demo phase.
Only 1 orientation of each SPC bowtie is baselined.

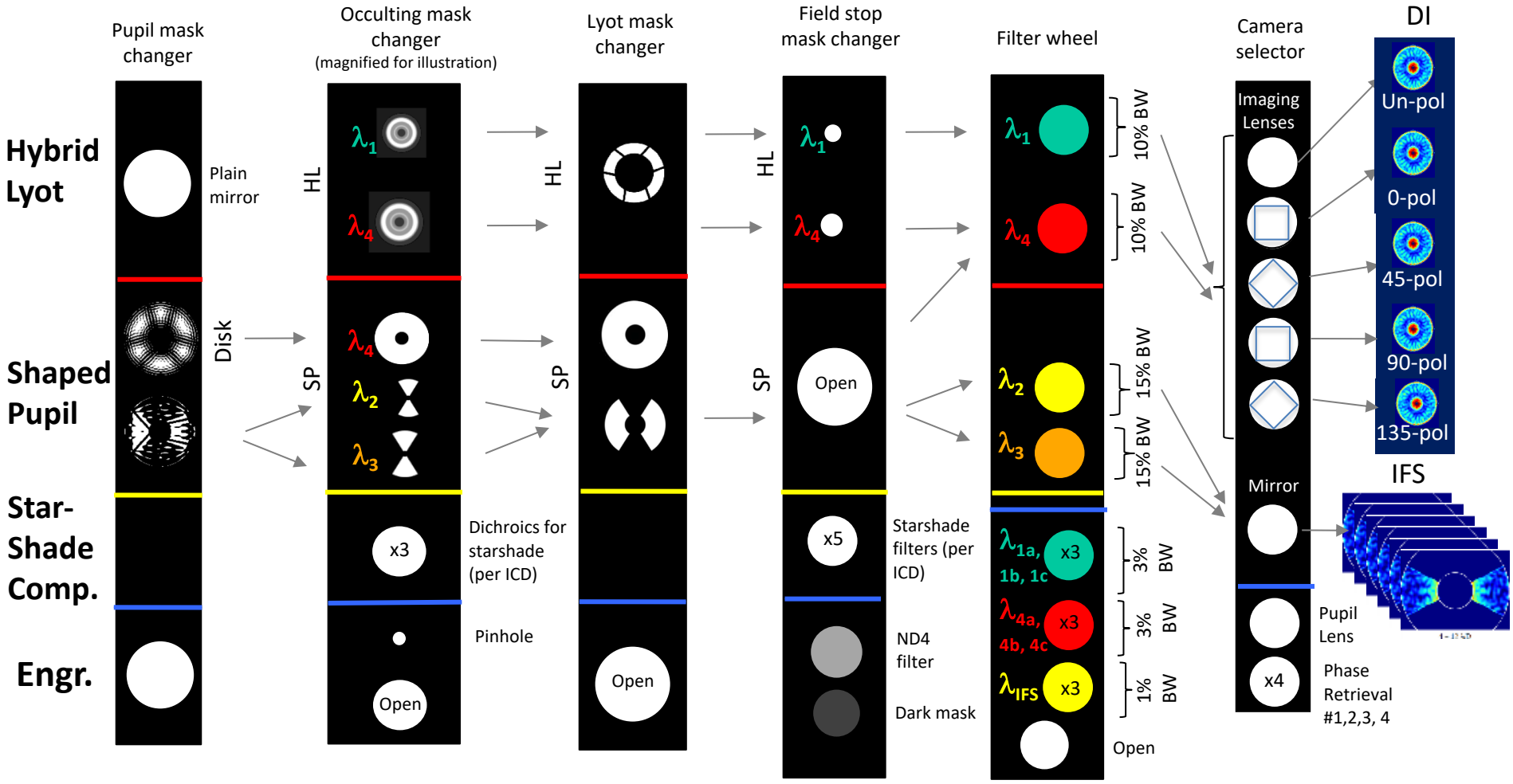
SPC = Shaped Pupil Coronagraph
HLC = Hybrid Lyot Corongraph

Coronagraph Layout



Architecture unchanged since mission SRR.

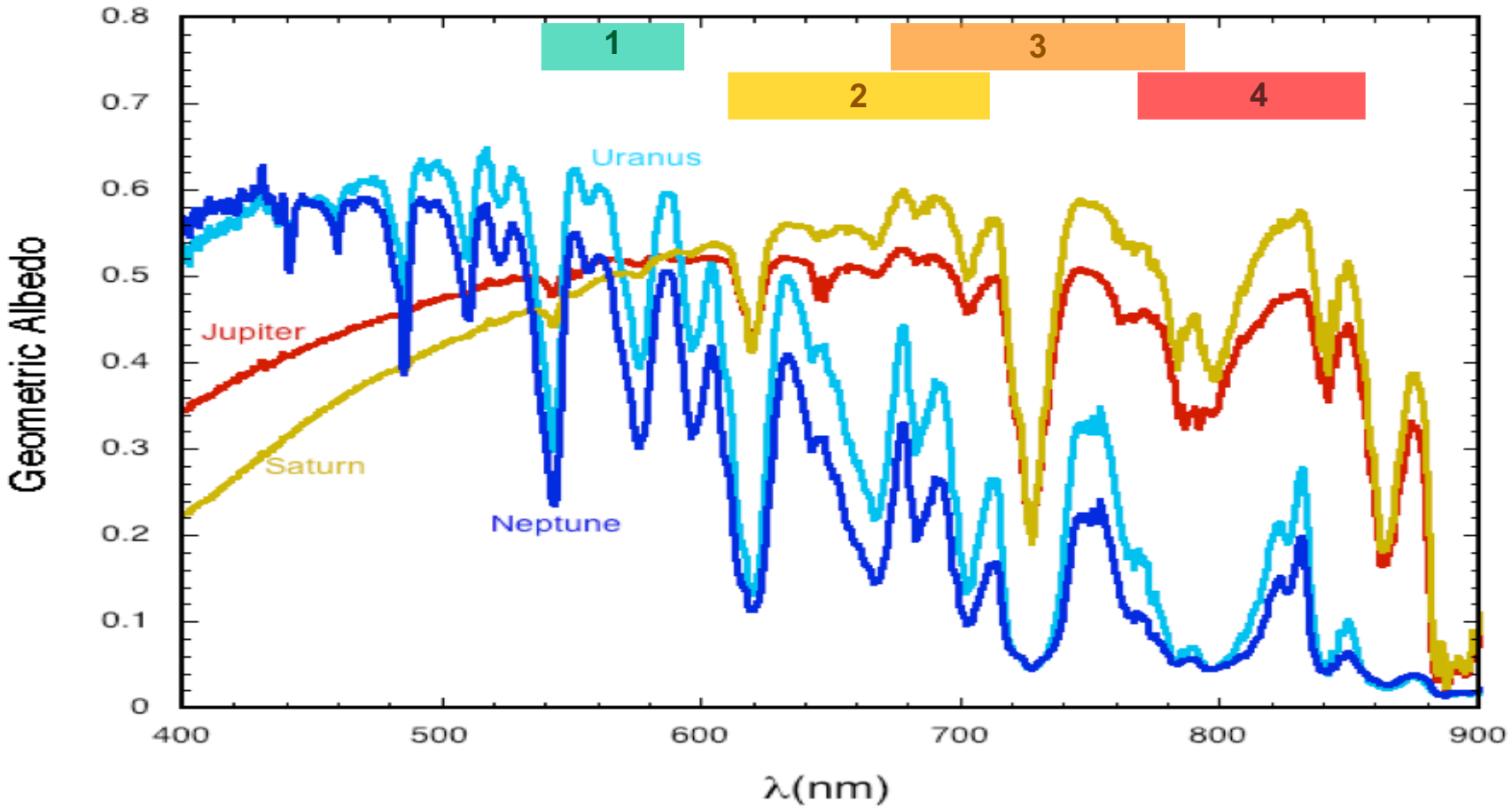
CGI filter and mask layout



λ_1=575 nm, 10% (annular, 3-9 λ/D)
λ_2=660 nm, 15% (bow-tie / IFS, 3-9 λ/D)
λ_3=730 nm, 15% (bow-tie / IFS, 3-9 λ/D)
λ_4=825 nm, 10% (annular, 3-19 λ/D)

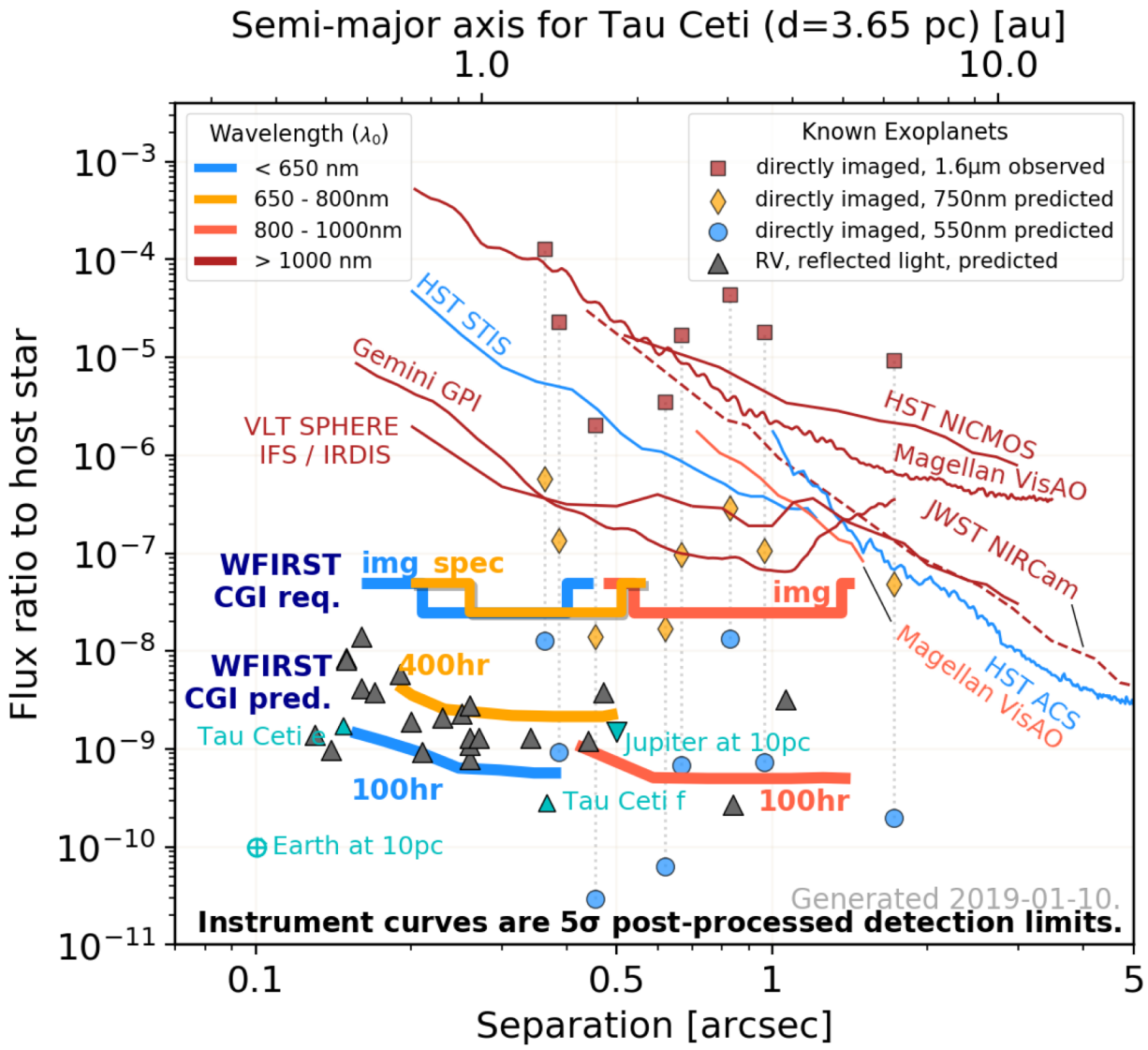
Diagram not to scale

Coronagraph Science Filters



λ_1 = 575 nm, 10% λ_2 = 660 nm, 15% λ_3 = 730 nm, 15% λ_4 = 825 nm, 10%

Coronagraph Predicted Performance



Engineering progress highlights

- Detailed design work throughout observatory and ground system
- Integrated modeling (structural-thermal-optical performance) used to validate detailed design and guide allocation of performance budgets
- Detailed signal-to-noise budgets likewise used to guide engineering trades and low-level requirements flowdown
  - New approach to OBA thermal control
  - Refined OTA thermal requirements: able to relax some requirements while simultaneously improving pupil obscuration & thermal background, reduced demands on heater power
  - New low-dispersion prism design optimized through close collaboration of optical and mechanical designers with science teams
  - New WFI design reduced mass and improved detector cooling
  - New aperture cover design reduced mass
  - CGI improving contrast over wider bandpasses w/dynamic disturbances

Science Operations

- Contracts with STScI & IPAC not yet signed, delayed by furlough
- Work on approaches to data processing, archiving, operations have continued over past year
  - Several new working groups established with Science Investigation Teams
  - Work defining pipeline architectures and processing environment has begun
  - Prototype archive environment with embedded analysis S/W environment is running – may not be final choice but is exercising many of the tools and architectures we expect to employ
  - Have some simulation tools ready for production running, others to come soon (some already public, others will be public as they become available)
    - Several square degrees of high-latitude survey imaging and grism simulations in progress
    - Several square degrees of nearby galaxies for resolved stellar populations in progress
    - Microlensing simulations for community data challenge released last Fall
    - Coronagraph simulations for community data challenge to be released later this year.

Science Investigations

- All observing time to be selected competitively
  - Some close to launch, the rest periodically thereafter
- All data will be public immediately
  - Archival research will be funded on a par with GO programs
- Scientific priorities to be updated throughout mission, based on landscape at the time
- Coronagraph available through a Participating Scientist Program
- Present Science Investigation Teams in place through CDR
  - Call for new teams to follow as soon as possible
- Some open questions:
  - How best to allocate time to large programs
  - How best to organize teams for large programs
  - Community workshops and data challenges will provide some input
    - Deep field workshop held last August
    - Microlensing community challenge & workshop last Fall & winter
    - Coronagraph data challenge/workshops later this year
    - Other topics in the future (Milky Way and nearby galaxies conference this summer)
  - Will be setting up a panel of scientists from the community to provide input.

QUESTIONS?