WFIRST Requirements Flowdown

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Requirements Flow

Program Level Requirements Appendix (PLRA)

Defines Objectives, Project organization, performance metrics, mission success criteria

Science Requirements Document

Provides flowdown from objectives to observatory & ground system capabilities

Mission Requirements Document

Provides flowdown to mission segment requirements

PLRA

- **Science Objectives**
  - **Mission Success Criteria**
    - **Science & Technical Requirements**
      (Baseline & Threshold Requirements) — **Level 1 Requirements**

- Science Requirements (SRD)
  - Mission Requirements (MRD) — Level 2 Requirements

- Instrument and Spacecraft Requirements — Level 3 Requirements
  - Component Requirements

Science Objectives

Science	Science Objective
NIR Survey	Conduct near-infrared (NIR) sky surveys in both imaging and spectroscopic modes, providing an imaging sensitivity for unresolved sources better than 26.5 AB magnitude.
Expansion History	Determine the expansion history of the Universe using GRS, WL, & SN, at redshifts up to $z = 2$ with high-precision cross-checks between techniques.
Growth of Structure	Determine the growth history of the largest structures in the Universe using WL, RSD, & Galaxy Clustering, at redshifts up to $z = 2$ with high-precision cross-checks between techniques.
Exoplanet Census	Carry out a statistical census of exoplanets from the outer habitable zone to free floating planets, including analogs to all of the planets in our Solar System $>M_{Mars}$, using microlensing.
GO Program	Devote a substantial fraction of the mission lifetime to a peer-reviewed GO program.
AR Program	Provide a public archive and a peer-reviewed archival research program.

Technology Demonstration Objectives

Technology	Technology Demonstration Objective
Active Wavefront Control	Demonstrate coronagraphy in space with an obscured aperture and active wavefront control
Coronagraph Elements	Advance the engineering and technical readiness of key coronagraph elements: coronagraph masks, low-order wavefront sensors, high actuator count deformable mirrors, low noise detectors, and integral field spectrographs.
Coronagraph Algorithms	Support development and in-flight demonstration of coronagraph software that could enhance the capability or simplify the architecture of future missions.
Performance Characterization	Perform measurements that characterize the integrated performance of the coronagraph and observatory as a function of time, wavelength, and polarization.
Data Processing	Demonstrate advanced data processing and analysis techniques required to identify, spectrally characterize and distinguish astronomical sources at high contrast.

SRD Flowdown Description

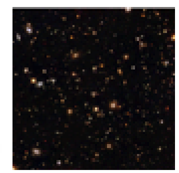

Objective

PLRA

SRD

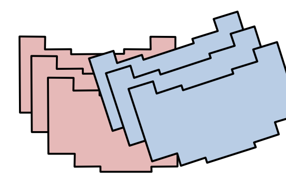
Science Requirements

Science Data Record
e.g., mosaics, catalogs



Calibrated Data Record
e.g., calibrated images

Raw Data Record
e.g., N_{images} (mag, filter, cadence)



MRD & Element Specs

Data Processing

Gnd Sys/Operations

Flight Hardware

Primary Objectives from PLRA

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

Dark Energy

Exoplanets

- Use 3 different methods to measure cosmic expansion history and growth of structure
- Enables tests of theories of accelerated expansion including Dark Energy and modifications to General Relativity

- Provide General Observer and Guest Investigator Programs for the community

- Direct Imaging (≥ Super Earth's & Disk Formation)
- Exoplanet Spectroscopy

Expand Census of Exoplanets (Outer Habitable Zone - Free floating, ≥ Mars Mass)

Science Objectives

- Dark Energy
  - Expansion History of the Universe
  - Growth of Structure in the Universe
- Exoplanets
  - Exoplanet Survey

Technology Objectives

- Demonstrate coronagraphy in space

Super-nova Survey	**High Latitude Imaging Survey**
High Latitude Spectral Survey	**Micro-Lensing Survey**

Direct Imaging

Spectro-scopy

High-Latitude Survey addresses 3 Objectives

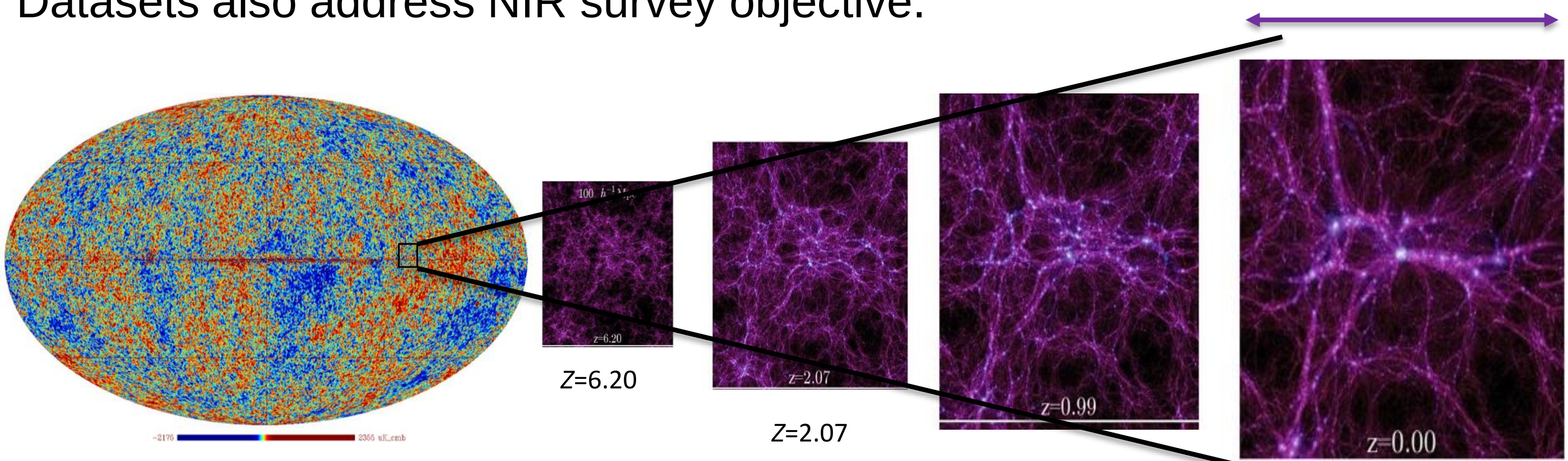
WFIRST will measure expansion history *and* growth of structure

- 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.

Datasets also address NIR survey objective.

~ 1 WFIRST FoV



Z=2.07

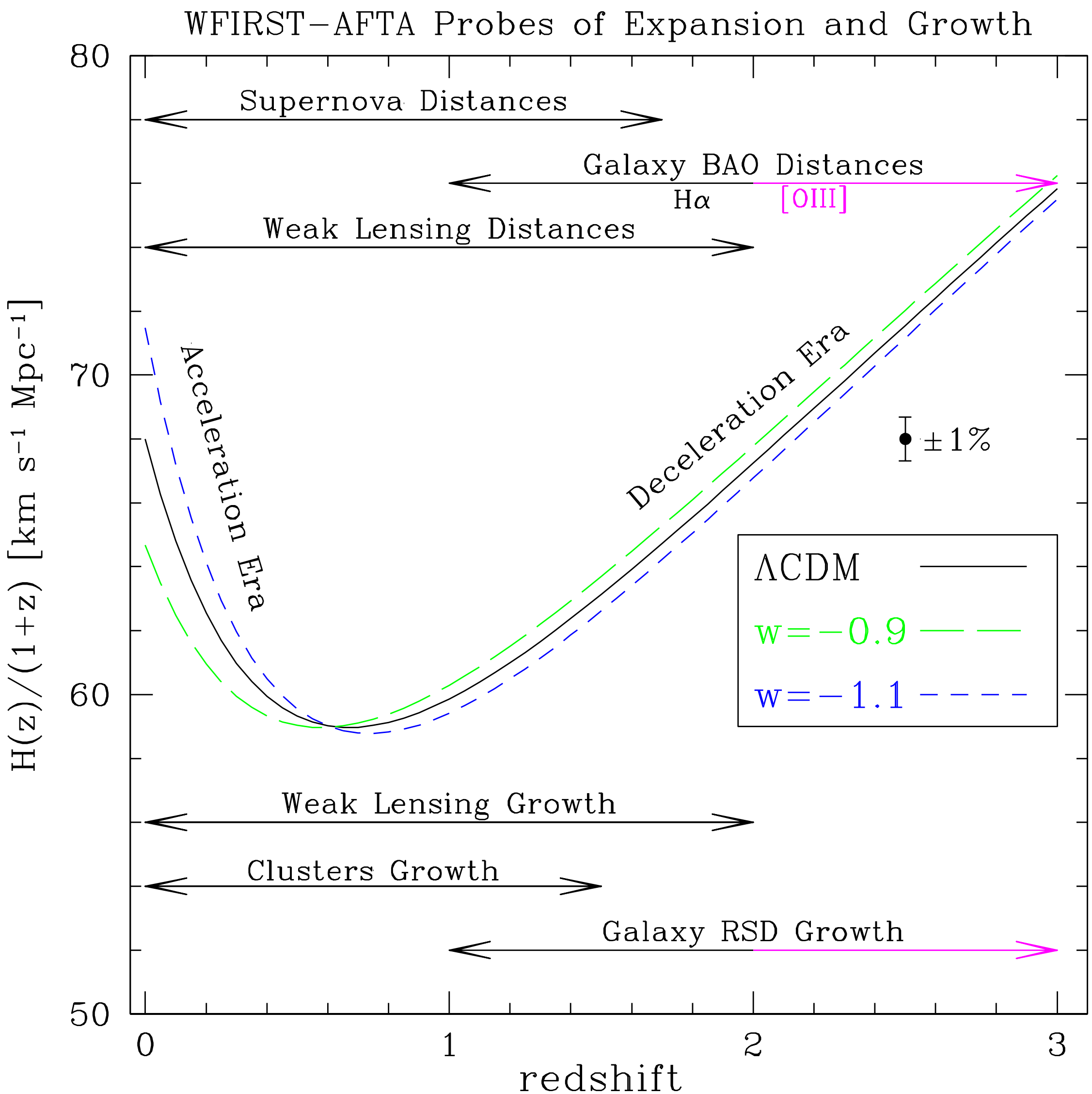
Z=0.99

Z=0.00

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

WFIRST Dark Energy Program

Super-nova Survey	High Latitude Imaging Survey
High Latitude Spectral Survey	



<u>Methods of Investigation for WFIRST</u>

- Weak lensing
- Galaxy Redshift Distortion
- Supernova

Weak Lensing
Measurement Requirements

High Latitude Imaging Survey

- Objective: Use weak gravitational lensing to sample matter distribution to z~2 over thousands of square degrees at a sampling density ≥27/sq arcminute.
- What data are needed to do that? *Galaxy morphologies & 3-D positions*
    - Obtain deep NIR (1-2µm) imaging in multiple bands
        - S/N>18 at AB≥24.4 for galaxies w/R(ee50)=180 mas, over ≥1700 sq degrees (corresponding survey rate is 0.2 deg^2/hour)
        - Baseline: shapes in 3 bands, plus 4th band to facilitate photo-z
    - Derive photometric redshifts by fitting spectral templates to multi-band images
        - Requires spectroscopic “training set” of galaxy sample
        - Places requirements on uniformity of flux calibration (<10mmag over angles 0.1°-10°), and relative calibration across filters (relative zeropoints known to 0.5%)

Weak Lensing

Measurement Requirements

- Gravitational lensing produces distortions of galaxy shapes correlated over many galaxies (“cosmic shear”).
- What is needed for this measurement?
  - Weak Gravitational Lensing effects are indeed weak:
    - ~1% typical “shear” on galaxy ellipticity; want 1% accuracy
  - Need small Point Spread Function
    - diffraction limited at 1.2μm
    - Increases number density of usable galaxies
    - Maximizes S/N of each measurement
      - Larger and/or irregular PSF degrades S/N, requiring longer exposures
  - Must *know (calibrate)* PSF size and shape.
    - Additive shear bias (independent of galaxy ellipticity) $\leq 2.7\text{x}10^{-4}$
      - Need PSF ellipticity knowledge to < $5.7 \text{ x } 10^{-4}$ rms
      - Need PSF second moment knowledge to <$7.2 \text{ x } 10^{-4}$ rms
      - $e_+ = (M_{xx} - M_{yy}) / (M_{xx} + M_{yy})$ $e_x = 2M_{xy} / (M_{xx}+M_{yy})$
      - $M_{xx} = \Sigma (x-x_c)(x-x_c)\, w(x,y)\, S(x,y) / \Sigma\, w(x,y)\, S(x,y)$
    - Multiplicative shear bias (proportional to galaxy ellipticity): <$3.2\text{x}10^{-4}$
      - Example: error in PSF size calibration
    - PSF knowledge will be derived from measurements of stars in each image

Weak Lensing
Requirements Validation

- Cosmological simulations & analytic models of WL observables set top-level SRD requirements (2.0.x)
- Detailed simulations of galaxy shape measurements performed on all scales
  - Simulations of individual instrumental effects, (*e.g.* inter-pixel capacitance), informs calibration rqmts
  - Wide area simulations (5 deg^2) with many (not yet all) astrophysical & instrumental uncertainties
    - Used to develop SRD requirements (2.1.x, 2.2.x, 2.3.x), calibration budgets, observing strategy
- Figure of Merit forecasts for each scenario compared to top-level requirement

High Latitude Imaging Survey

Weak Lensing

Requirements Summary

Survey Capability (HLIS 2.0.x)

1: FoM_{WL}>327400
2: N_{eff}>27/arcmin^2
3: Additive shear error <2.7 10^{-4}
4: Multiplicative shear bias <3.2 10^{-4}
5: deep field

Science Data Records (HLIS 2.1.x)

1: Mosaic images, astrometric frame
2: Mosaic images, metadata
3: source catalog contents, basic
4: source catalog contents, extended
5: source catalog contents, uncertainties
6: deleted
7: angular mask, noise maps
8: redshift probability distr.
9: redshift probability distribution shape
10: redshift sample bias
11: limiting sensitivity for galaxy sample
12: spectroscopic redshifts
13: source injection
14: processing simulated data

Calibrated Data Records (HLIS 2.2.x)

1: PSF knowledge for each image
2: flux calibration spatial uniformity
3: PSF ellipticity knowledge
4: PSF size knowledge
5: astrometric accuracy relative
6: astrometric accuracy absolute
7: pixel response
8: flux cal over FoV for known spectrum
9: flux calibration absolute
10: flux calibration over time
11: flux calibration across filters

Raw Data Records (HLIS 2.3.x)

1: Raw data
2: filter bandpasses
3: PSF R(EE50) in each filter
4: Survey strategy
5: Spectral datasets
6: Imaging deep fields
7: Downlinked data samples
8: Deleted
9: Spectral dispersion
10: Spectral bandpass
11: Spectrometer spatial resolution
12: Spectrometer FoV
13: Spectrometer R(EE50)

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

Key Weak Lensing Science Performance Requirements

Representative values shown; full details in SRD.		Expansion, Structure, NIR Survey		Expansion	Exoplanet
		Weak Lensing	Galaxy Redshift Survey	Supernovae	Microlensing
Surveys & Data	Area/Survey Speed	0.20 deg^2/hr (1,700 deg^2)			
	Redshift	0≤z≤3			
	Sensitivity	S/N≥18 @ 24.4/24.3/23.7 (AB J/H/F184) r_{eff}=0.18”			
	Cadence				
	Data Vol.	≥3 reads/exp			
PSF	Quality	EE50 ≤ 0.12” (J) EE50 ≤ 0.17” (IFC)			
	Stability	1 nm RMS ΔWFE in 180s			
	Knowledge	2nd moment ≤7.2x10^{-4} Ellipticity ≤5.7x10^{-4}			
Flux Calibration Relative Over	Time	0.5% /observing program			
	Wavelength	<2% abs/0.5% photo zeropt			
	Dynamic Range				
	Area	<10 mmag			
Color	Filters	4 NIR bands for photo-z, 3 reddest for shapes			
	Dispersion				

Key Wide Field Science Performance Requirements

Representative values shown; full details in SRD.

		Expansion, Structure, NIR Survey		Expansion	Exoplanet
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Surveys & Data	Area/Survey Speed	0.20 deg^2/hr (1,700 deg^2)	0.34 deg^2/hr (1,700 deg^2)	14, 5 deg^2 >100 SNe/Δz=0.1	586 deg^2-day Over 6+ seasons
	Redshift	0≤z≤3	1.1 < z < 1.9 (2.9 w/OIII)	0.2≤z≤1.7	
	Sensitivity	S/N≥18 @ 24.4/24.3/23.7 (AB J/H/F184) r_{eff}=0.18”	S/N≥6.5 for 1.0x10^{-16} erg/cm^2/s	S/N≥13 (brightest filters at peak)	S/N>100 for H_{AB}=21.4 star
	Cadence			~ 5 days	15 min
	Data Vol.	≥3 reads/exp	≥3 reads/exp	≥3 reads/exp	≥3 reads/exp
PSF	Quality	EE50 ≤ 0.12” (J) EE50 ≤ 0.17” (IFC)	EE50≤0.21”@1.5 μm	EE50 ≤ 0.12” (J) EE50 ≤ 0.14” (IFC)	EE50 ≤ 0.15” (wide)
	Stability	1 nm RMS **Δ**WFE in 180s			
	Knowledge	2nd moment ≤7.2x10^{-4} Ellipticity ≤5.7x10^{-4}		0.2%	
Flux Calibration Relative Over	Time	0.5% /observing program	<2% rel spect-photometry	<0.5% / 2 wk	<0.1%/season
	Wavelength	<2% abs/0.5% photo zeropt	<2% rel over bandpass	<2% abs/ 0.5% photo zeropt	<3% abs <1.4% photo zeropt
	Dynamic Range			<0.3% 15<AB<26	<0.1% over 2 mag
	Area	<10 mmag	<2% rel over survey area		
Color	Filters	4 NIR bands for photo-z, 3 reddest for shapes	Overlap with HLIS for 3 filter imaging	6 filters 0.5-2.0μm	Wide filter, & 1 short, 1 longward of 1μm
	Dispersion		10-12 Å/pix	70 < R < 150	

Coronagraphy as a Key Technology

NWNH: "the committee recommends a program to lay the technical and scientific foundations for a future space imaging and spectroscopy mission."

- Key drivers for technology demonstration are:
  - Low-order wavefront sensing and control
    - Deformable mirrors, fast steering mirror, use of IFS as wavefront sensor, control algorithms
  - Shaped pupil and occulting mask design and fabrication
    - Tailored for obstructed pupil
  - Ultra-low noise detectors
  - Manage polarization effects
  - Optical stability of entire observatory
    - Coronagraph doesn't drive observatory requirements, but integrated model validation is critical for future missions

Scientific Goals Inform Technology Development

NWNH: "This survey is recommending a program to explore the diversity and properties of planetary systems around other stars, …"

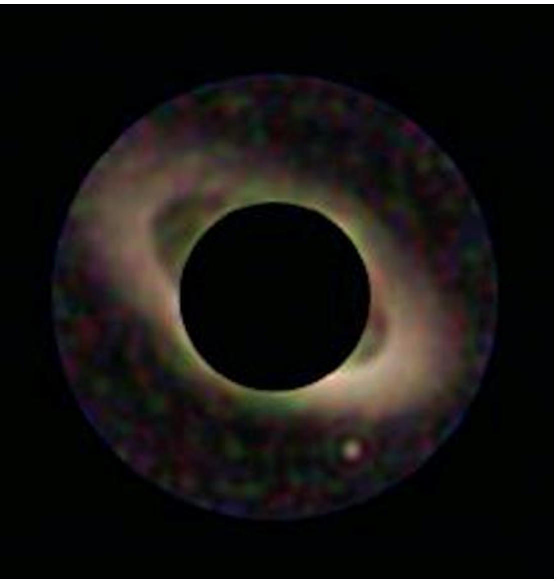
- Potential science program serves to drive technology requirements, informs instrument design parameter decisions
  - Characterize exoplanet atmospheres composition and temperature via imaging and R=50 spectroscopy
    - Determine depth of H_2O, methane, absorption to 15%
    - Determine semi-major axis, eccentricity, of each planet
      - Estimate planet masses, irradiance
  - Search for previously-undiscovered planets around nearby stars
  - Determine characteristics of protoplanetary and exo-zodiacal dust disks on wide range of angular scales

Coronagraphy
Observables

Direct Imaging

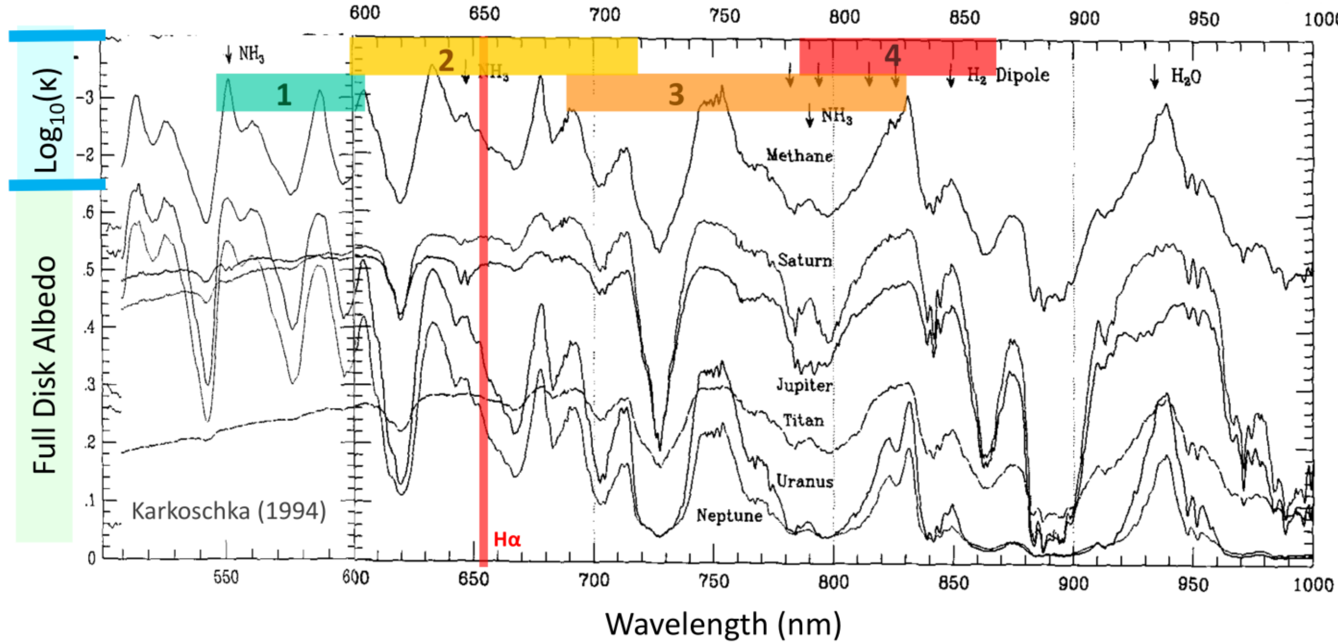
Spectro-scopy

Multi-band imaging, spectra at high contrast enables direct detection & characterization of exoplanets



WFIRST CGI multi-color imaging simulation of a Jupiter-mass planet around a Sun-like star, with a 10-zodi interplanetary dust structure.

Image credit: J. Krist



λ_1=575 nm, 10% (annular, 3-9 λ/D)

λ_2=660 nm, 18% (bow-tie / IFS, 3-9 λ/D)

λ_3=760 nm, 18% (bow-tie / IFS, 3-9 λ/D)

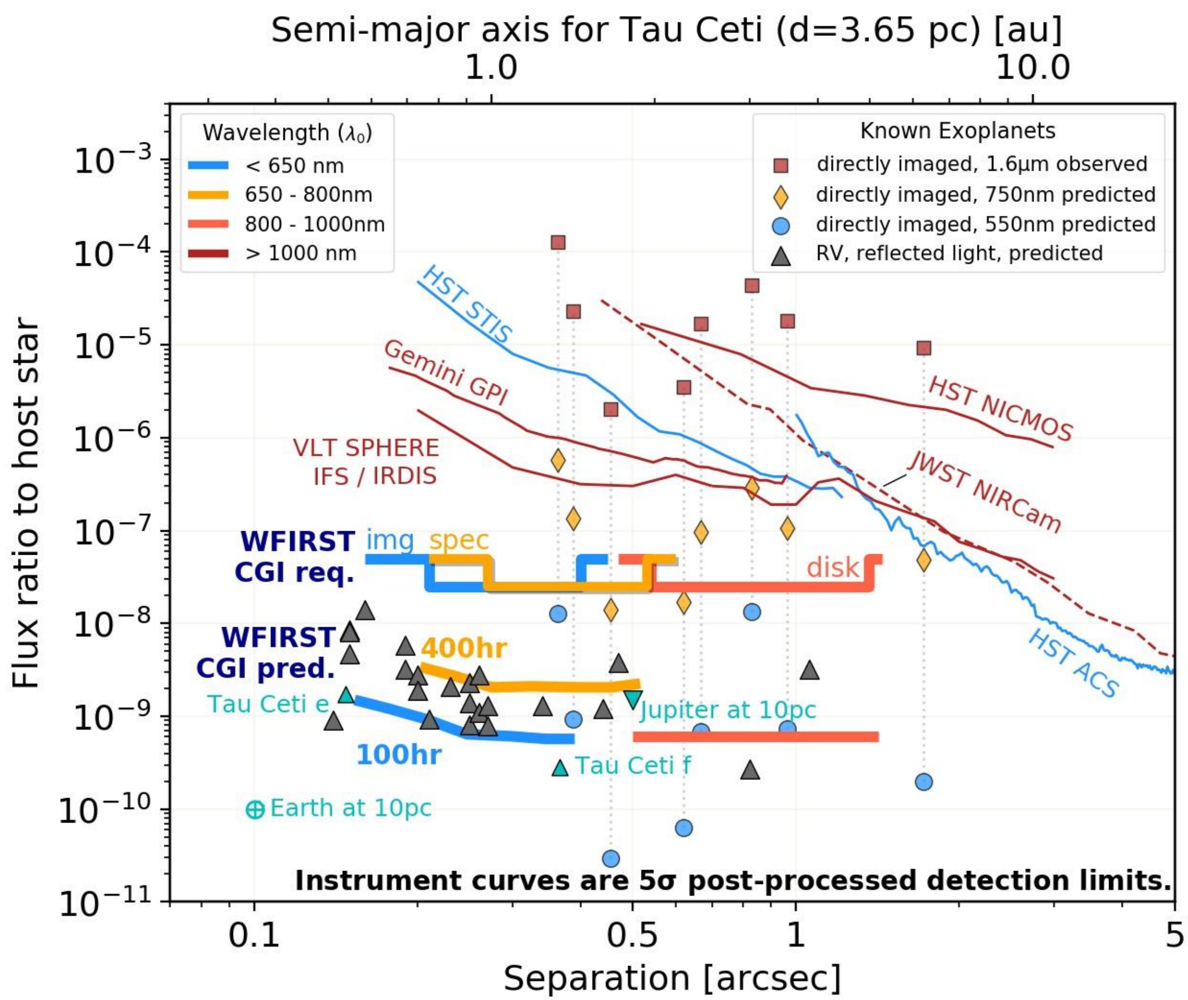
λ_4=825 nm, 10% (annular, 3-19 λ/D)

CGI can probe the atmospheric chemistry of Extra-Solar Giant Planets, as well as aerosol and cloud properties, providing unique constraints on their formation and evolution.

Coronagraphy
Performance Requirements

CGI implements both architectures & 3 modes:

- HLC imaging 3-9 λ/D
- SPC spectra 3-9 λ/D
- SPC imaging 6.5-20 λ/D



GO & AR Programs

- The General Observer and Archival Research objectives:
  - Do not impose unique requirements on the observatory
  - Do impose requirements on the ground system
    - User interfaces for observation planning, documentation, data analysis tools, query tools, etc.

Mission Requirements Document

Mission Requirements Doc
1.0 Mission Requirements
2.0 LV Requirements
3.0 Observatory Requirements
    3.1 Design Specifications
    3.2 OTA
    3.3 WFI
    3.4 CGI
    3.5 IC
    3.6 Spacecraft
4.0 Ground System Requirements

- The MRD contains the top level requirements for the mission, launch vehicle, the Observatory (Telescope, Wide Field, Coronagraph, Instrument Carrier & Spacecraft) and the Ground System. These flow from the:
  - PLRA – BTRs & BDRs, including CGI technology requirements
  - SRD – Science requirements decomposed into requirements on the mission
  - Mission architecture decisions – e.g., guiding from the WFI focal plane
- Mission-level requirements are decomposed in the MRD as necessary and allocated to each of the elements.
  - Each MRD requirement identifies the element(s) to which the requirement is allocated

Key Wide Field Science Performance Requirements

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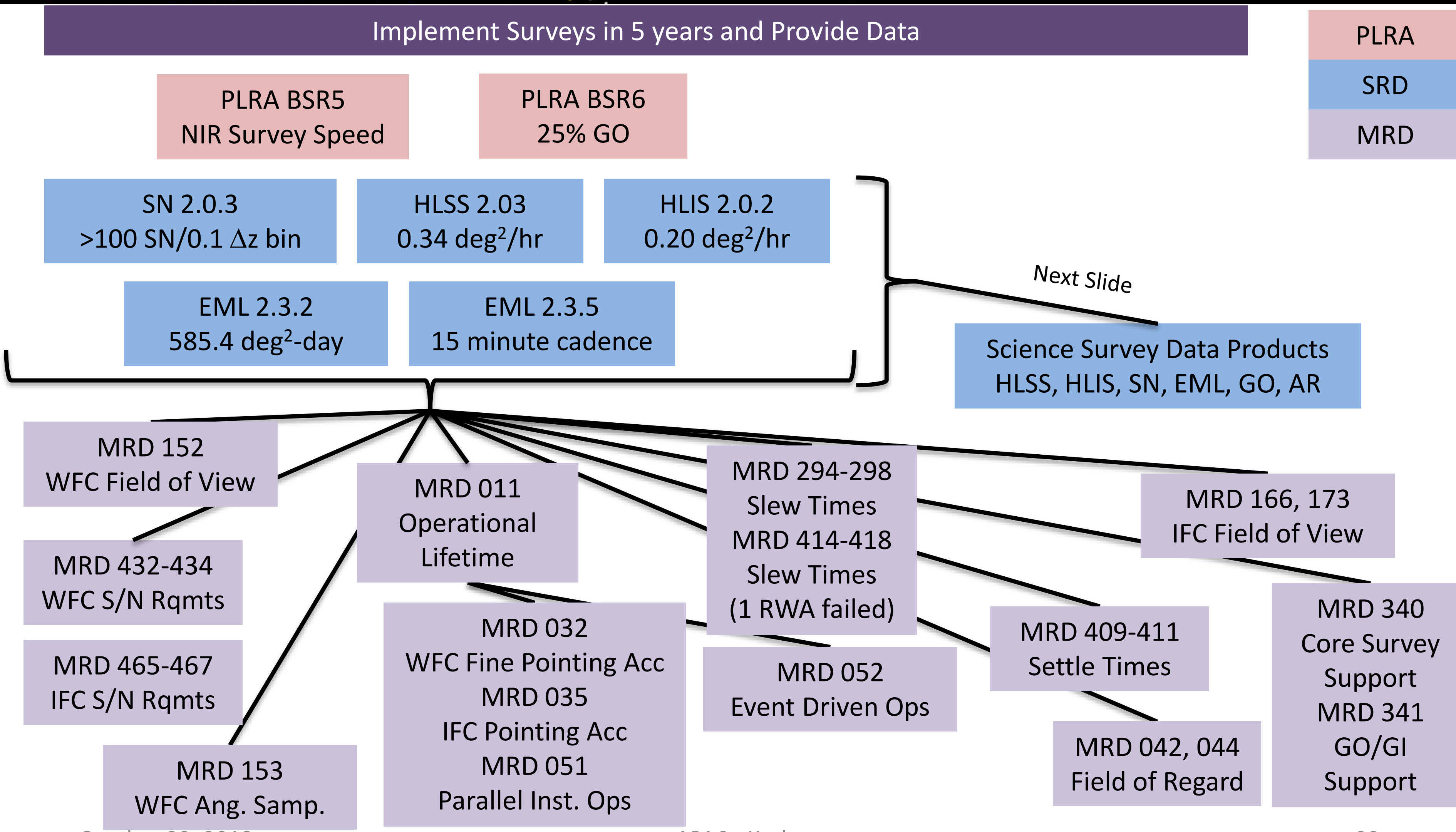
Implement Surveys in 5 years and Provide Data



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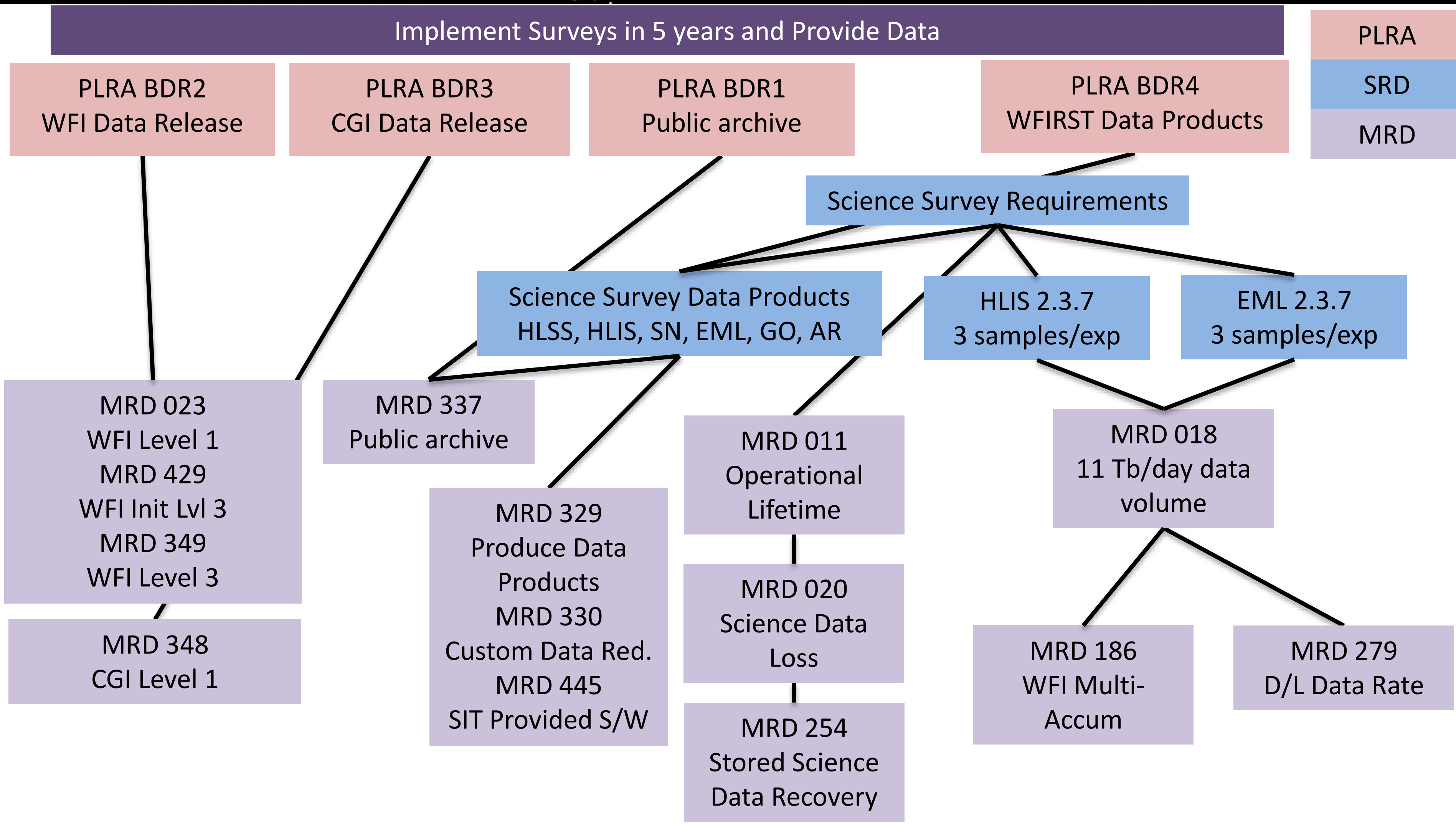

Implement Surveys in 5 years
Mission Implementation (1 of 3)

- MRD 011: Execute the science program in an operational phase lifetime of 5 years.
  - Flows to Observatory & Ground System – Establishes requirements for environments, redundancy, efficiency related requirements (parallel science & downlink, parallel instrument ops, event driven ops), power
- MRD-051: Support parallel science ops of both instruments without degrading the performance of the primary inst.
  - Flows to OTA for mechanisms, S/C for data recorder and Ground System for planning
- **MRD 052:** Perform event driven science observations.
  - Flows to Obs & Ground Sys – Provide TLM in response to commands, obs planning, script engine
- **MRD 042:** Operate continuously with the Observatory +X axis pointed between 54 degrees and 126 degrees from the Sun.
  - Flows to Observatory elements – – Establishes requirements for environments, solar array
- MRD 044: Operate continuously while maintaining the Sun vector within 15 degrees of the Observatory X/+Z half-plane.
  - Flows to Observatory elements – – Establishes requirements for environments, solar array
- **MRD 032:** Provide fine pointing of the Wide Field Channel FOV boresight within 640 milliarcsec (1 sigma) in pitch and yaw and 87 arcsec (1 sigma) in roll in the Observatory coordinate system, relative to the commanded attitude.
  - Flows to S/C, WFI and Ground Sys – see Pointing Budget
- **MRD 035:** Be able to place a source in one slice of the IFC accurate to 30 mas (1 sigma).
  - Flows to S/C, WFI and Ground Sys – see Pointing Budget

Remaining 4 slides in this section moved to MRD backup

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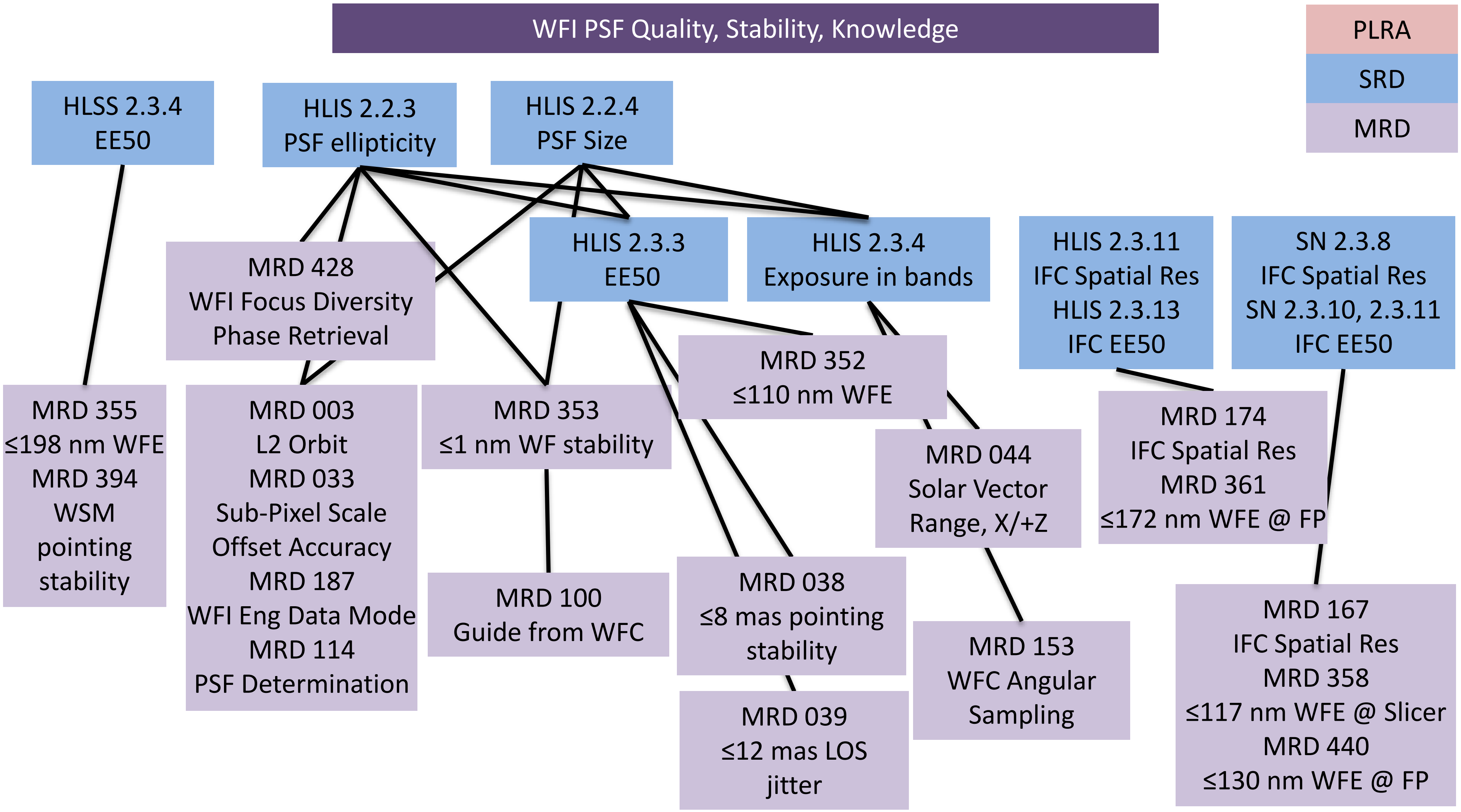
PSF Requirements



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Relative Flux Calibration Over:

WFIRST
Wide-Field Infrared Survey Telescope
Dark Energy • Exoplanets • Astrophysics

Time

- HLIS 2.2.10: Variance in photometric zero points
- SN 2.2.8: Time series calibrated spectra
- HLSS 2.2.4 Rel spectrophotometric flux calibration
- EML 2.2.6: Rel photometric systematic daily & seasonal precision
- EML 2.2.7: Rel photometric systematic from separate seasons

Wavelength

- SN 2.2.2: Relative instrumental bias on photo cal. btwn 2 filters
- HLIS 2.2.4: Absolute photometry
- SN 2.2.5: Absolute photometry
- SN 2.2.6: Variance in photometric zero points
- HLIS 2.2.9: Absolute photometry
- HLIS 2.2.11: Relative zero points of filter photometry knowledge
- EML 2.2.8: Absolute photometry
- EML 2.2.9: Relative zero points of filter photometry knowledge

Dynamic Range

- SN 2.2.3: Photometric cal accuracy btwn AB 26 and 15 sources

Spatial

- HLIS 2.2.2: Rel. photometric cal spatially uniform
- HLIS 2.2.8: SED corrected to 0.5%

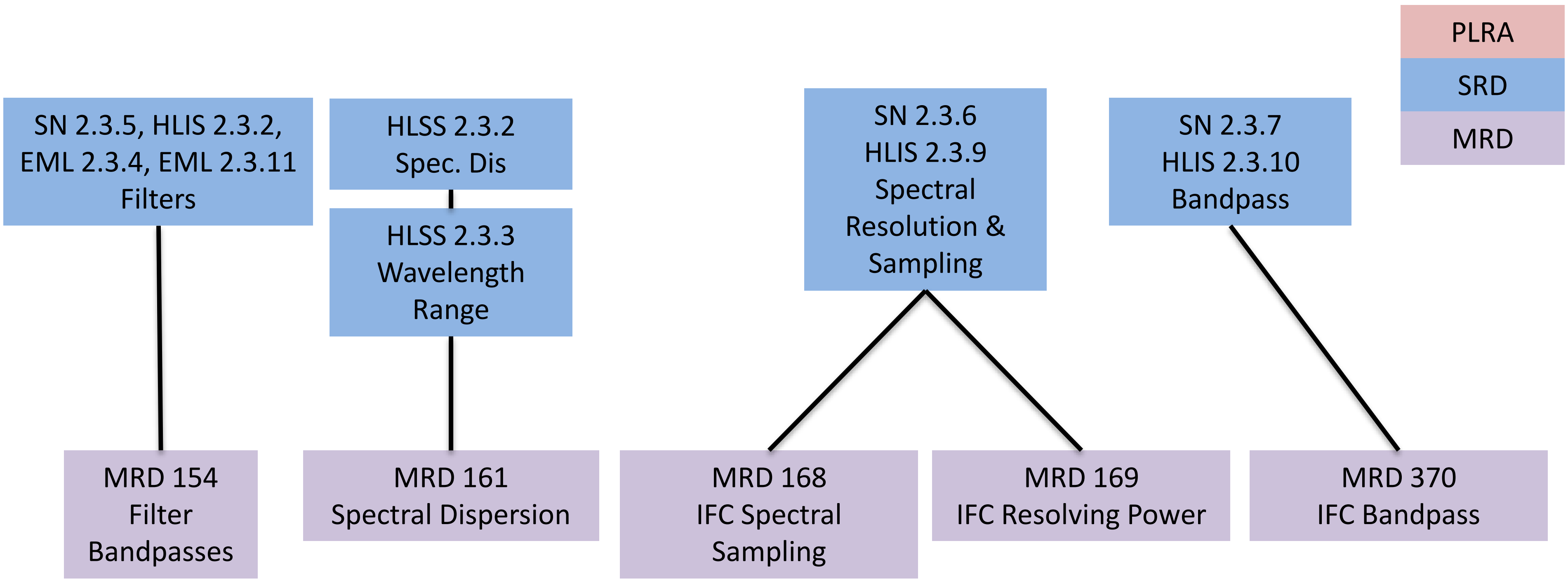
WFI Relative Calibration System

- MRD 181 Detector Linearity Cal.
- MRD 384 WFC Dark Setting
- MRD 385 IFC Dark Setting
- MRD 390 Flat Field Cal.
- MRD 391 Calibration Sources
- MRD 329 Produce Data Products
- MRD 330 Custom Data Red.
- MRD 445 SIT Provided S/W
- MRD 340 Core Survey Support
- MRD 187 WFI Eng Data Mode
- MRD 033 Sub-Pixel Scale Offset Accuracy
- MRD 406 Return Pointing & Offset Accuracy

Key Wide Field Science Performance Requirements

Representative values shown; full details in SRD.		Expansion, Structure, NIR Survey		Expansion	Exoplanet
		Weak Lensing	**Galaxy Redshift Survey**	**Supernovae**	**Microlensing**
Surveys & Data	**Area/Survey Speed**	0.20 deg^2/hr (1,700 deg^2)	0.34 deg^2/hr (1,700 deg^2)	14, 5 deg^2 >100 SNe/Δz=0.1	586 deg^2-day Over 6+ seasons
	Redshift	0≤z≤3	1.1 < z < 1.9 (2.9 w/OIII)	0.2≤z≤1.7	
	Sensitivity	S/N≥18 @ 24.4/24.3/23.7 (AB J/H/F184) r_{eff}=0.18”	S/N≥6.5 for 1.0×10^{-16} erg/cm^2/s	S/N≥13 (brightest filters at peak)	S/N>100 for H_{AB}=21.4 star
	Cadence			~ 5 days	15 min
	Data Vol.	≥3 reads/exp	≥3 reads/exp	≥3 reads/exp	≥3 reads/exp
PSF	**Quality**	EE50 ≤ 0.12” (J) EE50 ≤ 0.17” (IFC)	EE50≤0.21”@1.5 μm	EE50 ≤ 0.12” (J) EE50 ≤ 0.14” (IFC)	EE50 ≤ 0.15” (wide)
	Stability	1 nm RMS **Δ**WFE in 180s			
	Knowledge	2^{nd} moment ≤7.2×10^{-4} Ellipticity ≤5.7×10^{-4}		0.2%	
Flux Calibration Relative Over	**Time**	0.5% /observing program	<2% rel spect-photometry	<0.5% / 2 wk	<0.1%/season
	Wavelength	<2% abs/0.5% photo zeropt	<2% rel over bandpass	<2% abs/ 0.5% photo zeropt	<3% abs <1.4% photo zeropt
	Dynamic Range			<0.3% 15<AB<26	<0.1% over 2 mag
	Area	<10 mmag	<2% rel over survey area		
Color	**Filters**	4 NIR bands for photo-z, 3 reddest for shapes	Overlap with HLIS for 3 filter imaging	6 filters 0.5-2.0μm	Wide filter, & 1 short, 1 longward of 1μm
	Dispersion		10-12 Å/pix	70 < R < 150	

Color


PLRA
SRD
MRD
SN 2.3.5, HLIS 2.3.2, EML 2.3.4, EML 2.3.11 Filters
HLSS 2.3.2 Spec. Dis
HLSS 2.3.3 Wavelength Range
SN 2.3.6 HLIS 2.3.9 Spectral Resolution & Sampling
SN 2.3.7 HLIS 2.3.10 Bandpass
MRD 154 Filter Bandpasses
MRD 161 Spectral Dispersion
MRD 168 IFC Spectral Sampling
MRD 169 IFC Resolving Power
MRD 370 IFC Bandpass

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

PLRA Technical Flow Down

PLRA BTR1 5 year life	MRD 011 5 year life
PLRA BTR 2 2.36-m PM	MRD 392 2.36-m PM
PLRA BTR3 Servicing	MRD 058 Servicing
PLRA BTR4 Starshade Ready	MRD 063 Starshade Comp
PLRA BTR9 TOOs in 2 weeks	MRD 334 TOOs in 2 weeks

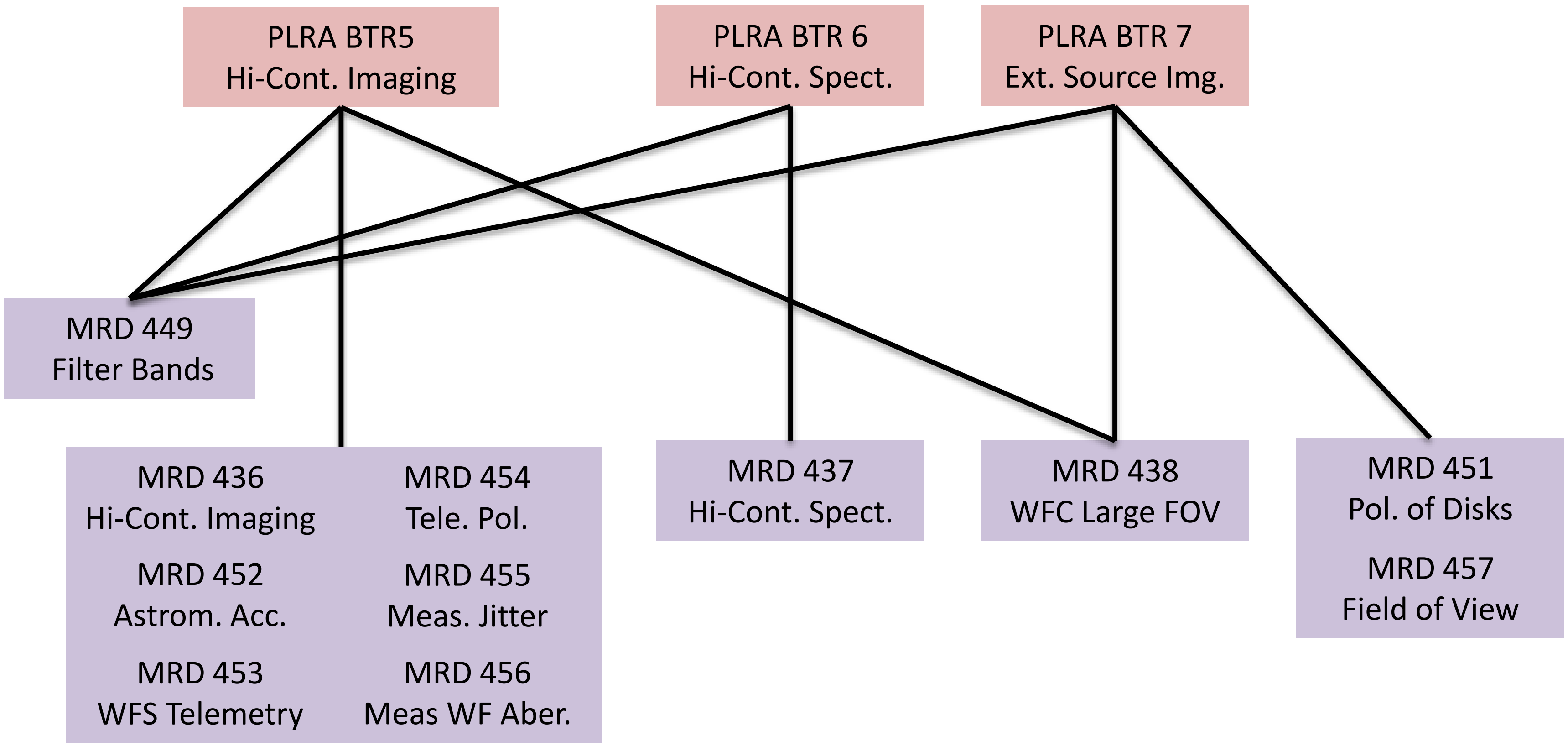
PLRA
SRD
MRD

Flow From Key Requirements

(Representative values shown; full details available in MRD)

Key Science Requirements ↓		Observatory	Optical System (OTA & WFI)	Ops Concept and Ground System
Surveys & Data	Area/Survey Speed Sensitivity Cadence	Field of Regard Slew/Settle Times Pointing Accuracy Event Driven Ops	≥0.25 deg² FOV ≤0.11 a-s/pix sampling S/N budget (throughput, background, electronic noise)	DRM – Tiling patterns, obs functions (e.g., momentum unloads, stationkeeping) GS – Execute surveys
	Data Vol.	11 Tb/day D/L, D/L Data Rate	Multi-Accum	Grd Receipt & Process, Data Recovery
PSF	Quality		WFE=110/198 nm (WIM/WSM) WFE=130 nm/172 (IFC) ≤1 nm WF stability, ≤8 mas drift, ≤12 mas LOS jitter Guide from WFC WFI FDPR	4-5 dither positions per orientation Recreate pointing history using Obs data Generate PSFs
	Stability	L2 Orbit Jitter isolation		
	Knowledge	D/L guide windows, IRU, RWA speeds		
Flux Calibration Relative Over	Time Wavelength Dynamic Range	Pixel scale offset pointing (dither) within 11 mas, return pointing within 1 pixel and offsets up to 20 pixels	Calibration System with cal sources over 5 orders of magnitude, 1 source/filter, flat fielding, dark to enable background measurement	Periodic calibration observations of astronomical sources and deep fields
Color	Filters		7 filters R,Z,Y,J,H,F184 & Wide 0.48-2.0 μm & 1.0-2.0 μm	
	Dispersion		10-12 Å/pix over 1.0-1.9 μm	

CGI Technology Flow Down



Update

- Material shown was current as of Mission SRR (Feb 22, 2018)
  - Apart from descope of the IFC, changes are minor
- Many Level-3 requirements documents are now baselined or will be very soon.
  - Attitude Control System, Telescope, Spacecraft, WFI, CGI, etc.

Backup

WFIRST Breadth

- WFIRST must meet the Decadal Survey’s vision for several ***science experiments:***
  - Dark energy / growth of structure via multiple techniques
  - Exoplanet census
- WFIRST must meet the Decadal Survey’s recommendation for ***technology development*** aimed at direct detection of exoplanets
- WFIRST must meet the Decadal Survey’s mandate for ***broad science impact in key areas*** via a general observer + guest investigator capability

Science Objectives vs. Mission Success

- The Science Objectives define expected science return for WFIRST.
- Mission Success defines minimum science return to declare WFIRST a success:

Science	Science Objective	Mission Success Criteria
NIR Survey	conduct near-infrared (NIR) sky surveys in both imaging and spectroscopic modes, providing an imaging sensitivity for unresolved sources better than 26.5 AB magnitude.	No corresponding success criteria
Expansion History	Determine the expansion history of the Universe using GRS, WL, & SN, at redshifts up to z = 2 with high-precision cross-checks between techniques.	Conduct surveys providing data for the measurement of the history of cosmic expansion and the growth of structure, achieving at least two of the following: • detect ≥10M galaxies spectroscopically over z = 1-2; • shape measurement of ≥100M galaxies over z = 1-3; • light curve measurement of ≥2000 supernovae at redshifts reaching at least 1;
Growth of Structure	Determine the growth history of the largest structures in the Universe using WL, RSD, & Galaxy Clustering, at redshifts up to z = 2 with high-precision cross-checks between techniques.	
Exoplanet Census	Carry out a statistical census of exoplanets from the outer habitable zone to free floating planets, including analogs to all of the planets in our Solar System >M_{Mars}, using microlensing.	Conduct a microlensing survey providing sufficient quality and quantity of data to detect at least 2000 microlensing events with source magnitudes of H<23 AB and impact parameters <1.
GO Program	Devote a substantial fraction of the mission lifetime to a peer-reviewed GO program and have an archive & GI program.	Provide a minimum of 15% of aggregated operational lifetime to a peer-reviewed GO program

Tech Demo Objectives and Fulfilling Them

- The Tech Demo Objectives define expected coronagraph technology advancement for WFIRST.
- Operational expectation – how WFIRST/CGI fulfills:

Technology	Technology Demonstration Objective	Operational Expectation
Active Wavefront Control	Demonstrate coronagraphy in space with an obscured aperture and active wavefront control	Detect a companion object next to a star, on at least two stars, at a contrast level and separation that requires a functional active coronagraph.
Coronagraph Elements	Advance the engineering and technical readiness of key coronagraph elements: coronagraph masks, low-order wavefront sensors, high actuator count deformable mirrors, low noise detectors, and integral field spectrographs.	Demonstrate in-space operation of the elements listed.
Coronagraph Algorithms	Support development and in-flight demonstration of coronagraph software that could enhance the capability or simplify the architecture of future missions.	Demonstrate the ability to modify the wavefront sensing and control algorithms during the prime science mission.
Performance Characterization	Perform measurements that characterize the integrated performance of the coronagraph and observatory as a function of time, wavelength, and polarization.	Gather data on a target star that enables in-flight performance characterization of the coronagraph, including a revisit and a repoint.
Data Processing	Demonstrate advanced data processing and analysis techniques required to identify, spectrally characterize and distinguish astronomical sources at high contrast.	Produce photometric, astrometric, and spectrographic measurements of at least one point source and at least one extended object.

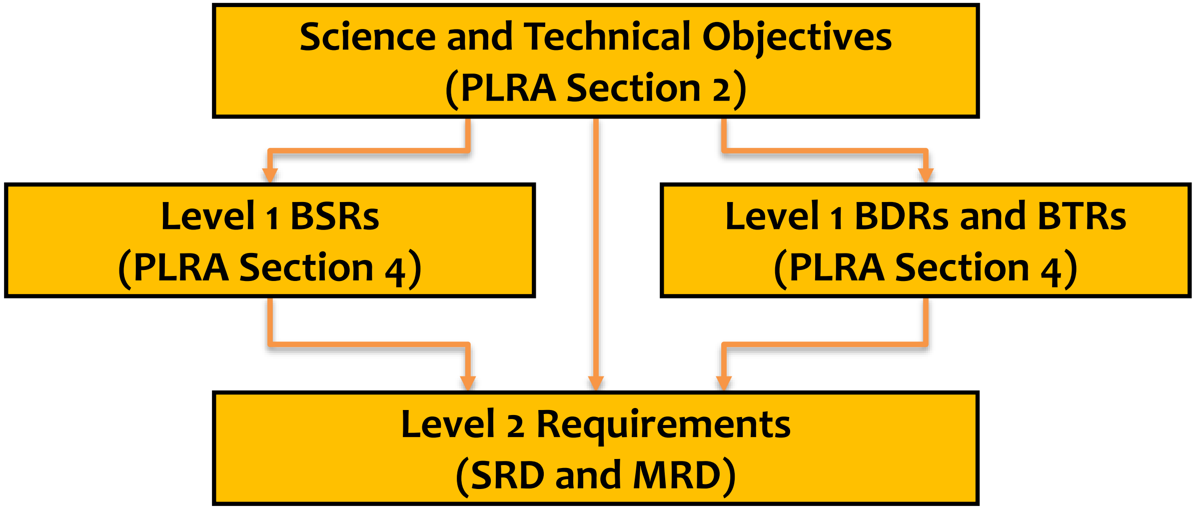
Level 1 Requirement Paradigm

- Objectives are ***science outcomes***
- Level 1 science requirements (BSRs) are ***critical instrument sensitivities*** that support those outcomes
  - Verifiable pre-launch
  - One called out for each survey
  - Used by HQ to ensure WFIRST capabilities sufficient to meet the objectives.
- Level 1 technical and data requirements include essential top-level items to fulfill all mission objectives
- Success criteria are ***expected measurements*** using those capabilities to support the science outcomes

L1/L2 Requirements Flow

Interrelationships:

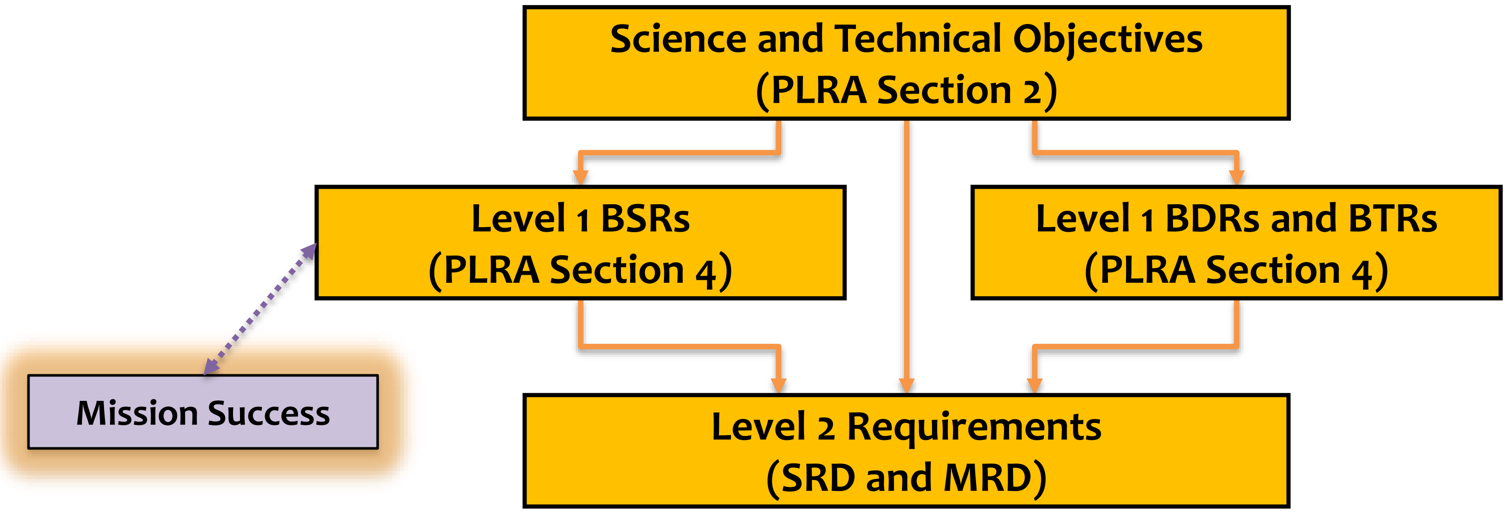
- **Level 1 science requirements** are ***critical instrument sensitivities*** that support objectives
- Set of **Level 2 requirements** flow from **Baselines** and flow directly from **Objectives** (for items that are less critical or don't describe sensitivity).



L1/L2 Requirements Flow

Notes:

- Mission success criteria associate **only** with science requirements



- "Any decision to abandon a **baseline** requirement in favor of its corresponding **threshold** requires the approval of the Science Mission Directorate Associate Administrator."
  Consider as predefined descope limits that fulfill success criteria.

Baseline & Threshold Science Requirements

BSR/ TSR #	Baseline Science	Threshold Science
1	Be able to measure positions and redshifts of Hα emission-line galaxies to a redshift precision of 1 part in 1000 (1σ) in the range z = 1.0 – 1.8 and a minimum detectable point-source line flux of **2**·10^{-16} ergs/cm²/s	Be able to measure positions and redshifts of Hα emission-line galaxies to a redshift precision of 1 part in 1000 (1σ) in the range z = 1.0 - 1.8 and a minimum detectable point-source line flux of **3**·10^{-16} ergs/cm²/s
2	Be able to measure positions, second moment shapes, and brightnesses **of 0.18" radius** galaxies in at least three infrared filters, to a depth of **26.2 AB in the shortest wavelength filter and** 25.6 AB in the longest	Be able to measure positions, second moment shapes, and brightnesses of galaxies in at least three infrared filters, to a depth of 25.6 AB in the longest wavelength
3	Be able to measure the brightness of point sources in three infrared filters to a depth of **26 AB** in each filter, providing a color uncertainty of <0.03 mag, and with the ability to repeat observations at least once every 5 days for ≥120 days	Be able to measure the brightness of point sources in three infrared filters to a depth of **25.6 AB** in each filter, providing a color uncertainty of <0.03 mag, and with the ability to repeat observations at least once every five days for ≥120 days
4	Be able to measure the brightness of stars with a statistical S/N of 100 per exposure for a H=**20.9 AB** star, with the ability to repeat observations of a star field at least once every 15 minutes for ≥60 days	Be able to measure the brightness of stars with a statistical S/N of 100 per exposure for a H=**20.4 AB** star, with the ability to repeat observations of a star field at least once every 15 minutes for ≥60 days
5	Be able to produce NIR sky images in multiple filters over 20°² at J = **26.5 AB** in each filter, and spectra over 9°² at F_{line} = **2**·10^{-16} erg cm^{-2} s^{-1} , each in <24 hours	Be able to produce NIR sky images in multiple filters over 20°² at H = **26.2 AB** in each filter, and spectra over 9°² at F_{line} = **3**·10^{-16} erg cm^{-2} s^{-1} , each in <24 hours
6	Provide a peer-reviewed General Observer program comprising **25%** of total time, **with access to the full sky within the mission lifetime**, and a peer-reviewed Guest Investigator program for archival research	Provide a peer-reviewed General Observer program comprising **15%** of the total time, and a peer-reviewed Guest Investigator program for archival research

Baseline & Threshold Technical Requirements

CGI-only

BTR/ TTR #	Baseline Technical	Threshold Technical
5	Be able to measure the brightness of an astrophysical point source located between **0.21″** and **0.40″** from an **adjacent star with a V magnitude as dim as 5**, with a flux ratio down to **$5{\cdot}10^{-8}$** in a 10% bandwidth with an SNR=**10** or better.	Be able to measure the brightness of an astrophysical source located between **0.30″** and **0.45″** from a **nearby star**, with a flux ratio down to **10^{-7}** in a 10% bandwidth with an SNR=**5** or better.
6	Be able to measure the spectrum of an astrophysical point source located between 0.27″ and 0.53″ from an adjacent star with a V magnitude as dim as 5, with a flux ratio down to $5{\cdot}10^{-8}$ over an 18% bandwidth at R=50 with an SNR=10 per spectral resolution element.	**Coronagraphic spectroscopy is not required at the threshold level.**
7	Be able to map the extended surface brightness from 0.6″ to 1.3″ around a host star with V magnitude as dim as 5, at an integrated surface brightness per resolution element sensitivity equivalent to a source-to-star flux ratio as faint as $5{\cdot}10^{-8}$ with an SNR of at least 10, and be able to map a linear polarization with a polarization fraction ≥0.3 with a systematic uncertainty of less than 0.03.	**Coronagraphic extended source imaging and polarimetry are not required at the threshold level.**

Baseline and Threshold Technical Requirements

Full list

BTR/ TTR #	Baseline Technical	Threshold Technical
1	Mission Duration: 5 year mission after checkout	Same
2	Telescope: existing components, including 2.36-m diameter PM	Same
3	Serviceability	**Not required at the threshold level.**
4	Starshade Compatibility	**Not required at the threshold level.**
5	Broadband High-Contrast Imaging	**Yes, but degraded.**
6	High-Contrast Imaging Spectroscopy	**Not required at the threshold level.**
7	High-Contrast Extended Source Imaging and Polarimetry	**Not required at the threshold level.**
8	Target of Opportunity – within two weeks	Same

Baseline and Threshold Data Requirements

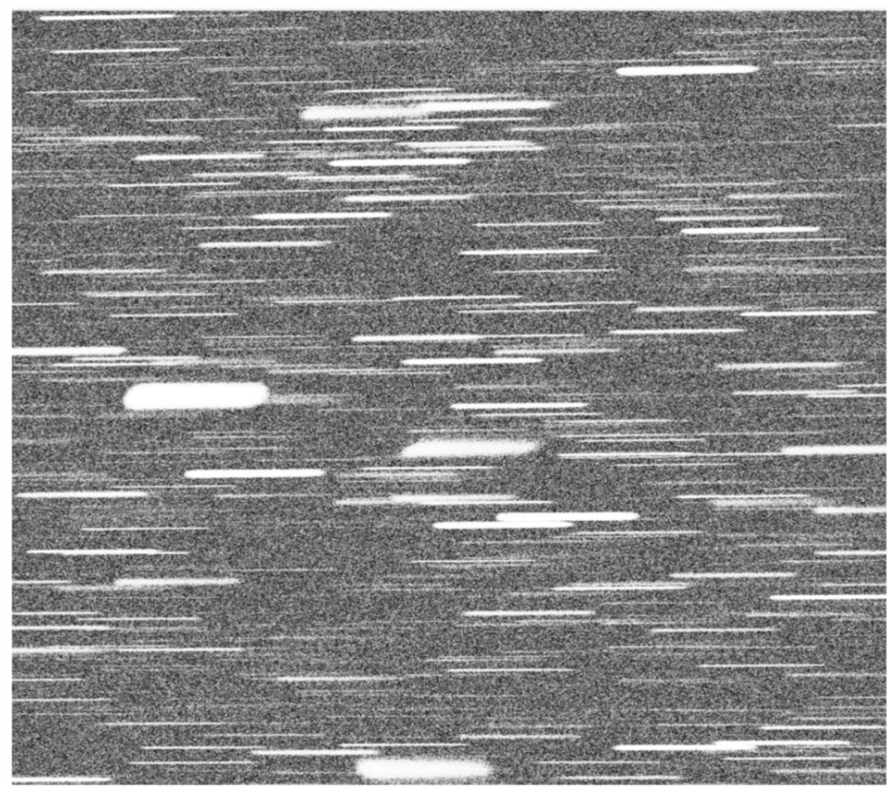
BDR/ TDR #	Baseline Data	Threshold Data
1	Provide a public archive of data products with capabilities that enable scientific studies and data mining of its data holdings.	**Provide a public archive of data products.**
2	Provide a public release, of **95%** of WFI data at: uncalibrated data ≤72 hours of acquisition on WFIRST; resampled/coadded prelim calibration ≤168 hours; resampled/coadded all final calibrated ≤6 months.	Provide a public release, of **90%** of WFI data at: uncalibrated data ≤72 hours of acquisition on WFIRST; resampled/coadded prelim calibration ≤168 hours; resampled/coadded all final calibrated ≤6 months.
3	Provide a public release, of **90%** of CGI data at: **uncalibrated** data ≤**72** hours.	Provide a public release, of **50%** of CGI data at: **packetized** data ≤**96** hours
4	Produce images, catalogs, and other high-level data products from its observations to be made available via the WFIRST archive for the benefit of the astronomical community, with no period of limited data access.	Same

BACKUP FOR SRD SECTION

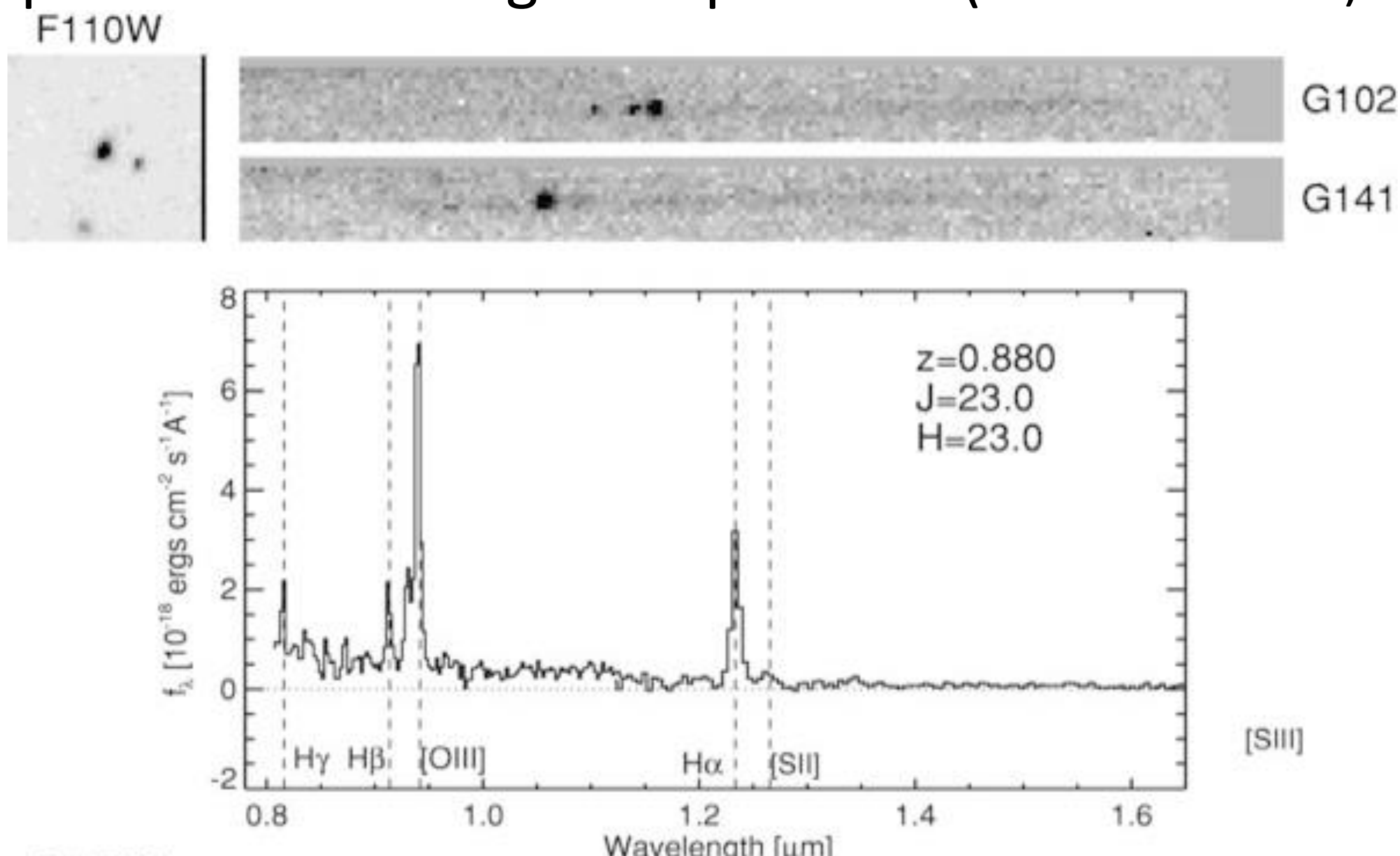
Galaxy Redshift Survey

Observables

Wide-field imaging & slitless spectroscopy measures 3-D galaxy distribution



Sample HST WFC3-IR grism spectrum (Atek et al 2010)



F110W

Galaxy Redshift Survey

Measurement Requirements

High Latitude Imaging Survey

High Latitude Spectral Survey

- Objective: Measure positions & redshifts of > 10^7 galaxies over 1<z<2 and thousands of square degrees
  - Obtain NIR images and spectra over >1700 sq deg
    - Measurement accuracy corresponds to $\sigma_z < 0.001(1+z)$
    - Sampling density sufficient to resolve features in galaxy power spectrum on spatial scales corresponding to k~0.2 h/Mpc
    - Spectroscopic survey rate >0.34 deg^2/hour
  - Requires good S/N on faint objects
    - $S/N \geq 6.5$ for 1×10^{-16} $ergs/cm^2/s$ limiting line flux
  - Requires good spatial uniformity of flux & wavelength cal.
    - Don't want to introduce sampling biases in galaxy distributions
    - $\sigma_\lambda/\lambda \leq 0.001$, varying field-to-field by $\leq 2\times10^{-5}$, σ_f/f uniform to < 0.02

Galaxy Redshift Survey

Measurement Requirements

- GRS measurement requirements
  - Obtain multi-object spectroscopy
    - WFIRST approach is slitless grism spectroscopy
    - Similar to HST grism spectroscopy, but higher resolving power for desired redshift accuracy.
    - Bandpass of at least 1.0-1.9μm for desired redshifts w/Hα
    - Need good temporal & spatial uniformity in flux calibrations, to understand survey depth
  - Obtain NIR images in at least one band
    - Required position measurement accuracy is easy
    - Multiple bands preferred: photometric redshifts reduce ambiguities in emission line identification.
    - Can use Weak Lensing imaging survey data
- Same dataset -> growth of structure via redshift-space distortions

Galaxy Redshift Survey

Requirements Validation

- Cosmological simulations & analytic models of GRS observables set top-level SRD requirements (2.0.x)
- Cosmological simulations and galaxy evolution models used to generate 4 deg^2 samples
  - probe astrophysical & instrumental systematic effects
    - changing bias of galaxies as tracers of overall matter, varying chemical composition (affects spectral diagnostics & potential redshift errors) etc.
    - Derive sensitivity to flux and wavelength calibration
  - Used to develop SRD requirements (2.1.x, 2.2.x, 2.3.x), calibration budgets, observing strategy
- Figure of Merit forecasts for each scenario compared to top-level requirement

Galaxy Redshift Survey

Requirements Summary

High Latitude Imaging Survey | High Latitude Spectral Survey

WFIRST — Wide-Field Infrared Survey Telescope — Dark Energy • Exoplanets • Astrophysics

Survey Capability (HLSS 2.0.x)

1: FoM_{BAO}>7533
2: FoM_{RSD}>4047
3: Slitless spectra
4: Completeness > 0.6
5: redshift accuracy, outlier fraction

Science Data Records (HLSS 2.1.x)

1: Completeness & depth systematics
2: outlier fraction knowledge
3: source catalog metadata
4: source catalog contents
5: extracted spectra
6: roll angle variation
7: spectral metadata
8: redshift determination
9: emission line wavelengths, flux
10: source position measurement
11: source imaging data

Calibrated Data Records (HLSS 2.2.x)

1: Calibrated spectra
2: Wavelength accuracy absolute
3: wavelength accuracy correlated errors
4: Flux calibration spatial uniformity

Raw Data Records (HLSS 2.3.x)

1: Raw data
2: Spectral dispersion
3: Spectral bandpass
4: PSF R(EE50)
5: Relative orientation of roll angles
6: Spectral deep fields

Key GRS Science Performance Requirements

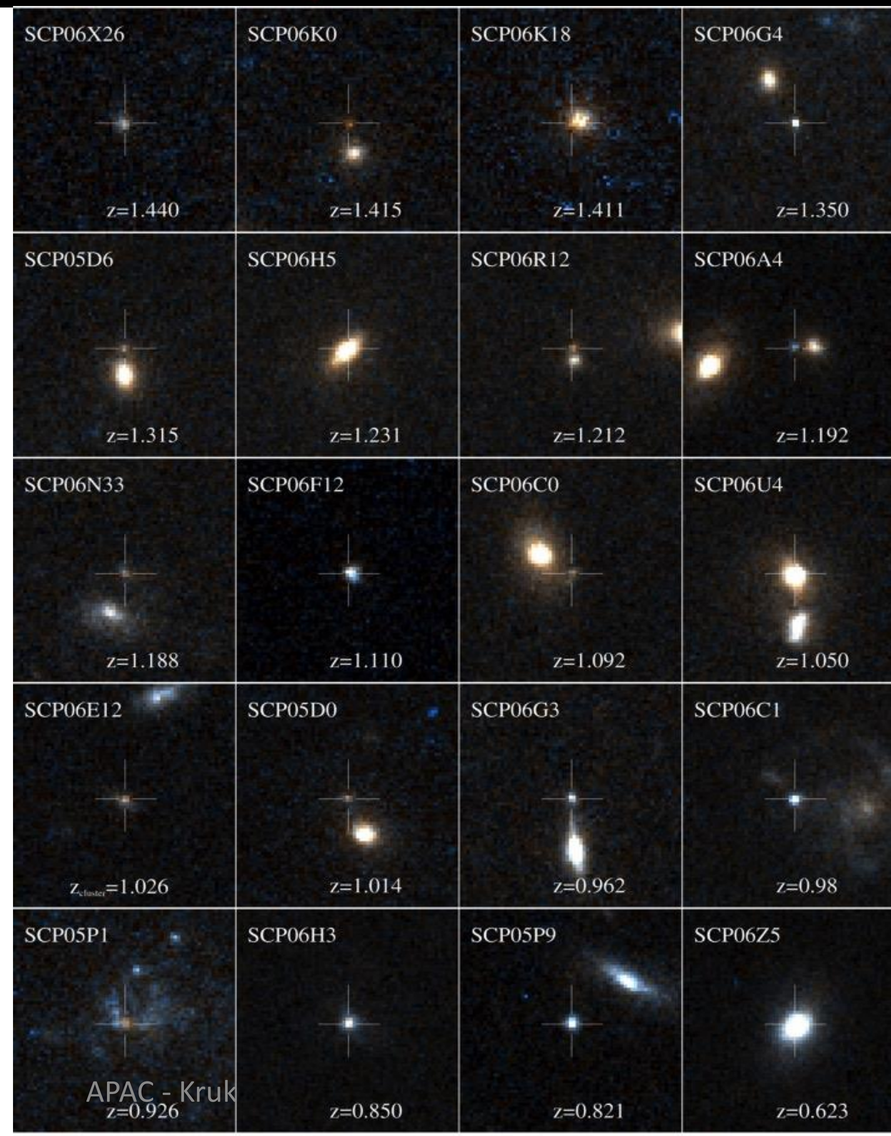
Representative values shown; full details in SRD.		Expansion, Structure, NIR Survey		Expansion	Exoplanet
		Weak Lensing	**Galaxy Redshift Survey**	**Supernovae**	**Microlensing**
Surveys & Data	**Area/Survey Speed**	0.20 deg^2/hr (1,700 deg^2)	0.34 deg^2/hr (1,700 deg^2)		
	Redshift	0≤z≤3	1.1 < z < 1.9 (2.9 w/OIII)		
	Sensitivity	S/N≥18 @ 24.4/24.3/23.7 (AB J/H/F184) r_{eff}=0.18”	S/N≥6.5 for 1.0x10^{-16} erg/cm^2/s		
	Cadence				
	Data Vol.	≥3 reads/exp	≥3 reads/exp		
PSF	**Quality**	EE50 ≤ 0.12” (J) EE50 ≤ 0.17” (IFC)	EE50≤0.21”@1.5 μm		
	Stability	1 nm RMS **Δ**WFE in 180s			
	Knowledge	2^{nd} moment ≤7.2x10^{-4} Ellipticity ≤5.7x10^{-4}			
Flux Calibration Relative Over	**Time**	0.5% /observing program	<2% rel spect-photometry		
	Wavelength	<2% abs/0.5% photo zeropt	<2% rel over bandpass		
	Dynamic Range				
	Area	<10 mmag	<2% rel over survey area		
Color	**Filters**	4 NIR bands for photo-z, 3 reddest for shapes	Overlap with HLIS for 3 filter imaging		
	Dispersion		10-12 Å/pix		

Super-
nova
Survey

Type Ia Supernovae
Observables

Sometimes SNe are well-separated from their host galaxy, and sometimes they're not!

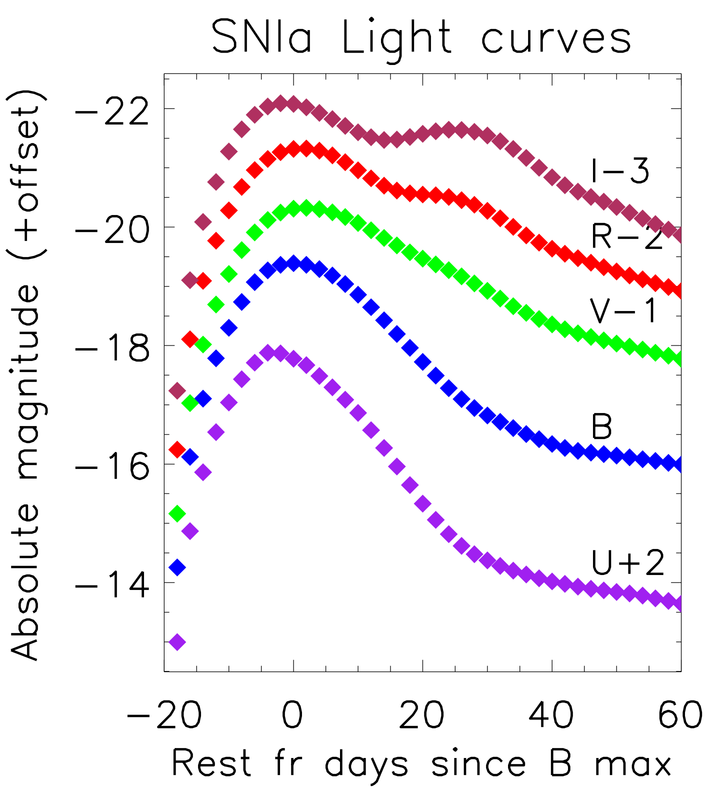
Have to accurately subtract the light of the host galaxy.

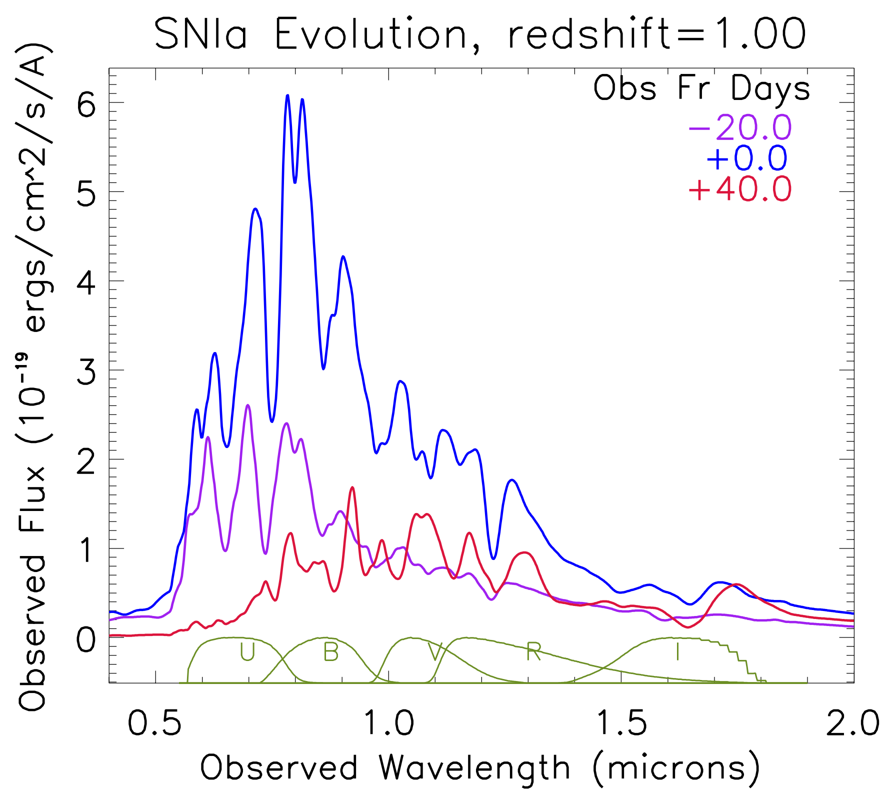


N. Suzuki et al. 2012 ApJ 746 85
doi:10.1088/0004-637X/746/1/85

Type Ia supernovae
Observables

- Shape of SNIa spectrum changes with time.
- Need at least one spectrum for redshift & confirm type (or host galaxy redshift)
- Need rest-frame spectrum to obtain luminosity and correct for dust extinction
  - Obtain spectra or multi-band imaging light-curves





Type Ia supernovae

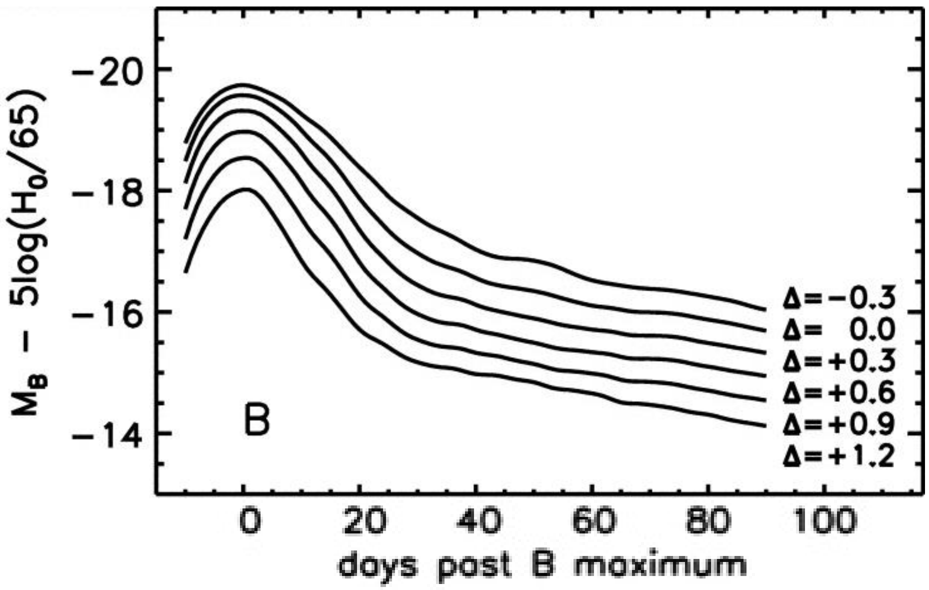
Observables

- Intrinsic brightness correlates with shape of light curve
  - Measure brightness at multiple times throughout evolution of each SN, *beginning prior to peak*

Figure shows rest-frame B band light curve templates.

SNIa with broader light curves are intrinsically brighter.

Jha, Riess, Kirschner 2007



Type Ia supernovae
Measurement Requirements

Super-nova Survey

- Objective: Obtain large sample of Type Ia supernovae: >100 per $\Delta z=0.1$ over $0.2 \leq z \leq 1.7$
  - Obtain NIR images in multiple bands on ~5 day cadence to discover SNe
    - Bands & area to monitor depend on redshift:

Sample SN imaging program; exposure times tailored to provide SN color uncertainty <0.03. Provides serendipitous multi-band deep field over wide area.

2-tier SNIa Discovery Imaging, cumulative 5σ point source depth in AB mag

Redshift Tier	Area Sq deg	R 0.48-0.76	Z 0.76-0.98	Y 0.92-1.19	J 1.13-1.45	H 1.38-1.77	F 1.68-2.0
<0.8	14	28.2	27.8	27.9	28.4	28.8	
<1.7	5		28.8	29.5	29.4	29.6	29.9

Type Ia supernovae

Measurement Requirements

- Type Ia supernovae – multiple possible observation approaches:
  - High-precision multi-band lightcurves, IFC spectra near peak for typing & redshift measurement *(WFIRST baseline)*
  - Discovery with multi-band NIR imaging, high-precision spectro-photometric follow-up throughout lightcurve with IFC
  - High-precision multi-band lightcurves, on-board prism or grism for redshifts of subset of SN or host galaxies
  - High-precision multi-band lightcurves, ground-based spectroscopy for redshifts (SN or host galaxy)

Type Ia supernovae

Measurement Requirements

- Type Ia supernovae - critical requirements (both imaging and spectrophotometry):
  - Relative (wavelength-dependent) flux calibrations
    - Slope of $(F_{true}(\lambda) – F_{meas}(\lambda))/F_{true}(\lambda)$ <0.005 over bandpass
  - Time-dependence of flux calibrations
    - Must be accurate to <0.5% over SN lightcurve and through host-galaxy measurement
  - PSF knowledge
    - sufficient for residuals of host-galaxy subtraction to be <0.5%
  - Non-linearity of flux calibrations must be <0.3% over a dynamic range of 15<AB<26
    - Transfer of standard star SED to SNe SED
  - Bias σ_z in mean redshift for a given redshift bin
    - must be $\sigma_z < 0.001(1+z)$
  - Observatory Field of Regard must provide access to SN survey region throughout SN lightcurves --> stable CVZ away from Galactic plane
  - Requires good S/N on faint objects (AB 25.5 or fainter)

Type Ia supernovae

Requirements Validation

- Cosmological simulations & analytic models of SNIa observables set top-level SRD requirements (SN 2.0.x)
- Individual supernovae & host galaxies are simulated to create mock datasets
  - Known ranges of properties of SNe are sampled randomly
  - Astrophysical & instrumental systematics are included
- Used to develop SRD requirements (2.1.x, 2.2.x, 2.3.x), calibration budgets, observing strategy
- Figure of Merit forecasts for each scenario compared to top-level requirement

Type Ia supernovae

Requirements Summary

Survey Capability (SN 2.0.x)

1: FoM_{SN}>325
2: $\mu(z)$, $0.2 \le z \le 1.7$
   $\sigma\mu \le 0.02$
   per Δz=0.1
3: >100 SNIa
   per Δz=0.1
4: $\sigma_z/(1 + z)$ bias

Science Data Records (SN 2.1.x)

1: Mosaic images
   each epoch
   ICRF astrometry
2: Mosaic image
   metadata
3: Mosaic images
   stacked over time
4: source catalog
   basic data
5: source catalog
   extended data
6: source catalog
   uncertainties

Calibrated Data Records (SN 2.2.x)

1: PSF & bandpass
   knowledge, each image
2: flux calibration
   wavelength dependence
3: flux calibration
   dynamic range
4: Wavelength accuracy
   absolute
5: flux calibration
   absolute
6: flux calibration
   over time
7: spectral data cubes
8: calibrated spectra
9: Spectrum characteristics
   & uncertainties

Raw Data Records (SN 2.3.x)

1: Raw data
2: low extinction
3: field of regard
4: observation cadence
5: imaging filters
6: spectral dispersion
7: spectral bandpass
8: spectral spatial
   resolution
9: spectrometer FoV
10: spectrometer PSF @
   image slicer
11: spectrometer PSF @
   focal plane
12: spectral follow-up
   latency
13: spectral S/N

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

Key Supernova Science Performance Requirements

Representative values shown; full details in SRD.		Expansion, Structure, NIR Survey		Expansion	Exoplanet
		Weak Lensing	Galaxy Redshift Survey	Supernovae	Microlensing
Surveys & Data	Area/Survey Speed	0.20 deg^2/hr (1,700 deg^2)	0.34 deg^2/hr (1,700 deg^2)	14, 5 deg^2 >100 SNe/Δz=0.1	
	Redshift	0≤z≤3	1.1 < z < 1.9 (2.9 w/OIII)	0.2≤z≤1.7	
	Sensitivity	S/N≥18 @ 24.4/24.3/23.7 (AB J/H/F184) r_{eff}=0.18”	S/N≥6.5 for 1.0×10^{-16} erg/cm^2/s	S/N≥13 (brightest filters at peak)	
	Cadence			~ 5 days	
	Data Vol.	≥3 reads/exp	≥3 reads/exp	≥3 reads/exp	
PSF	Quality	EE50 ≤ 0.12” (J) EE50 ≤ 0.17” (IFC)	EE50≤0.21”@1.5 μm	EE50 ≤ 0.12” (J) EE50 ≤ 0.14” (IFC)	
	Stability	1 nm RMS **Δ**WFE in 180s			
	Knowledge	2nd moment $\leq 7.2 \times 10^{-4}$ Ellipticity $\leq 5.7 \times 10^{-4}$		0.2%	
Flux Calibration Relative Over	Time	0.5% /observing program	<2% rel spect-photometry	<0.5% / 2 wk	
	Wavelength	<2% abs/0.5% photo zeropt	<2% rel over bandpass	<2% abs/ 0.5% photo zeropt	
	Dynamic Range			<0.3% 15<AB<26	
	Area	<10 mmag	<2% rel over survey area		
Color	Filters	4 NIR bands for photo-z, 3 reddest for shapes	Overlap with HLIS for 3 filter imaging	6 filters 0.5-2.0μm	
	Dispersion		10-12 Å/pix	70 < R < 150	

Scientific Objectives

High Latitude Imaging Survey

High Latitude Spectral Survey

Wide-Field IR Survey

WFIRST will conduct near-infrared (NIR) sky surveys in both imaging and spectroscopic modes, providing an imaging sensitivity for unresolved sources better than 26.5 AB magnitude.

This objective does not lead to any performance requirements not encompassed by the high-latitude survey.

Scientific Objectives

Micro Lensing Survey

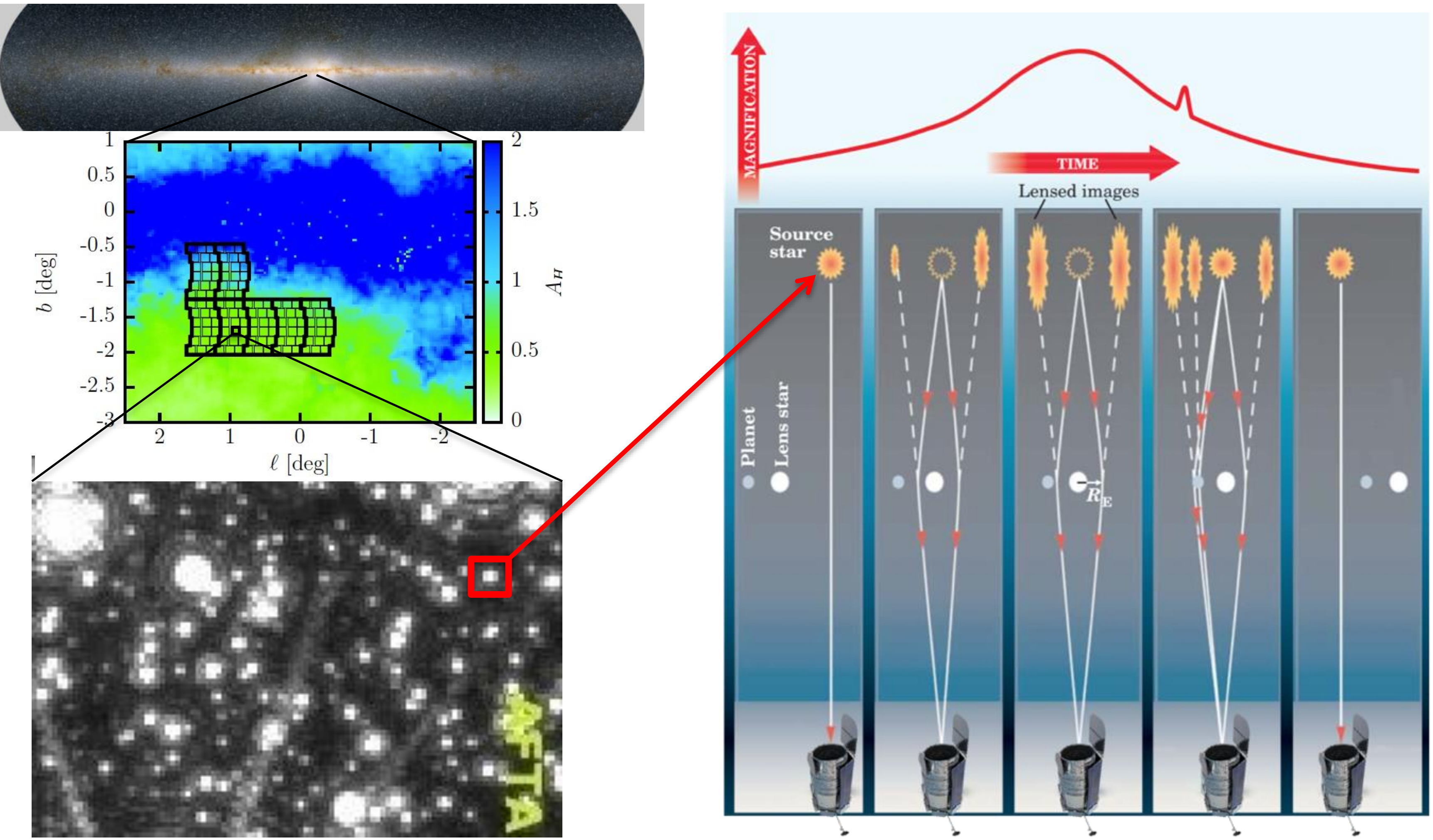
Exoplanet Census

WFIRST will carry out a statistical census of exo-planetary systems in the Galaxy, from the outer habitable zone to free floating planets, including analogs to all of the planets in our Solar System with the mass of Mars or greater, by monitoring stars toward the Galactic bulge using the microlensing technique.

Microlensing

Observables

Micro Lensing Survey



Great benefit of space observations in the crowded galactic bulge field

Microlensing
Observables

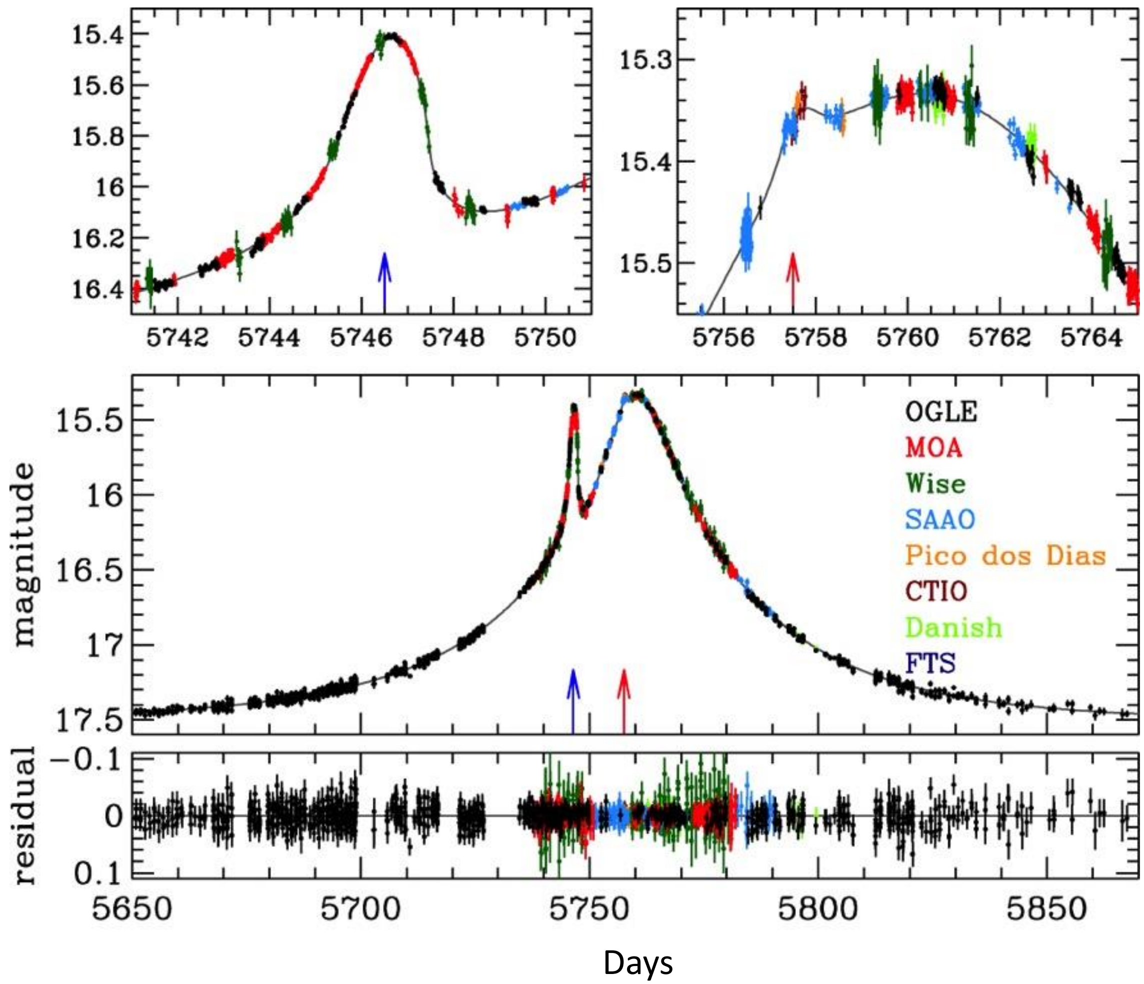
Micro Lensing Survey

Microlensing event from Jupiter-mass planet around an M-dwarf (Skowron et al 2015)

Shape of light curve is governed by changing geometry of source & host stars & planet; motion of Earth about Sun affects shape of star-star light curve.

High-precision relative photometry is essential

- Flux calibration over time
    - ≤0.1% over a season
- Flux calibration linearity



Microlensing
Measurement Requirements

- Microlensing Measurement Requirements & Observation Approach
  - Monitor fields in Galactic Bulge with NIR images at ~15 minute cadence
    - High density of stars maximizes event rate
    - NIR reduces effects of dust extinction -> access to higher density sightlines
  - Need accurate lightcurve shapes
    - 15 minute cadence samples planet event light curve (~2 hr timescale for low-mass planets)
    - Use wide filter (~1-2µm) to obtain high signal to noise (>100:1)
  - Need to determine distances of stars to break degeneracies in system masses and orbit parameters
    - Measure parallax
      - Astrometric precision <1mas/visit, ≤100 µas per season; observe both Fall & Spring seasons
    - Measure stars periodically in all filters
      - determine spectral type, improve position measurement accuracy
      - Absolute flux cal < 3%, relative filter zeropoints known to <1.4%
    - Maximize time from first to last observations to get best baseline for parallax and star-star separation for spectral typing
      - » Spectral type + brightness gives distance independent of parallax
  - Minimum monitor time: 60 days
    - Needed to characterize star-star lensing light curves
    - Drives Field of Regard: presently supports 72 day seasons

Microlensing

Requirements Validation

- Models of planet formation, knowledge of distributions inside habitable zone from Kepler used to set top-level requirements (SRD 2.0.x)
- Models of distribution of stars in the Galaxy, and models of planet formation are used to generate samples of microlensing events
- Events are then "observed" through a model of the observatory, and analyzed to set lower-level requirements (SRD 2.1.x, 2.2.x, 2.3.x)
  - Optimize observing strategy
    - Field placement, filters, cadence, exposure time, etc
  - Study instrumental effects such as persistence
  - Derive calibration requirements, data product requirements
- Forecasts of yields compared to top-level requirements

Microlensing

Requirements Summary

Micro Lensing Survey

Survey Capability
(EML 2.0.x)

1: Mass function for $1M_{Earth} < m < 30M_{jupiter}$ to <15%
2: Mass function for $0.1M_{Earth} < m < 0.3M_{Earth}$ to <25%
3: masses, distances to 40% host stars
4: free-floating planet frequency
5: estimate η_{Earth}

Science Data Records
(EML 2.1.x)

1: Mosaic images each season
2: source catalog basic data
3: source catalog extended data
4: source catalog uncertainties
5: daily calibrated moment curves
6: astrometry: ≤100 μas per season

Calibrated Data Records
(EML 2.2.x)

1: calibrated images
2: calibrated moment curves
3: astrometry per exposure ≤1 mas at AB=21.4
4: Stellar image radius precision <1% per day
5: Stellar image radius precision <0.2% per season
6: flux calibration <0.1% w/in a season
7: flux calibration <0.1% season to season
8: flux calibration absolute
9: flux calibration across filters

Raw Data Records
(EML 2.3.x)

1: Raw data
2: monitor 585 deg-days S/N=100 H_{AB}=21.4
3: S/N=100 H_{AB}=21.4 per exposure
4: filter bandpass
5: observation cadence
6: PSF R(EE50) <0.15”
7: data downlink
8: deleted
9: season duration (FoR)
10: duty cycle
11: additional filters
12: season interval
13: distortion calibration

Key Microlensing Science Performance Requirements

Representative values shown; full details in SRD.

		Expansion, Structure, NIR Survey		Expansion	Exoplanet
		Weak Lensing	**Galaxy Redshift Survey**	**Supernovae**	**Microlensing**
Surveys & Data	**Area/Survey Speed**	0.20 deg^2/hr (1,700 deg^2)	0.34 deg^2/hr (1,700 deg^2)	14, 5 deg^2 >100 SNe/Δz=0.1	586 deg^2-day Over 6+ seasons
	Redshift	0≤z≤3	1.1 < z < 1.9 (2.9 w/OIII)	0.2≤z≤1.7	
	Sensitivity	S/N≥18 @ 24.4/24.3/23.7 (AB J/H/F184) r_{eff}=0.18”	S/N≥6.5 for 1.0x10^{-16} erg/cm^2/s	S/N≥13 (brightest filters at peak)	S/N>100 for H_{AB}=21.4 star
	Cadence			~ 5 days	15 min
	Data Vol.	≥3 reads/exp	≥3 reads/exp	≥3 reads/exp	≥3 reads/exp
PSF	**Quality**	EE50 ≤ 0.12” (J) EE50 ≤ 0.17” (IFC)	EE50≤0.21”@1.5 μm	EE50 ≤ 0.12” (J) EE50 ≤ 0.14” (IFC)	EE50 ≤ 0.15” (wide)
	Stability	1 nm RMS **Δ**WFE in 180s			
	Knowledge	2^{nd} moment ≤7.2x10^{-4} Ellipticity ≤5.7x10^{-4}		0.2%	
Flux Calibration Relative Over	**Time**	0.5% /observing program	<2% rel spect-photometry	<0.5% / 2 wk	<0.1%/season
	Wavelength	<2% abs/0.5% photo zeropt	<2% rel over bandpass	<2% abs/ 0.5% photo zeropt	<3% abs <1.4% photo zeropt
	Dynamic Range			<0.3% 15<AB<26	<0.1% over 2 mag
	Area	<10 mmag	<2% rel over survey area		
Color	**Filters**	4 NIR bands for photo-z, 3 reddest for shapes	Overlap with HLIS for 3 filter imaging	6 filters 0.5-2.0μm	Wide filter, & 1 short, 1 longward of 1μm
	Dispersion		10-12 Å/pix	70 < R < 150	

Coronagraphy

Requirements Validation

- Performance forecasts are done with end-to-end simulations of planet observations
  - Emergent planet flux modeled with varying atmospheric compositions, stellar spectra, planet size and orbit radius, viewing conditions
  - Simulated observations done with high-fidelity integrated models of the observatory and coronagraph instrument.

WFI Data Processing

- Wide-Field Instrument
  - Initial data reduction of raw NIR detector data similar to that for WFC3/IR.
  - Assemble sequences of overlapping images into mosaics
    - PSF determination from stars in each image & from downlinked guide star image series
  - Identify sources, compute positions, fluxes, shapes, photometric redshifts, etc., populate catalogs
    - For weak lensing, additional steps for iterative shape determination, possible joint analysis with LSST data
    - Generate 3-D matter distribution maps from WL data
  - Galaxy redshift survey (GRS):
    - Extract spectra associated with sources in image catalog
    - Fit spectra, assign redshifts
    - Generate precise 3-D galaxy distribution
  - Cosmological analysis of WL, GRS: computing correlation functions over entire matter distribution dataset gives info on growth of structure and evolution of cosmic distance scale
  - Microlensing, SNIa monitoring:
    - Use successive images of field to compute time-series for each source
  - Microlensing analysis: Combination of light curve shapes, stellar photometry and astrometry gives planet masses & orbit radii
  - SNIa spectra
    - Derive 2-D spectral time series for each SN and host galaxy, extract SN spectra
    - Fit spectra, assign redshifts, compute rest-frame photometry
  - Cosmological analysis of SNIa done by fitting Hubble diagram of distance-redshift points

BACKUP FOR MRD

Implement Surveys in 5 years Mission Implementation (2 of 3)

- **MRD 152:** WFC have an active field of view ≥0.25 deg^2
  - Flows to WFI – Sets WFC focal plane size
- MRD 166: Supernova Spectroscopy FOV have a field of view ≥9 arcsec^2
  - Flows to WFI – Establishes requirements for Supernova Spectroscopy IFC optics
- MRD 173: Photometric Redshift Calibration Spectroscopy FOV have a field of view ≥36 arcsec^2
  - Flows to WFI (IFC) – Establishes requirements for Photometric Redshift Calibration Spectroscopy IFC optics
- **MRD 153:** Have an average angular sample of 0.11 arcsec/pix in the WFC.
  - Flows to OTA & WFI – Establishes requirements for optical prescription
- **MRD 294-298:** Slew in <23 sec for slew of 212 arcsecond (gap-filling), <56 sec for slew of 0.41 deg (short FoV), <78 sec for slew of 0.82 deg (long FoV), <92 sec for slew of 1.16 deg (ML return), <3700 sec for slew of 180 deg
  - Flows to S/C – Establishes requirements for number and size of wheels
- **MRD 409-411:** Settle within 10 sec for slew <1 deg, within 10 sec + 1 sec per degree of slew between 1 and 10 deg, within 20 seconds for slews >10 deg.
  - Flows to S/C – Establishes requirements for deployed frequency, centroiding algorithms

Implement Surveys in 5 years
Mission Implementation (3 of 3)

- **MRD 432:** Observatory throughput efficiency greater than the values listed in table.
  - Flows to OTA & WFI – See S/N Budget
- **MRD 433:** Intrinsic background contribution (thermal & dark current) from the Observatory less than values listed in table.
  - Flows to OTA & WFI – See S/N Budget
- **MRD 434:** WFC total noise less than 7.5e-.
  - Flows to WFI – See S/N Budget
- MRD 465: Observatory throughput efficiency for the IFC greater than 0.44 averaged over the bandpass in MRD-370.
  - Flows to OTA & WFI – See S/N Budget
- MRD 466: Intrinsic background contribution (thermal & dark current) from the Observatory in the IFC less than 0.0036 e-/pix at 2 μm and 0.0022 e-/pix at 0.45 μm .
  - Flows to OTA & WFI – See S/N Budget
- MRD 467: IFC total noise less than 7.5e-.
  - Flows to WFI – See S/N Budget
- MRD 340: Execute the core WFIRST surveys and calibration observations from the SITs
  - Flows to the Ground Sys – Establishes requirements for planning and scheduling system
- MRD 341: Execute the General Observer/Guest Investigator program.
  - Flows to the Ground Sys – Establishes requirements for planning and scheduling system

Provide Data Mission Implementation

- **MRD 018:** Total daily downlink of at least 11 Tbits on high rate science downlink
  - Decomposed in MRD to WFI, S/C & Ground
    - WFI requirements
      - MRD 186: WFI provide subsets of detector frames, either individual frames or linear combinations of frames at ground-specified intervals during an exposure
      - Also establishes requirement for WFI data compression
    - Ground Sys & S/C
      - MRD 279: Ka-Band downlink information rate up to 500 Mbps
- MRD 020: Limit total science data lost to <2%
  - MRD-254: Recover the daily science data volume from a missed contact within 7 days.
    - Establishes requirements for SSR size and scheduling downlink time to enable data recovery

Provide Data (Data Release Rqmts) Mission Implementation

- MRD 337: Archive raw, instrument housekeeping and processed/calibrated data generated as well as all higher-level science products in a public archive.
  - Flows to Ground Sys – Establishes requirements for sizing data archive
- **MRD 023:** Provide a public release of uncalibrated (Level 1) data within 72 hours of WFI data acquisition at least 95% of the time.
  - Flows to Ground Sys – Establishes requirements for latency for downlinking & processing data
- MRD 429: Provide a public release of WFI data processed to at least the resampled/coadded (Level 3) standard using then-available calibrations within 168 hours of acquisition at least 95% of the time.
  - Flows to Ground Sys – Establishes requirements for data processing
- MRD 349: Provide a public release of all WFI data processed to at least the resampled/coadded (Level 3) standard within 6 months of acquisition.
  - Flows to Ground Sys – Establishes requirements for data processing and data releases
- MRD 348: Provide a public release of uncalibrated (Level 1) data within 72 hours of CGI data acquisition at least 90% of the time.
  - Flows to Ground Sys – Establishes requirements for data processing
- **MRD 329:** Generate science data products for all observations per the applicable requirements in the Science Requirements Document (WFIRST-RQMT-05301).
  - Flows to Ground Sys – Establishes requirements for data processing pipeline
- MRD 330: Enable science investigators to perform custom data reduction of the WFIRST data set
  - Flows to Ground Sys – Establishes requirements for SOC tools
- MRD 445: Incorporate compatible software provide by SITs into operational high-level data processing pipelines
  - Flows to Ground Sys – Establishes requirements for data processing pipeline

PSF Requirements Mission Implementation (1 of 2)

- MRD 003: Operate the observatory in orbit about Sun-Earth L2
  - Flows to Observatory, Launch Vehicle & Ground System – Establishes requirements for environments, mass, S/C (ACS, comm, prop, power), flt dyn
- MRD 114: Provide data to support the determination of the PSF in the Wide Field Instrument for each exposure
  - Flows to WFI to provide guide window image data, S/C to provide IRU & wheel speed data, and Ground for PSF reconstruction
- MRD 187: Provide a capability to download all frames of science data without data compression from all WFC SCAs over an exposure
  - Flows to WFI & S/C – Establishes requirements for throughput of data system
- MRD 428: Provide a capability to perform focus diversity phase retrieval using the WFI
  - Flows to WFI for range & resolution of focus mechanism
- **MRD 353:** Provide wavefront stability of ≤1 nm RMS per 180 sec for at least 95% of exposures in WIM
  - Flows to IC, OTA & WFI – Establishes requirements for thermal stability, basis for architecture decision to guide from WFC FPA
- **MRD 352:** Provide a wavefront error of ≤110 nm rms, including line of sight motion, in WIM, for at least 95% of the exposures and over 95% of the FOV
  - Flows to IC, OTA, & WFI – see WFE & Align budget
- **MRD 038:** Maintain the WFC pointing stability within 8 milliarcsec (1-sigma per axis) in WIM for exposures up to 1000 seconds.
  - Flows to WFI & S/C – see Stability budget
- **MRD 039:** Maintain the WFC line of sight jitter within 12 milliarcsec (1-sigma per axis) in WIM WIM for exposures up to 1000 seconds.
  - Flows to S/C for RWA isolators, limiting RWA speed range and separating RWA wheel speeds, IC for payload isolation
- MRD 355: Provide a wavefront error of ≤198 nm rms at 1.5 μm for a monochromatic point source, including line of sight motion, for at least 95% of the exposures and over 95% of the FOV
  - Flows to IC, OTA, & WFI – see WFE & Align budget
- MRD 394: Maintain the WFC pointing stability within 99 milliarcsec (1-sigma) in the spectral dispersion direction on the WFC focal plane and 48.5 milliarcsec (1-sigma) in the cross-dispersion direction in WSM for exposures up to 360 seconds.
  - Flows to WFI & S/C – see Stability budget

PSF Requirements Mission Implementation (2 of 2)

- **MRD 033:** Perform sub-pixel scale slews of 22 milliarcsec relative to the current pointing with an accuracy of 11 milliarcsec (RMS/axis) about pitch and yaw in the WFC Focal Plane frame for the WIM
  - Flows to WFI & S/C – see Pointing budget, basis for architecture decision to guide from WFC FPA
- MRD 153: Have an average angular sample of 0.11 arcsec/pix in the WFC.
  - Flows to OTA & WFI – Establishes requirements for optical prescription
- MRD 167: SN Spectroscopy FOV have 2- to 4-pixel spatial resolution of ≤0.20 arcsec for at least 95% of the exposures and over 95% of the slicer FOV.
  - Flows to OTA, WFI – Establishes requirements for 2 slicer design, see WFE & Align budget
- MRD 174: Photometric Redshift Calibration Spectroscopy FOV shall have 2- to 4-pixel spatial resolution of ≤0.30 arcsec for at least 95% of the exposures and over 95% of the slicer FOV.
  - Flows to OTA, WFI – Establishes requirements for 2 slicer design, see WFE & Align budget
- MRD 358: Observatory provide a wavefront error of ≤ 117 nm RMS at a wavelength of 1.3 µm at the image slicer in the IFC for the Supernova Spectroscopy FOV, for at least 95% of the exposures and over 95% of the slicer FOV.
  - Flows to IC, OTA, & WFI – see WFE & Align budget
- MRD 440: Observatory provide a wavefront error of ≤ 130 nm RMS at a wavelength of 1.3 µm at the focal plane in the IFC for the Supernova Spectroscopy FOV, for at least 95% of the exposures and over 95% of the slicer FOV.
  - Flows to WFI – see WFE & Align budget
- MRD 361: Observatory provide a wavefront error of ≤ 172 nm RMS at a wavelength of 1.3 µm at the focal plane in the IFC for the Photometric Redshift Calibration Spectroscopy FOV, for at least 95% of the exposures and over 95% of the slicer FOV.
  - Flows to IC, OTA,& WFI – see WFE & Align budget
- **MRD 100:** Use stars in the Wide Field Instrument field of view to meet the fine pointing accuracy and stability requirements.
  - Flows to WFI, S/C & Ground Sys – Establishes requirements for use of guide window & ground selection of guide stars

Relative Flux Calibration Mission Implementation (1 of 2)

- Calibration implemented via calibration observations and using a WFI Relative Calibration System for calibrations which can't be performed using astronomical sources
- On-Board Calibration Requirements
  - **MRD 181:** WFI provide a flight cal light source to the WFI detectors, selectable and repeatable, over the range from a max full pixel well in 1 frame time to a min down 5 orders of magnitude.
  - **MRD 390:** WFI provide a cal light source to the WFI detectors that varies by no more than 50% peak-to-trough across each FPA
  - MRD 391: WFI provide at least 1 quasi-monochromatic source per filter bandpass
  - **MRD 384:** WFI provide a dark setting in the WFC that allows the instrumental background to be measured
  - MRD 385: WFI provide a dark setting in the IFC that allows the instrumental background to be measured
    - All flow to WFI - Establishes requirements for relative calibration system and dark capability

Relative Flux Calibration Mission Implementation (2 of 2)

- Astronomical Calibration Requirements
  - **MRD 340:** Execute the core WFIRST surveys and calibration observations from the SITs
    - Flows to the Ground Sys – Establishes requirements for planning and scheduling system
  - **MRD 033:** Perform sub-pixel scale slews of 22 milliarcsec relative to the current pointing with an accuracy of 11 milliarcsec (RMS/axis) about pitch and yaw in the WFC Focal Plane frame for the WIM
    - Flows to WFI & S/C – see Pointing budget, basis for architecture decision to guide from WFC FPA
  - **MRD 406:** Return on successive visits to a field such that the WFC FOV boresight is within 110 milliarcsec RMS of its commanded direction, and with offsets up to 2.2 arcsec from the nominal target
    - Flows to WFI & S/C – see Pointing budget, basis for architecture decision to guide from WFC FPA
- Ground Processing Requirements
  - MRD 329: Generate science data products for all observations per the applicable requirements in the Science Requirements Document (WFIRST-RQMT-05301).
    - Flows to Ground Sys – Establishes requirements for data processing pipeline
  - **MRD 330:** Enable science investigators to perform custom data reduction of the WFIRST data set
    - Flows to Ground Sys – Establishes requirements for SOC tools
  - **MRD 445:** Incorporate compatible software provide by SITs into operational high-level data processing pipelines
    - Flows to Ground Sys – Establishes requirements for data processing pipeline

Color
Mission Implementation

- **MRD 154:** WIM provide at least seven imaging filters spanning the range 0.48 µm to 2.0 µm with wavelength ranges as specified in the filter table
  - Flows to WFI – Establishes requirements for WFI filters, element wheel
- **MRD 161:** WSM provide slitless spectroscopy with a spectral dispersion between 1.0 nm/pix and 1.2 nm/pix over the bandpass 1.0 to 1.93 µm and across the full field.
  - Flows to WFI – Establishes requirements for WFI grism, element wheel

Filter	Blue Cutoff	Red Cutoff
F062	0.48	0.76
F087	0.76	0.98
F106	0.93	1.19
F129	1.13	1.45
F158	1.38	1.77
F184	1.68	2.00
F146	0.93	2.00

- **MRD 168:** IFC shall provide a spectral sampling of 2 to 4 pixels/slice.
- **MRD 169:** IFC shall provide integral field spectroscopy with a resolving power between 70 and 150 per one slice spectral resolution element over the bandpass of 0.6 µm – 2.0 µm.
- **MRD 370:** IFC shall have a bandpass spanning at least 0.45 -2.0 µm.
  - 168, 169, 370 flow to WFI – Establishes requirements for IFC design

PLRA Technical Flow Down Mission Implementation

- MRD 011: Execute the science program in an operational phase lifetime of 5 years.
  - Flows to Observatory & Ground System – Establishes requirements for environments, redundancy, efficiency related requirements (parallel science & downlink, parallel instrument ops, event driven ops), power
- **MRD 392:** Employ components of an existing telescope with a 2.36 m diameter primary mirror, on-axis secondary mirror, and associated metering structure.
  - Flows to Telescope – Establishes requirements for overall optical system design and observatory size
- **MRD 058:** Be designed to support on-orbit robotic servicing of the instruments and spacecraft.
  - Flows to WFI, CGI, IC, & S/C – Establishes requirements for instrument-IC interface, accessible instrument connectors, S/C services for orbital replacements & interfaces to servicer
- **MRD 063:** Be capable of performing observations in combination with a starshade occulter
  - Flows to CGI & S/C – Establishes requirements for additional filters, starshade lateral sensing, and thruster plume scattered starlight protection in CGI, addition of starshade acquisition camera and space-to-space comm link in S/C
- MRD 334: Execute a Target of Opportunity order within 2 weeks of approval of a request
  - Flows to Ground Sys – Establishes requirements for planning and scheduling system

CGI Technology Flow Down Mission Implementation (1 of 2)

- MRD 449: Provide at least four filters as specified in filter table
- **MRD 436:** Be able to measure the brightness of an astrophysical point source to an SNR of 10 or greater within 10 hours of integration time on the target in CGI Filter Band 1 for an object with a source-to-star flux ratio as faint as $1x10^{-7}$ at separations from 0.16 arcsec to 0.21 arcsec, $5x10^{-8}$ at separations from 0.21 arcsec to 0.4 arcsec, and $1x10^{-7}$ at separations from 0.4 arcsec to 0.45 arcsec.
- **MRD 437:** Be able to measure spectra of an astrophysical point source with R=50 or greater spectral resolution with a wavelength accuracy of 5 nm or smaller (TBR9) to an SNR of 10 within 100 hours of integration time on the target in CGI Filter Band 3 for an object with a source-to-star flux ratio as faint as $1x10^{-7}$ at separations from 0.21 arcsec to 0.27 arcsec, $5x10^{-8}$ at separations from 0.27arcsec to 0.53 arcsec, and $1x10^{-7}$ at separations from 0.53 arcsec to 0.60 arcsec.
- **MRD 438:** Be able to measure the brightness around a star as faint as V = 5 mag with an SNR of 10 or greater within 24 hours (TBR12) of integration time on the target in CGI Band 4 for an extended source with an integrated surface brightness per resolution element equivalent to a source-to-star flux ratio as faint as $1x10^{-7}$ at separations from 0.47 arcsec to 0.54 arcsec, $5x10^{-8}$ at separations from 0.54 arcsec to 1.36 arcsec, and $1x10^{-7}$ at separations from 1.36 arcsec to 1.44 arcsec.
- MRD 451: Be able to map the linear polarization of a circumstellar debris disk that has a polarization fraction greater or equal to 0.3 with an uncertainty of less than 0.03 in CGI Filter Band 1 and CGI Filter Band 4, assuming SNR of 100 per resolution element.

CGI Technology Flow Down Mission Implementation (2 of 2)

- MRD-452: Be able to measure the relative astrometry between an astrophysical point source and its host star, in photometric images, for separations from 0.21 arcsec to 1.36 arcsec, with an accuracy of 5 milliarcsec or less, assuming SNR of 10 or greater, including systematic errors.
- MRD-453: Be able to capture wavefront control system telemetry concurrently with science data, including raw wavefront sensor measurements and commanded deformable mirror actuator values
- **MRD-454:** Be able to measure the complex electric fields of incident light in two orthogonal polarization states.
- **MRD-455:** Be able to measure observatory tip/tilt disturbances at the CGI occulter at frequencies from 0.1 Hz to 100 Hz with accuracy better than 0.5 mas rms on sky per axis for a V=2 mag or brighter star
- MRD-456: Be able to estimate the average rate of change over 1 hour period at the CGI occulter for each of focus, astigmatism, coma, trefoil, and 3rd-order spherical aberrations, with accuracy better than 0.1 nm/hour, when pointed at a V=2 mag or brighter star.
- MRD-457: Direct imaging camera shall have a field of view with a radius of ≥3 arcseconds.
  - All Flow to CGI

- **Additionally, per the PLRA, CGI not allowed to drive observatory performance; therefore image quality and jitter requirements are derived from the CGI technology requirements consistent with Observatory requirements derived from wide field science requirements:**
  - Image quality requirements specified at input to CGI
  - Quasi-static optical interface requirements documented in Level 3 specs
  - CGI jitter requirements captured in CGI spec, met by operating over wheel speed range that provides low jitter

KEY REQUIREMENTS SORTED BY MISSION SEGMENT

OTA Key Requirements

- Implement Surveys & Provide Data
  - Image quality & stability requirements - MRD 352, 353, 355, 358, 361 & 420
    - Sub-allocated in WFE & Align Budget
  - Throughput, background, noise - MRD 432, 433, 465, 466
    - Sub-allocated in S/N budget
  - Prescription & Angular Sampling - MRD 79, 153
  - Common OTA alignment - MRD 102
- Directed Requirements
  - Use existing heritage hardware - MRD 392

WFI Key Requirements

- Implement Surveys & Provide Data
  - FOV - MRD 152(WFC), MRD 166 & 173 (IFC)
  - Throughput, background, noise - MRD 432-434, 465-467 (Sub-allocated in S/N budget)
  - Pointing – MRD 035 (Sub-allocated in Pointing Budget)
  - Data volume – MRD 018, 186
- PSF
  - Image quality & stability requirements - MRD 352, 353, 355, 358, 361, 440, 167, 174 (Sub-allocated in WFE & Align Budget)
  - Prescription & Angular Sampling – MRD 147, 153
  - Fine Guidance Sensor – MRD 177
  - Pointing – MRD 033, 038, 039, 394, 395, 430 (Sub-allocated in Pointing Budget)
  - Focus Diversity Phase Retrieval - MRD 428
- Calibration
  - Calibration requirements - MRD 181, 390, 391, 384, 385
  - WFI Engineering Data Mode - MRD 187
- Colors
  - Filters & Spectral Dispersion - MRD 154, 161
  - IFC – 168, 169, 370
- Directed Requirements
  - Serviceability - MRD 185

CGI Key Requirements

- Implement Surveys & Provide Data
  - Prescription – MRD 79
  - Pointing & stability accuracy – MRD 202
  - 3 Tbits/day data volume – MRD 204
- Directed Requirements
  - CGI technology requirements - MRD 436-438, 449-457
  - Serviceability – MRD 203
  - Starshade accommodation - MRD 206, 207, 426

IC Key Requirements

- PSF
  - Optically stable payload support - MRD 208
  - Image quality & stability requirements - MRD 352, 353, 355, 358, 361, 420, 038, 039, 394, 395
    - Sub-allocated in WFE & Align Budget
- Directed Requirements
  - Serviceable mechanical interfaces - MRD 209

Spacecraft Key Requirements

- Implement Surveys & Provide Data
  - Provide standard S/C services, e.g., power, data, comm, GN&C - MRD 214
  - Payload accommodation – MRD 219
  - Pointing - MRD 032, 035, 038, 394 (Sub-allocated in Pointing Budget), 100
  - Field of Regard - MRD 042, 044
  - Event Driven Ops - MRD 052
  - Slew Times/Settle Times - MRD 294-298, 414-418 /409-411
  - Data Volume, Stored Science Data Recovery, Ka-Band Downlink Rate - MRD 018, 254, 279
- PSF
  - Sub-Pixel Pointing - MRD 033 (Sub-allocated in Pointing Budget)
  - Jitter - MRD 039, 395
- Calibration
  - Return Pointing with Offset - MRD 406
  - WFI Engineering Data Mode - MRD 187
- Directed Requirements
  - Serviceability - MRD 223
  - Starshade accommodations - MRD 282, 310
- Other Key Requirements
  - Provide OBA - MRD 220

Ground System Key Requirements

- Implement Surveys & Provide Data
  - Implement core science surveys and GO/GI Program - MRD 050, 051, 372, 052, 340, 341
  - Routine Operations - MRD 053, 327, 388, 328
  - Observatory management - MRD 027, 387, 336
  - Manage Data Volume - MRD 018, 279, 447, 331
  - Science Data Processing & Archiving - MRD 329, 024, 025, 423, 429, 349, 337
- Calibration
  - Custom Data Reduction - MRD 330
  - SIT Provide S/W - MRD 445
- Directed Requirements
  - Target of Opportunity - MRD 334

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

Driving Requirements

Program	PSF			Flux Calibration relative over:			Slew & settle time	Data Volume
	Quality	Stability	Knowledge	Time	Wavelength	Dynamic range		
WL	✓✓	✓✓	✓✓	✓	✓		✓	✓
GRS	✓			✓			✓	
SNIa	✓	✓	✓	✓✓	✓✓	✓	✓	✓
ML			✓	✓		✓	✓✓	✓✓

✓ - Important for part of program, but perhaps not all, or is not most stressing case
✓✓ - Essential for entire program, and/or is most stressing case