~~Cosmic Shear~~ Weak Lensing with the Wide Field Infrared Survey Telescope (WFIRST)

Jason Rhodes (NASA JPL/Caltech/IPMU)

Gravlens 2016

Leiden July 15, 2016

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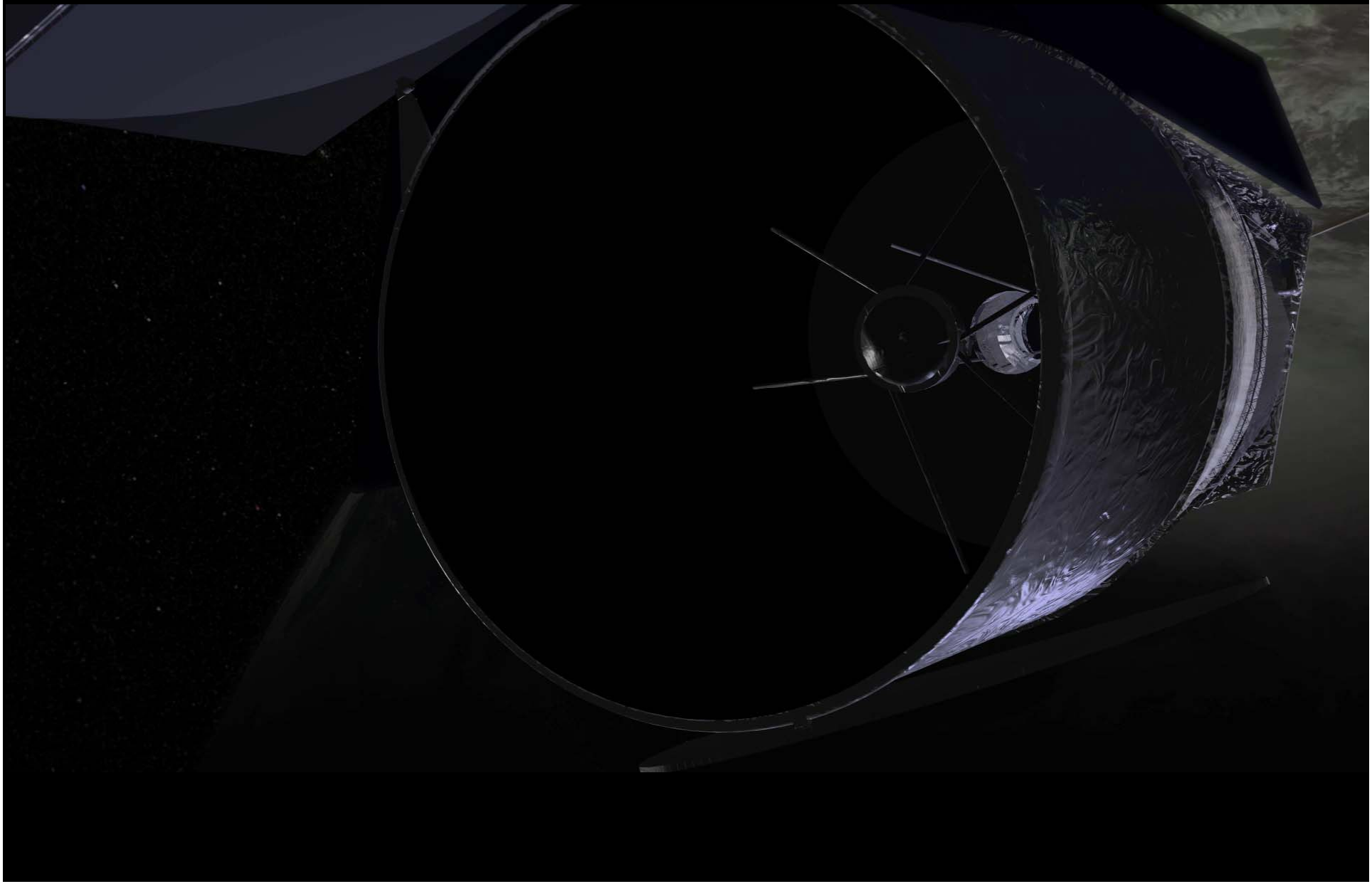
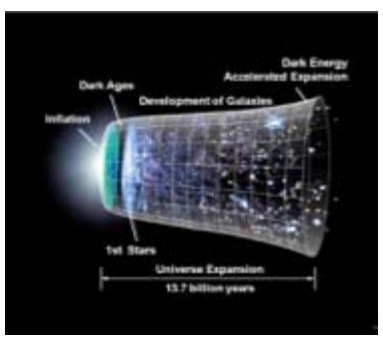


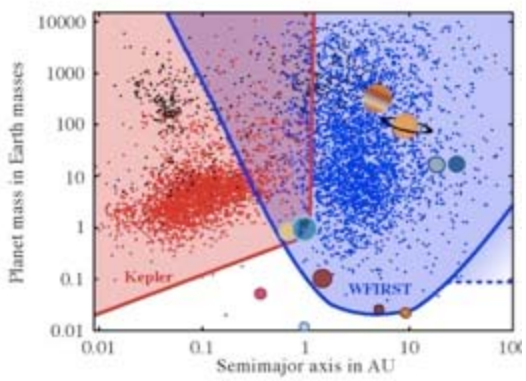
Introduction

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

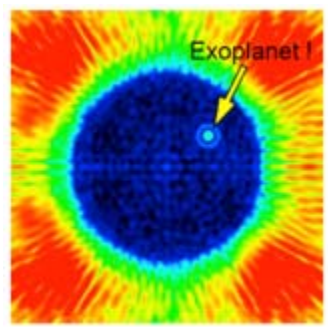
Dark Energy



Exoplanets

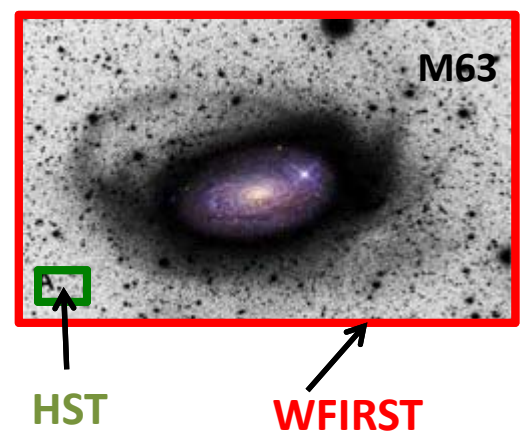


Microlensing

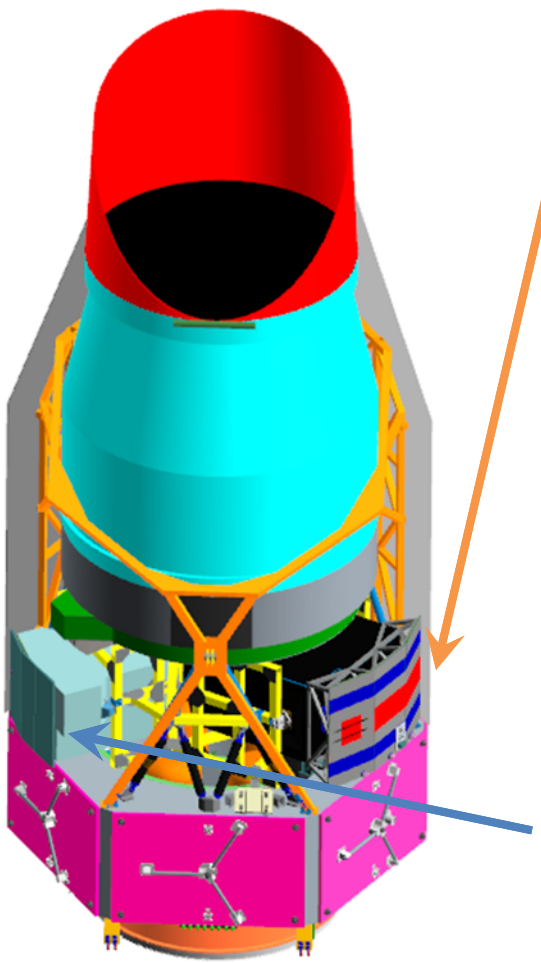


Coronagraph

Astrophysics



WFIRST Instruments



Wide-Field Instrument

- *Imaging & spectroscopy over 1000s of sq. deg.*
- *Monitoring of SN and microlensing fields*
- 0.7 – 2.0 μm (imaging) & 1.35-1.89 μm (spec.)
- 0.28 deg^2 FoV (100x JWST FoV)
- 18 H4RG detectors (288 Mpixels)
- 6 filter imaging, grism + IFC spectroscopy

Coronagraph

- *Image and spectra of exoplanets from super-Earths to giants*
- *Images of debris disks*
- 430 – 970 nm (imaging) & 600 – 970 nm (spec.)
- Final contrast of 10^{-9} or better
- Exoplanet images from 0.1 to 1.0 arcsec

WFIRST Status

- Significant WFIRST funding added to the NASA budget by Congress for FY14 and FY15 for a total of $106.5M. FY16 budget is $90M. Entry into Phase A (real project!) was in Feburary for a 2024-2025 launch
- Foreign contributions being actively pursued for hardware, science, and telescope time
  - Need to be decided during Phase A, in the next ~ year, with 'Acquisition Strategy Meeting' this month
- Formulation Science Working Group selected late 2015 to assist Project in requirements, methods, algorithm, simulations development through ~2021
  - Made up of 11 Science Investigation Teams and 2 Adjutant Scientists
  - 2 European, 1 Canadian, and one Japanese observer have been selected
- Operation science team selected in ~2021
- Foreign co-Is not selected for FSWG or SITs so that foreign partners can make their own selections
  - When foreign FSWG members are selected, they will participate in all discussions about WFIRST science

WIRST FSWG

Neil Gehrels GSFC Project Scientist, **Chair**
Jeremy Kasdin Princeton U. CGI Adjutant Scientist, Co-Chair
David Spergel Princeton U. WFI Adjutant Scientist, Co-Chair

SCIENCE TEAM PIs

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Saul Perlmutter LBNL Supernovae
James Rhoads Arizona State U. GO, Cosmic Dawn
Brant Robertson UC Santa Cruz GO, Extragalactic Science
Alexander Szalay Johns Hopkins U. GI, Archival Science
Margaret Turnbull SETI Institute Coronagraph
Benjamin Williams U. Washington GO, Nearby Galaxies

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Nikole Lewis STScI Coronagraph
Aki Roberge GSFC Corongraph
Yun Wang Caltech/IPAC Weak Lensing, Redshift Survey
David Weinberg Ohio State U. Weak Lensing, Redshift Survey

Nominal Capabilities*

WFI:

Imager **0.76-2.0 microns** 0.28˚ FoV, 0.11" pixel scale

Photo-z

Filters: z (0.76 - 0.98), Y (0.93-1.19), J (1.13-1.45), H(1.38-1.77), F184 (1.68-2.0), W149 (0.93-2.00)

Shapes

Grism: **1.35-1.89 microns** 0.28˚ FoV, R=461λ, 0.11" pixel scale

IFC: **0.6-2.0 microns** 3" & 6" FoV, R~100, 0.075" pixel scale

Coronagraph:

Imager: **0.43-0.97 microns** 1.63" FoV (radius), 0.01" pixel scale, 1k x 1k EMCCD, 10^{-9} final contrast, 100-200 mas inner working angle

IFS: **0.60-0.97 microns** 0.82" FoV (radius), R~70

Field of Regard: 54˚ - 126˚ 60% of sky

*filters and exact wavelength ranges are still being optimized

Design Reference Mission Yields

Attributes **WFIRST Yields**

Imag

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Num

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This is in a 6 year mission with:

- 2 years High Latitude Survey (HLS) imaging an spectroscopy
- ~6 months SN search and follow-up with IFU
- ~1 year for coronagraph
- ~1 year for microlensing planet search
- ~1.5 years (25%) dedicated to Guest Observers (GO)

An extended mission (10+ years) would consist of an expanded GO program

WFIRST is **serviceable** and doesn't have consumables that would preclude a 10+ year mission, detectors don't suffer extreme radiation degradation like CCDs

WFIRST DE Philosophy

- Use multiple independent probes of both the expansion history and growth of structure
- Allocate the time to two survey modes to balance the overall dark energy measurements
- Concentrate on higher redshift measurements than possible from ground or optical surveys for a longer baseline of dark energy evolution
- Exquisite control of systematics through multiple redundant measurements, mission optimization, internal cross-checks, and cross-probe analysis

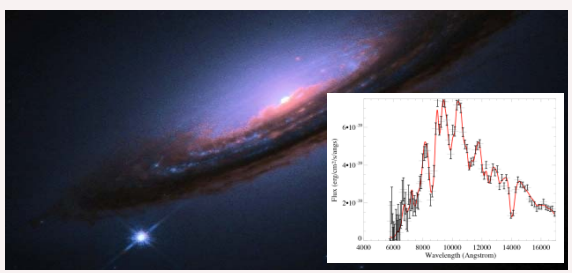
WFIRST-AFTA Dark Energy Roadmap

Supernova Survey

wide, medium, & deep imaging
+
IFU spectroscopy

2700 type Ia supernovae
z = 0.1–1.7

standard candle distances
z < 1 to 0.20% and z > 1 to 0.34%



High Latitude Survey

spectroscopic: galaxy redshifts

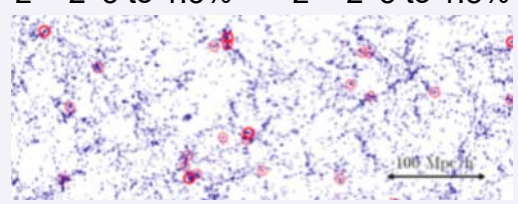
20 million Hα galaxies, z = 1–2
2 million [OIII] galaxies, z = 2–3

imaging: weak lensing shapes

400 million lensed galaxies
40,000 massive clusters

standard ruler

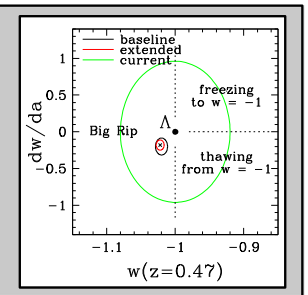
distances	expansion rate
z = 1–2 to 0.4%	z = 1–2 to 0.72%
z = 2–3 to 1.3%	z = 2–3 to 1.8%



dark matter clustering
z < 1 to 0.16% (WL); 0.14% (CL)
z > 1 to 0.54% (WL); 0.28% (CL)
1.2% (RSD)

history of dark energy
+
deviations from GR

$w(z)$, $\Delta G(z)$, Φ_{REL}/Φ_{NREL}



Spergel et al., 2015

Weak Lensing with WFIRST

- Powerful probe of matter distribution in the Universe
- S

  - Weak lensing stability and PSF requirements are being set so that WFIRST is still statistics limited in a 10,000+ square degree survey
    - Possible in a < 4 filter survey
    - Possible in an extended mission
    - Possible in a shallower survey

  – Dither pattern recovers full sampling

Unique (?)WFIRST Issues in WL

- Depth of required photo-z calibration will be a challenge, higher redshift and surface density than other experiments
- Multi-epoch and multi-filter observations
  - —Similar problems to LSST, but with only ~6 visits and ~3 exposures per visit per filter
- New detector family for this type of science (H4RG)
- Requires simulation of NIR data at the level Euclid and LSST need for optical data (less of this available at high resolution)
- Deblending due to high surface density (but different than LSST due to better resolution)

WFIRST Detector Issues

- Uses new generation of H4RG detectors designed for WFIRST (same family of detectors in NIR cameras on HST, JWST, Euclid)
- Does not have CTI, but other detector non-idealities
- Persistence, interpixel capacitance (IPC), non-linear response, reciprocity failure brighter/fatter?
- Correlated noise from readout electronics
- We are addressing these issues and so far all can be accommodated without throwing out data, ignoring certain spatial scales, or performing onboard calibrations beyond the 'usual'
- Full testing and validation remains to be done but personnel, labs, and timescale are in place

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The Impact of Interpixel Capacitance in CMOS Detectors on PSF shapes and Implications for WFIRST

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The effect of detector nonlinearity on WFIRST PSF profiles for weak gravitational lensing measurements

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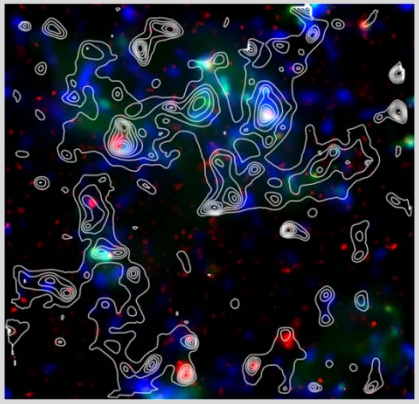
WL: A completely different regime

- WFIRST HLS (wide) survey will reach >45 galaxies per square arcminute
  — vs ~30 w/Euclid, and likely fewer from the ground
- With a deeper survey WFIRST could reach HUDF depths of **>200** galaxies per square arcminute

This is a fundamentally different WL regime that is not possible from the ground or with a smaller space telescope due to PSF size.

- Does not necessarily help with DE FoM (wide>deeper for FoM)
- Much better calibration data
- *Crucial* for understanding dark matter

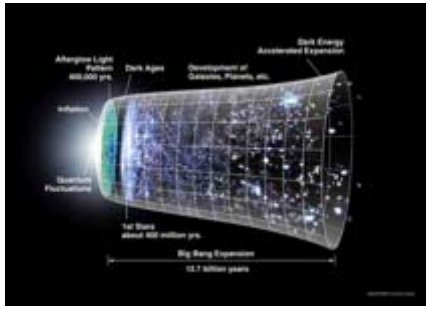


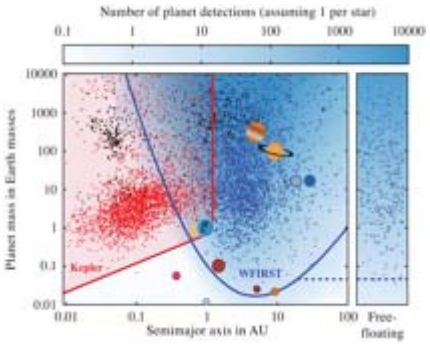
WFIRST Tiling

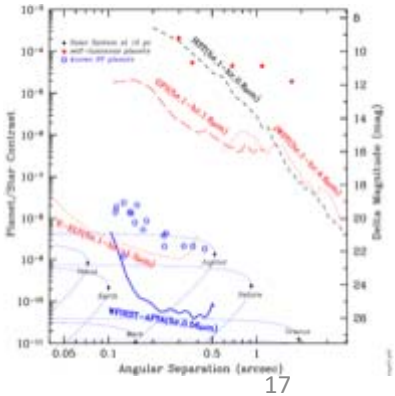
Extra Charts

WFIRST Science Objectives

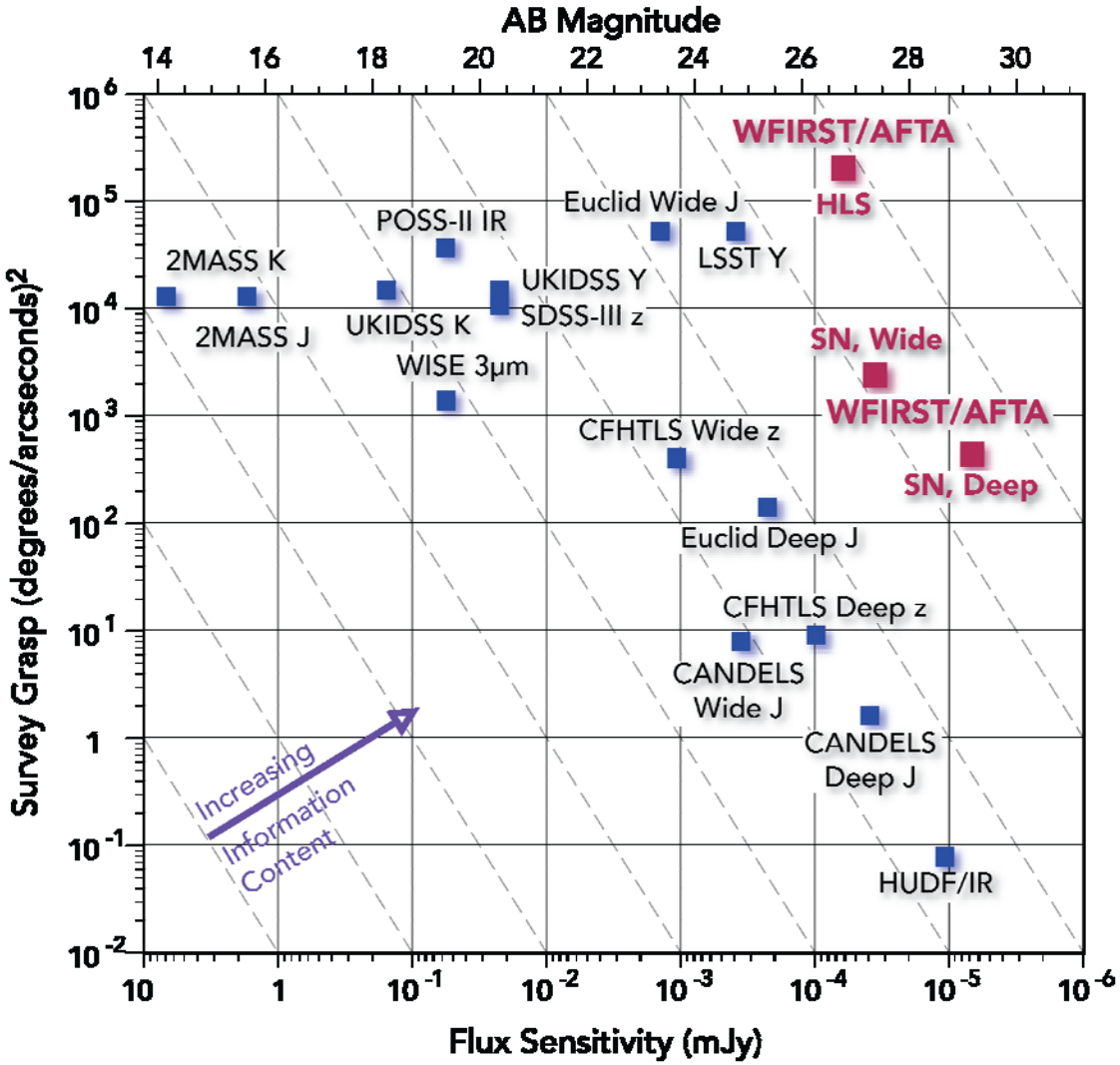
- Wide-Field Infrared Survey
  - Capable of producing NIR sky images in multiple-bands and spectra over thousands of square degrees with J = 27AB 5-sigma point-source imaging sensitivity and $F_{line} = 10^{-16}$ erg cm^{-2} s^{-1} 7-sigma line sensitivity.
- Expansion History of the Universe (Dark Energy)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







NIR Survey Grasp



Imaging Survey Comparison

	LSST	WFIRST	Euclid
Start	2022 (2020)	~2024	2021
Area	18,000	2,300*	15,000
Location	~south	Overlap LSST	Best
Time	10 years	2 of 6 years	6 years
Passes	Many	~5	1
Depth	25-28 optical	27 NIR	24.5 optical and NIR
Bands	ugrizy	4 NIR	1 wide optical, 3 NIR
Spectra	No	Grism & IFU	Grism

* Could be much larger in an extended mission or using GO time