# WFIRST Science Definition Team and Project Interim Report Presentation to the Astrophysics Sub-Committee


| | |
|---|---|
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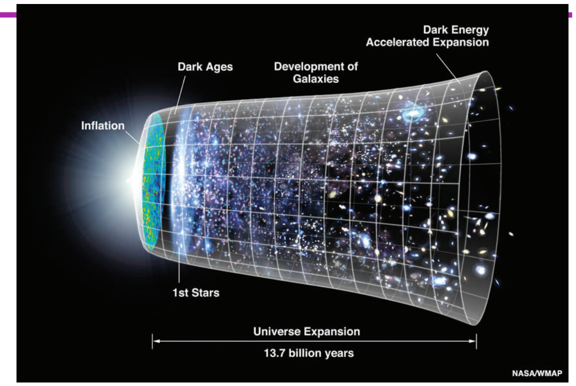
* These viewgraphs should not be read as a substitute for the full report.

July 13, 2011

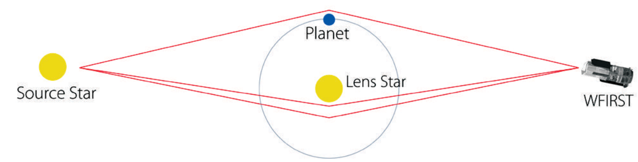
# WFIRST Summary

❖ WFIRST is the highest ranked large space mission in NWNH, and plans to:

- complete the statistical census of Galactic planetary systems using microlensing
- determine the nature of the dark energy that is driving the current accelerating expansion of the universe
- survey the NIR sky for the community

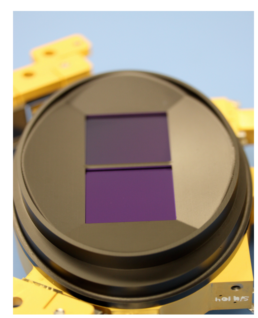


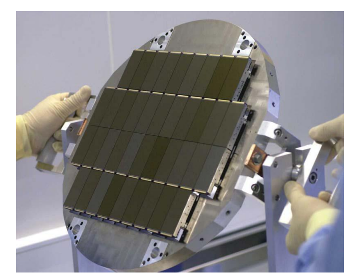

❖ Earth-Sun L2 orbit, 5 year lifetime, 10 year goal




❖ The current Interim Design Reference Mission has

- 1.3 m unobstructed telescope
- NIR instrument with ~36 HgCdTe detectors
- >10,000 $deg^2$ 5-sigma NIR survey at mag AB=25





❖ The time is ripe for WFIRST:

- Space-qualified large format HgCdTe detectors are US developed technology and flight ready

# SDT Charter

"The SDT is to provide science requirements, investigation approaches, key mission parameters, and any other scientific studies needed to support the definition of an optimized space mission concept satisfying the goals of the WFIRST mission as outlined by the Astro2010 Decadal Survey."

"In particular, the SDT report should present assessments about how best to proceed with the WFIRST mission, covering the cases that the Euclid mission, in its current or modified form, proceeds to flight development, or that ESA does not choose Euclid in the near future."

# WFIRST – Science Objectives

1) Complete the statistical census of planetary systems in the Galaxy, from habitable Earth-mass planets to free floating planets, including analogs to all of the planets in our Solar System except Mercury.

2) Determine the expansion history of the Universe and its growth of structure in order to test explanations of its apparent accelerating expansion including Dark Energy and possible modifications to Einstein's gravity.

3) Produce a deep map of the sky at NIR wavelengths, enabling new and fundamental discoveries ranging from mapping the Galactic plane to probing the reionization epoch by finding bright quasars at $z>10$.

# SDT Findings #1

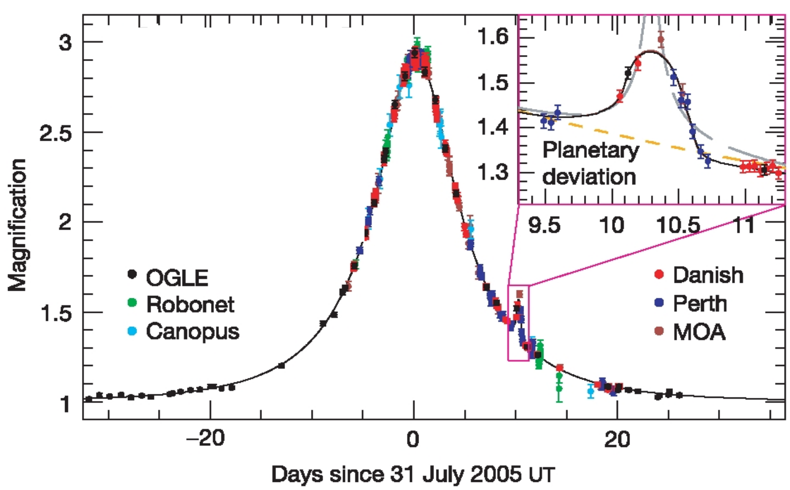
WFIRST should include all of the science objectives and utilize all of the techniques outlined in the NWNH recommendations:

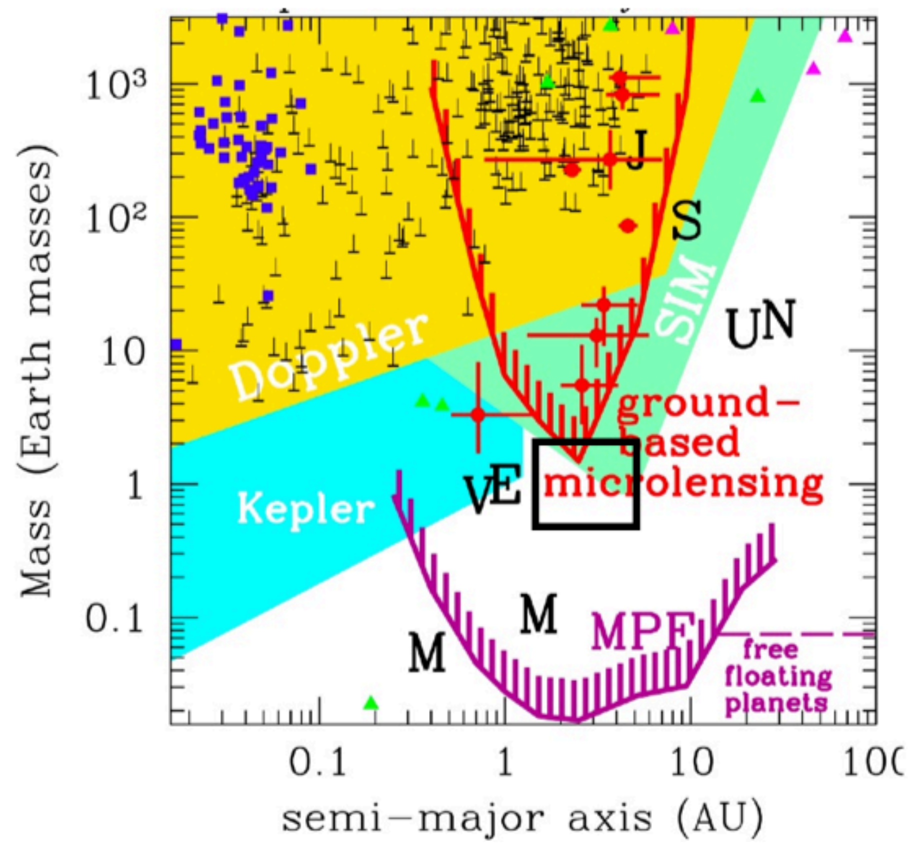
A: Baryon Acoustic Oscillation (BAO) Galaxy Redshift Survey
B: Exoplanet (ExP) Microlensing Survey
C: Supernova SNe-Ia Survey
D: Weak Lensing (WL) Galaxy Shape Survey
E: Near Infrared Sky Survey – w/Survey of the Galactic plane
F: Guest Investigator Program
G: *Redshift Space Distortions, or RSD, acquired in parallel with BAO for free*

**The WFIRST IDRM is compliant with the NWNH recommendation for groundbreaking observations in Dark Energy, Exoplanet and NIR sky surveys**

# Exoplanet Microlensing Technique

- Monitor Galactic bulge in NIR
- Detect microlensing events of background stars by foreground stars + planets
- Also detects free-floating planets
- Complementary to transit techniques (such as Kepler)



# Exoplanet Survey Capability

- Planet detection to 0.1 Earth mass ($M_{Earth}$)
- Detects ≥ 30 free floating planets of 1 $M_{Earth}$ in a 500 day survey*
- Detects ≥ 125 planets of $M_{Earth}$ (in 2 year orbits) in a 500 day survey*
- Detects ≥ 25 habitable zone† planets (0.5 to 10 $M_{Earth}$) in a 500 day survey *

* Assuming one such planet per star; "500 day surveys" are concurrent

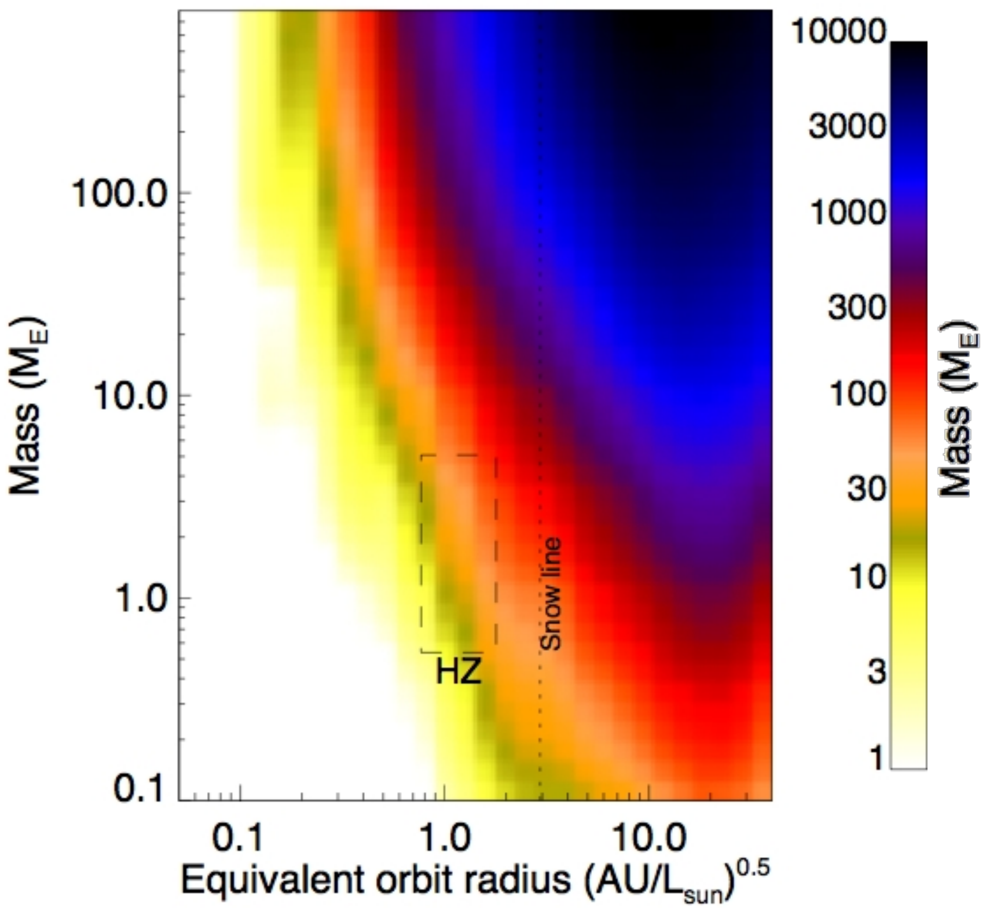
† 0.72-2.0 AU, scaling with the square root of host star luminosity

**Data Set Rqts include:**

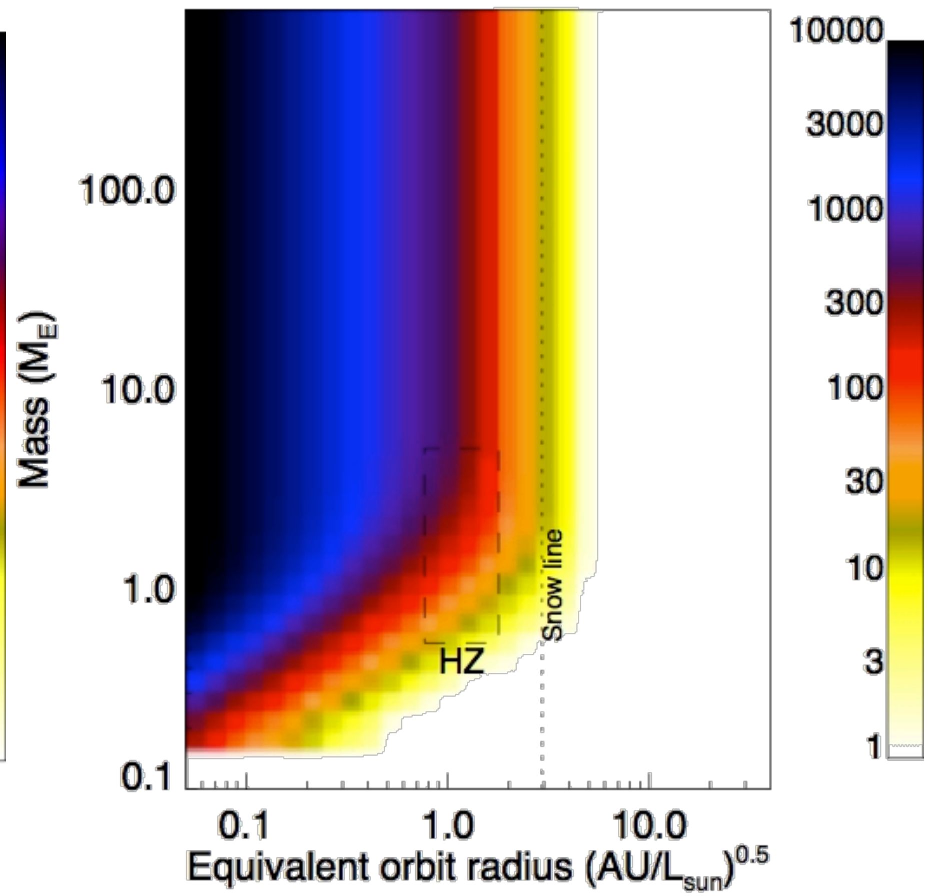
✓Observe ≥ 2 square degrees in the Galactic Bulge at ≤ 15 minute sampling cadence;
✓Minimum continuous monitoring time span: ~60 days;
✓Separation of ≥4 years between first and last observing seasons.

# Microlensing – Transit Comparison

WFIRST



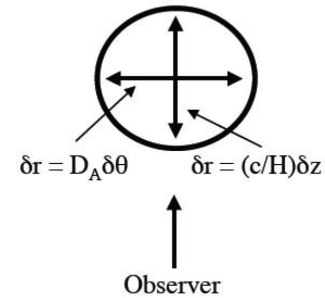

Kepler



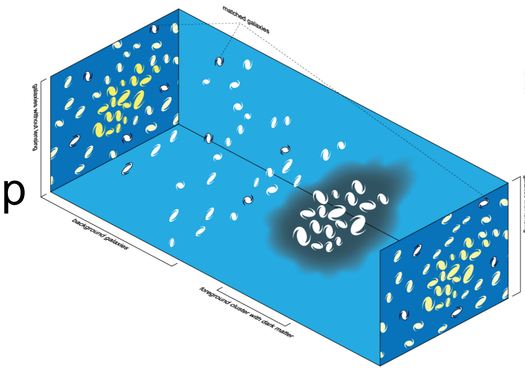

Figures from B. MacIntosh of the ExoPlanet Task Force

# Dark Energy Techniques

- Three most promising techniques each provide different physical observables and unique information:

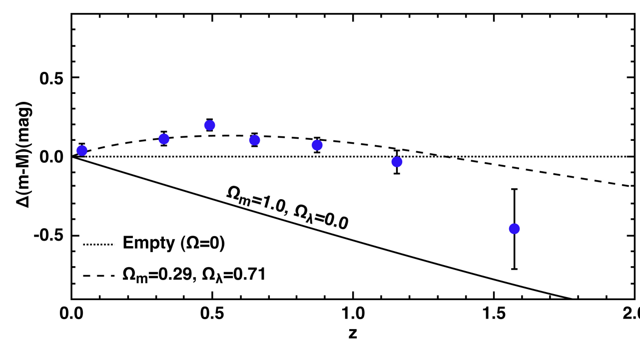



Baryon Acoustic Oscillation (BAO)
- Emission line galaxies positioned in 3D using strong $H\alpha$ line
- Spectroscopic redshift survey in NIR



Weak Lensing (WL)
- Precision shape measurement of galaxy shap
- Photo-z redshifts

Type Ia Supernovae (SNe)
- Type Ia supernovae detected into NIR



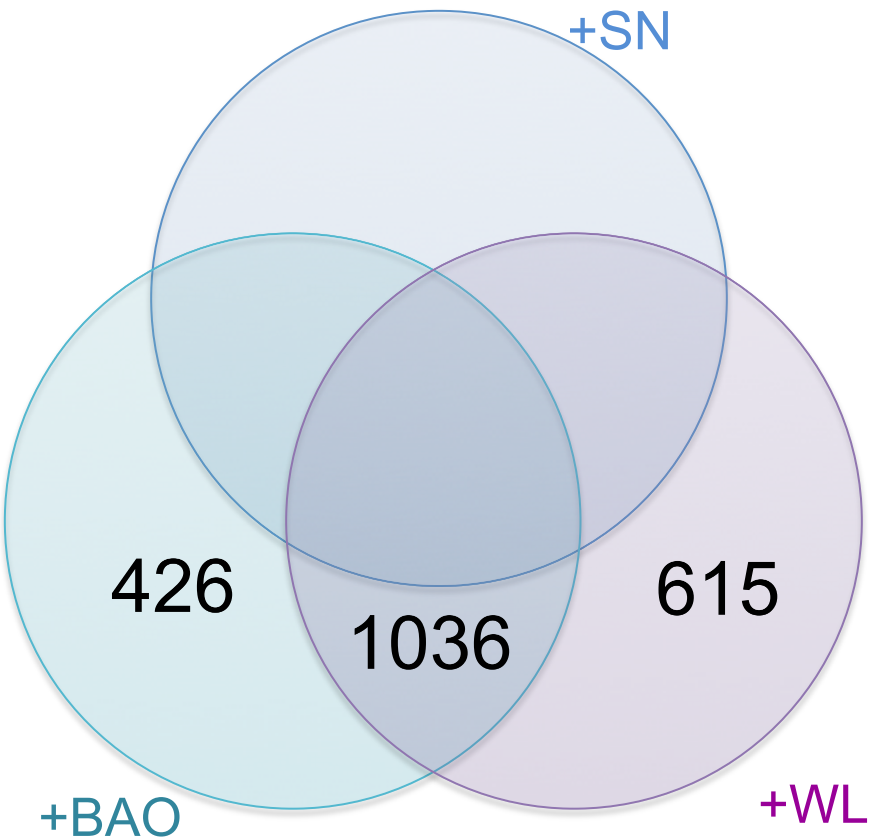

- Redshift Space Distortions (RSD)
  – Distortions in Hubble flow
  – Galaxy redshifts from BAO survey can give growth of structure info

# Dark Energy Survey Capabilities

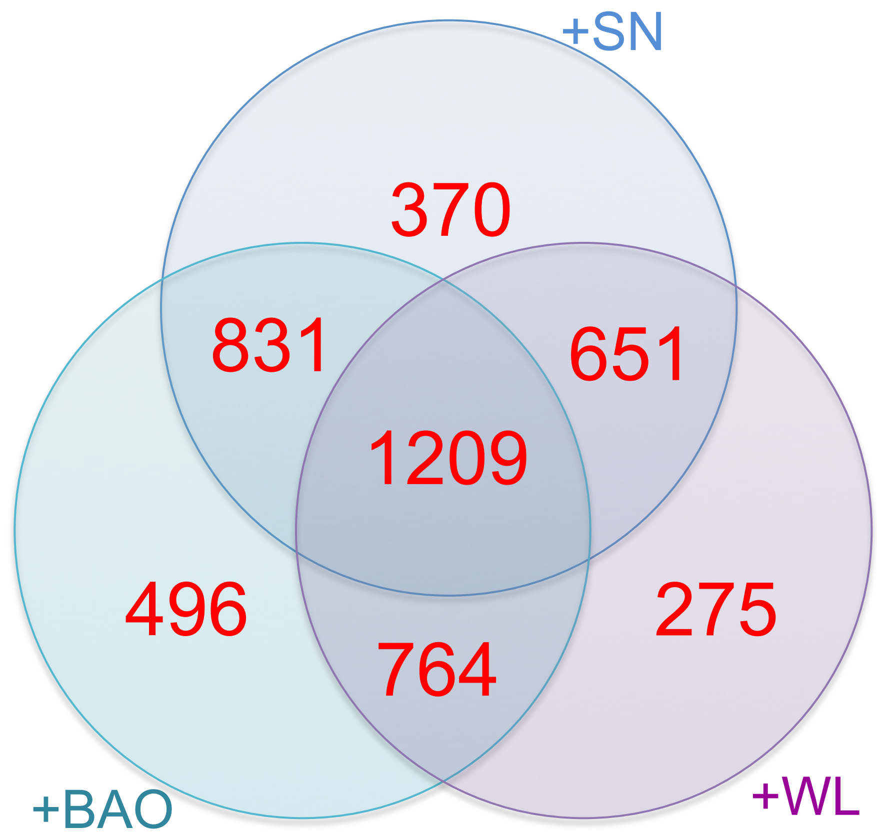
- BAO/RSD: ... “WIDE” survey mode
  - 11,000 $deg^2$/dedicated year
  - Redshift errors $\sigma_z \leq 0.001(1+z)$, over redshift range $0.7 \leq z \leq 2$
- Weak Lensing: ... “DEEP” survey mode
  - 2700 $deg^2$/dedicated year
  - Effective galaxy density ≥30/$amin^2$, shapes resolved plus photo-zs
- SNe-Ia Survey:
  - >100 SN per $\Delta z = 0.1$ bin for most bins $0.4 < z < 1.2$, per dedicated 6 months
  - Redshift error $\sigma_z \leq 0.005$ per supernova

# Comparison with EUCLID (DETF FoM)

EUCLID Optimistic:
5 year Dark Energy Measurement




WFIRST Optimistic:
2.5 year Dark Energy Measurement



# NIR Survey Capabilities

- Identify ≥100 quasars at redshift $z>7$
- Obtain broad-band NIR spectral energy distributions of ≥1e9 galaxies at $z>1$ to extend studies of galaxy formation and evolution
- Map the structure of the Galaxy using red giant clump stars as tracers

**Data Set Rqts include:**

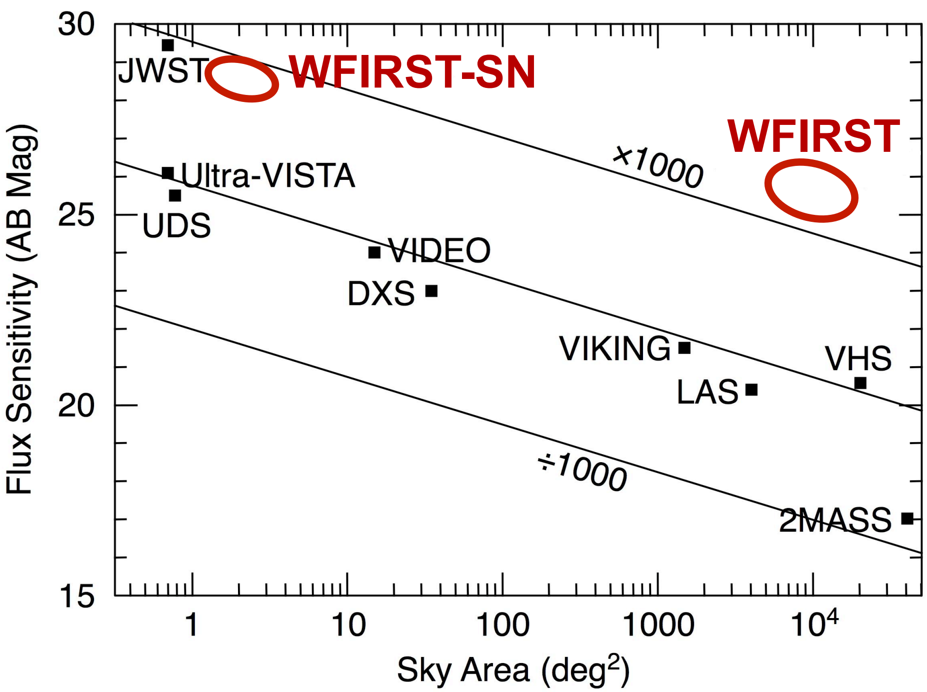
✓High Latitude data from Imager and Spectrometer channels during BAO/RSD and WL Surveys;
  - Image 2500 $deg^2$ in 3 NIR filters to mag AB=25 at S/N=5

✓Galactic Plane Survey (~0.5 yr, per EOS Panel);
  - Image 1500 $deg^2$ of the Galactic Plane in 3 NIR filters

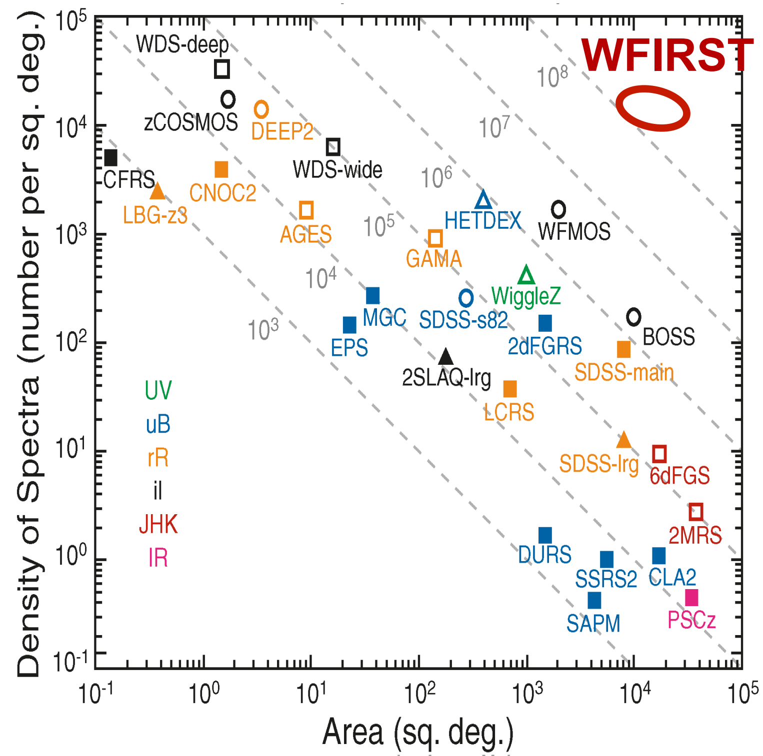
✓Guest Investigator observations (~1 yr, per EOS Panel) will supplement

# WFIRST NIR Surveys

## NIR Imaging Surveys




## NIR Redshift Surveys




**WFIRST provides a factor of 100 improvement in IR surveys**

# Guest Investigator (GI) Studies with WFIRST

WFIRST will be a unique platform for a broad range of astrophysical studies. The NWHM report strawman schedule allocates ~1 yr of the baseline 5 yr mission for competed Guest Investigator (GI) programs. Examples of potential such programs include:

- (time domain) surveys of the outer Solar System (Kuiper belt)
- follow-up of exoplanet transits (imaging and spectroscopic)
- wide-field (time domain) imaging of Galactic globular and open clusters
- deep imaging of Galactic supernova remnants
- transient surveys
- GI studies of galaxies in the nearby volume
- wedding cake galaxy evolution surveys (e.g., GI programs would fill in layers of the wedding cake missed by the dark energy surveys; imaging and spectroscopic)
- deep studies of massive, high-redshift galaxy clusters
- clustering of z>7 Lyman-alpha emitters
- environments of z~10 quasars

# Science Return

## Mission Performance: EOS Panel vs WFIRST IDRM

| Science Investigation | EOS Panel Report | WFIRST IDRM |
|---|---|---|
| WL Survey | 4000 $deg^2$ | 2700 $deg^2$/yr |
| BAO Survey | 8000 $deg^2$ | 11,000 $deg^2$/yr |
| SNe | Not Mentioned | 1200 SNe per 6 months |
| Exoplanet Microlensing | 500 total days | 500 total days |
| Galactic Plane Survey | 0.5 yr GP Survey | 0.5 yr GP Survey |
| Guest Investigators | 1 year GI observations | 1 year GI observations |

## Dark Energy Performance: NWNH Main Report vs WFIRST IDRM

| DE Technique | NWNH Main Report | WFIRST IDRM 5 yr mission | WFIRST IDRM 5 yr Dark Energy* |
|---|---|---|---|
| WL Galaxy Shapes | 2 billion | 300 million (1 yr) | 600 million (2 yr) |
| BAO Galaxy Redshifts | 200 million | 60 million (1 yr) | 120 million (2 yr) |
| Supernova SNe-Ia | 2000 | 1200 (1/2 yr) | 2400 (1 yr) |

***Including 5 year extended mission**

# Science Return Summary

- WFIRST meets or comes close to meeting the time allocations and sky coverages given in the EOS Panel Report.
- For Dark Energy, WFIRST has fewer galaxies surveyed and SNe monitored than called for in the NWNH Main Report. The NWNH numbers were taken from the JDEM-IDECS RFI with 5 years of Dark Energy observations and were never (particularly the numbers of galaxies) feasible for WFIRST or JDEM-Omega (even with 5 years of DE).
- Still, the WFIRST IDRM has excellent performance compared to overall NWNH objectives as reviewed by the SDT. The FoM numbers are good for all science areas.

# SDT Findings #2

## How would WFIRST change if Euclid is selected?

- Due to the importance of the scientific questions and need for verification of the results, WFIRST should proceed with all of its *observational capabilities* intact regardless of the ESA decision on Euclid.
- WFIRST has superior design for BAO (fixed prism) and WL (unobscured telescope) and has unique coverage of SNe and Exoplanet microlensing.
- The actual *observation program* would likely be altered in light of Euclid's selection or in response to any Euclid results prior to WFIRST's launch.

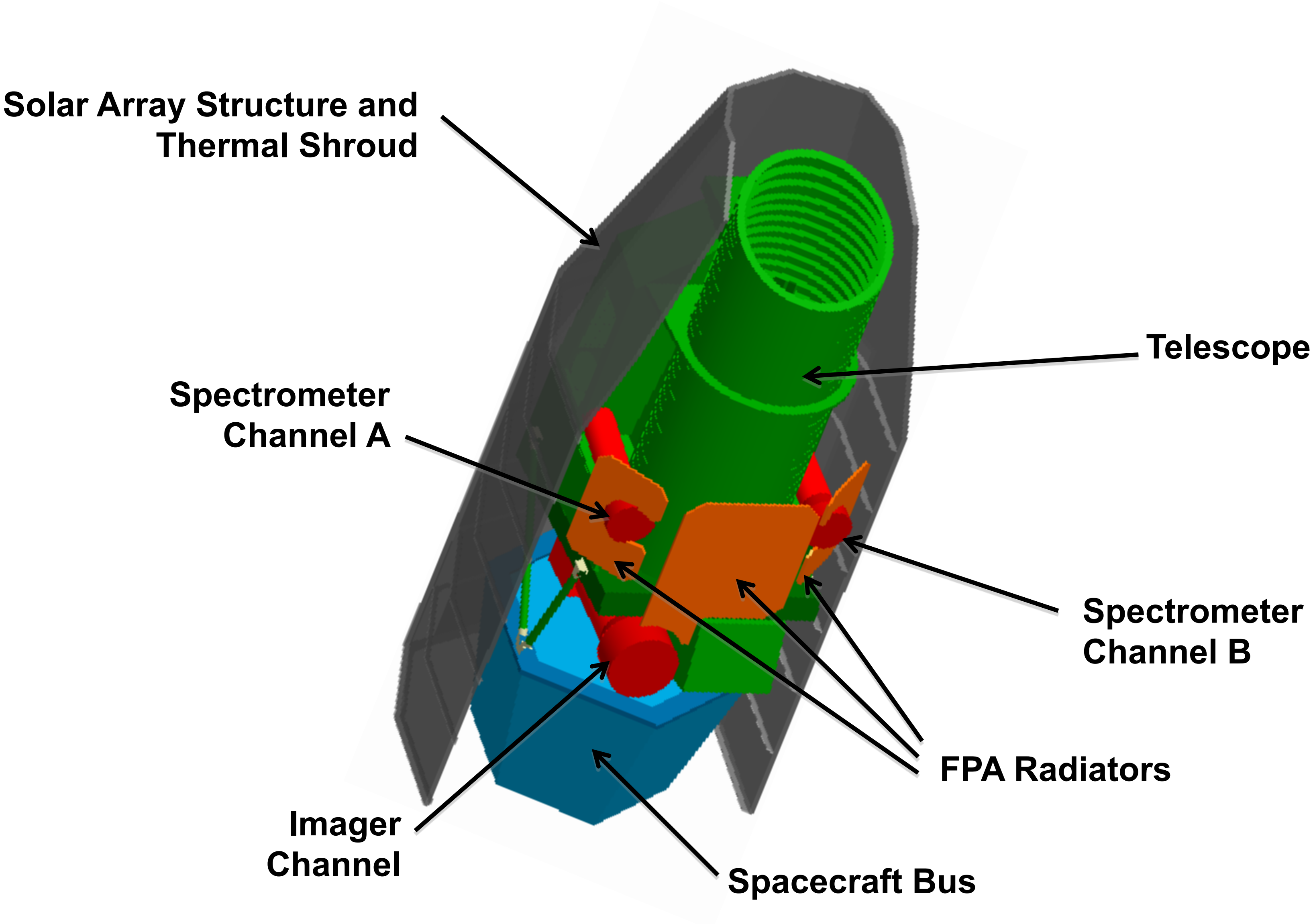
# SDT Findings #3

Should NASA and ESA decide to pursue a joint mission or program, all of the scientific approaches and broad objectives currently included in WFIRST must be included in the joint mission or program.

# Future Study Areas

- IDRM design/analysis cycle underway and continuing into FY12.
- Re-assessment of Euclid when Red Book is published.
- Assessment of collaboration opportunities with ESA once the status of Euclid is clarified in October 2011.
- Study of technical feasibility and scientific trades of increasing maximum wavelength beyond 2 microns.
- Study of technical feasibility and scientific trades of substituting a slit spectrometer or IFU for SN spectroscopy (instead of the slitless prism w/supporting instrumentation).

# WFIRST IDRM
# Observatory Layout



# Key Hardware Changes

## WFIRST IDRM vs JDEM-Omega

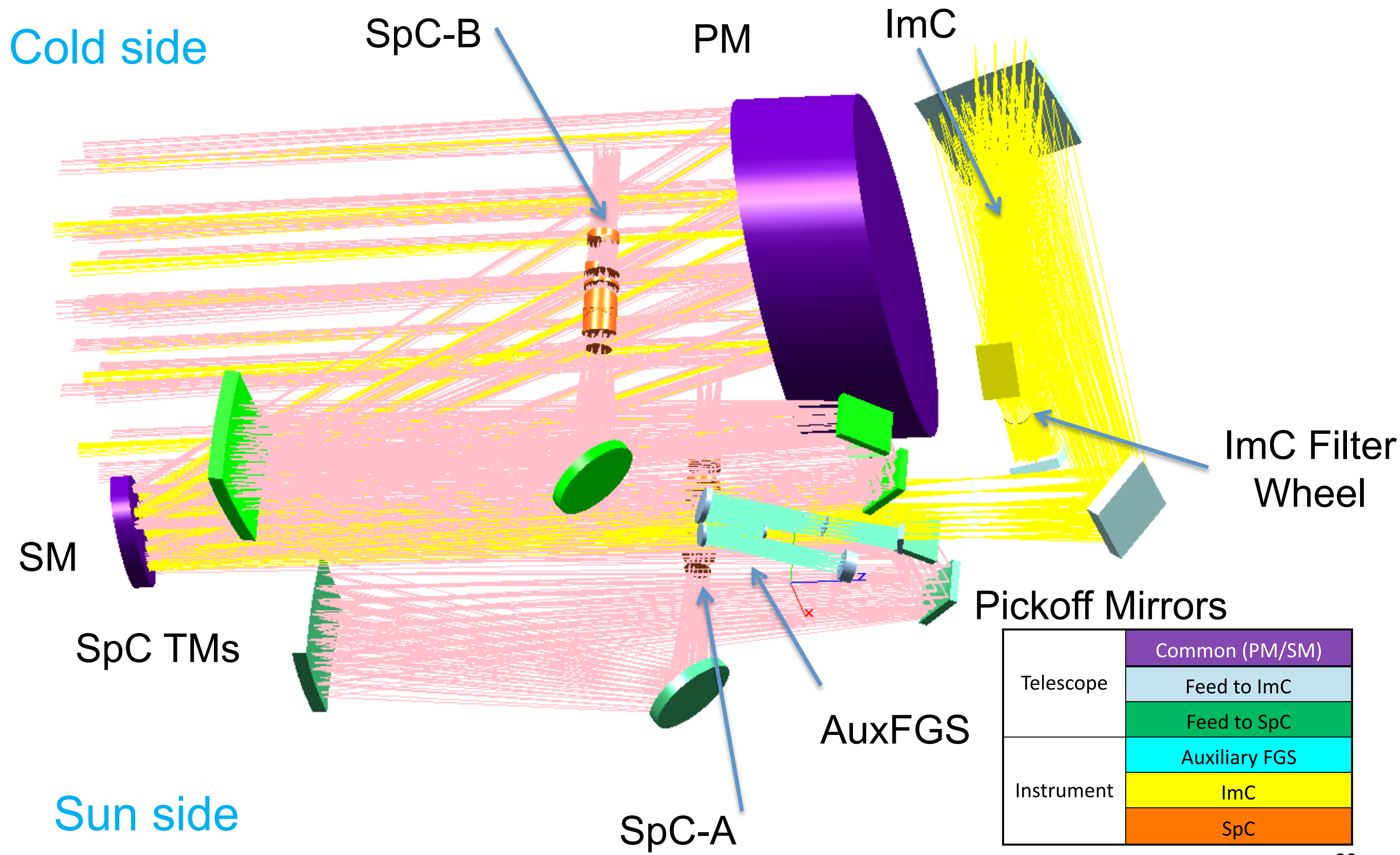
- 1.3m unobscured telescope vs 1.5m obscured for JDEM-Omega.
  *Better imaging performance. Faster integration times. Comparable cost.*

- 4 detectors moved from Spectrometer to Imager, and Spectrometer pixel scale increased.
  *Increased sky coverage for Imager while keeping Spectrometer sky coverage constant.*

- Larger Field of Regard (range of pitch angles off the sun)
  *Increased sky availability to meet Exoplanet Galactic Bulge field monitoring requirements in tandem with SNe field monitoring*

- Focal designs for ImC/SpC vs afocal SpC design for JDEM-Omega
  *Allowed removal of large, complex 4 asphere collimator feed to SpC*

# IDRM Payload Optics – Ray trace




| | |
|---|---|
| Telescope | Common (PM/SM) |
| | Feed to ImC |
| | Feed to SpC |
| Instrument | Auxiliary FGS |
| | ImC |
| | SpC |

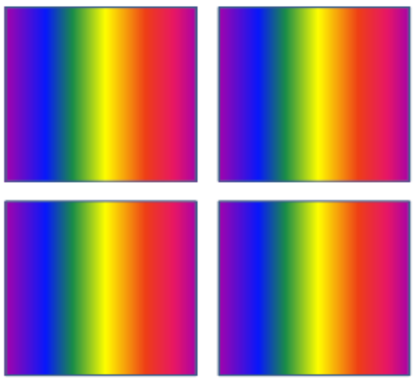
# Channel field layout for WFIRST IDRM

Moon (average size seen from Earth)

**The Fields of view of the imaging channel (ImC), spectroscopy channels (SpCs), and guiding modes (FGS) are shown to scale with the Moon, HST, and JWST. Each square is a 4Mpix vis-NIR sensor chip assembly (SCA)**

ImC: 7x4 @ 0.18"/p; SpC 2(2x2)@0.45"/p
[xfield center, yfield center, degrees]

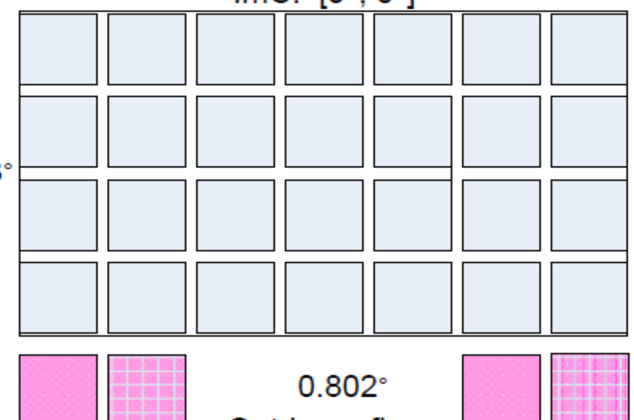
SpC-B [-0.9275°,0°]



0.536°

0.536°

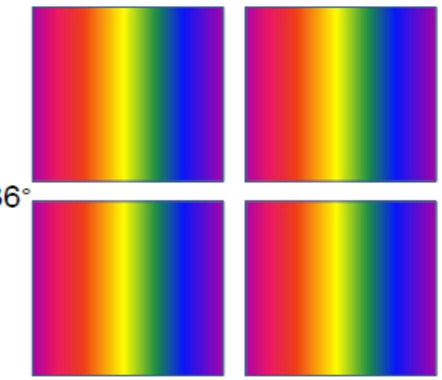
ImC: [0°, 0°]




0.463°

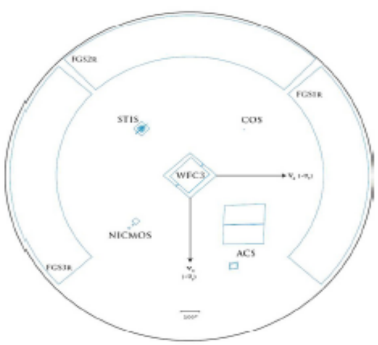
Outrigger fine guidance sensors

SpC-A [0.9275°,0°]



0.536°

0.536°




HST [all instruments]

0.142°

0.31°

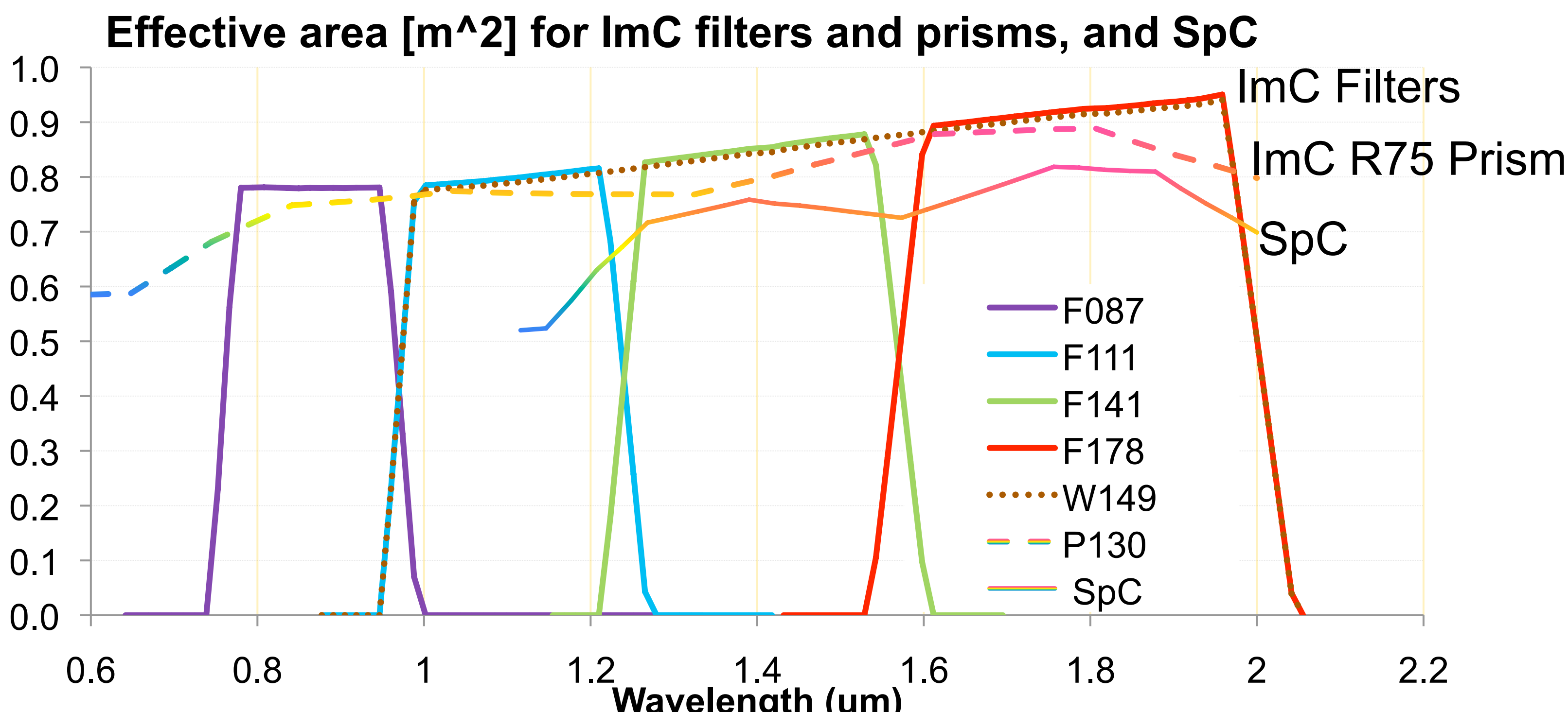
Auxiliary Fine Guidance System: 2@0.25"/p [0°, -0.6°]

JWST [all instruments]

# Throughput

- Plot shows effective areas for each instrument configuration: Each of 2 identical Spectrometer channels (SpCs), and each element in the Imager filter wheel, per filter table below.

| name | min | max | center | type |
|---|---|---|---|---|
| F087 | 0.760 | 0.970 | 0.865 | ImC filter |
| F111 | 0.970 | 1.240 | 1.105 | ImC filter |
| F141 | 1.240 | 1.570 | 1.405 | ImC filter |
| F178 | 1.570 | 2.000 | 1.785 | ImC filter |
| W149 | 0.970 | 2.000 | 1.485 | ImC filter |
| P130 | 0.6 | 2 | 1.3 | R75 ImC prism |
| SpC | 1.114 | 2 | 1.557 | R200 SpC prism |



# One Page Flow Down - Purpose

- Substantiate that the IDRM can achieve the science objectives mandated by NWNH.
- Trace WFIRST's Science Objectives to a set of derived Survey and Data Set requirements, and flow these down to a responsive Interim Observatory Design and Ops Concept
- IDRM is an **Interim** Reference Design
  - o Design implementation is not prescriptive and is preliminary
  - o Multiple designs can meet the science requirements

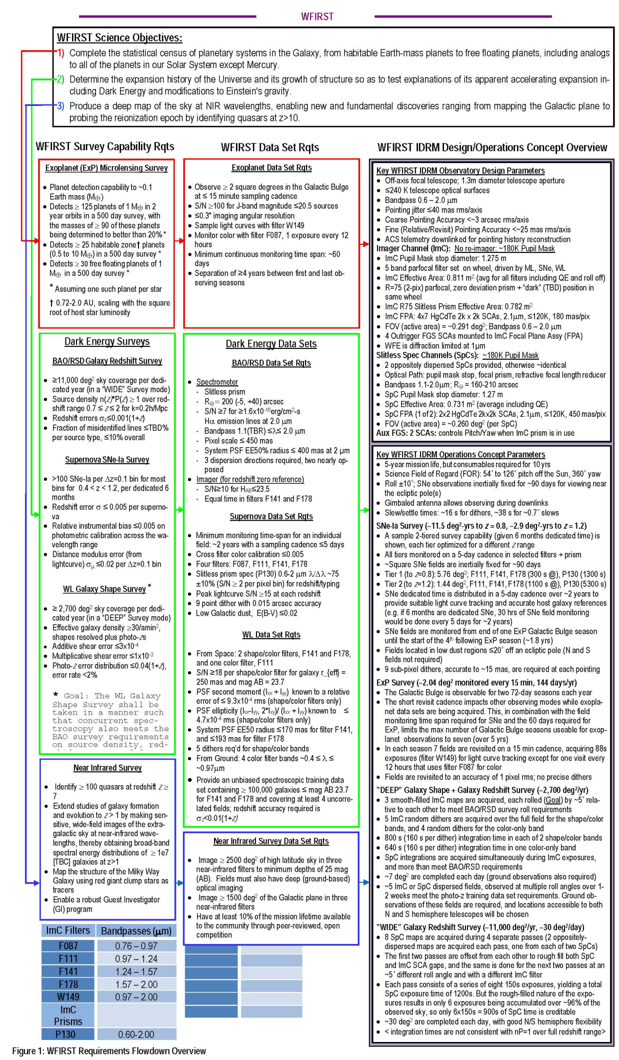


Figure 1: WFIRST Requirements Flowdown Overview

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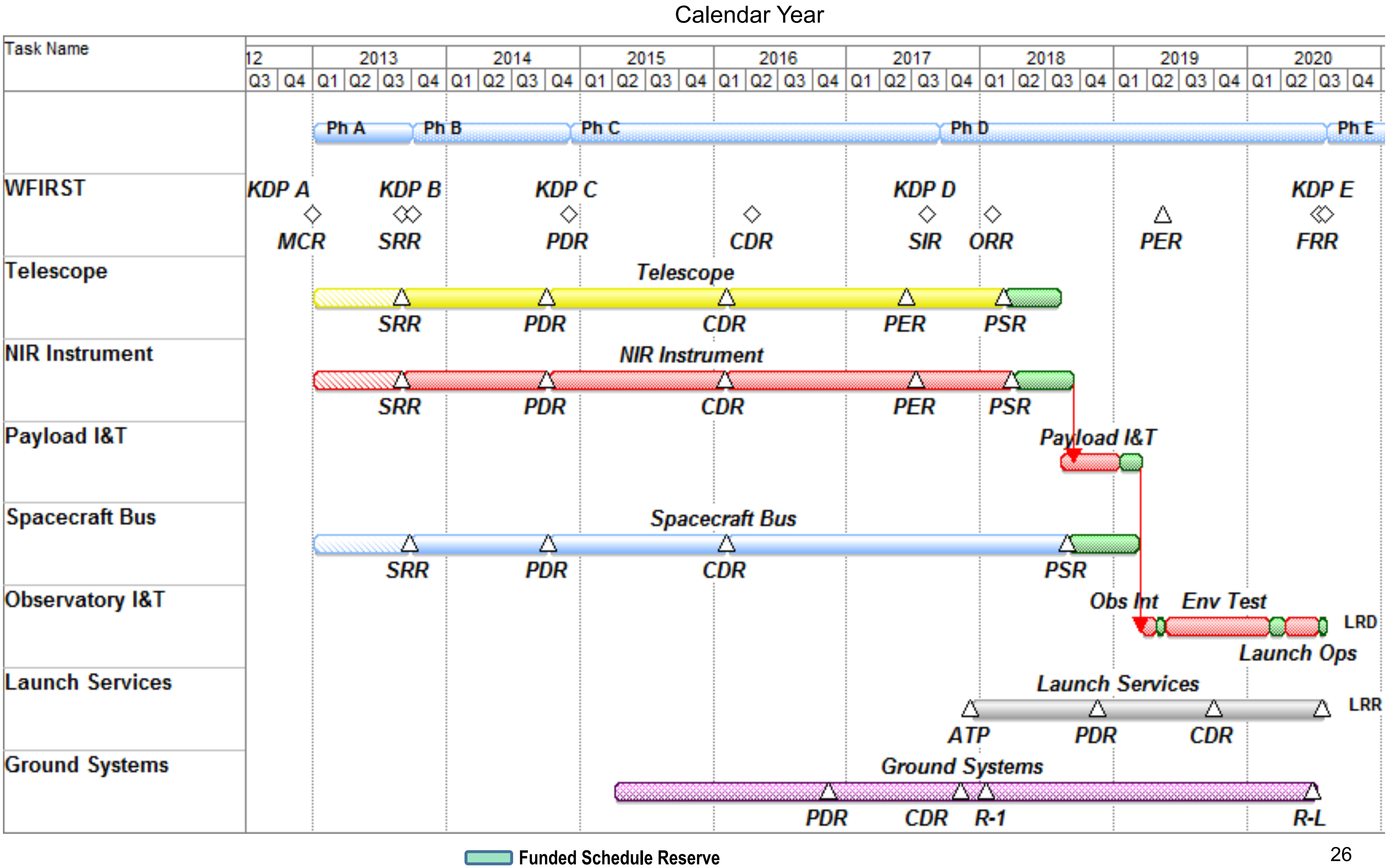
# WFIRST IDRM Schedule Estimate



# Summary

- WFIRST has broad science capabilities
  – The most pressing fields in astrophysics all require a near infrared survey capability. WFIRST can satisfy all of the observational requirements . Our biggest problem is dividing up the observing time: proof of its scientific viability
- WFIRST is technologically mature
  – We could start development as soon as funding is available
- WFIRST is cost effective
  – $1.6B is a lot of money, but this cost estimate has been independently verified with the latest methodology and is credible
  – Given that WFIRST is the decadal #1 priority, and the broad science return in multiple areas, we believe that WFIRST is a bargain

- *WFIRST can move astrophysics forward into new frontiers of knowledge, and do it in less than a decade*