Astrophysics Focused Telescope Assets (AFTA)

Presentation to P. Hertz   April 19, 2013

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OUTLINE
- Executive Summary
- Science enabled by AFTA
- Costs and schedule
- Future activities
- Conclusions

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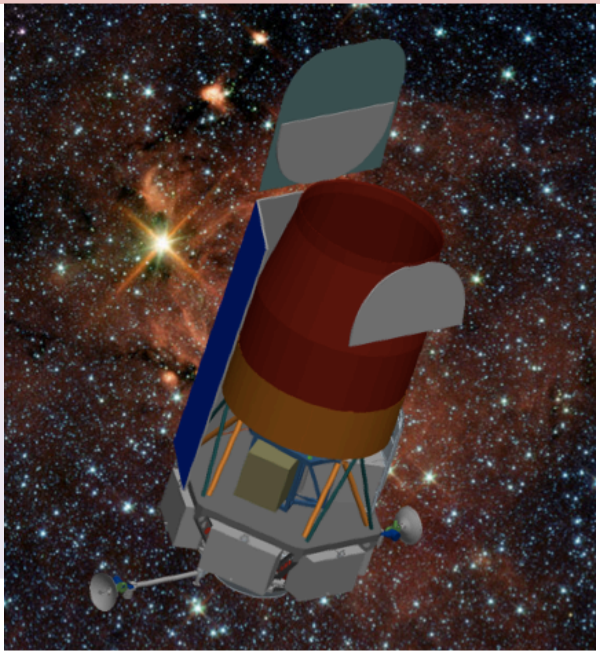
Executive Summary

AFTA will deliver extraordinary science

A 2.4m telescope offers sensitive sharp images at optical and near IR wavelengths across a wide field. With higher resolution and sensitivity in the near IR than planned for the early WFIRST designs, AFTA will be an even more powerful and compelling mission.

AFTA offers both a rich program of community observations and directed programs that address fundamental astronomy questions:

- What is dark energy?
- Is our solar system special?
- Are the planets around nearby stars like those of our own solar system?
- How do galaxies form and evolve?



AFTA is low risk and low cost

- Cost similar to DRM1 & Astro2010 WFIRST
- Existing telescope lowers risk
- 2021 launch feasible if budget is available

AFTA Achieves Multiple NASA Goals

Hits 5 of 6 NASA
Strategic Goals

#1 Large Mission Priority
WFIRST science

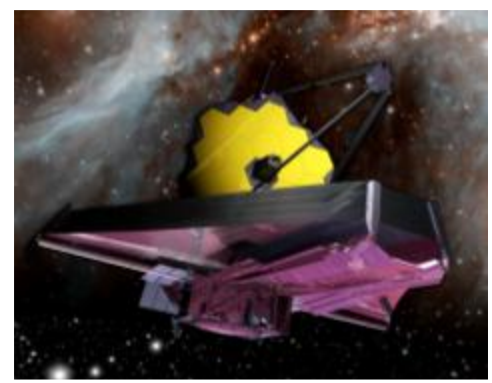
#1 Medium Scale Priority
Exoplanet Imaging

Nobel Prize
science

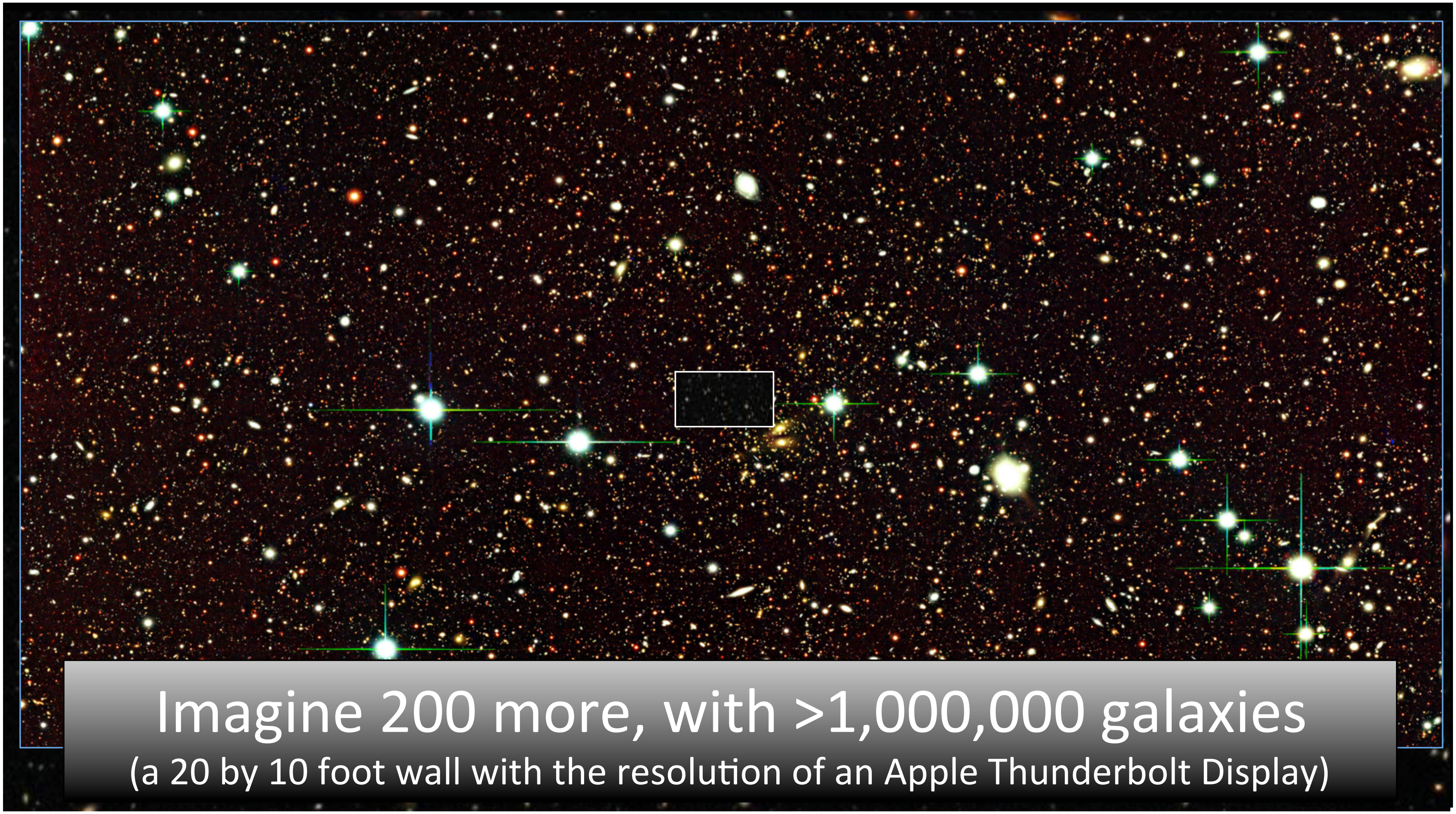
COST EFFECTIVE – LOW RISK – MATURE TECHNOLOGIES

Brings Universe to STEM
Next generation citizen science

Foundation for discovering
Earth-like planets



Complements and
enhances JWST science



The Hubble Ultra Deep Field (IR)

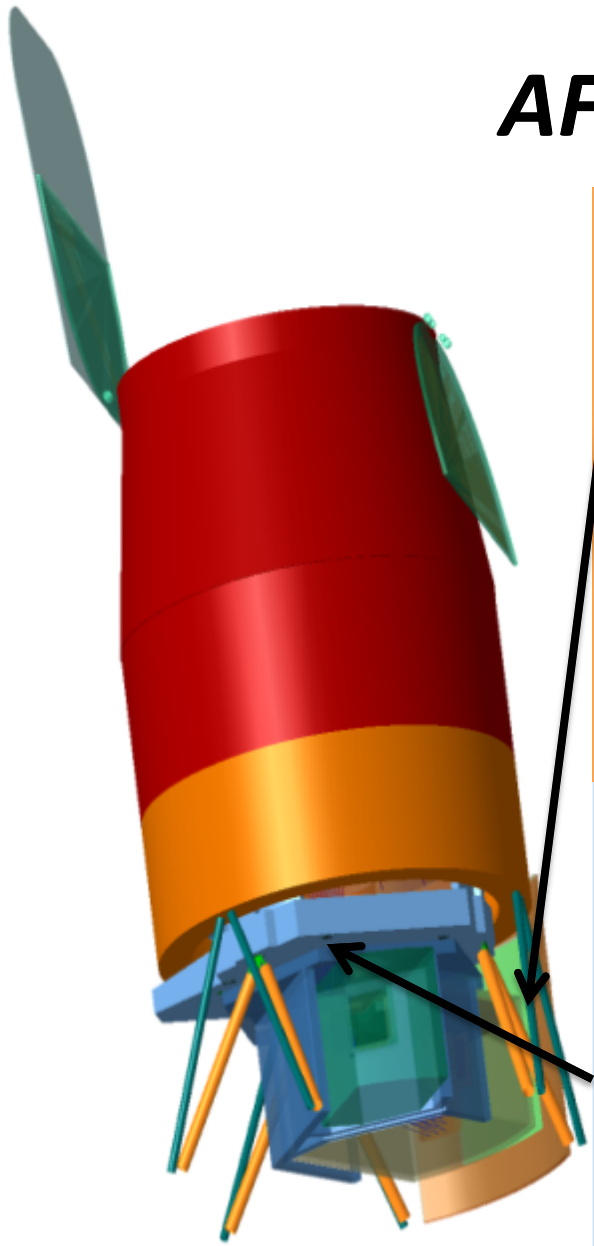
Imagine this wall of a million galaxies, a single image from AFTA, filling walls of schools and museums and providing a wealth of citizen science.

AFTA is well matched to the WFIRST Requirements

- Existing Hardware: high quality mirror and optical system
- Easily used in Three Mirror Anastigmat (TMA)
  - Wide field of view
  - 3rd mirror in Wide-Field instrument
- AFTA's 2.4 m aperture + wide field imager meets (and exceeds) WFIRST requirements:
  - Higher spatial resolution enhances science capability
  - Larger collecting area enables more science in fixed time
- AFTA's 2.4m aperture enables richer scientific return at much lower cost than a dedicated smaller coronagraphic telescope mission

Study concluded that these assets satisfy all mission requirements.

AFTA Instruments



Wide-Field Instrument

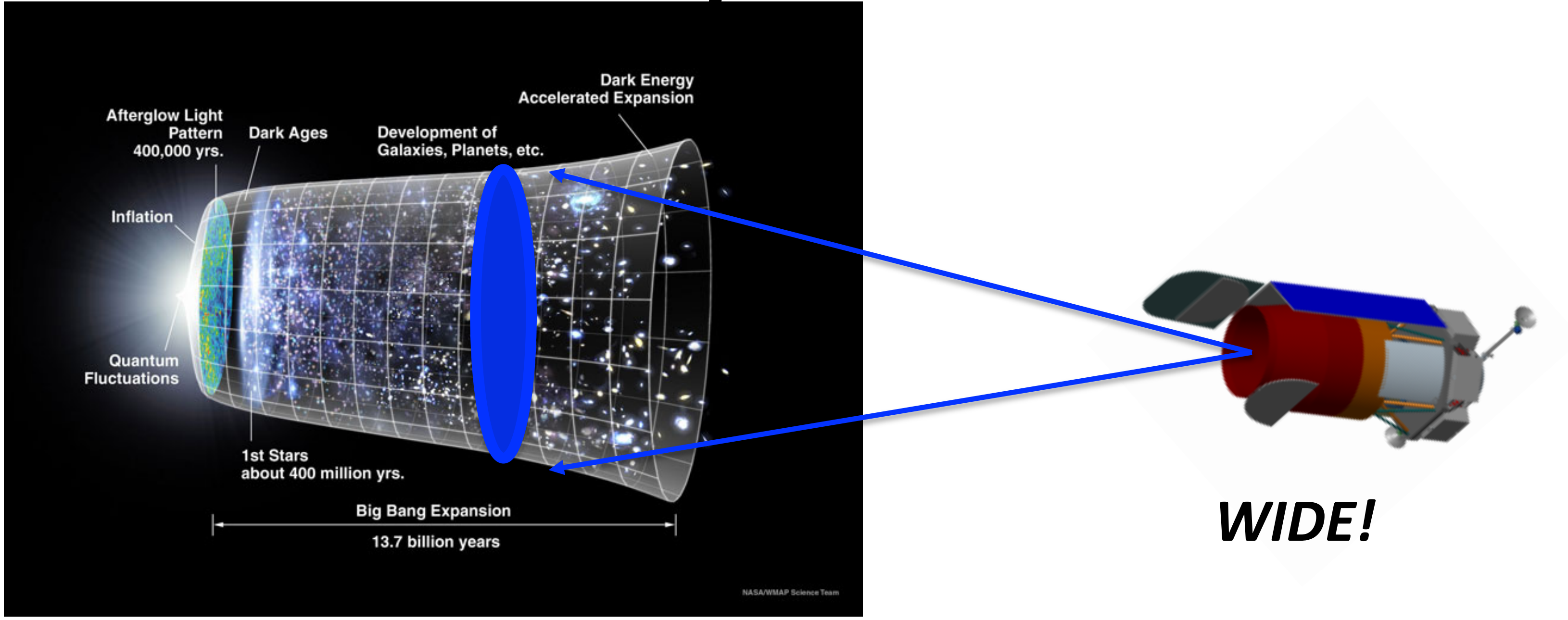
- *Imaging & spectroscopy over 1000s sq deg.*
- *Monitoring of SN and microlensing fields*
- 0.7 – 2.0 micron bandpass
- 0.28 sq deg FoV (100x JWST FoV)
- 18 H4RG detectors (288 Mpixels)
- 4 filter imaging, grism + IFU spectroscopy

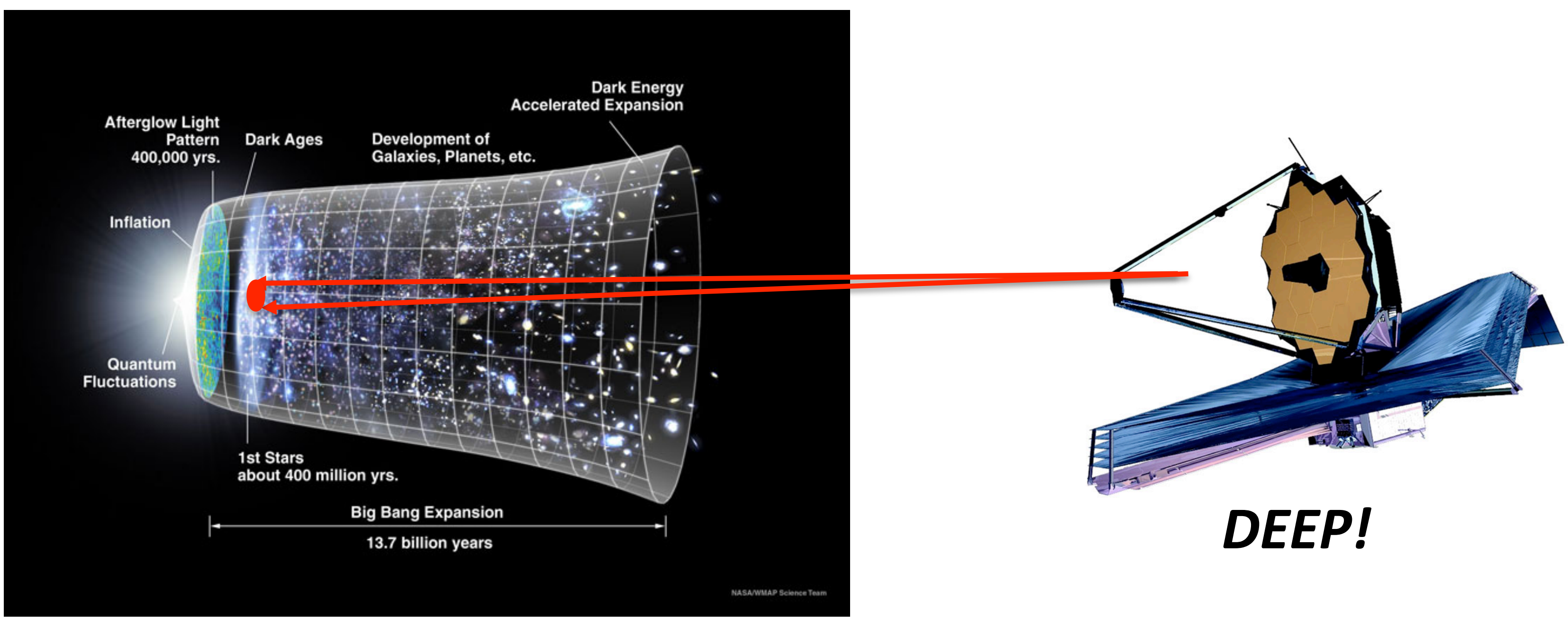
Coronagraph (study option)

- *Imaging of ice & gas giant exoplanets*
- *Imaging of debris disks*
- 400 – 1000 nm bandpass
- 10^{-9} contrast
- 100 milliarcsec inner working angle at 400 nm

Requires focused tech. development ASAP for 2021 launch

AFTA Complements JWST





Science Enabled by AFTA Concept

AFTA carries out the WFIRST science program (the top ranked decadal priority).

+

AFTA's larger aperture enables astronomers to make important contributions towards many of the enduring questions listed in the decadal survey through both surveys and peer-reviewed observing programs.

+

Equipped with a coronagraph, AFTA can image Jupiter and Saturn-like planets around the nearest stars. AFTA will be an essential stepping stone towards finding signs of life around nearby stars.

AFTA Telescope Address Many of the Enduring Questions of Astrophysics

	New Worlds New Horizons Questions
1. Frontiers of Knowledge	•*Why is the universe accelerating?* •*What is the dark matter?* •*What are the properties of neutrinos?*
2. Cosmic Order: Exoplanets	•*How diverse are planetary systems?* •*Do habitable worlds exist around other stars, and can we identify the telltale signs of life on an exoplanet?* •*How do circumstellar disks evolve and form planetary systems?*
3. Understanding our Origins	•*How did the universe begin?* •*What were the first objects to light up the universe, and when did they do it?* •*How do cosmic structures form and evolve?* •*What are the connections between dark and luminous matter?* •*What is the fossil record of galaxy assembly from the first stars to the present?*
4. Cosmic Order: Stars + Galaxies	•*What controls the mass-energy-chemical cycles within galaxies?* •*How do the lives of massive stars end?* •*What are the progenitors of Type Ia supernovae and how do they explode?*

1. Frontiers of Knowledge

- ***Why is the universe accelerating?***
- ***What is the dark matter?***
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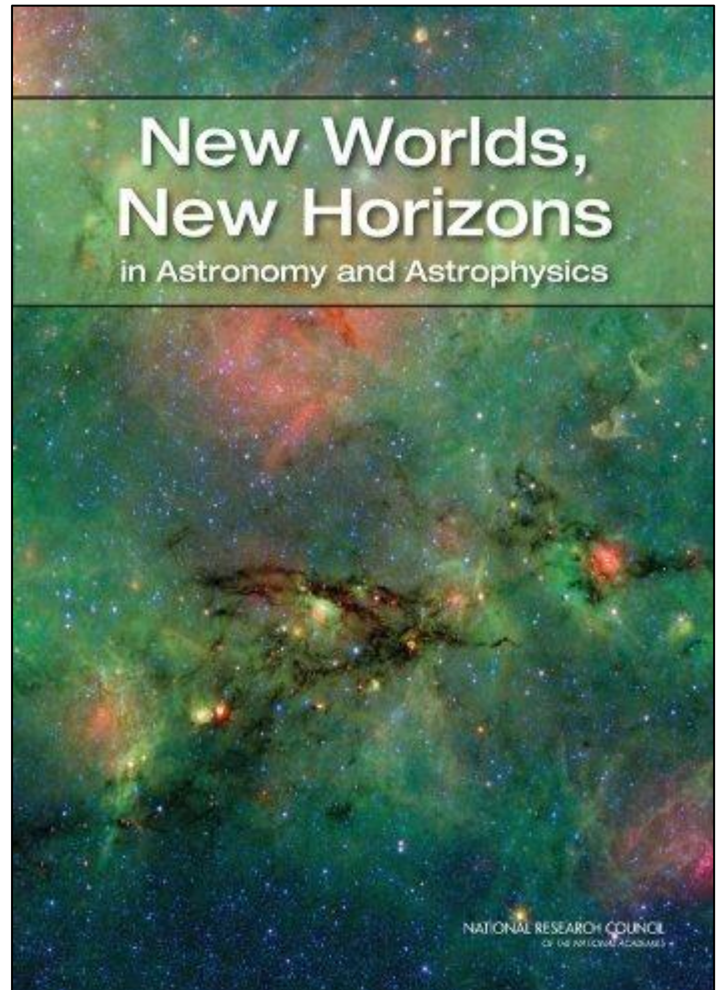
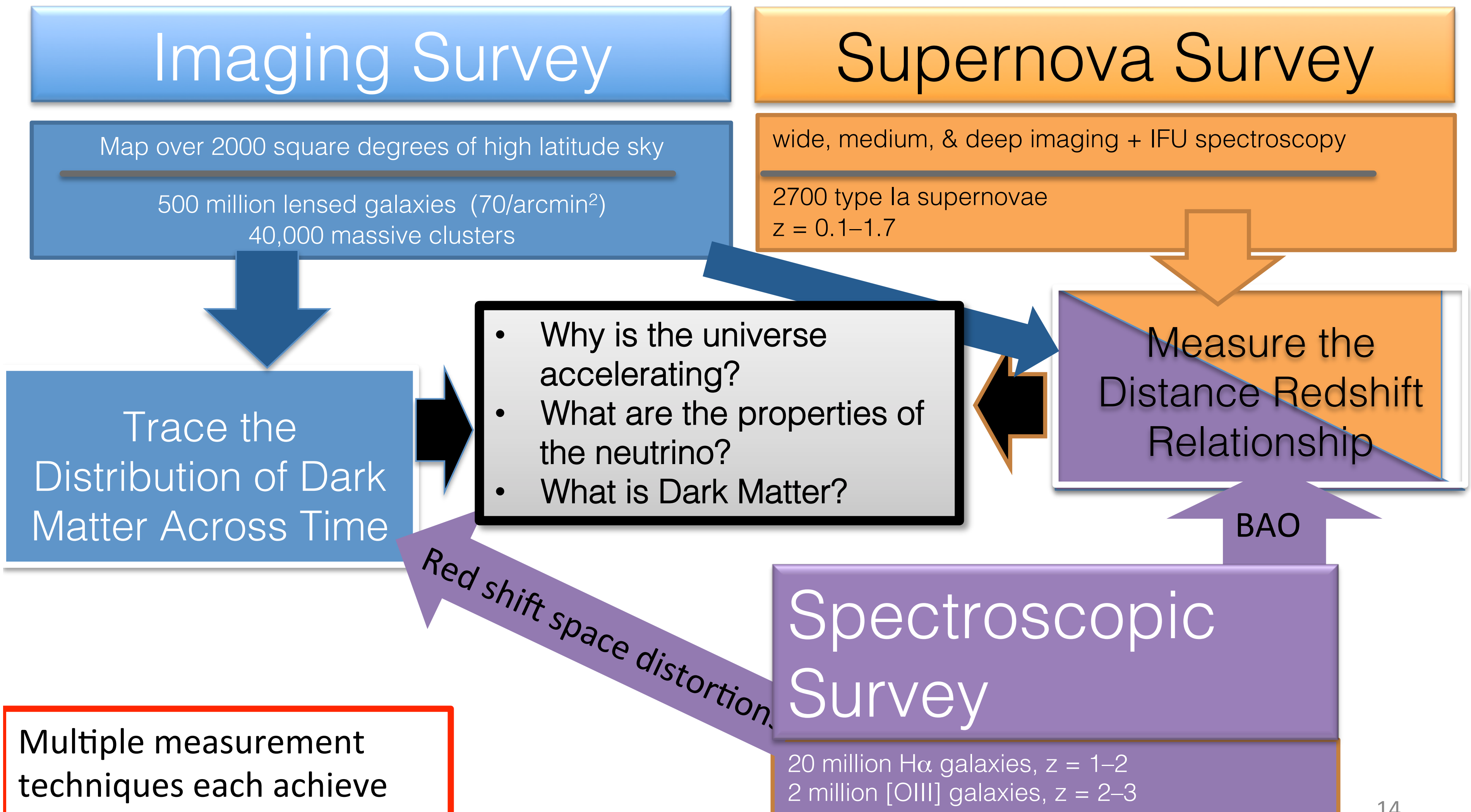


The discovery of the accelerating universe fundamentally challenged our notions of gravity

- Does Einstein's general relativity fail on the largest scales?
- Is space filled with "dark energy"?
- Will this "dark energy" rip apart the universe or "merely" drive its rapid expansion?

Frontiers of Knowledge

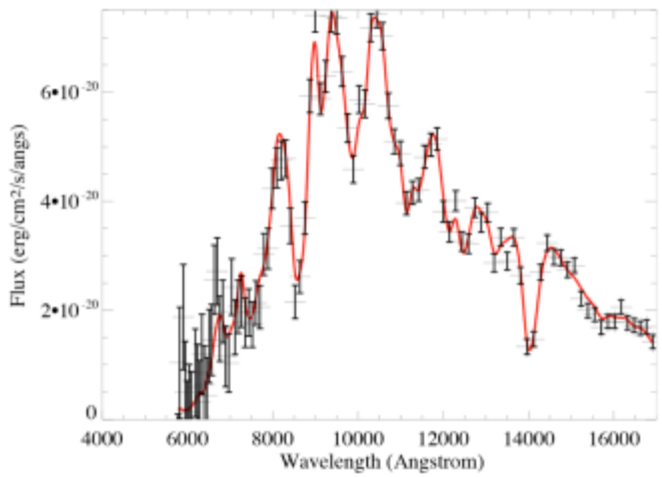
As envisioned in NWNH, AFTA uses multiple approaches to measure the growth rate of structure and the geometry of the universe to exquisite precision. These measurements will address the central questions of cosmology

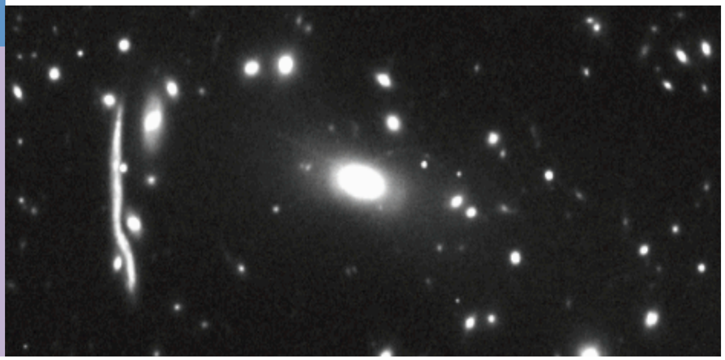


Multiple measurement techniques each achieve 0.1-0.4% precision

AFTA is a more capable dark energy mission than previous DRMs

- **Larger telescope + integral field channel enable high S/N spectrophotometry**
  - **More supernovae out to higher redshift**
  - **Systematic errors addressed: eliminate K-correction, improved calibration, measure SN spectral diagnostics.**
- **Deeper weak lensing survey**
  - **3x fainter, 1.9x smaller PSF, 2x n_{eff}**
  - **more accurate lensing maps to higher redshift**
  - **Better sampling for higher-order WL statistics**
  - **Lensing masses for 40,000 M ≥ $10^{14}M_{sun}$ clusters in the 2000 deg^2 area of the high-latitude survey**
- **Much deeper galaxy redshift survey at 1 < z< 2, [OIII] extends redshift range to z =3.**
  - **Can use multiple tracers.**
  - **Improve redshift-space distortion measurements, test systematics.**
  - **Better measurements of high-order clustering.**





AFTA and Euclid have complementary strengths for dark energy studies

AFTA:

Deep Infrared Survey (2000 sq. deg)

Lensing:

- High Resolution (70 -250 gal/arcmin^2)
- 5 lensing power spectrum

Supernovae:

- High quality IFU spectra of 2700 SN

Redshift survey

- High number density of galaxies
- Redshift range extends to z = 3

Euclid:

Wide optical Survey (15000 sq. deg)

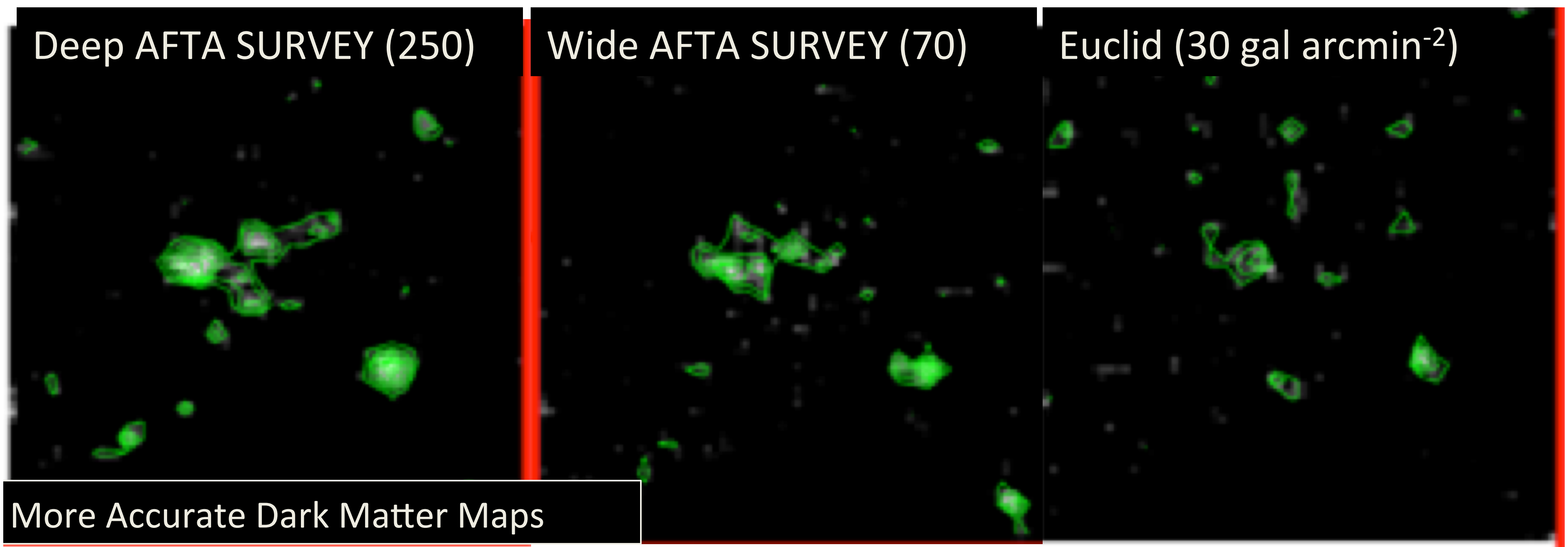
Lensing:

- Lower Resolution (30 gal/arcmin^2)
- 1 lensing power spectrum

No supernovae program

Redshift survey:

- Low number density of galaxies
- Significant number of low redshift galaxies



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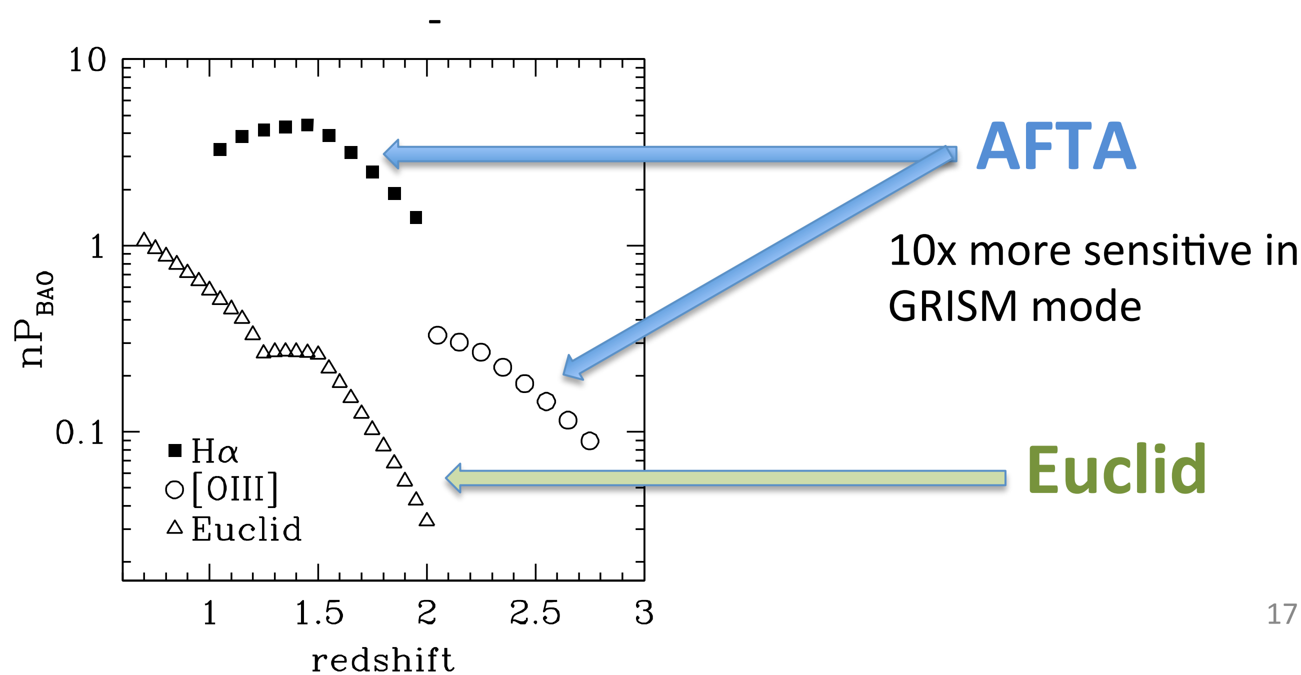
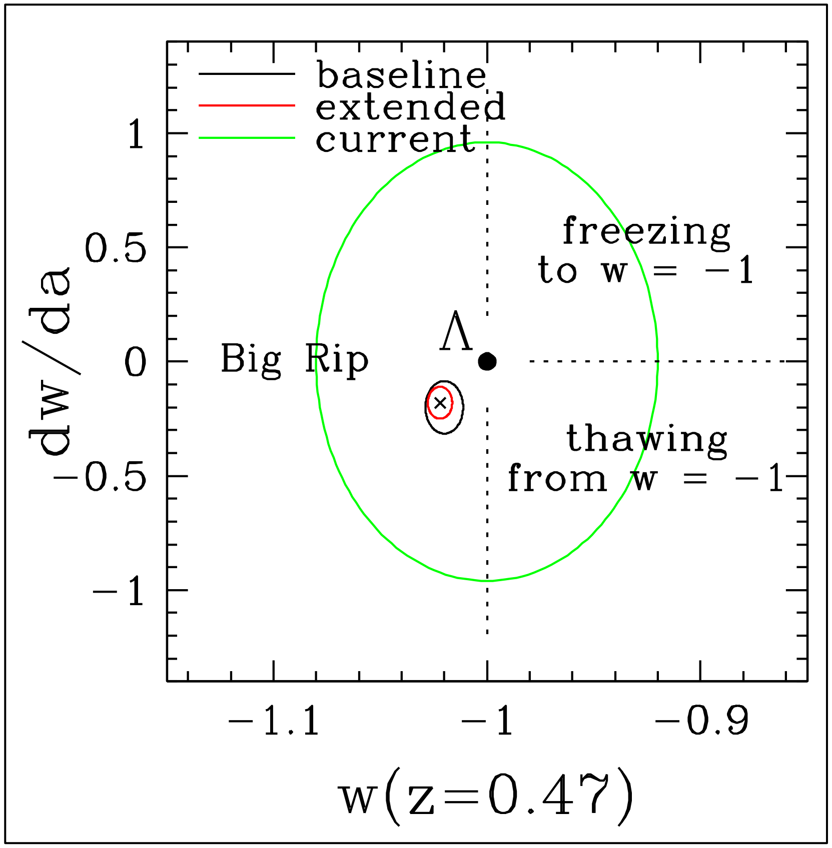


AFTA will have the sensitivity and the control of systematics to enable a major discovery of the nature of dark energy!

By measuring the relationship between distance and redshift, we will be able to determine the properties of dark energy.

These properties are often characterized by w and its time derivative, dw/da.

If w < -1, the universe will someday by torn apart in a “big rip” that destroys spacetime.



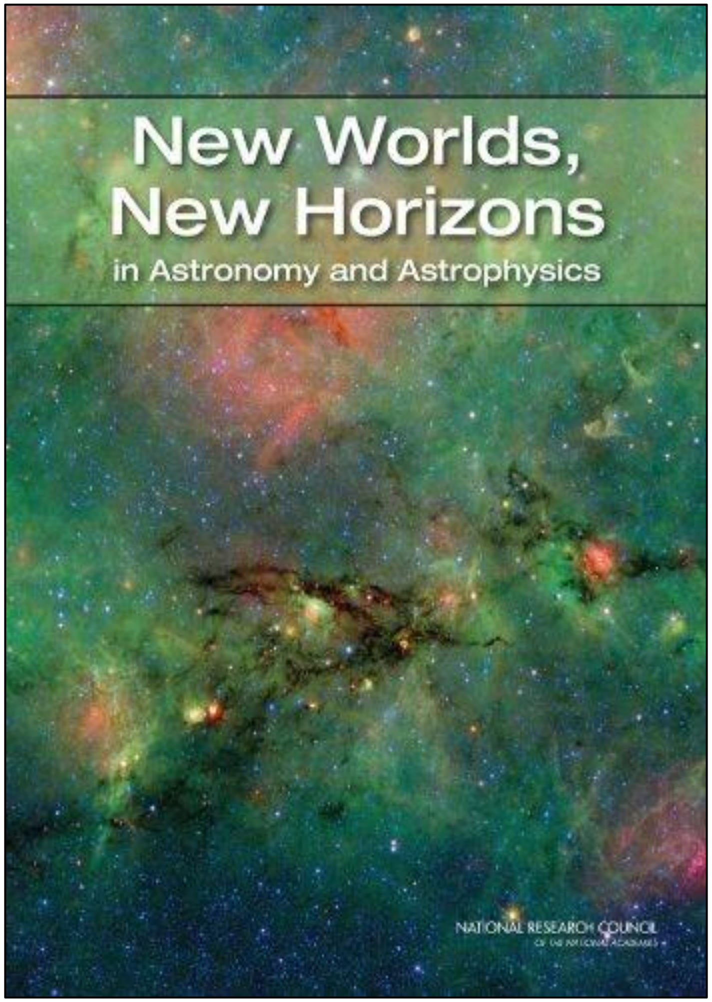
2. Cosmic Order: Exoplanet Science

- How diverse are planetary systems?
- Do habitable worlds exist around other stars, and can we identify the telltale signs of life on an exoplanet?
- How do circumstellar disks evolve and form planetary systems?

Discovery Science

- Identification and characterization of nearby habitable exoplanets

ExoPAG community meeting: strong endorsement of coronagraph



Decadal Survey's Enduring Questions & Discovery Areas

AFTA Exoplanet Science

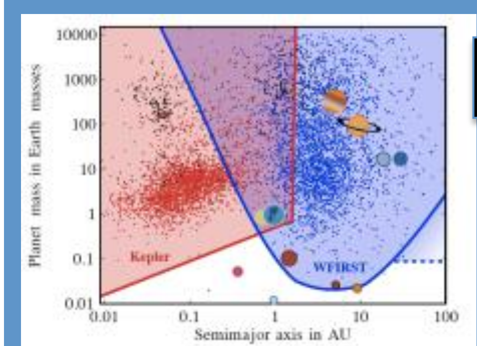
The combination of microlensing and direct imaging will dramatically expand our knowledge of other solar systems and will provide a first glimpse at the planetary families of our nearest neighbor stars.

Microlensing Survey

Monitor 200 million Galactic bulge stars every 15 minutes for 1.2 years

2800 cold exoplanets
300 Earth-mass planets
40 Mars-mass or smaller planets
40 free-floating Earth-mass planets

Complete the Exoplanet Census

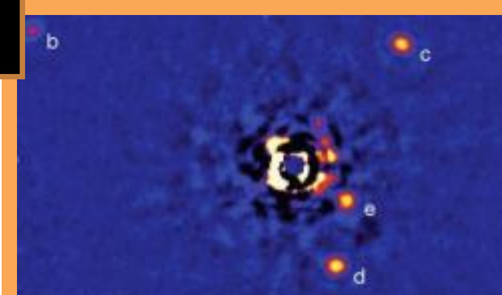


High Contrast Imaging

Survey up to 200 nearby stars for planets and debris disks at contrast levels of 10^{-9} on angular scales > 0.2”
R=70 spectra and polarization between 400-1000 nm

Detailed characterization of up to a dozen giant planets.
Discovery and characterization of several Neptunes
Detection of massive debris disks.

Discover and Characterize Nearby Worlds



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- How do circumstellar disks evolve and form planetary systems?
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Toward the "Pale Blue Dot"

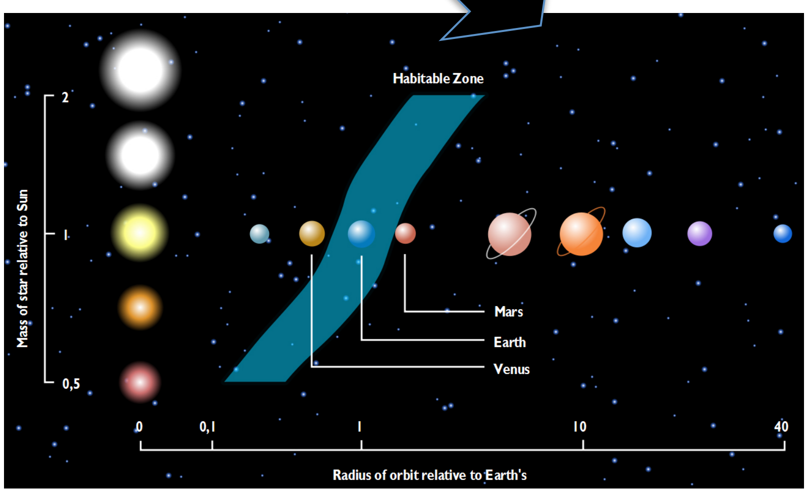
AFTA will lay the foundation for a future flagship direct imaging mission capable of detection and characterization of Earthlike planets.

Microlensing Survey

- Inventory the outer parts of planetary systems, potentially the source of the water for habitable planets.
- Quantify the frequency of solar systems like our own.
- Confirm and improve Kepler's estimate of the frequency of potentially habitable planets.
- When combined with Kepler, provide statistical constraints on the densities and heavy atmospheres of potentially habitable planets.

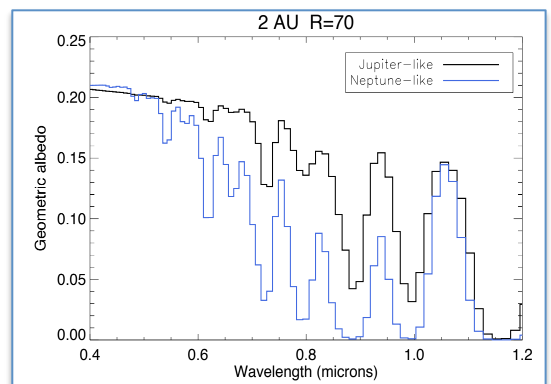
High Contrast Imaging

- Provide direct images of planets around our nearest neighbors similar to our own giant planets.
- Provide important insights about the physics of planetary atmospheres through comparative planetology.
- Assay the population of massive debris disks that will serve as sources of noise and confusion for a flagship mission.
- Develop crucial technologies for a future mission, and provide practical demonstration of these technologies *in flight.*

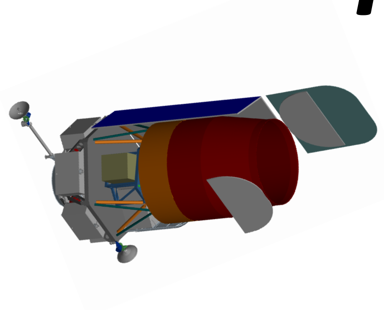


Courtesy of Jim Kasting.

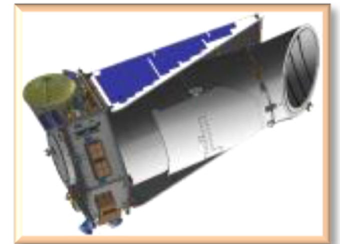
Science and technology foundation for the New Worlds Mission.



Exoplanet Microlensing Survey

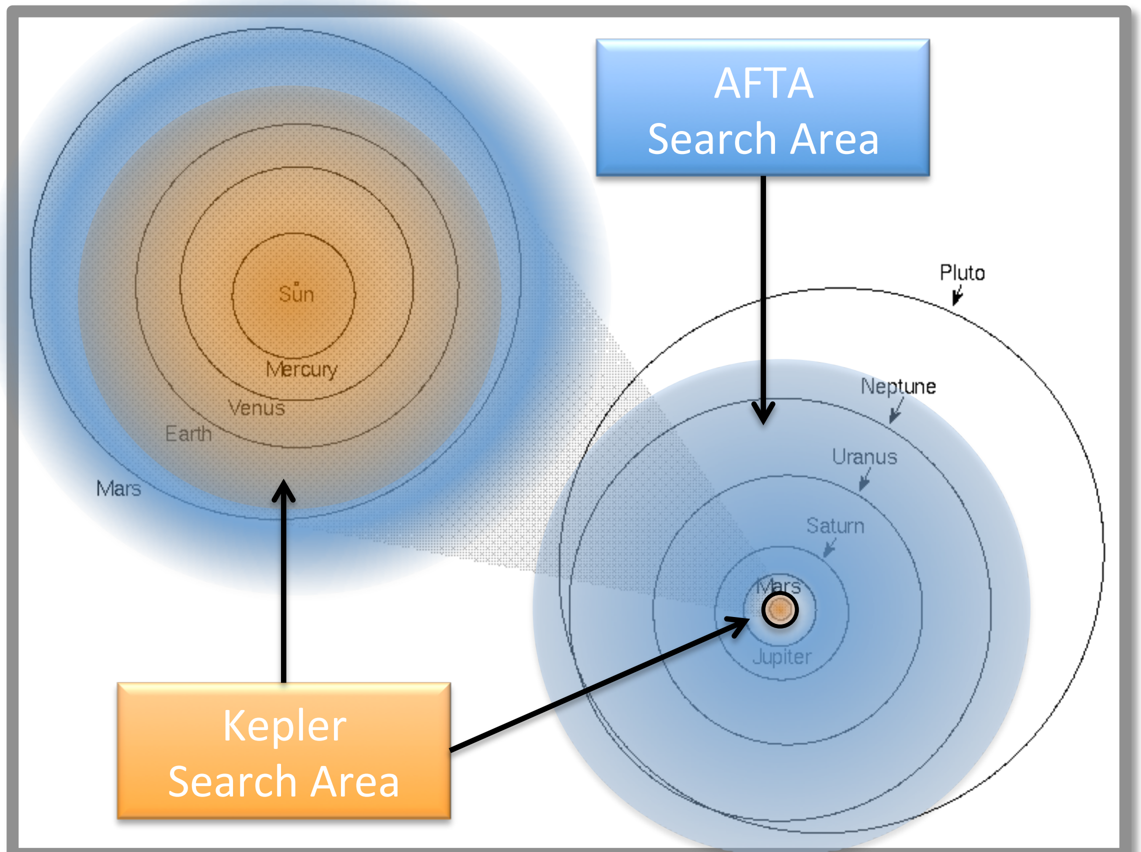


Together, Kepler and AFTA complete the statistical census of planetary systems in the Galaxy.

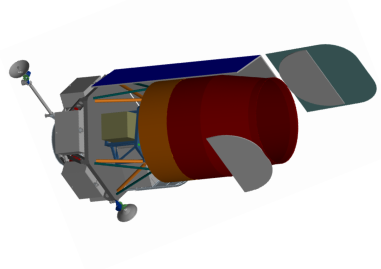


AFTA will:

- Detect 2800 planets, with orbits from the habitable zone outward, and masses down to a few times the mass of the Moon.
- Be sensitive to analogs of all the solar system's planets except Mercury.
- Measure the abundance of free-floating planets in the Galaxy with masses down to the mass of Mars



Exoplanet Microlensing Survey



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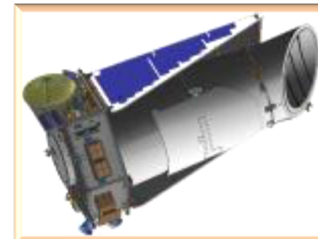

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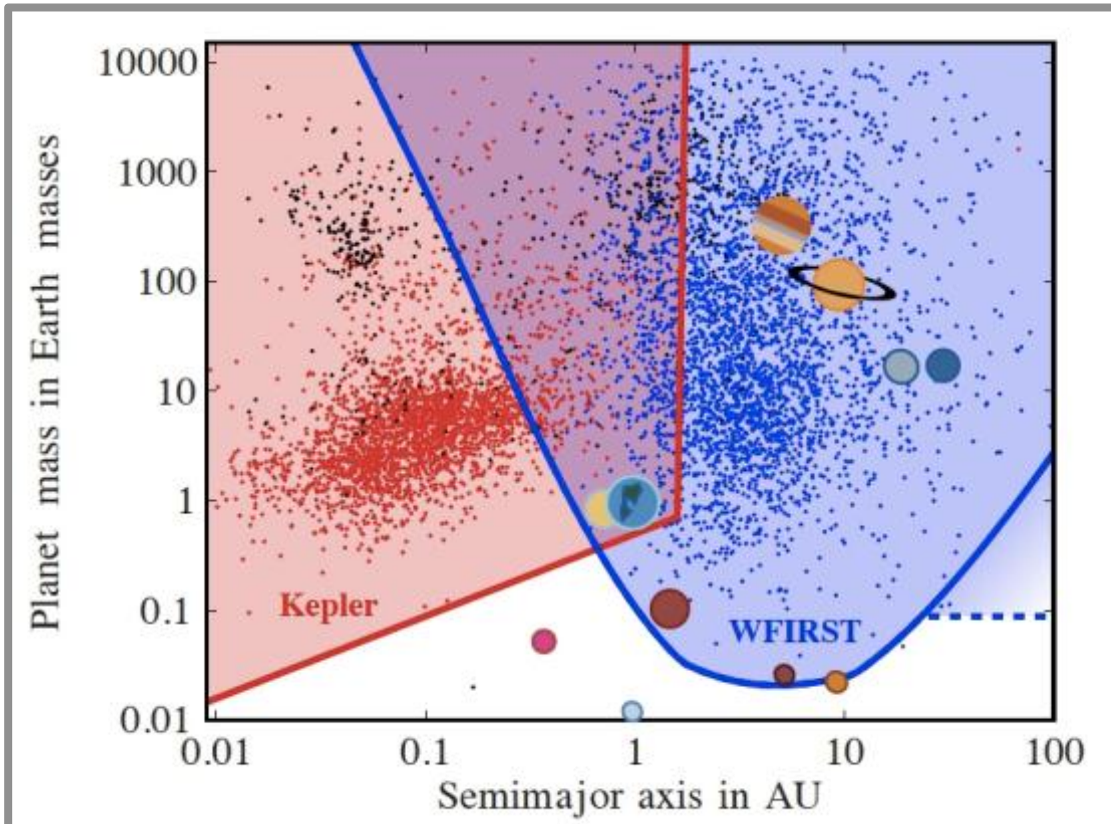
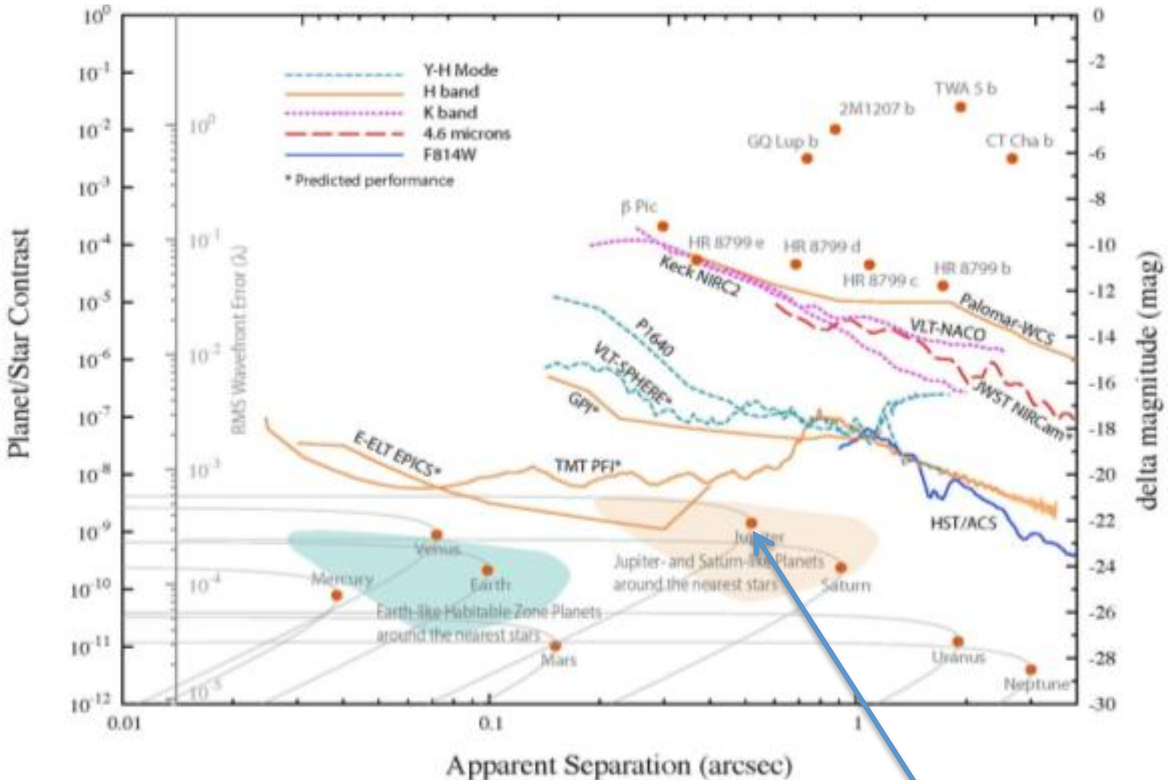
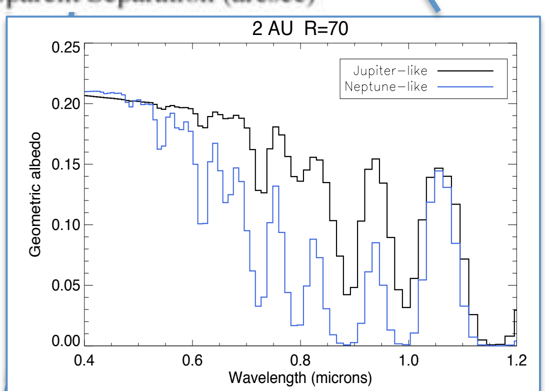


Exoplanet Direct Imaging



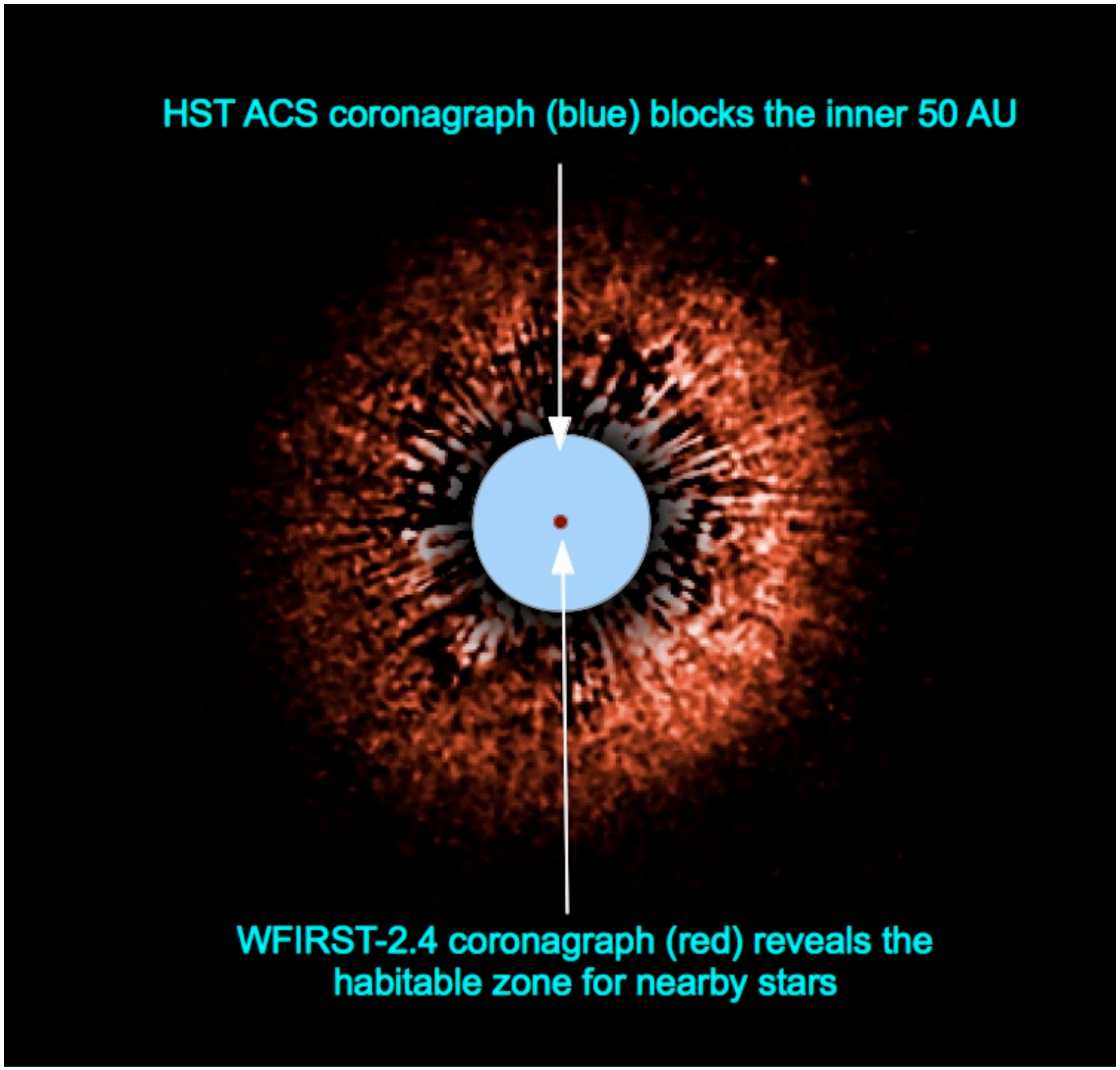
Spectra at R=70 easily distinguishes between a Jupiter-like and Neptune-like planets of different metallicity.



AFTA will:

- Characterize the spectra of over a dozen radial velocity planets.
- Discover and characterize up to a dozen more ice and gas giants.
- Provide crucial information on the physics of planetary atmospheres and clues to planet formation.
- Respond to decadal survey to mature coronagraph technologies, leading to first images of a nearby Earth.

Debris Disk Imaging



http://hubblesite.org/newscenter/archive/releases/2004/33/image/c/

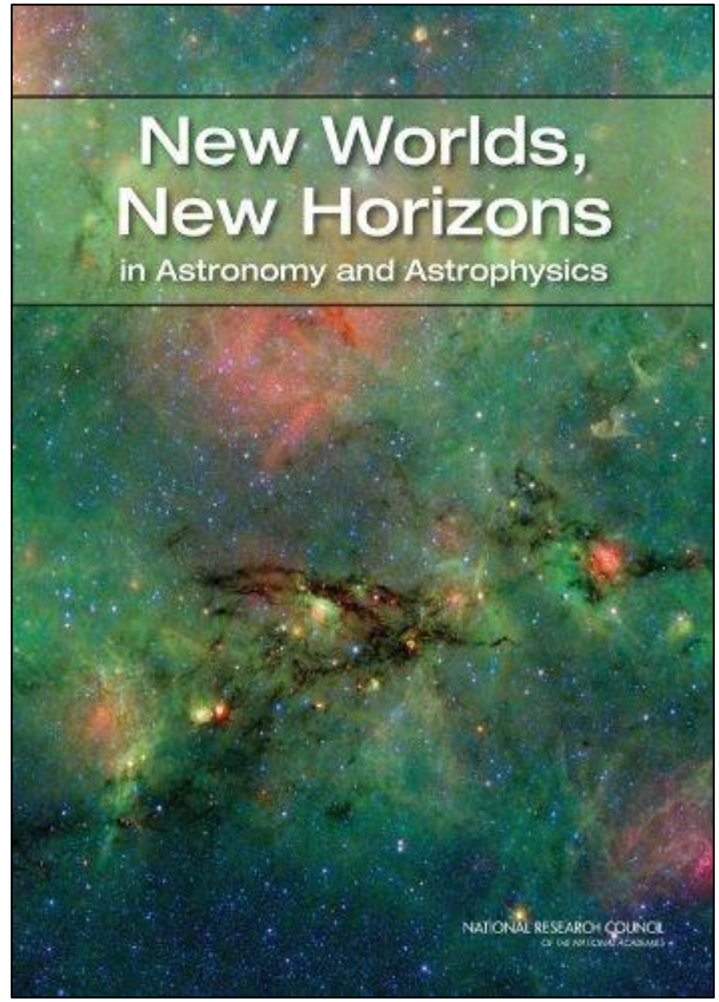
AFTA will:

- Measure the amount and distribution of circumstellar dust.
- Measure the large scale structure of disks, revealing the presence of asteroid belts and gaps due to unseen planets.
- Measure the size and distribution of dust grains.
- Provide measurements of the zodiacal cloud in other systems.

Debris disk around the young (~100 Myr), nearby (28 pc) sun-like (G2 V0) star HD 107146

3. Understanding Our Origins

- ***How did the universe begin?***
- ***What were the first objects to light up the universe, and when did they do it?***
- ***How do cosmic structures form and evolve?***
- ***What are the connections between dark and luminous matter?***
- ***What is the fossil record of galaxy assembly from the first stars to the present?***



Decadal Survey's Enduring Questions

Understanding Our Origins

By tracing the distribution of dark matter over 2000 square degrees and the large-scale structure traced by galaxies, AFTA will provide precise measurements of the relationship between dark matter halos and luminous galaxies

Imaging Survey → Trace the Distribution of Dark Matter

Spectroscopic Survey → Trace Large-Scale Distribution of Galaxies

- *How did the universe begin?*
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- *What are the connections between dark and luminous matter?*

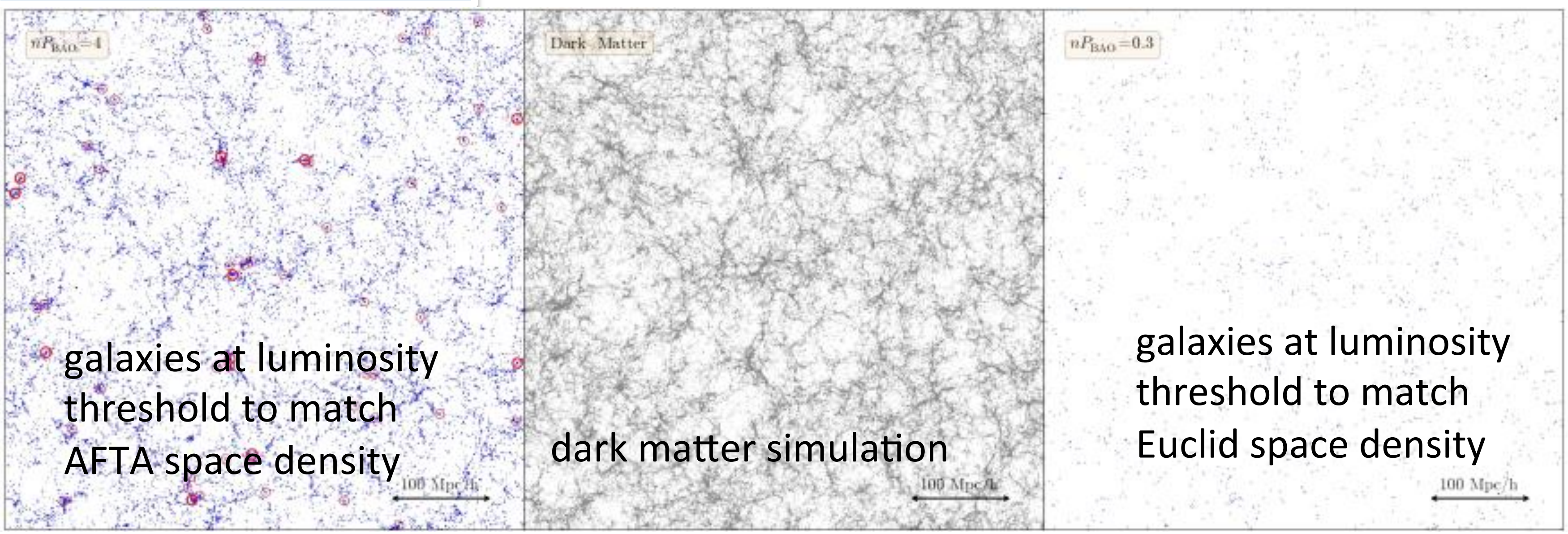
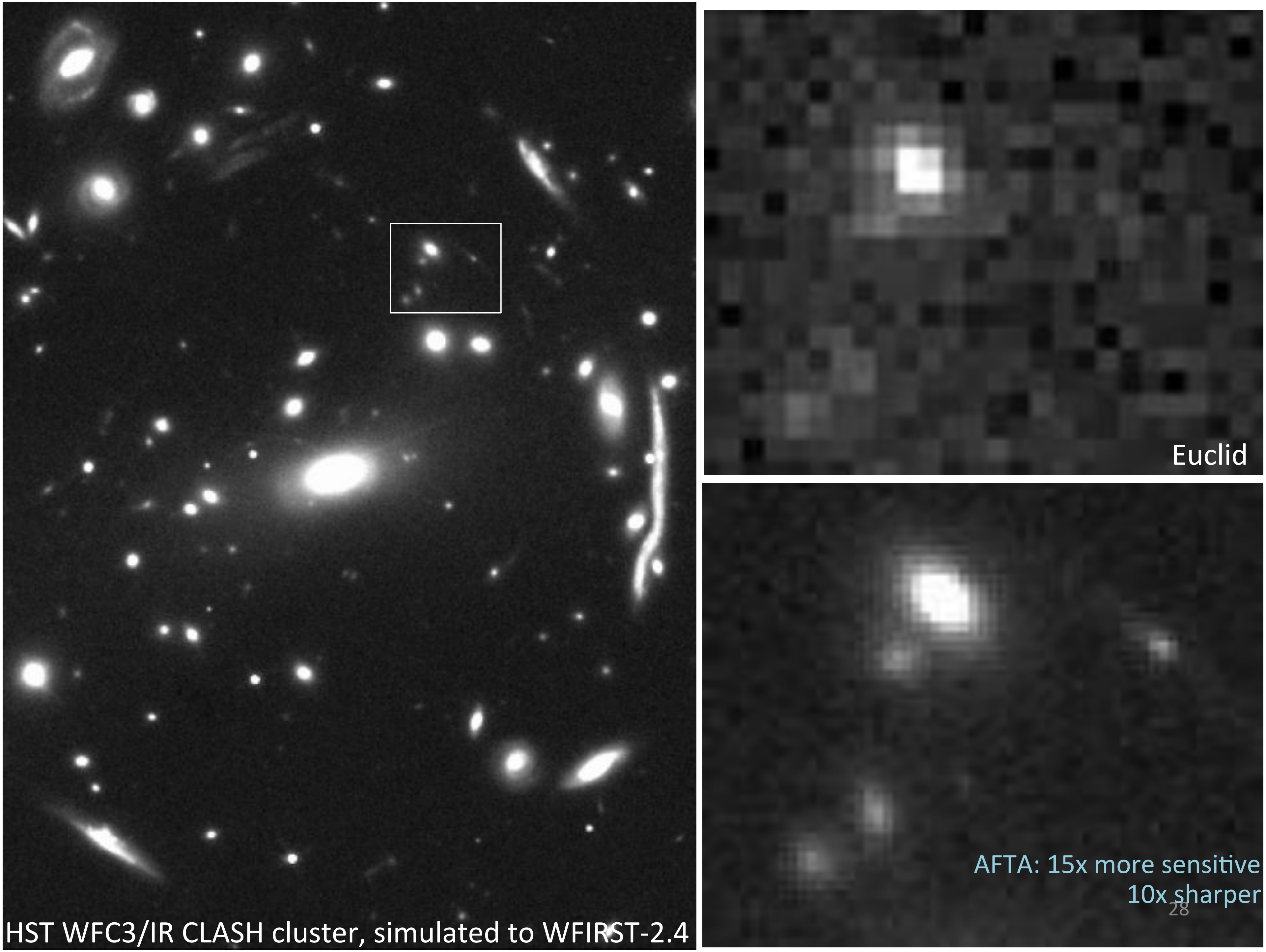
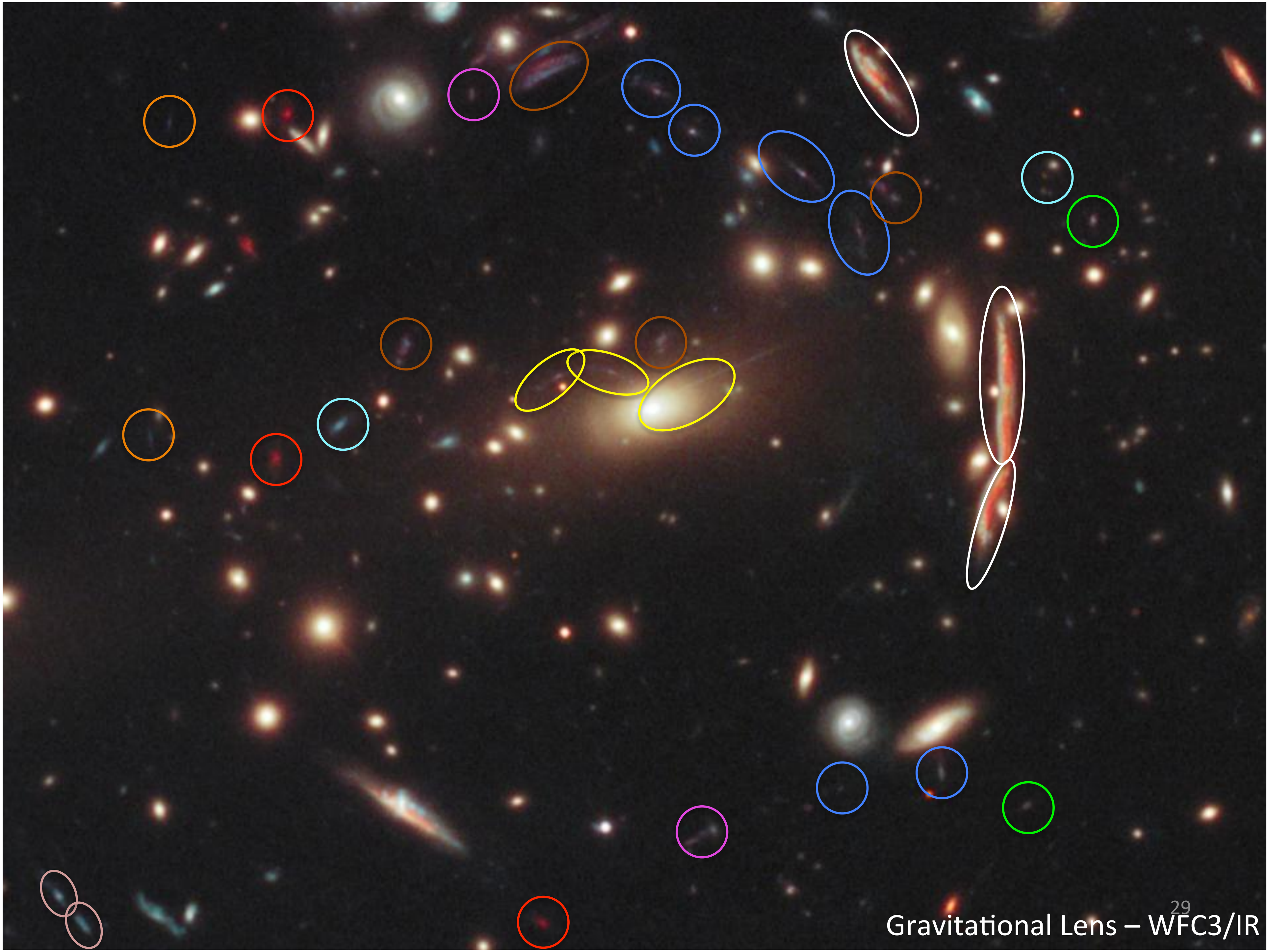


Figure by Y. Zu


HST WFC3/IR CLASH cluster, simulated to WFIRST-2.4
Euclid
AFTA: 15x more sensitive
10x sharper



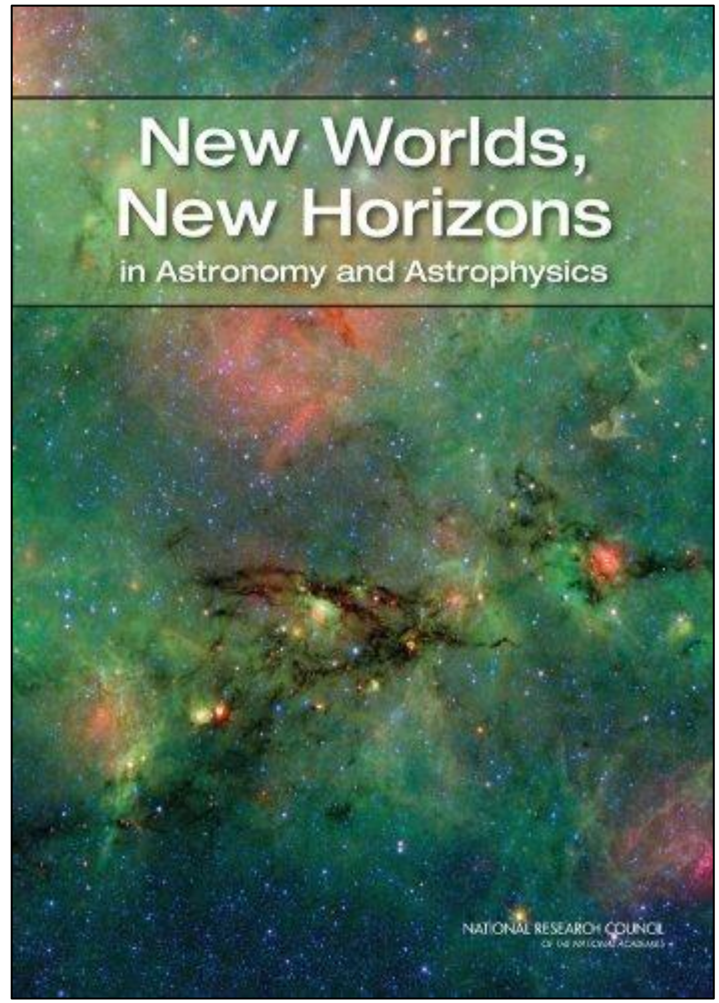
Gravitational Lens – WFC3/IR

Understanding Our Origins

- What were the first objects to light up the universe, and when did they do it?
- What is the fossil record of galaxy assembly from the first stars to the present?
- How do stars form?

Discovery Science

- Epoch of reionization



Decadal Survey's Enduring Questions & Discovery Area

Understanding Our Origins

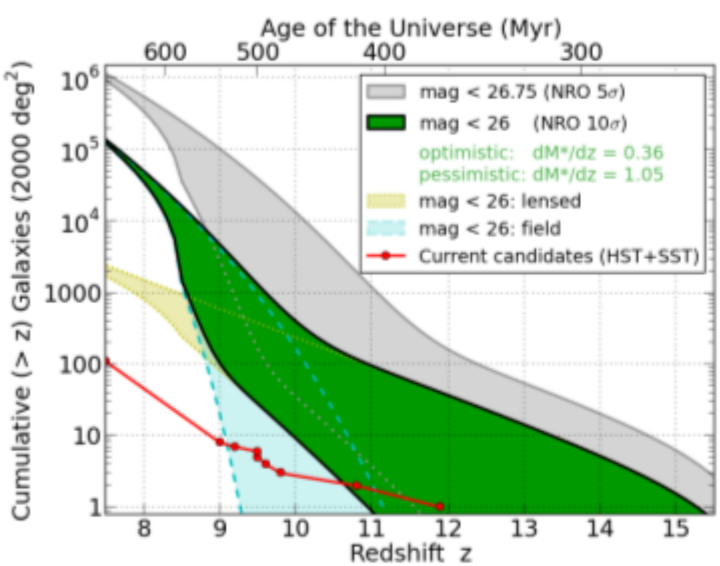
AFTA's sensitivity and large field of view will enable the discovery of rare faint objects including the most distant galaxies, supernova and quasars. AFTA will also likely be used to map many of the nearby galaxies

Imaging Survey + Community Survey

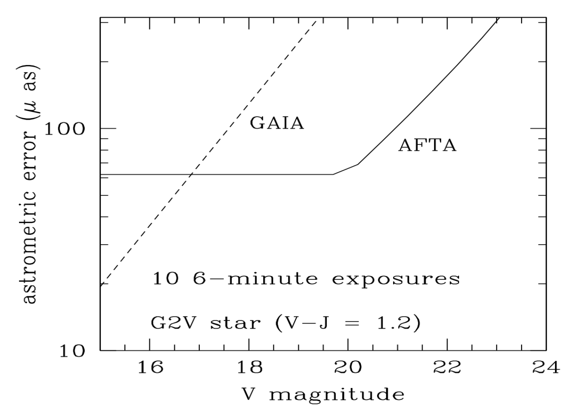
- Discover the earliest galaxies
- Discover high redshift supernova

- What were the first objects to light up the universe, and when did they do it?
- What is the fossil record of galaxy assembly from the first stars to the present?
- How do stars form?

- Trace Motions of Stars in galactic bulge and halo
- Map the stars in the nearby galaxies

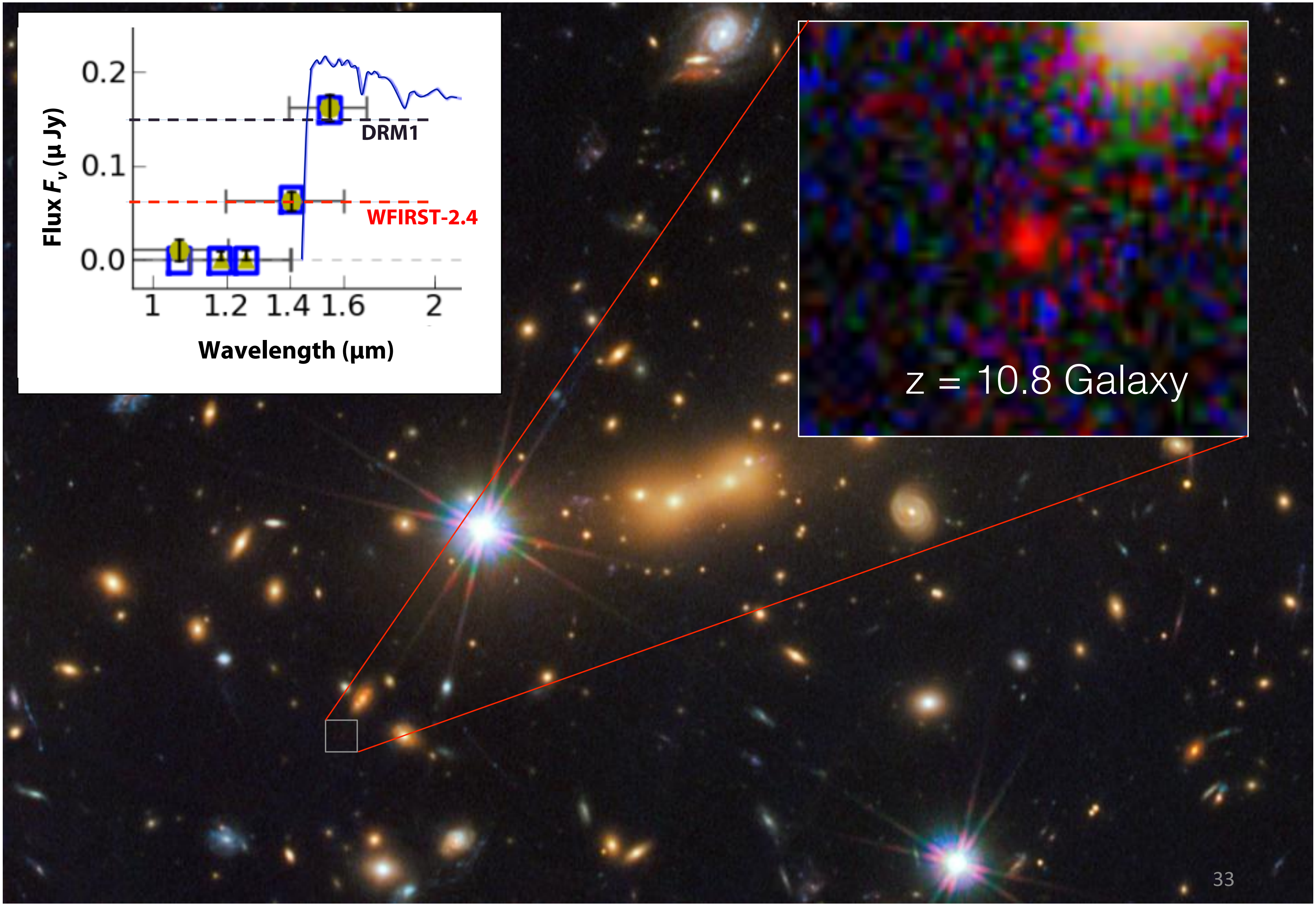


Cumulative number of high-z galaxies expected in the HLS. JWST will be able to follow-up on these high z galaxies and make detailed observations of their properties. By providing targets for JWST, WFIRST will enhance the JWST science return.

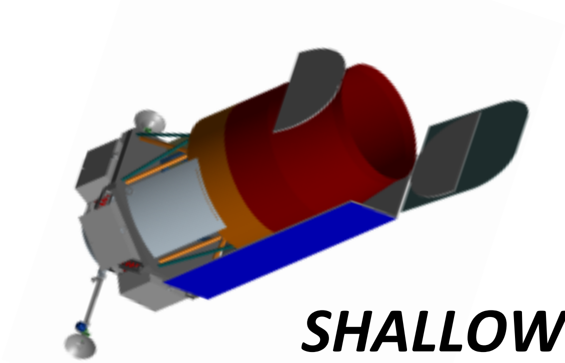


AFTA will obtain positions and velocities for 200,000,000 stars

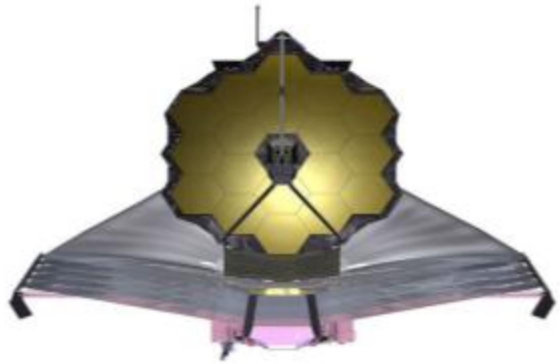
Hubble x 200 Discovery of High-z Galaxies



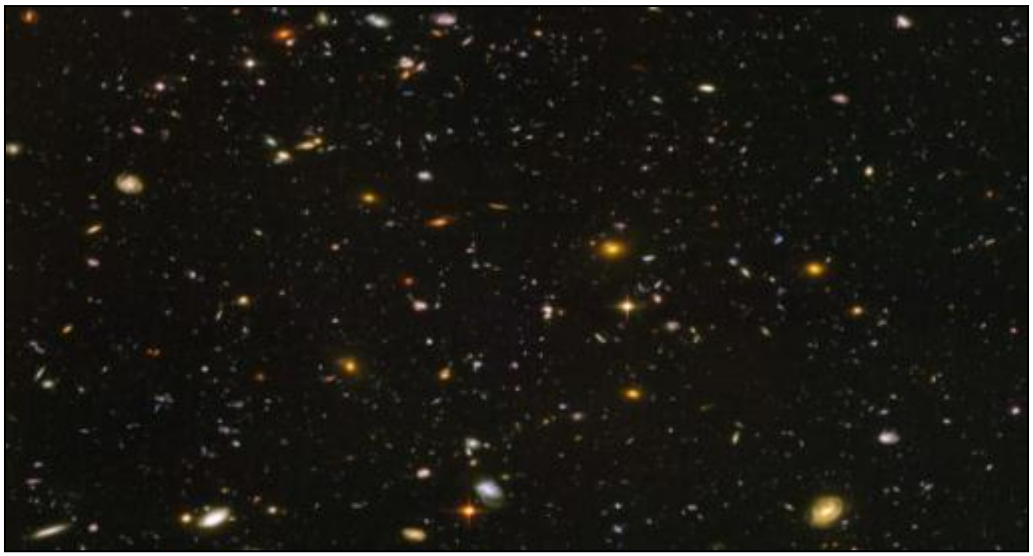
AFTA *Enhances* *JWST* *Science*



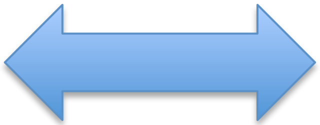
SHALLOW-WIDE!



DEEP-NARROW!



AFTA discovery of high-z galaxies
AFTA finds first stellar explosions
AFTA wide field survey of galaxies
AFTA maps of halo tidal streams
AFTA monitoring of exoplanets



JWST NIR and MIR detailed spectroscopy
JWST light curves and host galaxy properties
JWST Sne spectra with pre-detonation images
JWST ages and abundances of substructure
JWST transit spectroscopy of atmospheres

Appendix B of SDT Report

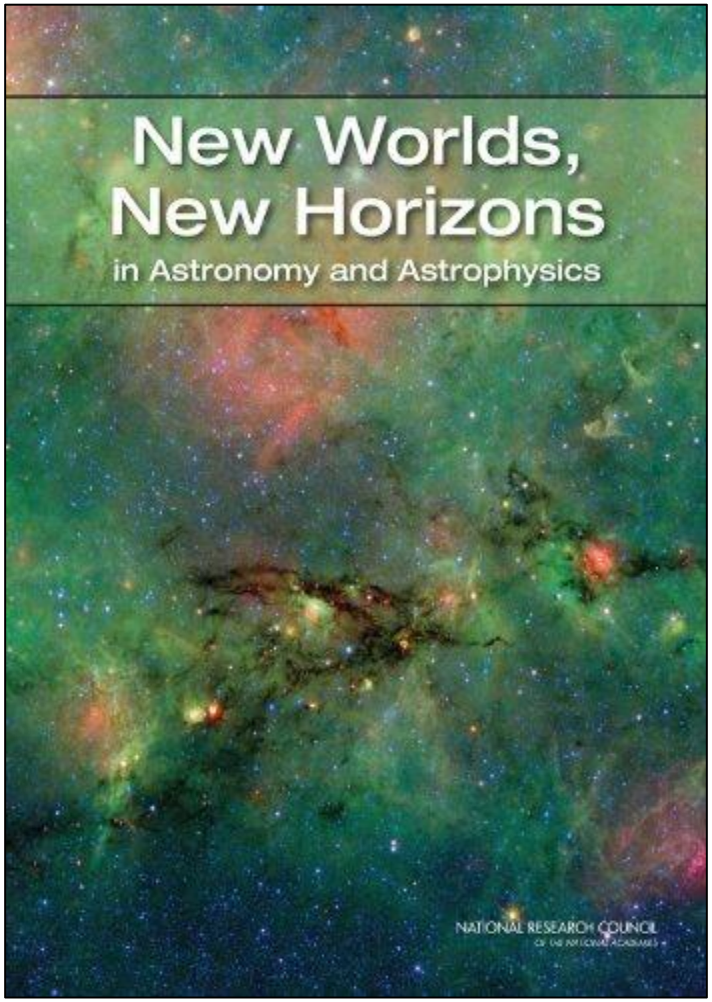
4. Cosmic Order

NWNH Fundamental Questions:

- What controls the mass-energy-chemical cycles within galaxies?
- How do the lives of massive stars end?
- What are the progenitors of Type Ia supernovae and how do they explode?

NWNH Discovery Science Areas:

- Time-domain astronomy
- Astrometry
- Gravitational wave astronomy



Decadal Survey's Enduring Questions

Discovery Science & Cosmic Order

The combination of the AFTA 2.4 meter telescope resolution and wide field of view enables a wide range of peer-reviewed community observations and analyses of the survey data that address top decadal science priorities

Community Observations (>25% of time)

Guest Observer

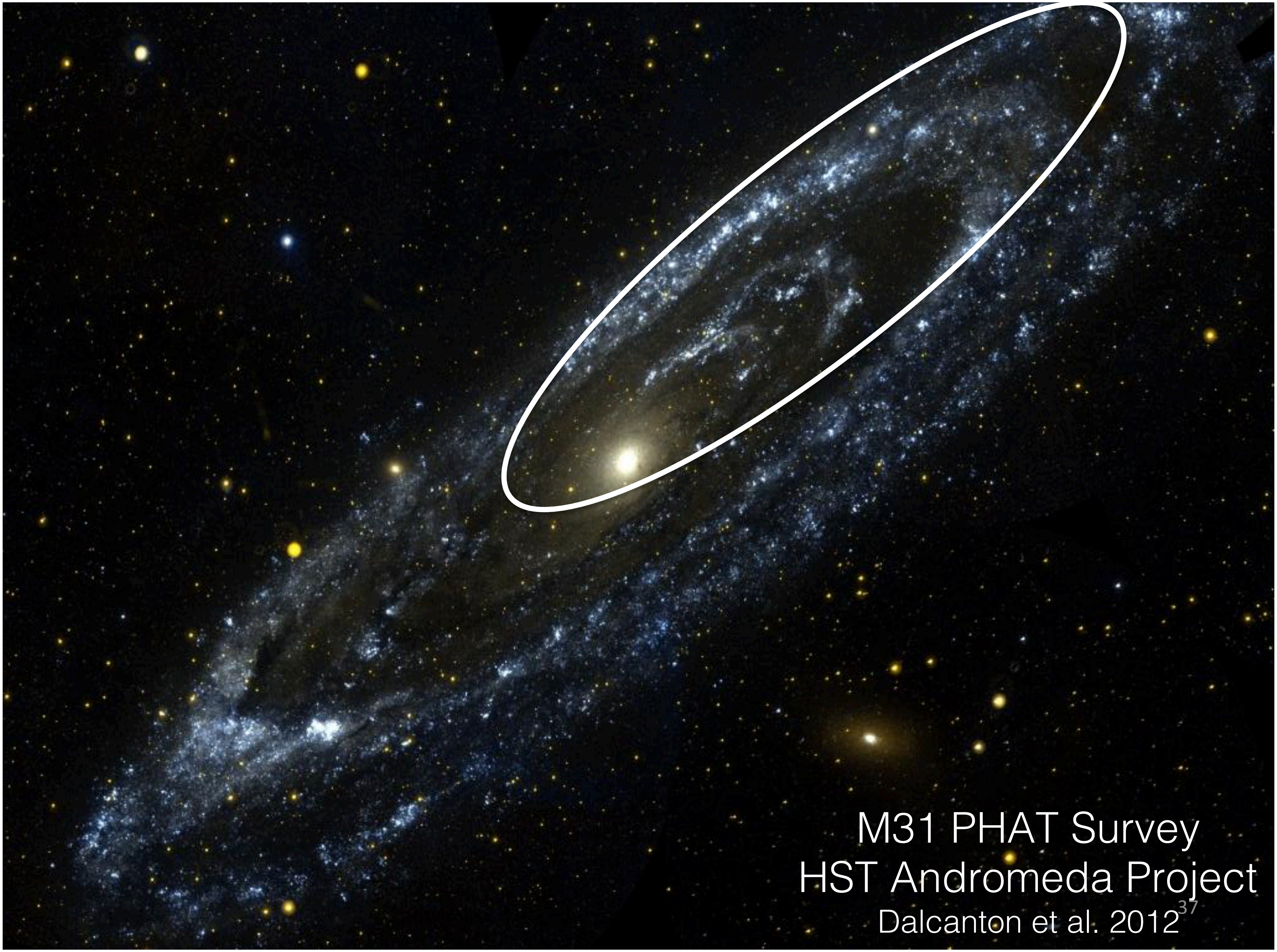
- Ultradeep wide fields with 100 times HST volume
- Transient followup
- Gravitational wave followup
- Use strong lensing to probe black hole disk structure
- Detect supernova progenitors in nearby galaxies

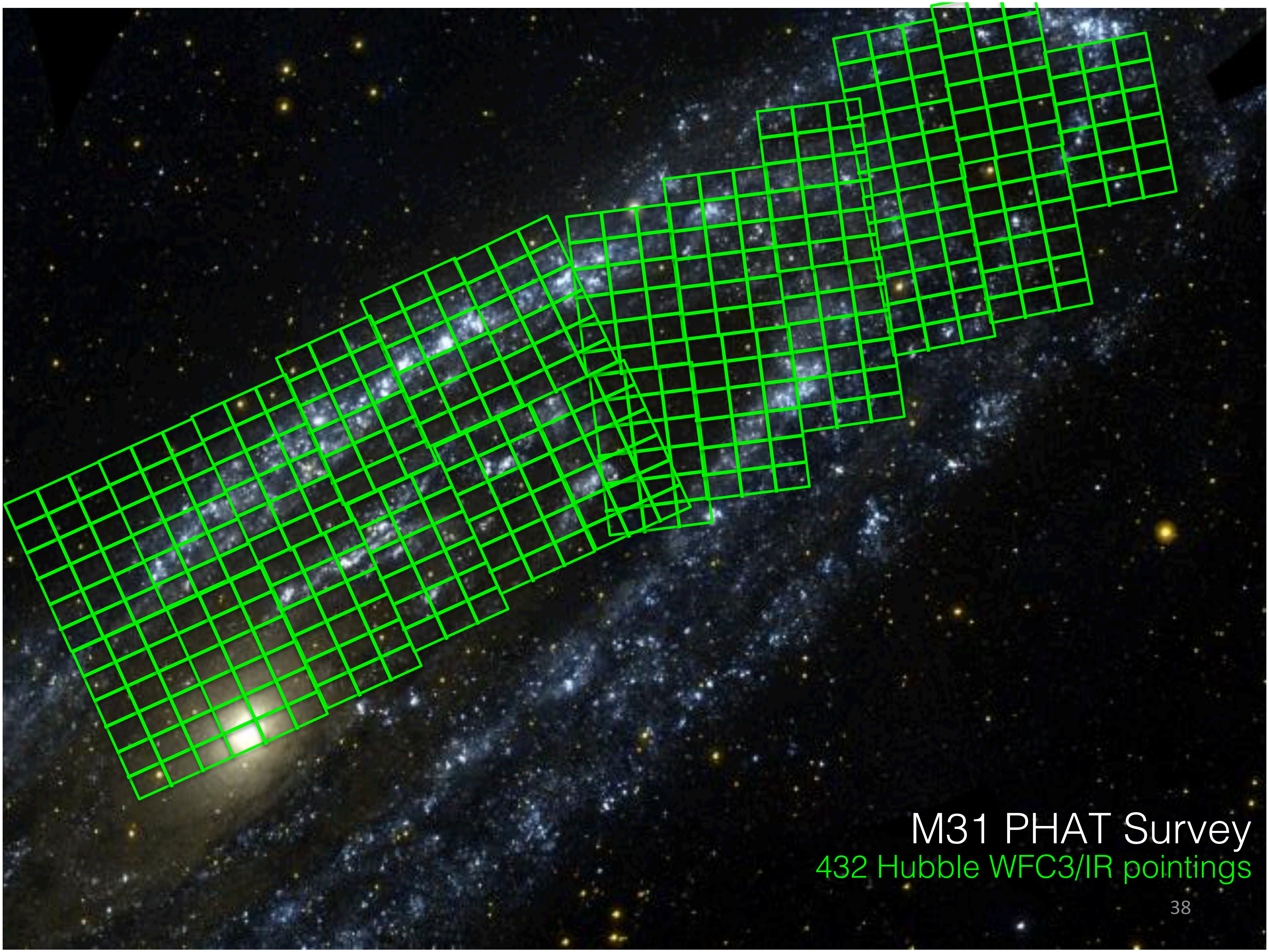
- *Time-domain astronomy*
- *Astrometry*
- *Gravitational wave astronomy*
- *What controls the mass-energy-chemical cycles within galaxies?*
- *How do the lives of massive stars end?*
- *What are the progenitors of Type Ia supernovae and how do they explode?*

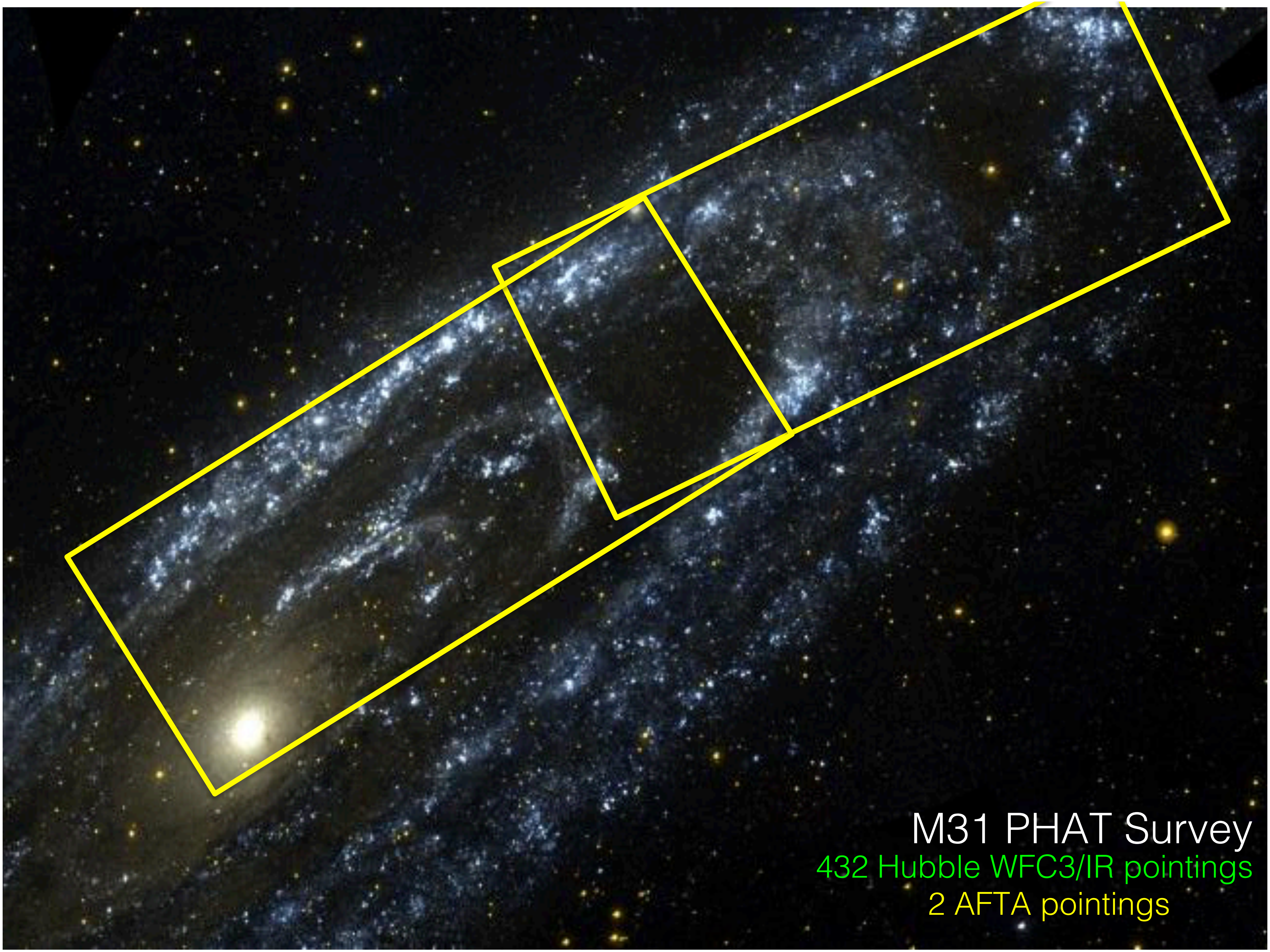
Guest Investigator

- Joint LSST/WFIRST analyses
- Discover the most extreme star-forming galaxies and quasars
- Microlensing census of black holes in the Milky Way

The larger aperture enables astronomers to address many of the essential questions and opens up new discovery

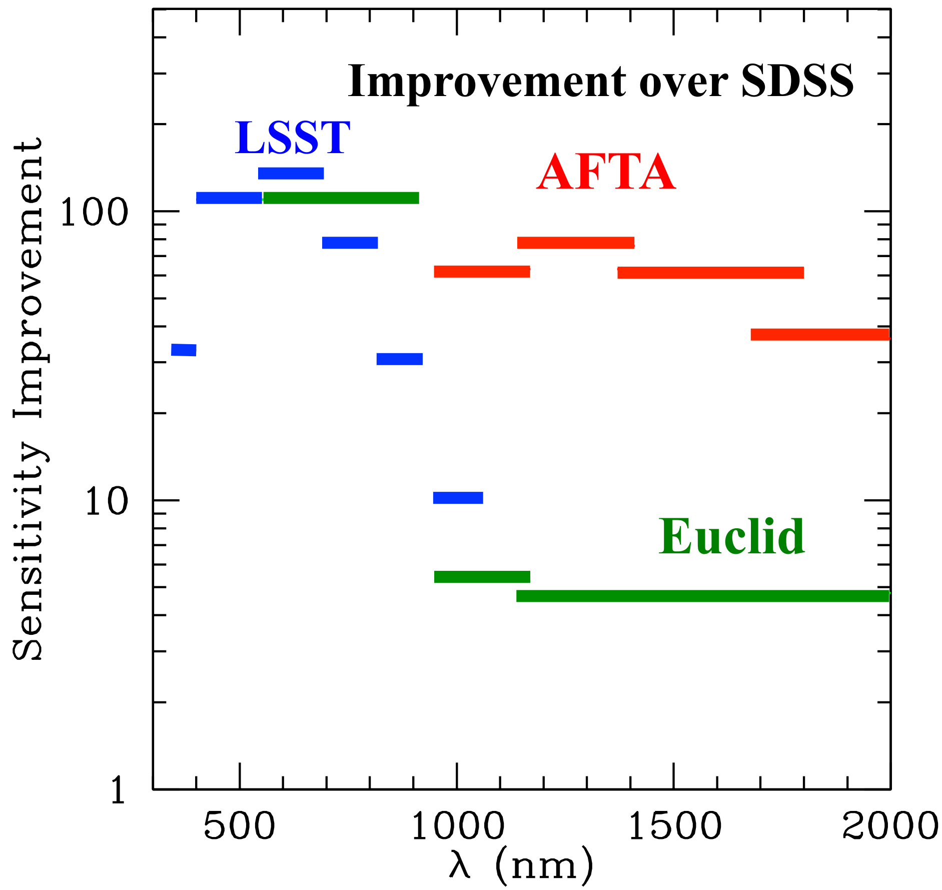

M31 PHAT Survey
HST Andromeda Project
Dalcanton et al. 2012


M31 PHAT Survey
432 Hubble WFC3/IR pointings


M31 PHAT Survey
432 Hubble WFC3/IR pointings
2 AFTA pointings


MASSIVE
OUTPOURING
OF INTEREST
FROM THE
ASTRONOMICAL
COMMUNITY

LSST/AFTA/Euclid Combined Survey: Community Guest Investigator Program

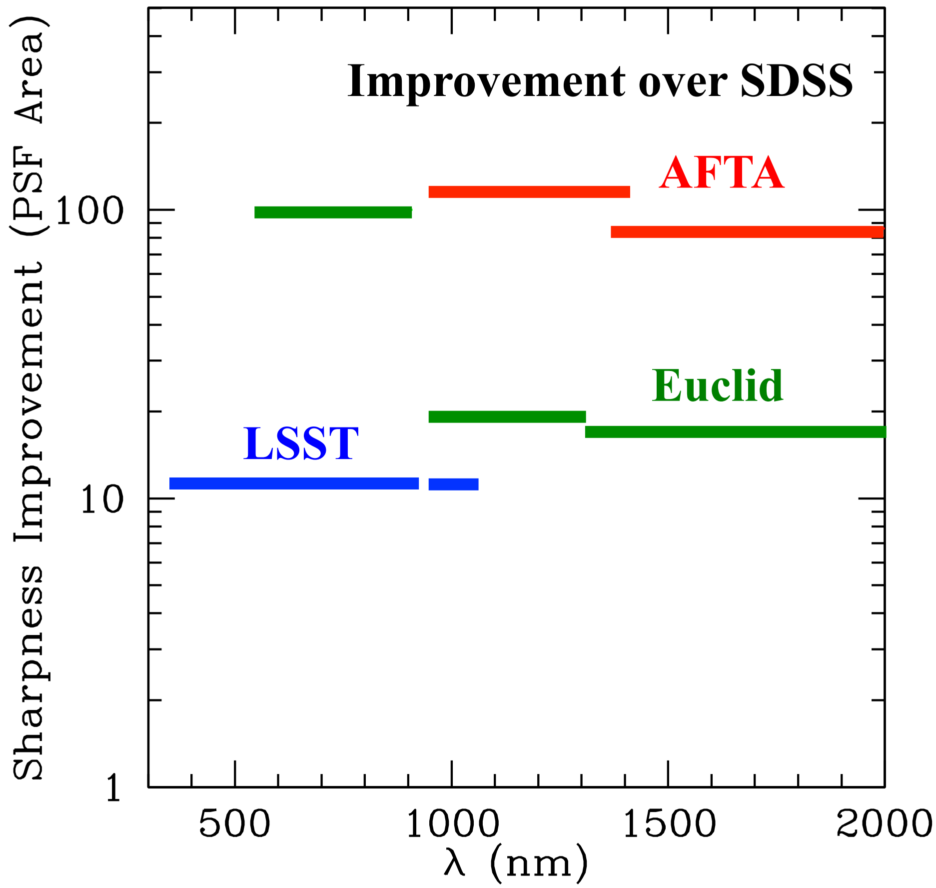


WFIRST-2.4 IR depth well matched to LSST optical survey. Scan strategy achieves 100% overlap with LSST.

AFTA is a 3x more sensitive than WFIRST DRM1

The 2000 square degree combined survey will be ~100 times more sensitive than the Sloan Survey, and extends the wavelength coverage to 2 microns. AFTA will produce >100 times sharper images than the Sloan telescope.

LSST/AFTA/Euclid Combined Survey: Community Guest Investigator Program



- WFIRST-2.4 is ~15x deeper and produces 10x sharper images than Euclid NIR.
- Well matched to Euclid sharpness in the optical.

- AFTA images are 1.9 X sharper than DRM1

The 2000 square degree combined survey will be ~100 times more sensitive than the Sloan Survey, and extends the wavelength coverage to 2 microns. AFTA will produce ~100 times sharper images than the Sloan telescope.

AFTA

- Addresses the “big” questions of astronomy that are NASA strategic plan for astronomy (p. 14):

“discover how the universe works,

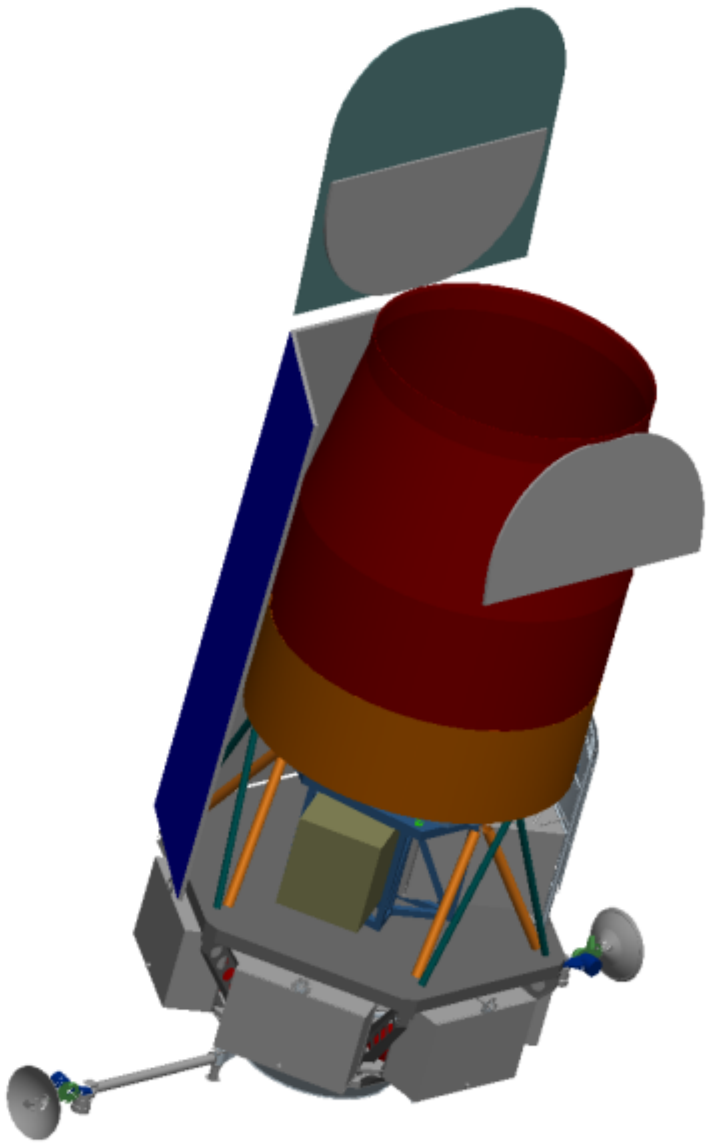
explore how it began and evolved, and

search for Earth-like planets”

- Enables a wealth of science across astronomy
- Stunning images will both excite public and reveal new insights into the nature of our universe.

Project

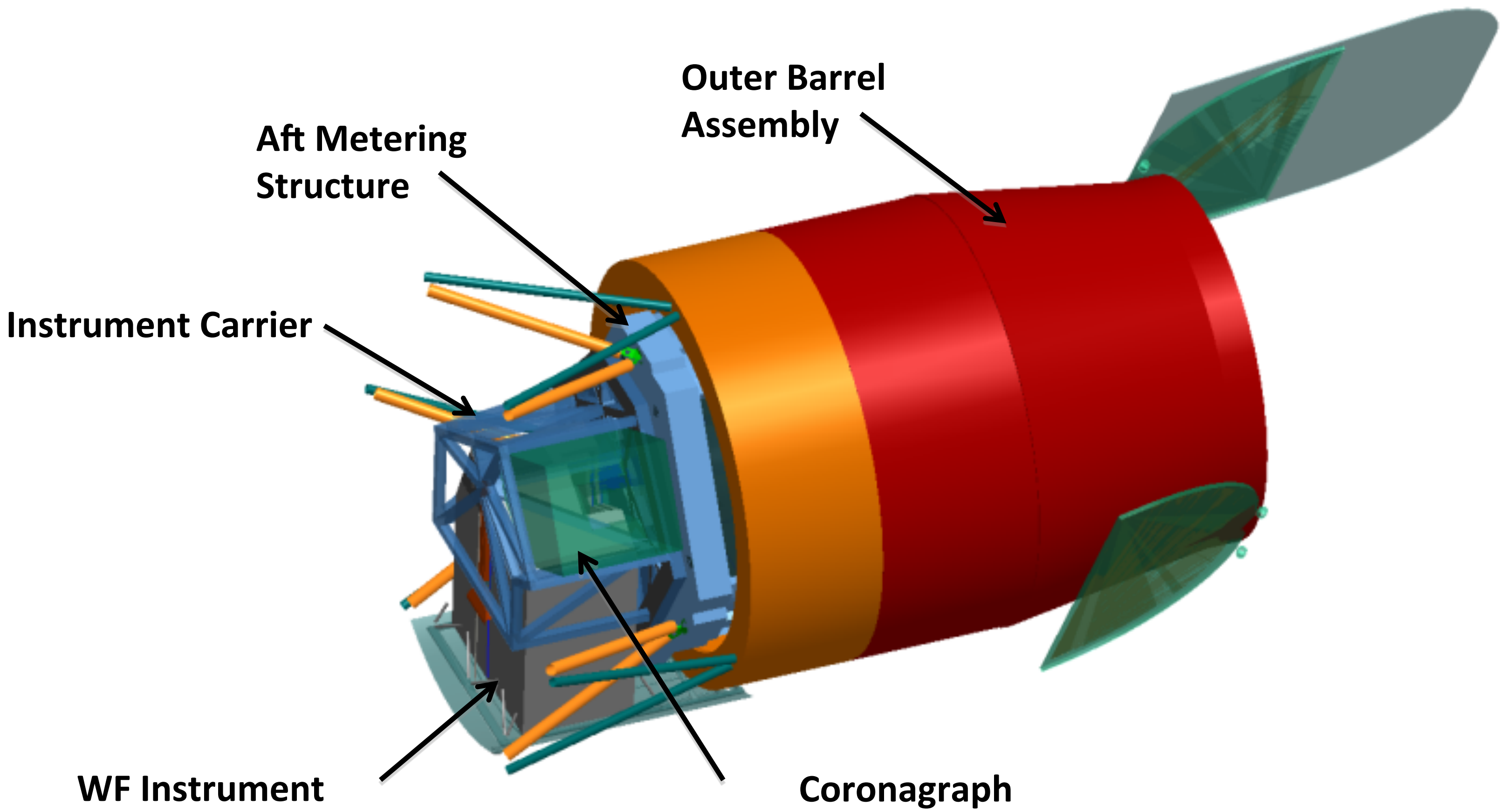
AFTA Observatory Concept



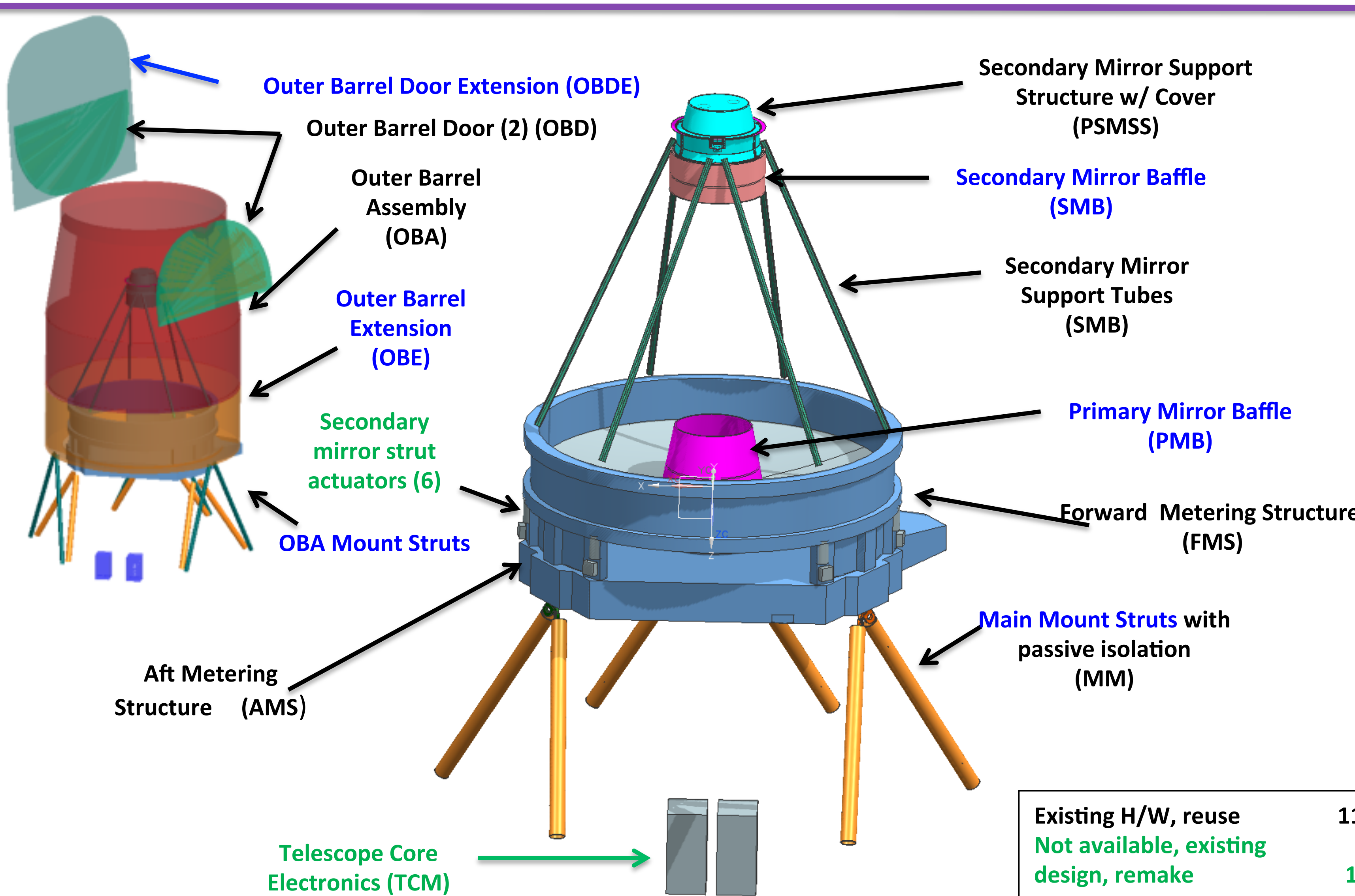
Key Features

- **Telescope – 2.4m aperture primary**
- **Instrument – Single channel widefield instrument, 18 HgCdTe detectors; integral field unit spectrometer incorporated in wide field for SNe observing**
- **Overall Mass – ~6300 kg (CBE) with components assembled in modules; ~2550 kg propellant; ~3750 kg (CBE dry mass)**
- **Primary Structure – Graphite Epoxy**
- **Downlink Rate – Continuous 150 mbps Ka-band to Ground Station**
- **Thermal – passive radiator**
- **Power – 2800 W**
- **GN&C – reaction wheels & thruster unloading**
- **Propulsion – bipropellant**
- **GEO orbit**
- **Launch Vehicle – AtlasV 541**

AFTA Payload Design Concept



AFTA Telescope

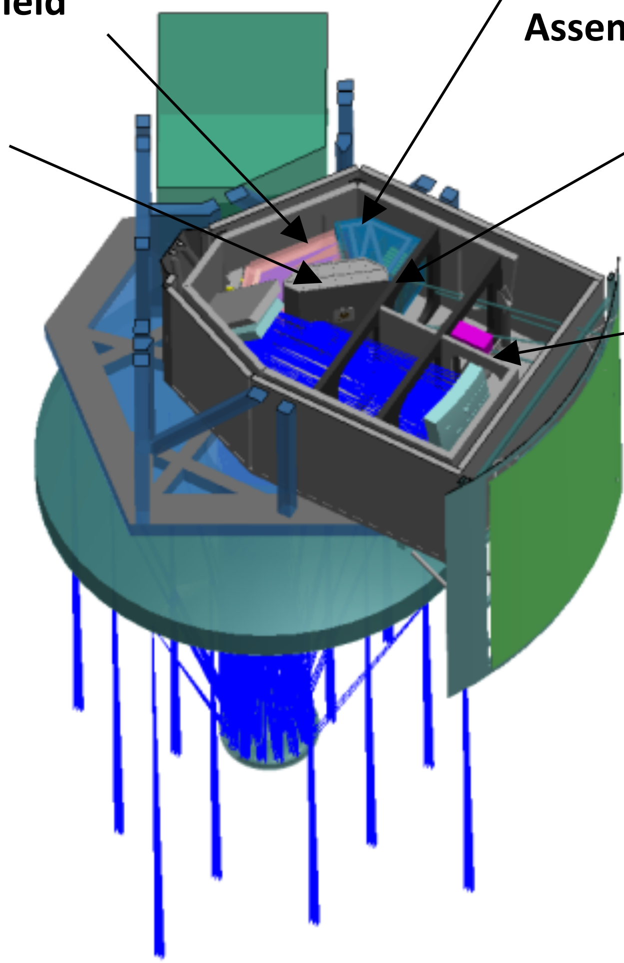


Existing H/W, reuse	1188 kg
Not available, existing design, remake	153 kg
New design	254 kg
TOTAL:	1595 kg

100% of the existing telescope hardware is being re-used.
Actuators, electronics and baffles not available and must be replaced.

AFTA Wide field Instrument Layout

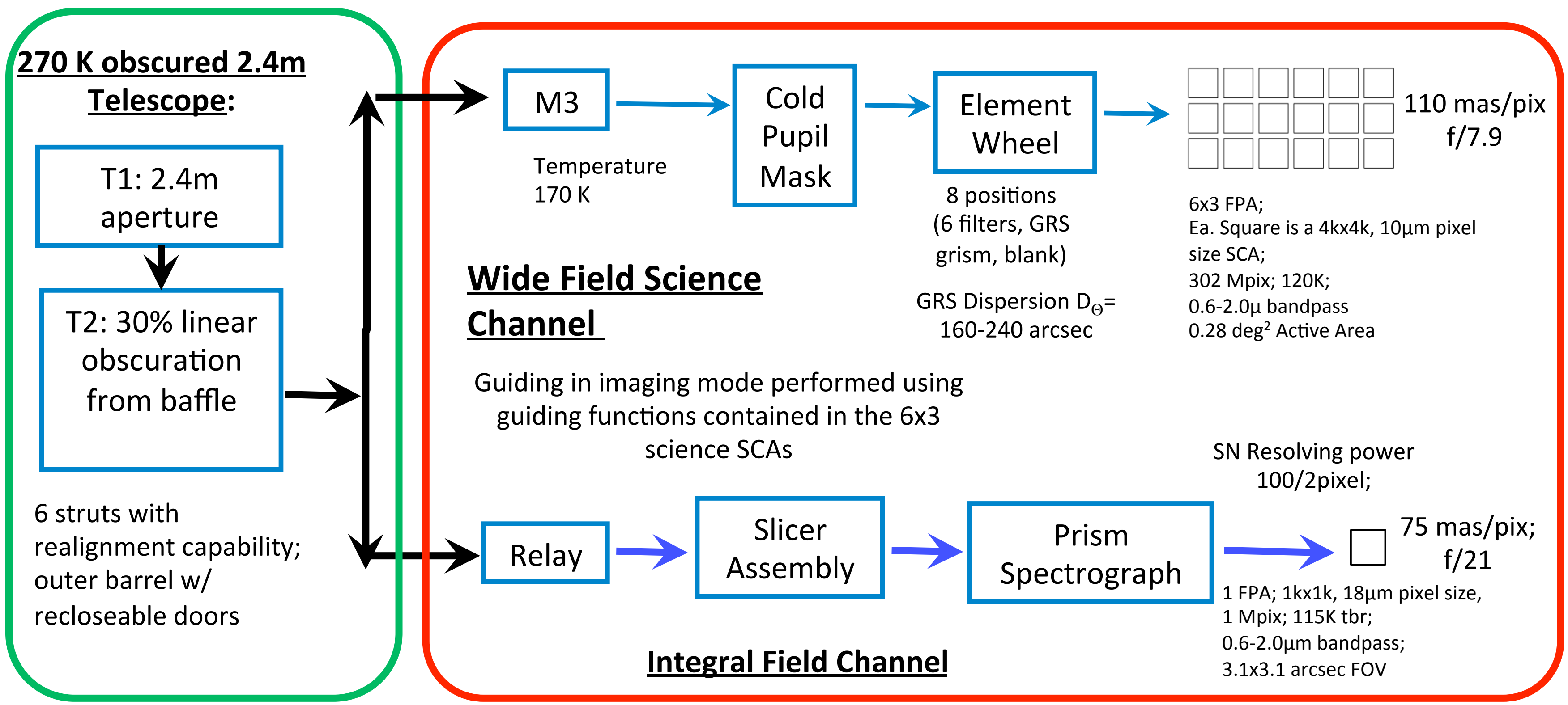
- Single wide field channel instrument
- 3 mirrors, 1 powered
- 18 4K x 4K HgCdTe detectors
- 0.11 arc-sec plate scale
- IFU for SNe spectra, single HgCdTe detector
- Single filter wheel
- Grism used for GRS survey
- Thermal control – passive radiator



AFTA Payload Block Diagram

Telescope

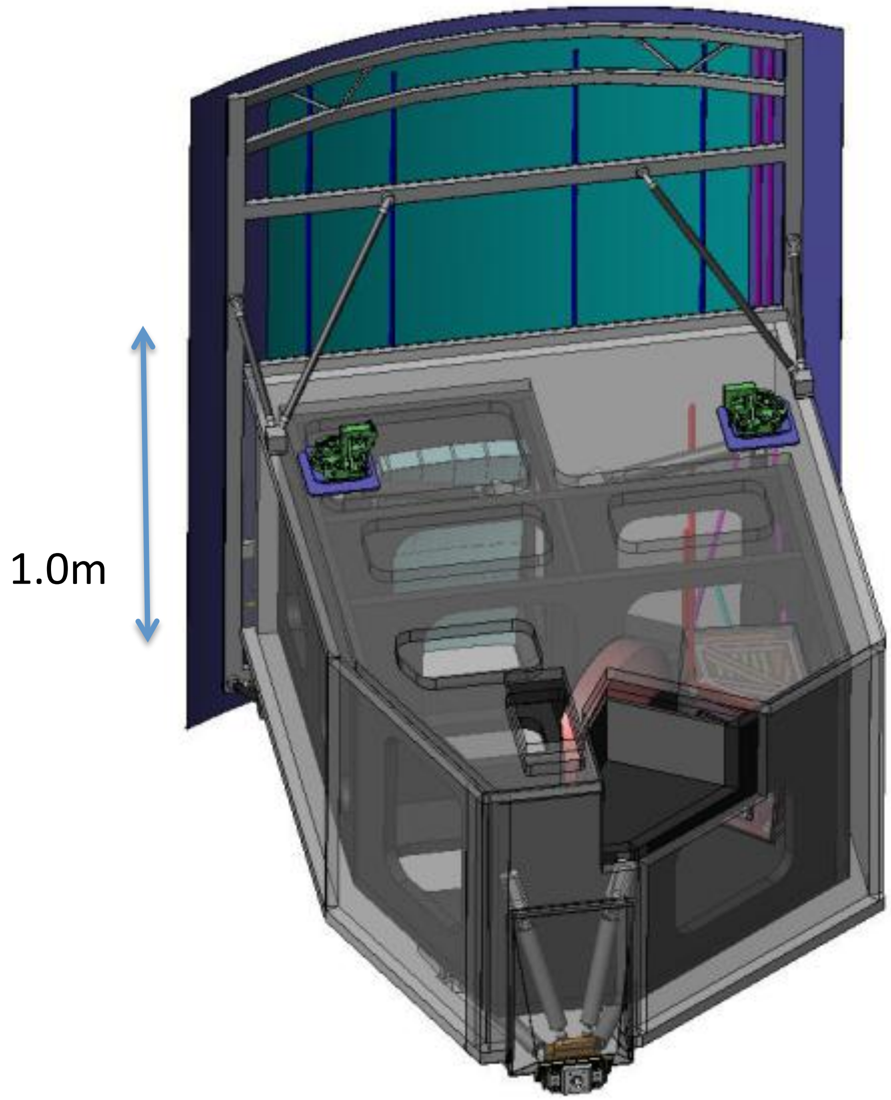
Wide Field Instrument



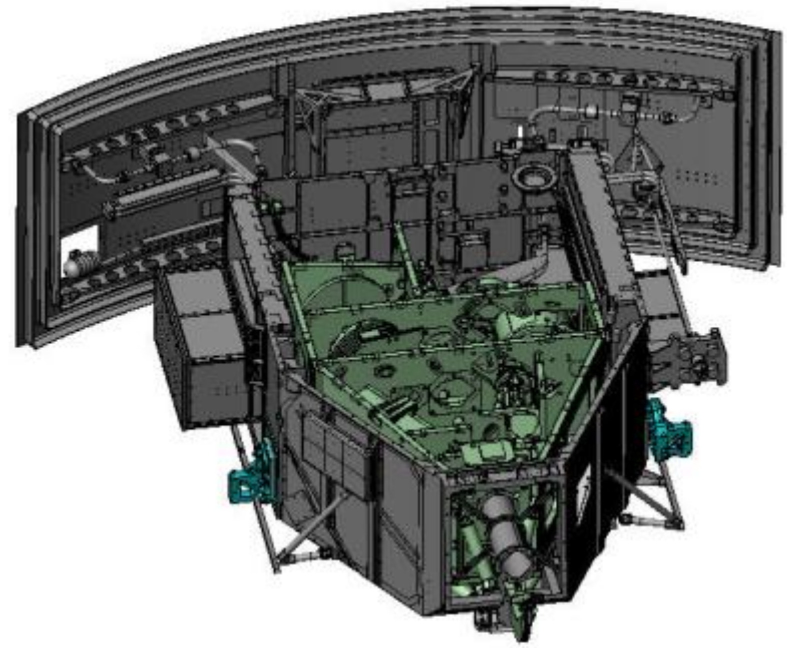
GRS = Galaxy Redshift Survey
SCA = Sensor Chip Assembly
SN = Type1a Supernovae

2 fold mirrors in WF channel and 3 TBR in IFC not shown

Wide field Instrument Shares Architecture and Heritage with HST/WFC3



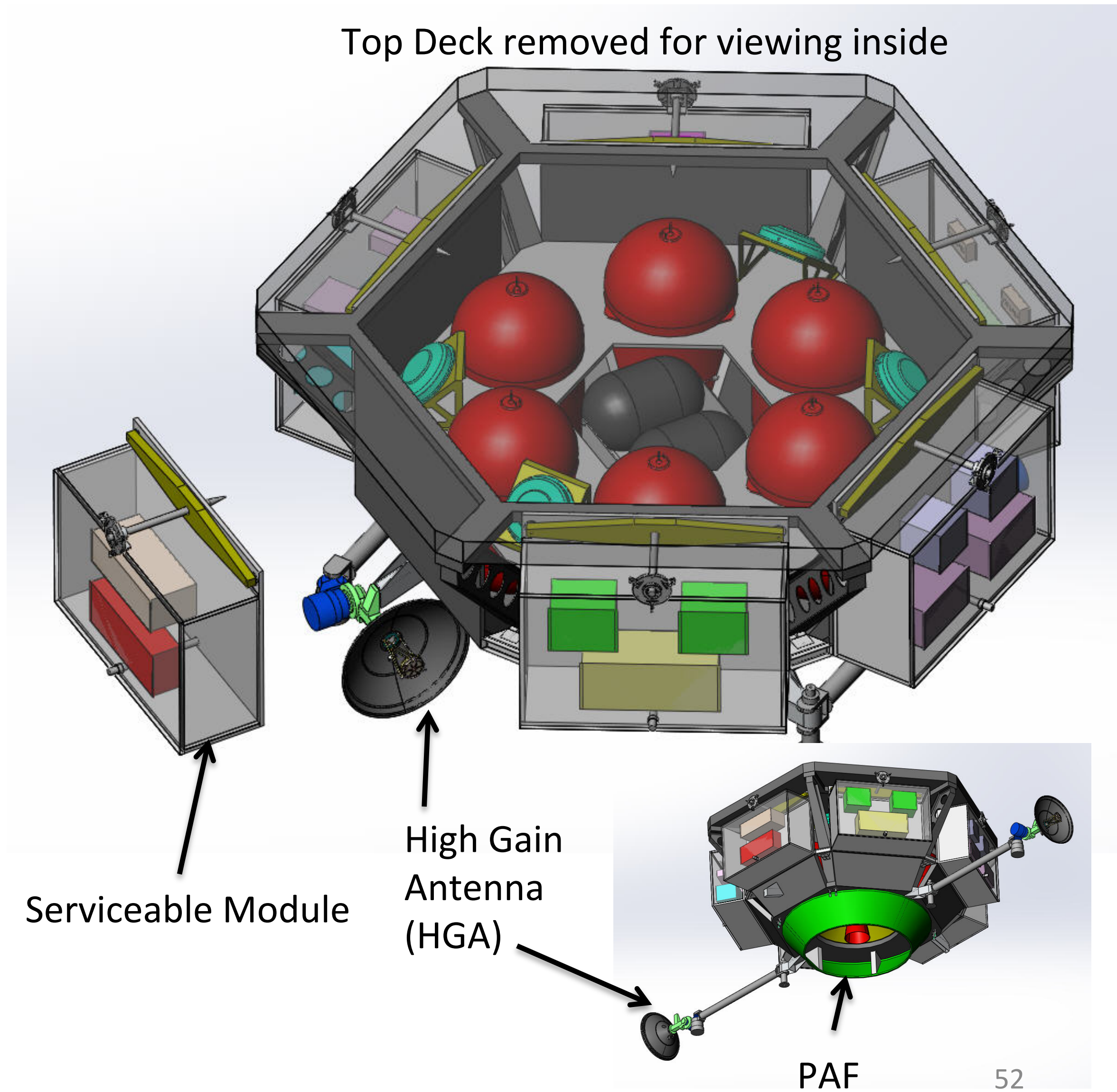
WFIRST wide field



HST/WFC3

Spacecraft Concept

- Spacecraft bus design relies on recent GSFC in-house spacecraft designs, primarily SDO and GPM
- 6 serviceable/removable modules
  - Power
  - Communications
  - C&DH
  - Attitude Control
  - Telescope Electronics
  - Wide Field Electronics
- Latch design reused from Multimission Modular Spacecraft (MMS)
- 2 deployable/restowable HGAs
- Atlas V 541 Payload Attach Fitting (PAF)
- 6 propellant tanks



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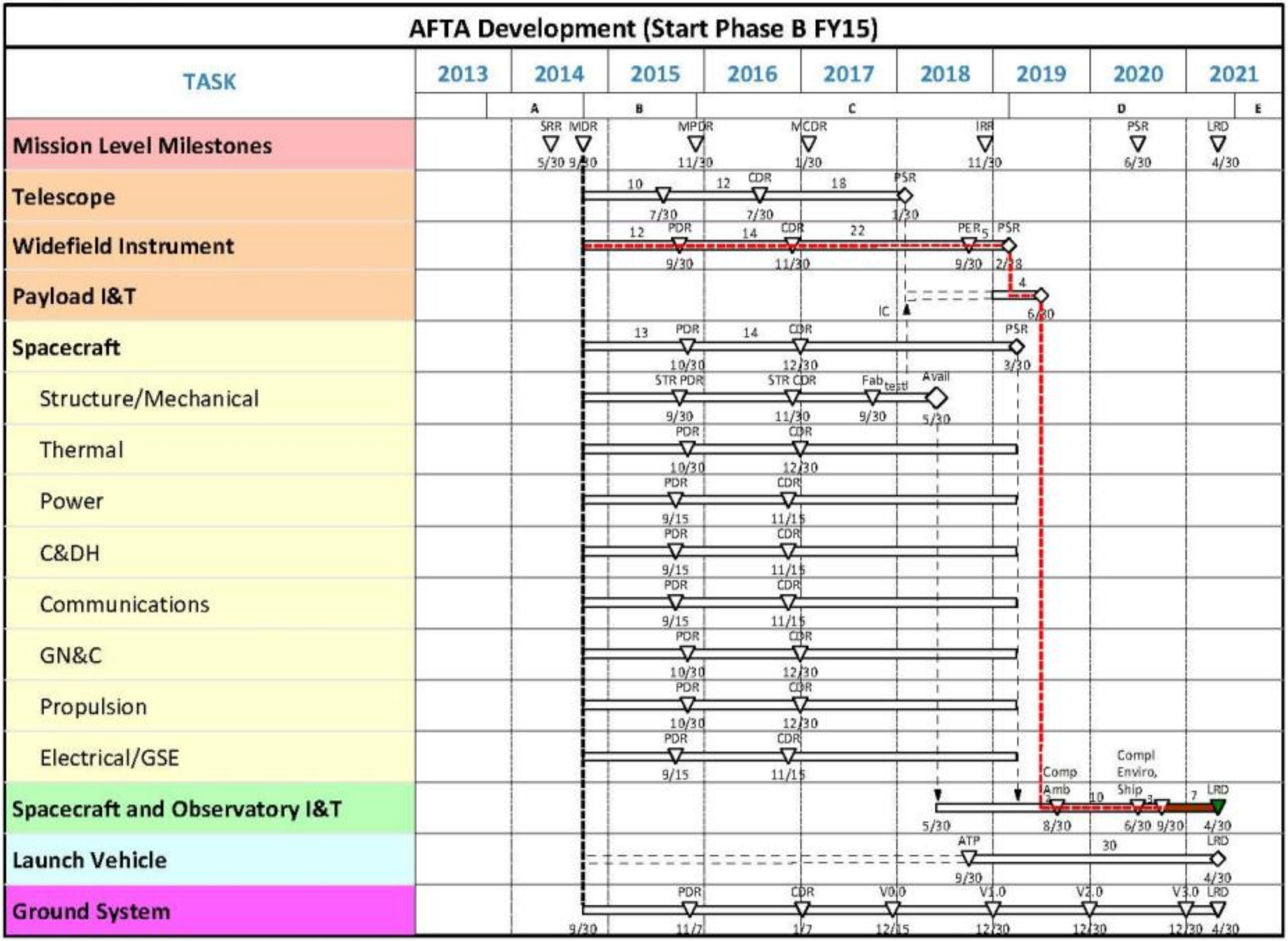
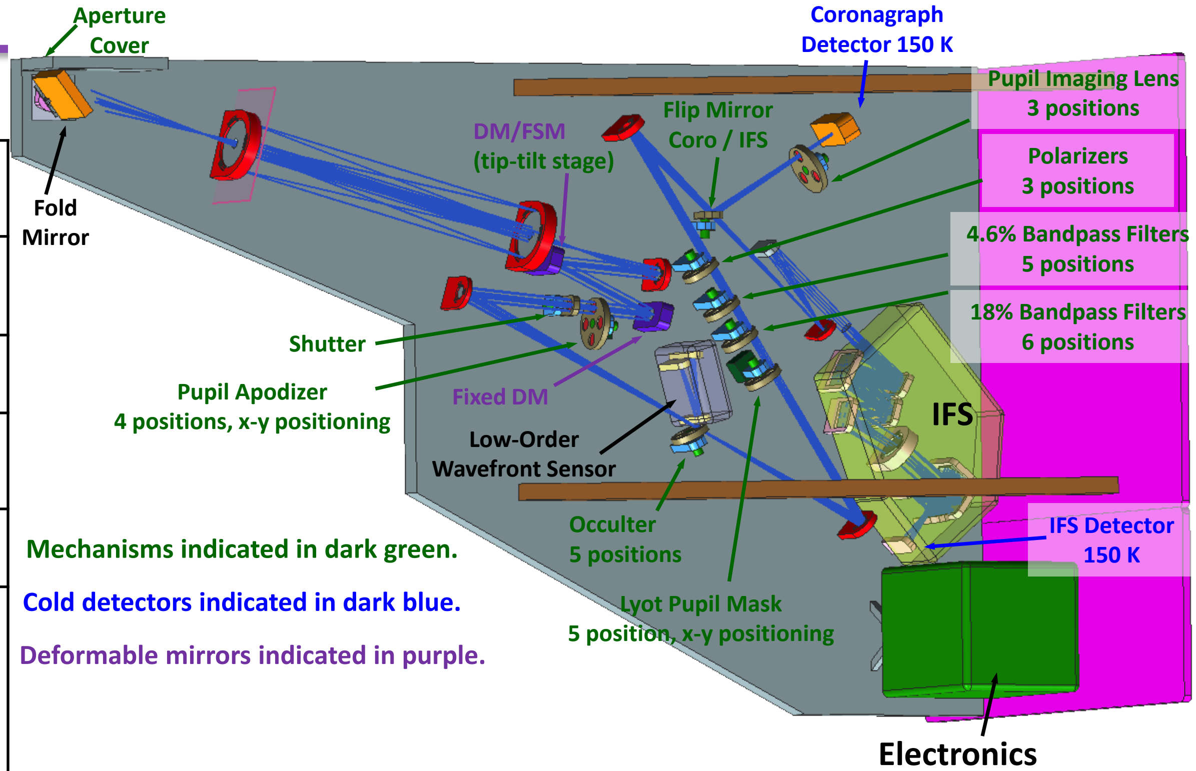


Critical Path

Coronagraph

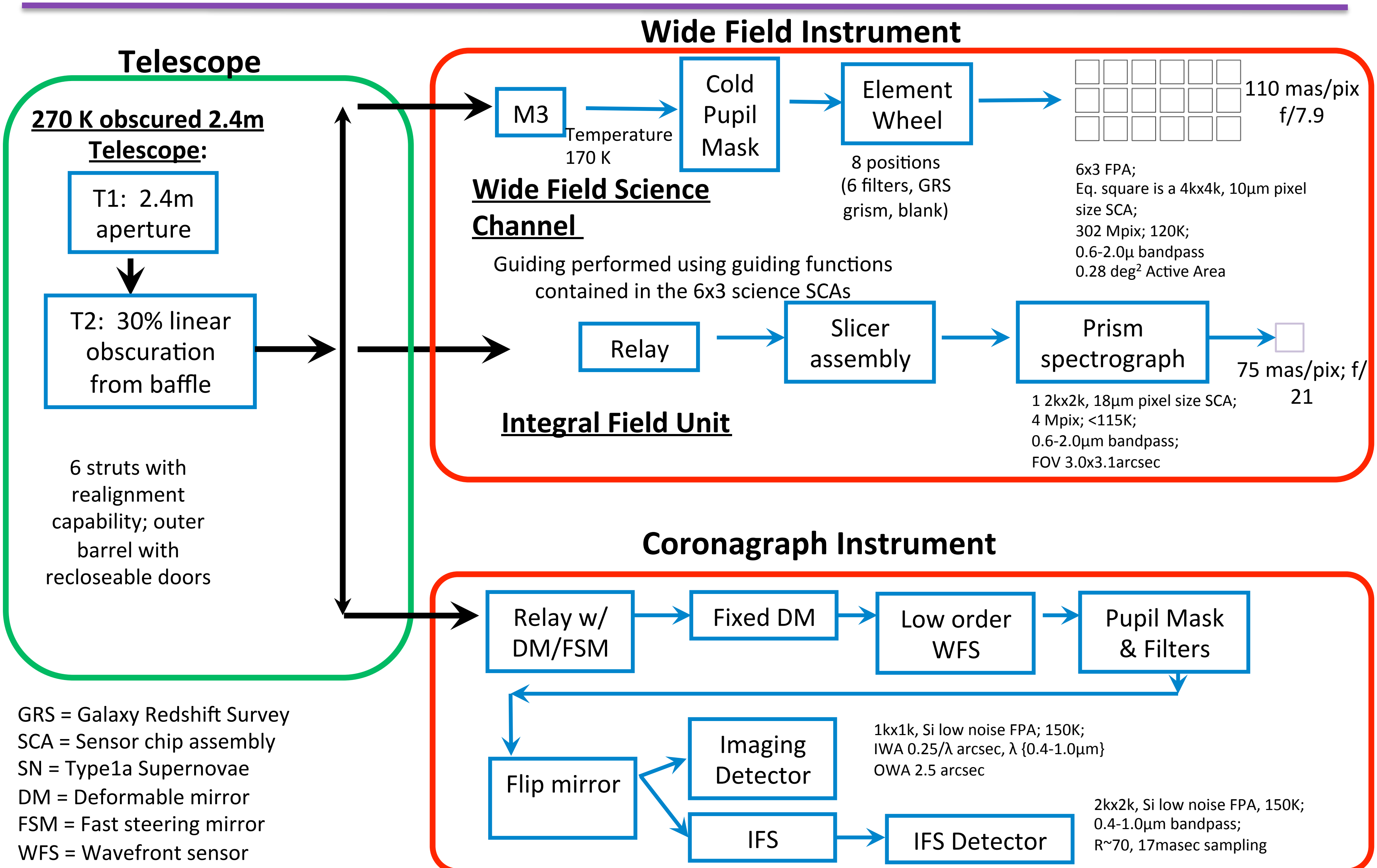
AFTA Coronagraph Concept

Bandpass	400-1000 nm	Measured sequentially in five 18% bands
Inner Working Angle	100 mas	at 400 nm, 3 λ/D driven by challenging pupil
	250 mas	at 1 μm
Outer Working Angle	1 arcsec	at 400 nm, limited by 64x64 DM
	2.5 arcsec	at 1 μm
Detection Limit	Contrast=10^{-9}	Cold Jupiters. Deeper contrast looks unlikely due to pupil shape and extreme stability requirements.
Spectral Resolution	70	With IFS
IFS Spatial Sampling	17 mas	This is Nyquist for λ = 400 nm



- **Representative coronagraph design shown for one of either a Shaped Pupil, Lyot, Vector Vortex coronagraph option for starlight suppression including polarizers.**
- **Design for PIAA coronagraph exists**
- **Future studies to narrow-down coronagraph to a single option**

AFTA Payload Block Diagram

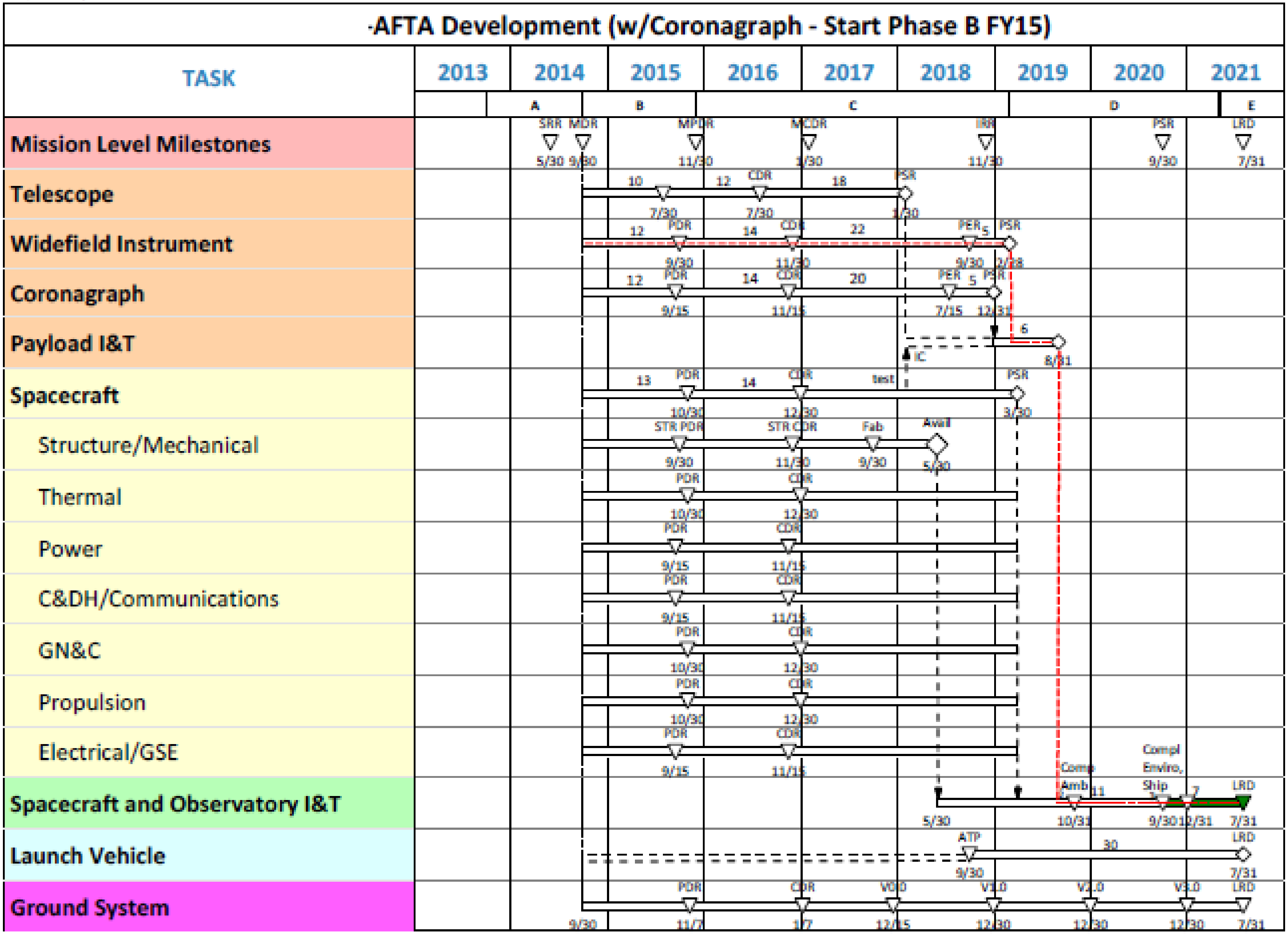


GRS = Galaxy Redshift Survey
SCA = Sensor chip assembly
SN = Type1a Supernovae
DM = Deformable mirror
FSM = Fast steering mirror
WFS = Wavefront sensor
IFS = Integral field spectrograph

Observatory Performance Required by Coronagraph

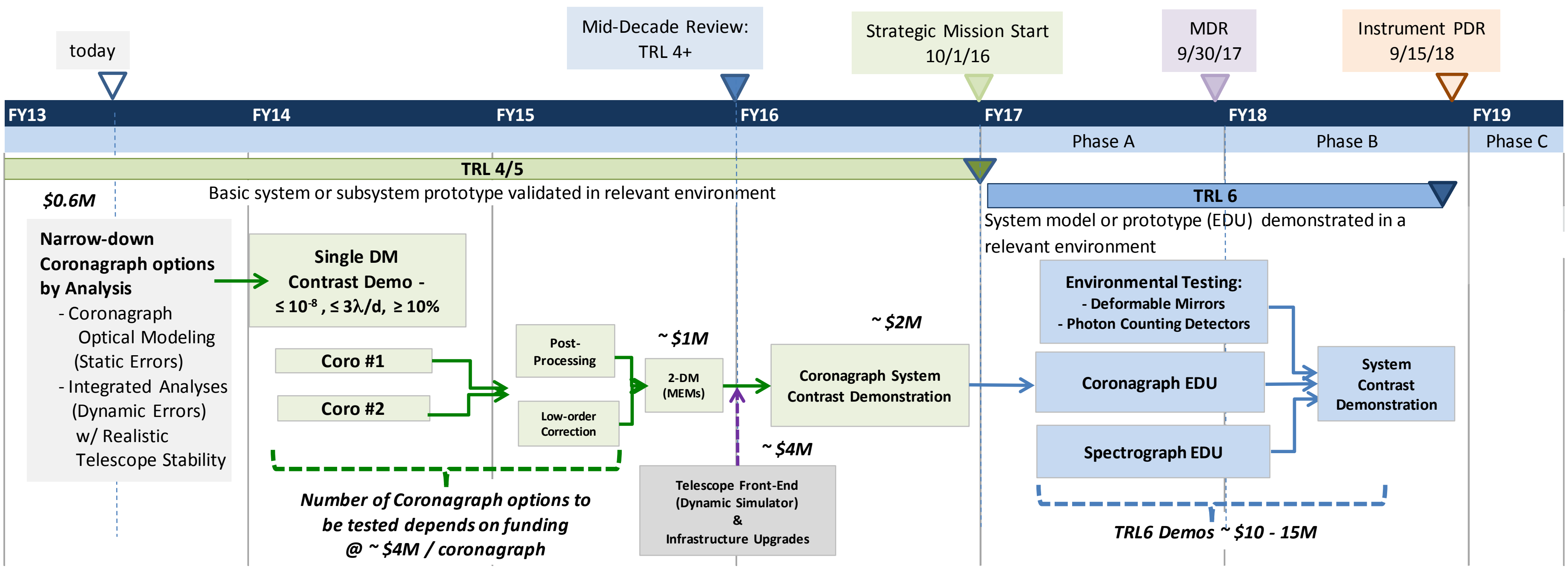
- Interfaces within existing WFIRST-AFTA baseline capabilities
  - 80W power (CBE)
  - View to space for radiators
  - 29 Gbits/day (CBE)
  - Standard 1553 and SpaceWire interfaces
- Preliminary estimates for observatory stability appear achievable:
  - ➢ requires more detailed observatory design and analyses
  - ➢ If necessary, accept graceful degradation of coronagraph performance
    - 10 mas (1 sigma) jitter is within the coronagraph wavefront/tip-tilt pointing control system capability
    - mK–level telescope thermal stability to be studied through observatory active thermal management system design
    - 0.5 µm dimensional stability between telescope and coronagraph with contributions coming from instrument carrier latch for servicing and overall thermal stability.

4/12 1:50pm



Critical Path

AFTA Coronagraph Technology Development Path to TRL 6 by PDR (2018)



- Technology builds upon successful coronagraph demonstrations in the ExEP High Contrast Imaging Testbed at AFTA contrast performance of 10^{-9} & >10% bandwidths
- AFTA implementation brings new challenges for centrally obscured pupil coronagraphs
- TRL 6 Tech demonstration requires AFTA-like system integration & telescope simulator
- **Mission Directed Coronagraph Technology Program must start now!**
  – FY13 activities not currently in plan. Tech development to be submitted as overguide for PY15 PPBE
  – Plan does not address how technologies will be funded: Competed TDEMs or Directed Technology

Approach to developing AFTA Coronagraph on Accelerated Schedule (PDR 7/15)

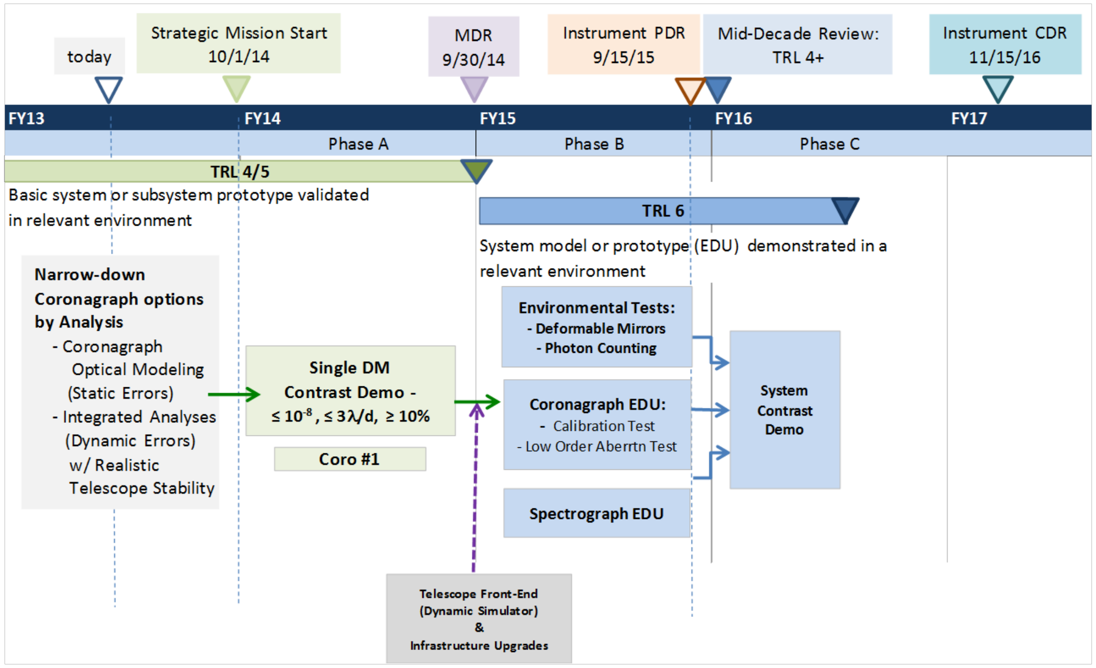
- Treat the AFTA Coronagraph primarily as a flight technology demonstration
  - Accept technical risk & graceful performance degradation:
    - At minimum, key components technologies will be brought to TRL 9 through flight: Deformable Mirrors, Detectors, Wavefront Sensing & Control, Instrument Pointing, Modeling
  - Perform science on a best effort basis w/ acceptable contrast ≤ 10^{-8} for Disk Science

- Adopt SMD Management Handbook standard #5.4.2.4 for Flight Technology Demos:

http://www.nasa.gov/pdf/484498main_SMD%20HANDBOOK%2008-FEB-2008%20.pdf

Unlike science focused missions, technology demonstration missions may have technologies developed below TRL 5 during Phase B but must have all technologies at least to TRL 5 by the Phase B-to-C transition point

- Pick a single coronagraph mask design immediately based on models & analyses
  - Fast track the contrast performance demonstration w/ single deformable mirror
  - System demonstration after PDR

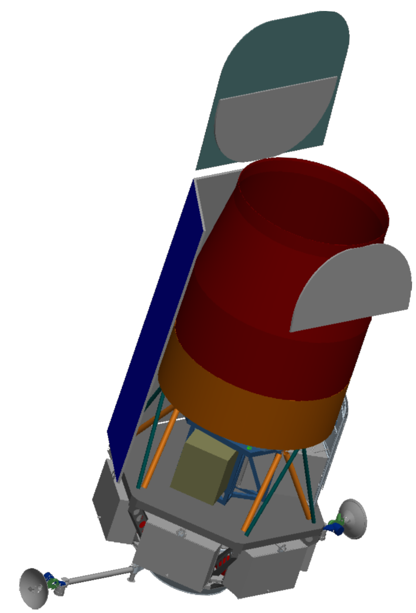


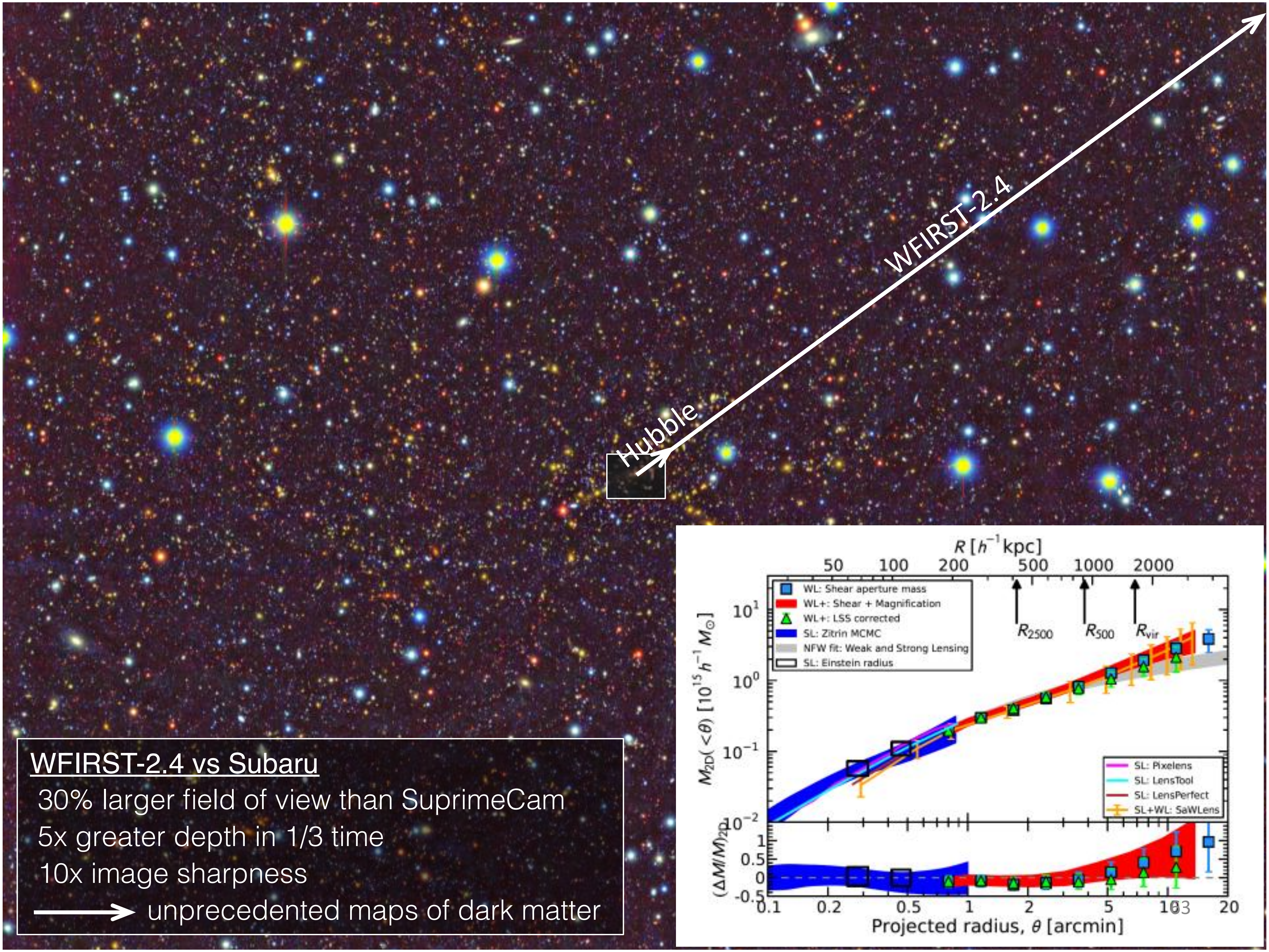
Back-up

“Discover how the universe works, explore how it began and evolved, and search for Earth-like planets”
NASA Strategic Plan (p. 14)

AFTA-2.4m

- Dark energy
  * Accelerating expansion of the universe
  * Growth of structure
- Exoplanet microlensing
- Exoplanet coronagraphy (optional)
- Galactic and extragalactic astronomy
- Guest Investigator & Observer program





WFIRST-2.4 vs Subaru

30% larger field of view than SuprimeCam

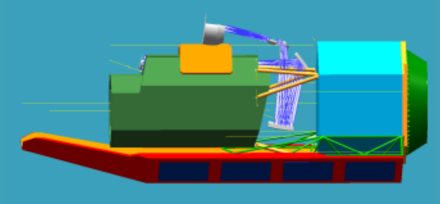
5x greater depth in 1/3 time

10x image sharpness

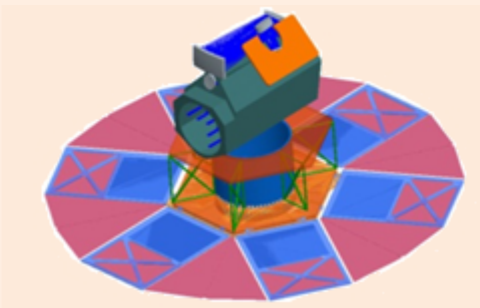
→ unprecedented maps of dark matter

Evolution of WFIRST Concepts to AFTA

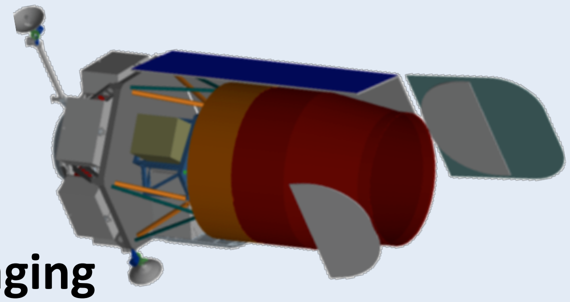
- **DRM1**
  - **1.3 meter off-axis telescope**
  - **150 Mpixels, 0.4 deg²**
  - **5 year mission (15% GO time)**



- **DRM2**
  - **1.1 meter off-axis telescope**
  - **234 Mpixels, 0.6 deg²**
  - **3 year mission (15% GO time)**



- **2.4m AFTA**
  - **2.4 meter on-axis telescope**
  - **288 Mpixels, 0.3 deg²**
  - **Additional IFU for SN slit spectroscopy**
  - **Additional coronagraph for exoplanet imaging**
  - **5 year mission (25% GO time)**

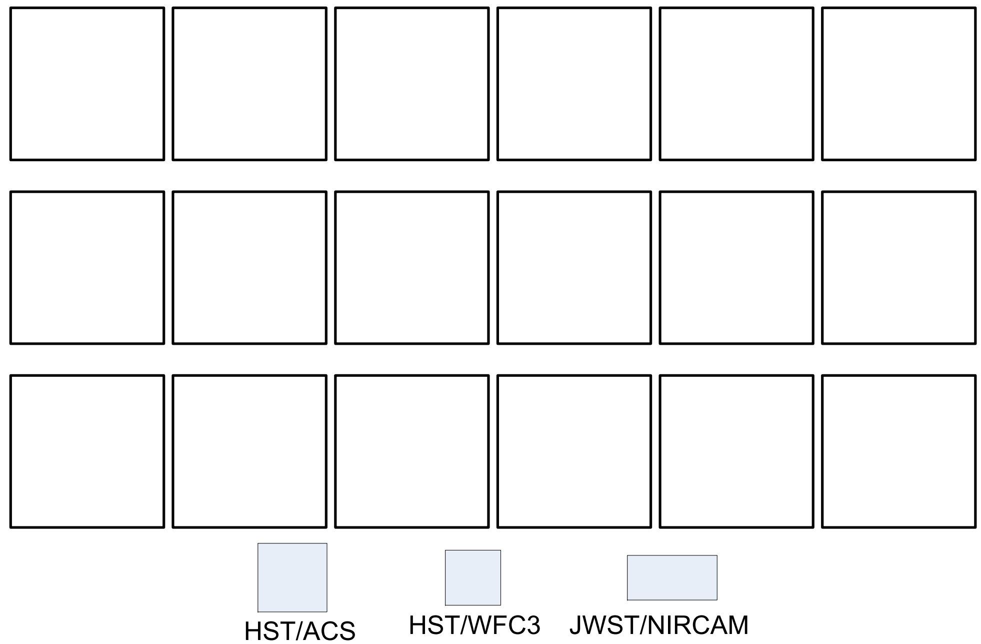


Detector Layout on Sky

18 NIR detectors

0.11 arcsec/pixel   0.28 deg^2

Moon (average size seen from Earth)



Each square is a H4RG-10

4k x 4k, 10 micron pitch

288 Mpixels total

Slitless spectroscopy with grism in filter wheel

R_θ ~ 100 arcsec/micron

AFTA can survey both deep and wide!

If early results suggest intriguing new insights into dark energy, AFTA is capable of doing even more dark energy science in extended operations by increasing sky coverage.