1. Introduction &
2. Assessing AFTA version of WFIRST against NWNH WFIRST

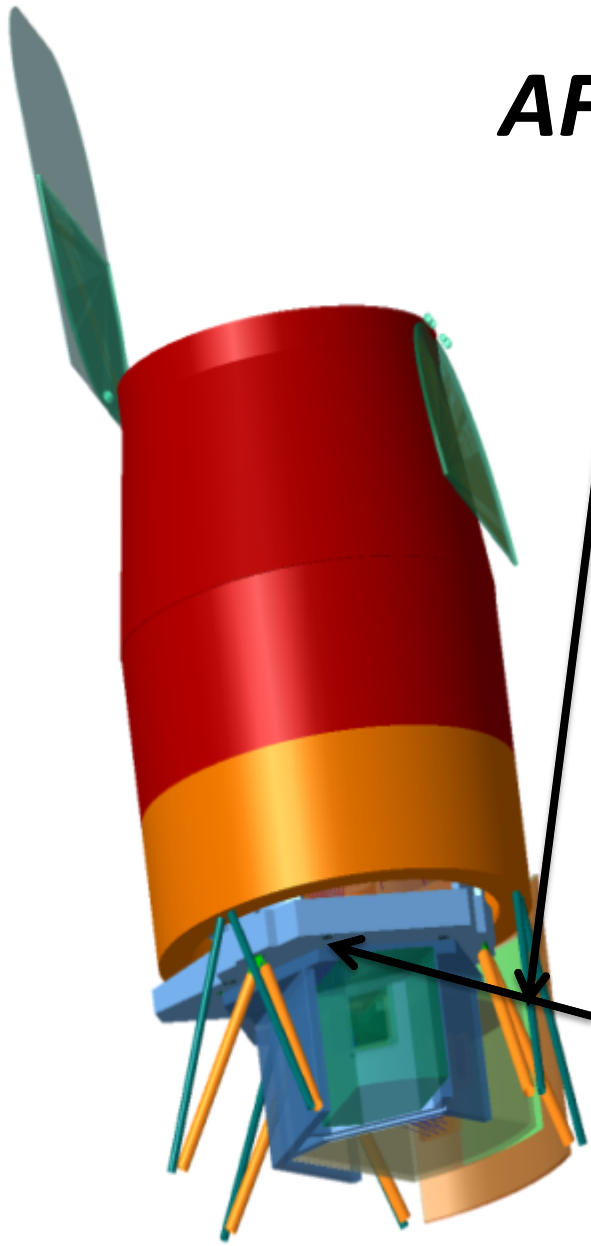
Neil Gehrels (GSFC)	AFTA SDT Co-Chair
David Spergel (Princeton)	AFTA SDT Co-Chair

NRC Committee to Assess AFTA Concept
January 12, 2014

Executive Summary

- AFTA with 2.4m mirror gives HST imaging over 1000's of square degrees in the NIR
- 1.8X deeper and 1.6X better PSF than NWNH WFIRST (IDRM)
- More complementary to Euclid & LSST than IDRM. More synergistic with JWST.
- Enables coronagraphy of giant planets and debris disks to address "new worlds" science of NWNH
- Faster & finer telescope opens new discovery areas and permits twice as much time for GO science
- Cost is 10% larger than NWNH WFIRST without coronagraph assuming Falcon 9 heavy launcher. Coronagraph adds an additional 17% cost, some of which is from different sources of funds.
- AFTA addresses changes in landscape since NWNH: Euclid selection & Kepler discoveries.
- Use of NRO telescope and addition of coronagraph have greatly increased the interest in WFIRST in government, scientific community and the public.

AFTA Instruments



Wide-Field Instrument

- *Imaging & spectroscopy over 1000s sq deg.*
- *Monitoring of SN and microlensing fields*
- 0.7 – 2.0 (2.4) micron bandpass
- 0.28 sq deg FoV (100x JWST FoV)
- 18 H4RG detectors (288 Mpixels)
- 4 filter imaging, grism + IFU spectroscopy

Coronagraph

- *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

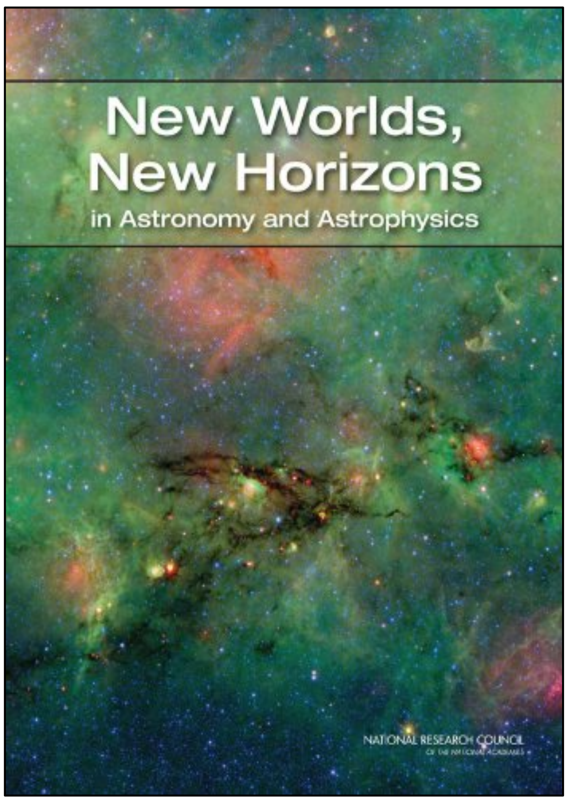
AFTA is perfect match for *many aspects of NWNH*

Frequently discussed

#1 Large-Scale Priority - Dark Energy, Exoplanets

#1 Medium-Scale Priority - New Worlds Tech. Development (prepare for 2020's planet imaging mission)

But, AFTA provides improvement over IDRM in many other areas….



5 Discovery Science Areas

ID & Characterize Nearby Habitable Exoplanets
Time-Domain Astronomy
Astrometry
Epoch of Reionization
Gravitational Wave Astrometry

20 Key Science Questions

Origins (7 key areas)
Understanding the Cosmic Order (10 key areas)
Frontiers of Knowledge (4 key areas)

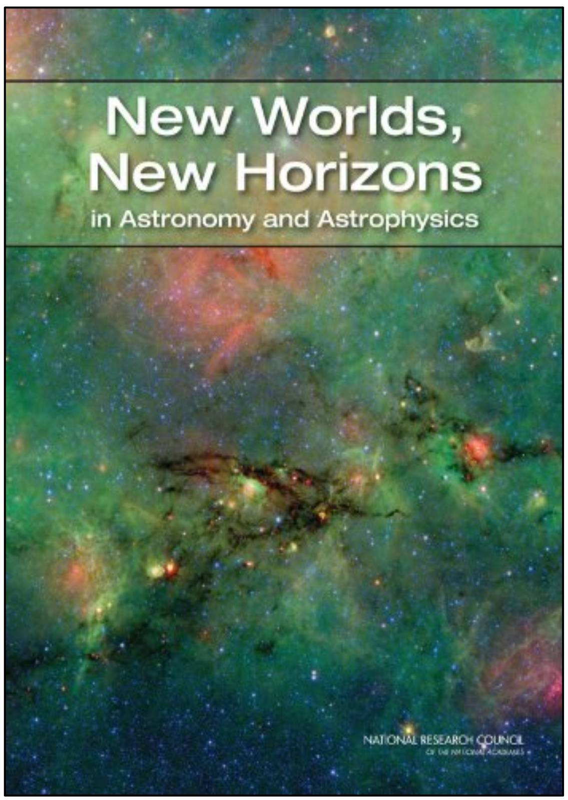
AFTA is perfect match for *many aspects of NWNH*

Frequently discussed

#1 Large-Scale Priority - Dark Energy, Exoplanets

#1 Medium-Scale Priority - New Worlds Tech. Development
(prepare for 2020's planet imaging mission)

But, AFTA provides improvement over IDRM in many other areas….



5 Discovery Science Areas

- ID & Characterize Nearby Habitable Exoplanets ✔
- Time-Domain Astronomy ✔
- Astrometry ✔
- Epoch of Reionization ✔
- Gravitational Wave Astrometry

20 Key Science Questions

- Origins **(7/7 key areas)**
- Understanding the Cosmic Order **(6/10 key areas)**
- Frontiers of Knowledge **(3/4 key areas)**

See Table in the AFTA SDT report (p 8 -10) for specific gains over IDRM

AFTA has a more robust GO program than IDRM

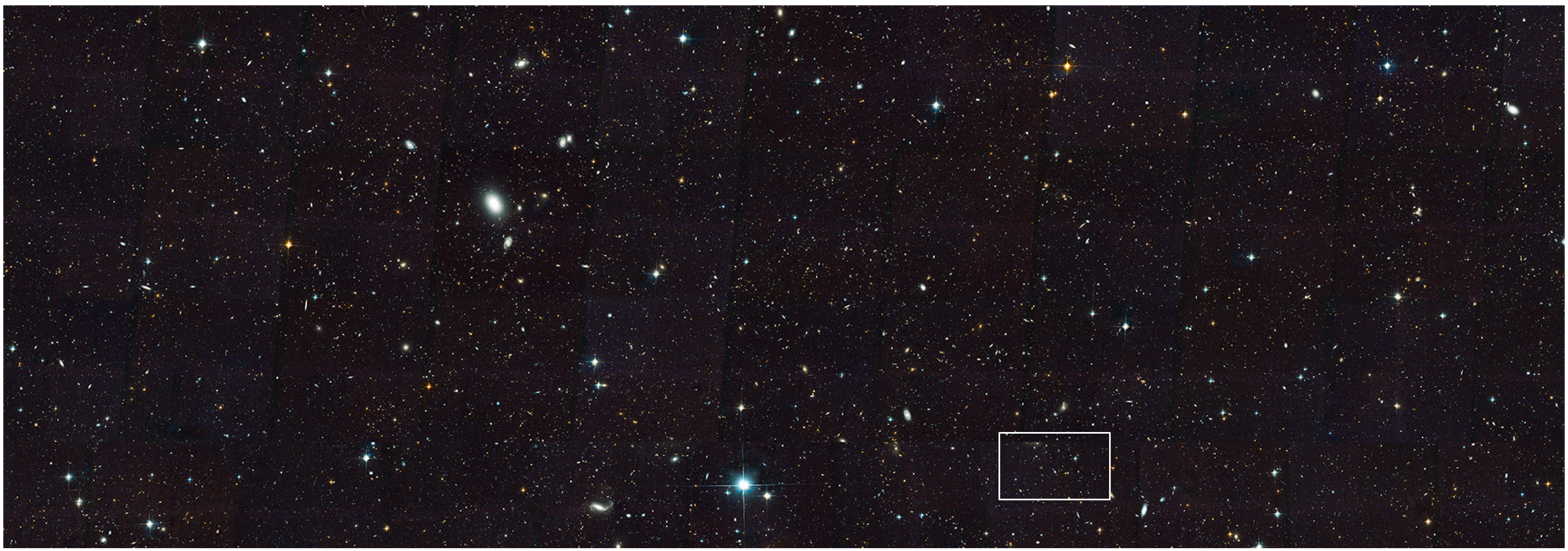
Peer-Review and Competed Guest Observer Program
Establishes broad community engagement
Tackles diverse set of astrophysical questions in changing paradigms
Maximizes synergies with JWST and other future telescopes
Open competition inspires creativity
Ensures long-term scientific discovery potential

25% of AFTA is a Guest Observer Program

(2.5x Larger than IDRM)

AFTA vs Hubble

Hubble Ultra Deep Field - IR
~5,000 galaxies in one image



WFIRST2.4 Deep Field
>1,000,000 galaxies in each image

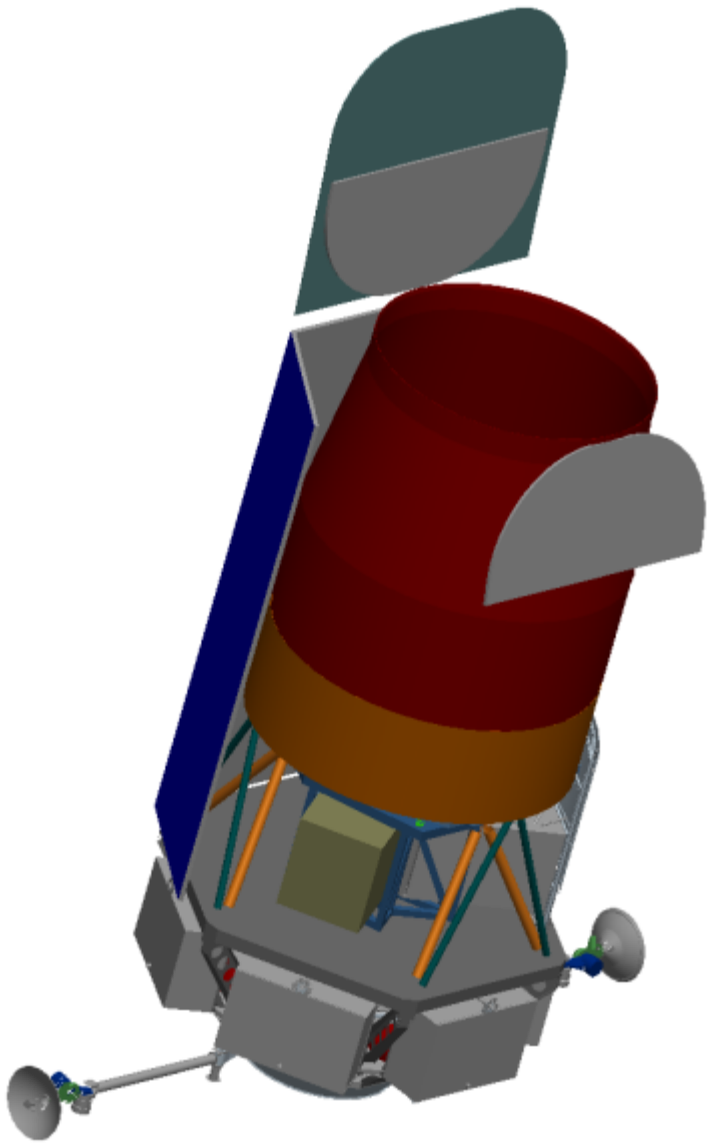
AFTA vs Hubble GO Program

Hubble
Hubble/WFC3-IR is 25% of all observations
Hubble/WFC3-IR data led to 2 publications per week in 2013

AFTA
AFTA is 200x faster than Hubble WFC3/IR
AFTA has higher resolution than Hubble WFC3/IR
AFTA has higher efficiency than Hubble (i.e., on-source time)
→ Assume a conservative factor of 5 gain in science productivity

Assuming a conservative factor of 5 gain in science productivity
→ AFTA could yield **~500 scientific papers per year** from its GO mode

AFTA Observatory Concept



<u>Key Features</u>

- 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

Instrument Comparisons

Feature	IDRM	AFTA
Mirror Diameter	1.3 m	2.4 m
Imager		
Area on Sky	0.29 sq deg	0.28 sq deg
Plate Scale	0.18”/pix	0.11”/pix
Wavelength	0.6 – 2.0 μ	0.6 – 2.0 (2.4) μ
Spectrometer	Slitless Grism	Slitless Grism & IFU
Coronagraph	no	yes

PSF-3: How diverse are planetary systems?

Discovery and characterization of nearby planets and disks

NWNH/IDRM	AFTA	AFTA + Coronagraph
No capability for nearby planet or disk discovery, but an important science goal of NWNW – the New Worlds component	No capability	• Survey 100-200 nearby stars for giant to sub-Neptune planets and low surface brightness (~100 zodi or less) circumstellar disks → Significantly extends understanding of planetary systems of nearby stars from HZs to 10s of AU. → Provides insight into their formation and evolution (planet ranges, locations, dust) → Identifies good and poor candidates for followup terrestrial planet imaging missions
No capability for nearby planet characterization, but an important science goal of NWNW – the New Worlds component	No capability	• Spectrally characterize reflected light from ~10 nearby giant planets including ones with known masses (from RV) → Investigate composition / abundances to understand their formation with little ambiguity (known masses, validated SS techniques) → Samples much more of the atmosphere than transit spectroscopy → Targets inaccessible via ground-based AO

PSF-3: How diverse are planetary systems?
PSF-4: Do habitable worlds exist around other stars

Census via microlensing of planets in galactic bulge

NWNH/IDRM	AFTA	AFTA + Coronagraph
Planetary systems M/M_Earth = 1 → Unique census of >1 AU exoplanets Yield = 200	Planetary systems M/M_Earth = 1 → Unique census of >1 AU exoplanets Yield = 301	Same as with no coronagraph
Planetary systems M/M_Earth = 1000 → Unique census of >1 AU exoplanets Yield = 299	Planetary systems M/M_Earth = 1000 → Unique census of >1 AU exoplanets Yield = 460	Same as with no coronagraph
Free floating planets M/M_Earth = 1 Yield = 23	Free floating planets M/M_Earth = 1 Yield = 41	

SSE-D Time Domain Surveys
GAN-D1 Time Domain Astronomy

Transient sources (rare SNe, GW mergers, GRBs, radio transients)

NWNH/IDRM	AFTA	AFTA + Coronagraph
Follow-up on 2 days times J = 26	Follow-up on hour times Constant contact in GEO → **Tremendous capability for rapid transients.** J = 27	Same as with no coronagraph
Discovery of transients and variable in SNe and microlensing repeated fields J = 26 5 day timescales	Discovery of transients and variable in SNe and microlensing repeated fields J = 27 5 day timescales	Same as with no coronagraph

GAN-4 What are the connections between dark and luminous matter?

Large-scale imaging surveys

NWNH/IDRM	AFTA	AFTA + Coronagraph
??	HST imaging over 2000 sq degree → COSMOS galaxy survey x 1000 → CLASH cluster survey x 100 The bias between dark and luminous matter in the redshift range (0<z<2)will be revealed over 2000f square degrees with AFTA.	Same as with no coronagraph
??	Dark matter will be studied by surveying the dwarf galaxy population around neighboring galaxies – look for “missing halos.” Strongly dependent on PSF, so substantially better than IDRM	Same as with no coronagraph

GAN-4 What are the connections between dark and luminous matter?

Large-scale weak lensing survey

NWNH/IDRM	AFTA	AFTA + Coronagraph
WL survey over 2000 sq deg with n_eff ~ 30 and pixel size 0.18"	WL survey over 2000 sq deg with n_eff >70 and pixel size 0.11" → Factor of 2-3 times higher surface density enables new science via dark matter mapping → Fundamentally different WL regime that is not possible from the ground due to seeing or with a 1.3 meter class space telescope due to PSF size, regardless of survey depth → Mass resolution of dark matter maps scales with n_eff → AFTA enables the study of detailed dark matter and baryonic matter distributions in individual systems in statistically significant numbers.	Same as with no coronagraph

GCT-1 How do cosmic structures form and evolve?

Survey the local dark matter distribution

NWNH/IDRM	AFTA	AFTA + Coronagraph
Chart the process of reionization: find proto-galaxies 6 < z < 10 with Lyman-break technique to maximum depth **(AB=29)** over tens of square degrees. The apparent large-scale structure is dominated by distribution of HI opacity and shows location of ionizing sources. Map the emergence of the "cosmic web" at z ~ 6, just after reionization has been completed. Deep (AB=29) and wide (tens of sq deg) multiband imaging. Unique to WFIRST-type facility	Chart process of reionization: find proto-galaxies 6 < z < 10 with Lyman-break technique to maximum depth **(AB=30)** over tens of sq deg. The large-scale structure is dominated by distribution of HI opacity and shows location of ionizing sources. → Extra depth pushes AFTA into much more frontier territory than IDRM. Map the emergence of the "cosmic web" at z ~ 6, just after reionization has been completed. Deep (AB=29) and wide (tens of sq deg) multiband imaging. Unique to WFIRST-type facility → Depth and breath similar to IDRM but at 3x the speed.	Same as with no coronagraph

GCT-1 How do cosmic structures form and evolve?

Measure structure at cluster scales

NWNH/IDRM	AFTA	AFTA + Coronagraph
Sample of several thousand clusters in AFTA HLS will measure the cluster mass function as a function of redshift. Strong and independent test of cosmology and structure formation models. Best sensitivity at 0.7 < z < 1.6. NIR survey optimal for this redshift range.	Sample of several thousand clusters in AFTA HLS will measure the cluster mass function as a function of redshift. Strong and independent test of cosmology and structure formation models. Best sensitivity at 0.7 < z < 1.6. NIR survey optimal for this redshift range. → Depth increase over IDRM yields >3x improvement in WL+SL mass estimate accuracy	Same as with no coronagraph

GCT-1 How do cosmic structures form and evolve?

Measure structure at galaxy scales

NWNH/IDRM	AFTA	AFTA + Coronagraph
IDRM survey will discover hundreds of z > 8 galaxies and, potentially, and tens of highly magnified z ~ 10 galaxies that would be within reach of EELT and JWST spectrographs.	AFTA survey will discover thousands of z > 8 galaxies and, potentially, tens to hundreds of highly magnified z ~ 10 galaxies that would be within reach of EELT and JWST spectrographs. → Increased resolution and depth over IDRM yields up to 20x more objects detected at z > 8 and at least 2x more detected objects at z > 12. → Provides unparalleled constraints on early star formation history and on the sources of re-ionization. Space density of such high-z galaxies also provides an independent constraint on the mass of WDM particle.	Same as with no coronagraph

CFP-2 Why is the universe accelerating?

TBD

NWNH/IDRM	AFTA	AFTA + Coronagraph
TBD	TBD	Same as with no coronagraph

From SDT Report – April 30, 2013

DISCOVERY SCIENCE

	Key Observation	Improvement over DRM1	Section
Identification and characterization of nearby habitable exoplanets	Characterize tens of Jupiter-like planets around nearby stars. Potential to detect Earth-like planets around nearest stars	**Coronagraph**	2.5.2 A-6, A-8
Gravitational wave astronomy	Detect optical counterparts	*Ability to detect fainter sources*	A-52
Time-domain astronomy	Repeated observations	*3x more sensitive, well matched to LSST*	A-48
Astrometry	Measure star positions and motions	*Achieve same level of accuracy 9x faster*	2.3.3 A-6, A-17, A-18 A-19, A-22, A-23 A-24, A-25, A-26
The epoch of reionization	Detect early galaxies for follow-up by JWST, ALMA, and next generation ground-based telescopes	***~10x increase in JWST targets***	**2.3.1** A-40, A-44, A-45 A-46, **B-4**

ORIGINS

	Key Observation	Improvement over DRM1	Section
What were the first objects to light up the universe, and when did they do it?	Detect early galaxies and quasars for follow-up by JWST, ALMA, and next generation ground-based telescopes	***~10x increase in high z JWST target galaxies*** ***Very high-z supernova***	**2.3.1** A-43, A-45, A-46 **B-5**
How do cosmic structures form and evolve?	Trace evolution of galaxy properties	*1.9x sharper galaxy images*	A-31, A-32, A-39 A-47, **B-13**
What are the connections between dark and luminous matter?	High resolution 2000 sq. deg map of dark matter distribution and still higher resolution maps in selected fields Dark Matter distribution in dwarfs to rich clusters	*Double the number density of lensed galaxies per unit area.* *Capable of observing 200-300 lensed galaxies/arcmin^2* *Astrometry of stars in nearby dwarfs*	A-25, A-26, A-33 A-35, A-36, A-37 A-38, A-50
What is the fossil record of galaxy assembly from the first stars to the present?	Map the motions and properties of stars in the Milky Way + its neighbors Find faint dwarfs	*3x increase in photometric sensitivity + 9x increase in astrometric speed* *JWST follow-up*	A-21, A-22, A-25 A-26, A-27, A-28 A-29, A-30, **B-19**
How do stars form?	Survey stellar populations across wide range of luminosities, ages and environments	**IFU spectroscopy** *3x more sensitive + 1.9x sharper galaxy images*	A-11, A-12, A-13 A-14, A-15, A-16 A-47, **B-8, B-11**
How do circumstellar disks evolve and form planetary systems?	Image debris disks	**Coronagraph**	2.5.2

ORIGINS cont.

How did the universe begin?	Measure the shape of the galaxy power spectrum at high precision; test for signatures of non-Gaussianity and stochastic bias	*Higher space density of galaxy tracers; higher space density of lensed galaxies*	2.2

UNDERSTANDING THE COSMIC ORDER

	Key Observation	Improvement over DRM1	Section
How do baryons cycle in and out of galaxies, and what do they do while they are there?	Discover the most extreme star forming galaxies and quasars		2.3.4
What are the flows of matter and energy in the circum-galactic medium?			
What controls the mass-energy-chemical cycles within galaxies?	Study effects of black holes on environment	**IFU Spectroscopy**	A-34
How do black holes grow, radiate, and influence their surroundings?	Identify and characterize quasars and AGNs, black hole hosts Use strong lensing to probe black hole disk structure	*Excellent match to LSST sensitivity* *1.9x sharper images*	A-41, A-43, A-48
How do rotation and magnetic fields affect stars?			

UNDERSTANDING THE COSMIC ORDER cont.

How do the lives of massive stars end?	Microlensing census of black holes in the Milky Way		A-18
What are the progenitors of Type Ia supernovae and how do they explode?	Study supernova Ia across cosmic time Detect SN progenitors in near-by galaxies	**IFU Spectroscopy**	**B-7**
How diverse are planetary systems?	Detect 3000 cold exoplanets and complete the census of ex-oplanetary systems throughout the Galaxy.	*60% increase in the number of Earth size and smaller planets detected by microlensing, im-proved characterization of the planetary systems*	2.5.1, 2.5.2.3 A-6, A-7, A-8 **B-15, B-17**

Backup

- GSFC and JPL working together
- cost of coronagraph partly from NASA technology funds (SMD & STMD)
- IFU added for multi-object spectroscopy
- Red limit (NWNH 2 microns, AFTA study to 2.2 or 2.4 microns)
- Rodger Thompson & Grindlay SALSOs
- History slide
- What has changed since NWNH – Euclid selection. AFTA is more complementary to Euclid than WFIRST was. Kepler discoveries.
- GO program