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

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NRC Committee to Assess AFTA Concept
January 12, 2014

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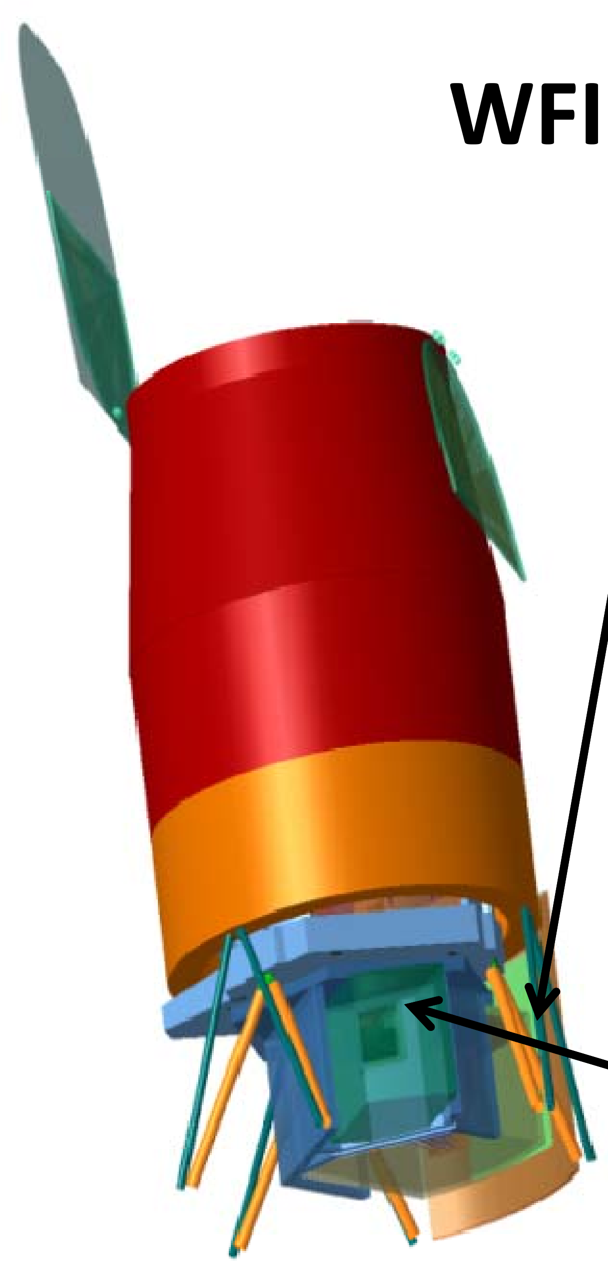
Executive Summary

- WFIRST-AFTA gives HST imaging over 1000's of square degrees in the NIR
- 2.5x deeper and 1.6x better PSF than 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
- Fine angular resolution and high sensitivity open new discovery areas to the community. More GO science time (25%) than for IDRM.
- CATE cost is 8% larger than WFIRST IDRM (19% with launch vehicle risk). Coronagraph adds an additional 13% cost, but also addresses another NWNH recommendation.
- WFIRST-AFTA addresses changes in landscape since NWNH: Euclid selection & Kepler discovery that 1-4 Earth radii planets are common.
- Use of NRO telescope and addition of coronagraph have greatly increased the interest in WFIRST in government, scientific community and the public.
- Growing international interest. SDT members from Canada, ESA and Japan. Potential partners may reduce cost (or enhance science).

* IDRM = 2011 WFIRST mission design to match NWNH

WFIRST-AFTA Instruments



Wide-Field Instrument

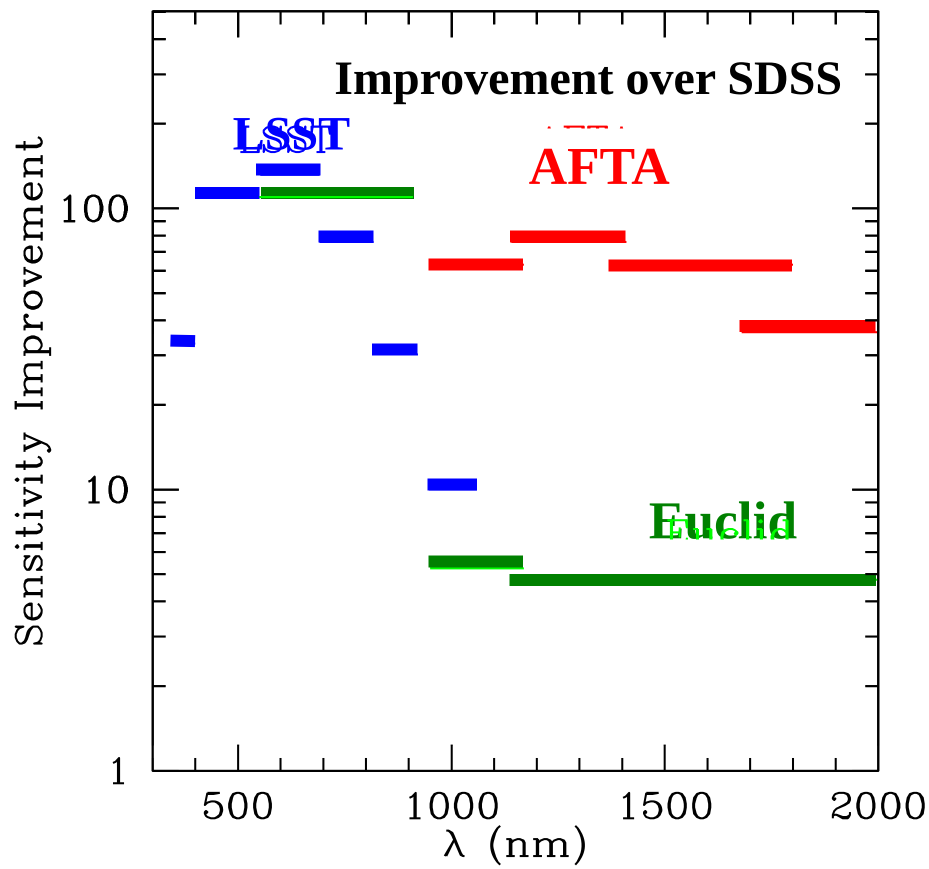
- *Imaging & spectroscopy over 1000s sq deg.*
- *Monitoring of SN and microlensing fields*
- 0.7 – 2.0 (2.4) micron bandpass
- 0.28 sq deg FoV (100x JWST FoV)
- 18 H4RG detectors (288 Mpixels)
- 4 filter imaging, grism + IFU spectroscopy

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

WFIRST-AFTA Surveys

- Multiple surveys:
  - High Latitude Survey
    - Imaging, spectroscopy, supernova follow
  - Repeated Observations of Bulge Fields
  - Guest Observer Program
  - Coronagraph Observations
- Flexibility to choose optimal approach



High Latitude Survey is 2.5x fainter and 1.6x sharper than IDRM

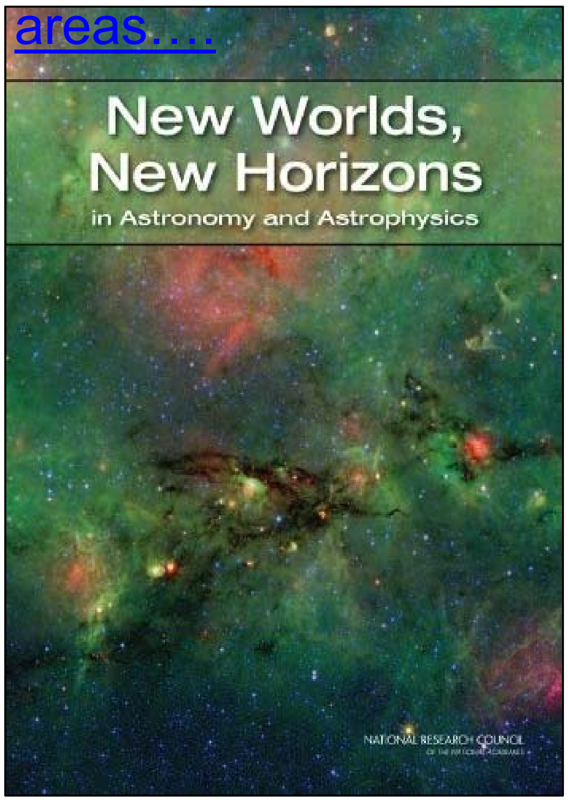
WFIRST-AFTA is perfect match for *many aspects of NWNH*

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, WFIRST-AFTA provides improvement over IDRM in many others areas….



5 Discovery Science Areas

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

20 Key Science Questions

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

WFIRST-AFTA is perfect match for *many aspects of NWNH*

Frequently discussed

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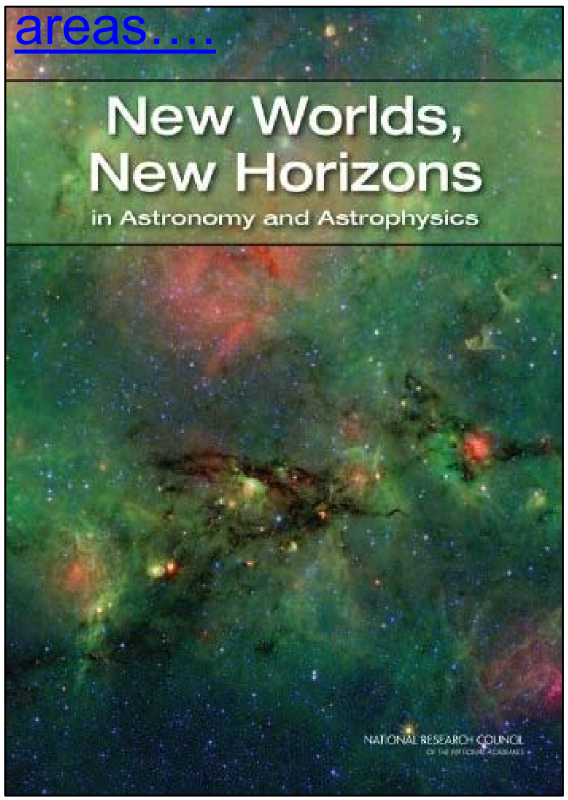


5 Discovery Science Areas

- ID & Characterize Habitable Exoplanets ✔ (giants)
- Time-Domain Astronomy ✔
- Astrometry ✔
- Epoch of Reionization ✔
- Gravitational Wave Astronomy ✔ (follow-up)

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-Reviewed 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

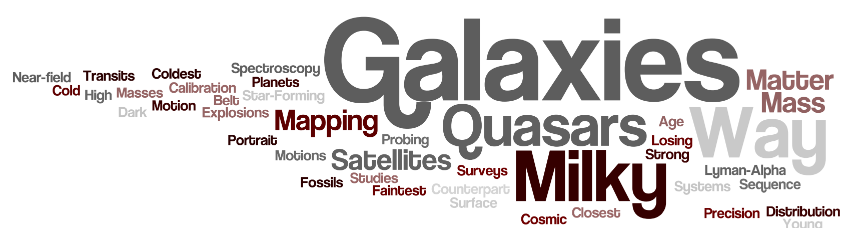
Ensures long-term scientific discovery potential

25% of AFTA is a Guest Observer Program

(2.5x Large

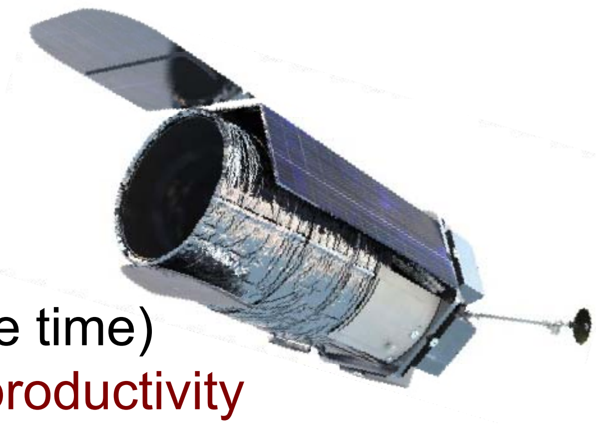
Jason Kalirai

Alan Dressler



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

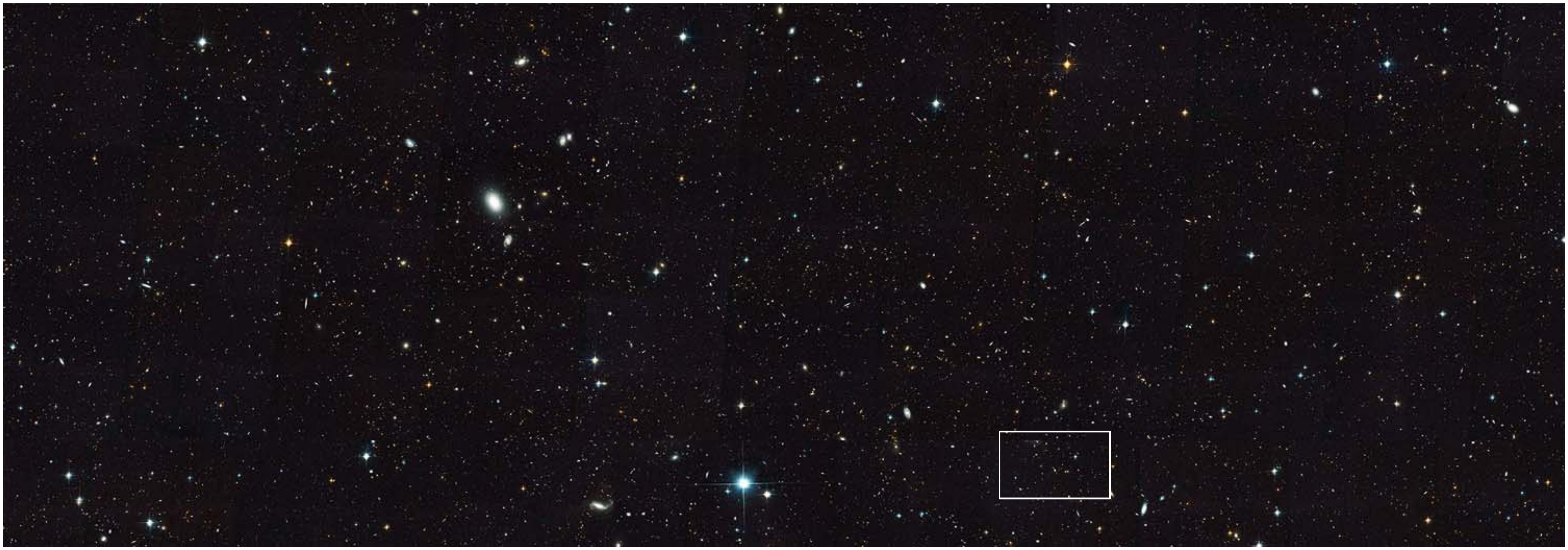


AFTA
AFTA is 200x faster than Hubble WFC3/IR
AFTA has higher resolution than Hubble WFC3/IR
AFTA has higher efficiency than Hubble (i.e., on-source time)
→ Assume a conservative factor of 5 gain in science productivity

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

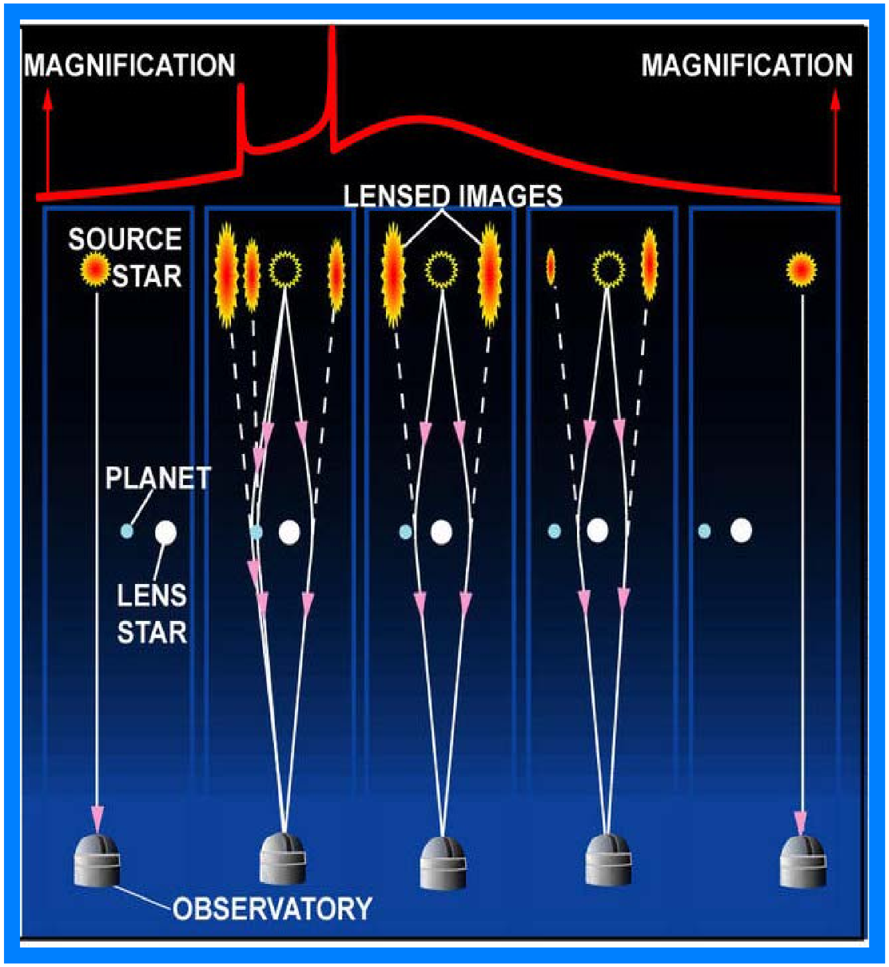
AFTA vs Hubble

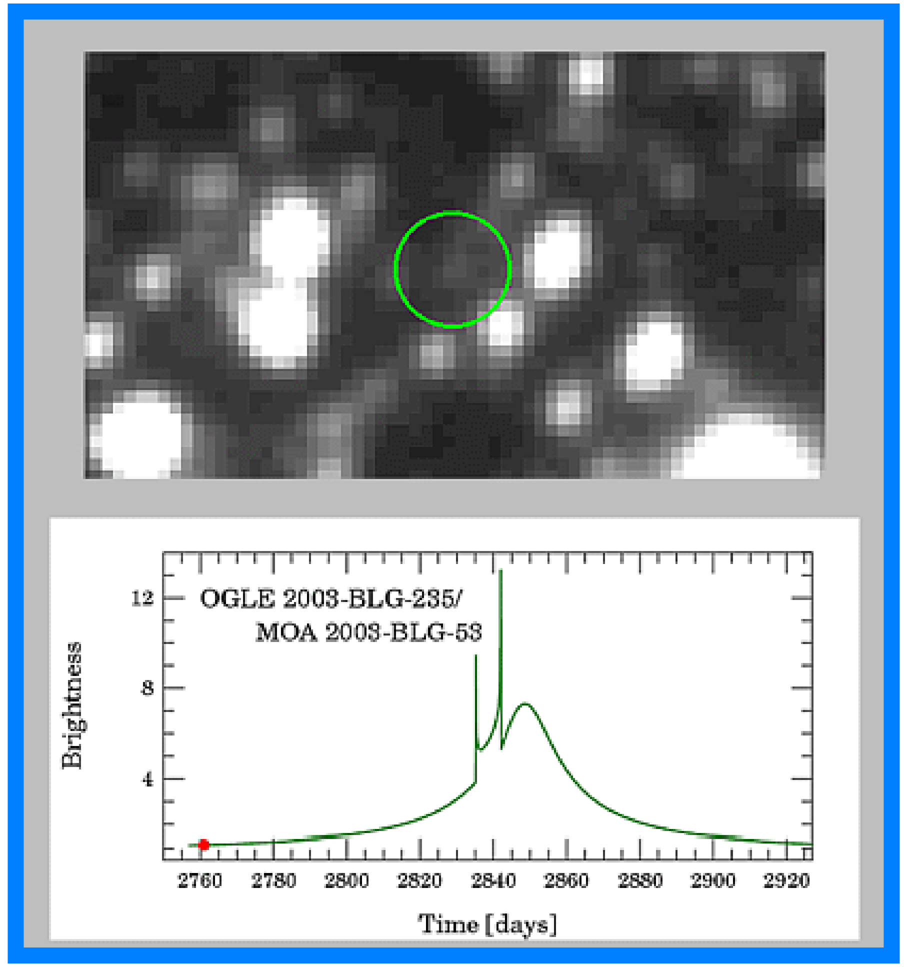
Hubble Ultra Deep Field - IR
~5,000 galaxies in one image



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

Detecting Planets with Microlensing





Microlensing Survey: IDRM vs. WFIRST-AFTA

- Per unit observing time, WFIRST-AFTA* is more capable than the IDRM design.
- The primary advantages are:
  - The exoplanet yields of WFIRST-AFTA are ~1.6 times larger than IDRM for a fixed observing time.
  - Significantly improved (factor of two) sensitivity to planets with mass less than that of the Earth.
  - WFIRST-AFTA will have a dramatically improved ability to measure masses and distances to the microlensing host stars.
  - WFIRST-AFTA images will be more directly comparable to those from HST/WFC3 images, facilitating WFIRST-AFTA software development and field selection.

*Because the microlensing survey only uses the wide-field instrument, we do not make a distinction between WFIRST-AFTA with and without the coronagraph.

Predicted Microlensing Planet Yields.

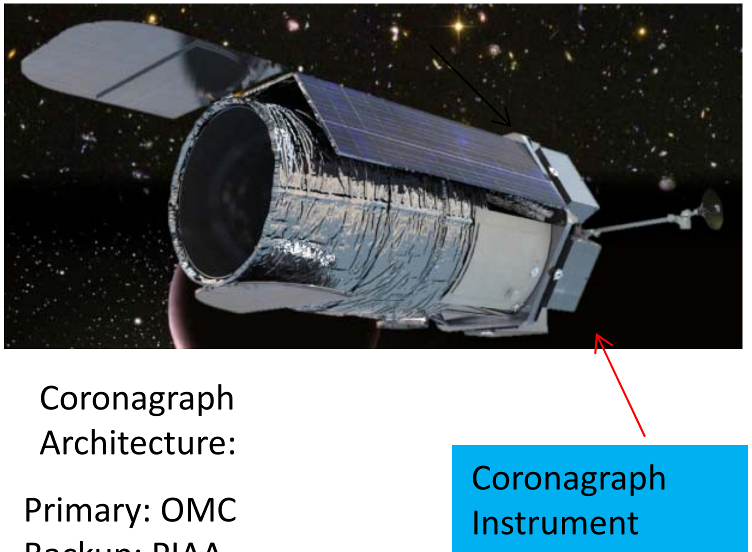
Bound

M/M_{Earth}	IDRM	Euclid	DRM1	WFIRST-AFTA
0.1	21	10	30	39
1	202	66	239	301
10	576	197	794	995
100	470	144	630	791
1000	299	88	367	460
10,000	129	41	160	201
Total	1697	546	2221	2787

F.F. Earth

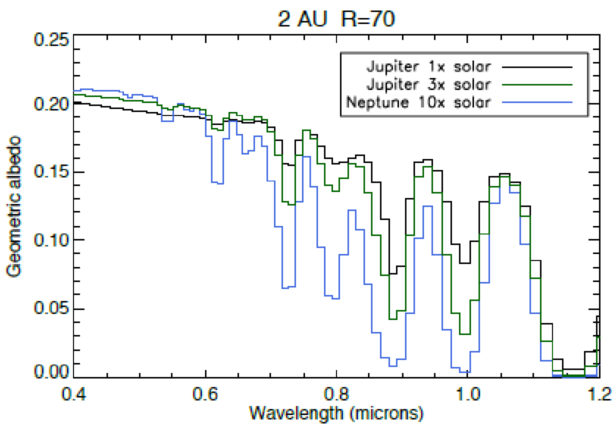
IDRM	Euclid	DRM1	WFIRST-AFTA
23	5	33	41

AFTA Coronagraphy



Coronagraph Architecture:

Primary: OMC
Backup: PIAA



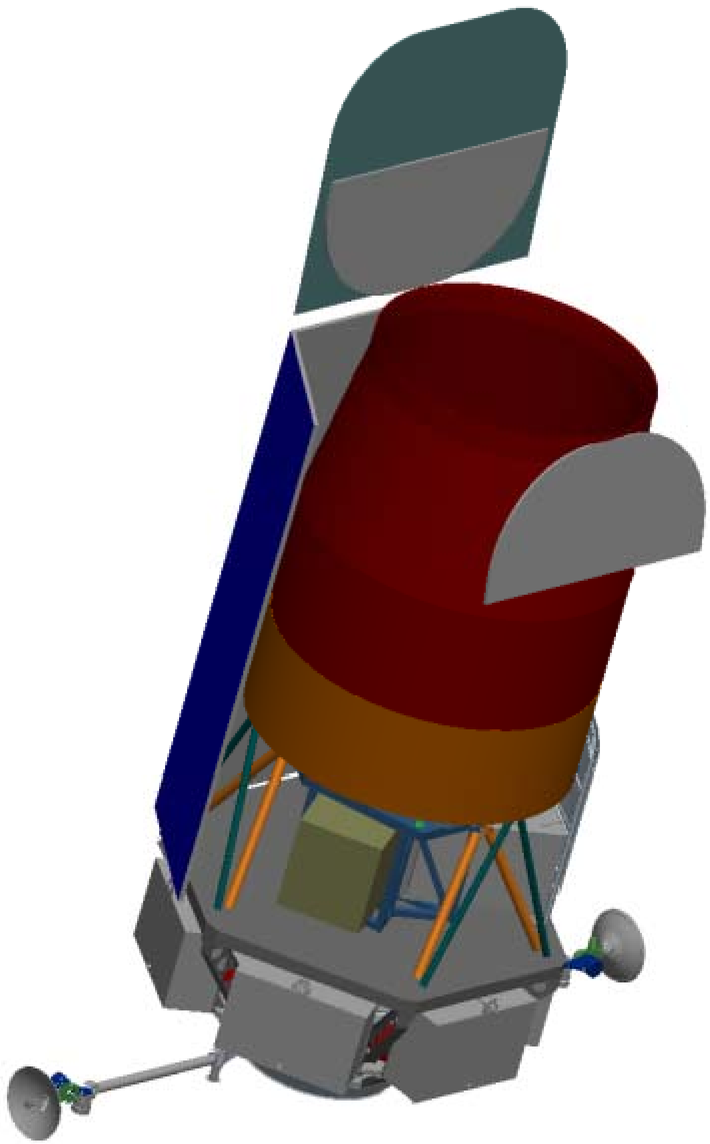
Exo-planet Spectroscopy

Bandpass	430 – 980nm	Measured sequentially in five ~10% bands
Inner working angle	100 – 250 mas	~3λ/D, driven by science
Detection Limit	Contrast $\leq 10^{-9}$ (After post processing)	Cold Jupiters, Neptunes, down to ~2 RE
Spectral Res.	~70	With IFS, R~70 across 600 – 980 nm
Number exoplanets	~20	Imaged in 4 spectral bands

AFTA Coronagraphy Advances Multiple Decadal Goals

- Technology Development
- Observations of disks
  - Zodiacal dust levels
  - Formation
- Characterization and detection of extrasolar planets (gas giants)
  - Complemented by GAIA+AFTA astrometric studies

WFIRST-AFTA Observatory Concept



Key Features

- Telescope – 2.4m aperture primary
- Instruments – Single channel widefield instrument, 18 HgCdTe detectors; integral field unit spectrometer incorporated in wide field for SNe observing; coronagraph
- Overall Mass – ~6800 kg (CBE) with components assembled in modules; ~260 kg propellant; ~3800 kg (CBE dry mass)
- 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 – Atlas V 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
Pixel Scale	0.18”	0.11”
Wavelength	0.6 – 2.0 μ	0.6 – 2.0 (2.4) μ
Spectrometer	Slitless prism	Slitless grism & IFU
Coronagraph	no	yes

PSF-2: How do circumstellar disks evolve and form planetary systems?

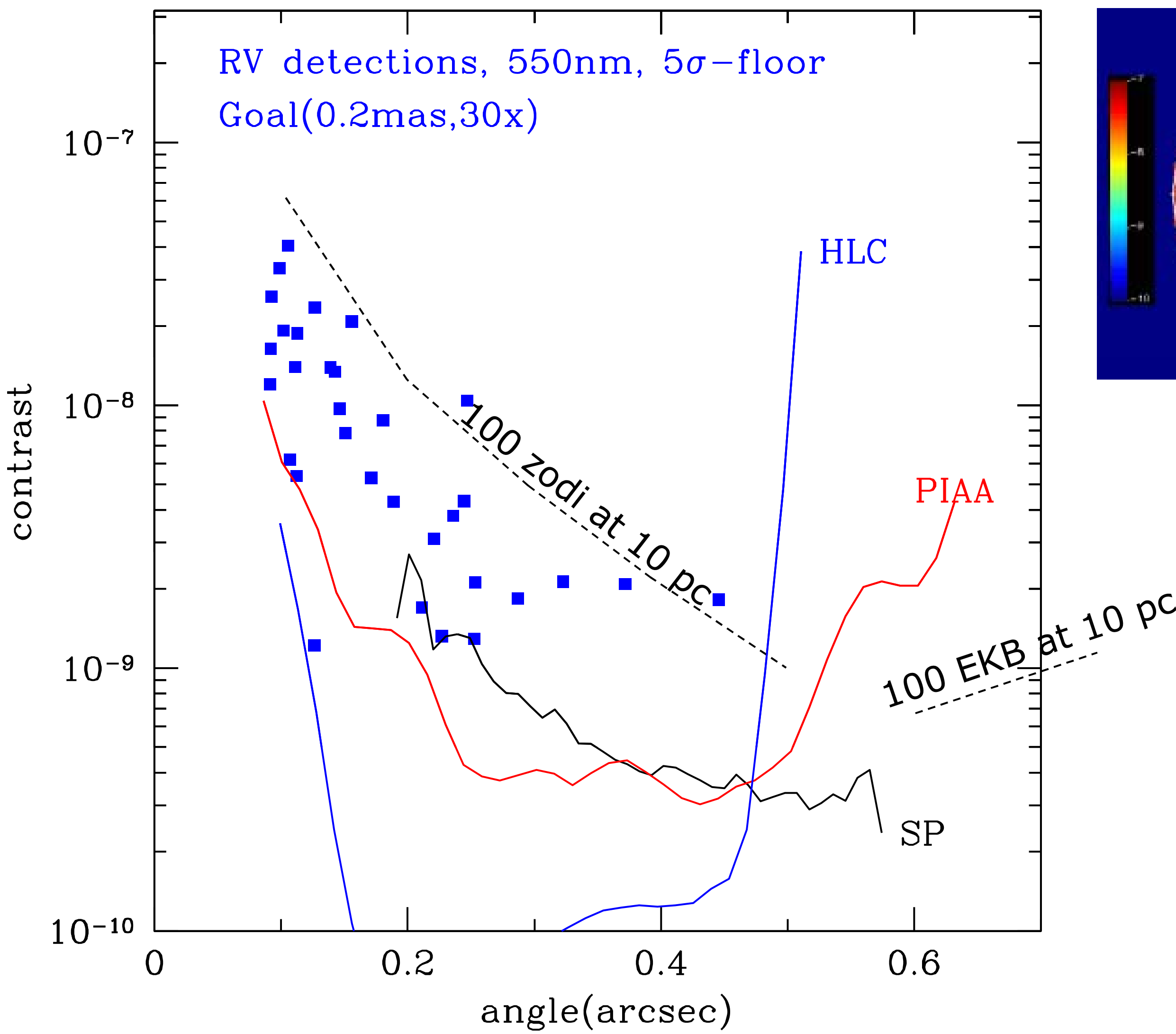
PSF-3: How diverse are planetary systems?

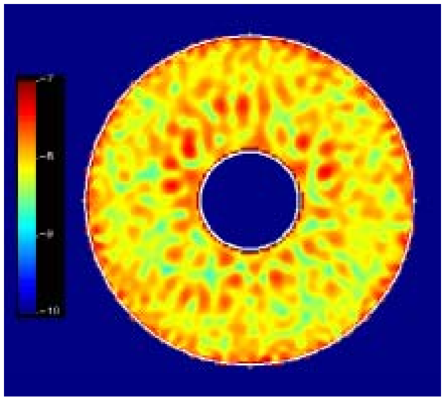
PSF-4: Do habitable worlds exist around other stars?

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 NWNH – the New Worlds component	Astrometric detection of super-Earth mass planets around nearby stars. AFTA astrometry is 9x faster than NWNH baseline	• 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 follow-up terrestrial planet imaging missions → Photometrically constrain the atmospheric properties of a sample of 1-3 RE planets.
No capability for nearby planet characterization, but an important science goal of NWNH – the New Worlds component	Astrometric detection of super-Earth mass planets around nearby stars. AFTA astrometry is 9x faster than NWNH baseline.	• 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
No capability for nearby planet characterization, but an important science goal of NWNH – the New Worlds component	No capability	• Study nearby, young planetary systems. → Characterize the atmospheres of young, self-luminous planets at 0.8-1 micron to complement ground-based AO → Coronagraphic studies of young planet-forming disks at 0.1”

Contrast vs Angle from Star

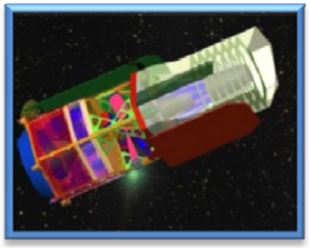




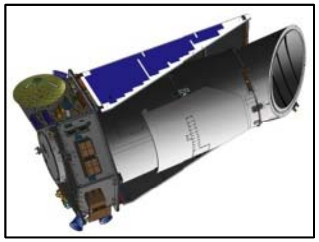
PSF-3: How diverse are planetary systems?
PSF-4: Do habitable worlds exist around other stars

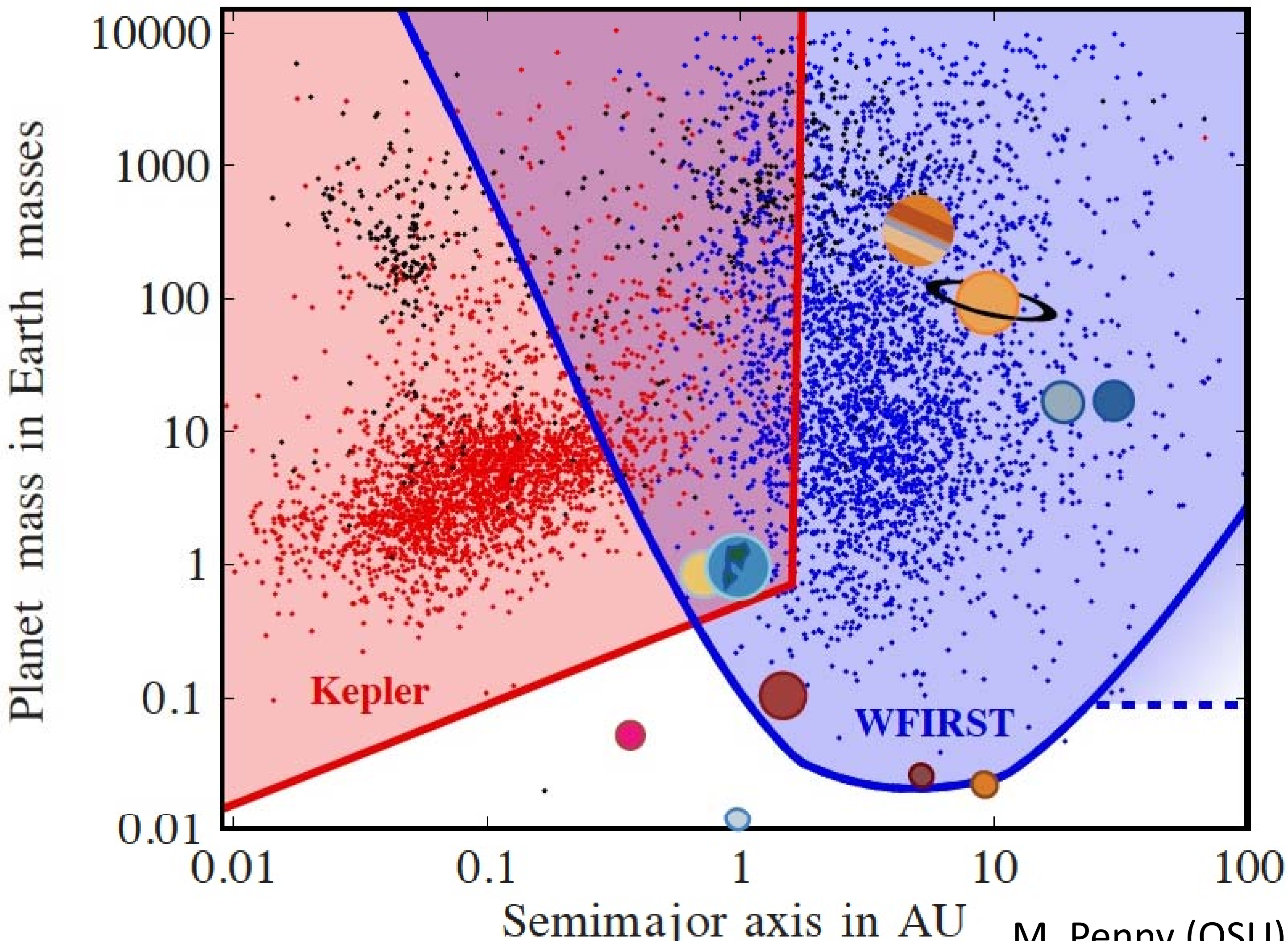
Census via microlensing of Galactic planets.

NWNH/IDRM	AFTA	AFTA + Coronagraph
• Complete the statistical census of planetary systems in the Galaxy → Detect 3000 bound "cold" planets, including 350 terrestrial planets. → Sensitivity to planets with mass greater than 2x the moon. → Measure the masses and distances of planets and host stars. → Detect free floating planets down to the mass of Mars	• Factor of 1.6-2 times higher yields than IDRM. • Dramatically improved ability to measure masses and distances to the microlensing host stars, although this has not yet been quantified in detail. Synergy with JWST.	Same as with no coronagraph
• Independently measure the frequency of habitable zone planets, improving on Kepler's estimate. • Characterize planetary systems beyond snow line to understand the origins of water.	• Factor of 1.6-2 times higher yields than IDRM for most planets • Roughly order of magnitude improvement in the sensitivity to habitable planets.	Same as with no coronagraph



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





M. Penny (OSU)

PSF-2: How do circumstellar disks evolve and form planetary systems?

PSF-3: How diverse are planetary systems?

PSF-4: Do habitable worlds exist around other stars?

GO Investigations.

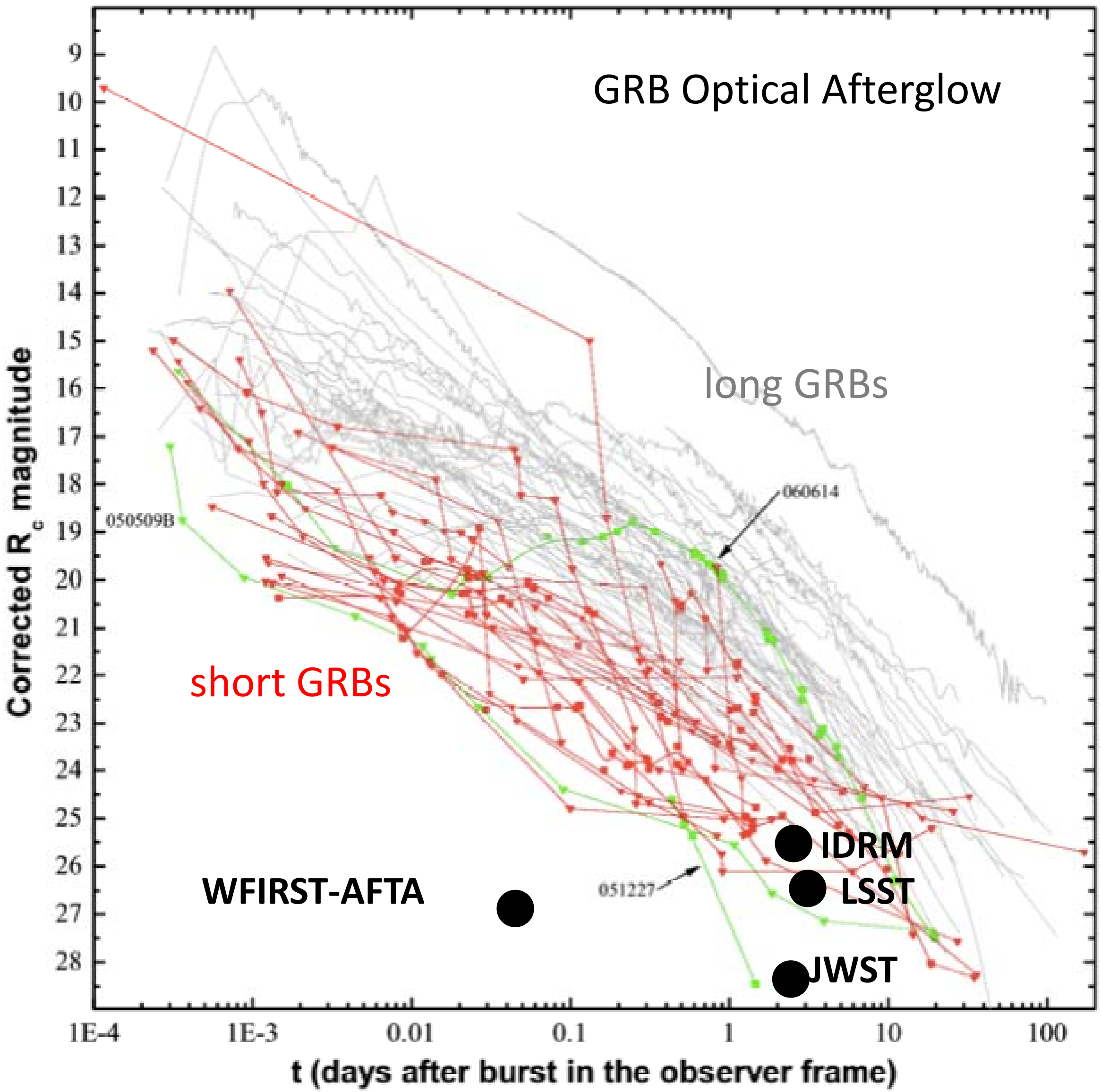
NWNH/IDRM	AFTA	AFTA + Coronagraph
• Studies of exoplanet atmospheres using transit spectroscopy and eclipse mapping.	Improved capability due to larger aperture, better resolution, and IFU.	Same as with no coronagraph
• Survey ~100 nearby K+M dwarfs to astrometrically detect planets with mass greater than a few Earth masses and periods of less than 20 years.	Improved capability due to larger aperture and better resolution.	Same as with no coronagraph
• Survey nearby Galaxies to detect extragalactic planets using gravitational microlensing.	Improved capability due to larger aperture and better resolution.	Same as with no coronagraph
• Detect hundreds of thousands of transiting planets in the Galactic bulge with periods out to several years.	Improved capability due to larger aperture and better resolution.	Same as with no coronagraph
• Wide field survey of the Kuiper belt will increase the known population by over an order of magnitude.	Improved sensitivity and spatial resolution due to larger aperture.	Same as with no coronagraph
• Confirmation and characterization of Kepler and TESS planets with precise near-IR photometry.	Improved capability due to large aperture.	Same as with no coronagraph

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

GRBs and Gravitational Waves



Gravitational Waves from NS-NS mergers

Same origin as short GRBs

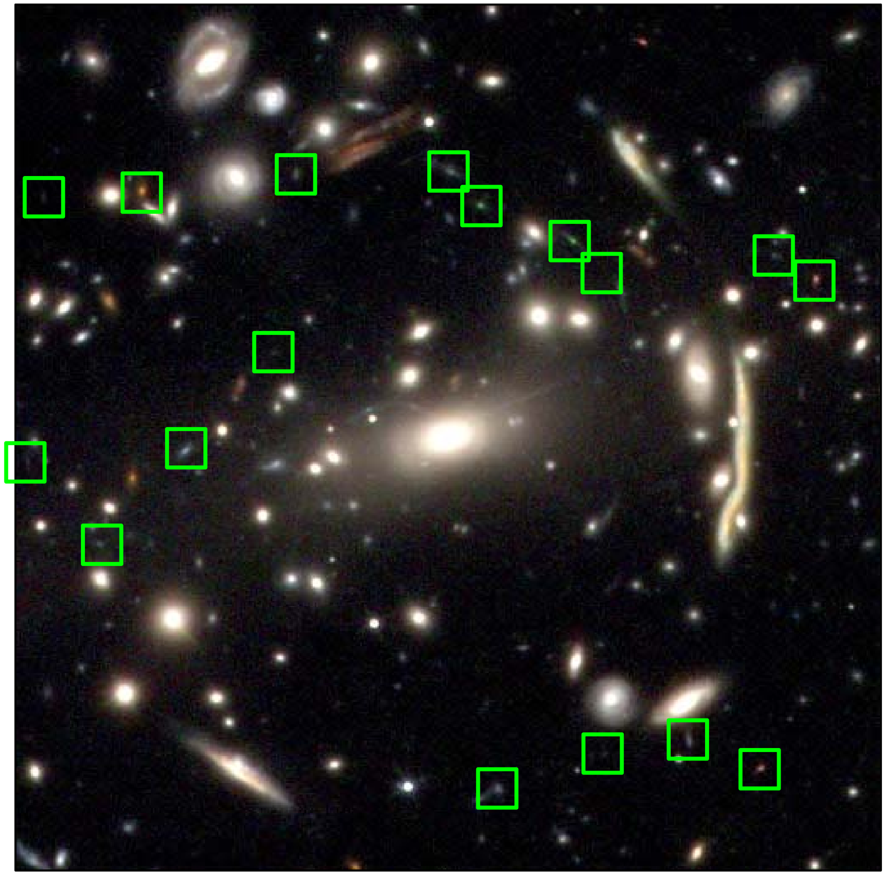
Kann+ 08

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

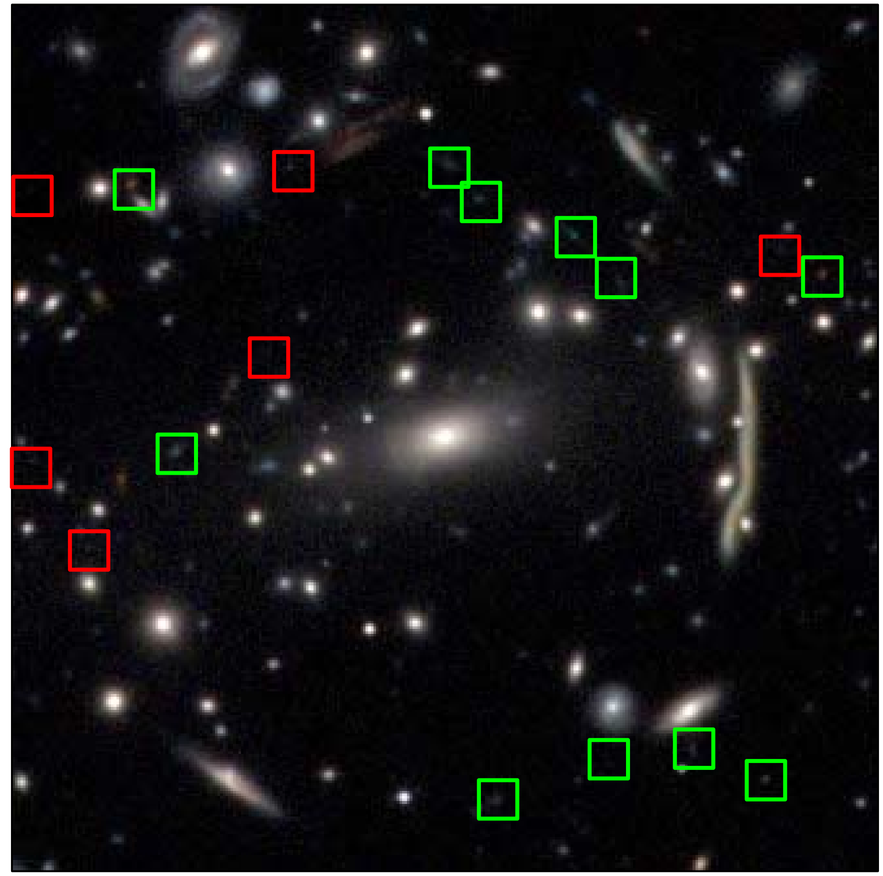
Probing DM in High-Density Galaxy Environments

NWNH/IDRM	AFTA	AFTA + Coronagraph
Map DM distribution (via strong and weak lensing) in galaxy clusters and galaxy groups.	• Map DM distribution (via strong lensing) in galaxy clusters and galaxy groups. • Depth and resolution increase over IDRM yields up to 4x as many multiply lensed images per cluster. Enables one to map cluster DM with ~2x the spatial resolution. • Depth and resolution increase over IDRM yields allows one to detect lensing signal around lower mass systems.	Same as with no coronagraph
Not Discussed in IDRM	• Survey the dwarf galaxy population around neighboring galaxies – look for "missing halos." Strongly dependent on PSF. • Trace dark matter in tidal tails. Astrometry 9x faster than IDRM.	Same as with no coronagraph

Cluster MACS J1206-0848 (z = 0.44)



AFTA-WFIRST (Y+J+H)

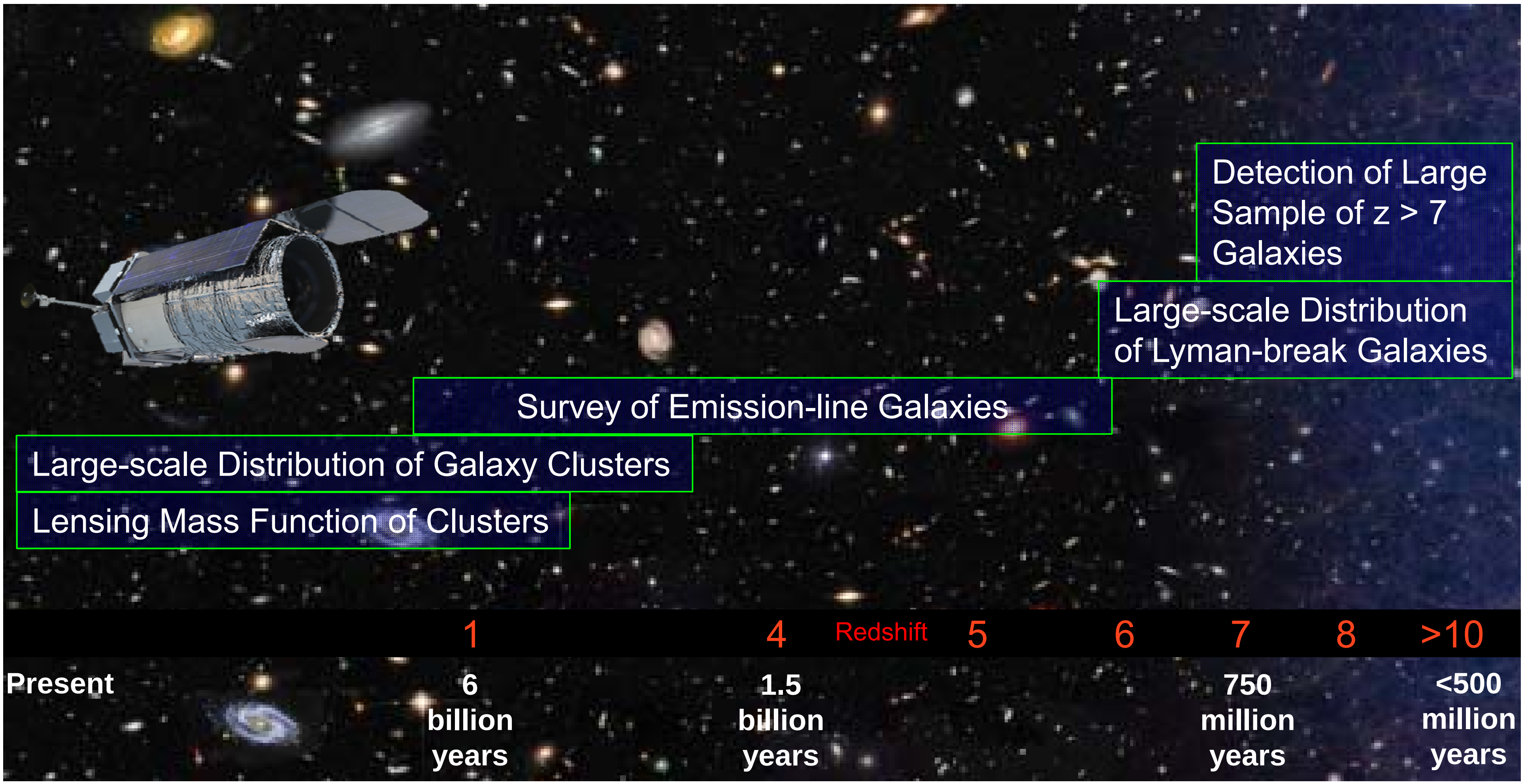


IDRM (Y+J+H)

AFTA: 100% of the known multiply imaged arcs detected
IDRM: ~60% of all multiply imaged arcs detected (~40% missed)

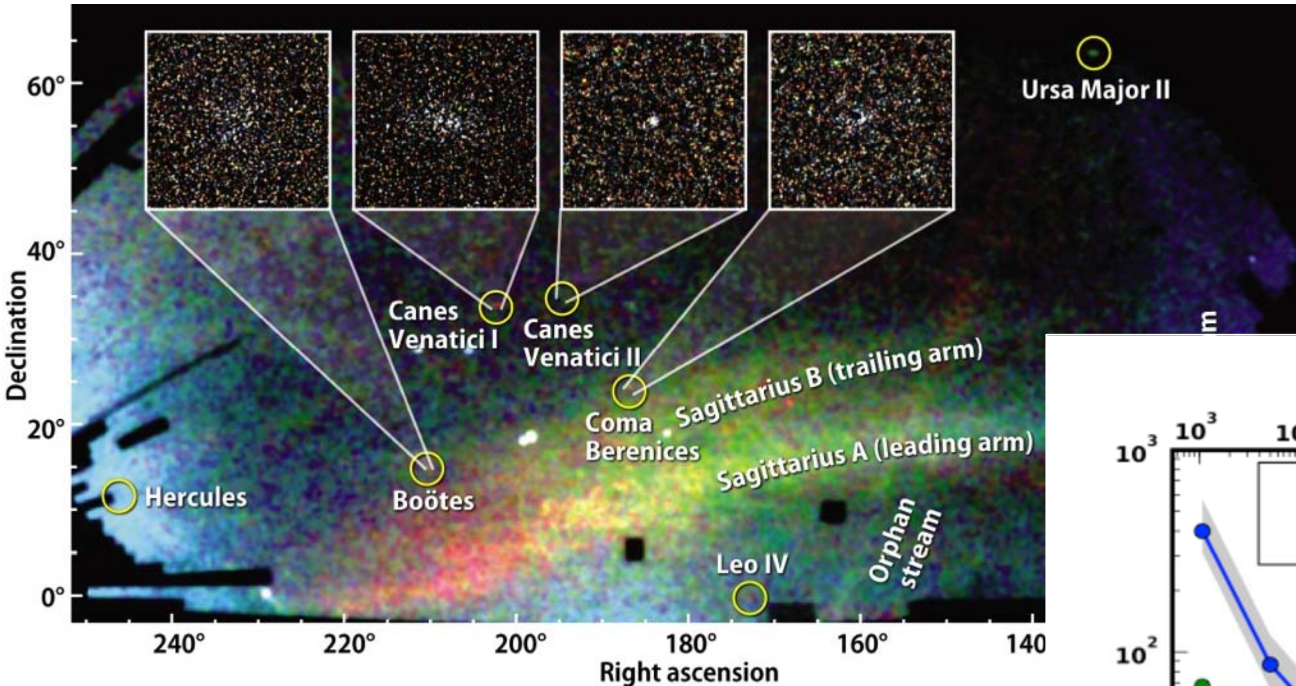
AFTA: A Unique Probe of Cosmic Structure Formation History

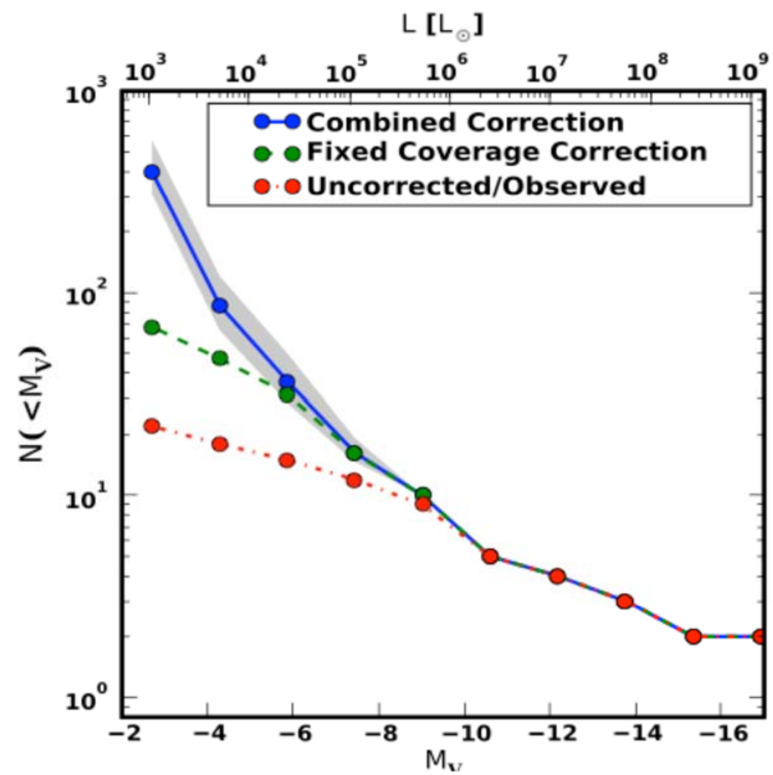
Using Observations from the High-Latitude Survey and GO Programs



Dark Matter Properties - Luminous Tracers

AFTA will survey 2000 sq deg of MW Halo at Hubble's power and IR image quality





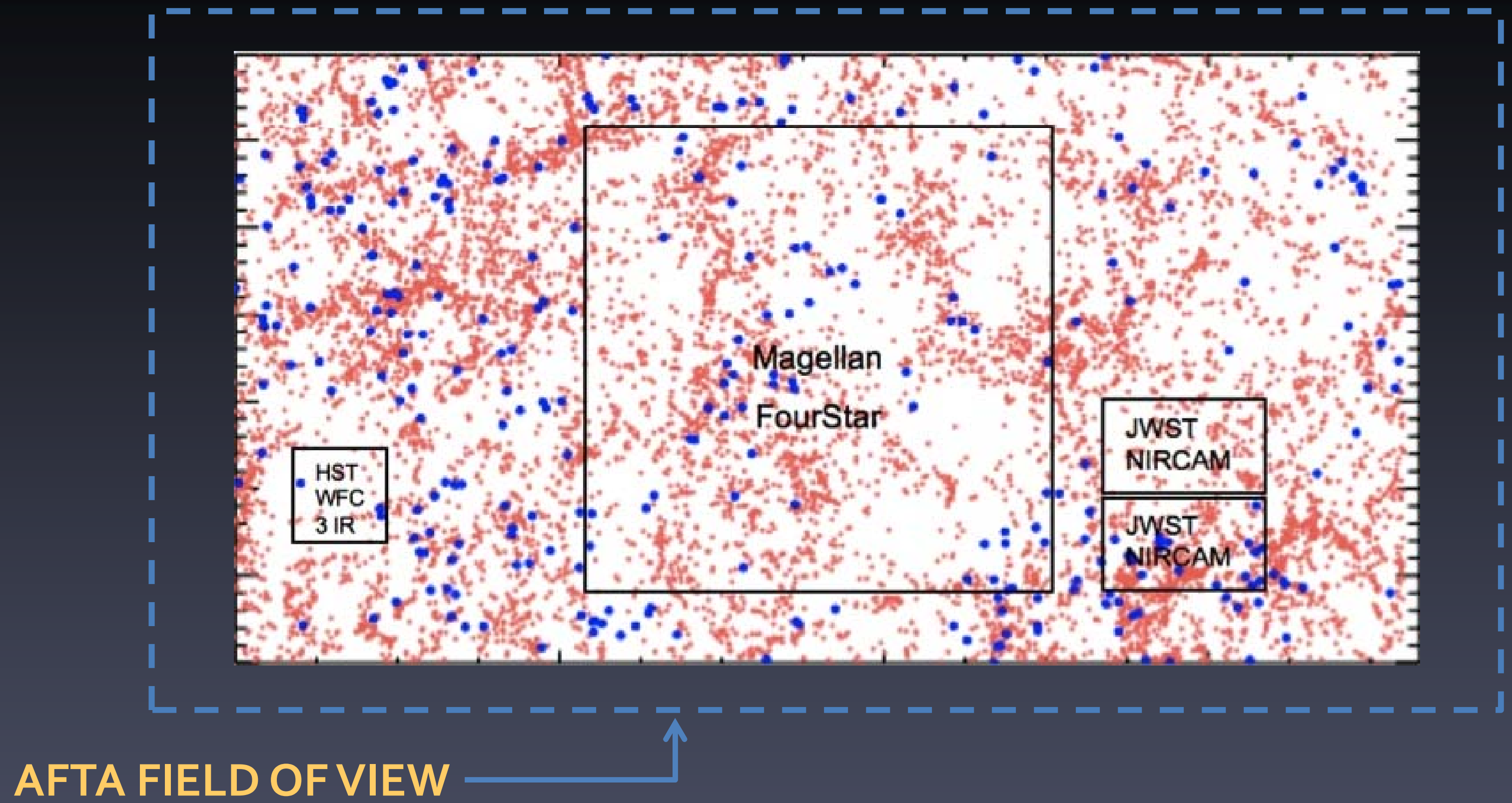
Current census of Milky Way DM-dominated streams and dSphs is heavily incomplete

GCT-1 How do cosmic structures form and evolve?

Large Scale Structure

NWNH/IDRM	AFTA	AFTA + Coronagraph
Not possible with IDRM	**Chart the growth of the galaxies and the "cosmic web" through the reionization epoch:** find proto-galaxies 6 < z < 10 with Lyman-break technique to **AB=31** – the depth of the *Hubble eXtreme Deep Field (XDF)*. Begin with a single WFIRST-AFTA field – a 20 day exposure – but later expand to more than one square degree. Follow-up with proto-galaxy spectra and emission-line (LAE) search with JWST and future ELTs to map the progress of **reionization** and to connect **galaxy evolution** to the growth of the dark matter web. → Unique combination of area and depth. Survey depth pushes WFIRST-AFTA into frontier territory, beyond IDRM's reach.	Same as with no coronagraph

Simulated Distribution of z=6.5 Galaxies



N-body simulation by Tilvi+2009 (ApJ 704, 724) showing large-scale structure at z=6.5 over a field 30% smaller than that of WFIRST-AFTA. Red dots are dark matter halos M > 2.5 x 10^9 M_{sun}, the probable location of proto-galaxies (Lyman break objects). Blue dots are high-density peaks in the dark matter, predicted positions of Lyman-alpha emitters (LAEs).

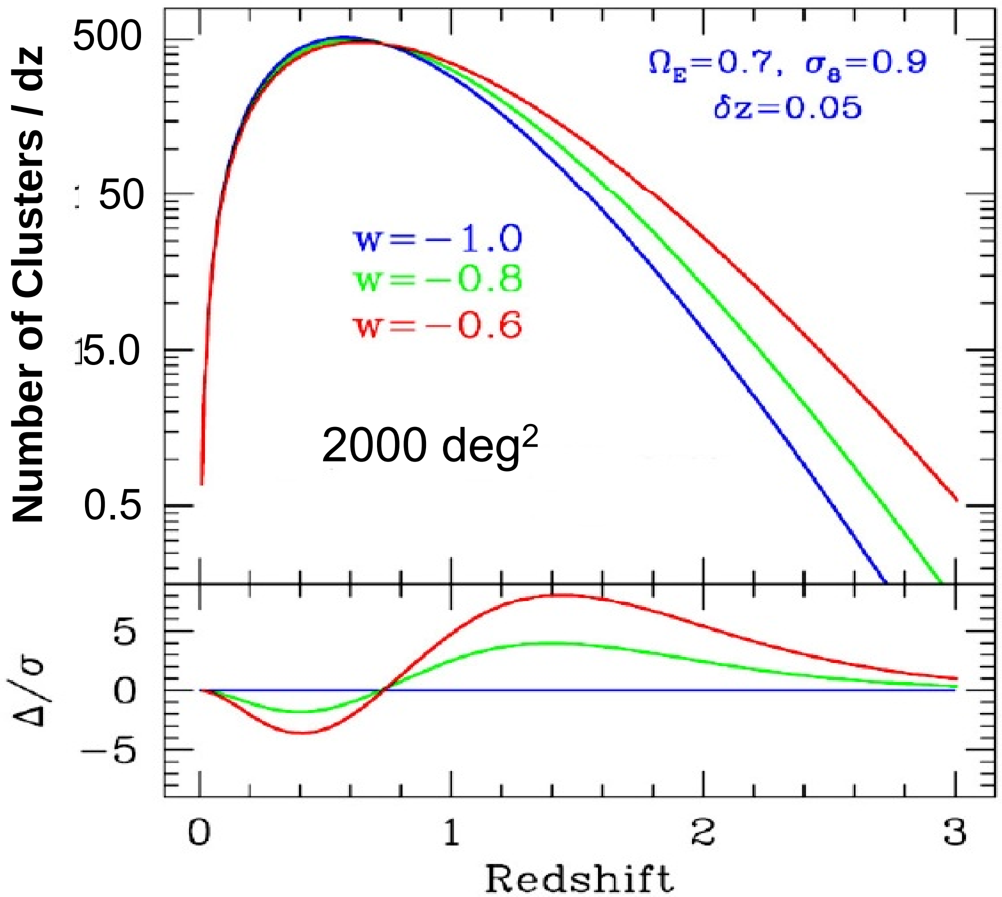
Note JWST NIRCam's comparatively small field. Cameras on ground-based (such as Magellan's FourStar) can achieve much larger fields, but far lower sensitivity than WFIRST-AFTA restricts their galaxy maps to the relatively late epochs of z < 3.

GCT-1 How do cosmic structures form and evolve?

Measure structure and dark matter on 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 and resolution increase over IDRM yields >3x improvement in lensing-based mass estimate accuracy (for each cluster) due to increased number density of background galaxy density and better detection of faint multiply imaged (strongly-lensed) galaxies.	Same as with no coronagraph

Cluster Cosmology & Evolution



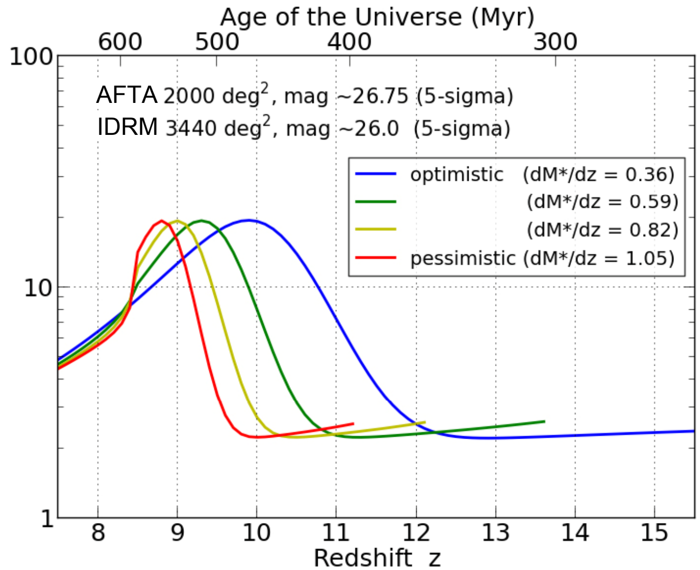
Sample of several thousand clusters in AFTA HLS will superbly measure the cluster mass function as a function of redshift → strong and independent test of cosmology and structure formation models. Best sensitivity at $0.7 < z < 1.6$. NIR survey optimal for this redshift range.
Depth increase over IDRM yields >3x improvement in WL+SL mass estimate accuracy.

GCT-1 How do cosmic structures form and evolve?

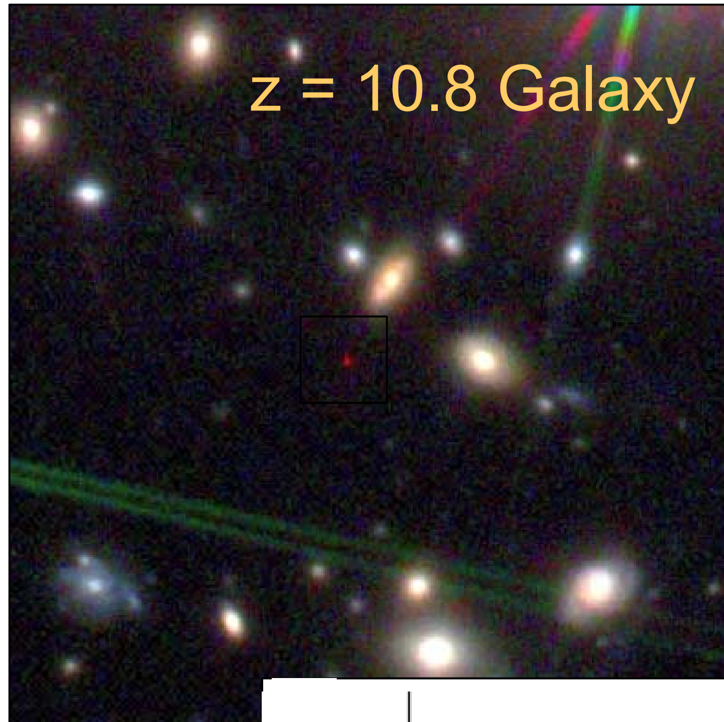
Measure structure on galaxy scales

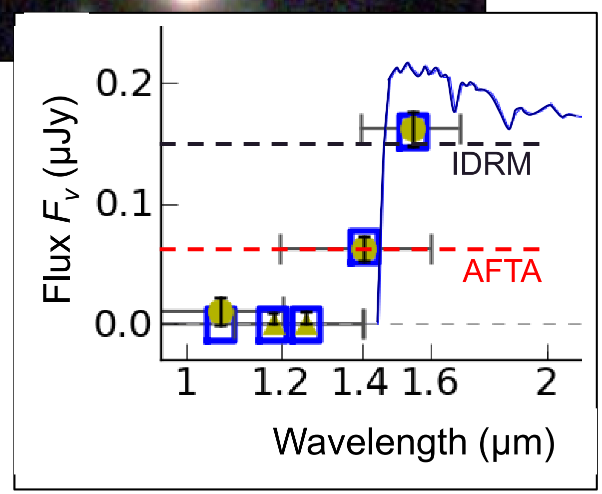
NWNH/IDRM	AFTA	AFTA + Coronagraph
IDRM survey will discover hundreds of z > 8 galaxies and, potentially, and tens of highly magnified z ~ 10 galaxies that would be within reach of EELT and JWST spectrographs.	AFTA survey will discover thousands of z > 8 galaxies and, potentially, tens to hundreds of 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 warm dark matter particle.	Same as with no coronagraph

Galaxy Formation in the First 500 Myrs



Cumulative number ratio (AFTA vs IDRM) of detected hi-z galaxies





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.

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

Large-scale weak lensing survey

<table>
<tr><th>NWNH/IDRM</th><th>AFTA</th><th>AFTA + Coronagraph</th></tr>
<tr><td>WL survey over 2000 sq deg with n_{eff} ~ 30 and pixel size 0.18"</td><td>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.</td><td>Same</td></tr>
</table>

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**

Executive Summary

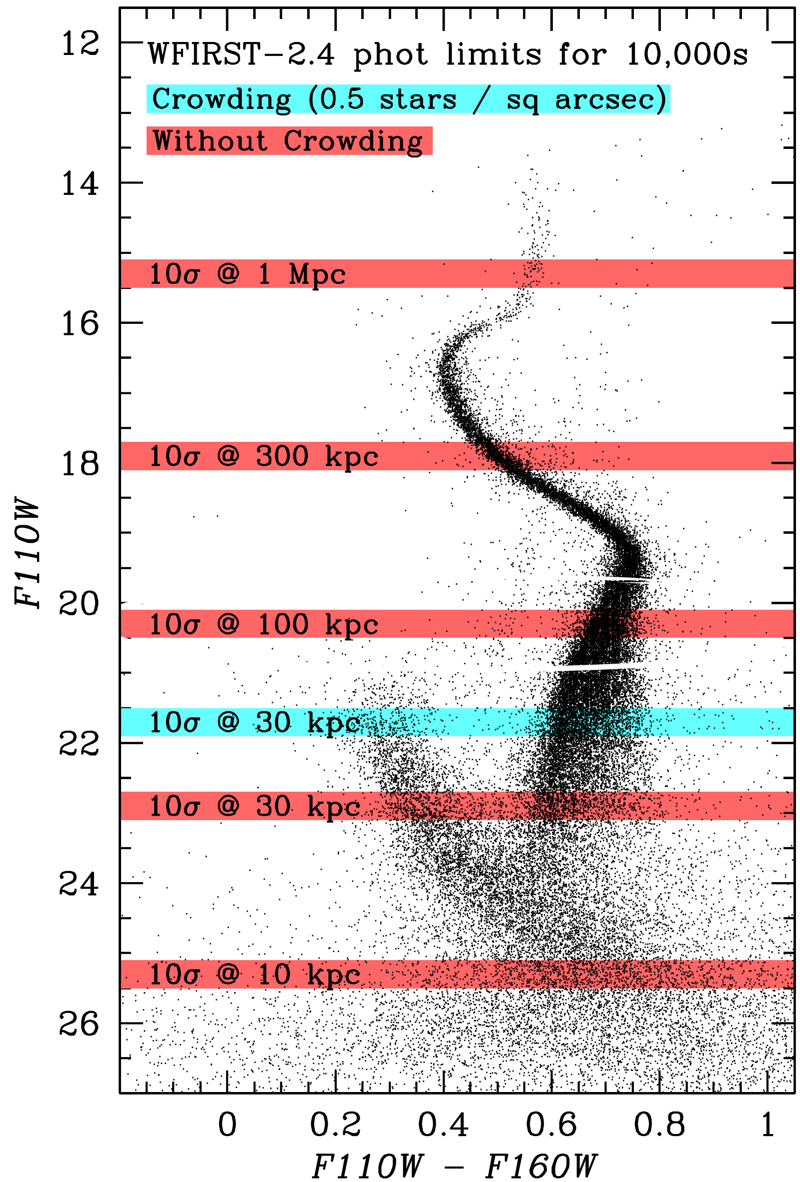
- WFIRST-AFTA gives HST imaging over 1000's of square degrees in the NIR
- 2.5x deeper and 1.6x better PSF than IDRM*
- More complementary to Euclid & LSST than IDRM. More synergistic with JWST.
- Enables coronagraphy of giant planets and debris disks to address "new worlds" science of NWNH
- Fine angular resolution and high sensitivity open new discovery areas to the community. More GO science time (25%) than for IDRM.
- CATE cost is 8% larger than WFIRST IDRM (19% with launch vehicle risk). Coronagraph adds an additional 13% cost, but also addresses another NWNH recommendation.
- WFIRST-AFTA addresses changes in landscape since NWNH: Euclid selection & Kepler discovery that 1-4 Earth radii planets are common.
- Use of NRO telescope and addition of coronagraph have greatly increased the interest in WFIRST in government, scientific community and the public.
- Growing international interest. SDT members from Canada, ESA and Japan. Potential partners may reduce cost (or enhance science).

* IDRM = 2011 WFIRST mission design to match NWNH

Backup

Discovery: Luminous and Dark Matter

A stellar population in the IR (Kalirai et al. 2012)



M dwarfs out to the edge of the Milky Way

- Exquisite star/galaxy separation
- High-precision photometry
- Takes advantage of rising stellar lum func.

→ Discovery of dozens of low SB systems

→ IMFs, SFHs, SB profiles, and structure

Factor of XX worst photometry and resolution in IDRM prevents such studies in the remote halo

Characterization: Luminous and Dark Matter

Masses of the Faintest Milky Way Satellites

80 micro-arcsec/year gives individual star internal velocities.

→ provides estimates of dark matter mass and density

→ <2 km/s for 50 stars @ 100 kpc, in 3 years

The Mass of the Milky Way

Tangential velocities of distant tracers in the Milky Way halo

→ <40 km/s error in v_{TAN} at 100 kpc, less than the expected velocity dispersion

→ Breaks the mass-anisotropy degeneracy in the distant halo

Cold vs Warm Dark Matter

Distinguish central density profiles

Extrapolate dark matter mass profiles

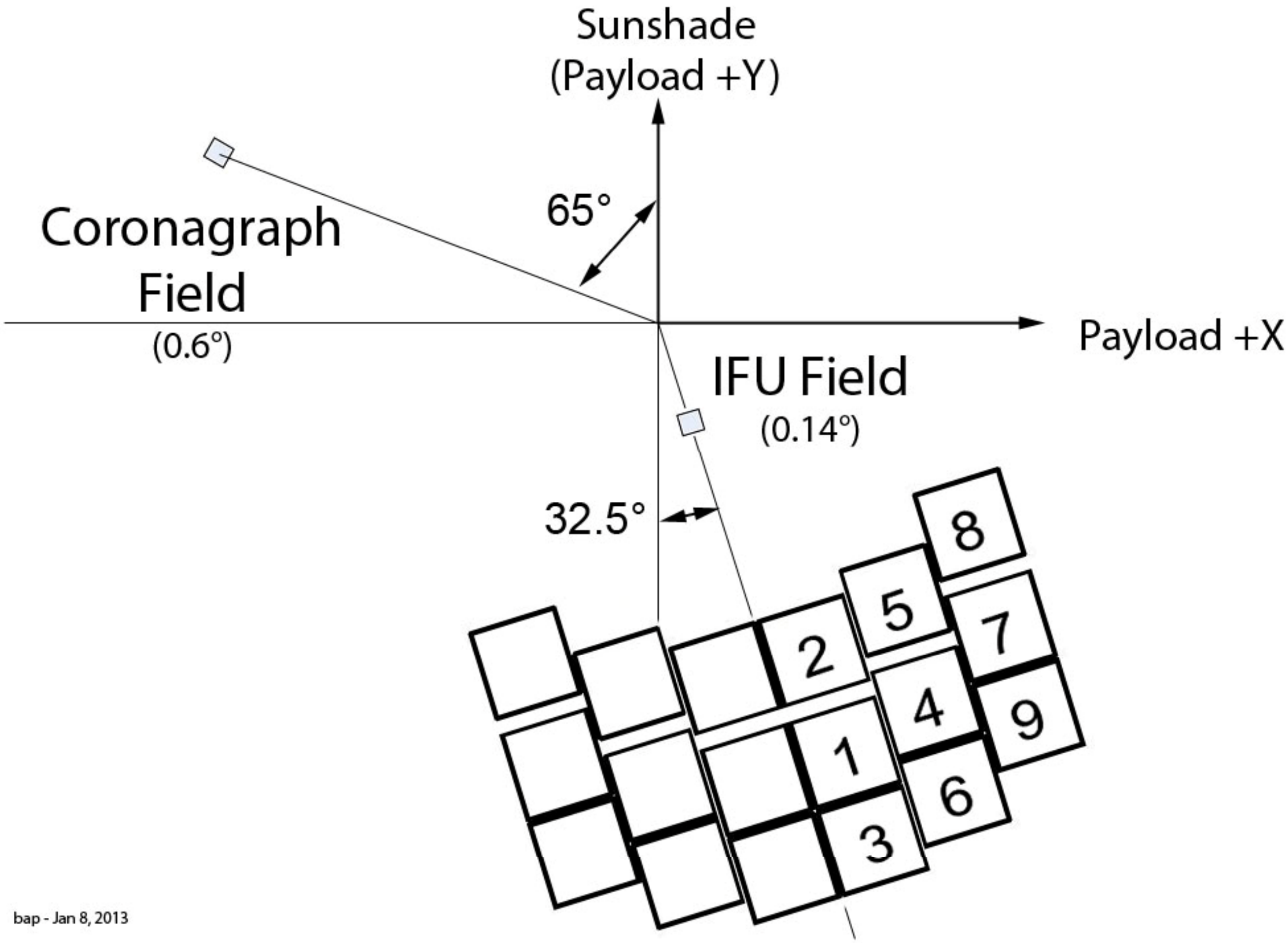
Current v_{RAD} lead to degeneracy b/w the central slope of DM profile and vel anisotropy.

Factor of 9 worst astrometry in IDRM limits such studies to the nearest satellit

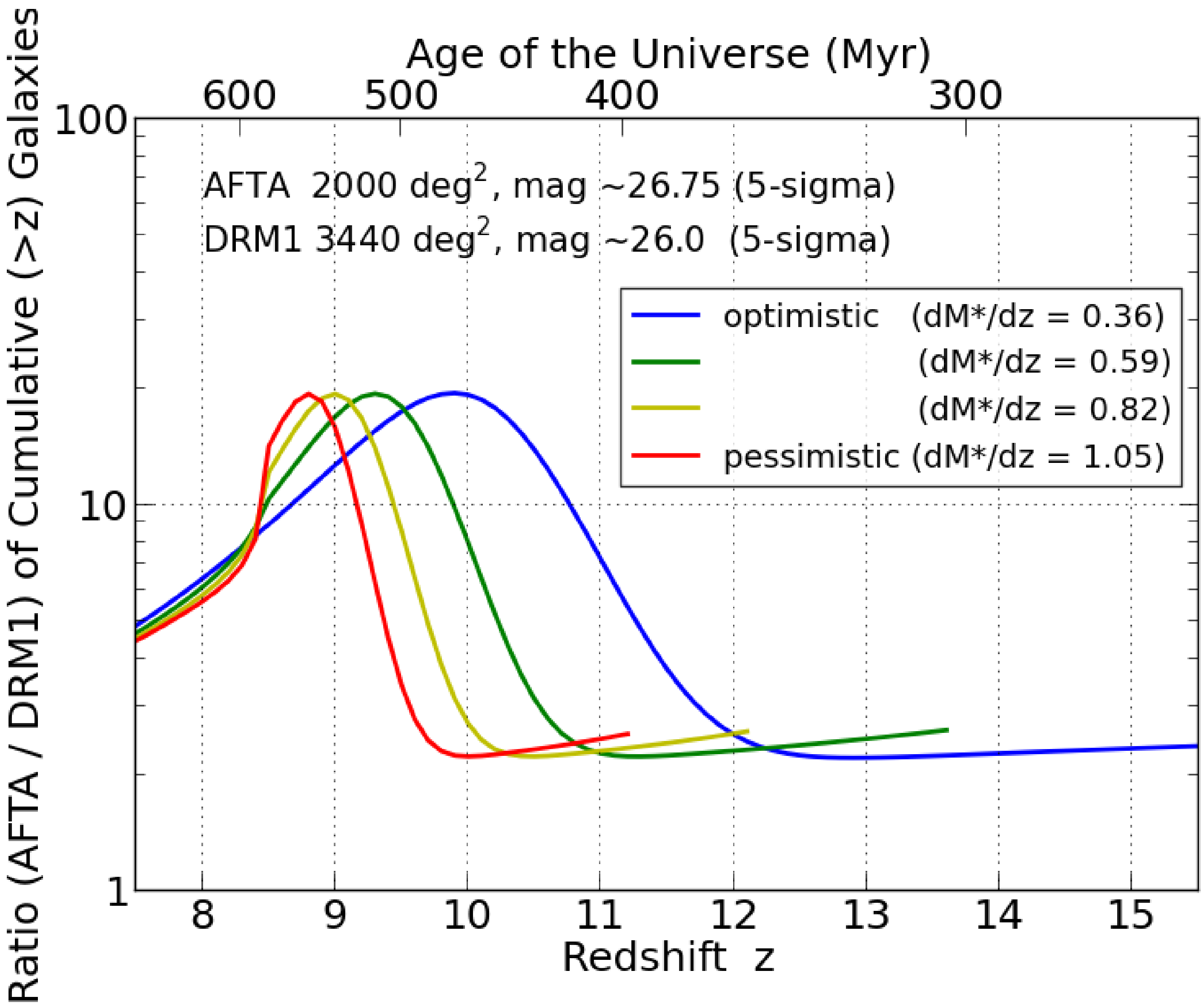
Channel Field Layout for AFTA-WFIRST Instruments

[Cycle 4]

As Projected on Sky



High Redshift Galaxies



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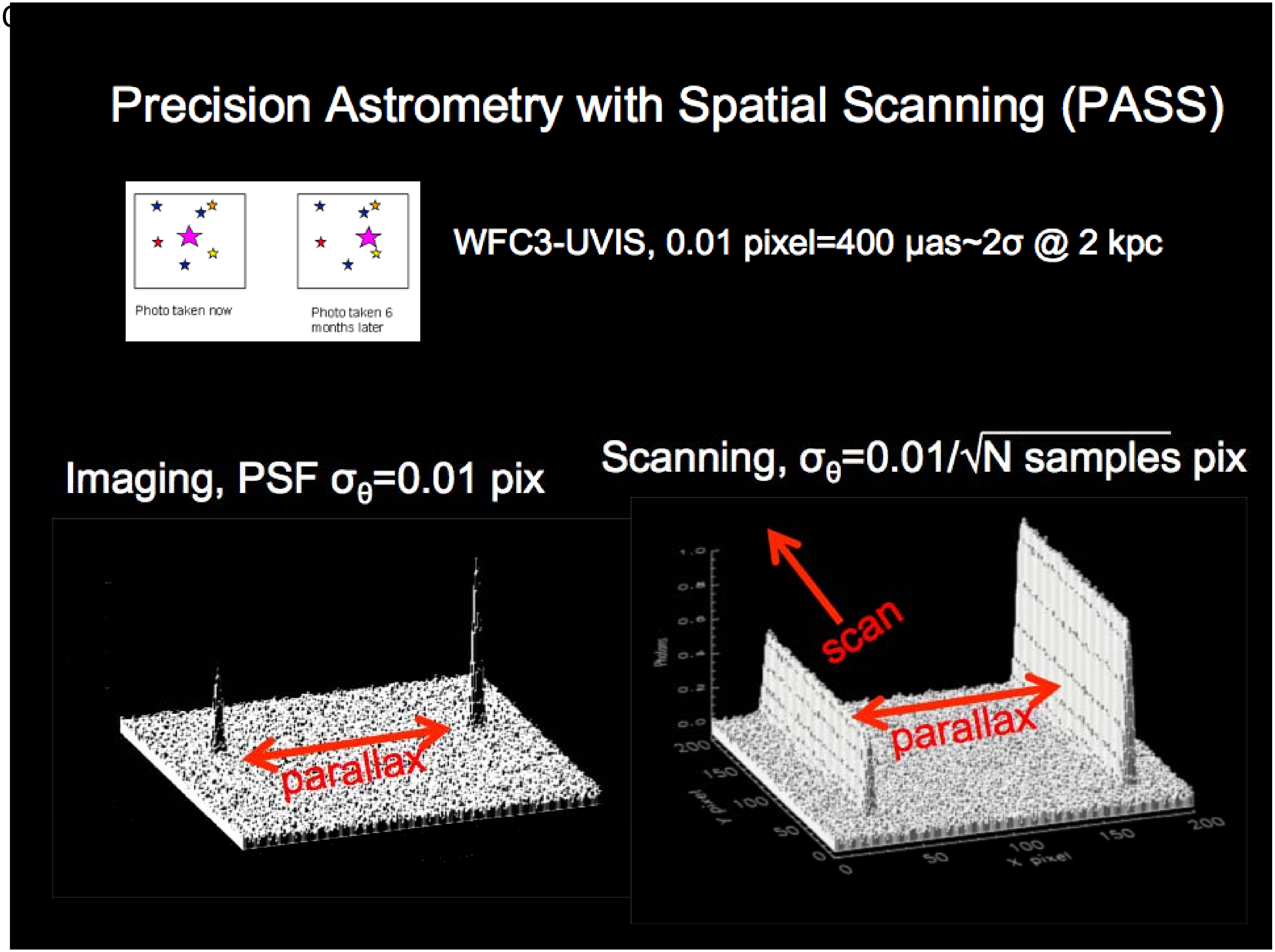
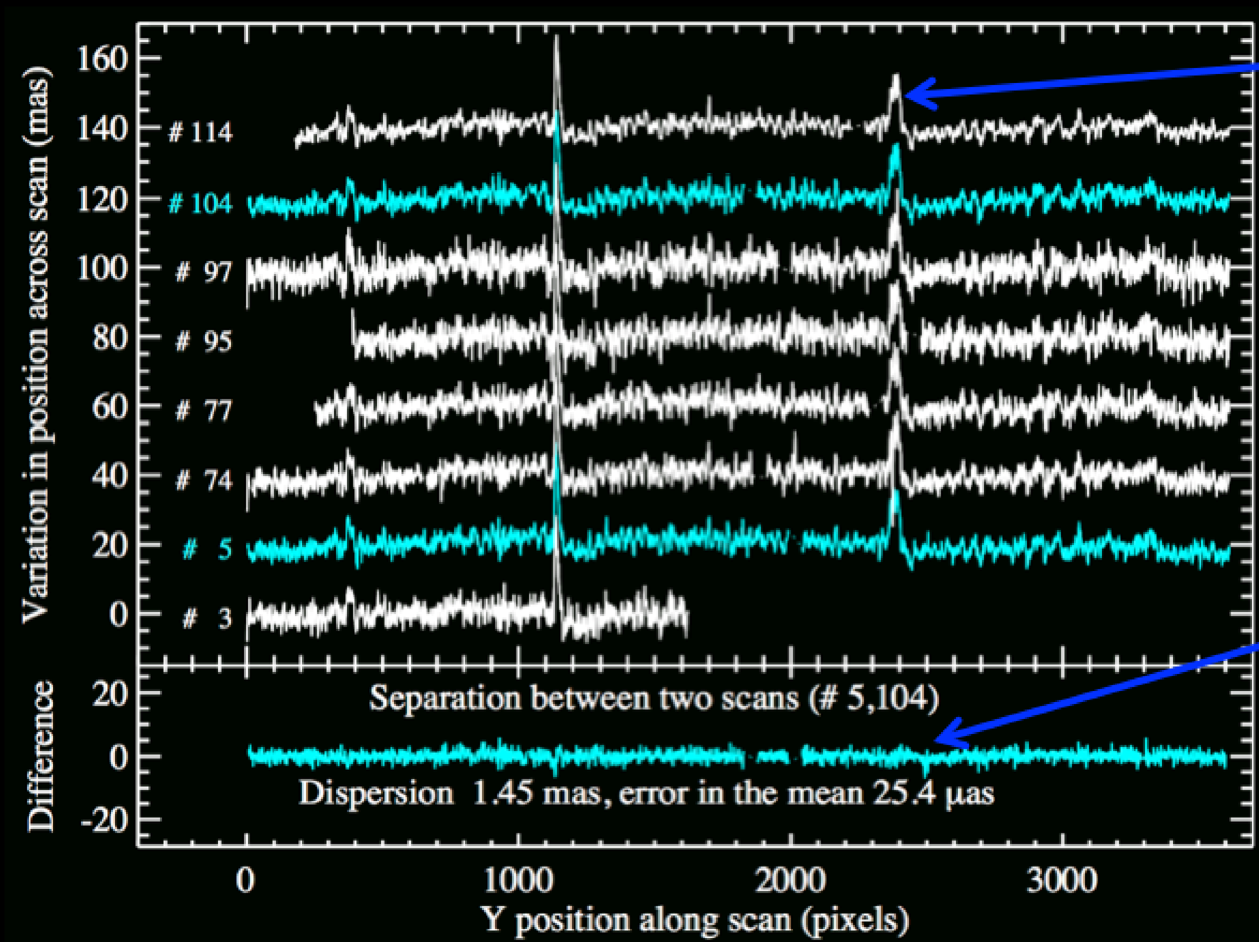


Precision Astrometry with Spatial Scanning (PASS)
Photo taken now
Photo taken 6 months later
WFC3-UVIS, 0.01 pixel=400 μas~2σ @ 2 kpc
Imaging, PSF σθ=0.01 pix
Scanning, σθ=0.01/√N samples pix
parallax
scan
parallax

Two Features of Spatial Scans, Jitter and Repetition

Average all scan lines to produce “reference line”

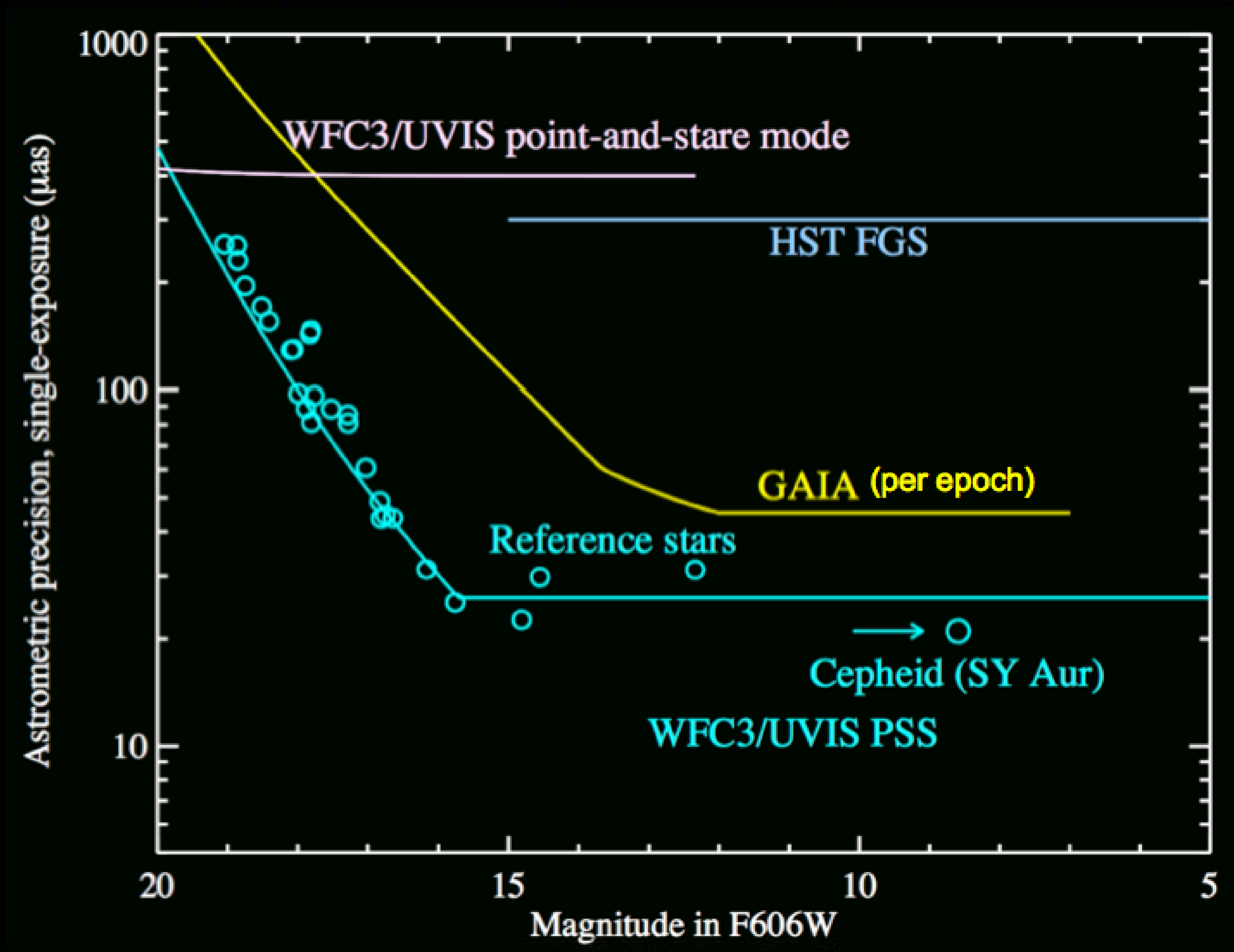


Jitter between lines is *coherent*, subtracted in line separations (vs time) *approach is doubly differential*

Target scanned over ~4000 pix, improves snr by up to ~40 (or 10 for correlated errors on scales of 40 pix)

F

Astrometric Precision Per Exposure



Need high snr *per pixel* so bright targets give best results (350 sec scan In F606W)

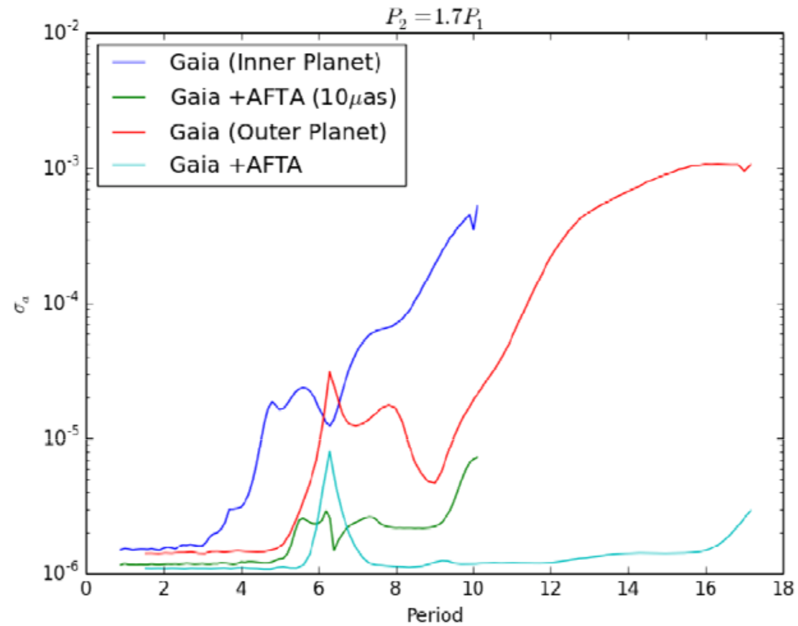
And we can measure Cepheid photometry on same system

Applying Same Approach to AFTA

- Bigger camera should enable improved sensitivity- scales as $\sqrt{N_{pixel}}$
- At J=13.5, S/N = 400 and saturate central pixel in one second (WFC3 simulator).
- In a 3 minute integration, stars brighter than J = 19 are saturated.
- Scan at 3 degree/minute = 1600 pixels/second
- Spreads signal over 24,000 pixels
  - Assume 5x improvement over HST's 1/2000th pixel performance or 1/100th of a pixel /√24,000 (7 μas)
- Repeated 30 second integration. Achieves 10 μas astrometry for J < 10 in each integration, 25 μas for the ~30 stars with J < 14 and 100 μas for ~200 stars with J < 19
- Saturates for J = 4 at 3 deg./min, J = 3 at 10 deg/min

Nearby K and M Star Survey

- Combine GAIA and AFTA data for 5 < V < 12 and J > 3 stars.
- Make use of 15 year baseline!
- 119 stars (G8-M4.5) d< 10 pc
- Can detect Earth mass planets around nearby stars with period less than 18 yr
- 8400 obs. x 2 min= 280 hr



$$M_p > 3\ M_{\rm Earth} \left(\frac{d}{7\ \rm pc}\right)\left(\frac{M_*}{0.5\ M_\odot}\right)^{2/3}\left(\frac{\tau}{3\ \rm yr}\right)^{-2/3}$$

- Estimate sensitivity based on 70 Gaia + 70 AFTA observations and Fisher mtrix for 19 parameters (position, prop. motion, parallax and 2 planets x 7 parameters)