WFIRST-AFTA計画と銀河進化研究

山田亨（東北大学）
on behalf of 「WFIRST 連絡会」

- 口径2.4m の望遠鏡 (Hubble Space Telescope と同じ口径）
- 広視野　近赤外
- JWST に続く NASA の戦略ミッション
- 2023－2025年以降の打ち上げを目指している

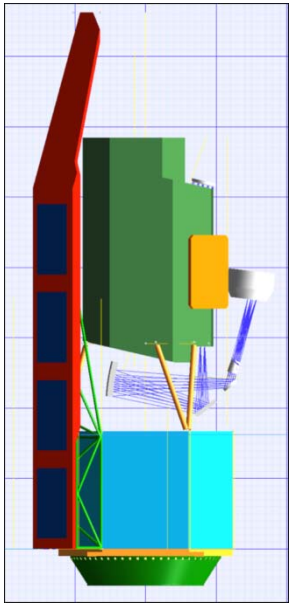
http://wfirst.gsfc.nasa.gov/

http://wfirst.gsfc.nasa.gov/science/sdt_public/

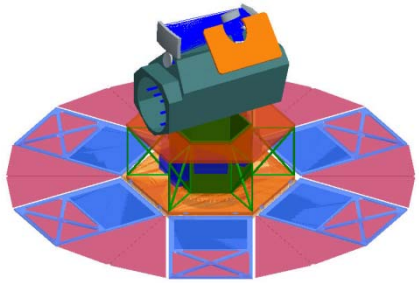
SDT中間報告

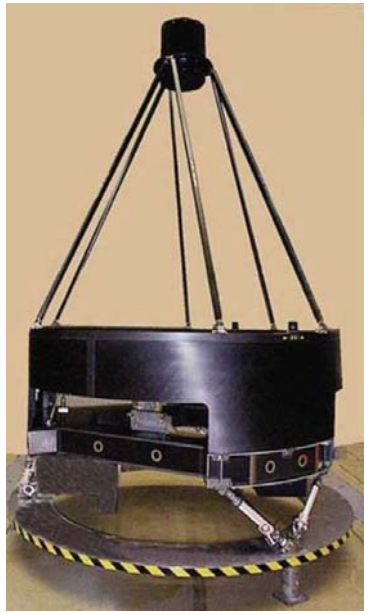
WFIRST 計画の検討の経緯

DRM1
1.3m



DRM2 1.1m
Cost-down





NRO
2.4m

2012
NASA
に供与

US Astro2010 Decadal survey
“JDEM” の衛星案に基づく

DRM=Design Reference Model

- 米国 Decadal Survey で宇宙論、系外惑星（マイクロレンズ）、サーベイの複合計画
- WFIRST-SDT による検討 (DRM1 / DRM2)
- 2012 NASA がNROから2.4m 望遠鏡を供与される。
- WFIRST-AFTA として2.4m 版を検討
- 系外惑星直接観測コロナグラフ装置を加えた案を検討

WFIRST-2.4m (AFTA) の現状について

これまでの WFIRST Design Reference Mission モデルとの比較

WFIRST Version	CATE Date	Primary Mirror Dia. (m)	Pixel Scale (as/pix)	Active FOV (deg^2)	Science Detectors	Notes
SDT #1: Interim DRM	2011	1.3	0.18	0.29	36 H2RG-18	1 – 4x7 Imaging FPA
			0.45	0.26/ea		2 – 2x2 Spec FPAs
SDT #1: DRM1	N/A	1.3	0.18	0.375	36 H2RG-18	Imaging & Spec in single FPA with GRS and SN prisms in a filter wheel
SDT #1: DRM2	2012	1.1	0.18	0.585	14 H4RG-10	Imaging & Spec in single FPA with GRS and SN prisms in a filter wheel
SDT #2: WFIRST-2.4	2013	2.4	0.11	0.281	18-H4RG-10	Imaging & Spec in single FPA with GRS grism in a wheel
			0.11	9.45 as^2	1 H2RG-18	IFU for SN spectra
						Optional coronagraph for exoplanet imaging

Table 1-1. Comparison to past WFIRST Design Reference Missions.

WFIRST-AFTA観測計画概要

宇宙論サーベイ(~2.5年)

= **High Latitude Survey (HLS)**

2000平方度、撮像(YJH)＋分光 (R~800)

Y<26.7, J<26.9, H<26.7, F184W<26.2

＋ **Supernova Survey**

5, 9, 27平方度 (DMW)

撮像モニタリング＋IFU分光 (R~100)

（最終的な深さ）H<28.9 (deep)

重力レンズ、クラスタリング、Ia超新星

＋

系外惑星マイクロレンズ(~1年)

銀河中心方向、軌道半径大きい地球型

系外惑星コロナグラフ観測(~1年)

可視、コントラスト 10^{-9}, IWA 0.2″

Guest Observer **観測**（25%,1.5年）

JAXA/ISAS 計画検討参加の経緯

2013年7月　JAXA-NASA bilateral 会議
常田所長が WFIRST Science Definition Team に
JAXA representative 1名の参加を招請される

2014年１月～山田が参加

（１）WFIRST 計画の推進に貢献すること
（２）国内の宇宙・地上天文学および関連分野の関係者と
WFIRSTとのリエゾンの役割を果たすこと
（３）将来の国際的フラッグシップミッションWFIRSTに
日本・ISAS のプレゼンスを確保すること、特に、
日本からの機器供給の可能性について検討をすすめること

日本におけるアクション

WFIRST連絡会 山田（東北大）または住（大阪大）

2-3 か月に１回
SDT活動とのリエゾン
宇宙論・銀河形成進化・位置天文学・
マイクロレンズ系外惑星・コロナグラフ、他

WFIRSTコロナグラフ装置開発協力

JAXA/ISAS 理学委員会 WACO-WG
小規模ミッション枠（国際協力）

米国の研究者と装置開発協力の議論をすすめる

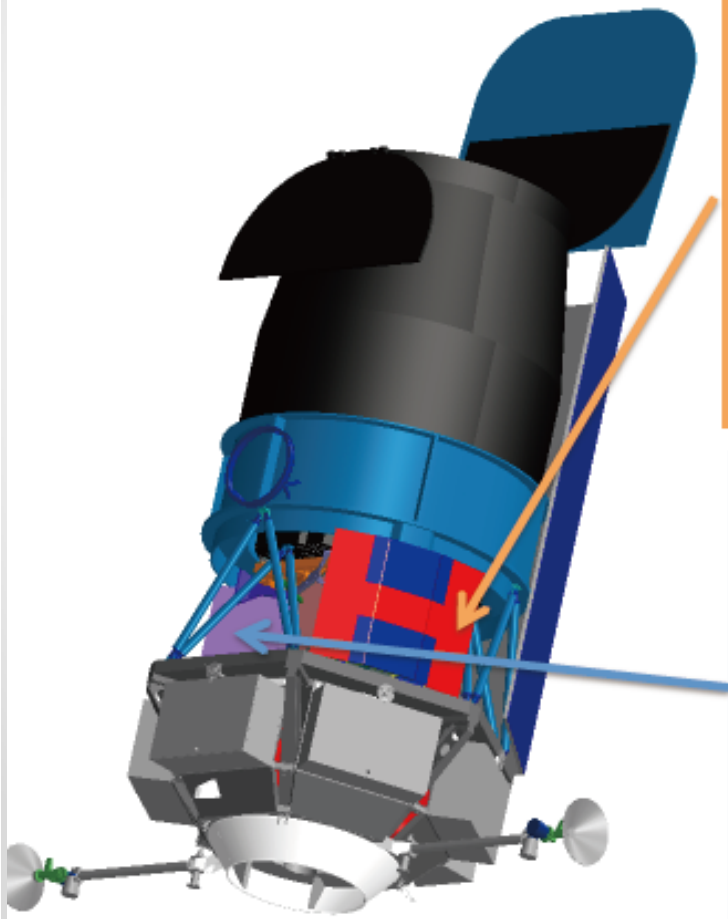
WFIRST-AFTA 概要

Key Features

- **Telescope** – 2.4m aperture primary
- **Instruments**
  - Single channel wide field instrument, 18 4k x 4k HgCdTe detectors; integral field unit spectrometer incorporated in wide field for SNe observing
  - Internal coronagraph with integral field spectrometer
- **Overall Mass** – ~6500 kg (CBE) with components assembled in modules; ~2600 kg propellant; ~3900 kg (CBE dry mass)
- **Primary Structure** – Graphite Epoxy
- **Downlink Rate** – Continuous 150 Mbps Ka-band to Ground Station
- **Thermal** – passive radiator
- **Power** – 2100 W
- **GN&C** – reaction wheels & thruster unloading
- **Propulsion** – bipropellant
- **GEO orbit**
- **Launch Vehicle** – Atlas V 551

2014/6/8 9

WFIRST-AFTA 観測装置の概要



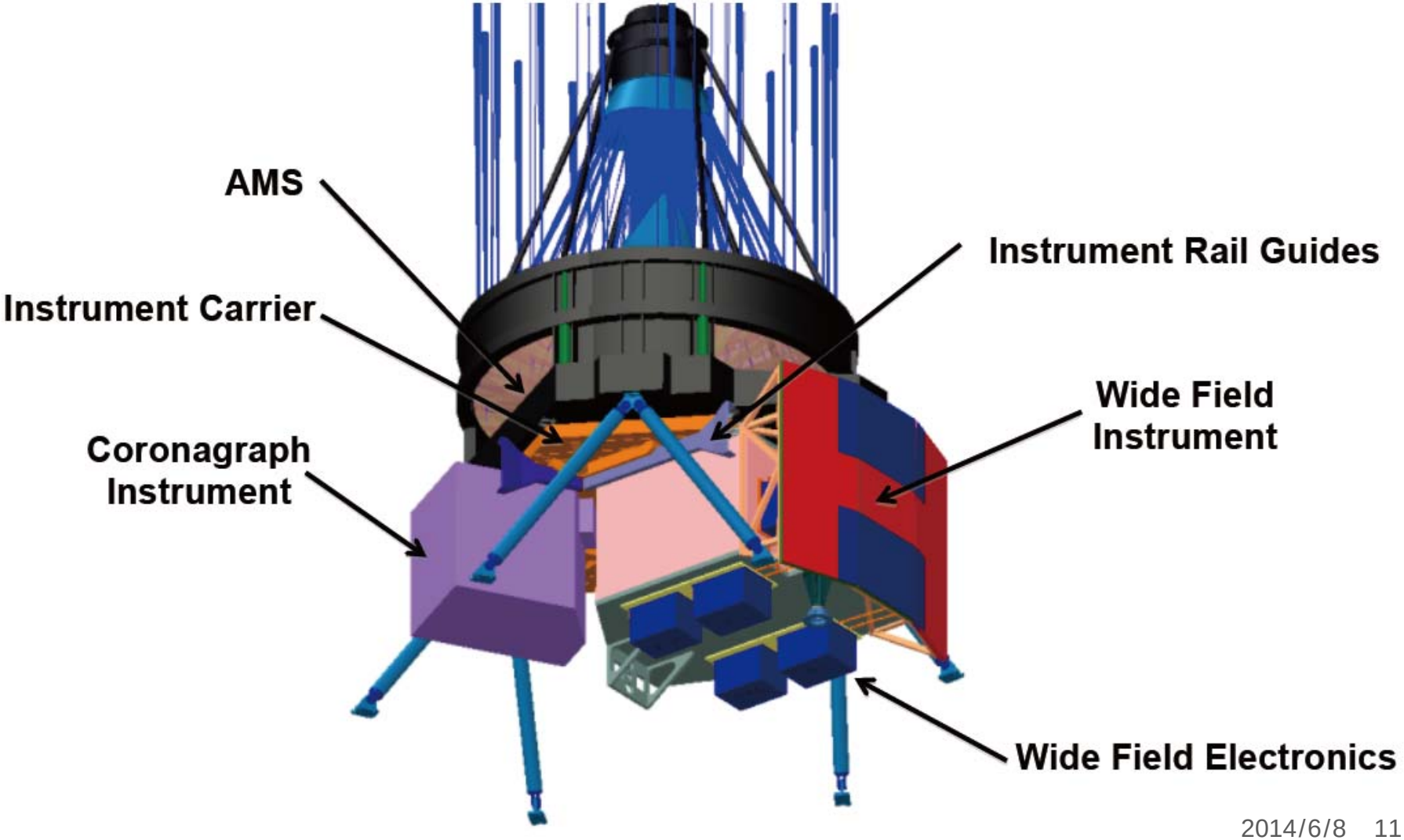
Wide-Field Instrument

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

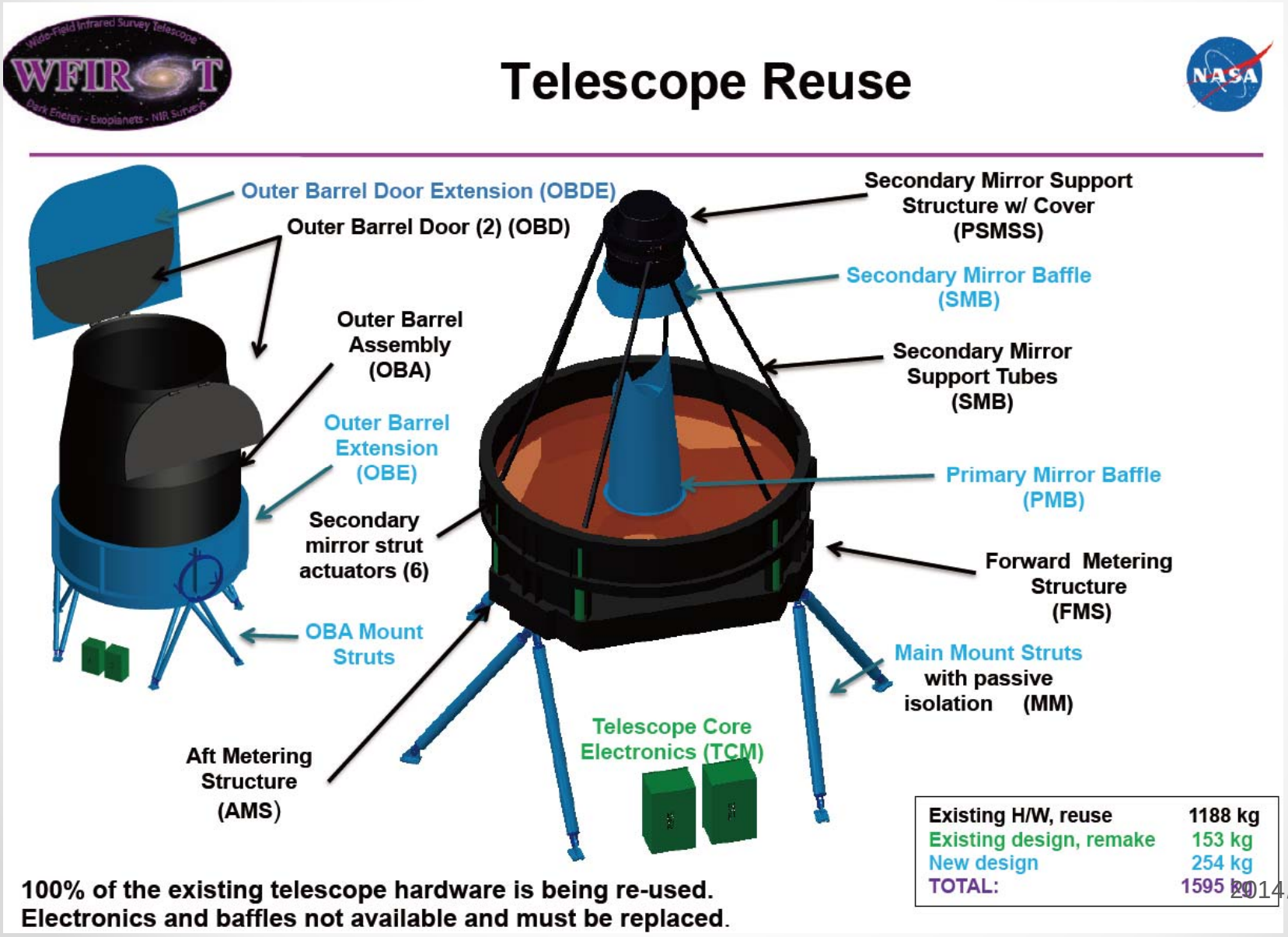
Coronagraph

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

WFIRST-AFTA ペイロード



WFIRST-AFTA ペイロード



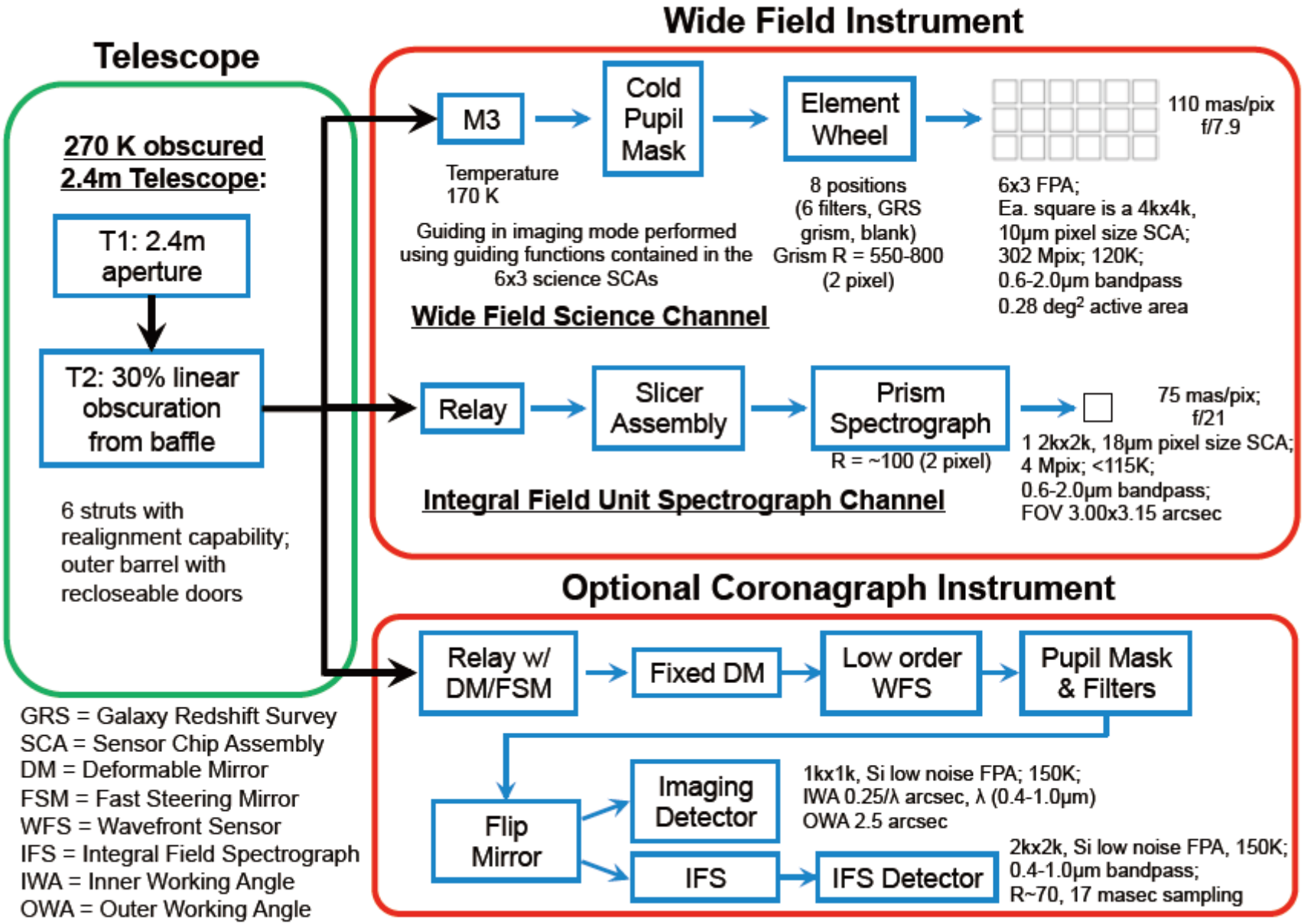


Figure 3-2: WFIRST-2.4 payload optical block diagram.

Wide-Field Imager フィルタ基本案

Name	Bandpasses (μm)
Z087	0.760 – 0.977
Y106	0.927 – 1.192
J129	1.131 – 1.454
H158	1.380 – 1.774
F184	1.683 – 2.000
W149	0.927 – 2.000
GRS Grism	1.350 –1.950

望遠鏡を ~250K に冷却できれば、 2-2.4μm の “K” バンドが可能
ただし、製作、コスト、スケジュールリスクで異論もある。

WFIRST-2.4m DRM の基本性能と基本サーベイ計画

WFIRST-2.4 Design Reference Mission Capabilities						
Imaging Capability	0.281 deg^2		0.11 arcsec/pix		0.6 – 2.0 μm	
Filters	Z087	Y106	J129	H158	F184	W149
Wavelength (μm)	0.760-0.977	0.927-1.192	1.131-1.454	1.380-1.774	1.683-2.000	0.927-2.000
PSF EE50 (arcsec)	0.11	0.12	0.12	0.14	0.14	0.13
Spectroscopic Capability	Grism (0.281 deg^2)				IFU (3.00 x 3.15 arcsec)	
	1.35 – 1.95 μm, R = 550-800				0.6 – 2.0 μm, R = ~100	

Baseline Survey Characteristics					
Survey	Bandpass	Area (deg^2)	Depth	Duration	Cadence
Exoplanet Microlensing	Z, W	2.81	n/a	6 x 72 days	W: 15 min Z: 12 hrs
HLS Imaging	Y, J, H, F184	2000	Y = 26.7, J = 26.9 H = 26.7, F184 = 26.2	1.3 years	n/a
HLS Spectroscopy	1.35 – 1.95 μm	2000	0.5x10^{-16} erg/s/cm^2 @ 1.65 μm	0.6 years	n/a
SN Survey				0.5 years (in a 2-yr interval)	5 days
Wide	Y, J	27.44	Y = 27.1, J = 27.5		
Medium	J, H	8.96	J = 27.6, H = 28.1		
Deep	J, H	5.04	J = 29.3, H = 29.4		
IFU Spec	7 exposures with S/N=3/pix, 1 near peak with S/N=10/pix, 1 post-SN reference with S/N=6/pix Parallel imaging during deep tier IFU spectroscopy: Z, Y, J, H ~29.5, F184 ~29.0				

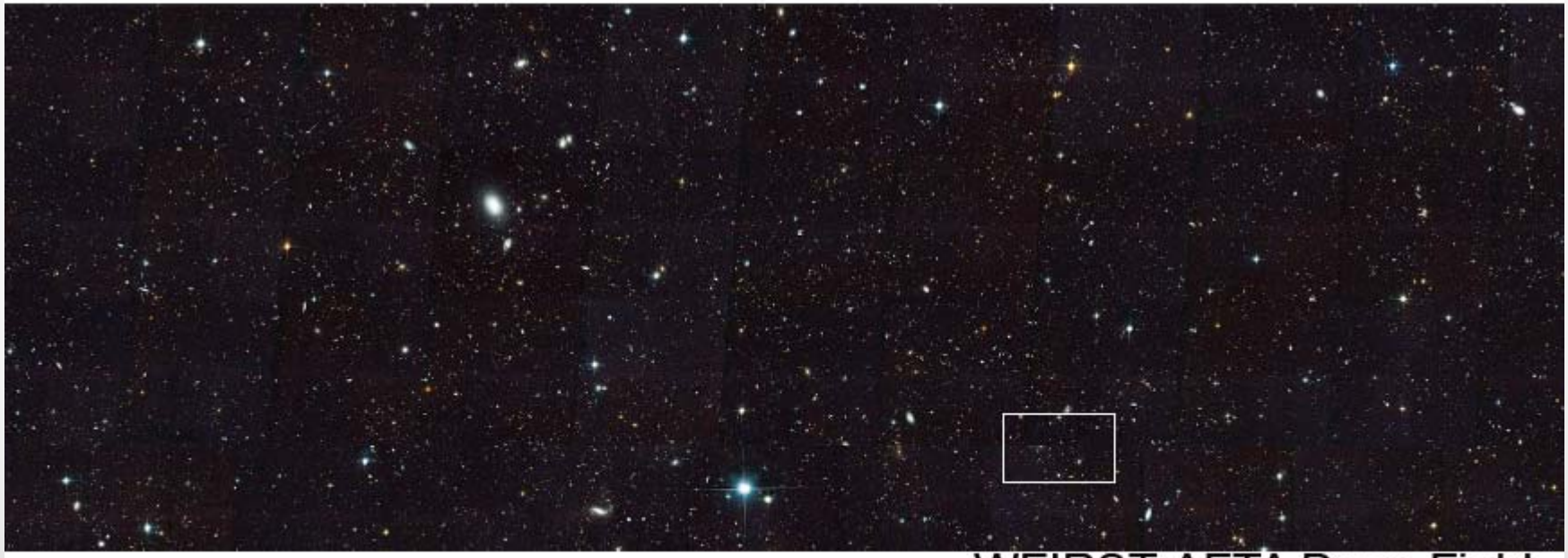
点源
5σ
7σ

HLS: High Latitude Survey

Guest Observer Capabilities						
1.4 years of the 5 year prime mission						
	Z087	Y106	J129	H158	F184	W149
Imaging depth in 1000 seconds (m_{AB})	27.15	27.13	27.14	27.12	26.15	27.67
t_{exp} for $\sigma_{read} = \sigma_{sky}$ (secs)	200	190	180	180	240	90
Grism depth in 1000 sec	S/N=10 per R=~600 element at AB=20.4 (1.45 μm) or 20.5 (1.75 μm) t_{exp} for $\sigma_{read} = \sigma_{sky}$: 170 secs					
IFU depth in 1000 sec	S/N=10 per R~100 element at AB=24.2 (1.5 μm)					
Slew and settle time	chip gap step: 13 sec, full field step: 61 sec, 10 deg step: 178 sec					
Optional Coronagraph Capabilities						
1 year in addition to the 5-year primary mission, interspersed, for a 6-year total mission						
Field of view	Annular region around star, with 0.2 to 2.0 arcsec inner and outer radii					
Sensitivity	Able to detect gas-giant planets and bright debris disks at the 1 ppb brightness level					
Wavelength range	400 to 1000 nm					
Image mode	Images of full annular region with sequential 10% bandpass filters					
Spectroscopy mode	Spectra of full annular region with spectral resolution of 70					
Polarization mode	Imaging in 10% filters with full Stokes polarization					
Stretch goals	0.1 arcsec inner annulus radius, and super-Earth planets					

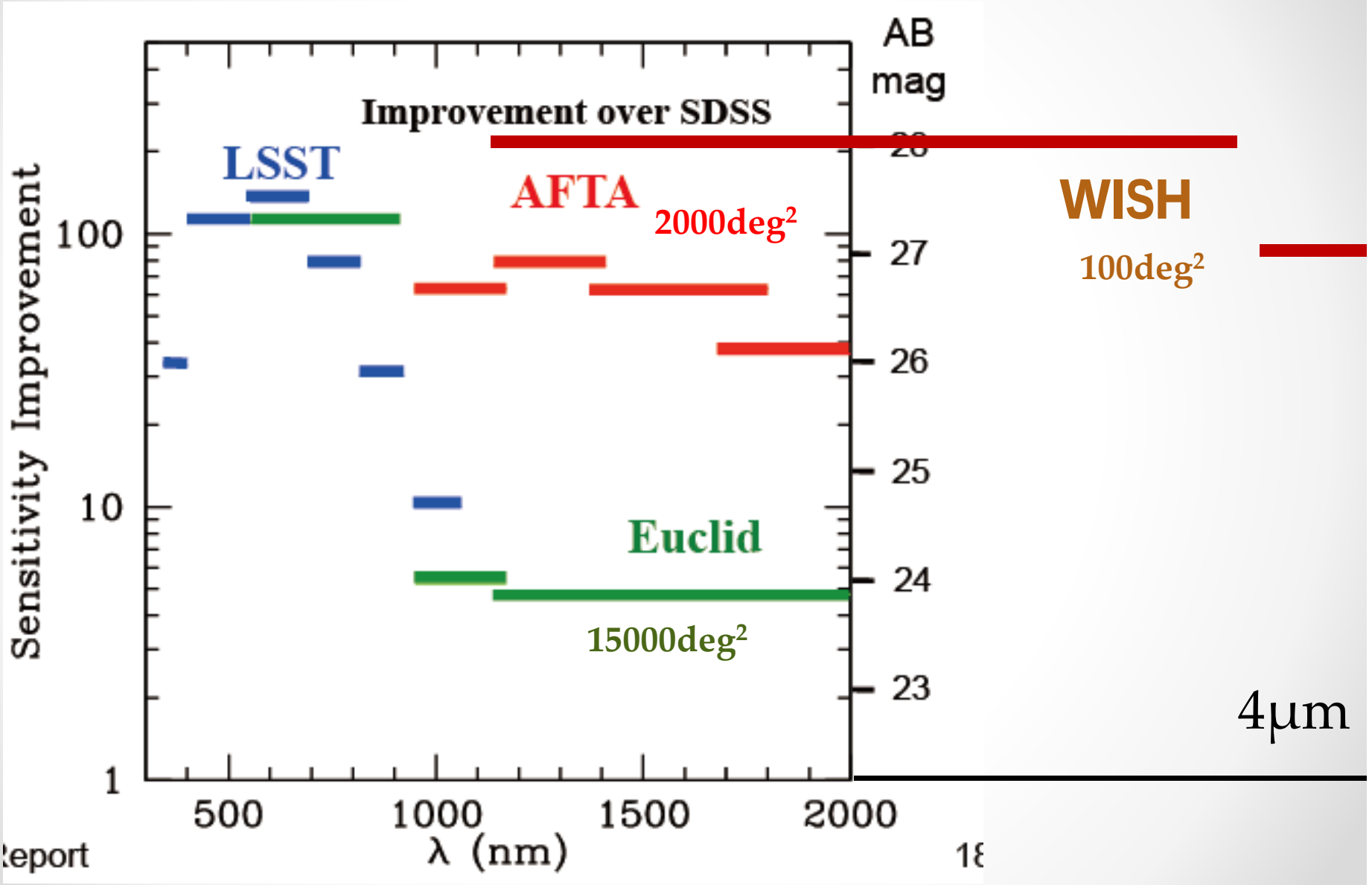
WFIRST-AFTA vs Hubble

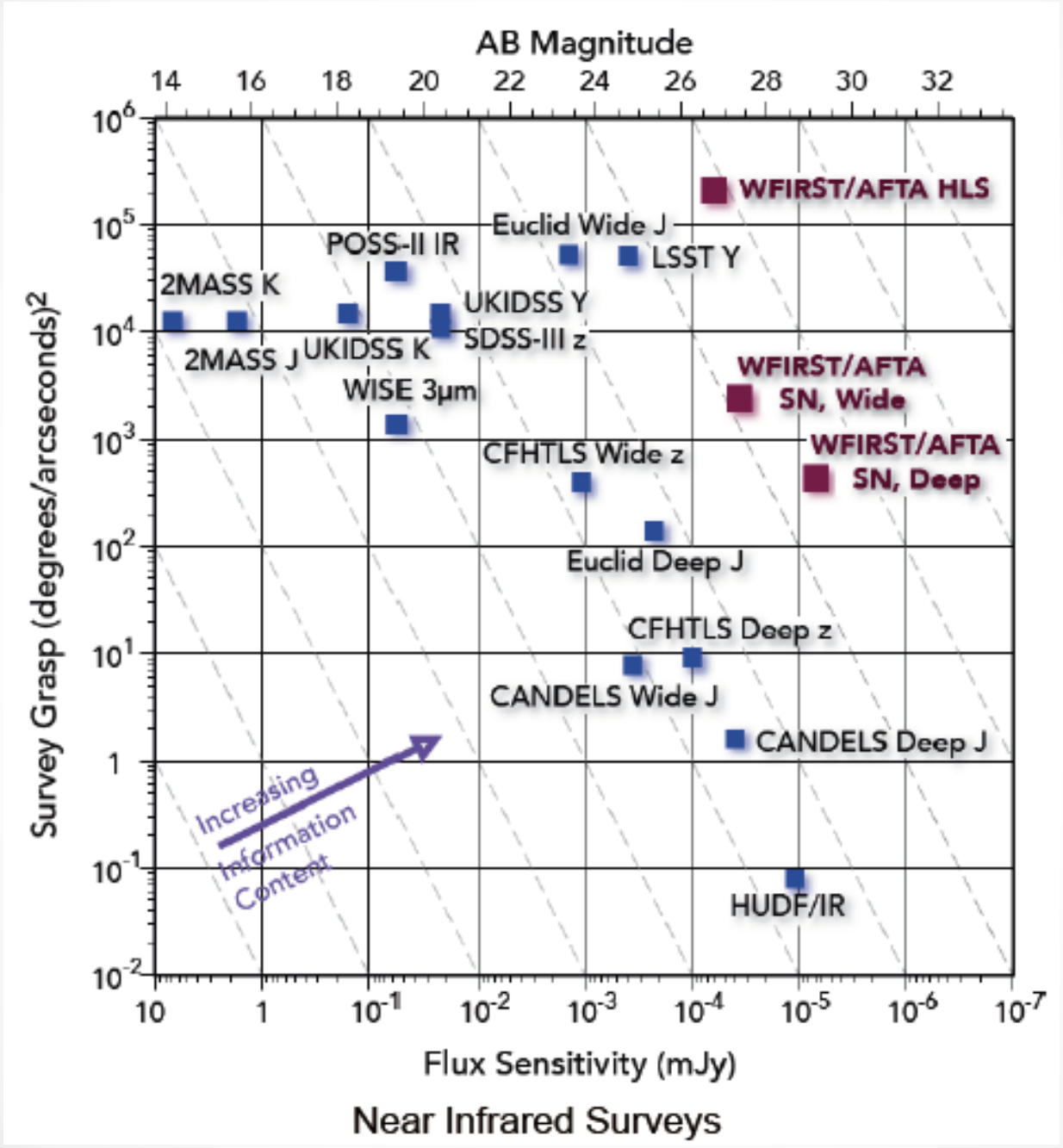
Hubble Ultra Deep Field - IR
~5,000 galaxies in one image



WFIRST-AFTA Deep Field
>1,000,000 galaxies in each image

WFIRST-AFTA Survey Sensitivity





Near Infrared Surveys

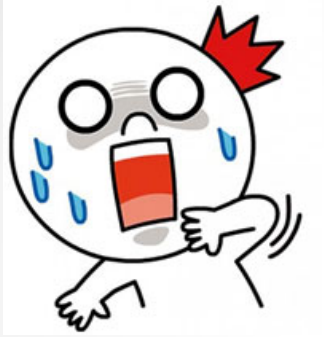
WFIRST

Unique Parameter Space for IR Astronomy

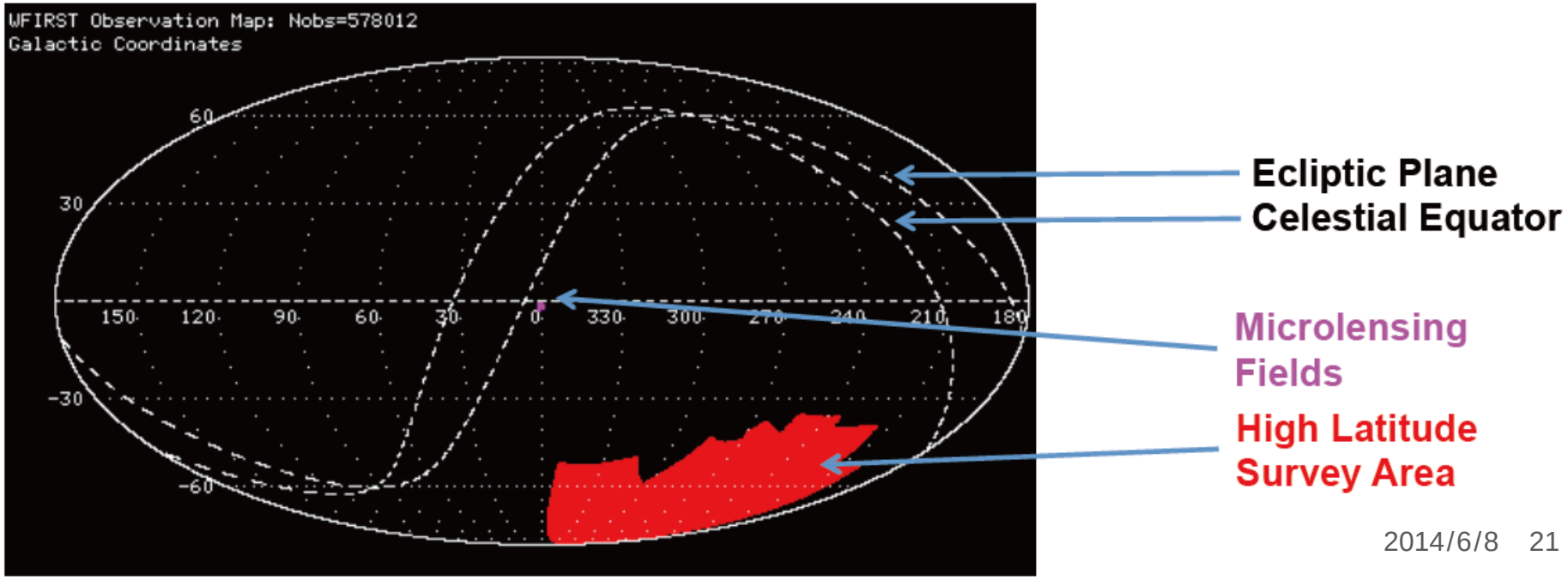
Instrument	Telescope	Pixel Scale	Field of View	Wavelength
WISE	0.4 m	2.75 arcsec	2209 arcmin^2	3 – 28 μm
ISO	0.6 m	12 arcsec	9 arcmin^2	2.4 – 240 μm
Akari	0.7 m	1.5 arcsec	95 arcmin^2	1.8 – 180 μm
Spitzer/IRAC	0.85 m	1.2 arcsec	27 arcmin^2	3 – 10 μm
Hubble/NICMOS	2.4 m	0.04 – 0.20 arcsec	0.03-0.72 arcmin^2	0.8 – 2.5 μm
Hubble/WFC3 IR	2.4 m	0.13 arcsec	4.65 arcmin^2	0.9 – 1.7 μm
WFIRST-AFTA High-Lat Survey	**2.4 m**	**0.11 arcsec**	**1008 arcmin^2**	**1.0 – 2.0 μm**
WISH	**1.5m**	**0.156 arcsec**	**850 arcmin^2**	**1.0-5.0 μm**

WFIRST 観測視野案（これまで）

このままでは すばるもTMTも見えない！！

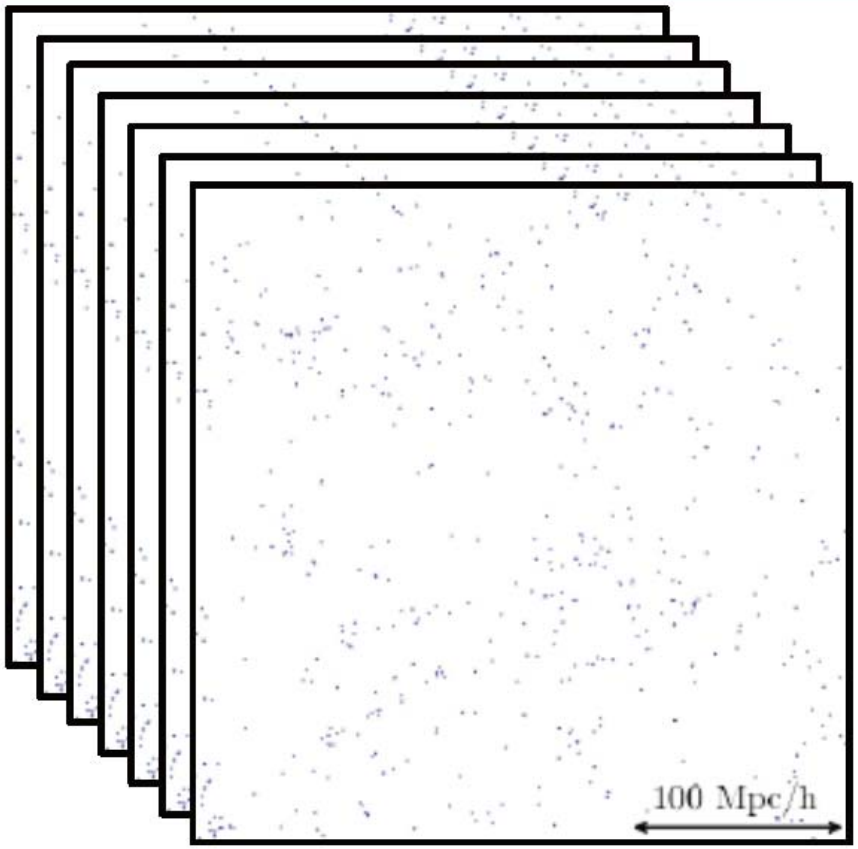


2014/11/17-20
WFIRST Workshop @ Pasadena
AFTA で観測計画を議論する機会か

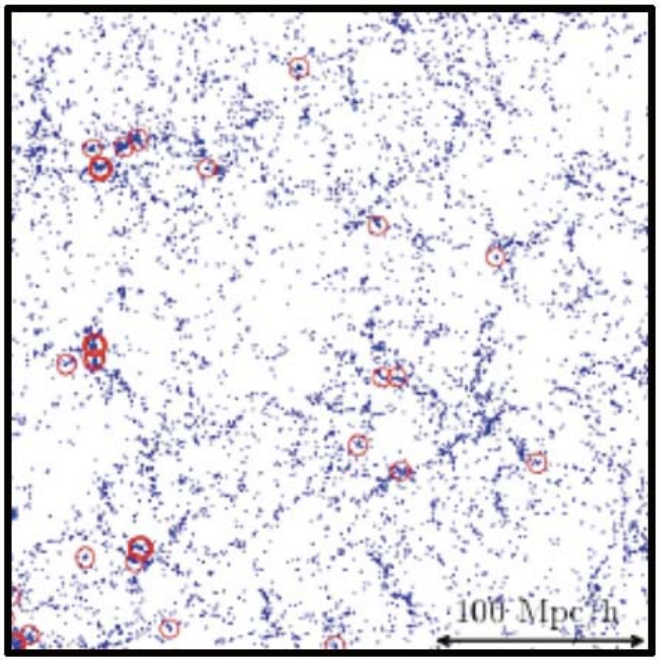


WFIRST vs Euclid

Detailed 3D Map of Large Scale Structure at z = 1-2



Large scale structure simulation showing 0.1% of the total WFIRST-AFTA Galaxy Redshift Survey Volume

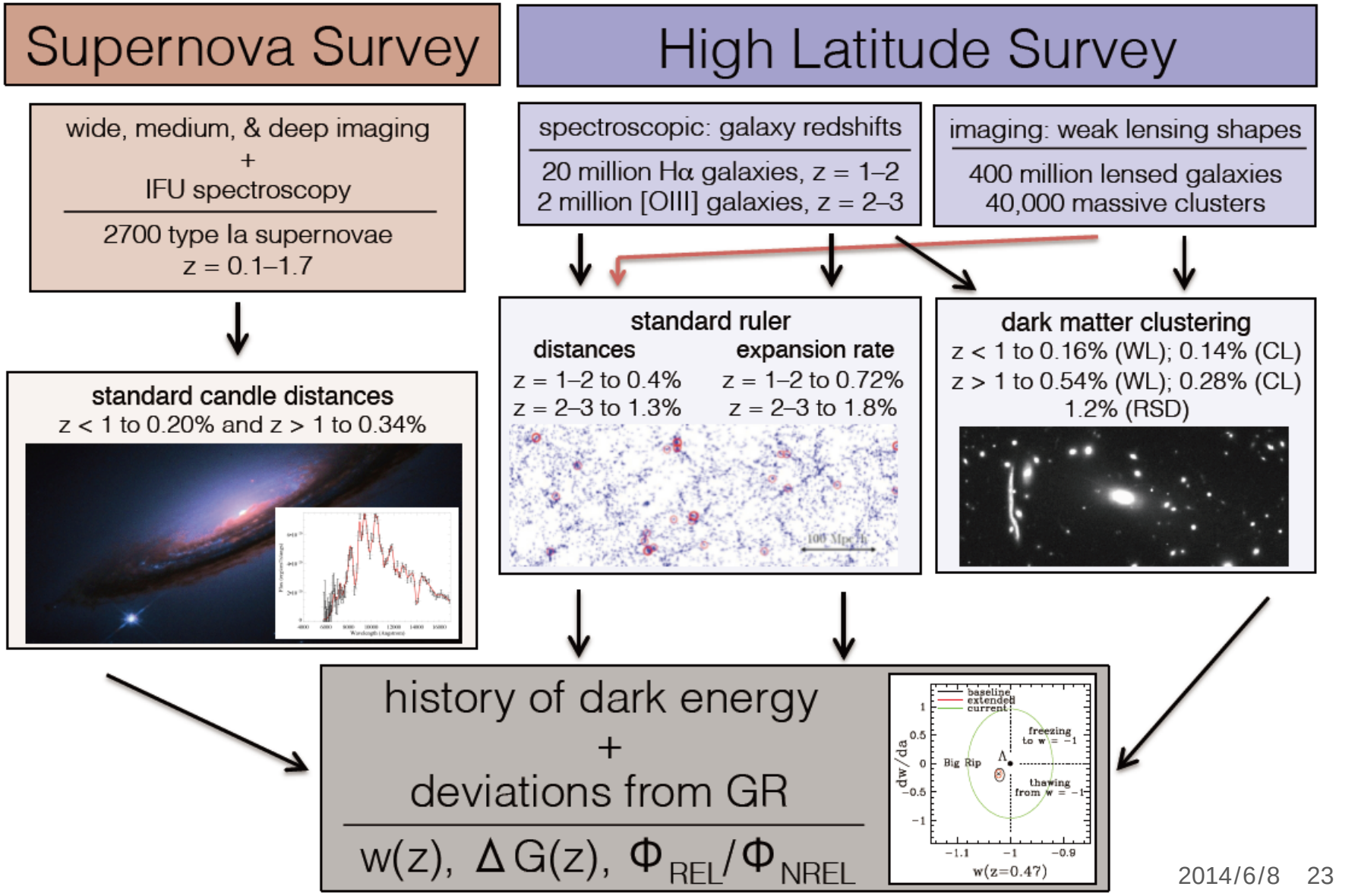


Euclid
15,000 deg^2 @ 1700 gal/deg^2

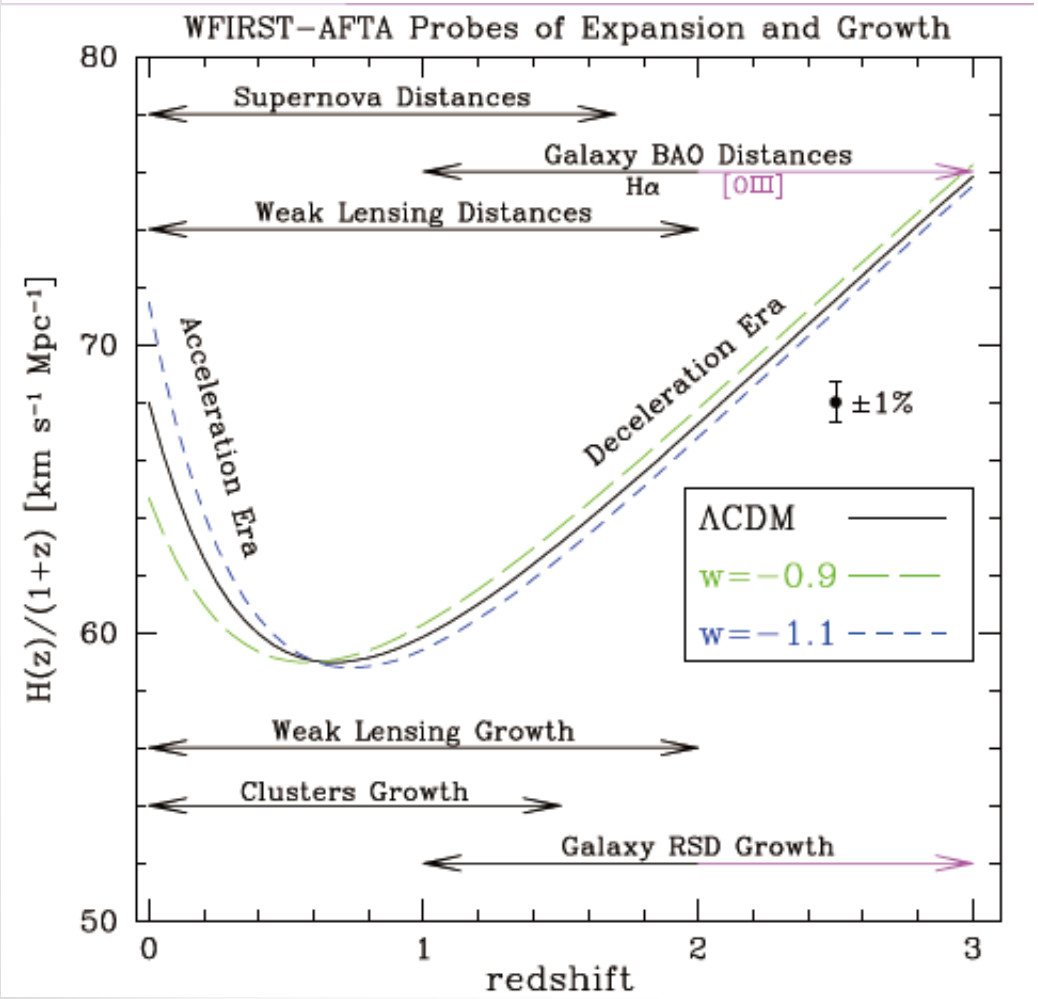
WFIRST
2,400 deg^2 @ 12,600 gal/deg^2

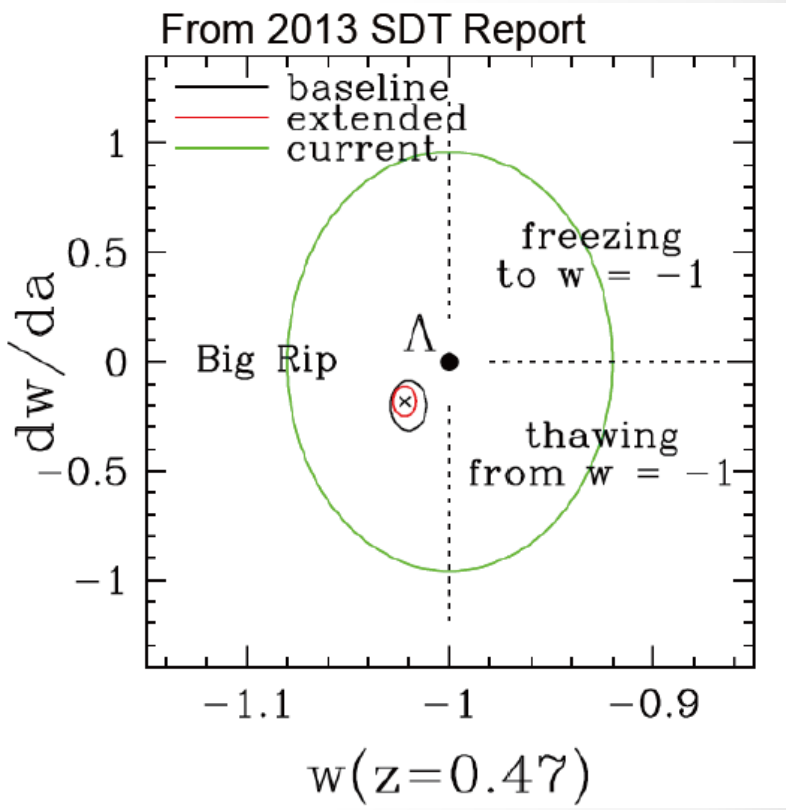
Large scale structure simulations from 2013 SDT Report – courtesy of Ying Zu
Thin and thick red circles mark clusters with masses exceeding 5 x 10^{13} M_{Sun} and 10^{14} M_{Sun}, respectively

WFIRST-AFTA による宇宙論

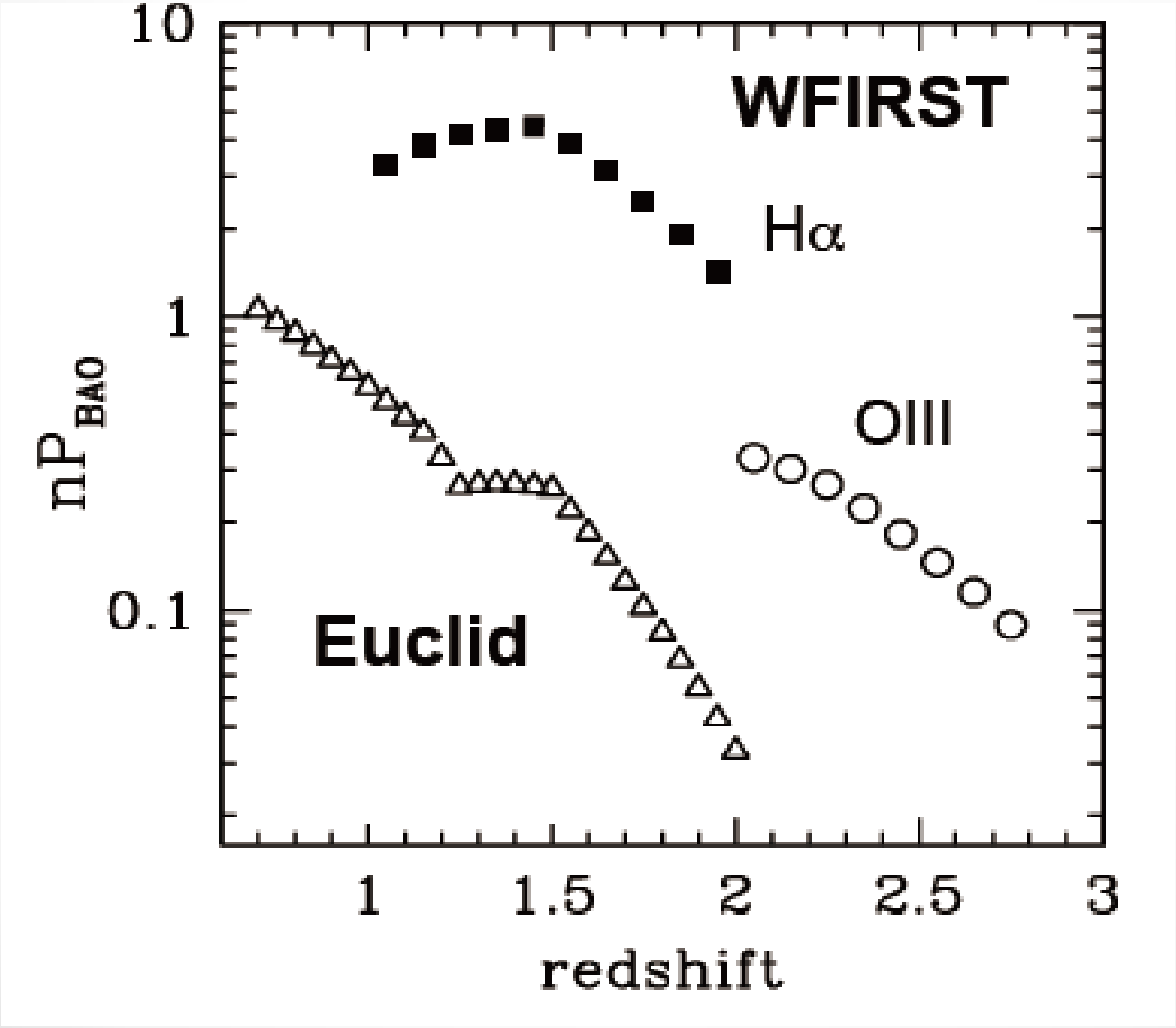


WFIRST-AFTA による宇宙論





宇宙論 WFIRST-AFTA vs Euclid



WFIRST-AFTA & Euclid Complementary for Dark Energy

WFIRST-AFTA

Deep Infrared Survey (2400 deg^2)

Lensing

- High Resolution (2.5x the Euclid number density of galaxies)
- Galaxy shapes in IR
- 5 lensing power spectra

Supernovae:

- High quality IFU spectra of >2000 SN

Redshift survey

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

Euclid

Wide Optical and Shallow Infrared Survey (15000 deg^2)

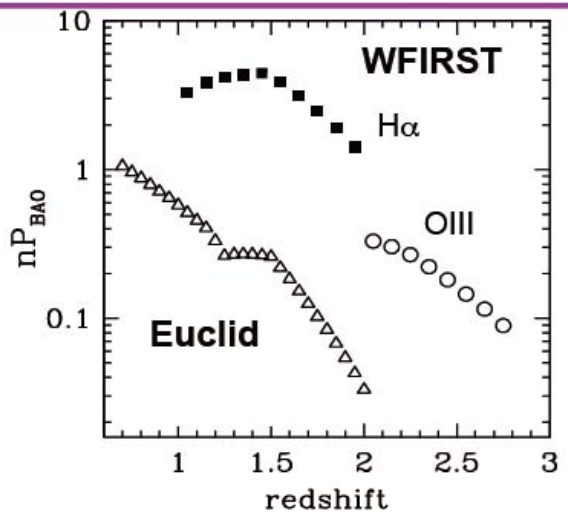
Lensing:

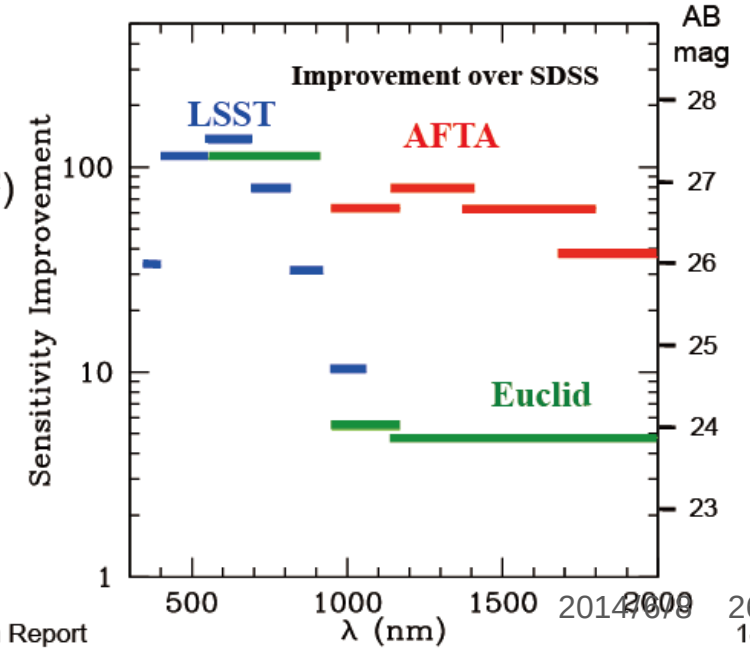
- Lower Resolution
- Galaxy shapes in optical
- 1 lensing power spectrum

No supernova program

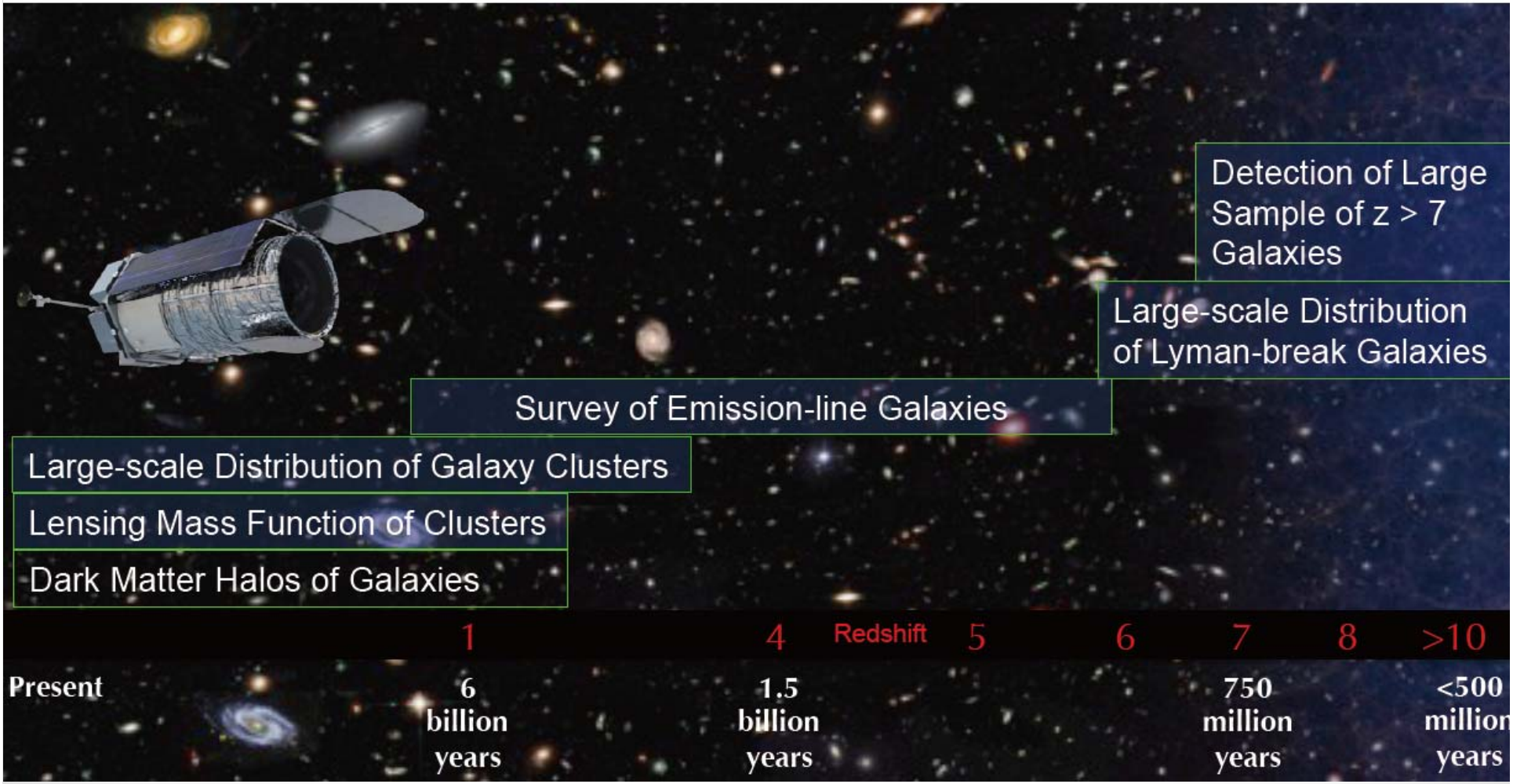
Redshift survey:

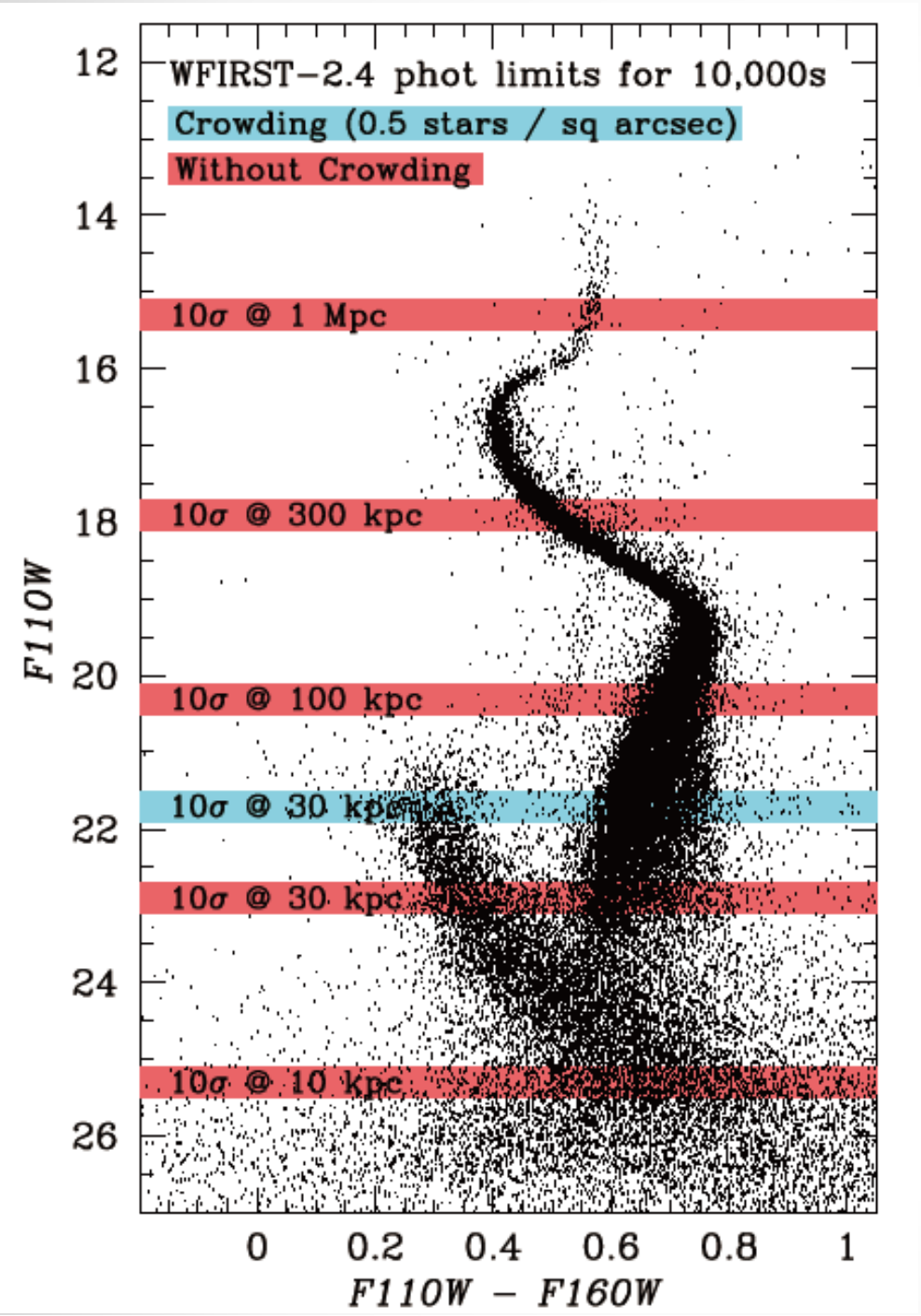
- Low number density of galaxies
- Redshift range z = 0.7 - 2





Using Observations from the High Latitude Survey and GO Programs





近傍銀河を星に分解して観測する

WFIRST による系外惑星研究

Microlensing Survey

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

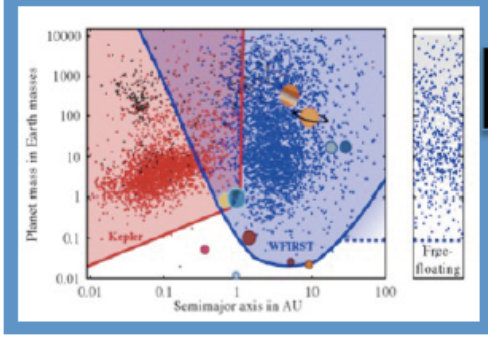
3000 cold exoplanets
300 Earth-mass planets
40 Mars-mass or smaller planets
40 free-floating Earth-mass planets

High Contrast Imaging

Survey up to 200 nearby stars for planets and debris disks at contrast levels of 10^{-9} on angular scales > 0.1"
R=70 spectra and polarization between 400-1000 nm

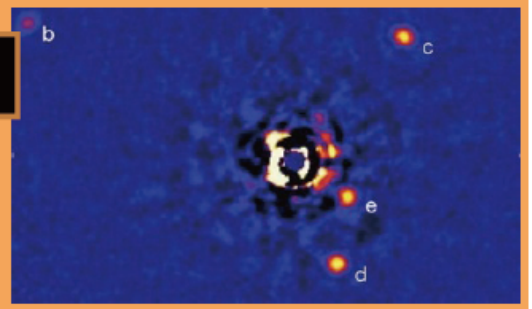
Detailed characterization of up to a dozen giant planets.
Discovery and characterization of several Neptunes
Detection of massive debris disks.

Complete the Exoplanet Census

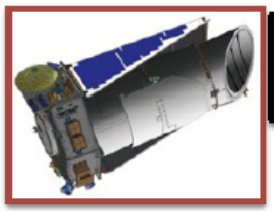


- How do planetary systems form and evolve?
- What are the constituents and dominant physical processes in planetary atmospheres?
- What kinds of unexpected systems inhabit the outer regions of planetary systems?
- What are the masses, compositions, and structure of nearby circumstellar disks?
- Do small planets in the habitable zone have heavy hydrogen/helium atmospheres?

Discover and Characterize Nearby Worlds

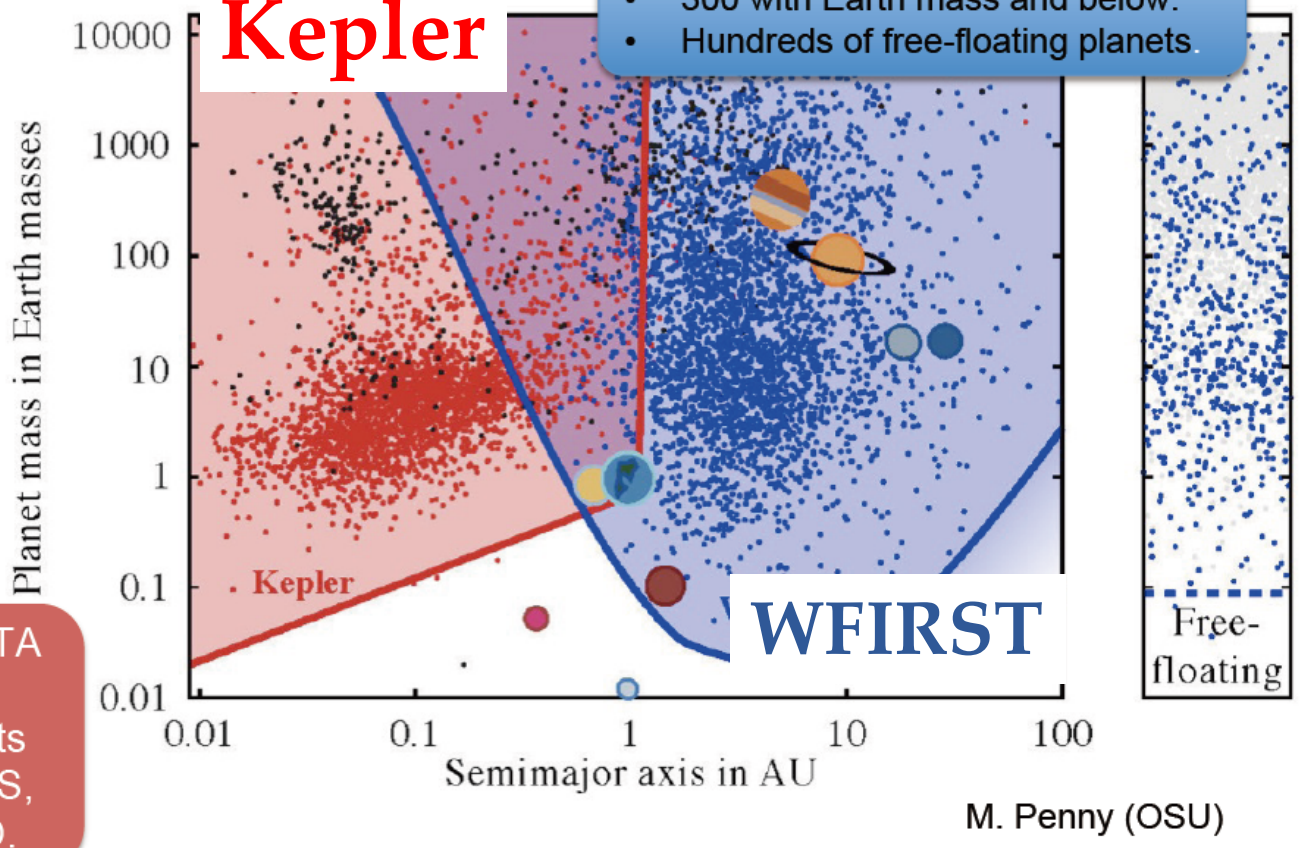


WFIRST マイクロレンズ系外惑星研究



Combined with space-based transit surveys, WFIRST-AFTA completes the statistical census of planetary systems in the Galaxy.

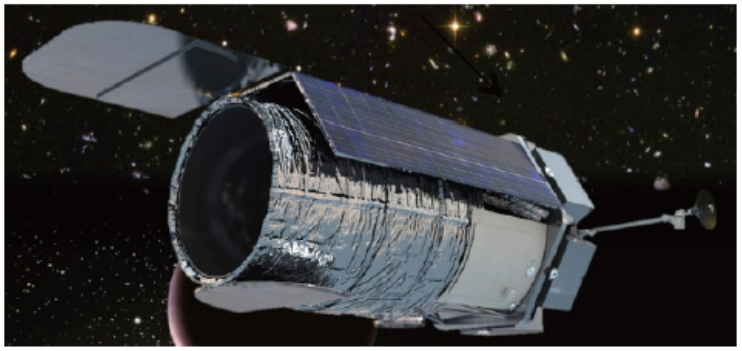
- ~3000 planet detections.
- 300 with Earth mass and below.
- Hundreds of free-floating planets.

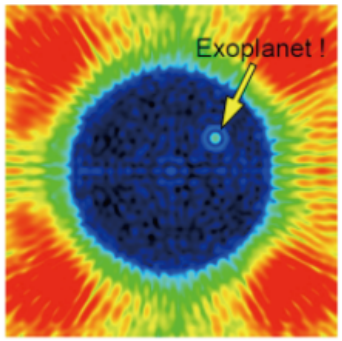


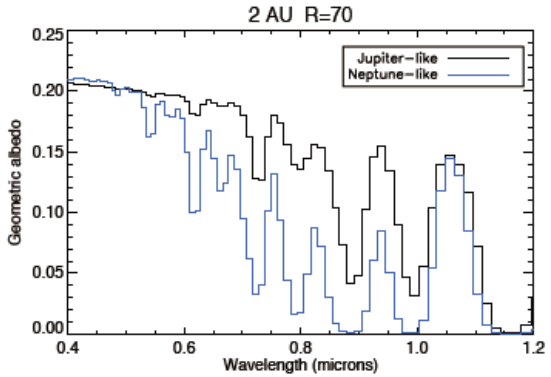
M. Penny (OSU)

WFIRST-AFTA perfectly complements Kepler, TESS, and PLATO.

WFIRST コロナグラフ装置







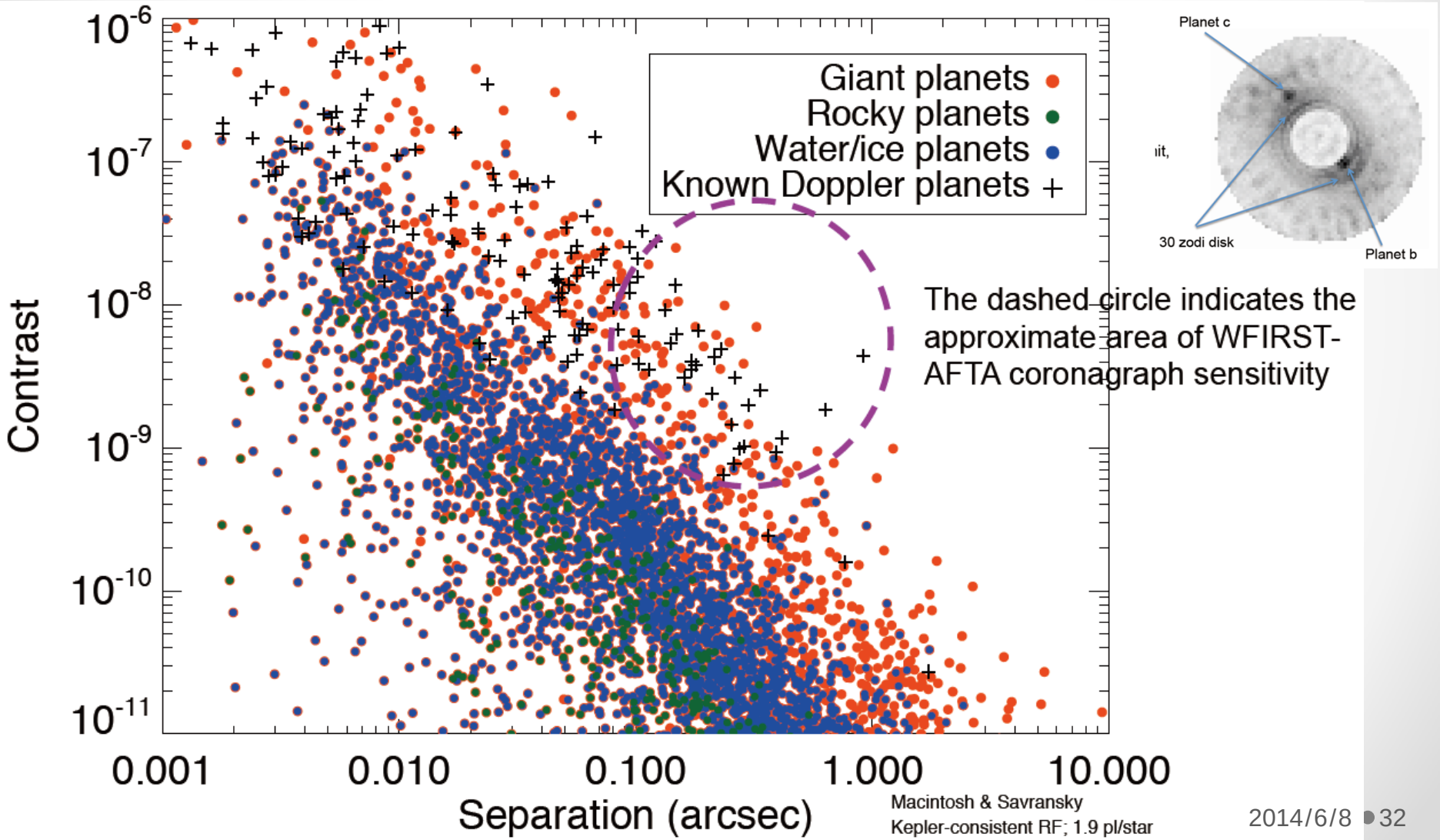
Coronagraph Architecture:
Primary: Occulting Mask (OMC)
Backup: Phase Induced Amplitude Apodization (PIAA)

Exoplanet Direct Imaging

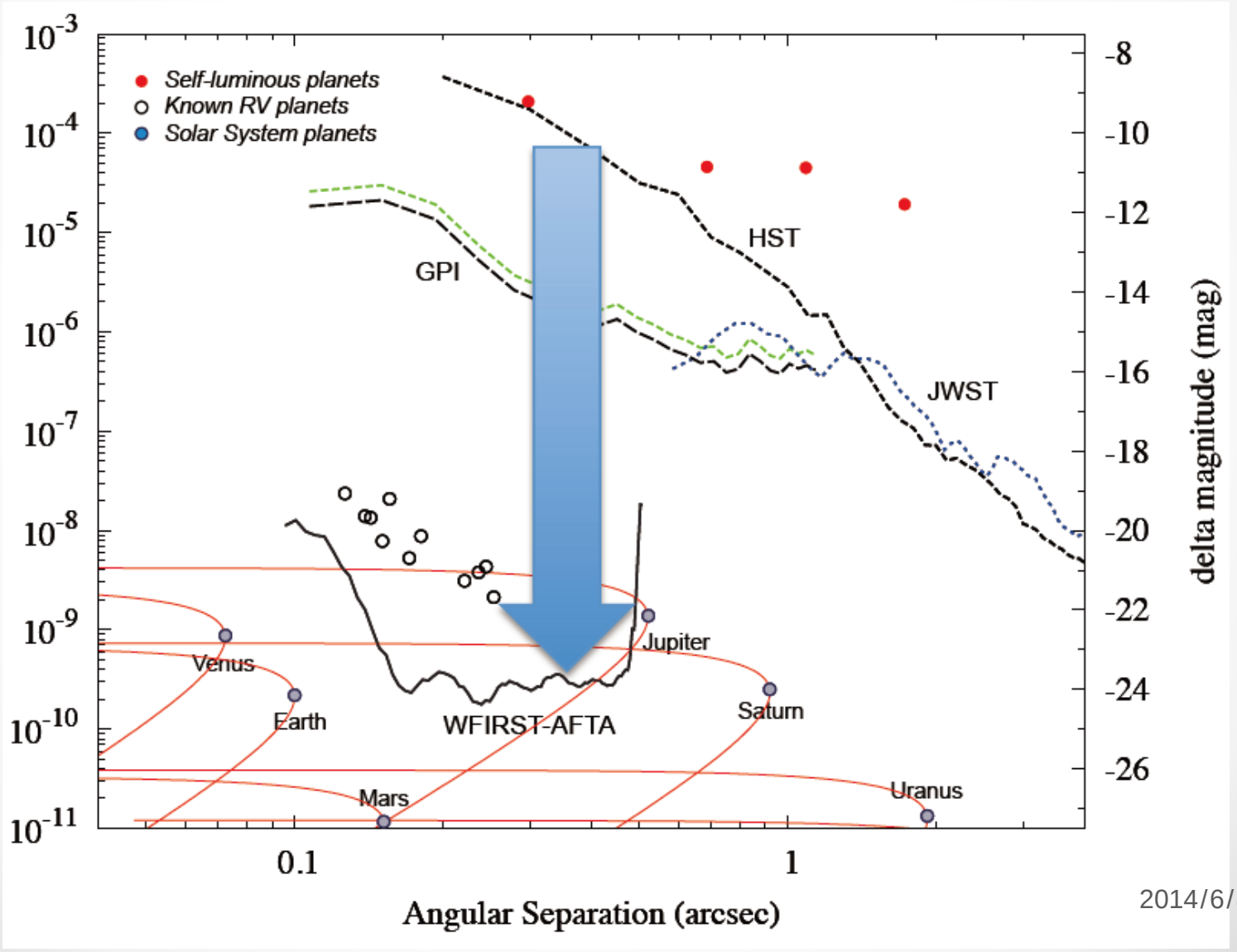
Exoplanet Spectroscopy

Bandpass	400 – 1000 nm	Measured sequentially in five ~10% bands
Inner working angle	100 – 250 mas	~3λ/D
Outer working angle	0.75 – 1.8 arcsec	By 48x48 DM
Detection Limit	Contrast ≤ 10^{-9} (after post processing)	Cold Jupiters, Neptunes, and icy planets down to ~2 RE
Spectral Resolution	~70	With IFS, R~70 across 600 – 980 nm
Spatial Sampling	17 mas	Nyquist for λ~430nm

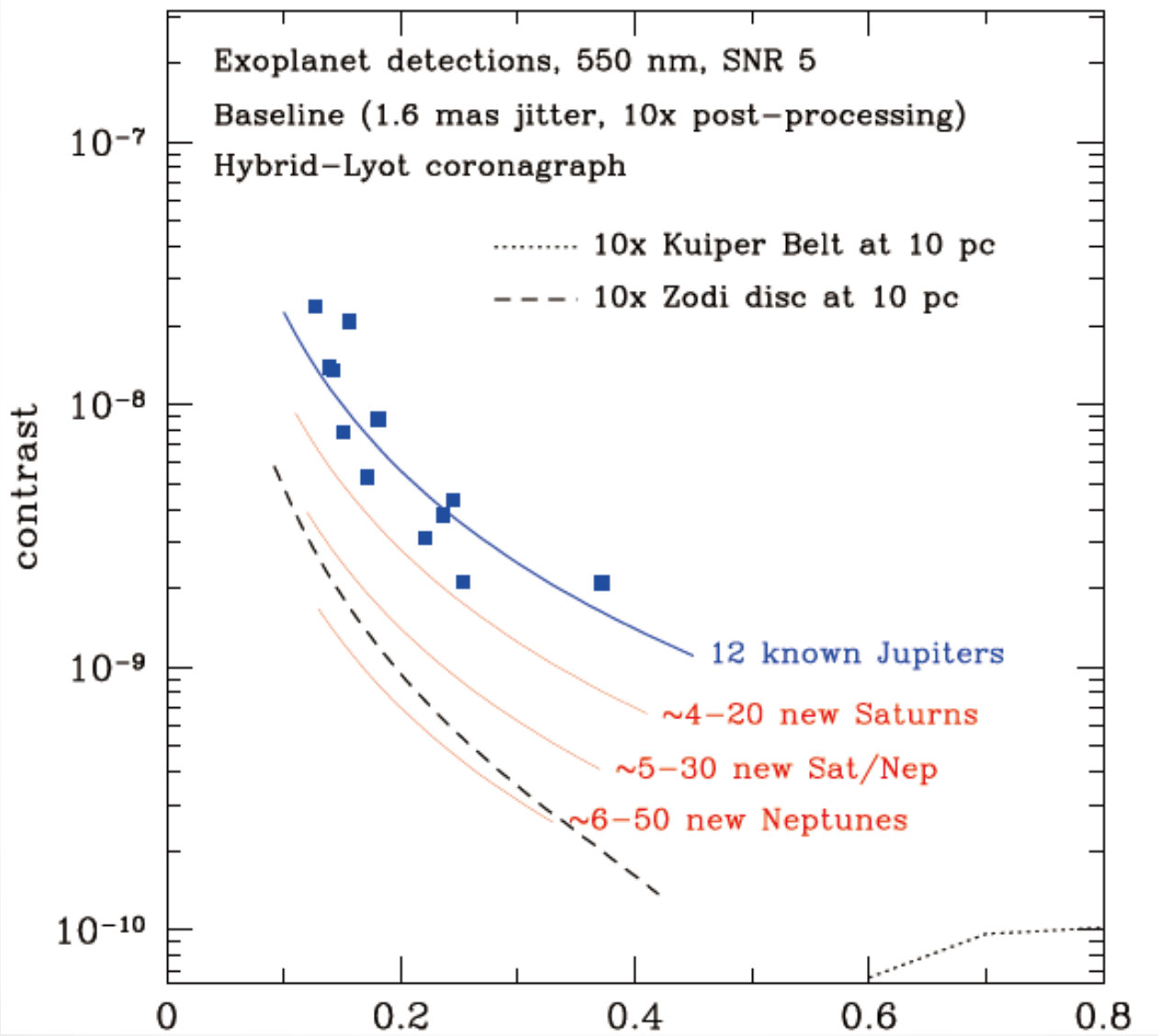
WFIRST コロナグラフ装置



WFIRST コロナグラフ装置



WFIRST コロナグラフ装置



日本におけるアクション

WFIRST連絡会

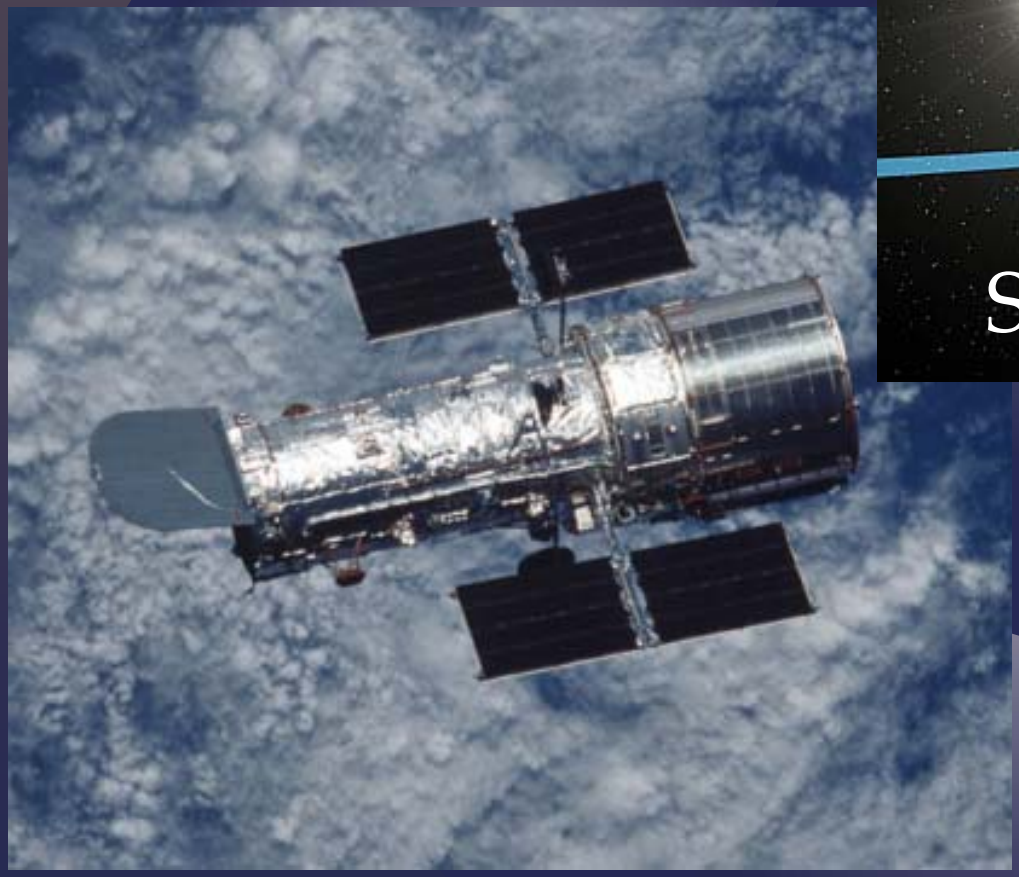
- 2-3 か月に１回
- SDT活動とのリエゾン
- 宇宙論・銀河形成進化・位置天文学・
- マイクロレンズ系外惑星・コロナグラフ、他

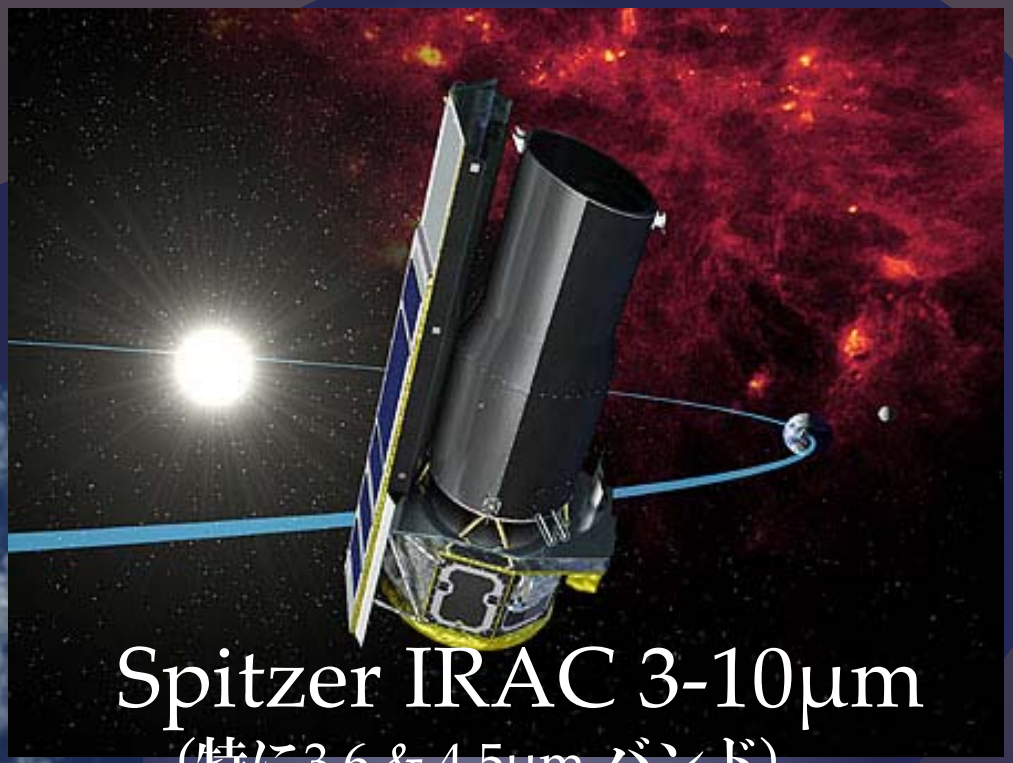
WFIRSTコロナグラフ装置開発協力

- JAXA/ISAS 理学委員会 WACO-WG
- 小規模ミッション枠（国際協力）

米国の研究者と装置開発協力の議論をすすめる

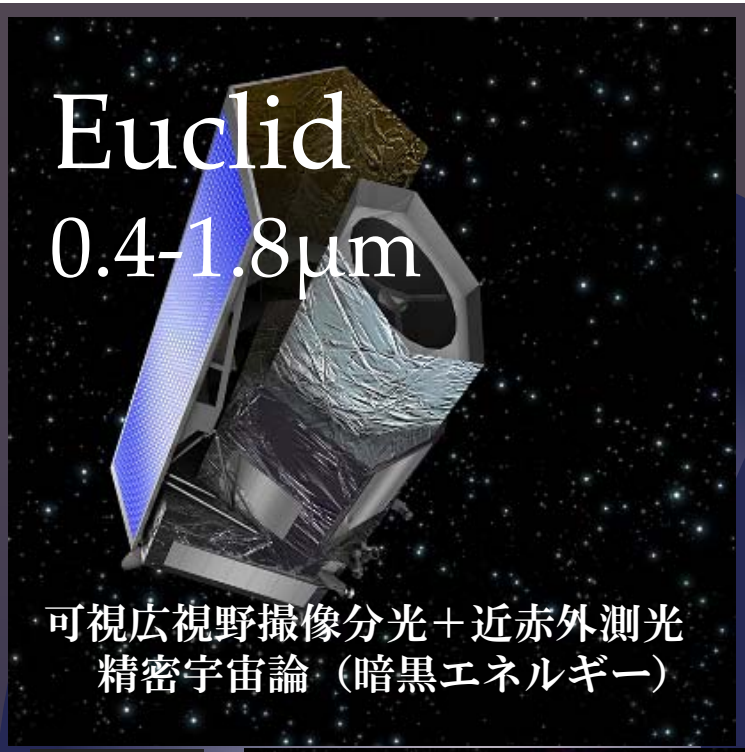
Hubble
0.1-1.8μm

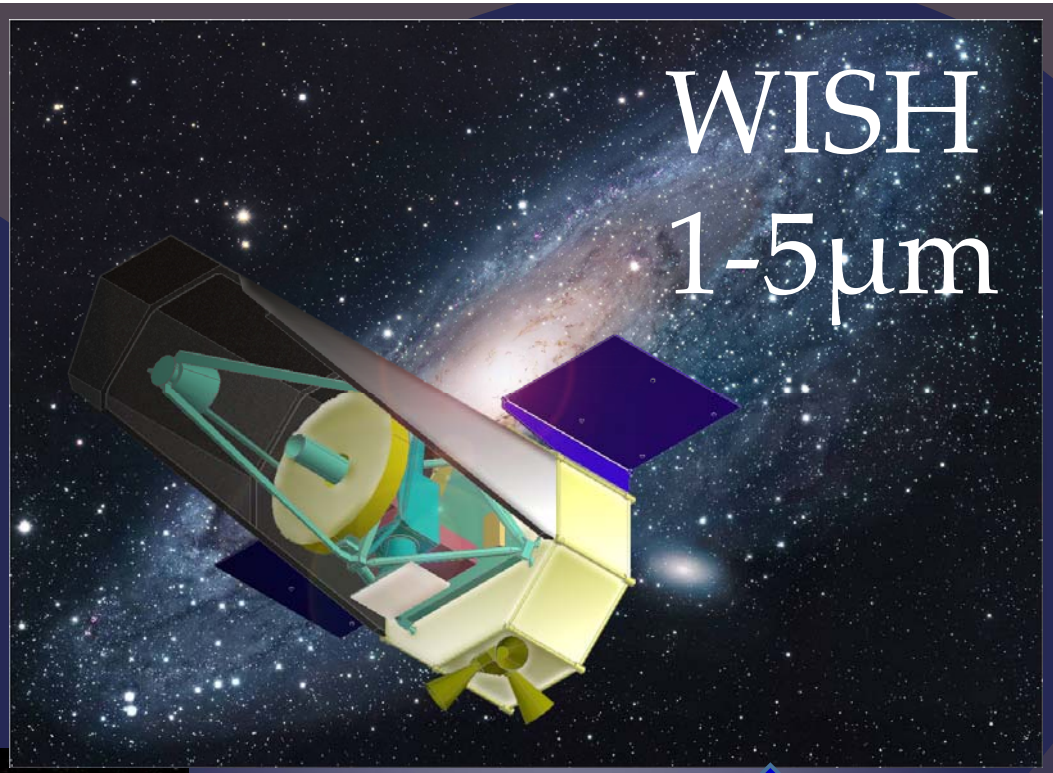


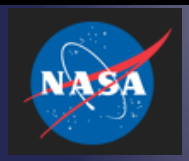


Spitzer IRAC 3-10μm
(特に3.6 & 4.5μm バンド)

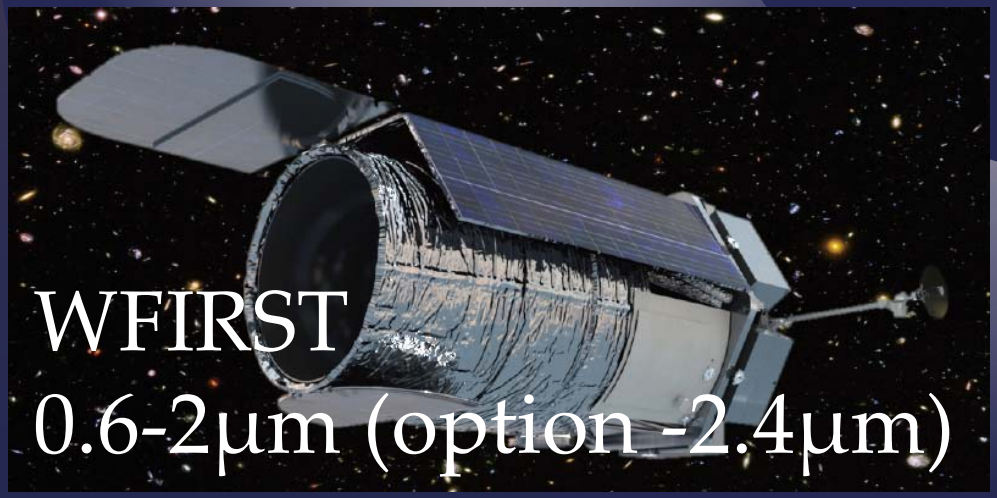
Akari IRC NIR 2-5μm







WFIRST-AFTA
Wide-Field Infrared Survey Telescope



広視野
0.2″ 程度のサイズの
天体の測光サーベイ
スピードは WISH が
JWST の２倍